EXPLORATIONS IN TURKESTAN

WITH AN ACCOUNT OF

THE BASIN OF EASTERN PERSIA AND SISTAN

Expedition of 1903, under the Direction of

RAPHAEL PUMPELLY

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Archeological and Physico-Geographical Reconnaissance in Turkestan
By Raphael Pumpelly

A Journey Across Turkestan . . . By William M. Davis

Physiographic Observations Between the Syr Darya and Lake Kara Kul, on the Pamir, in 1903 . By Raphael W. Pumpelly

A Geologic and Physiographic Reconnaissance in Central Turkestan
By Ellsworth Huntington

The Basin of Eastern Persia and Sistan, By Ellsworth Huntington

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ARCHEOLOGICAL AND PHYSICO-GEOGRAPHICAL
RECONNAISSANCE IN TURKESTAN

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ARCHEOLOGICAL AND PHYSICO-GEOGRAPHICAL RECONNAISSANCE IN TURKESTAN.

BY RAPHAEL PUMPELLY.

INTRODUCTION.

AT the end of 1902 the Carnegie Institution voted a grant to me "for the purpose of making, during the year 1903, a preliminary examination of the Trans-Caspian region, and of collecting and arranging all available existing information necessary in organizing the further investigation of the past and present physico-geographical conditions and archeological remains of the region."

The investigation was proposed because (1) there is a school that still holds the belief that central Asia is the region in which the great civilizations of the far East and of the West had their origins; and (2) because of the supposed occurrence in that region, in prehistoric times, of great changes in climate, resulting in the formation and recession of an extensive Asian Mediterranean, of which the Aral, Caspian, and Black seas are the principal remnants.

It had long seemed to me that a study of Central-Asian archeology would probably yield important evidence in the genealogy of the great civilizations and of several, at least, of the dominant races, and that a parallel study of the traces of physical changes during Quaternary time might show some coincidence between the phases of social evolution and the changes in environment; further, that it might be possible to correlate the physical and human records and thus furnish a contribution to the time scale of recent geology.

At my request Professor William M. Davis assumed charge of the physico-geographical part of the preliminary reconnaissance.

ITINERARY.

I left Boston March 18, accompanied by Mr. R. W. Pumpelly as assistant, and stopping over at London, Paris, and Berlin, reached St. Petersburg on April 23. There I had to remain several weeks to perfect arrangements and obtain the papers necessary for an extended journey in Turkestan. On May 15 we left St. Petersburg, with Mr. Serge de Brovtzin as interpreter, and having been joined at Baku by Professor Davis and Mr. Ellsworth Huntington, a research assistant of the Carnegie Institution of Washington, we crossed the Caspian.

I found throughout our stay in Turkestan that orders had been sent from St. Petersburg to assist the expedition in all ways, and everything was done to facilitate

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the work. Prince Hilkof's orders obtained for us the continuous use of a car throughout our stay in Turkestan.

While I became deeply indebted to the general hospitality of all with whom we came in contact, I am under special obligations to several gentlemen to whose ready assistance the expedition owes much of its success. From their excellencies Count Cassini and the Hon. Joseph H. Choate, Assistant Secretary of State Mr. Herbert Pierce, and Baron von Richthofen I received valuable letters to St. Petersburg. There, from His Excellency Mr. Semenof, vice-president of the Imperial Geographical Society, I had letters of great importance to high authorities in Turkestan, as well as from Generals Stubendorf and Artemonof. Valuable assistance was rendered by Mr. McCormick, our ambassador, and Mr. Ridler, secretary of the embassy.

Their Excellencies Prince Hilkof, Minister of Ways and Communications; Mr. Plehve, Minister of the Interior, and Mr. Yermolof, Minister of Agriculture, gave me circular letters to all the employees of their departments; while from the office of the Minister of War, who has control of Turkestan, orders were telegraphed to extend any desired aid to the members of the expedition. My plans were also cordially furthered by the Imperial Academy of Sciences at St. Petersburg, which passed a resolution asking the Minister of the Interior to facilitate our journey; by Mr. Karpinsky, then director of the Imperial Geological Survey; Professor Schmidt, and Mr. Bogdanovitch, and by Mr. Tchernachef, now director of the Imperial Geological Survey.

In Turkestan we enjoyed the hospitality and assistance of their Excellencies the Governor-General and Madame Ivanof; General Medinsky, governor of Samarkand; General Nalifkin, vice-governor of Fergana, and Madam Nalifkin; General Ussakovsky, governor of Transcaspia; Colonel and Madame Volkovnikof, local governor of Krasnovodsk; Colonel Kukol-Yasnopolski, governor of Askhabad; General Ulianin, director of the Trans-Caspian railway; General Poslovsky, General Gedeonof, and Colonel Poulovtsoff. I owe the success of our Pamir expedition largely to the active interest and help of Colonel Zaitza, governor of Osh. To Baron Cherkasof, political agent at Bokhara, I owe much for his kindness during my visit to that place. At Old Merv we were entertained with great hospitality by Mr. Dubosof, superintendent of the Imperial estate.

Using the railroad as a base and having horses and escorts wherever needed, we made flying excursions to many points, at different distances from the railroad, both in going and coming.

From Askhabad we made an excursion across the mountains of Khorassan into Persia, accompanied by Mr. Yanchevetzki, the secretary of the governor, and his intimate acquaintance with the water problems and with the country from the Aral south was of great use to us. On our return to Askhabad we were joined by Mr. Richard Norton, who accompanied me throughout the journey.

The next stop was at Old Merv, where we spent several days among the extensive ruins. Thence, passing by Bokhara, and making only a preliminary visit to Samarkand, we went to Tashkent, the residence of the governor-general of Turkestan. Here the party divided, Professor Davis and Mr. Huntington going eastward

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to Issik Kul, where, after a month of joint work, they separated, Mr. Davis returning to America via Omsk and St. Petersburg, and Mr. Huntington going on to Kashgar.

After Tashkent, I visited Marghilan and Andizhan, the end of the railroad.

Continuing our journey to Osh, at the entrance of the mountain region, we organized an expedition to the Pamir, with the courteous aid of its governor, Colonel Zaitza. The way to the Pamir covered part of the route and two of the passes, the Terek and Taldik, in one of the great currents of ancient trade between China and western Asia, and it promised light on the physico-geographical part of our problem. After returning from the Pamir we visited the ruins of Ak-si, in the northern part of Khokand, beyond the Syr Darya, and examined the ruined sites of Samarkand, and of Paikent in Bokhara and a trenched tumulus at Anau near Askhabad.

Throughout the journey, both by rail and in the side excursions, we had occasion to note the existence and position of a great number of former sites of occupation, both towns and tumuli.

It had been my wish to examine Balkh, the site of ancient Bactra, and other ruins of northern Afghanistan, but this was found to be impossible on account of the hostile attitude of the Afghans toward even Russians.

OUTLINE SKETCH OF THE REGION.

A glance at a map of the Eurasian continent shows that the three seas, the Aral, Caspian, and Black, occupy parts of one great basin, bounded on the south and east by great mountains, and on the north by the Aral-Arctic divide.

If the Bosporus were closed and there should exist a continued excess of rainfall over evaporation, these seas would merge and the basin would fill till it overflowed into the Northern Ocean. The area of this Asian Mediterranean would be determined by the height of the northern divide, which is as yet unknown. In any event, it would be sufficient to submerge a large part of southern Russia and much of Russian Turkestan.

If, on the other hand, there should be a continued increase of excess of evaporation, the seas would dry up; the whole basin would be transformed into a vast desert, on the borders of which the retreating river mouths would be lost in the sands. Turkestan, once largely covered by water, is now in a state approaching this condition of aridity. The greater basin is broken up into smaller, disconnected ones, of which only the Black Sea has an outlet. The Aral stands 159 feet above the ocean, the Black Sea practically at ocean level, the Caspian 84 feet below ocean level. The great Volga and several small streams reach the Caspian; east of the Caspian only two rivers, the Syr and Amu (Jaxartes and Oxus), reach the Aral; and they gather water only at their sources in snow-clad mountains; all other streams are consumed by direct evaporation and irrigation and have short courses, ending in desert sand.

According to Schwartz, about three-quarters of all this vast region is desert and one-quarter is capable of supporting the herds of the nomads. Water can be distributed on about 2 per cent of the entire area, on land free from drifted sands.

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Along the base of the southern mountains stretches a chain of narrow oases at the mouths of the mountain valleys; there are other very narrow strips along the larger river courses, and more extensive areas inclosed between the projecting spurs of the eastern mountains; all the rest of the basin has become the prey of the moving sands, which are still very slowly but surely invading the oases. The boundary is sharply defined; within it is high cultivation; beyond it is a sea of waves of sand.

As they extend eastward the southern mountains increase in height, till both they and the great spurs of the Tian Shan, giant snow and ice covered crests and peaks, dominate the oases which are the offspring of their waters. It is on these mountains of snow and ice that the life of the whole region is and has been from a remote period absolutely dependent.

This life is also limited by another factor—itself a result of the desiccation—the moving sands. For, other things remaining equal, while the shrinkage of the water areas can continue only till equilibrium between supply and evaporation is reached, and while there might be also cyclical periods of revivifying afflux, these compensations are offset in the oases by the slow but steadily overwhelming progress of the sands.

The progressive desiccation of Turkestan is shown by direct observations during the past century, by artificial landmarks, by historical statements, and by natural records. The Aibughir Gulf of the Aral was 133 kilometers long and 3,500 square kilometers in area in 1842, and dry land in 1872.

The volume of the Syr Darya has diminished greatly, as shown by the remains of old irrigating canals along its whole lower course, which are now too high to receive water. The statements of Arabian writers show that, within recent historical times, there was a far more numerous population than the country could support now, when all available water is utilized. Old water-level lines occur at various heights up to 225 feet above the Aral.

The progress is not uniform, but is broken by periods of temporarily increased precipitation. Dorandt measured in 1874–75 a fall of 70 mm. in the year in the Aral Sea. Schultz, in comparing his surveys of 1880 with earlier maps, found a lowering of the level of 38 cm. in nine years. On the other hand, Berg, in 1901, comparing the gage established by Tillo, found the level 121 cm. higher than in 1874. He calculates the total rise between 1882 and 1901 to be at least 3 meters, or 178 mm. yearly.

Judging from our observations and from those of others, especially of the Arabian writers and of the later Russian explorers, it would seem that the country has long been an interior region, dependent for its life mainly on the snows and glaciers of the mountains; that there have been within the present geological period great fluctuations in the amount of water derived from the mountains, as recorded in high and low shorelines of the seas and in the strata containing living forms left by different expansions of the united waters of the Aral and Caspian, and that man already existed within the region during at least the last great maximum of moisture.

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EVIDENCES OF FORMER OCCUPATION.

In our earliest historical records we find the country occupied as now by dwellers in numerous cities, surrounded by deserts in which lived nomad peoples. The town dwellers seem to have been at least largely of Aryan stock and the nomads of Turanian.

Who were the contemporaneous and the successive dwellers in the many towns? To what different races may they have belonged? Whence did they come into the land? What were their civilizations and what their relations to other civilizations and to those of the modern world? These are our questions, and they can be answered only to a greater or less extent by a study of the results of excavation and in the concentrated light of comparative science in archeology, ethnology, and language and of survivals in arts and customs; for the answers to some of these questions will be found rooted deep in the human strata of the ancient world. Asia abounds in the fragmentary survivals of stocks, arts, customs, and languages.

The vestiges of former occupation by man are varied in character—in the eastern mountains are pictographic inscriptions recalling those of American aborigines, some rock sculpturing, and rough stone idols. At Lake Son Kul Professor Davis describes stone circles, recalling some of the dolmen-like forms, and at Issik Kul submerged buildings were reported in the lake.

Along the river courses are abandoned canals which can no longer be supplied with water, and the Russian maps abound in indications of ruined towns, "forts," etc. The most important remains are the tumuli and the town sites.

TUMULI (OR KURGANS).

The tumuli proper are accumulations of earth, of rounded, generally symmetrical form, often more or less elliptical in horizontal section. We met with them first along the base of the mountains east of the Caspian, but I saw none at a lower elevation than 250 feet above that sea. From this point eastward they abounded, with some interruptions, as far as to near Andizhan. Generally they were large—100 to 200 feet long and 30 to 50 feet high. They are much more abundant east of the Oxus than to the west. At one point I counted fifteen in sight at once. Besides these larger tumuli, there are, especially along the Syr Darya in Fergana, localities with a great number of small mounds a few yards only in diameter, suggesting burial after battles.

Mounds more or less resembling the larger ones are described by De Morgan at points in northern Persia, and they occur through southern Siberia and on the plains of southern Russia and of Hungary. In all these countries they probably have different origins—different reasons for their existence. Those in Siberia and on the Black Sea have been extensively excavated. There has been some unsatisfactory excavation of those in Turkestan, mostly with unrecorded results. The kurgan at Anau, near Askhabad, which was trenched some years ago by General Komorof, afforded the best exposure of internal structure. It is nearly 200 feet long by 40 feet high and slightly elliptical in horizontal section. It consists of fine, horizontally stratified layers of made earth. Layers of silt and broken cobbles

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alternate with layers rich in gray ashes and charcoal, and others of closely matted fragments of pottery. Animal bones, teeth, and jaws, some of which are partially calcined, occur frequently in all layers, with a few human bones and skulls. Several whole vases and muffle-shaped chests, made of coarse pottery mixed with dung, had been cut by the trench. These appeared to contain only fine ashes and charcoal. Most of the fragmentary pottery is of this coarse quality, but there are also, even at the bottom of the trench, many fragments of finer texture, decorated with

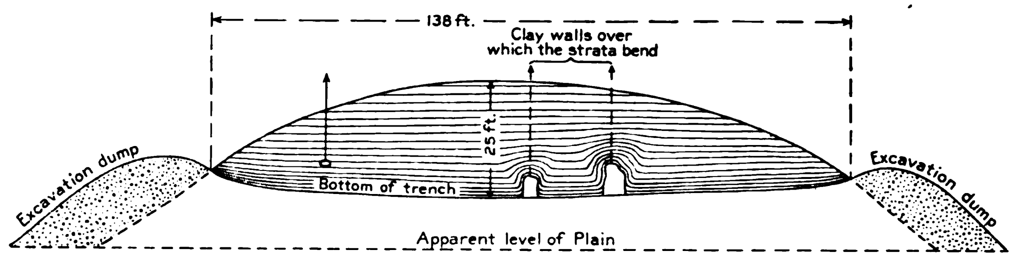

Fig. 1.—Section of the Trenched Tumulus at Anau.

simple designs of black on red. We found several granite stones with curved-plane surface, which had evidently been shaped for mealing grain by the *metate* method, and also a roughly spherical stone, which had apparently been pierced for the insertion of a handle, then to be used as a maul. The whole character of the tumulus shows that it grew from the plain upwards, as a slow accumulation of the débris of long occupation. The fact that the layers, even at the top, extend horizontally to the edges proves that it was formerly flat-topped and much larger, for had it during occupation ever assumed a spherical surface the growth would have

Fig. 2.—The Trench in the Anau Tumulus.

Fig. 3.—The Maul in the Anau Tumulus.

been in concentric layers. The same reasoning would show that it was never abandoned for a long time and again occupied. Since its surface has not been gullied, it seems possible that it was shaped by wind action, although the earth is somewhat firmly cemented. General Komorof found one celt of quartzite and some needles of bone, but absolutely no metal. Of the bones, I sent a representative collection to Professor Zittel, in Munich, for determination.

One peculiar feature in the structure is the interruption and bending over of the layers at the two apparent earth walls. (Fig. 5.)

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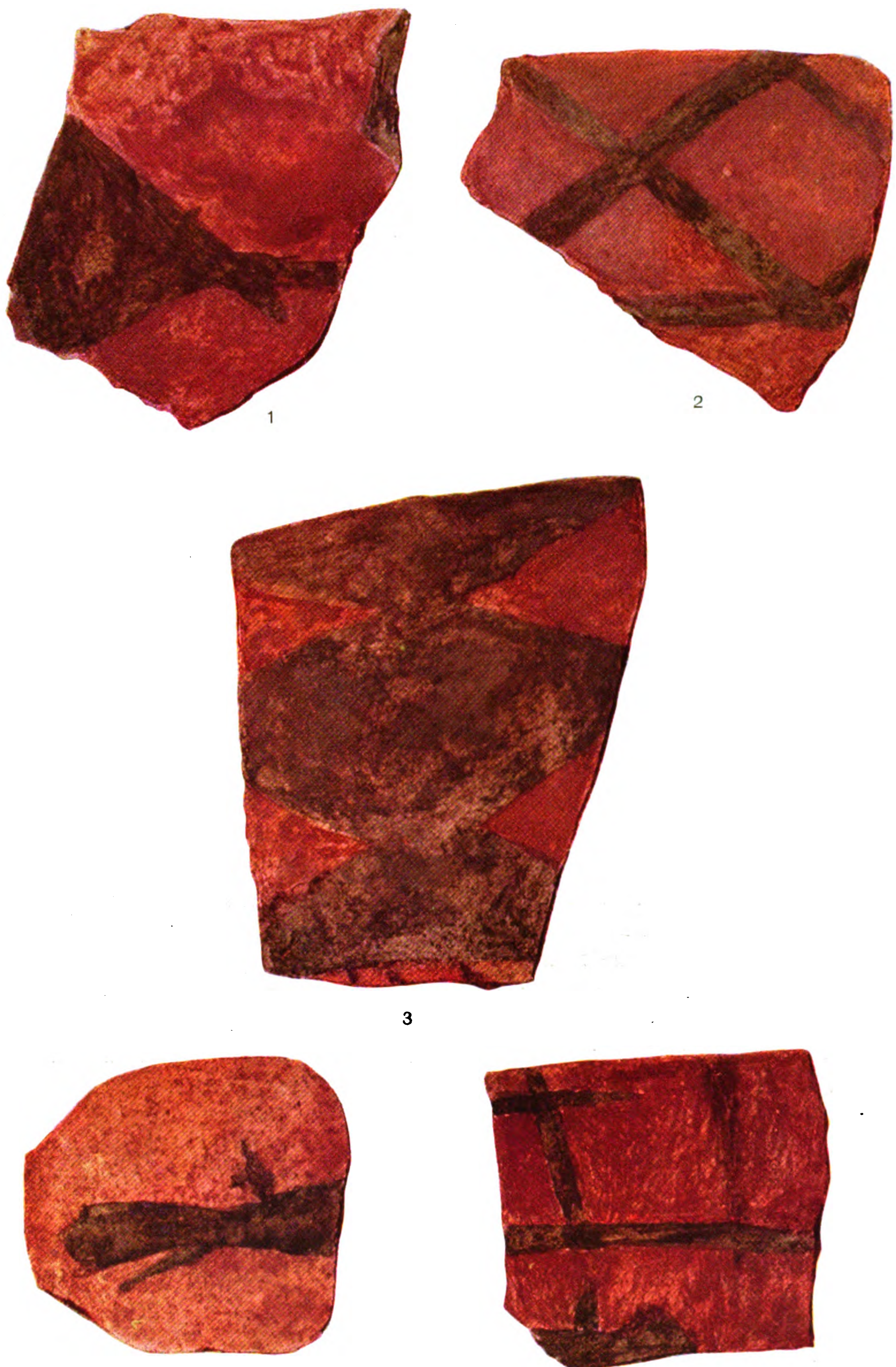

DECORATED POTTERY FROM THE ANAU TUMULUS.

TAKEN FROM THE SIDES AT BOTTOM OF TRENCH ABOUT 10 FEET ABOVE LEVEL OF PLAIN, 1903.

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Several other kurgans that we examined, which had been partially cut away for brick-making, etc., and some of these were much larger and higher than that at Anau, showed the same horizontal stratification of earth, burnt earth, ashes, charcoal, and fragments of bones and of pottery. In the upper part of some of these we observed traces of walls of unburned bricks. The only artifacts found in

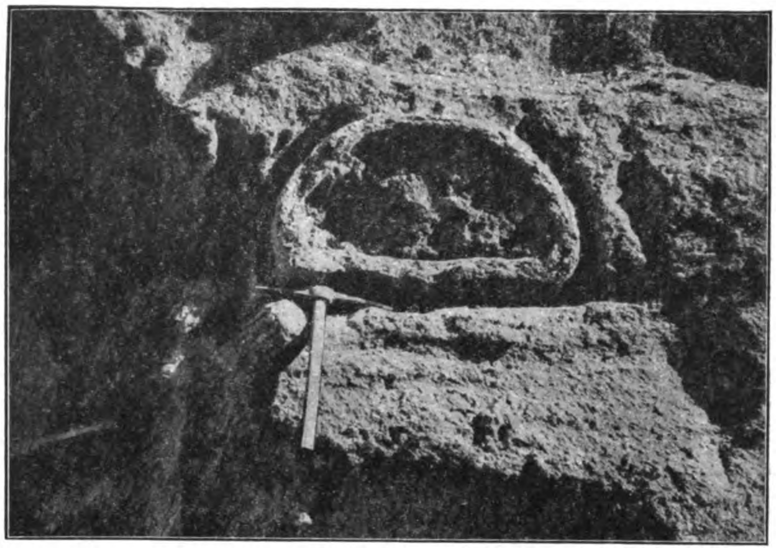

Fig. 4.—Section through a Small Muffle-shaped Object in the Anau Tumulus.

these were the simplest form of flat stone for grinding grain (like those found in the Anau kurgan) and some flat stones, each with a hole drilled wholly or partially through it from both sides.

ANCIENT TOWNS.

The absence of easily obtainable stone for construction throughout the lowlands of Turkestan determined the use, almost exclusively, in construction, of clay, both unburned and burned. Unburned clay predominated immensely, used both as sun-dried bricks and in heavy layers of raw clay. In consequence of this, all ruins older than a late Mussulman period are represented only by accumulations of earth filled with broken pottery and fragments of burned bricks. These accumulations are flat-topped mounds, ranging up to half a square mile or more in area and from 15 to 20 feet upward in height, and in places, as at Merv, occurring in groups covering many square miles. They occur within areas in which now, or formerly, water was accessible, and are found also more or less buried in sands beyond the mouths of the retreating rivers, in places once fertile and now desolate.

Ruins near Atrek River.—A type of regional desolation and abandonment is in the territory between the lower Atrek and the Caspian. Here, over an area of many square miles, are the ruins of cities, 30 or 40 miles from the river Atrek, the

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nearest water, and in the heart of the desert. The remains of canals show that the cities were watered from the Atrek, but the river now lies too low to feed the canals.

Ancient Merv.—The ruins of ancient Merv are said to cover about 30 square miles and consist of several cities of different ages. Two of these—the Ghiaur Kala and the Iskender Kala—appear to be the more ancient. The remains of a circular wall extend, with a radius of about 4 miles, all around these several cities. To judge from its degraded condition, it may possibly represent a very ancient inclosure, within which diminishing populations have rebuilt after successive destructions by war. Merv existed in remote antiquity and is one of the cities mentioned in the Zend Avesta.

The walls of Ghiaur Kala, though now reduced to a hillocky ridge perhaps 50 or 60 feet high, of accumulated débris, inclose plateaus 30 to 50 or more feet high,

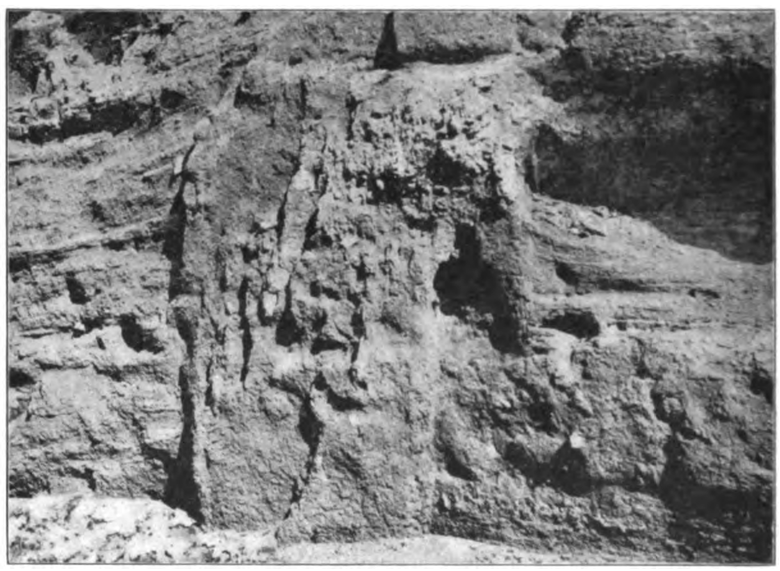

Fig. 5.—Remains of Earthen Wall in the Anau Tumulus.

and a mound 80 feet high which was evidently a citadel. From these walls we could see far away on the northern horizon, in the desert, other flat-topped mounds apparently of great height and extent.

Ruins of Paikent.—The ruins of Paikent represent the type of cities abandoned for lack of water and then buried by the progressing desert sands. Paikent was a great center of wealth and of commerce between China and the west and south till in the early centuries of our era. The recessions of the lower ends of the Zerafshan river brought its doom. Now only its citadel mound and the top of parts of its walls rise above the waves of the invading sands. (Fig. 7.)

Samarkand.—Next to those of Merv the ruins of Samarkand are the most extensive. Its position must have made it an important center of commerce and wealth probably throughout the whole period of prehistoric occupation, as it has been

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during historic times. Situated in the heart of the very fertile oasis of the Zerafshan River, it lies also on the most open and easiest caravan routes connecting China and eastern Turkestan with Afghanistan, India, and Persia.

Samarkand has, even within the past two thousand years, been sacked, destroyed, and rebuilt many times. Like Merv, its rebuildings have often been on adjoining sites, and the determining of the whole area covered by these various sites remains to be made. There is evidence that it is very extensive. The most ancient seems to be the plateau or "tell" called "Afrosiab," to which tradition assigns the site of the Samarkand Maracanda of Alexander the Great. This is a plateau of "made earth," the débris of ruins, standing on the "loess" plain. It is covered to a great extent with Mohammedan cemeteries, with some traces of Mussulman

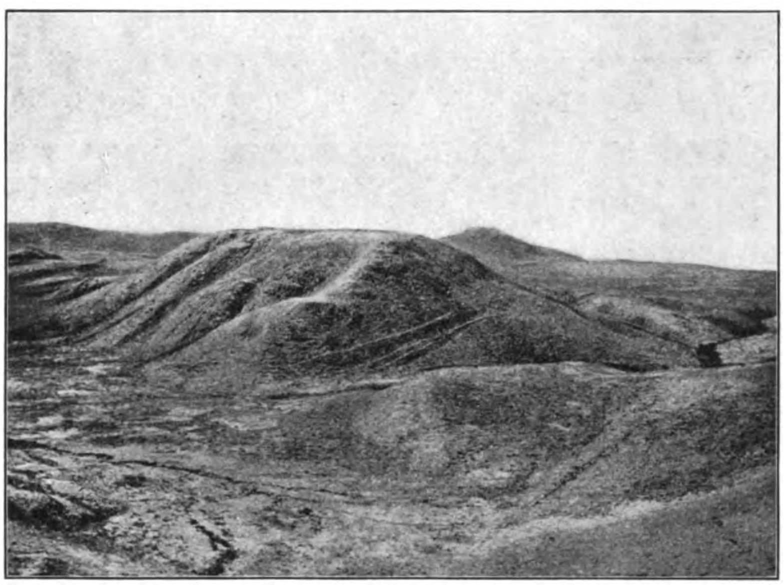

Fig. 6.—Plateau of Accumulated Debris of Occupation in Ghiaur Kala.

occupation, and with fragments of pottery and of bricks. The loess plain is deeply dissected by a stream, and several gullies have been cut in both the plateau of the ruins and the loess. It is difficult to distinguish between the "made earth" of the plateau and the underlying "loess," except through the presence of fragments of pottery, charcoal, and bones.

We found such fragments down to a depth of about 40 feet below the general surface, in the gullies, and it is not improbable that the thickness of débris is still greater. Above this general surface rises the citadel mound to an additional height of 30 to 40 feet, or 170 feet above the stream at its base. Judging from the excellent topographical map of Afrosiab, of the general staff, the loess plain lies about 50 feet above the stream. This would make it possible that the citadel mound represents an accumulation of over 100 feet of débris. The surface of the rest of Afrosiab is very irregular. While in general it ranges from 100 to 140 feet above the stream,

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there are numerous depressions, the bottoms of which are level plains, 150 to 300 feet in diameter, standing 70 to 80 feet above the stream.

The general arrangement of these depressions is such that if filled with water they would form a connected, irregular system of water-basins; and there is a channel about 100 feet wide which opens out on the stream valley, after communicating with most of the depressions. It all suggests a former water system maintaining pleasant pools like those which still form an attractive feature of Bokhara.

The former walls of the city are represented now by ridges rising 20 or 30 feet above the surface within. Where the walls are cut by gullies old galleries are exposed which seem to have been continuous with the wall. Quintus Curtius states 70 stadia as the extent of the walls in the time of Alexander. This, if the short stadia were meant, would be about 3 miles, which would be approximately the circumference of that part of Samarkand now called Afrosiab.

As in all Turkestan, so at Samarkand, the older structures still standing are those of the Mohammedan period. The many immense and wonderfully decorated

Fig. 7.—Paikent, a Sand-buried City.

mosques built by Tamerlane, though now falling into ruin, belong among the wonders of the world; and this not only on account of their great size, but also because of the beauty of their decoration. Seen from Afrosiab, these ruins tower high above the rich foliage of the oasis city—evidence of the wealth of treasure that Tamerlane had accumulated in Turkestan within two centuries after Genghis Khan had sacked the country and massacred much of its population.

REVIEW OF THE FIELD.

What I have been able here to say regarding the archeology of Russian Turkestan seems but a meager statement; but it was soon clear that all that could be accomplished in such a reconnaissance would be the observation of the character and abundance of the evidences of former occupation, and to obtain some idea of their distribution and size.

Our reconnaissance covered a territory nearly 1,400 miles long. It was necessarily only of a preliminary character, and intended to supply a general idea of the problems to be solved and of the best points at which to begin.

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While we have been surprised at the abundance of the data in natural and artificial records offered by the region toward these solutions, we are impressed with a realization of the intimate relation in which this region stands to the Quaternary and prehistoric history of the whole continent. Physically it forms part of the great interior region extending from the Mediterranean to Manchuria, whose history has been one of progressive desiccation, but in Russian Turkestan the effects of this have been mitigated by the snows of the lofty ranges and the lower altitude of the plains.

Archeologically this region has, through a long period, been a center of production and commerce, connecting the eastern, western, and southern nations, and its accumulating wealth has made it repeatedly the prey of invading armies. It has been from remote time the field of contact and contest between the Turanian

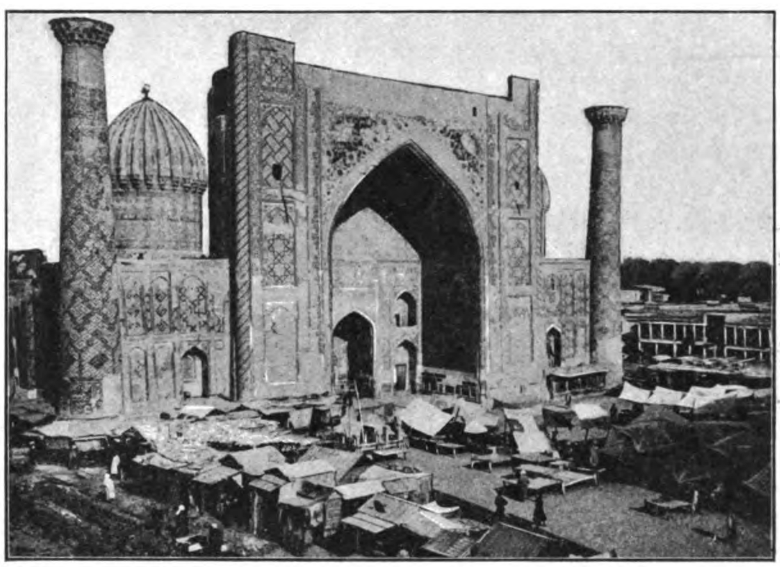

Fig. 8.—A Mosque of Mediæval Samarkand.

and Aryan stocks; but its problems, both physical and archeological, are parts of the greater problem underlying the study of the development of man and his civilization on the great continent and of the environment conditioning that development.

The many fragmentary peoples surviving in the remote corners and in the protected mountain fastnesses of Asia, preserving different languages, arts, and customs, indicate a very remote period of differentiation, with subsequent long periods for separate development. They point also to the long periods of unrest and battling in which the survivors of the vanquished were forced into their present refuges. And this unrest was probably the remote prototype of that which in the later prehistoric and historic time sent out its waves from the Aralo-Caspian basin. It was probably from the beginning a condition in which the slowly progressive change toward aridity in interior Asia was ever forcing emigration outward, displacing

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other peoples, and thus working against the establishment of a stable equilibrium of population. Asia is thus the field for applying all the comparative sciences that relate to the history of man. The materials lie in cave deposits, in rock pictographs, in tumuli, dolmens, and ruined towns, in languages, customs, religions, design patterns, and anthropological measurements.

Turkestan, from its geographical position, must have been the stage on which the drama of Asiatic life was epitomized through all these ages of ferment. Peoples and civilizations appeared and disappeared, leaving their records buried in ashes and earth; but the fertility of the soil produced wealth, and the position kept it ever a commercial center.

So far as our problems of archeology and physical geography are concerned, Turkestan is practically a virgin field. In geology and cartography the Russians have done a surprising amount of excellent work; but the modern methods of physico-geographic study have only begun to be applied, and the little archeological work done there has been mostly in the nature of hunting for curios and treasure, chiefly by foreigners, and in so destructive a manner that the Russian government has till now wisely prohibited excavations.

The importance of Russian Turkestan as a field of archeological research becomes evident when we consider, on the one hand, its vast number of sites of former occupation, and on the other the great distances that separate it from points at which such research has been conducted. To the south the whole region from India to Susa, on the border of Mesopotamia, is practically untouched. To the west we must cross the Caspian, to find, in the Caucasus and around the Black Sea, scientifically conducted excavations. On the east, beyond the high passes of the Tienshan, some good work has been done by Stein and Gruenwedel in the buried

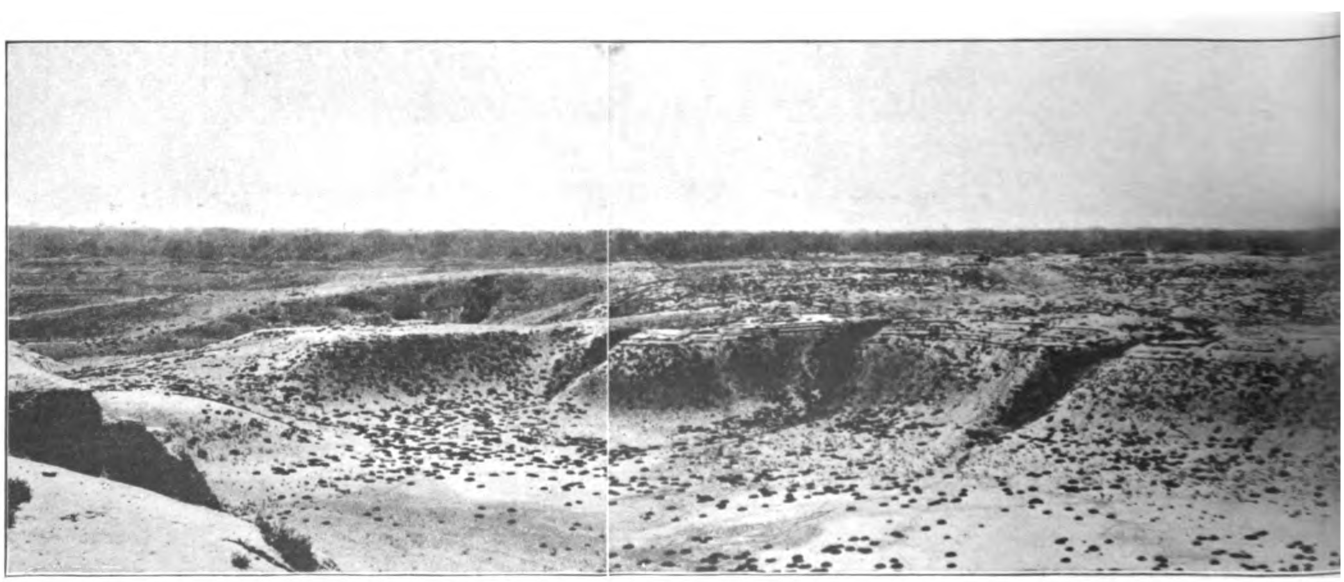


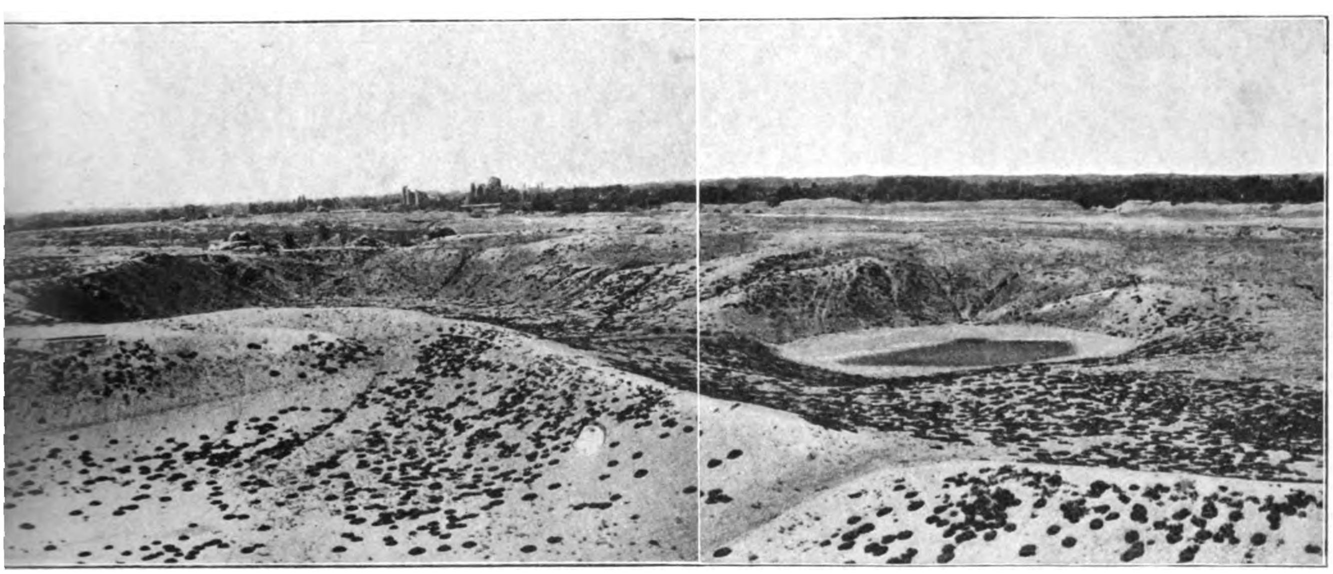
Fig. 9.—Water Pool System in the (

cities of Chinese Turkestan, and much more, of a destructive character, by others. To the north we must cross the great deserts and steppes to reach in Siberia the nearest systematic excavations of Radloff and others.

In Persia, M. J. de Morgan has for several years been conducting a thoroughly scientific investigation at several points, and especially at Susa, where he has already obtained results of the greatest interest. The acropolis of Susa is 105 feet high. M. de Morgan's preliminary tunnels, run into the hill at different levels, showed it to be composed of made earth from the base upward. Stone implements and pottery abounded up to 36 feet from the top. The pottery improved from below up, and among the fragments he recognized a variety belonging to a group peculiar to Egypt, Syria, Cyprus, and most of Asia Minor, but not known from Mesopotamia. De Morgan had found this in predynastic tombs in Egypt, and ascribed it to a period before the eighteenth century B. C. At 45 feet below the top he found tablets and cylinders with cuneiform inscriptions which Scheil considers as belonging to a period before the fortieth century B. C.

M. de Morgan asks: "If the refined civilizations of the past 6,000 years, with their great structures and fortifications, have left only 45 feet of débris, how many centuries must it have required to accumulate the lower 60 feet, when man used more simple materials in the construction of his abodes?"

The thickness of made earth in the abandoned sites of Turkestan is sufficient to give reason for expecting evidences of very long continued occupation. The dryness of the climate makes possible the preservation of any traces of written or incised documents that may have existed. Excavation conducted with the idea that everything met with—the earth itself, the character, position, and association of fragments—is part of history, can not fail to be most fruitful in results.



...lations of Ancient Samarkand.

It is the opinion of an important school of archeologists that the earliest products of metallurgy in bronze and iron successively progressed to the western world from the far East—a progress that in each case carried with it a revolution in civilizations. We do not know whether this region saw the birth of the metallurgy of those elemental substances which—beginning with copper and tin and progressing through bronze to iron and steel and the use of coal—marks the birth of civilization and its great revolutions. If it was not the birthplace of this art, and if it was a distributing center, it is a long step nearer to any far eastern source, whether this was China, East Turkestan, India, or Persia.

RESULTS IN PHYSICAL GEOGRAPHY.

Both our own observations and the excellent and extensive work of the Russian geologists show that the progressive desiccation of the region has greatly diminished both the area of cultivable land and the volume of water, and greatly reduced the population. Is this change a phase of cyclical phenomena—of cycles of long periodicity? In what relation have the geologically recent secular phenomena in central Asia stood to man and civilization in that region and to the outside world?

One of the chief objects of the reconnaissance of the past season was to determine whether a systematic investigation would be likely to throw light on these questions. Perhaps the most important result is our finding that successive physical events have left such abundant records, written in large strokes, all over the mountains and the plains.

The work of this year has not only made a most promising beginning in this interpretation, but has shown that it is probably possible to correlate the different events among themselves and with the period of human occupation, and possibly with similar physical events in Europe.

As an interior region, central Asia is arid and dependent for its water almost wholly on its bordering mountains. It is also self-contained, *i. e.*, without drainage to the ocean. Changes of climate, resulting in great fluctuations of water supply, would therefore probably be recorded by old shorelines at different levels. They might also be more or less legibly recorded in the evidences of repeated glaciation and erosion in the high mountains.

It will be seen from the report of Professor Davis that he has found traces of an old shoreline about 600 feet above the west shore of the Caspian Sea, and a very distinctly marked one on the east side, at an elevation of 200 feet or more. Further search for shorelines was left to form the object of a more extended special study than could be made in our general reconnaissance.

In the eastern mountains, near Issik Kul and Son Kul, Professor Davis found clear evidence of two and probably three glacial epochs. Mr. Ellsworth Huntington, working in the higher Tian Shan, found proof of three epochs, and later of five phases, in the successive moraines of a large number of glaciers studied by him in

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the Alai Mountains. Between some, at least, of these there were long interglacial intervals. Mr. Huntington reports records of climate oscillation shown not only in these moraines, but also in the valley terraces, and considers them to be members of a group of sympathetic glacial phenomena.

Professor Davis noted along the northern edge of the Kopet Dagh, the mountains bordering the plains east of the Caspian Sea, and in the eastern mountains evidence of a longitudinal dislocation, accompanied by great block uplifts, formed apparently after the wearing down of the mountain masses to a peneplain and preceding an active dissection of the elevated mass. This dislocation had been already observed by Muschketof, who states that it extends far along the edge of the Kopet Dagh.

Mr. R. W. Pumpelly studied independently the region from the Syr Darya southward across the two mighty snow and ice ranges, the Alai and Trans-Alai. He found clear evidence of two long-separated glacial epochs recorded in extensive moraines, and, on the Pamir, in apparently corresponding high shorelines around Lake Kara Kul. These glacial epochs he has correlated with orogenic movements of the Trans-Alai, there being a definite relation between the glacial trough bottoms of the two epochs and the present stream floors. In the Alai range, he found that there had been a block uplift followed by a block tilt, both with a dislocation through the border of the lowland plains to the north, and leaving their records in alluvium-capped hills and terraces along the valley sides and in the dragging up or tilting of the fluvial sediments or river fans on the lowland borders. These movements he has correlated with the glacial geology, making the block tilt an interglacial event.

These block uplifts, by lowering the base level, caused a remodeling of the mountains, and have left their record on the lowland plains, which they have helped to create, by the vast amount of material poured out on them by the eroding streams.

The block-uplifting and the tilting being correlated with the growth of the alluvial Fergana lowlands, and the relation of the glacial expansions to the valley-cuttings in the Trans-Alai range being clearly recorded, it becomes a matter of great interest to correlate these Quaternary events of the Trans-Alai valleys with those of the Alai range and the lowlands, and the growth of the plains with the progress of human occupation.

It is not impossible that, by extending the study of glacial records from the Central-Asian ranges through the Elburg and Caucasus, it may be practicable to correlate Asiatic and Alpine glacial events; and since the great basin was fed both by glaciers of the southern ranges and by the great ice cap of Russia, this correlation of both might be effected; for, in view of the great orogenic movements to which the Caucasus, the Persian Mountains, and the Tian Shan have been subjected, it can not be positively asserted that the Central-Asian glacial expansions were all contemporaneous with phases of the mundane glacial epoch.

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RECOMMENDATIONS.

Since Turkestan is under the control of the Minister of War and much of its frontier is closed to travelers, it is necessary to have the permission and good will of the government in order to pursue investigations. To inaugurate any extensive plan of archeological excavations will require tactful negotiation at St. Petersburg. I have good reasons for believing that the desired concessions can be had on a basis of division of objects found, and with a sufficient time allowance for the study of all the material. Such a plan should include both town sites and large and small tumuli. Of town sites I would recommend the following, as points to begin on, in the order stated:

Town sites.—Afrosiab (Samarkand), Ghiaur Kala (Old Merv), Paikent (west of Bokhara), Aksi (on the Syr Darya); the high ruins seen several miles to the north of Ghiaur Kala; a very high one seen from the railroad a few miles west of the Amu Darya.

Tumuli.—Both the tumulus mentioned at Anau, near Askhabad, and another a short distance from it; others west of Askhabad, north of Old Merv, and near Jizak; also many mounds of small size which seem to have a different significance.

As bearing on the age of the tumuli, it is important that the relation of the base of the mound to the surrounding earth be studied to determine by how much, if any, the level of the plain has been built up since the first occupation of the site, and to see also by how much the mound has shrunken in size at its base, as it certainly has in horizontal section at the top. In connection with the question of age of the tumuli and in relation to the last expansion of the Aralo-Caspian seas, it would be very desirable to determine the lower altitude limit of distribution. I did not see any below 250 feet above the Caspian.

Similar observations are needed on the west coast of the Caspian, where De Morgan found no antiquities on the lowlands in the Lenkoran country, but at a higher level abundant tombs of the bronze period and of the transition to iron.

As further connected with the relation of human occupation to the formerly expanded water area, there is needed a determination of the altitudes of the Manytsch divide between the Caspian and the Black Sea, and of that between the Aral and the Arctic Ocean. Both of these are now not far from railroad bases.

As regards further work in physical geography, Professor Davis writes:

"The order in which I should like to see the * * * studies taken up on the plains, in order to define most rapidly the conditions of early human history, is as follows:

"The shorelines of the Caspian and Aral seas; first on the southwest, south, and southeast, then on the northeast and the associated plains.

"The double belt of piedmont plains and bordering ranges with special work in certain glaciated valleys.

"The deposits of loess from Samarkand to Tashkent.

"The Issik Kul basin, by a special, independent party.

"Secondarily, Block mountains and the Narin formation."

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SUMMARY.

We have shown that the recent physical history of the region is legibly recorded in glacial sculpture and moraines, in orogenic movements, in valley cutting and terracings, in lake expansions, and in the building up of the plains, and we have made some progress in correlating these events.

We have also found full confirmation of the statements as to a progressive desiccation of the region of long standing, which has from a remote period continually converted cultivable lands into deserts and buried cities in sands.

We have found, widely distributed, great and small abandoned sites of human occupation, with evidences of great antiquity.

We have reason to think that a correlation of these physical and human events may be obtained through continuance of the investigation, and that archeological excavations will throw light on the origin of Western and Eastern civilizations.

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A JOURNEY ACROSS TURKESTAN.

By WILLIAM M. DAVIS,

Sturgis-Hooper Professor of Geology, Harvard University.

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A Journey Across Turkestan.

By William M. Davis,
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ITINERARY.

On April 17, 1903, accompanied by Mr. Ellsworth Huntington, who had been appointed research assistant by the Carnegie Institution of Washington, I left Boston; sailed from New York, April 18; landed at Cherbourg, April 24; spent April 25 in Paris, April 28 in Vienna, and May 1 to 3 in Constantinople; crossed the Black Sea to Batoum, May 4 to 8; and went thence by rail to Tiflis, May 10, and to Baku on the Caspian, where we arrived May 12. We crossed the Caspian on the night of May 22, and started from Krasnovodsk on the Central Asiatic Railway on the afternoon of May 24. After making short stops at Jebel, May 25, Kizil Arvat, May 26, and Bakharden, May 27, to examine the piedmont border of the great plains of Turkestan, we delayed at Askhabad, May 27 to June 9, long enough to make a five-day excursion, May 30 to June 4, into the Kopet Dagh, the mountain range along the Russo-Persian frontier. Leaving Askhabad by train the evening of June 9, we stopped at Merv, June 11 to 14, and Samarkand, June 16, and on June 17 reached Tashkent, where we remained three days. On June 20, accompanied by Mr. Huntington and Mr. Brovtzine, interpreter, I went by rail to Andizhan, where we stopped from June 21 to June 27, to outfit for an excursion across the western ranges of the Tian Shan Mountains to Lake Issik Kul. We set out from Andizhan, June 27; spent two days, July 8 and 9, at Lake Son Kul; reached Issik Kul on July 14; made a short trip into the mountains on its southwestern side, and then moved along the northern shore to the Russian settlement of Sazanovka. Here, on July 22, Mr. Huntington turned southward to begin his excursion to Kashgar, with the object of continuing over a large district of the high ranges the study of old moraines and terraces that we had begun together on the road to Issik Kul; while I turned northward with Mr. Brovtzine and began my homeward journey. Vyernyi was reached July 26; we went in tarantass to Semipalatinsk, August 2; by boat down the Irtysh to Omsk, August 7; by train to St. Petersburg, August 15, where Mr. Brovtzine resided; I continued by train to Ostend and London, August 17; and by steamer from Liverpool to Boston, August 20 to 28.

NATURE OF OBSERVATIONS.

In the geologic and physiographic reconnaissance of the region traversed, the chief subdivisions of Turkestan were visited in the following order: The Caspian Sea on the west, the central plains, and the mountains on the south and east.

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While it may be desirable later to make as precise a determination as possible of the geological date and of the physiographic surroundings of human monuments or artifacts, it did not seem advisable to combine detailed local observations with a general reconnaissance during our first season in the field. My work was therefore directed to gaining a broad view of the region and its development, from which it should be possible to plan and direct a series of more thorough studies regarding the subdivisions of later geological time, in case such studies are to be undertaken in the coming years. It is a matter of regret that, owing to the deficient representation of Russian material in our libraries, it has not been possible to make as full a study of the work of earlier observers as was desired in the preparation of this report.

THE CASPIAN REGION.

The region traversed naturally divides itself into three parts: The sea on the west, the mountains on the south and east, and the plains between the two. The waters of the Caspian are gathered in an area of relative depression; the mountains are the scene of active erosion because of their relative elevation; the rivers strive to carry the waste of the mountains down the very gentle slope of the plains and deposit it in the sea. The climatic changes, well proved to have taken place over other parts of the world in later geological times, may be believed to have had their effect in this region also. The Caspian is known to have stood at a greater height and to have covered a much larger area in Quaternary time, especially to the east and north, as is attested by its abandoned strands and shell deposits; the existing glaciers of the eastern mountains have been longer than they are now, as proved by their abandoned Quaternary moraines, reported by various explorers; the rivers between the mountains and the sea must have, in some way appropriate to themselves, responded to these varying conditions at their two extremities, and hence even in the strata of the plains some record of Quaternary climatic variations may be discovered.

There can be no question, however, that the record of Quaternary climatic variations on the plains would be of much more difficult recognition than in the mountain valleys on the east, or around the great sea basin on the west. It was for this reason that my reconnaissance was directed chiefly to the Caspian shorelines and to the extinct glaciers of the Tian Shan, and that the study of the plains was left to a later year.

THE TERTIARY AND QUATERNARY CASPIAN.

The existing Caspian Sea is the successor of the expanded water body of late Tertiary time which made the Black, the Caspian, and the Aral basins confluent and which laid down a series of stratified deposits, known as the (Tertiary) Aralo-Caspian formation, apparently the equivalent of the Congerian or Pontic stage of Europe. These deposits are now more or less deformed and eroded; for example, near Baku and next eastward in the Apsheron peninsula, where the Caucasus range

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descends into the Caspian. Here a typical section shows anticlinal and monoclinal Aralo-Caspian ridges, with strata dipping 20° or 30°, and crests rising from 600 to 800 feet over the present Caspian level. The existing Caspian is by a still greater measure of time separated from that ancestral water body in which the Akchlagyl strata of the Ust-urt plateau as described by Andrussof (1902) were laid down, these being pre-Pontic and post-Sarmatian. The Tertiary seas represented by the Sarmatian and Mediterranean stages (Miocene) were yet more ancient. Their deposits are so widely distributed on existing lands and so much deformed and eroded that their parent waters had little resemblance to the seas of to-day.

The Quaternary Caspian, with whose shorelines and deposits we are concerned, is more modern than the latest of the seas above named. It does not seem to have been the immediate successor of the expanded Tertiary seas, for although Neumayr thought that there had been a progressive diminution of water area from Sarmatian times, not interrupted by expansion even during the glacial period (1875, 32), Andrussof says that at the end of the Tertiary the Caspian was probably lower than at present (1888, 113). Our observations confirm the latter view. There must have been indeed a considerable period of late Tertiary or early Quaternary time when the Caspian had a lower level than now, for not only the high-level Quaternary shorelines, but even the present Caspian shorelines, contour around the eroded ridges of the deformed (Tertiary) Aralo-Caspian strata at Baku. The low-water epoch between the Tertiary and Quaternary periods of Caspian expansion must have endured for a much longer measure of time than that of the Quaternary high-water stage and the present mid-water stage, taken together; for the erosion that the deformed (Tertiary) Aralo-Caspian strata suffered before the Quaternary Caspian rose upon them at Baku is hundreds of times greater than the sum of the erosions recorded in the Quaternary strands, and thousands of times greater than the erosion that the strands have suffered since the waters retired from them. It is also important to note that the historic oscillations of the Caspian are all short-lived events, and that their order and rate of change can not be safely used to determine the time since the high-level Quaternary shorelines were occupied.

The Quaternary Caspian appears to have been confluent with the Aral on the east, as will be more fully stated farther on; hence the term Aralo-Caspian has been applied to this expansion of the sea as well as to that of late Tertiary time; and it is not always easy to understand which sea is meant when this ambiguous name is employed. The Quaternary Caspian was also confluent with the Black Sea, for its strands are hundreds of feet above the existing water level, while the pass between the two seas in the Manych depression north of the Caucasus range is only 26 feet over the Black Sea, and 112 feet over the Caspian. It is indeed eminently possible that the confluence of the Caspian and Black seas may have taken place at the time when the Bosporus was a normal river; hence our passing sight of this beautiful water passage was of peculiar interest in connection with our later observations farther east.

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THE BOSPORUS.

The Bosporus has been well described by Philippson (1897) as a young river valley incised in an uplifted peneplain ("eine typische Denudationsfläche"); a very modern depression has changed the normal river valley to a strait, about 160 feet deep, leaving the uplands of the peneplain still from 700 to 1,000 feet above sea level. All that I saw from the steamer's deck, on two passages through the Bosporus, and from a walk on the uplands back of Robert College, about 5 miles north of the Golden Horn, fully confirmed this interpretation. The deformed rocks in the walls of the gorge, the wide view over the undulating uplands with their subdued residual hills or monadnocks (fig. 10), the sharp dissection of the upland by the winding main valley and its branches, and the general appearance of submergence along the present shorelines, admit of no other explanation. The space available for occupation along shore is commonly so narrow that houses are often built directly on the water's edge. The water is so deep close to the shore that large vessels may make near approach to the land. As a result, collisions not infrequently occur between bowsprits and house walls; we saw a house from which one corner had been torn out in such an encounter. The Golden Horn is simply the drowned lower part of a side valley that comes into the Bosporus at Constantinople from the northwest and north. Philippson dates the erosion of the gorge as not older than the Upper Pliocene; the depression of the region, changing the Bosporus from a river to a strait, is placed in the recent past, during the existence of man.

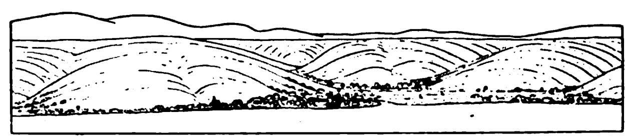

Fig. 10.—Sketch of the Uplands across the Bosporus, looking eastward from near Robert College, north of Constantinople.

THE SOUTH COAST OF THE BLACK SEA.

The reasons for suggesting that the Caspian and the Black seas may have been confluent before the Bosporus was submerged are based on certain indications that the land at the southeastern end of the Black Sea was lower than now at the time when the land at the southwestern end was higher. These indications are as follows: The coast at and to the east of the Bosporus (fig. 11), as seen from the passing steamer, showed sharply cut modern cliffs, but no benches or terraces above the present shoreline. The map of the region, in Stieler's Hand-Atlas, shows no delta at the south of the Sakaria River, about 90 miles east of the Bosporus. At Samsun, near the middle of the south coast, where our steamer

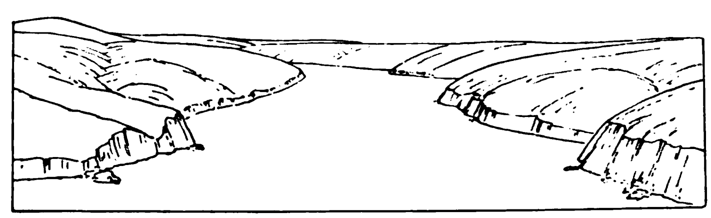

Fig. 11.—Bird's-eye Diagram of the Bosporus at its exit from the Black Sea.

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stopped for a day, the headlands to the west and east showed no elevated sea-cut benches, but they were both well cliffed with respect to the present shoreline; a low foreland, from 300 to 600 feet wide, stretched in front of the western cliff, as in fig. 12. Whether the foreland was a slightly elevated wave-cut bench, or simply a broadened wave-built beach, I could not determine, as it was seen only from the steamer; but in either case its attitude is inconsistent with any strong recent movement of depression or elevation. Further indication of modern coastal stability in this district is seen in the large deltas of the Kyzil Irmak and Yeshil Irmak (the Halys and Iris rivers of ancient times), 20 miles west and east of Samsun. Stieler's Hand-Atlas makes the radius of these deltas 12 or 15 miles, although the Yeshil, the smaller of the two rivers, has a drainage basin of less area than the Sakaria, where no delta is shown. A heavy rain fell while we lay in the roadstead of Samsun, and a stream east of the city spread its yellow flood gradually farther and farther from the shore. When the discolored water reached the steamer, half a mile from land, it still formed so thin a film that the oars of passing boats disclosed the blue water beneath. We steamed eastward past the delta of the Yeshil about sunset. It is an extensive plain, hardly above sea level, in strong contrast to the bold coast that we had seen earlier.

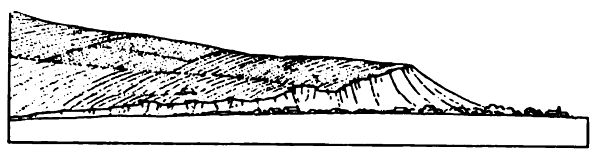

Fig. 12.—Sketch of Headland and Foreland, west of Samsun, south coast of Black Sea, looking west.

When we reached Trebizonde, near the southeastern corner of the sea, the profile of the sloping spur next east of the harbor exhibited three well-defined benches, outlined in fig. 13, which we estimated to stand 20, 100, and 250 feet above sea level; and a small stream that passed through the city flowed in a narrow, steep-sided gorge. Thus there seems to be indication of a modern depression of 160 feet at the Bosporus, of no significant modern movement at Samsun, and of a modern elevation of from 100 to 250 feet at Trebizonde. But somewhat farther northeast, at Batum, there was again indication of stability rather than of elevation. No benches were seen there on the hillsides, but the Choruk-Su (river), of drainage area similar to that of the Yeshil, has a well-formed gravel delta that stretches several miles forward from the end of its steep-sided valley through the mainland hills. The absence of elevated shorelines here makes it hazardous to extrapolate, towards the Manych depression and the Caspian, the indications of recent tilting that we found on the south coast.

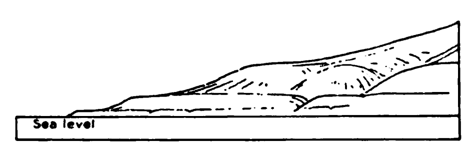

Fig. 13.—Profile of Elevated Shorelines east of Trebizonde, south coast of Black Sea, looking east.

A few words may be said on the possible eastward extension of the uplifted peneplain in which the Bosporus trench is cut. The south coast of the Black Sea is submountainous. The valleys that we saw were rather sharply incised in uplands that sloped with moderate irregularity from higher hills or mountains in the background toward the cliffs of the shoreline. It seemed plausible to associate

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these sloping uplands with the more nearly horizontal uplands of the Bosporus, and to regard them both as parts of a peneplain, with many unconsumed residuals or monadnocks, in a late Tertiary cycle of erosion. A very moderate warping would suffice to have depressed part of the peneplain in what is now the basin of the Black Sea, and to have raised an adjoining part in what is now the sloping northern border of Asia Minor. The sloping uplands would then be dissected by valleys, whose depth would rapidly increase inland, and whose sides would have a younger expression than that of the uplands in which they eroded, as was so distinctly the case along those western, middle, and eastern parts of the coast that we saw.

A day ashore at Trebizonde was given chiefly to the gravels that lie on the uplands back of the city. Level beds of ashy gray sands and gravels, covered with angular waste which has crept down from the next higher ledges, were found in two localities on the steep hillside about 300 feet above the sea level (A, fig. 14);

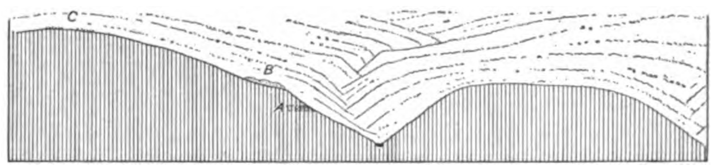

Fig. 14.—Diagram to illustrate the occurrence of gravels near Trebizonde.

more extensive beds of yellowish gravel (B) occurred at a height of 500 or 550 feet on the shoulders of the sloping upland where it was cut by the narrow valleys. Scattered pebbles (C) occurred at still higher levels, up to about 800 feet. These gravels have been described by Wright, who regards them as later than "the entire rock erosion of the region" (p. 249).

It was not possible, in the short time at our disposal, to reach an independent conclusion as to whether the gravels were older or younger than the valleys of the district. No fossils were found in them, and hence it can not be said whether they are of marine or fluviatile origin. It should be stated that the uplifted shorelines, next east of Trebizonde, seemed to turn somewhat inland along a valley side; hence the relation of higher sea level and valley erosion is not a simple problem.

THE QUATERNARY CASPIAN SHORELINES NEAR BAKU.

It has already been pointed out that the present shoreline, as well as the elevated shorelines, of the Caspian skirt an eroded surface of late Tertiary Aralo-Caspian strata in the Baku district. Hence the waters of the sea must have been, for a considerable part of early Quaternary time, lower than they are now. This lower water stand, inferred from physiographic evidence, should not be confused with the lower water stand during the historical Middle Ages, about the tenth century, as demonstrated by the occurrence of the walls of several buildings (H, fig. 15), nearly submerged a few hundred feet offshore in Baku Harbor. Nor should the

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rate of lowering of the Aral in the past century be taken, as it has been by Obruchef (1890, 253), as a basis for calculating the antiquity of the Aralo-Caspian Sea; the fluctuations of the Caspian and the Aral in modern times, or of Great Salt Lake, are episodes of the existing climate, and should not be assumed to have been in continuous progress since the middle Quaternary. It should be noted, however, that a long-continued tendency toward increased aridity appears to characterize the Caspian region in the historic centuries. A detailed account of recorded changes of level in the Caspian is given in Brückner's excellent summary (1890). The story, current in Baku, concerning an old road marked by wheel tracks that descend below water level on the island of Nargin, 8 miles from Baku, appears to be without valid foundation. We visited the island and walked all around its

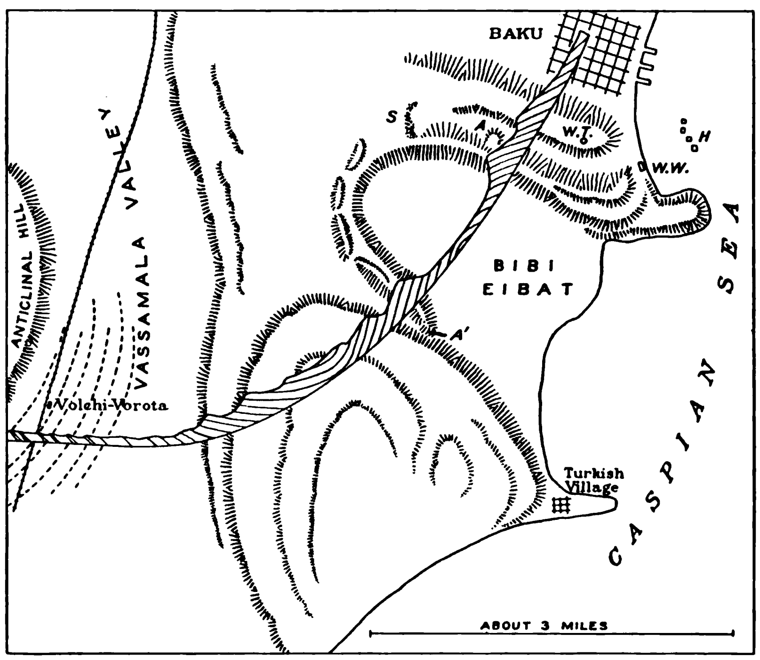

Fig. 15.—Sketch Map of the District southwest of Baku.

shores without finding the semblance of an old road, thus unconsciously repeating the negative conclusion of Eichwald and Chanykof (cited by Brückner, 64). It is worth noting that the chief water supply for Baku, apart from certain springs that are unpalatable to the European residents, is derived from distillation of the brackish Caspian water with cheap petroleum fuel; the latent heat given out in condensation of the steam is economically used in warming the next intake of water from the sea. The water works (WW) and the water tower (WT) are indicated in fig. 15.

The most notable feature of the elevated Caspian shorelines near Baku is their comparative faintness. They are not marked by strongly cut cliffs or by continuous benches, but by rather discontinuous benches, much less pronounced than the shorelines of to-day. In spite of the large size of the Caspian, its abandoned shore-

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lines are much less developed than are those of our Quaternary Lakes Bonneville and Lahontan in Utah and Nevada, or of our Laurentian Glacial Great Lakes in New York and farther west. The Caspian shorelines are, however, easily recognized at many points on the hillsides about Baku, where they are marked by horizontal benches of cobbles, gravel, and shells, more or less cemented, at various levels up to 300 or 500 feet (fig. 16). Sjögren says that the last rise of the Caspian left marls and clays 50 or 55 meters over the present water level. On the most exposed headland that we visited, about 6 miles northeast of Baku and 160 feet above the sea, blocks of sandstone, 5 or 10 feet in size, were detached from their ledges and left standing in disorderly attitudes, which seemed less the result of ordinary pro-

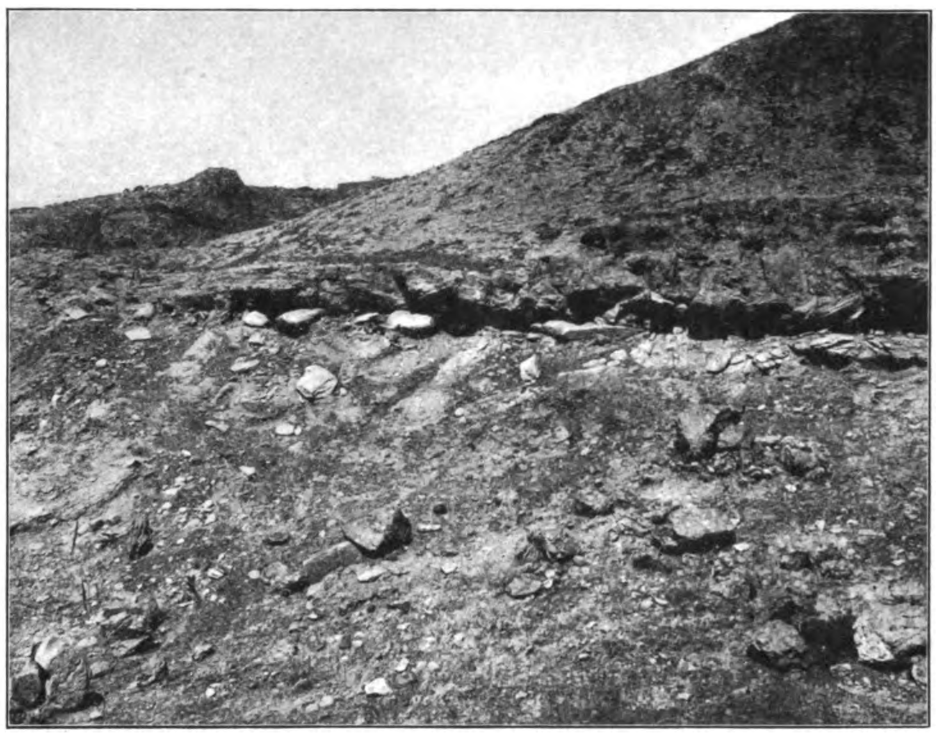

Fig. 16.—An old Caspian Shoreline, near Baku.

cesses of weathering than of former seashore forces. There are also occasional mounds or delta-like deposits of fine silt in protected re-entrants of former shorelines as at A, fig. 15, at altitudes similar to those of the cobble benches; but these features are so discontinuous that it was not possible to correlate them safely. Their discontinuity does not appear to be due to subsequent erosion, for none of the shore records seem to have suffered significant change, except one of the silt deposits that lies in a ravine, and that has been channeled by its wet-weather stream. This silt deposit (A′, fig. 15) is just west of Bibi-Eibat and contains land shells in its upper part, but its form and position are such as to indicate the deposition of its greater volume as a delta. It lies on a bed of well-rounded cobbles and bowlders, exposed

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in the ravine, and thus shows that the high-water stand when the silt was deposited had been preceded by a time of less high water. A few miles east of Baku, a flat hill-top (B, fig. 17) was sparsely strewn with water-worn cobbles at a height of 430 feet; and here we found a well-formed pothole, about 3 feet in diameter, and of somewhat less depth, with a round stone lying in it. Southwest of Baku, near the southern end of the monoclinal ridge beyond the oil-wells of Bibi-Eibat, a small patch of cemented cobbles, pebbles, and broken shells lay at a height of about 460 feet; but it may be that this is simply a remnant of a Pliocene deposit.

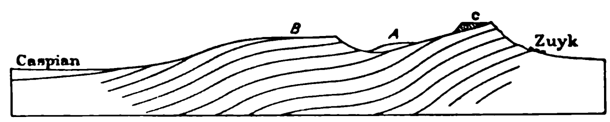

Fig. 17.—Three-mile section of Ridge, six miles northeast of Baku, looking north.

The most interesting records of the modern high-level Caspian near Baku were found in three cobble spits at about 600 feet altitude above the present water level. As no accounts of the Baku district that I have read make mention of shore records

Fig. 18.—The Oil-Wells of Bibi-Eibat, two miles south of Baku, looking south.

at so great an altitude, these spits will be described in some detail. The first one was found at S, fig. 15, on the top of the horseshoe ridge of the late Tertiary Aralo-Caspian (Pontic) sandstones that incloses the anticlinal valley of the Bibi-Eibat oil-wells. The spit was somewhat east of the apex of the ridge curve. The anticline is figured in section in the little handbook, "Guide VII des Excursions du VII

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Congres international géologique," and the section is reproduced by Mushketof (1899, I, 304). The ridge may be reached by going up-hill, southwest from Baku, past a church and cemetery on a gravel-covered bench that overlooks the city at a height of about 330 feet. A quarry on this bench shows the late Tertiary strata, with abundant shells. The view from the ridge over the Bibi-Eibat valley with its oil-wells and the Caspian beyond (fig. 18) is a repaying one. The spit is 250 feet wide at its proximal end, 20 or 25 feet thick, and 1,300 feet long; it trends N. 20° W. (magnetic) for most of its length, but turns N. 70° E. near its end. It descends gradually, so that the northern or free end is 50 feet lower than the southern or attached end. Its eastern or seaward side slopes about 5°; its western or landward side slopes 18°. A number of pits that have been dug in its western

Fig.. 19.—A Cobble Spit on a ridge near Zuyk, seven miles northeast of Baku, looking north; fissured Aralo-Caspian Strata in the foreground.

side show that it is made in great part of small pebbles that seem to have been derived from the somewhat pebbly sandstone of the horseshoe ridge; but it also contains rounded sandstone and conglomerate cobbles and bowlders up to 3 or 4 feet in diameter. The anomalous feature here is the absence of corresponding marks of shore action on the slopes of the higher ground to the southwest, where the hill-tops are nearly 300 feet higher than the ridge on which the spit is formed. Furthermore, on crossing the barren monoclinal valley of the Vassamala (which is followed by the railroad to Tiflis, a few miles west of Baku, fig. 15), to the anticlinal hills of petroleum-bearing strata, whose summits reach about 1,000 feet altitude, we were unable to find any well-defined shore marks corresponding to the level of the long spit. The highest safe record here was a bed of cobbles at 200 feet altitude.

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We were therefore disposed to doubt the existence of a 600-foot shoreline until further search on the hills east of Baku, in a much more exposed situation than that of the anticlinal hills to the west, discovered other cobble spits on the west slope of the north-south monoclinal ridge of west-dipping Aralo-Caspian (Pontic) calcareous sandstones over the little village of Zuyk, at essentially the same altitude as the long spit on the Bibi-Eibat ridge. The position of these spits is shown at C, in fig. 17, and the profile of one of them in fig. 19. It should be remarked that they are on the western side of the ridge, and therefore turned away from the open Caspian. They are about 600 feet apart. Each one has the form of a flat spur, a little lower than the crest of the ridge, about 160 feet wide and 250 feet long, falling off with a steep western face of 15 feet on the free western side. They are composed, as far as may be judged from their surface materials, of rock slabs, from 2 to 4 feet in diameter, and of rounded cobbles, derived from the ridge; also of pebbles, worn from the ridge-making pebbly sandstone. Close by the southern spit is a small patch of cobbles, lying on the bare rock of the ridge slope; 1,000 feet further south is a larger oval patch, 250 feet in diameter and 8 or 10 feet thick, of cobbles up to 2 feet in diameter. Although the inner structure of these spits and patches was not revealed, we were constrained by the significance of their materials, form, and position to interpret them as the mark of a former Caspian shore, when the crest of the monoclinal ridge appeared only as a low island, exposed to the full force of deep-water waves, by which the slabs were torn from the exposed eastern face of the island and thrown on its western side. As in the case of the cobble spit on the Bibi-Eibat ridge, these spits must have been rapidly formed during a relatively brief high-level stand of the Caspian. In any case, a special importance attaches to the highest shoreline, and it was therefore with no small degree of interest that we looked forward from our stay at Baku to the opportunity of studying the eastern coast of the Caspian at Krasnovodsk.

THE QUATERNARY SHORELINES NEAR KRASNOVODSK AND JEBEL

Krasnovodsk is on the north side of a bay that is inclosed from the Caspian by a long south-pointing sand-spit. Here we were courteously received by Colonel Volkofnikof, governor of the district, who detailed one of his mounted guards to serve as a guide. An afternoon and a morning gave us time to measure a number of elevated beaches and to find some high-lying cobble beds of doubtful relations. The barrenness of the landscape was remarkable, in view of its immediate proximity to the sea, whose waters stretch beyond the horizon to the south and west. The town stands in part on the eastern slope of a "tombolo" or gravel reef, which, with a similar but higher reef a mile or more to the west, has tied a former island of granitic rock to the limestone escarpment of the mainland on the north, as shown in fig. 20. The eastern reef is about 135 feet over the Caspian; the western reef, more exposed to the sea waves at its time of making, reaches a height of 185 feet. A ditch that had been cut through the eastern reef disclosed something of its structure, from which we inferred that it was built during a time of rising water.

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Beaches and cobble beds in the same neighborhood were noted at 8, 20, 35, 45, 60, 115, 135, and 210 feet. The precipitous southern escarpment of the barren Kuba Dagh, which stretches east and west, a mile north of Krasnovodsk, has a steeper slope and a lighter color near its base than above, because of the subrecent under-cutting by the high-level Caspian waves and the resulting exposure of unweathered rock; this suggests a very recent high-water stand of the sea. The elevated beaches that extend from the eastern tombolo along the mountain base are skirted by the railroad for some miles. Many sections of their rolled gravels are exposed. All these reef and beach deposits are so laid as to show that previous to their formation the surface on which they rest had been subject to subaerial erosion. Hence here, as at Baku, the Caspian rose to its former levels, yet whether from a lower level than to-day I can not affirm; but Walther quotes the record of a boring on the shore of the Caspian southeast of Krasnovodsk in which "dune sands" were found

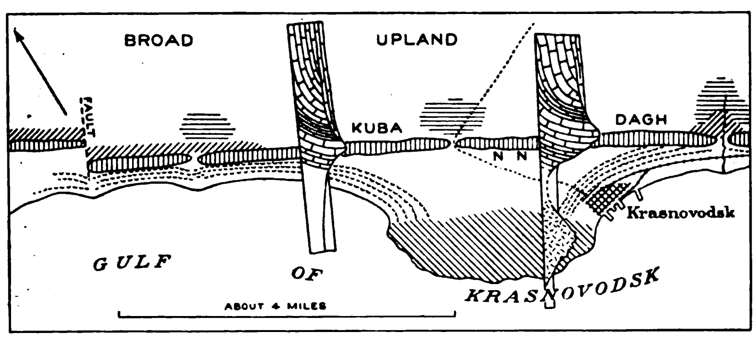

Fig. 20.—Rough Sketch Map and Sections of the District about Krasnovodsk.

to a depth of 35 meters (1898, 211). The volume of material in these reefs and beaches, on the lee shore of the Caspian, was much greater than in those about Baku, and the beaches were comparable in size to the beaches on the elevated shorelines of the Bonneville and Laurentian lakes. The size of the spit that incloses the bay of Krasnovodsk at present sea level is also much larger than any wave-built shore forms that we had seen near Baku.

Shorelines of similar altitude were seen on the flanks of the Balkhan Mountains, near Jebel station of the Central Asiatic railroad, about 100 miles east of Krasnovodsk. The station was 56 feet over the Caspian, and from this we determined the neighboring delta beaches, a mile or two distant, to be 150 and 250 feet over the same base. One of the higher deltas is shown in fig. 21. There was nothing indicative of shore-wave work seen at still higher levels on the mountain side. It was to deposits of the Pliocene Caspian that Konshin (1886, 383) refers in a neighboring locality as giving unmistakable traces of seashore action at a height of almost "50 sazhen" (roughly 300 feet) over the present Caspian. Walther makes brief reference to the deltas near Jebel (p. 103). It is to be noted that the delta beaches of the two levels here recorded occur in the lower part of ravines eroded in the northwest face of the mountain, and show that here as elsewhere

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the processes of erosion had had a lower baselevel before the beaches were built; that is, the Caspian here as elsewhere rose upon the mountain flanks from a formerly lower level.

The more problematic cobble deposits near Krasnovodsk lie at altitudes of from 400 to 470 feet over the Caspian, in notches (NN, fig. 20) on the steep southern face of the high escarpment, the Kuba Dagh, formed of vertical Jurassic limestones, whose sharp points rise 600 or 1,000 feet above the sea. There can be little doubt that the well-rounded cobbles and bowlders, from 2 to 5 feet in diameter, indicate wave action, but it is not clear when the wave action took place. A curious feature is the occurrence with the cobbles of subangular scraps of dark crystalline rock, up to 5 or 6 inches in diameter, apparently derived from the crystalline ridge at the

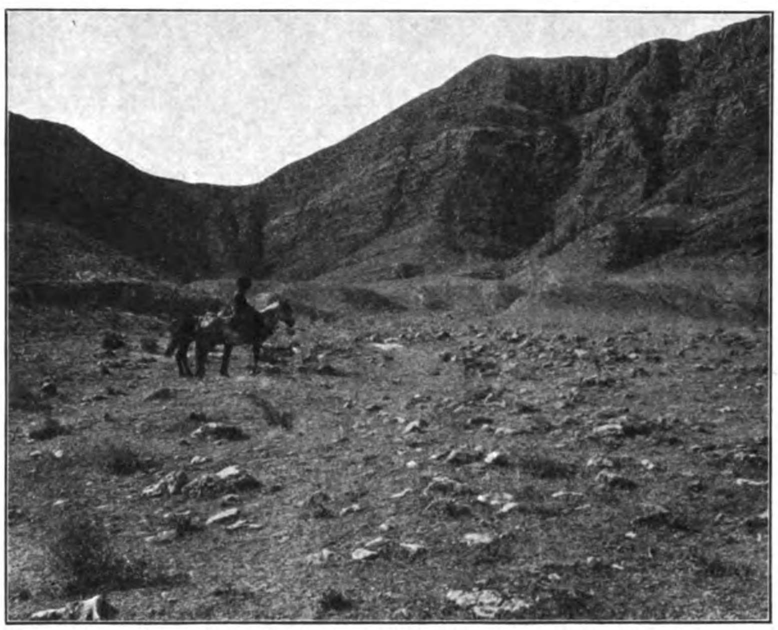

Fig. 21.—An Elevated Caspian Shoreline in the Balkhan Mountains, near Jebel Station, Central Asiatic Railway.

end of the tombolos, although a mile of low land now separates the ridge from the Kuba Dagh. It is eminently possible that the cobbles should be associated with the horizontal marls and limestones, Andrussow's "Aktschlagylschichten," a section of which we saw on the caravan route to Khiva on the north side of the Kuba Dagh, uncomformably overlying its vertical layers, as in fig. 20; and if so, they would be much older than the modern Caspian shorelines that we were looking for.

The only safe test to apply to these cobble beds, as well as to those in the 600-foot spits near Baku, will be to search for them at other points where the coast is high enough to have received similar marks. If we provisionally accept the Baku spits as marking a temporary shoreline, it is possible that much of their exceptional height may be due to relatively local warping. Such a supposition is not inherently

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improbable, for Baku lies on the line of the Caucasus range, where great disturbances have taken place in not remote geological periods, and where minor movements might expectably be continued into recent time. It should be noted, moreover, that the highest shorelines at Krasnovodsk, 210 feet, and at Jebel, 250 feet, differ by a greater amount than should be ascribed to error of barometer readings, and that both of these levels are decidedly below the undoubtable signs of modern wave work near Baku, at 400 feet. In further confirmation of warping, we may quote Mushketof's statement (1886, I, 692) to the effect that in the southern Caspian the Quaternary Aralo-Caspian shoreline almost merges with the present shoreline. In view of this it is desirable to measure the elevated shorelines of the Caspian at many points before attempting to restore its outline at the time of its maximum extension. It is very possible that the relative dates of the various shorelines may finally be better determined by means of the amount of warping that they have suffered—the latest ones the least—than in any other way.

Further consideration of the eastern extension of the Caspian will be found in subsequent pages.

THE PLAINS OF SOUTHERN TURKESTAN.

A great part of Turkestan, south and east of the Aral Sea, is a desert plain connecting southwestward with the lowland bordering the southern Caspian by the Balkhan gateway in the belt of highlands that, farther to the southeast, forms the boundary of the Russian and Persian dominions. A large part of the desert plain is described by some of the Russian geologists as having been covered by the Pliocene Aralo-Caspian Sea, and a smaller southwestern part by the post-Pliocene sea, whose waters have since then gradually withdrawn to their present separate basins. It is evident that the varying area of this great inland sea must have, directly and indirectly, exerted a controlling influence on the distribution of the contemporary human inhabitants of the region, if any such there were; hence the importance of gaining as full a knowledge as possible of Aralo-Caspian history in the course of our explorations.

The following summary concerning the relation of the southern Turkestan plains to the Aralo-Caspian problem, as determined by Russian observers, may serve as an introduction to the record of our own observations. One has frequent occasion, in reviewing the reports of the Russian explorers, to admire the persistence with which they penetrated the desert region, and to perceive in their successful subjugation of this part of the Asiatic wilderness a close similarity to our "winning of the west," except that theirs is the greater task; for the deserts of Asia are broader and more barren than those of North America, and the mountain ranges are higher there than here. The settlers of the United States had a continent of moderate width to cross and found within it only a scattered native population, and on its Pacific side only a slightly resistant offshoot of Spanish power, while the Russians are expanding into the broadest of the land masses, where the people of the interior are well established, where the British occupation of the populous peninsula of India is more aggressive than the Spanish occupation of Mexico, and where the enormous populations of the Pacific border find no American analogy.

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The plains of southern Turkestan are described by Mushketof and others as occupying an extensive area of depression which has received the waste washed into it from the surrounding higher lands. These higher lands are as follows: The Ust-urt plateau on the west is an uplift of late Tertiary strata, being covered in its western part at least by the Akchlagyl formation of Andrussof (1902). Krasnovodsk lies southwest of this upland, and the sections already given in fig. 20, as well as the escarpment of the Ust-urt farther east, suggests that the upland is bordered by a fault along its southern and southeastern margin. The Kopet Dagh, on the south, has been described by Bogdanovich (1887). The range is largely composed of Mesozoic and Tertiary limestones, folded in a somewhat orderly fashion, with axes trending west-northwest. The northwestern part of this line of disturbance is known as the Kurian Dagh, the Small and Great Balkhans, and the Kuba Dagh (the last rising back of Krasnovodsk). The farther extension of the same line leads to the Caucasus range. The plains are bounded on the east by the out-reaching members of the great mountain systems of Central Asia, well known to involve late Tertiary and post-Tertiary uplifts, as will further appear in Mr. Huntington's report. To the north the plains continue far beyond the region here considered.

The depressed area between these higher lands, the southern Turkestan depression, is called a *graben* by Mushketof, at least that part between the Ust-urt and the Kopet Dagh. It seems to have been kept below the surrounding highlands by repeated differential movements, and it has therefore long been receiving their waste. It slopes away from the higher borders after the fashion of piedmont fluviatile plains, of which it seems to be in large part an excellent example. Its surface materials are coarse near the margin, but become finer farther forward. Many of the streams that descend from the mountains wither away on the plains; only the largest rivers, the Amu and the Syr, succeed in reaching the Aral. The Tejen and the Murg-ab disappear on the southern plains; the Zerafshan, greatly reduced by use in irrigation in Bokhara, approaches but fails to reach the Amu; and the Chu wastes away on the plains farther north.

It is the district south of the Amu with which we are at present concerned. This part of the plains is chiefly a barren waste, the Desert of the Black Sands, the Kara-Kum.

THE QUATERNARY ARALO-CASPIAN IN THE KARA-KUM.

The deposits of the Pliocene Aralo-Caspian are described by some writers as underlying all the Kara-Kum, but there does not seem to be entire agreement on this point. The Quaternary Aralo-Caspian is believed to have been of less extent, but it has not been well defined in Turkestan (cf. Mushketof, 1886, I, 696), probably because of the difficulty of exploration in the desert. Jakalof (1882) speaks of the general belief that the Kara-Kum is the bed of the expanded Aralo-Caspian Sea, but notes that sea shells are not found in the desert. Sjögren (1888) briefly states that the last rise of the Caspian covered the Kara-Kum. Konshin (1896) gives a sketch-map of the sea, showing its area at the beginning and at the middle of the Quaternary period and at the opening of the present or historic period, and thus

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indicating a progressive diminution of size. A continuous decrease from the larger Pliocene to the diminishing Quaternary area is inferred by this observer and explained by drying winds and by uplift of the eastern part of the plain, where the surface is now 2,000 feet above sea-level. Obruchef also describes the Quaternary Aralo-Caspian as the direct successor of the Pliocene sea, the decrease of area being ascribed to uplift on the east (1890, 25). Neither of these observers gives explicit recognition to the idea that the Quaternary sea resulted from the expansion of a smaller early-Quaternary sea, to which the waters had shrunk from their great Pliocene extension.

The Aralo-Caspian is marked by Konshin, in the article just referred to, as reaching, at the beginning of the Quaternary, eastward to the present ends of the Murg-ab and Tejen rivers, and southward to the base of the mountains at Kizil-Arvat; farther west it connected with the Caspian basin by the Balkhan gateway; to the northwest it spread beyond the present Aral; to the northeast it had a well-defined boundary south of the Amu River. Here a higher northeastern part of the Kara-Kum, underlaid by Pliocene and older strata, breaks off in a dissected, south-facing escarpment, the Ungus, which Obruchef ascribes to a fault (1890, 250), and along the base of which Konshin describes shorelines (1887, 238), probably contemporaneous with those at Krasnovodsk and Jebel. The floor of the depression south of the Ungus is stated by Lessar to be 44.6 meters below the Caspian (1889, 714). This escarpment and the shorelines along its base are features toward which future observation might well be directed, with the hope of deciphering the history of the sea in greater detail. If I understand Konshin's description, the dissection of the Pliocene strata in the escarpment must have taken place before the shorelines were made at its base. It might, therefore, here be possible to recognize the time interval that observations elsewhere lead us to suppose elapsed between extensions of the Pliocene and the Quaternary Aralo-Caspian Sea, and perhaps to decipher the presumably complicated history of the Quaternary sea itself.

In the late Quaternary, the sea was reduced to lower and lower levels, and the Caspian and the Aral were thus separated, except for a water passage or channel, the Usboi, which passes along the southeastern base of the Ust-urt and through the Balkhan gateway. There has been much discussion regarding the nature and origin of this channel. As it has the form of a river channel, and as the Amu is the only large river in the region, the Usboi has been repeatedly said to be the former course of the Amu. For example, Sievers (1873) describes the Usboi as a channel so well preserved that it seems to have been only lately abandoned; it is about 65 feet deep, two-thirds of a mile wide, eroded in the unconsolidated deposits of the steppe or in the firmer Miocene beds on the border of the Ust-urt. The channel has many bends; it often divides, so as to include islands, but there are no branch channels entering it. Other observers have noted that the gentle southwestward descent of the channel is broken by the sills of rapids at several points, from which it may be inferred that the stream by which the channel was eroded did not endure long. The Amu being a large river not far distant, its former connection with the Usboi seems to have been assumed without waiting to trace an actual connection between

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the two. So, in 1881, when Konshin first saw the Usboi, he also took it for the old path of the Amu (1886, 380), but on further examination he concluded that while the depression in which the Usboi is eroded had served as a strait to unite the expanded Aral and Caspian seas, it had never served as the path of overflow from the Aral to the Caspian, and that the river-like channel along the axis of the depression was the work of local wet-weather streams (1886, 427–431); but it should be noted that one reason for this conclusion was the deductive belief that the Aral could not have had a water supply sufficient for overflow after the climate had become so dry as to cause the Caspian to shrink below the Aral level (1886, 428).

Some ten years later (1895) Konshin reversed this earlier opinion, and treated the Usboi as the channel carved by the Aral overflow outlet. He still maintained, however, that the Amu had never flowed directly into the Usboi, and in evidence of this he pointed out that there was no channel leading from the Amu to the head of the Usboi; that the Sary-Kamish depression lay between the two, and that the Usboi channel was decidedly smaller than that of the Amu to-day. More than one writer notes the absence of canals and ruins along the Usboi, and concludes that the river which eroded the channel must therefore have been salt and unattractive to settlement. This conclusion unfortunately begs the important question of the existence of a house-building and canal-cutting human population at the time the Usboi was formed. No independent proof of man's existence at that time and in that place has yet been found. In this connection the levels at some critical points may be introduced. Bala Ishem, 336 feet (72 meters) above the Caspian, is at the divide between the Aral and the Caspian districts; the Usboi is eroded on the gentle slope southwest from the divide; no channel occurs on the northeast slope. Sary-Kamish is the name of some salt lakes in the bottom of a depression north of Bala Ishem, 50 feet (15 meters) below the Caspian, whose separation from the Aral of to-day may be due to the growth of the great Amu delta between the two basins. Walther quotes various other altitudes (1898,212). As the Amu now enters the Aral alone, the former waters of the Sary-Kamish depression have been evaporated almost to dryness, thus repeating the case of the Colorado River at the head of the Gulf of California. The Usboi channel must have lengthened southwestward as the Caspian retreated, thus producing features similar to those well known in the Bonneville basin of Utah. It is pertinent to quote in this connection Semenof's observation that the plain bordering the Caspian southeast of Krasnovodsk appears to be the remains of spacious deltas formed by large rivers which for many centuries here entered the sea from the east (1888, 292). Konshin (1887, 237) notes that Caspian shells are abundant on the desert plain for 125 miles (200 km.) east of the present shore and up to nearly 200 feet (60 meters) above the present level; but they are not mentioned in association with the shorelines of the Ungus. Obruchef gives similar statements (1890, 246).

There seems to have been comparatively little discussion of the relation of the Quaternary Aralo-Caspian in Turkestan to the climatic changes of the glacial period. Sjögren (1888) explains the expansion of the sea by the greater volume of water received from the glaciated area of northern Russia, and suggests that as far as

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the Aralo-Caspian region is concerned, the expansion of the sea was the cause rather than the consequence of local climatic changes. Petrusevitch (1880) ascribes the shrinkage of the sea and the withering of the Murg-ab and the Tejen from an inferred connection with the Amu, to an assumed destruction of forests in the neighboring mountains. The probability of repeated Quaternary expansions of the sea does not appear to have been considered; but in this statement I may be doing injustice to Russian observers, whose more recent articles I have not been able to consult.

THE PIEDMONT PLAINS.

Since the withdrawal of the Pliocene sea, the eastern and southern borders of the plains of southern Turkestan appear to have been aggraded by the rivers that flow out upon them from the mountains. That a certain measure of such constructive action has taken place is announced by the Russian geologists, but it is not apparent that the full measure of river action has been recognized. Some of the strata of the plains are said to be not fluviatile but lacustrine, because they are of fine texture and uniform structure, without the variable layers of gravel that are by implication supposed to be always indicative of river work; but this seems to be a simpler solution than the problem deserves. There are many rivers that do not carry gravel, and there are many river plains whose smooth surface must receive very even and uniform deposits of flood-laid silts over large areas. Records of borings are quoted by Walther (1888, 210) which show river muds on sand and loess to a depth of nearly 50 meters beneath the bed of the Amu River at Charjui, where the great railroad bridge was built. The record of a well boring at Askhabad, quoted by the same author (1900, 105) shows variable piedmont deposits over 2,000 feet deep. It seems, indeed, as if we had in the plains of Turkestan and the Great Plains of our West one of the most striking of the many physiographic resemblances between Eurasia and North America; and that there as well as here an increasing share may be given to the action of aggrading rivers in forming the plains, as observations are extended. It is well known that the tide of geological opinion in this country has in recent years turned more and more toward a fluviatile origin for the strata of the Great Plains that slope eastward from the Rocky Mountains, and the traditional lacustrine origin of the plains strata has been repeatedly questioned; so we may expect, as closer attention is given to the details of river-laid formations, that a larger and larger share of the fresh-water strata that slope westward from the mountains of Central Asia may be interpreted as fluviatile rather than as lacustrine.

In one respect, however, the comparison between the two continents reveals a contrast. In North America the rivers that flow eastward from the Rocky Mountains are now dissecting the plains that they once built up, as has been so well shown by Johnson; while in Turkestan the rivers that emerge from the mountains, heavily silt-laden, are still engaged in building up the plains. This is notably the case with the Murg-ab and the Tejen, as will be more fully stated below, for these rivers wither away without reaching the sea, and every particle of sand and silt that they bring from their headwater valleys in the mountains must be laid down as they dwindle to dryness on the plains. Moreover, while the rivers at present bring abundant gravels out from the mountains and spread them on the nearer parts of

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the plains, the rivers of late Tertiary time must have had a much smaller quantity of coarse detritus; for, at that epoch, the mountains had been reduced to relatively low relief, as will be shown particularly in Mr. Huntington's report, and the waste that they then shed must have been for the most part of fine texture. It appears, therefore, that a very careful examination of the fresh-water Tertiary and Quaternary strata in the plains of Turkestan should be made with a view of determining not only the date, but also the physical conditions of their deposition. It is evident that the opportunity for organic life, and especially for human life, would have been very different, according as the plains are of lacustrine or fluviatile origin. Inasmuch as many mounds and ruins occur within the area of debatable action, the solution of this problem has a close relation to the objects of our expedition.

THE AKHAL-TEKIN OASES.

The gently sloping plain that lies piedmont to the Kopet Dagh and the associated ranges—the mountains that divide Persia and Turkestan—is a case in point. The plain here receives from point to point sufficient water from the mountains to support a series of villages, known as the Akhal-tekin oases. The Central Asiatic railroad, from Krasnovodsk to Tashkent, naturally was constructed through this settled belt on the way into the interior. A section of the mountains at Kizil Arvat is given by Bogdanovitch (1887), in which the north-dipping Miocene limestones and clays on the crests and flanks are followed by the horizontal layers of the plains, which are labeled Aralo-Caspian. Again, Konshin's sketch map (1896) of the Quaternary sea brings its border close to the mountain base at Kizil-Arvat. He had earlier (1883, 383) reported the occurrence of variegated clays in the gorges back of Kizil-Arvat, which he referred to the Pliocene Aralo-Caspian.

During our brief stop at Kizil-Arvat we rode out to the mountains and had a good view of their structure. The mountain-making rocks are heavy limestones, underlaid and overlaid with clays or shales, all compressed into great folds, and much denuded. We looked from one of the anticlinal limestone ridges into an inner synclinal valley, where the weak clays that overlie the limestones were terraced. The stream from this inner valley cuts a narrow gorge near the end of the west-pitching limestone anticline, but the road follows a valley around the west end of the anticline. Where the stream issues from the mountains it has terraced the reddish and yellowish clays on the northern slope at several levels, and has strewn gravels on the terrace floors. The terraces decrease in height northward, as if they would merge in the plain, but the front of the higher terrace has been much consumed and eroded into a sort of bad-land topography, shown in fig. 22, during the production of the lower terraces. This suggests a recent uplift, with its greatest measure in the range and rapidly decreasing toward the plains. The spurs of the mountain ridges hereabout seem to have been graded to moderate slopes with reference to the uppermost terrace, while narrow ravines and gulches are cut in the mountain flanks with respect to the present valley floors. Evidently a much longer time must have been devoted to the erosion of the highest terrace floor, which once extended continuously along the mountain base, than in opening the

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narrow valley floor of the present stream. Evidence of similar terracing in the range southwest of Askhabad will be given in a later section. We saw no indications of deltas or other shoreline features here—nothing but the results of forward-washing stream action. It may be that the chief evidence for drawing the Quaternary Caspian shoreline near Kizil-Arvat is to be found in the agreement of the altitude of the plain, a few miles from the mountain base, with the level of the sea as determined by recognizable shorelines elsewhere. In that case its location can, of course, be only approximate.

At Bakharden, between Kizil-Arvat and Askhabad, we rode out to the dunes along the course of a small stream, whose occasional floods keep a graded passage open among the sands for several miles from the mountains. The surface of the

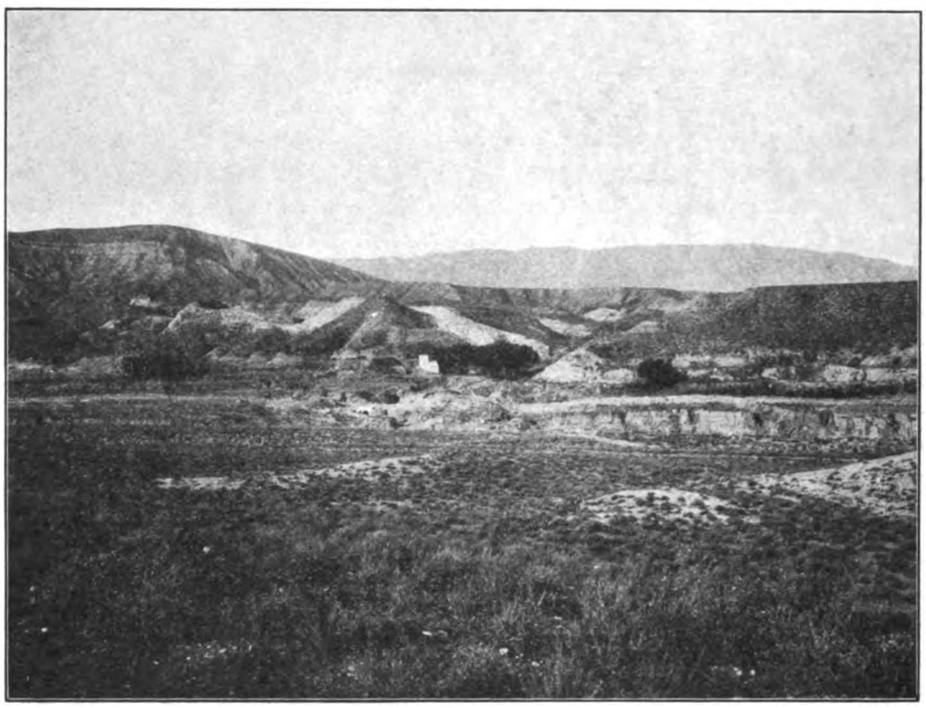

Fig. 22.—Dissected Terraces at the base of the Kopet Dagh, south of the Kizil-Arvat, looking southwest. The horizontal limestones of the Mountain on the left are suddenly bent down so as to pass under the clays of the Terraces in the middle distance.

sands was irregular at first (fig. 23); then the dunes began in moderate relief, seldom exceeding 15 feet in height. The scarps of the crescentic dunes or barkhans (fig. 24) were to the west, as if the sands had been drifted by easterly winds. The sand bore a scanty growth of grass, except on the freshest dunes. Between the dunes and the mountains there was no sign of shore-terrace or delta observed. The piedmont slope extends forward without interruption as far as we saw it. It should, of course, be remembered that the abandoned Caspian shorelines, wherever they stand on the piedmont plain, may be faint and not easily recognizable; nevertheless, they were recognized so easily at Baku, Krasnovodsk, and Jebel, that failure to see

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them at Bakharden and elsewhere along the base of the Kopet Dagh may be fairly taken to indicate that they do not exist there. The little deltas in the ravines on the mountain flank near Jebel were recognized at the first glance, though a mile or more away; the strands at Krasnovodsk were visible as such from the steamer before reaching land. The treeless piedmont plain on which the Akhal-tekin oases are distributed is open, as soon as one leaves the villages, without obstruction to the view for miles together, and yet shows nothing that could be interpreted as a shoreline. It may be noted that familiarity with the Bonneville shorelines in Utah gave us all the more confidence in the correctness of our conclusion that no shorelines occur along the base of the Kopet Dagh at Kizil-Arvat and farther eastward.

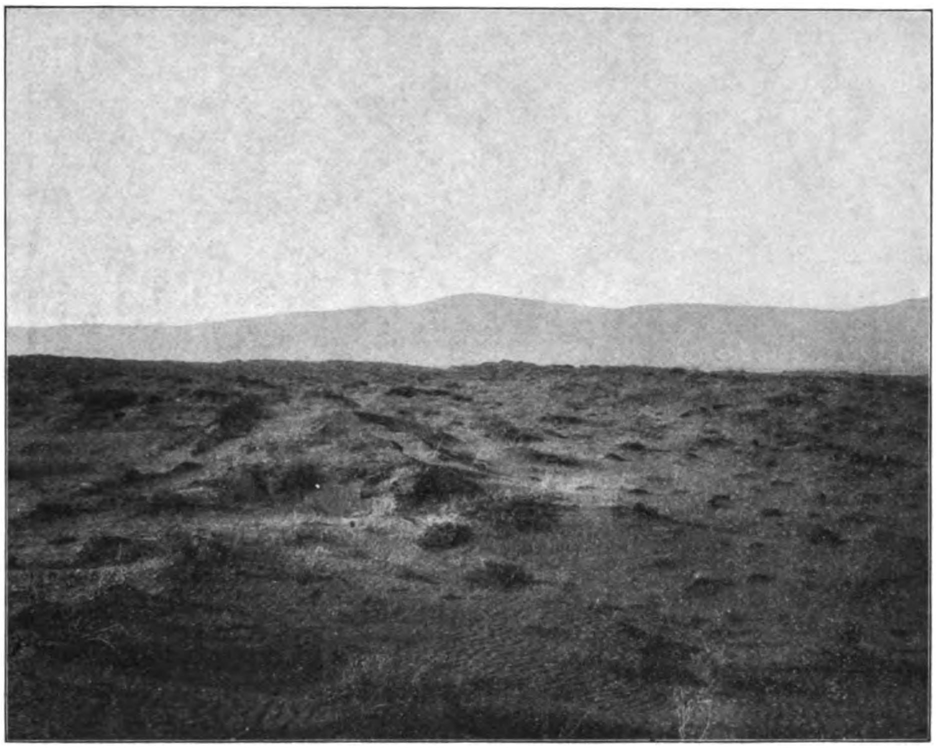

Fig. 23.—Sand-hills near Bakharden, looking south.

The railroad journey through the belt of oases afforded excellent opportunity for many general views of the piedmont slope. Gorges in the barren mountains open upon fans, whose long forward descent was well seen in profile before or after passing them. They had no resemblance to the flat-topped deltas built in the high-level Bonneville waters along the base of the Wasatch Mountains in Utah. In a district where the limited water supply hardly suffices for the needs of even a scanty population, and where the unredeemed desert counts more area in miles than the fields rescued from it count in acres, it was curious to note the precautions taken to guard the railroad from destruction by floods. The faintly convex surface of the fans sheds the floods now on one radius, now on another; the point where a flood will reach the track

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can not be foretold. Embankments or dikes are therefore thrown up in oblique lines on the up-slope from the track, so as to guide the floods toward strong culverts under the roadbed. Yet even these safeguards do not always suffice. Not long after we left this part of the country the news overtook us of a destructive flood by which a part of the track near Kizil-Arvat had been washed away.

The irregular structure of the piedmont slope, as exposed in cuts along the railroad line, is well described by Walther (1900, 104). There is a frequent and irregular alteration of stratified or massive loess-like clay, finely stratified sands, and coarse gravel, with many local unconformities; all this being the result of the variable action of floods that sweep suddenly, unguided by channels, down the

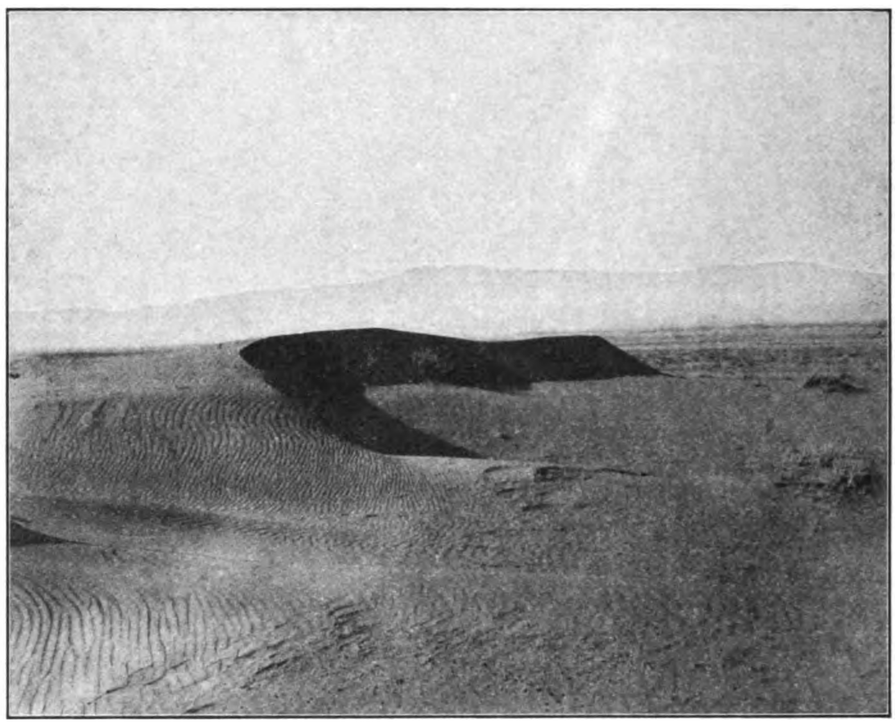

Fig. 24.—A Barkhan near Bakharden, looking south.

piedmont slope; now eroding, now depositing; here sweeping along coarse blocks, there depositing fine silts. Ten miles south of Askhabad, where the railroad station is 819 feet altitude, we saw, when returning by the Meshed road from an excursion in the Kopet Dagh, more abundant piedmont deposits of mountain-waste dissected to depths of several hundred feet. A great thickness of these deposits has been penetrated by the artesian boring in the suburbs of Askhabad, already mentioned, 2,000 feet deep, and therefore with more than half its depth below sea level, but without securing a water supply. The whole depth, as shown in the record quoted by Walther (1900, 105), is in variable layers of clay, sand, and gravel, similar to the deposits seen in the borrow-pits near the railroad embankments, or in the natural

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sections; and all of this heavy deposit is therefore best explained by conditions and processes like those of to-day during persistent depression of the surface. The failure to secure a water supply from this deep well is in itself very suggestive of the irregular underground structures and of their torrential origin.

Among the most interesting features of this region are the gently ascending tunnels that are driven in search of water into the gravels of the piedmont slope, near the mountain base. Streams of sufficient size to use in irrigation are thus led forth. The practice is an ancient one, and is in use from Turkestan to India. It has lately been introduced, with good results, in the arid parts of southern California, where piedmont fans of mountain-waste are extensively developed. We were told

Fig. 25.—A Village of Turkoman Kibitkas, near Kizil-Arvat.

at Askhabad that trouble frequently arises between neighboring villages when the excavation of a new tunnel causes a lessening of the water supply from an older tunnel. The native villages (fig. 25) seemed wretchedly poor at first sight, yet some of the circular tents—kibitkas—are well furnished on the scale by which the people there measure the needs of life; and the carpets and wall-bags are woven—one should rather say crocheted—with a remarkable degree of taste in design and color, and of skill in memorized execution. We were entertained one afternoon near Askhabad by the head man of the native village, who had been with us on an excursion. Rugs were spread in his little orchard, tea and fruit were served, and native music was provided.

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THE KOPET DAGH.

Our intention in making an excursion from Askhabad into the Kopet Dagh range was to make further search for any geologic or physiographic features in the mountains which might suggest subdivisions of recent geological time, the correlatives of which could then perhaps be recognized in the more monotonous structure of the piedmont plain. We were fairly successful as far as the mountains were concerned, for indications of subrecent terracing were found in the valleys here even more distinctly than back of Kizil-Arvat, but the recognition of the effects of the

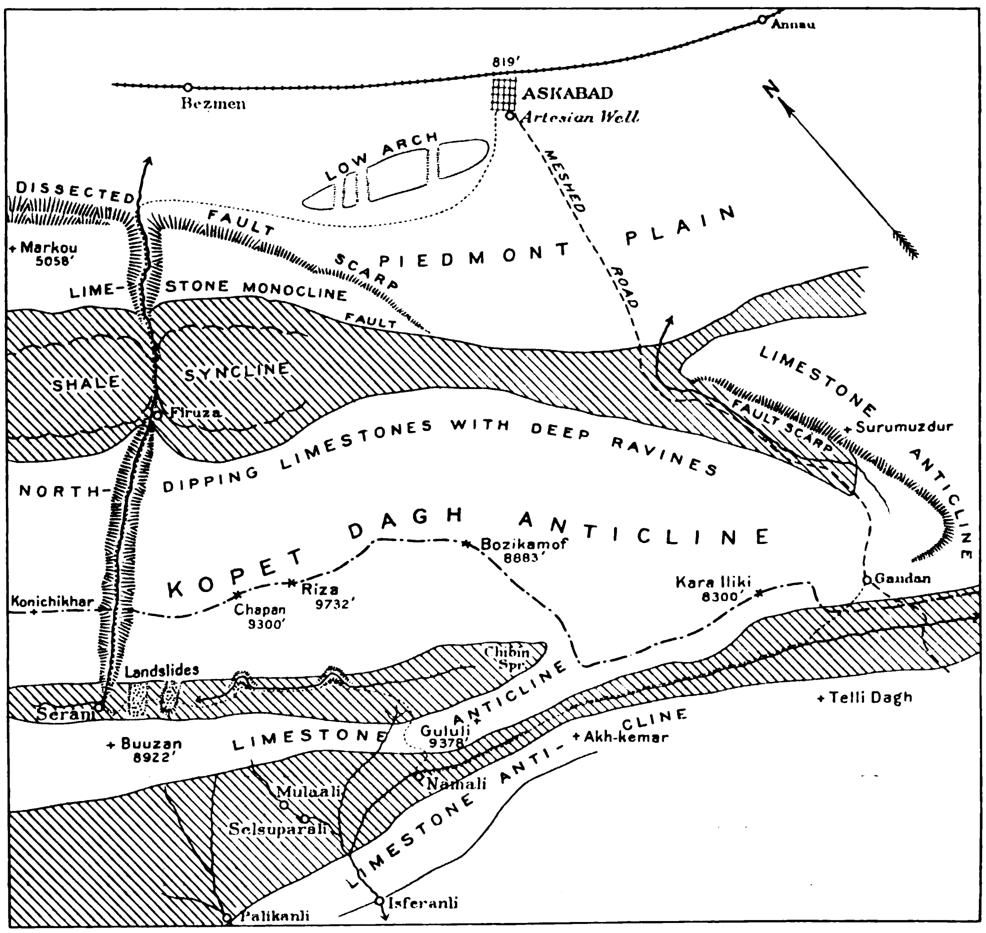

Fig. 26.—Geological Outline Map of the Kopet Dagh, southwest of Askhabad.

terracing in causing a change in the deposits of the plains will be more difficult. The changes in the mountains are made clear by a revival of activity in the streams in eroding their valleys; but the contemporaneous changes on the plains are concealed by the deposition of waste that the eroded mountain valleys have furnished. The excursion gave us a good sight of the structure of several ranges in a district that is little visited, and the results of our observations are therefore briefly set forth.

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As our proposed route led us across the main range into Persian territory, General Ussakovsky, governor of the province of Transcaspia, was good enough to advise us concerning the necessary diplomatic arrangements, and the Persian consul at Askhabad informed his government of our plans by telegraph. General Ussakovsky also instructed Colonel Kukol-Yasnopolsky, district governor of Askhabad, to arrange for our escort of three mounted native guards, or "jiggits," and detailed his secretary, Vasily Gregorievitch Yanchevetzky, to accompany us. The latter gentleman proved most helpful from his acquaintance with the country and the people. He has since then accompanied Mr. Huntington on a winter journey to Sistan, on the border between Persia and Afghanistan.

It may be well to say at the outset that we gave practically no attention to the paleontology of the formations traversed; but we found some Echini in the mountain-making limestones, and an Ostrea in the shales of the valleys. Geological descriptions of the formations noted below are given in the report by Bogdanovitch (1887). Figure 17 is based upon unpublished maps prepared by Russian topographers and kindly lent to us by the officials at Askhabad, with permission to publish our traced outlines. The original scale is 5 versts to an inch, here reduced to 10 versts to an inch. The altitudes are given on the map in feet, and are so quoted here. The unshaded areas are the ranges, anticlinal for the most part, of heavy Cretaceous limestones, whose total thickness must be 2,000 or 3,000 feet. The oblique shading represents the valleys, synclinal for the most part, of Cretaceous shales and sandstones. The unshaded area on the upper border of the map is the piedmont plain of mountain waste.

THE FIRUZA BASIN.

On the first day, May 30, we drove from Askhabad to Firuza, a village situated at an altitude of about 2,000 feet, in a picturesque valley-basin that is inclosed from the plains by a local up-faulted front range. Here amid pleasant groves of trees the Russian officers stationed at Askhabad have their summer houses, one of which was courteously placed at our disposal for the night's stop. The monoclinal front range, which rises at Mount Markou to 5,068 feet, as well as the broad anticline of the main range, whose summits exceed 9,000 feet in altitude, are trenched across by deep gorges cut by a stream which rises in the inner Serani synclinal valley. There is a terrace along the valley where it is eroded in the shales, by which an uplift at its headwaters with respect to the plains seems to be indicated, as will be understood from the following facts. At the mouth of the lower gorge (altitude about 1,300 feet), the stream has entrenched itself about 50 feet below the piedmont plain. Within the gorge, whose generally transverse course is modified by pronounced serpentine curves, the lower rock walls repeatedly steepen at their base, and so tend to cause the renewed dissection of the upper walls, whose slopes seem to have been formerly better graded. Seven miles up the stream, at Firuza, we ascended some of the hills, gaining a fine view of the synclinal basin, and noting a dissected terrace or bench, covered with coarse gravels, cobbles, and silt, here 220 feet over the stream. The increase in depth of the present valley floor beneath the earlier valley

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floor, as one goes up-stream, is evidently suggestive of uplift. From the highest hill, a monoclinal ridge of brownish sandstones, 835 feet over Firuza, we could see the modern flood plain, about a quarter mile wide, etched below the dissected gravel bench, which must in its prime have been from half a mile to a mile in width.

It may be noted that about 10 miles southeast of the gorge the monocline of the outer (Markou) limestone range narrows, becomes lower, and ends, and further on the flanks of the main anticline descend to the plains. Northwest of the gorge the front monocline rapidly increases in height for several miles, and its southwest slope exposes great, bare sheets of heavy, steep-dipping limestones. This range is believed to be faulted up along its front, because the strata in the neighborhood of the gorge either dip southwest into the range or lie nearly horizontal. The scarp of the range, much ravined, looks directly upon the open plains. General subaerial erosion can not have removed the forward extension of the strata to any great extent, for erosion has as yet only succeeded in battering back somewhat the steep walls of the gorge; hence the absence of the strata in front of the range can only be explained by faulting. It should be noted that we caught a glimpse, while we were still on the plains, of what seemed to be steep northeast dips in the strata of the front scarp a few miles northwest of the gorge; hence the faulted monocline may there assume the character of a torn anticline.

The treeless hills of the Firuza syncline revealed their structure most clearly. The dip of the strata was distinctly steeper on the northeast than on the southwest side; the lower beds were gray shales, on which subsequent valleys were opened; the upper ones brownish sandstones, which rose in ridges. The total thickness was probably 1,500 or 2,000 feet. The limestone flanks of the main range exhibited many smooth structural slopes of moderate dip, green with vegetation, and deeply gashed by consequent streams. The upper Firuza gorge was seen as a deep chasm, which we followed through the next day. Its stream was only 10 or 15 feet wide, but about a month after our visit we heard that it rose in a destructive flood and swept through the village, doing much damage to the houses and gardens.

The upper gorge is as fine an example of a transverse through-going defile as I have seen. It is 10 miles long, and in that distance the valley floor rises about 2,500 feet. For the first half of the way there is a narrow flood plain between precipitous walls, hundreds of feet in height; then after passing a strong fault, expressed by local deformation and a change in the character of the limestones, the walls are less steep and the floor is more encroached upon by talus and fans. The mountain tops, 4,000 or 5,000 feet above the stream, could not be seen. As the wagon road ended at Firuza, our further progress was on horseback with pack train, and thus we crossed the boundary into Persia. We met a few men in the gorge driving donkeys laden with fagots, but came upon no habitations till we reached the open longitudinal consequent valley where the little Persian village of Serani is situated amid green irrigated fields, at an altitude of about 4,700 feet. The irrigating stream is chiefly supplied from a large spring at the base of the limestone range on the southwest side of the valley. The stream is used to drive a primitive mill near its source.

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THE SERANI VALLEY.

The Serani Valley is worn down on the gray shales of a pinched and torn syncline, between the broad limestone anticline of the main range on the northeast and the torn or faulted anticline of the Buuzan range (8,922 feet) on the southwest. The shales are largely removed and the limestone flanks of the valley are sharply ravined near the exit gorge; but a few miles to the northwest we saw the terraced remnants of a higher valley floor (fig. 27), estimated to be 600 or 800 feet over the present stream. It was noted that the limestone flanks of the mountains sloped by relatively gentle and somewhat graded declivity to these terraces, and that the flanks descended by much steeper and more ragged walls to the floor of the new valley near the outlet gorge, where the terraces had been largely removed.

Fig. 27.—Terraces in the Serani Valley, looking northwest.

When the high terraces of the Serani Valley are considered in connection with the lower ones already described at Firuza and at the mouth of the lower gorge, a differential uplift of the region is suggested. Such an uplift of the Serani Valley with respect to the mountain front would not be measured simply by the height of the valley terraces. Under the supposition of uplift, the slope of the stream in the gorge must have been much more gradual when it connected the now dissected floors of the earlier Serani and Firuza valleys than it is to-day; for the earlier valley floor must have approached maturity, as is shown by its greater width in the Firuza syncline and by the more nearly graded slopes of the limestone mountains over the Serani terraces, while the present valley is relatively immature, as is shown by its narrowness in the shales of the Firuza syncline and by its abrupt walls and its land-slides near Serani; and it is well known that mature valleys in a mountainous district must have a much more gradual slope than immature valleys. It is therefore reasonable to estimate the inferred recent axial uplift of the range at 1,000 feet at least; indeed, 2,000 feet does not seem to me an excessive measure.

On following the Serani Valley to the southeast on the morning of June 1, we soon passed two large landslides (see fig. 26). The second one was a good mile in length, with irregular mounds and hollows strewn with huge limestone blocks. The slides seemed to have come from the main range and to have been precipitated by the revival of valley erosion, whereby the basset edges of the limestones on the torn slope of the anticline were undermined. Beyond the slides the valley floor was aggraded for a mile or more, and the stream was here lost in its own deposits. At about 6 miles from Serani the valley is obstructed by a broad spur of shale, which remains there because the stream has become engaged in the limestones on the flank of the main range, in which it has cut an impassable chasm. The trail climbed the shale spur, which we then recognized to be, like the terraces at the other end of the Serani Valley, a remnant of an old wide-open valley floor, 400 or 500 feet above the present stream. The chasm by which the stream passes around the spur is therefore to be regarded as a result of a local wandering of the stream

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to the northeast side of its former valley floor before the revival of erosion; so that, when the recent downcutting began, the stream became superposed on the limestones, from which it has not yet been able to escape. The spur gives location to a cross-trail, by which the Persian villagers in the headwater valleys of the Atrek system traverse both the limestone anticlines on their way to Askhabad.

Leaving our pack train to make camp on the stream (altitude about 6,100 feet) just beyond the shale spur, Huntington and I, with one of our jiggits, followed the cross-trail to a high pass in the main range, and then climbed on foot to the summit of Chapan (about 9,300 feet), where we enjoyed a grand view in all directions. Riza, the highest summit of the region (9,732 feet, according to the Russian map), lay a mile to the east—a broad dome, in which the limestones were nearly horizontal, as they were indeed all along the mountain crest. The slope toward the Serani Valley was moderately dissected; the slope toward the plains, 8,000 feet below us on the north, was deeply gashed with enormous ravines. Askhabad was clearly in sight, being only about 20 miles distant; the farther plains faded away in the haze of the lower atmosphere. It was difficult to realize, while we were enjoying the fresh, clear air of the mountain top, that the plains were still as hot as we had found them a few days before in the glare of noon on the railroad. The Firuza synclinal basin was reviewed; its inclosing monoclinal range was seen to be of moderate length, perhaps 20 or 30 miles; the syncline of the basin was terminated on the west by a great anticlinal dome, on whose northeastern flank a curious meandering gorge is cut in the slanting limestone, probably another case of structural superposition. The view southward into Persia showed a broad synclinal shale basin south of the Buuzan anticline, and several other limestone anticlines, with which we made closer acquaintance on the following day. What with form and color, it was comparatively easy to sketch the general structure for miles around.

We followed the Serani stream nearly to its head on June 2. A second chasm, due to stream displacement, was passed about 2 miles above the first; then the valley shallowed rapidly, and soon opened in a broad upland, about 7,000 feet in altitude, which we may call the Chibin upland, from a spring that is noted on the map at its southwestern end, and here we came upon some Kurds in their summer camps. On the south rose the narrow and sharply serrate anticline of Giluli peak (9,378 feet), which seems to open and blend with the main anticline farther southeast, and which soon weakens to the northwest, leaving a broad and low ridge between it and the Buuzan anticline. These two ranges are so closely in line that they should be regarded as parts of a single upfolding, the variation in height along the line being probably referable to differences in degree and sharpness of folding, and perhaps in part to faulting.

THE SELSUPARALI BASIN.

Our road led us across the lowest point of the broad ridge, which we approached by gentle ascent from the Chibin upland on the north; but its aspect changed when, on looking down its southern slope, we found there a rapid descent of 1,000 or 1,500 feet into the open basin of the broad Selsuparali shale syncline. This basin is drained through gorges in the Isferanli anticlinal

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range by headwaters of the Atrek which finds its way westward through the mountains to the southern Caspian. On account of the lower level of the Persian than of the Turkestan drainage system at this point, one of the headwaters of the Atrek system is actively gnawing its way through the escarpment at the lowest part of the divide into the Chibin upland and capturing drainage from the headwaters of the Serani Valley.

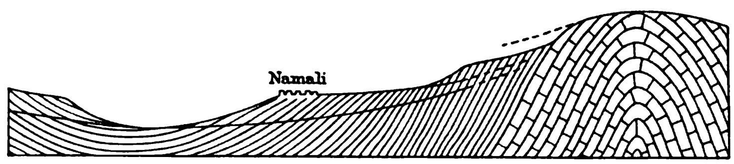

Fig. 28.—Two-mile profile of Terraces at Namali, looking east.

After studying the view from the crest of the unsymmetrical divide, we descended by a zig-zag trail and hired permission to camp in a grassy apricot orchard, among irrigated fields on a narrow valley floor at an altitude of about 5,500 feet. Above us was the village of Namali, a cluster of mud houses on the end of an interfluve. The village had seemed picturesque enough when first seen from the escarpment, but it appeared squalid and miserable on nearer approach. In the afternoon I ascended one of the interfluves for a review of the district.

Like the Serani Valley, the Selsuparali basin shows signs of revived erosion. The mature branching streams occupy valleys 200 or 300 feet below the even-topped interfluves, whose fairly accordant levels indicate pretty clearly that the weak shales of the basin had been reduced to a peneplain before the valleys were eroded. There were, furthermore, faint signs of earlier cycles of erosion, not perceived at Serani or Firuza, and hardly worth recording here but for their confirmation farther east on the following day. The earliest cycle is indicated by the round-shouldered form of the Isferanli and Akh-kemar limestone anticlines on the south and southeast of the basin, where the curved surface over the crest truncates the strata, as if with reference to a baselevel of which there is no record preserved in the less resistant shales. Certain benches on the mountain flank back of Namali appear to be remnants of graded spurs at an intermediate level. Then come the interfluves and the valleys of to-day, as shown in fig. 28.

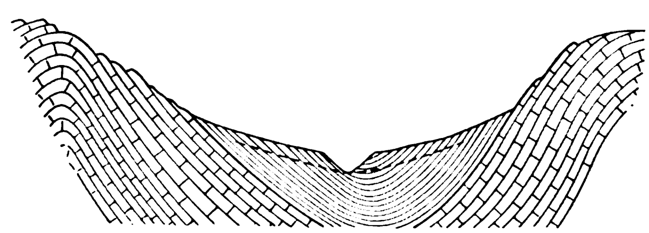

Fig. 23.—Two-mile section of Synclinal Valley, southeast of Namali.

The broad synclinal basin of Selsuparali, between the Buuzan and the Isferanli anticlines, becomes narrower southeast of Namali, where the closely folded and serrate inclosing ranges may be named the Giluli and the Akh-kemar, after their chief peaks. On June 3 we followed the longitudinal consequent Namali stream

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to its head, about 6 miles distant. While crossing the headwater col, as well as while descending the opposing longitudinal stream of Duruigar Valley southeastward, we passed a number of Kurd encampments. The valley was well inclosed at the col by the steep mountain walls, where great triangular sheets of limestone rose between successive lateral consequent ravines. The floor of the col, smoothly worn on the shales of the valley syncline at an altitude of nearly 7,000 feet, seemed to belong to the earlier cycle of erosion; the opposing longitudinal streams have intrenched their competing valleys so as to leave terraces of the older floor on either side, as in fig. 29. We camped on the further stream, about 10 miles from its head, and went up on the terraces in the afternoon.

THE TERRACES OF DURUIGAR VALLEY.

Successive cycles or impulses of valley deepening in the eastward extension of the synclinal valley were shown here more clearly than near Namali. The southern anticlinal range, now called the Telli Dagh, showed unmistakable graded slopes beveling the inclined limestone strata far up toward the crest of the range, as in fig. 30; remnants of sloping terraces occurred on the shales at less altitude; then came the chief terrace, below which the present valley floor is eroded along the axis

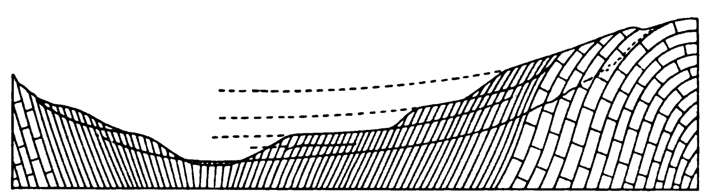

Fig. 30.—Two-mile profile of Terraces in the Duruigar Valley, looking east.

of the shale syncline. The period in which the upper limestone slopes were beveled and graded must have been the longest of those here shown; the later periods produced graded slopes only in the weak shales. It may be noted, however, that, by whatever process the terraces were produced, their record of terracing impulses is probably incomplete, for the reason that each long-lasting period of wide-valley erosion must have obliterated the work of earlier, shorter periods. In the ideal case of eight impulses to deeper erosion and terracing, shown in fig. 31, the records of only three are preserved to-day. In such cases it is only the successively smaller and smaller maxima of the whole series of impulses that make themselves known, as is well shown in the beach lines made by successive storms of decreasing intensity; for example, in the so-called "curbs" of the great Chesil bank of southern England. The four valley floors in the Kopet Dagh must not, therefore, be taken to imply that there have been only four periods of renewed erosion; there may have been many more.

It is difficult to determine the cause of the terraces by which the valleys in the Kopet Dagh are ornamented. Terraces may result from certain changes of climate on a stationary land mass; or from uplifts of the land in an unchanged climate; or from the interaction of these two causes. The slope that would lead, in the present altitude of the mountains, from the high-level floor of the Serani Valley through the former floor of the Firuza gorge to the plains, seems rather steep for a graded valley, its fall being about 4,000 feet in 20 miles; yet it does not seem impossible that under a climate even drier than that of to-day such a grade might have been developed and maintained by a stream of small volume and abundant load, after which a moister climate would permit valley erosion to a greater depth. On the other hand, it is manifest that uplifts of the mountain mass, whereby the streams were periodically accelerated, would result in terraces of a depth proportionate to the amount of uplift, and of a breadth proportionate to the interval of time between uplifts. The choice between these two possible explanations is not advisedly made by following a preference for one or the other, but rather by means of some *crux*, which contradicts one explanation and supports the other. This *crux* may perhaps be found on further exploration, if the terraced valleys are found to interlock in such fashion that no simple movement of uplift could have accelerated all the terracing streams, as is believed by Mr. Huntington to be the case for the Tian Shan valleys. Our few days in the Kopet Dagh did not enable us to apply this test there.

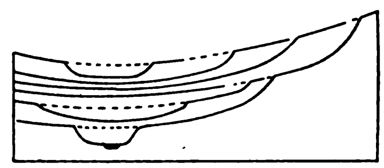

Fig. 31.—Scheme of Terrace Development.

We continued southeastward on June 4 along the Duruigar Valley. It soon widened; the Telli Dagh, on the south, becoming a broad anticline with moderate dips, and the Kara Ilikhi, as the continuation of the Giluli range is called, on the north, seeming to be cut off by faults. In the wide valley thus formed the shales have been broadly planed and covered with from 50 to 150 feet of gravel in continuation with the chief terrace seen on the preceding afternoon. A patch of higher terrace, associated with a beveled limestone slope behind it, was seen on the side of the Kara Ilikhi range. The modern valley is cut about 300 feet beneath the main terrace, and here has gained a width of half a mile at an altitude of about 4,800 feet.

Leaving the valley, we crossed the gravelly terrace plain eastward, and after about 3 miles descended to the Russian frontier post, Gaudan (about 4,440 feet altitude), on the great Meshed-Askhabad road, which had crossed the terrace plain somewhat to the southeast of our trail. The main anticline of the Kopet Dagh here breaks down in some manner, but is soon replaced by the Suru-muzdar anticline, an open but crooked valley separating the two. The bend of this valley into the Suru-muzdar anticline seemed to give opportunity of seeing the basal members of the heavy mountain-making limestones, but we had no time to leave the road to search for them. The head of the valley is gnawing southward into the broad, gravel-covered terrace. The road follows northward along the valley, which is manifestly enough guided by an oblique fault as it opens on the plains; for here we had the eastern dips of the heavy limestones overlaid with the shales of the main anticline on our left, and a bold scarp of the same limestones in the obliquely breached Suru-muzdar anticline on our right. Farther on the shales were beveled in smooth, graded slopes, covered with 100 or 200 feet of cobbles and

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gravels, and now dissected by the revived streams in ravines from 300 to 500 feet deep near the mountain base, but shallowing as the graded slopes descended to the plains. The return along the road from the frontier to Askhabad, some 30 miles, we covered rapidly in carriages.

The net results of the excursion into the Kopet Dagh, in so far as they bear on the work of the expedition, are as follows: A series of changing conditions has prompted the streams to terrace their valleys at several levels. The successive changes in the behavior of the streams indicated by the terraces have probably had some recognizable effect in changing the character of the piedmont deposits; the latter changes may possibly be recognized by borings and may then be correlated with the changes in the mountain valleys. It is very probable that terraces similar to the ones that we saw occur in other parts of the range. If the valleys were examined at intervals of 30 or 40 miles all around the border of the plains on the south and east, it might be possible to connect the dates of the several terraces on the west with the history of the Quaternary Aralo-Caspian Sea, and on the east with the glacial records of the more lofty ranges. Thus successive piedmont deposits could be dated. It is evident, however, that there are many difficulties in the solution of such a problem, and that much time and patience would be required before a solution could be reached. Yet in no other way does it seem possible to decipher the recent history of the piedmont fluviatile deposits.

THE DESERT PLAINS.

The railroad journey across the desert plains from Askhabad to Samarkand with three days stop at Old Merv, was extremely interesting, even if monotonous. The surface was absolutely plain to the eye, except for the dunes, and the dunes departed from the plain only as wind-waves at sea depart from a calm surface. Although apparently level, the plain has slope enough to give the Tejen, the Murg-ab, and the Amu rapid currents, in which these rivers carry forward a great volume of mountain waste. Mushketof (1891) describes this part of the plain as of fluviatile origin. Obruchef does the same, adding that the thickness of the river-laid layers is only several fathoms (1887; 1890, 247). The rivers have great variation of volume. The population of Merv, depending entirely on the Murg-ab for irrigation, had crops abundant enough in 1891 to export some of the surplus to Russia; and in 1892 had but little more than half the ordinary yield (Tarnovski, 1895). We were fortunate enough to see the Tejen and the Murg-ab in flood. The former had overflowed its channel and spread in a thin sheet for miles over the plain. The latter would have spread but for the restraint of dikes at Merv. Some of its waters had escaped further upstream and came to the railroad, wandering across the plain among the dunes, a curious combination of too much and too little water supply. The rivers had been still higher a few weeks before our arrival, and the Tejen bridge had been carried away, as well as some of the track on the plain west of Merv, causing great delay to traffic and especially to freight transport. By the time of our arrival, June 10, a temporary foot-bridge had been built across

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the Tejen, and the track elsewhere was relaid sufficiently to allow trains to cross the breaks at low speed. An engine that had approached the flooded Tejen too closely was seen mired in the softened mud of the plain; the track had collapsed under it.

THE AGGRADING RIVERS OF THE PLAINS.

The most notable feature of this district was the absence of valleys. The rivers have channels in which their waters are usually restrained, but there were no valleys in which the river floods were limited. The plains were open to overflow as far as flood supply held out. We were told, however, that some distance upstream (to the south) the Murg-ab has a flood-plain slightly depressed beneath the plain. This we interpreted as meaning that the river had there changed its habit from aggrading to degrading. On crossing the Amu at Charjui we saw a low bluff on the north or right of its course, although on the south the plain is not significantly above the river.

The general absence of valleys is a natural, indeed an essential, feature of a fluviatile plain in process of aggradation by flood deposits. It is peculiarly appropriate to rivers like the Tejen and Murg-ab, which dwindle away and end on the plain, so that every grain of sand and every particle of silt must be laid down as the water volume lessens and disappears. The absence of valleys would, on the other hand, be surprising in a lacustrine or a marine plain, for the reason that coincidence could hardly be expected between the slope that might be given to such a plain when it is laid bare and the slope that is satisfactory to the graded rivers that run across it. It is not, however, as has already been pointed out, always the case that fluviatile plains have no valleys eroded beneath their general level. The river-made plains of northern India are now commonly somewhat trenched by their rivers. Our Great Plains, piedmont to the Rocky Mountains, are likewise in process of dissection by their rivers. The plains of Turkestan are therefore somewhat exceptional in this respect. As a result we had unfortunately no opportunity of seeing sections of the plains in which the structure of the deposits could be examined. A well on the Czar's estate at Bairam Ali, a modern village near Old Merv, where we were most agreeably entertained by the superintendent, Mr. Dubassof, was said to have shown nothing but "sand and loess." The desert and river deposits found by borings beneath the Amu River bed at Charjui have already been noted. The inspection of these vast plains of silt was very suggestive in connection with the problematic origin of the fresh-water Tertiary formations of the western United States. Certainly no one who sees the river-made area of the plains of Turkestan can doubt the capacity of rivers to lay down extensive fine-textured deposits.

The ruins of old Merv are situated on the fluviatile plain, where large canals must have once led a plentiful water-supply from the upper Murg-ab. They lie some 12 miles east of the oasis of modern Merv, in which the greater part of the river is now used for irrigation. It is therefore especially desirable to make careful examination of the earliest of the ruins with respect to the level of their foundation and its relation to the surface of the surrounding plain. Some of the ruins are only a few centuries old; the cities that they represent are known to history. Others have

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the appearance of much greater age, being more completely decayed. The largest of these, Ghaiur Kala (fig. 32), a group of huge mounds within a degraded wall, must have had a beginning very long ago. The relation of its earliest, deepest-lying artifacts to the strata of the plain deserves the closest scrutiny.

As no sections could be found, it is impossible to say whether any subdivisions can be established in the fluviatile deposits of the plains. The best means of determining this point would be by the aid of a soil auger, the use of which is to be recommended. As an encouragement to study of this kind, it should be remembered that graded rivers, like those of these desert plains, are in a very delicate

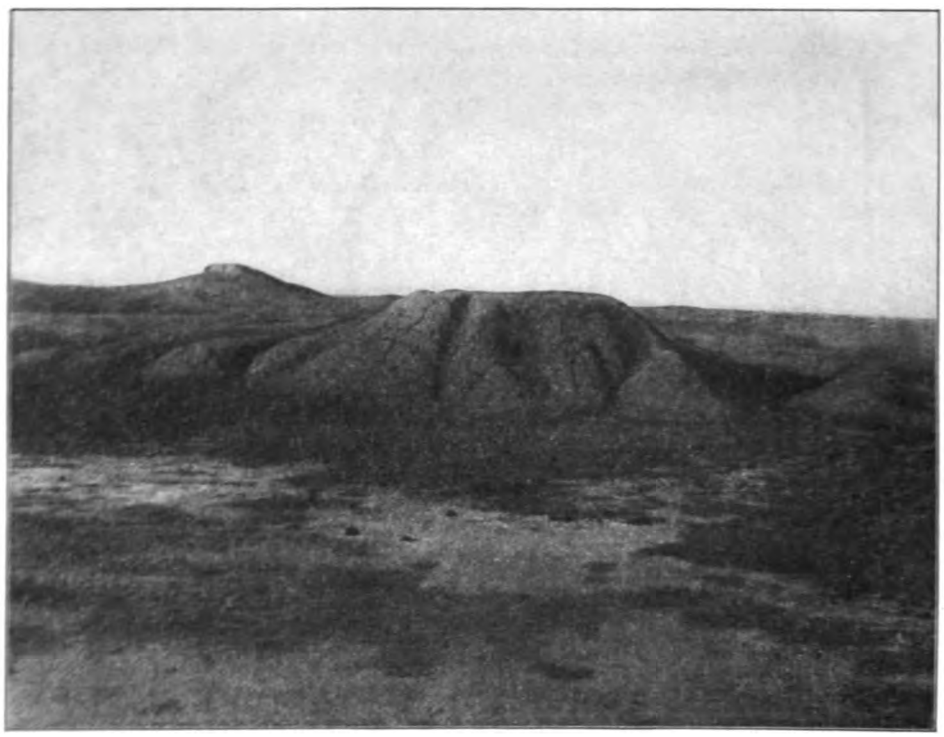

Fig. 32. -The Central Mound of Ghaiur Kala, from 60 to 80 feet high, in Old Merv, looking north.

adjustment, and that a change of climate or a change in the altitude of their head-waters should expectably produce a change in their régime. During a moister or cooler climatic period these withering rivers must have been longer than they now are; indeed, they would probably be longer than they are to-day if their waters were not distributed over the fields of the oases. There is good reason for believing, as various observers have suggested, that the Zerafshan would now reach the Amu but for its use on the fields of Samarkand and Bokhara. But whether the climate of the region has been moist or cool enough in Quaternary time to extend the Murg-ab and the Tejen so that they might join the Amu, as has been suggested, has not yet been proved.

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The right-handed shifting and bluff-cutting of the Amu, as a result of which the admirably irrigated and fertile oasis of Charjui is on its left side, has been taken as an illustration of the deflective force of the earth's rotation (cf. Walther, 61, 114); but it is still questionable whether this small force is sufficient to produce the results that are ascribed to it. The doubt on this point has greatly increased in my mind by reason of the measured deflection of the Mississippi, as determined recently by one of my students from the maps published by the Mississippi River Commission, being greater on the east (left) than on the west (right) in a period of twelve years. In any case, the bluff-cutting by the Amu must be determined by some other cause

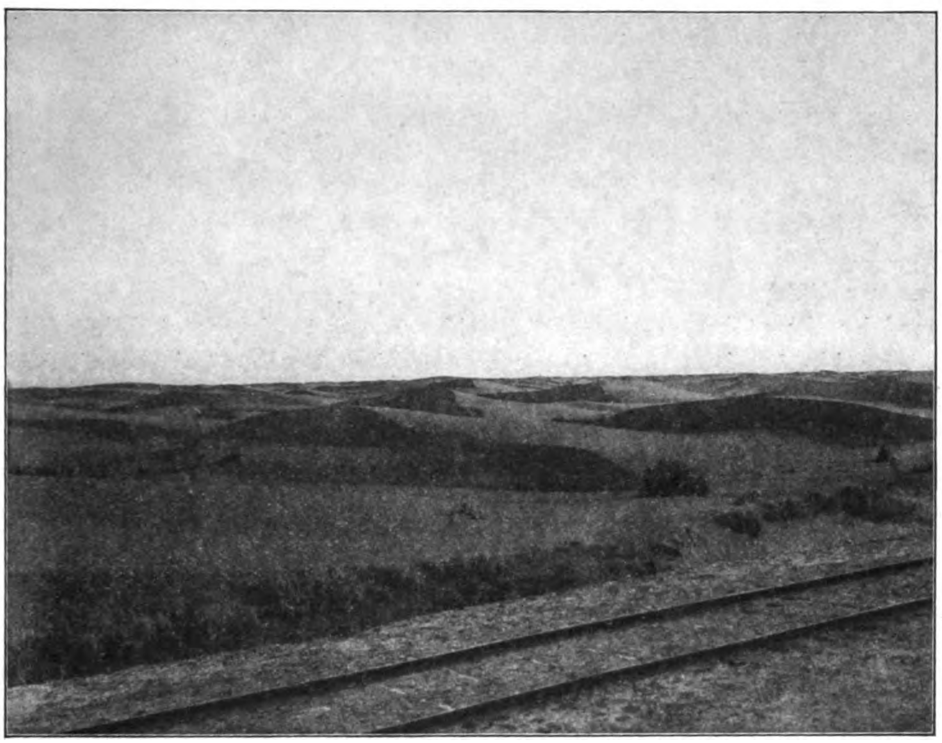

Fig. 33.—Sand Dunes south of Charjui, looking northwest.

besides the earth's rotation, inasmuch as it involves not merely a right-handed shifting, but a degrading action at the same time; and degradation by such a river implies some alteration in individual régime, such as climatic change or crustal movement would produce.

The railroad crosses a tract of typical crescentic dunes (barkhans) before reaching the oasis of Charjui on the Amu. Some areas had scattered bushes among the sands; others were essentially without vegetation, and there the dunes were at their best (fig. 33). They were under the influence of northerly winds, for their longer slopes were to the north, and their steep scarps and lateral horns were to the south. According to Russian observers, the form of the barkhans has a seasonal variation, following the change in the prevailing winds. Besides the seasonal variation of dune form, there appears to be a secular extension of the dune-covered area, in some places averaging 20 feet a year (Walther, 1900, 119).

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The dune-covered area was abruptly cut off as we entered the irrigated fields of Charjui on the plain bordering the Amu on the south. The fields of the gently sloping plain are delicately graded to level surfaces, each fed by a little canal and bordered by a little dike next to its lower neighbor. The canals are divided and subdivided, like nerve endings, the smallest ones being hardly noticeable. Many of them are bordered with trees. The houses and the walls of inclosed gardens are of gray, sun-dried mud. There are no fences between the fields; hence horses and cattle are tended or tethered while pasturing. Grain, lucern, and cotton were the principal crops noted. The change from the desolate sands to this thriving oasis was a beautiful example of the beneficent work of irrigation in the desert.

LOESS DEPOSITS.

It was suggested by Professor Penck, during our conference with him at Vienna on the outward journey, that special attention should be given to deposits of loess, in order to determine in how far they are now in process of accumulation, or in how far they should be referred to some period of past time. This problem was made the more interesting by seeing at Krems, on the Danube, above Vienna, a well-defined deposit of loess from which some 15,000 artifacts have been gathered by the patient work of Dr. Strobl. Some specimens of rudely chipped flints were kindly given to us to serve as samples of things to be searched for in the loess of Turkestan. Our hurried movements made it impossible to undertake any such search, or indeed to make any close examination of loess-covered areas; but we passed certain loess deposits regarding which our observations, even though made only from train windows or from post-wagon, seem worth placing on record.

LOESS NEAR SAMARKAND.

On approaching Samarkand, June 15, the railroad crosses an extensive deposit of loess, at once seen to be unlike the gravelly piedmont slopes near Bokhara, and equally unlike the sea of sand-dunes on the plain south of the Amu, but not easily distinguishable in a passing view from the fine silts of the Murg-ab and the Tejen plains, except that the surface of the deposit here was not level, but broadly undulating and sub-maturely dissected. A 30-foot cut, where the railroad made its way between opposite valley heads, was unfortunately passed in the twilight. At Samarkand a deep valley is cut in loess, well seen a short distance east of the railroad station. A few miles farther on, near the ridge across the Zerafshan, the hill slopes are cloaked with loess, on which a thin cover of angular waste has crept down. All these deposits, therefore, seem to be and to have long been in process of dissection rather than of accumulation. It occurred to me that even if other conditions were now favorable for the accumulation of loess in this district, the irrigation and cultivation of the Zerafshan flood plain is distinctly unfavorable to its accumulation; for the cultivation of crops and, perhaps even to a greater extent, the growth of trees, lifts the wind from the ground, and thus greatly diminishes the amount of fine silt that can be carried from the flood plain and deposited elsewhere. In the absence of cultivation the flood plain

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would be relatively barren and the finer material would be blown from it with relative ease. It is here assumed that the loess is not chiefly supplied from the products of weathering on uplands and mountains, where the finer soil has less lime than loess contains, but that it comes in greater part from flood plains, where the finer silt, largely produced by the mechanical attrition of cobbles and gravels, may be highly calcareous, as has been pointed out by Penck.

LOESS NEAR JIZAK.

A loess deposit of unusual interest was seen on June 17 on the uplands north of the Zerafshan, where the railroad contours around the eastern spurs of a detached part of the Turkestan range, west of the valley of the Sankar. The Sankar follows a valley that is rather sharply cut down in an upland or local peneplain. The upland and the loess upon it are briefly described by Mushketof (1886, 355). The valley is about 100 feet deep where the railroad enters it, but the depth increases to 300 or 400 feet farther north, where it opens on the broad

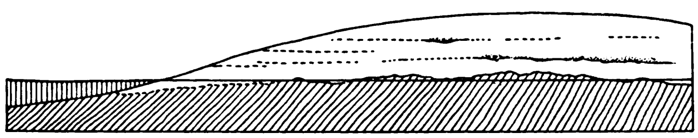

Fig. 34.—Diagram of Railroad Cut, south of Jizak.

Hunger (Golodnaia) steppe near the town of Jizak. The valley floor is usually about a quarter of a mile wide; it narrows where a belt of harder rocks forms "Timur's Gate." The valley sides are graded, except for the outcrops of the most resistant ledges. The upland or peneplain, where it is preserved on the spurs between the numerous side valleys, truncates the disturbed rocks of the district very evenly. The side valleys that dissect it are fairly well open and graded far up the mountain slopes on the west. Kurgans (mounds) occur in some of these valleys. As the steppe is approached, the side valleys increase in depth and width, and the even upland of the spurs is replaced by maturely rounded hills. Then the steppe suddenly opens, as if the upland were terminated by a fault or sharp bend; for if the level of the upland were prolonged northward it would run out into the air, far above the present plain. Its even profile was well seen by looking back from the train after we had run some miles out on the plain. The main and branch valleys of the Sankar must have been eroded after the faulting and uplift of the district with respect to the steppe.

The railroad must be many hundred feet above the main valley where it crosses the divide between the Zerafshan and the Sankar; it descends to the Sankar across many of the spurs and side valleys, cutting the first and filling the second. Our train ran at moderate speed and we had a good sight of the cuts, whose fresh walls disclosed sections that are generalized in fig. 34. A somewhat uneven rock floor was cloaked with loess to a thickness of 10 or 15 feet. The loess contained sharply

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irregular partings, carrying a thin deposit of angular stony waste; it also showed faint color bands, nearly horizontal, which were distinctly cut by the slopes of the spur sides; hence the valleys were regarded as younger than the loess. If this interpretation be correct, there is reason for thinking that the loess of the spurs is older than the uplift on the north-bounding fault, by which the revival of valley erosion was prompted. Evidently, then, this loess deposit ceased accumulating long ago, and has since then been much eroded. The fine loess-like deposit of the southern part of the Hunger steppe is colored as river-wash on Muhsketof's map. Its surface is gently rolling, and the railroad cuts in the swells repeatedly show its fine, uniform texture. Near the mountains on the south it is traversed by the flat-floored valleys of dwindling streams, where we saw many cattle pasturing.

The uplands and loess-capped spurs over the Sankar Valley, and their relation to the Hunger steppe, impressed me as particularly well worth a closer study.

A considerable area of dissected loess was passed after the railroad had crossed the Syr on the way to Tashkent. Like the other deposits, this showed every sign of having long submitted to normal erosion. Where the Syr swung against it there are vertical bluffs 100 feet or more in height.

LOESS IN FERGANA.

The interesting ride through the Fergana basin, from Chernyayevo junction, on the main line, eastward to the end of the branch line at Andizhan, deserves mention in this connection, from the striking suggestion that it gave of the conditions, favorable and unfavorable, for the supply of loess from rivers. At various points, as near Posietovka, Kokan, and Andizhan, there were extensive plains of gravel, washed, from time to time, by the flooded streams from the mountains on the south. The plains were usually barren and open to the action of the wind. Dunes were sometimes seen upon them. Such surfaces might afford much silt fine enough for carriage by the winds, after the floods that bring the silt subside. Neighboring areas of fine soil were irrigated and seemed richly productive with crops of cotton, wheat, rice, and lucern, with vines and fruit trees, and many rows of poplars. Much silk is produced here. It is woven in several of the cities. Many cases of cocoons are sent to France. The silt is deposited in the fields by the turbid irrigating streams, as well as by the winds, and is protected from the winds by the trees and smaller plants. There can be little question that the occupation of this basin for many centuries past has caused a considerable deposit of silt on the cultivated areas and held it from being swept away to the uplands by the winds. If the water were not led about in canals and spread out on delicately terraced fields it would run wild, and much of the silt that is now detained under plant protection would be more open to wind transportation from the torrent flood plains. Cultivation thus seems to be distinctly favorable to the deposition of stream-borne silt on the valley plains and unfavorable to the deposition of wind-borne loess on the neighboring uplands.

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There is, however, another condition that is even more adverse to the supply of wind-borne silts. This is found where the streams have incised their courses in narrow gorges instead of broadly spreading their floods over torrential fans; that is, where the streams are engaged in degrading instead of aggrading their beds. We crossed a degrading stream about 7 miles west of Khojent. It had for some reason cut a sharp and deep trench in the plain, so that it was not seen until we were close upon it. There was no possibility of its overflowing the plain, and so all its silt was washed along its channel. The sprawling and shifting streams elsewhere seen on the fans were in most marked contrast to this secretive river. Hence, in so far as loess is derived from rivers, there can be little question that it comes from aggrading rather than from degrading streams; and this conclusion seems to be applicable to the loess of the Alpine region, as described by Penck, and to that of the Mississippi basin, as described by Shimek and others, as well as to that of Turkestan.

The ride through Fergana was most entertaining from its variety. The great snowy ranges of the Alai rose in the south. Their Alpine crests and snow fields were brilliantly clear in the early morning. By noon they were much hidden under diurnal cumulus clouds. We could see, with our field glasses, many features of glacial origin, further described below. Northeast of Khojent was an excellent example of one of those sharply dissected ranges at whose base a series of digitate spurs interlock with branching valley floors, so as to make a most sinuous base line, in strong contrast to mountain ranges of simple border, like the range south of Jizak. The latter seems to belong to the class of somewhat dissected fault blocks; the former, if it ever had a faulted front, has lost all signs of it. South of Maxram rose a high dissected dome of apparently crystalline core, wrapped around by colored sedimentaries—first, a dark belt that lapped on the flanks of the dome, then a weak gray belt; then more resistant red beds. The colored belts are much narrowed as they curve around the northern base of the dome from east and west, as if they were torn by marginal faulting or tilted to steep dips. Dissected fans stand forth from the larger ravines of the dome; younger and smoother fans are built at their base; then come the gravelly flood plains of the streams, with many dunes heaped on them. Near Marghilan we passed benches of uplifted gravels, probably corresponding to the uplifted and dissected sub-recent ridges that we saw a few days later on a ride south of Andizhan. Here the strata dipped 10° or 15° northward, and fine gray silts alternated with coarse gravels. Similar alternations of gravels and loess-like silts were seen in the borders of the Kugart Valley, where we entered the Tian Shan ranges on June 30.

LOESS IN SEMIRYETSHENSK.

Much loess was seen on the steppe west of Vyernyi at the northern base of the Trans-Ili Ala-tau; it seemed less dissected than the deposits west of Samarkand and south of Tashkent. More remarkable deposits of loess were seen while posting across Semiryetshensk—the Seven-river district—from Vyernyi northward

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to Semipalatinsk, July 28 to August 2, in several headwater valleys of the Karatal, a river that flows into the mid-southern side of Lake Balkash from the western spurs of the Cis-Ili Ala-tau. Near the village of Kugalinsk (see sheet 12 of the 40-verst Russian map), the northwest slopes of the Chulak range were cloaked with grassy loess and somewhat dissected by small consequent valleys, across which the road had many ups and downs. On the ridge between Kugalinsk and Tzaratzinsk the slopes are strewn with irregular mounds of loess of small relief, in which the roadside cuts were creamy white. The surface was well covered with grass; hay had been cut in places. On the next ridge, which divides the Kok from one of its branches, there was a curious mixture of fresh and hackly ledges and smooth mounds of loess, in which some road-cuts were 10 feet deep. The mounds seemed to have a trend from the northwest or west-northwest, and occurred up to altitudes of 4,000 or 4,500 feet.

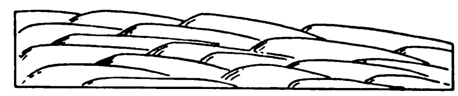
Fig. 35.—Diagram of Loess Drifts, near Kara-bulak, looking south.

The valley of the Kusak, near Kara-bulak village, afforded the most significant features, for here the drifted form of the loess became very pronounced. The valley floor, at an altitude of about 2,800 feet, very smooth and about a mile wide, opens westward between long spurs descending from the range on the east. The stream has cut a narrow trench, 20 or 30 feet below the floor, along the base of the northern spur. The current is rapid, with large cobbles on its banks. A few miles to the west the trench opens on a broad, fan-like plain, where the road was very rough from the abundance of rolled stones. The valley-side spurs were covered with loess drifts, hundreds of feet in length, thinly overgrown with herbage, somewhat barkhan-like in form, gracefully convex in their longer ascent from the west and falling off steep to the east; crowded together and overlapping like a school of fish hurrying upstream; more closely packed to the west, and thinning out to the east. Their form is too systematically drawn in fig. 35. The difference between these aggraded drifts and the normally dissected slopes of the spurs of country rock farther up the valley was very striking and suggestive. The latter had all the down-hill lines that indicate the work of ordinary erosive forces, and repeated the ravined forms so familiar elsewhere. The former showed no sign of down-hill grading, but expressed most clearly the sweeping of the wind over their graceful curves. Hence, unlike the deposits near Samarkand and Tashkent, the loess here is of so recent a date as to be unchanneled. It preserves most perfectly its wind-swept form; it may still be growing. The phrase, "wind-swept form," is used because, although the loess drifts are now covered with scanty herbage, the profile of the drifts, gently convex to windward and falling more abruptly to leeward, suggests that the actual motion of the wind has had much to do with shaping them. As to the constitution of the drifts, we had the most convincing evidence while descending across them on the southern side of the valley. An impalpable white dust was raised in a blinding, smothering cloud by our galloping horses and rolling wheels; and the penetrating power of the dust here and elsewhere was

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shown at the end of the ride by the condition of our clothes, which had been carried in a well-wrapped valise, unwisely tied on at the back of our tarentass.

The form and distribution of the drifts by Kara-bulak leaves no doubt as to the recent derivation of the loess from the plains on the west and northwest. Not only does the fan-like flood plain of the Kusak open in that direction, but the great sandy wastes of the lower Ili and Karatal, south of Lake Balkash, stretch for scores of miles beyond. All this gives further support for the supposition that, in this region at least, loess is not derived from mountains, but from the river plains. To be sure, the waste that is laid on the plains comes originally from the waste of the mountains, but in the mountains the slopes are often plant-covered, and are therefore better fitted to gather loess than to furnish it, as seems to be attested in the loess mounds that have been so manifestly laid up on the ridges over the Kok River above mentioned. It is not from ordinary river valleys that loess is best supplied, but from the open plains of aggrading rivers; and, moreover, it is chiefly while the aggrading rivers are wandering over their plains that loess can be furnished in greatest quantity, as was pointed out in the notes on Fergana, above. The former broad valley floor of the Kusak by Kara-bulak, for example, is not to-day in condition to furnish loess, because it has been plant-covered since the river has intrenched itself below the plain, and the river trench is as yet too narrow for the outspreading of silts. Fúrther west, where the same river emerges from its trench to wander upon a broad plain, loess may now be swept off in good quantity by the westerly winds, to settle on the plant-covered hills.

LOESS IN THE (WESTERN) KUGART VALLEY.

The loess drifts of the Kusak valley-sides give me confidence to put on record certain notes made in the valley of the (western) Kugart, in the outer spurs of the Tian Shan, about 20 miles northeast of the town of Jellabad, in northeastern Fergana. The treeless hillsides seemed often to be loess-covered, and in many places the loess had slipped down, leaving a scar. Ravines were worn through the loess, hence it was not of very modern date. The loess and the valley floor were well covered with herbage. But the most significant feature was the drift-like appearance of the loess; it seemed to lie in pillow-like masses (fig. 64), whose lines of modeling were not down-hill, except where the drifts were gashed by ravines, but along the hillsides, as if here it had been wind-swept down the valley to the southwest. We asked our jiggits, who had been detailed by the native chief of the department to accompany us to the head of the pass, from what direction the wind blew in winter; and the answer was, "Strong from the northeast."

The Kugart River is to-day intrenched from 300 to 400 feet below its former valley floor, which was here a mile or more wide. The terraced walls of the trench show the valley to have been heavily aggraded with gravels and sands. It is therefore probable that the loess on the hillsides was largely supplied from the valley floor during the period of aggradation, and that since terracing began the accumulation of loess has ceased.

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THE TIAN SHAN MOUNTAINS.

The general geology of the mountain ranges that border the plains of Turkestan on the east is too large a subject and too little connected with the special interests of our expedition to have been itself an object of special study by our party. Moreover, it is precisely in general geology that Russian explorers have done such excellent work in this region. But the more modern history of the mountains, as recorded in their physiographic development, seems to have been less examined; and since this phase of the subject is closely associated with our study of the plains, we gave it our first attention here, as we had previously done in the Kopet Dagh. My own report deals with the Tian Shan ranges between the provinces of Fergana and Semiryetshensk. The report of Mr. Huntington sets forth the results of his visit to Kashgar after leaving me at Issik Kul. The report hereto appended by Mr. R. W. Pumpelly tells of his observations on the mountains south of Fergana during a visit to Lake Kara Kul on the Pamir.

PREPARATION FOR THE MOUNTAIN JOURNEY.

My party from Andizhan across the mountains to Lake Issik Kul included Mr. Huntington as assistant and Mr. Brovtzine as interpreter. General Ivanof, governor-general of Turkestan, had given us during our stay at Tashkent letters of introduction to various officials; among others, to the governor of the Andizhan district, Colonel Korytof, from whom we had much assistance in securing our outfit. He detailed a member of his police force, a Sart of marked intelligence, to act as our head-man and cook, and we had much efficient service from him. A second man was engaged to look after our three pack horses. We received generous aid also from Captain Asatians, secretary of the Military Club at New Marghilan, where we went for certain supplies. It was by Mr. Polovtzof, diplomatic official at Tashkent, and his secretary, Mr. Andreef, that we had been given the practical suggestion of carrying colored handkerchiefs of bright and varied patterns, to serve as small change when paying the Kirghiz for supplies of mutton and milk and for service as guides in the mountains. We had a small canvas tent, but seldom found occasion to use it, as the clean felt tents or "yurts" in the summer camps of the Kirghiz, well furnished with felts, rugs, and silk quilts, were much to be preferred in the cool and occasionally rainy nights in the mountains. We carried no firearms. Besides the local sheets of the 40-verst map of the "Southern Boundary of Asiatic Russia" (1889), blue-print copies of the contoured 2-versts-to-an-inch map, as far as the sheets were completed along our route, were supplied to us by Major-General Gedeonof, chief of the topographical office at Tashkent, and we can testify to their accurate expression of surface forms. While at Andizhan we had the good fortune to meet Academician Chernichef, director of the Russian Geological Survey, and his assistant, Mr. Korolkof, on their return from a journey to Kashgar. Professor Chernichef gave us much information from his unpublished notes on the geological structure of the mountains; and Mr. Korolkof gave to Mr. Huntington a letter of introduction to his father, General Korolkof, in Przhevalsk, at the eastern end of Lake Issik Kul.

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Andizhan had been badly injured by an earthquake a year before our arrival, and the Russian part of the city had hardly begun to recover from the destructive effects of the shock. Many of the inhabitants had left their shattered houses and still were living in box freight cars that were standing in trains on temporary tracks in the streets near the railway station. In the absence of any hotel, we spent the few days of inevitable delay, while outfitting, in the small service car that had been obligingly put at our disposition by the railway superintendent at Tashkent, where we had left the rest of the party in the larger car that had brought us all from Merv. It was during this interval that we visited the ridges of tilted and dissected gravels and silts a few miles south of Andizhan, to which reference has already been made.

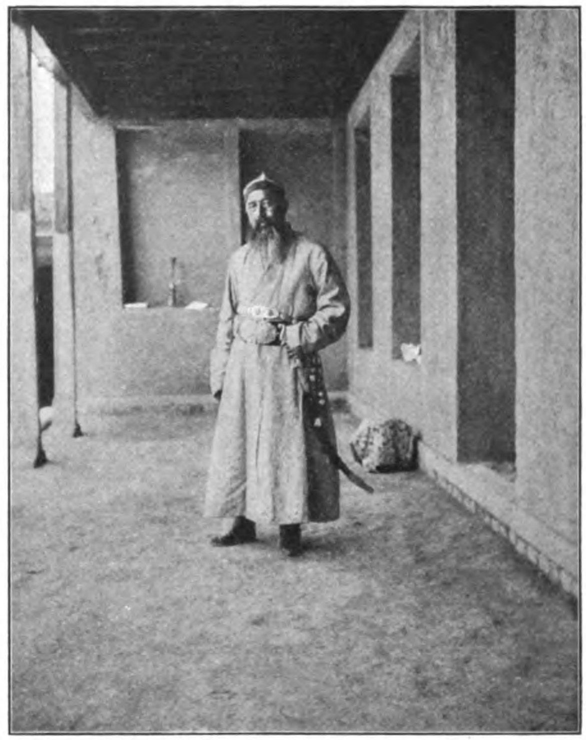

Fig. 36.—Kambar-Ali, the Min-Bashi of Kugart.

One of the most interesting experiences of this part of our journey was the companionship, for the first three days, of Kambar-Ali, the Min-bashi or native chief (fig. 36) of the department of Kugart, through which we had to pass. Colonel Korytof summoned the Min-bashi to Andizhan the day before we left that city, and presented us to him as foreign travelers to whom he should show every attention. The Min-bashi accordingly met us shortly after sunrise on June 27, with his interpreter and several jiggits, or mounted police. Thus escorted, our cavalcade rode forth along shaded roads, through the fields and villages on the fertile and populous plain of Fergana. One of the jiggits, riding ahead, announced the coming of his chief, whereupon all other travelers dismounted and remained standing on the roadside to salute the Min-bashi and his party as we rode by. We lunched at a native restaurant, where tea, rolls, and apricots were served. The first night was spent in the town of Kurgan Tepe, where we were the guests of another native chief, a friend of our host. On June 28 we crossed the Kara-darya, a rushing, turbid river, in high-wheeled carts. The river was at that time about 200 meters wide in a mile-wide, barren flood plain of cobbles, gravel, and silt. The cultivated fields on the north and south were from 3 to 5 meters higher. We then crossed extensive wheat fields, owned by the Min-bashi, and were entertained for the night at our host's house, a spacious but simple residence near the village of Chanket. Here we met

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several of his sons, but his wives and daughters remained in retirement in another part of the mansion. Among the objects of interest that were shown to us with justifiable pride was a photograph of chiefs and officers, the Min-bashi among them, who attended the coronation of the present Tsar. Although our conversation was retarded by the necessity of two translations, the courtesy of our host never failed. When we took leave of him, on June 29, at one of his summer houses near the town of Jellabad (fig. 37), it was with regret that we lost so genial a companion. Three of his jiggits went on with us to the limits of his department. For four days we found that couriers had been sent ahead to make announcements of our coming, and to secure us a welcome among the people of the mountains.

Fig. 37.—The Min-Bashi of Kugart and his Men.

The Kirghiz were always helpful and hospitable. The Russians had described them as untrustworthy, and doubtless they resemble people in other parts of the world in including some who are lazy and evasive with others who are thrifty and truthful. Some of our felts were stolen in a village in the Tuluk Valley, but they were soon recovered. A similar experience has befallen me in a mining town in Montana. The leaders in the villages seemed to be men of energy and ability. They always received us with courteous attention and gave us of their best. In the midsummer season of our visit, the rude, mud-house winter villages in the valleys were almost deserted. We saw many of the houses open and empty; only a few men remained there to look after the irrigation of the wheat and grass fields. The rest of the population, with all their possessions, were found in the high valleys. Around Son Kul in particular, at an altitude over 9,000 feet, we saw great numbers of summer camps. The habit of life was that of seasonal migrants rather than

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strictly nomadic. The chief men were certainly well-to-do, and seemed to want for nothing. One of these, Kuve Gen Shigai-ef (fig. 38), had been a judge among his people (fig. 39). He invited us to lunch in his yurt at Akh Tash (White Stone) on the Son Kul plain. The yurt was one of the finest we had seen, with a hundred sticks supporting the clean felts of the roof. His two wives, wearing heavy, white turban-like head-dresses, were seated by him, embroidering. His eldest son wrote the names of the family in my notebook in Turkish characters with a ready hand. The judge told us—through two translators, as usual—some of his experiences in settling disputes, chiefly about pasture land, and gave us much information about our route, directing one of his sons to accompany us to his winter village, not far from Issik Kul, a three days' journey. In another village, where the local chief was absent, his elderly father entertained us most genially. He was particularly interested in our maps, and asked many questions as to the names of mountains and streams, their distance and direction from his camp, and found much pleasure in confirming our readings by reference to his men. At the end of the evening's talk our host said: "You have traveled far and have seen much of the world; you must know many things. We are simple, ignorant people, who know only our own mountains and valleys."

Fig. 38.—Kuve-Gen-Shigai-ef, his Younger Wife and Children, and our Head Man, Ma'raim.

ROUTE OVER THE MOUNTAINS.

Our route, briefly indicated at the beginning of this report, may here be given in more detail in so far as the journey beyond Andizhan is concerned; and it may be noted at the outset that there are wagon roads in the larger valleys, with bridges over some of the streams, while trails cross the mountains in all directions. In the prevailing absence of forests, movement is easy, except in certain narrow and rock-walled gorges which some of the rivers have worn in their passage through the ranges.

After leaving Andizhan on June 27, we went northeastward up the terraced valley (fig. 63) of the (western) Kugart River, a branch of the Kara Darya, following a wagon road half the way, and then crossed by a trail over Kugart pass in the Fergana range, about 10,500 feet altitude, in the afternoon of July 1, and descended eastward, to camp in the valley of the (eastern) Kugart (figs. 67 and 68), a branch of the Narin, both the Narin and the Kara Darya being branches of the Syr. On July 2 we crossed the Oi-Kain pass eastward to a branch of the (eastern) Kugart, and camped at Urgas-Khan, a summer village of Kirghiz, in a grassy valley at about 8,000 feet elevation. At noon of this day we overtook a large caravan of horses and camels laden with merchandise for the interior. An open pass led us eastward to the headwaters of the Makmal on the morning of July 3, and after crossing a belt of badlands southward, we camped by a new bridge over the Alabuga River. Here we met a Russian lieutenant of engineers, on his way to superintend work on a

Fig. 39.—Kuve-Gen-Shigai-ef and some of his Men at Akh Tash, Son Kul.

road over the Kugart pass. He had lately been in Kashgar, and gave Mr. Huntington some useful suggestions about the road thither. We followed a good road down the Alabuga Valley northeastward (fig. 60) on July 4, and rested over Sunday, July 5, in the garden of a Kirghiz winter village, Tot-kui. On July 6 we reached the junction of the Alabuga and the Narin, and turned eastward up the Narin Valley, camping for the night on the river bank at an altitude of about 6,500 feet, near a party of Sart sheep dealers, who had just brought a flock of some 3,600 sheep across the river with a loss of only ten, on their way to Fergana. Since July 3 the road had been in a dissected basin of Tertiary conglomerates and clays, which continued eastward far up the Narin Valley.

On July 7 we forded the Narin, and turned northward along a trail up a side valley, camping in the mountains with a party of Kirghiz, who were driving their

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flocks to summer pasture by Lake Son Kul. The next day, July 8, we went on with the Kirghiz, crossing the Dongus-tau range at about 10,000 feet elevation, reaching the lake about noon, and camping above 9,300 feet in one of the summer villages on its southern border, after an afternoon ride to a small glaciated valley. The gray yurts of many Kirghiz encampments were dotted around the lake, and near each camp the grassy meadows gave pasture to camels by the score, horses and cattle by the hundred, and sheep and goats by the thousand. On July 9 we forded the outlet of the lake at its southeastern corner, went northward along the plains on its eastern side, visited two glaciated valleys of the Kok-tal range in the afternoon and then had our view of the flat-topped Bural-bas-tau range to the southeast; we camped in another summer village for the night. On July 10 we crossed the Kum-ashu pass in the Kok-tal range and descended northward to the Tuluk Valley, camping again in a Kirghiz village. Having seen during the descent a large moraine in the Chalai range (fig. 49), north of the valley, we went up to it (fig. 50) on the morning of July 11, and in the afternoon followed down the Tuluk-su, eastward to its junction with the Juvan-arik (so-called by a post-master, but named Kara-khojur on the 40-verst map), and there stayed in the post station, Sari-bulak, on the road from Kashgar and Narinsk through the mountains to the open country of the north. On July 12 we went northward through deep gorges in the Yukok-tau range down the Juvan-arik to its junction with the Kach-kar River in the Kach-kar basin, south of the Alexander range, and rested at Serai Kara-gol over July 13. The river below the junction is the upper trunk stream of the Chu, which farther on escapes northward from the mountains and then flows far west to disappear on the plains; but it is here called the Urta-Takoi. We followed it eastward on July 14 and camped on the plain that borders the western end of Issik Kul at an altitude of 5,300 feet.

On July 15 and 16 we made a detour south of the lake to see some glaciated valleys in the Terskei Ala-tau range, camping the first night at a small spring in the mountains, and the second night enjoying the comfort of an excellent yurt at a summer village in the upper valley of the Ula-khol, an affluent of the lake. On July 17 we returned to the west end of Issik Kul, where the rapid Chu makes a sharp bend from a northward to a westward course, and at the elbow gives out a small distributary, the Kute-maldi, which flows with sluggish current eastward to the lake. On July 18 we followed the post road eastward along the north side of the lake and spent Sunday, July 19, at Turaigir station. We still followed the post road eastward on July 20 and 21, reaching the Russian village of Sazanovka. There Mr. Huntington left us on the morning of July 22, our head-man going with him, on the road around the east end of the lake, and thence southwest and south over the Tian Shan to Kashgar, as is duly set forth in his report. Mr. Brovtzine and I turned northward, hoping to cross the Kungei Ala-tau range by the Sutto-bulak pass on the direct way to Vyernyi. We spent the night of July 22 at a Kirghiz camp in a moraine basin, at about 8,000 feet altitude, but on July 23 were disappointed to find the valley head below the pass covered with deep snow. We attempted to beat a track for our horses (fig. 52), but gave it up on reaching the

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top of a fresh moraine at a height of over 11,000 feet, near the end of a small glacier, and finding a mile of snow and nearly a thousand feet of ascent still before us. Our Kirghiz guides then said they had known it would not be possible for us to make the pass. We had asked them many questions the day before and they had promised to show us the trail. Their silence about the difficulty of the pass apparently resulted from a feeling of deference to foreign travelers. We returned to Sazanovka, sold our horses at about half purchase price, discharged our packer, and set out in post wagon (fig. 45), retracing the road along the lake through the afternoon and night of July 24, descending northward through the Buam gorge of the Chu, between the Kungei Ala-tau and the Alexander ranges on July 25, crossing northeastward over the western branch of the Trans-Ili Ala-tau range in the night, following the piedmont plain eastward through the morning of Sunday, July 26, and reaching Vyernyi in the afternoon (altitude 2,400 feet).

On July 27 we called on General Yonof, governor of the province of Semiryetshensk, and on July 28 started for a ride of 1,000 versts northward across the steppes (fig. 48) in a tarentass, or springless post wagon (fig. 45). We made good time, stopping only to change horses and for meals, and in spite of the loss of seven hours from breaking one wheel and from binding another, reached Semipalatinsk, on the Irtysh, in the afternoon of August 2. The guest rooms in the post stations on the road were, with very few exceptions, clean and neatly furnished. Tea, bread, milk, and honey were among the chief articles of food to be had. At Semipalatinsk we waited two days for a boat to go down the river, starting in the early morning of August 5, and reaching Omsk on August 7. The fast express on the Siberian railway carried us westward from Omsk at midnight, August 8.

This journey furnished many entertaining incidents, some of which I have narrated elsewhere. It afforded continued opportunity for observations of geologic and physiographic interest, of which the most suggestive are here presented in classified rather than in narrative order, under such headings as mountains, glacial records, Tertiary basins, valleys with gorges and terraces, and lakes. The features of the mountains and the Tertiary basins do not bear directly on the work in hand. The other headings afford material of a kind that may, if sufficiently extended by further observation, suffice to determine a number of subdivisions of Quaternary time. On all these subjects, except the Tertiary basins, Mr. Huntington's report on his journey south to Kashgar and west to Fergana in August and September contains important information supplementing that which was gathered while we were together through July.

WEATHER, CLIMATE, AND VEGETATION IN THE TIAN SHAN.

The oppressive heat of the southern plains had already moderated at Samarkand and Tashkent. After leaving Andizhan the days were not uncomfortably warm, except for a few noon hours in the upper Narin Valley, and the nights were always cool or cold. Water froze near our tent at Son Kul on the night of

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July 8–9. Rain fell not infrequently between noon and night, for the most part from the mountain-made, overgrown cumulus or nimbus clouds, which drifted slowly eastward, their cirro-stratus cover far outreaching the main cloud mass. Many of the showers fell only on the mountains, leaving the open, inter-range depressions, such as the Alabuga and Narin valleys and the Issik Kul basin, dry and of subarid appearance. Thunder showers swept by while we were in the (western) Kugart Valley, June 30, and while we were crossing the Kugart and Oi-Kain passes, July 1 and 2; heavy rain and hail showers drifted over us at Son Kul, July 10. We wore long, black woolen waterproof cloaks (burkas) of the Caucasus, that protected us admirably while riding in the rain. The Chaar Tash range, ending eastward in the angle between the Alabuga and Narin rivers, fed a series of floating cumuli (July 6), which slowly dissolved as they drifted beyond the mountains. We saw a number of distant thunder storms over the mountains by Issik Kul. The fair-weather days on this lake were characterized by clear sky over the water and by long rows of cumuli over the snowy Kungei and Terskei Alatau to the north and south. We were troubled with high wind only on July 17, when a dry gale from the west swept over the plain by Issik Kul; and for a short time in the afternoon of August 2, when a furious dust squall from the west beset us as we rode into Semipalatinsk.

The only climatic feature which our short excursion brought clearly forth is the contrast between the mountains and the deeper valleys as to rainfall and relative aridity. As already noted in the Kopet Dagh, a difference of elevation of a few thousand feet produced a marked difference in the appearance of the surface. Vegetation was scanty in June in the deeper interior valleys or basins of the Tian Shan at elevations of 7,000 feet or less; it was abundant in the higher valleys above 8,000 feet. The cause of this contrast did not seem to reside merely in increase of rainfall with altitude, and in the protection of the inner valleys from the rain-bringing winds by the inclosing mountain barriers, but also in the direct excitement of rain-making processes on the mountain ranges and in the cessation or perhaps even the reversal of these processes in the large, open valleys. The preceding paragraph tells of several examples in which the growth of thunder-shower clouds was intimately associated with mountain ranges, thus suggesting their dependence on the ascending diurnal breezes on the mountain sides, as has often been noted elsewhere. In contrast with the mountain cloud masses was the prevailingly clear sky over the open depressions, as noted in the Alabuga and Narin valleys and over Issik Kul; and here a descending component of atmospheric movement should prevail to compensate for the ascending component where the cloud masses occur. Hence the open valleys not only receive very little summer rainfall, but they are swept over by air whose dryness has been increased by the descending component of its motion. Their descending component is not merely that by which a wind should, after crossing a range, turn downward into a basin. The descending component of this general origin must be largely increased by the local convectional circulation that is excited by the mountains. Thus the basins not only get little rainfall, but are parched by evaporation into the drying winds that settle upon them. The seasonal migration of the Kirghiz, with their herds

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and flocks, is an immediate response to the distribution of vegetation, as thus determined.

The prevailing absence of trees is the most notable feature of the vegetation. There were open groves of poplars close by some of the streams, but where the more important trails followed the valleys the trees had been unmercifully trimmed or felled for firewood, and few remained standing. In one of the branch valleys of the Alabuga a single large tree serves as so notable a landmark that it is entered upon the large-scale Russian map. On our way from the Narin Valley up to Son Kul, we passed through fine groves of coniferous trees, but their occurrence was exceptional. Nothing of the sort was seen at similar altitudes when descending from Son Kul into the Tuluk Valley. Again, during our ascent into one of the south-opening valleys of the Kungei Ala-tau, north of Issik Kul, fine groves of conifers occupied the more shaded slopes of the side ravines. The line between trees and herbage was often very sharply defined. This was noted by Severtzof, who ascribed the general absence of trees to a recent change from a moister to a drier climate (1875, 66, 67); but it is difficult to believe that the prevailing absence of trees is natural on mountain slopes where flourishing groves are occasionally found. It seems more reasonable to ascribe the treelessness of the mountain sides to their long occupation by nomadic pastoral tribes, to whom pastures were of greater value than forests. It would be interesting, in this connection, to inclose and protect certain of the mountain tracts from grazing, and to plant them with tree seeds or young trees; and it would be surprising if a thrifty growth did not result. It is also noteworthy that the absence of trees is not accompanied either by small rainfall or by barrenness on the mountain sides. Rains were abundant in the higher ranges in July, and grassy herbage grew there luxuriantly.

An interesting contrast in the relation of vegetation to insolation was noted in passing from the deeper valleys to the higher mountains. In the bad-lands of the Narin basin, at altitudes of 6,500 or 7,000 feet, the sunny slopes were prevailingly bare and minutely dissected, while the shady slopes were occupied by a sparse herbage and were of smoother form. On the high spurs of the Kungei Ala-tau, at altitudes of 10,000 feet or more, and above the tree line, the sunny slopes had the better cover of grass, while the shady slopes were relatively barren. In the first case, sunshine promotes aridity and excludes vegetation. In the second case, sunshine promotes snow-melting and favors vegetation.

DEVELOPMENT OF THE TIAN SHAN MOUNTAINS.

A number of the mountain ranges that we saw were of vigorous form, with sharp peaks and deep-carved valleys, in which it was impossible to recognize any trace of the original unsculptured mass; but certain observations made in the central and northern ranges, near Lakes Son Kul and Issik Kul, and on the steppes that border the mountains on the north, led to the belief that the region had been very generally worn down to moderate or small relief since the time of greater deformation, which probably occurred in the Mesozoic age; that large areas of subdued or extinguished mountain structures are still to be seen in the low ranges and in the

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steppes north of the Ili River; and that the present relief of many of the higher Tian Shan ranges is the result of a somewhat disorderly uplift and of a more or less complete dissection of dislocated parts of the worn-down region. Mr. Huntington's report shows the application of these conclusions to a large part of the central and southern Tian Shan.

THE BURAL-BAS-TAU.

The first range that led to this belief was the Bural-bas-tau, which rises north of the Narin Valley and southeast of Son Kul. Its name is taken from the Russian 40-verst map. Friedrichsen (1899) calls it the Mulda-aschu. We saw the range some 50 miles away as we were riding down the Alabuga Valley on July 4; the

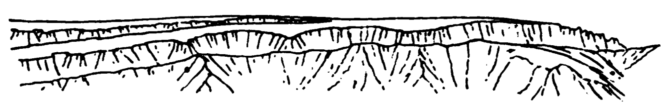

Fig. 40.—The Flat-Topped Bural-bas-tau, looking Southeast.

evenness of its snow-covered crest suggested that it must be a plateau-like mass of horizontal structure, amid its deformed neighbors. It was lost to sight after we had entered the Narin Valley, and was not seen again until July 9, when we climbed the Kok-tal range northeast of Son Kul. It was there that figures 40 and 41 were

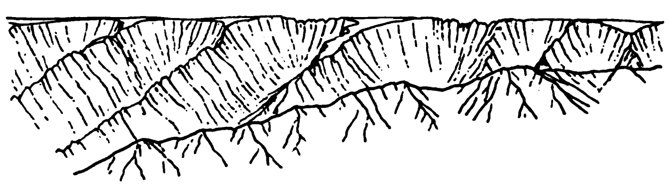

Fig. 41.—The Flat-Topped Bural-bas-tau, looking South.

sketched. The evenness of the plateau-like highland, all snow-covered at an estimated height of at least 12,000 or 13,000 feet, was most remarkable, and all the more so as our field-glasses now showed the range to be composed of massive rocks, probably granites, such as are plentiful thereabouts. The highland has faint undulations, and slopes gently to the north and east. Great ravines, heading in glacial cirques, are carved in its northern flank. The spurs between the ravines preserve their even crest for a short distance, but are then converted into sharp arêtes. One ravine, longer than the others, cuts the highland obliquely. It reminded us of the Colorado Canyon in the Kanab plateau of Arizona, as we had seen it from the top of Mount Trumbull in the summer of 1902. One ravine-heading cirque, opening northward, seemed to head against another, opening southward, and there the even highland surface was reduced to a serrate ridge that sagged a little below the general level. The highland ascends gradually westward, and in that direction its detached portions, with flat tops, are seen beyond encroaching valleys; then, still farther west, these are succeeded by peaks and ridges of ordinary form in the Dongus-tau range south of Son Kul.

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There can be no question that the highland of the Bural-bas-tau was once part of a well-finished lowland of erosion, presumably a peneplain of subærial degradation. It must have gained its present altitude with comparative rapidity, and in geologically modern time; otherwise it would be more dissected to-day. When it still lay low, the lowland of which it was a part must have been much more extensive than the present area of the highland; for lowlands can not be worn down on resistant crystalline rocks without the very general reduction of all neighboring and quiescent structures. It thus becomes probable, from the consideration of this range alone, that many neighboring ranges have shared its history, and if they do not all to-day imitate its plateau-like form, it must be that they were somewhat less worn down in the previous cycle of erosion, or, like the Dongus-tau, already more consumed (owing to greater uplift or to weaker structure) in the present cycle, or both. This conclusion did not long remain a matter of speculation only, for at Son Kul and around Issik Kul we found many other ranges that supported it.

THE KOK-TAL RANGE AND THE SON KUL BASIN.

The steep-sided glacial troughs that we examined in the Kok-tal range northeast of Son Kul are eroded in a granitic upland of moderate relief that slopes toward the lake basin. The sloping upland was continued east of the lake, where it gradually descended to a broad granite floor, across which the lake outlet has cut an open trench, 75 or 100 feet deep. All this granite surface is to-day suffering dissection and gaining stronger relief. The lake outlet must fall rapidly in descending 3,000 feet to the Narin River, and a deep gorge will in time be cut along its course. The side streams from the north will, therefore, intrench themselves deeply, and the granite slope between them will be converted into a series of sharp spurs in the mature stage of the present cycle of erosion. The simple surface in which the glacial troughs and stream valleys have already been eroded is itself a surface of erosion, but it could not have been produced in its present attitude; it must have long stood lower and more nearly level. Its present elevated and inclined attitude must have been gained by a warping uplift in modern geological time. We are, therefore, disposed to look upon the sloping upland as once having made part of the peneplain that is more clearly proclaimed in the highland of the Bural-bas-tau. The basin of Son Kul is probably the result of warping or faulting the same peneplain. The northern slope of the Kok-tal range descends rapidly into the valley of the Tuluk, and its slope is sharply dissected by many side streams. When seen from the moraines in the Chalai range, north of the Tuluk, the crest of the Kok-tal has a rather even crest line, much more even than the serrate crest of the Chalai range itself.

THE RANGES NEAR ISSIK KUL.

The road through the gorges of the Juvan-arik gave us no sight of the mountain crests; but when we entered the open Kach-kar basin, the long slope of the Alexander range ascended northward from the farther side of the basin, and its general appearance at once suggested block-faulting. This suggestion was con-

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firmed by many features noted afterward. The south slope of the range had a hackly surface, due to the erosion of many small branching valleys among its varicolored crystalline ledges; but when seen in profile a few days later from the west end of Issik Kul, the smaller irregularities of the slope were lost in a remarkably simple outline, sketched in figure 42. The crest rose above the snow patches of mid-July; one of its highest parts, isolated between two encroaching valley heads, had an obliquely truncated summit in line with the long back (south) slope. The northeastern face of the range was much steeper and more sharply dissected by the side streams of the Chu. It was therefore concluded that the Alexander range is a faulted block of a peneplain, of which the former lowland surface is now uplifted, tilted to the south and moderately dissected, while the steeper northern faulted face is deeply carved in great spurs and ravines. The Kach-kar basin is apparently an aggraded area on the relatively depressed southern side of the block, as will be again considered farther on.

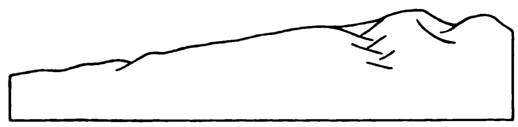

Fig. 42.—Distant Profile of the Alexander Range, looking west.

Three small mountain masses (A, B, C, fig. 43), between the Alexander range and Issik Kul, had much the appearance of tilted and dissected blocks, sloping to the south and facing to the north. If this be true, their displacement ceased longer ago and their dissection has progressed farther than is the case in certain parts of the Wasatch range of Utah which I examined in 1902; for the spurs on the faulted face of the ranges by Issik Kul do not possess terminal facets, and the ravines between the spurs on both the front and the back slopes have open mouths. On the other hand, the back slopes of these ranges still have general profiles of greater regularity than those of the Utah ranges that I have seen. This may be because the Issik Kul ranges were more smoothly worn down in the pre-faulting cycle than were the Utah ranges. The only sure indication of recent dislocation among these ranges was a fault scarp, 10 to 50 feet in height, more than a mile in length, and trending northwestward across the gravel fans at the northeastern corner of range B. It should be stated that this scarp was only seen at a distance of a mile or more; but it was closely examined through a good field-glass from different points of view and in different lights. The manner in which it was crossed by the gullies radiating from the mountain ravines left no doubt in my mind as to its meaning and origin, A large fan, spreading into the Urta-takoi basin on the south side of the same range.

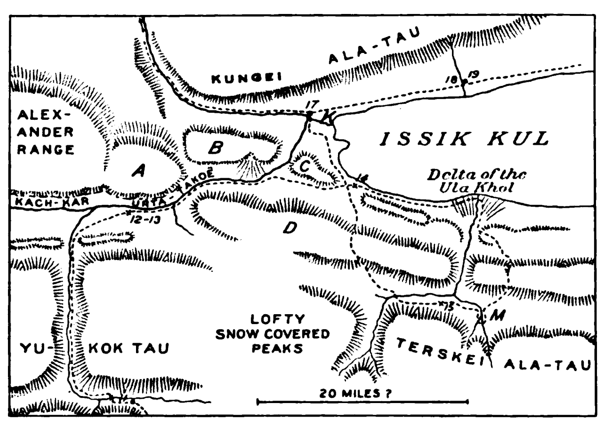

Fig. 43.—Rough Sketch Map of the Ranges southwest of Issik Kul.

as well as many smaller fans at the base of other ranges, showed no signs of faulting. Their radial slopes were smooth and unbroken. The small range or block C, fig. 43, appears to be cut off from the larger block, B, by the gorge of the Urta-takoi (Chu) River. The post-road goes north through the gorge, but we turned eastward and followed the aggraded trough between ranges C and D, directly to the lake. A dry-stream bed, gathering all the wash from the piedmont gravels of the much higher range, D, on the south, was pushed close to the base of the back slope of the smaller range, C, on the north, sometimes even undercutting the base of its spurs. The northern range was, where we saw it, composed of rough conglomerates and sandstones, dipping steep to the south, and to all appearance much older than the modern conglomerates of the Issik Kul basin. Their strike to the east-northeast ran obliquely to the trend of the range. The strata were obliquely truncated by the general back slope of the range, as in figure 44. The conglomerates and sand stones, generally dull-red on fresh surfaces, were so darkly weathered with "desert varnish" that we at first took them to be basaltic lavas; they were often cut by black dikes. The northern face of this range was much steeper than the southern. Range D, on the south, gave no conclusive evidence of block-faulting, for it was much dissected; but its comparatively straight northern base-line and the great body of waste that has accumulated beneath it are suggestive of differential movements, with the appropriate consequences of degradation of the uplifted block and aggradation of the depressed block. A few knobs of rock rise through the piedmont gravel slope. They may be interpreted as remnants of narrow blocks, on Gilbert's theory of faulting, or as remnants of a broader mountain mass on Spurr's theory of compound erosion of the Utah-Nevada ranges.

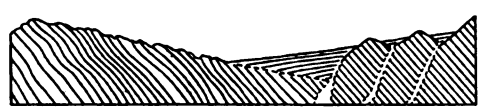

Fig. 44.—Ideal Section from Range C to D, Figure 43, looking east.

The Kungei Ala-tau, north of the west end of Issik Kul, is a dissected block-like mass with a plateau-like crest. It rises and becomes more and more dissected to the east. There is much evidence of subordinate faulting along part of its southern base, as will be more fully set forth in the chapter on Issik Kul. North of the middle of the lake this range is of well-developed Alpine form, with cirques and glaciers that are further described in the chapter on glacial records.

It may here be noted that earthquakes, of no infrequent occurrence in the Tian Shan, are regarded by Mushketof (1890) as due to movement on fault lines along the base of certain ranges, the Alexander range being one. The shocks by which Vyernyi was destroyed on May 28, 1887 (O. S.), were ascribed by this observer to a fault along the northern base of the Trans-Ili Ala-tau. The shocks continued for about two years. Wosnessensky (1888) showed that they varied with the changes of atmospheric pressure, increasing with the occurrence of low pressure. We were told that Sazanovka, a Russian settlement on the north side of Issik Kul, was destroyed by an earthquake six years ago.

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THE RANGES AND STEPPES OF SEMIRYETSHENSK AND SEMIPALATINSK.

Our hurried northward ride from Vyernyi across the Seven-river and Seven-house provinces, above-named—one in Turkestan, the other in Siberia—to the city of Semipalatinsk, allowed no opportunity for deliberate observation, yet it gave a sight of certain physiographic features that could be appreciated even from a rattling tarentass (fig. 45), and which deserve brief record.

The post-road crosses a broad plain, apparently loess-covered and certainly very dusty, north of the Trans-Ili Ala-tau, and gradually descends to a bridge across the Ili River at Iliisk. North of the river ledges appear and the surface rises more rapidly. The upland plain continues to the northwest, where we saw in the distance a narrow, rock-walled gorge, through which the river flows to the desert bordering Lake Balkash. A solitary monadnock-like mound rose above the broad plain near the gorge. Northeast of Iliisk low mountains of subdued form were crossed in the early evening.

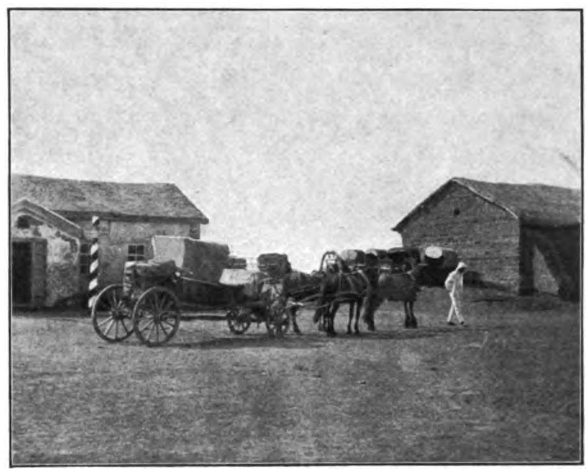

Fig. 45.—A Tarentass at a Station on the Post-road between Vyernyi and Semipalatinsk.

The next morning a western spur of the subdued Borochoro range north of the Kok River, by Tzaratzin post-station, presented forms that suggested block-faulting, and that found no explanation in the structure of the crystalline rocks of which it was composed. It had a nearly even sky line, an abrupt southern face with simple base line, and short, steep ravines. The river flows through an open valley by Tzaratzin, but enters and leaves the valley by narrow gorges. Farther northwest and north the relief decreases. It was hereabouts that we saw the first of the loess drifts, described above.

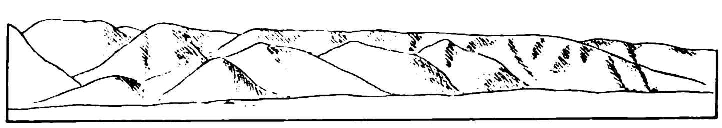

Fig. 46.—Rough outline of the Dsungarian Ala-tau, looking south.

On the third morning we had passed the western end of the Dsungarian Ala-tau, and saw it to the south of Arasan station at sunrise. Its sky line is notably even, although the northern flank is deeply carved, as in fig. 46. It gains greater height and greater irregularity to the east. Between Arasan and Abakumof stations we crossed a branch of this range by an open pass at about 4,000 feet elevation, an easy rise from the south being followed by a steeper descent for the better

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part of 1,000 feet to the north. Here one of the hind wheels of our wagon broke down, and we had leisure to look about while the postilion rode on for a new one. The branch range was composed of slates, with vertical cleavage striking about east-west. Its summit was a broadly-rolling upland of gentle relief, while sharply-cut ravines were gnawing into its steep northern slope. When we had advanced some miles across the broad plain north of the range, its upland was seen rising gradually eastward in a warped slope. Its northern face was finely carved in sharp spurs and ravines. Figure 47 is hardly more than a diagram of these features, very hastily sketched, yet it presents their essential character. Nothing but uplift and partial dissection of a peneplain can account for so remarkable a contrast of old and young forms. The plain continued till nightfall, with small change of form.

The fourth day opened on a broad, gently rolling steppe, stretching from Ashi-bulak to Arganatinskaya. Occasional outcrops showed at first a crystalline rock, then a belt of slaty limestones, and finally a series of much disturbed slates. Gray loess-like silts, with angular rock scraps, occupied the shallow depressions. A lake a few miles long was seen to the east. The steppe, as a whole, was sometimes rather

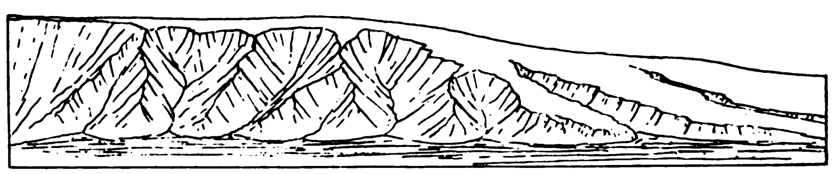

Fig. 47.—Rough Sketch of a Range near Abukumof Station, looking south.

too uneven to be called a peneplain, although certain areas fully justified that term. The sky line was generally of moderate irregularity, and the galloping pace of our horses on a road that turned but little for mile after mile testified to the gentleness of the slopes. The low-arching hills seldom deserved to be called monadnocks, except for a few knobs that rose over a broad swell in the belt of limestones and slates. Etymologists, who have not hesitated to give our language the word "antepenult," as well as "penult," might name a region in this stage of degradation an "antepeneplain"; but physiographers do not yet recognize the need of so elaborate a term. There was the appearance of a general and gradual rise northward, until we lost sight of the upland by descending a narrow and winding valley worn in the contorted and jointed slates by a north-flowing stream. When the valley had gained a depth of about a hundred feet it suddenly opened upon the broad plain that stretches eastward of Lake Balkash. On looking back toward the upland we saw it descend to the plain by a low, regular, but somewhat dissected escarpment. A gentle slope of slaty gravel stretched a short distance forward from the escarpment to a clay plain, varied with dusty dunes and marshy swales overgrown with reeds. The road was very bad here in sand or mire. Nothing that could be called an old shoreline of Balkash was noted. Toward evening we saw some low hills; the plain became gravelly, and low mounds of angular slate waste suggested that the rock was not far below the surface. The road at once improved, and in the night we had the best sleep of our posting trip.

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All of the fifth day was passed on a rolling steppe (fig. 48). In the morning, near Sergiopol, the country rock was granite, but the relief was small. The uplands stretched broadly between the shallow valleys. Once the road led through a rather narrow transverse valley in a low swelling ridge. A few of the ridges might be called mountains in a flat country, but they hardly deserve so strong a name; even the highest of them was of subdued form. Near Arkut station we saw the only sharp form of the day. A ragged ridge, 300 or 400 feet high, was silhouetted against the sunset sky. It may have been a dike of more resistant rock than that on either side.

The peneplanation of the region improved in the final 40 miles of the road on the sixth day. In the morning some of the broad ridges of steep-dipping slates and slaty limestones, trending east and west, were from 300 to 500 feet over the inter-

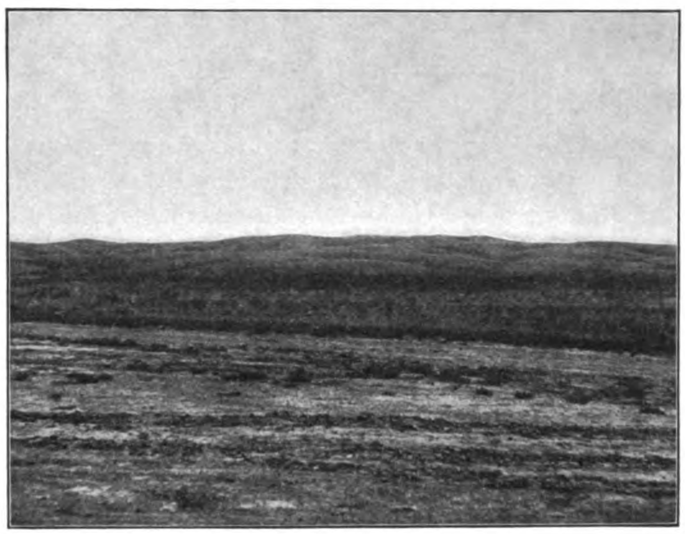

Fig. 48.—The Rolling Steppe north of Sergiopol, Semipalatinsk.

vales, but the latter were 2 or 3 miles wide. In the afternoon the relief decreased; low mounds, irregularly distributed, were strewn with angular scraps of quartz. The sky line was here so even and its occasional hills were so faint that sketching could do little justice to it. For some miles before reaching Semipalatinsk the country seemed perfectly level.

The Irtysh River at Semipalatinsk occupies a good part of a valley floor that is from half a mile to a mile wide, and about 30 feet below the surrounding plain. The valley sides disclose vertical beds of slate and sandstone, with strike about north and south, evenly truncated by the surface of the plain and veneered with sand and gravel, in which occasional boulders up to 2 feet in diameter were seen. This district shows as fine an example of a low-lying peneplain as I have ever seen. The vigorous Irtysh has begun the dissection of the plain; but a few miles from the river the small streams still lie on the floor of the broad hollows between the low ridges.

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ORIGIN OF THE EXISTING RANGES OF THE TIAN SHAN.

When the features here described from Son Kul to Semipalatinsk are considered in a broad way, they suggest many reflections of interest in theoretical geology. The extended occurrence of surfaces of small relief, indifferent to the rock structures which they truncate, implies a long cycle of uninterrupted degradation, continued past late maturity, even to old age. The earlier form of the eroded region may well have been mountainous; witness the steep-dipping or vertical strata seen at various points, as well as the occurrence at the surface of rocks whose origin must have been deep-seated, like granites. The agency of erosion was not the sea, of whose presence in modern geological time the region gives no indication; nor was it the lateral swinging of rivers, as Philippson (1898) has supposed for the plains of central European Russia, for the eroded surface frequently possesses a minor relief that is inconsistent with such a process of planation. The various processes of subaerial erosion, of which the swinging river is but one, best explain the widespread peneplanation here observed.

Although the peneplain was not observed by any means continuously from Son Kul to Semipalatinsk, there is good ground for thinking that it once stretched as an almost continuous lowland, interrupted only by residual ranges, over all this distance, and indeed over still greater distances; for it is not reasonable to believe that a cycle of erosion which sufficed to develop a peneplain even on granitic rocks should find other rocks resistant enough to maintain a great relief, unless, indeed, uplift came to aid resistance. There is, however, no direct evidence of uplift during the cycle of peneplanation. Where great relief occurs in the region to-day, it is accompanied by the suggestion of uplift after peneplanation—or, at least, after a very late mature stage of erosion—had already been reached. Witness the peaks of the Dongus-tau below the westward prolongation of the highland surface of the Bural-bas-tau, or the peaks of the central Kungei Ala-tau below the eastward prolongation of the even crest in the western part of the same range. If certain ranges do not to-day present such evidence of a former cycle of erosion, it is more consistent with the general features of the region and with the general principles of mountain sculpture to suppose that they have lost the evidence than that they have never had it.

This conclusion, based on my own observations, is strongly supported by the observations made independently by Mr. Huntington and presented in the report on his Kashgar journey. He describes large highland areas of the Tian Shan between Issik Kul and Kashgar as broadly uplifted peneplains, here and there bearing subdued mountains, the whole being in process of revived erosion. He therefore names the region "the Tian Shan plateau." It is, as he happily phrases it, not actually but only potentially mountainous. Previous observers have recognized the plateau-like highlands of the Tian Shan, but most of them do not seem to have recognized their meaning. Roborovsky, reporting on an expedition led by Pievtsoff in 1889, briefly describes a high plateau, between Issik Kul and the Tarim basin, called the Syrt, 100 miles wide, and at an altitude of 10,000 or 11,000 feet. "Scattered over it are separate mountain groups and ridges, running east and west" (1890, 23). St. Ives, who crossed this region later, says that it is an immense

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plateau, known to the Kirghiz as the "Arpa," 3,000 meters in altitude, overlooked by serrated ranges and traversed by low hills (1900, 125). Almasy, who traveled somewhat farther east in 1900, gives "syrt" as the Kirghiz name of the plateau, which he describes as occupied by highland meadows (1901, 254). In Friedrichsen's thorough review of all that has been written about these mountains, there is no clear statement concerning the plateau-like quality of the inner region; but it may be inferred from the statement that the general law of vertical relief in the Tian Shan is an increase of absolute height accompanied by a decrease of relative height in passing from north to south (1899, 209). In Friedrichsen's account of his own exploration, however, there is an explicit statement. He traversed the syrt or highland southeast of Issik Kul at an altitude of 3,000 meters, and found it to be an extended, gently inclined plain in which the granite, gneiss, and steep clay slates are broadly truncated, above which the snowy ranges (4,000 meters) rise with relatively small relief, and below which deep, canyon-like valleys are eroded by the Sary-jass River and its tributaries. He recognized it to be a "Denudationsfläche" or peneplain (1903, 99).

The deformation that the great peneplain has suffered in that part of its area which is now mountainous seems to have involved late or post-Tertiary movements of relatively local uplift, as in the Bural-bas-tau; or of much broader uplift, as south of Issik Kul; or of moderate warping, as in the branch of the Dsungarian Ala-tau; or of block faulting and tilting, as about the west end of Issik Kul. This is consistent with the account of the Tian Shan furnished to Suess by Mushketof, in which it is stated that the earlier deformation of these mountains was not before the Trias, and that the final configuration of the ranges was given in post-Tertiary time. The latter statement is based on the occurrence of Tertiary strata at great altitudes, no mention being made of the evidence from peneplanation (Suess, 1897, i, 619).

It is noteworthy that there is no general evidence of crustal compression in the later deformation that the Tian Shan seems to have suffered. True, the vertical strata and the vertical cleavage of slates imply that the region suffered a strong compression in some time previous to peneplanation; but the existing Tian Shan ranges, so far as they are described, are not the result of that ancient compression. They are due to a later system of deformation that gives little evidence of compression. The contrast between the earlier Tian Shan system and the present ranges is similar to that pointed out by Gilbert between the Appalachians and the Basin ranges of Utah and Nevada:

> In the Appalachians corrugation has been produced commonly by folding, exceptionally by faulting; in the Basin ranges, commonly by faulting, exceptionally by flexure. The regular alternation of curved synclinals and anticlinals is contrasted with rigid bodies of inclined strata, bounded by faults. The former demand the assumption of great horizontal diminution of the space covered by the disturbed strata, and suggest lateral pressure as the immediate force concerned; the latter involve little horizontal diminution, and suggest the application of vertical pressure from below. * * * In the case of the Appalachians the primary phenomena are superficial; in that of the Basin ranges they are deep-seated, the superficial being secondary; that such a force as has crowded together the strata of the Appalachians—whatever may have been its source—has acted in the ranges on some portion of the earth's crust beneath the immediate surface; and the upper strata, continually adapting themselves, under gravity, to the inequalities of the lower, have assumed the forms we see (1875, 61, 62).

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It therefore does not seem advisable to adduce the Tian Shan ranges in illustration of the direct action of a "tangential movement," as has been done by Suess (1897, i, 619) on the basis of Mushketof's description. It is truly possible that compression may have had some share in producing the existing disordered attitude of the mountain blocks, for folds of late or post-Tertiary date occur in the Narin formation, as is further stated below; but the share that compression had in raising the block ranges is so problematic that it should not to-day be accepted as an established fact, and still less should it be employed as the base of further theoretical considerations.

THE BEARING OF THE TIAN SHAN RANGES ON THE THEORY OF HORSTS.

The Bural-bas-tau and its fellows deserve special consideration in connection with the theory of the origin of horsts, or upstanding crustal blocks, as set forth by Suess, who regards such horsts as stationary parts of the earth's crust, with respect to which the surrounding lower land has sunk (1897, i, 263, 774, 777, 782). The evidence for this conclusion is chiefly that "we know of no force whatever that is capable of uplifting from below, between two plane surfaces, large or small mountainous masses, and of maintaining them permanently in such a situation, against the action of gravity" (1897, i, 782; also 775). This conclusion and the reason for it both seem to me to place too high a value upon what we do not know. It is, of course, conceivable that horsts have stood still while the surrounding lands have sunk down, but it is also conceivable that the horsts have been raised, while the surrounding lands have remained stationary; that the horsts have risen and the surrounding lands have sunk; and that both have risen, the horsts more than the rest, under conditions suggested by the citation from Gilbert, above made. The last supposition seems eminently applicable to the Tian Shan. Direct observation seldom, if ever, furnishes evidence by which one can choose among these various mechanical possibilities. In the case of the Tian Shan there is certainly not enough now known concerning the attitudes of the fault planes by which various blocks are divided to make it worth while to discuss this recondite aspect of the problem. As to the way in which blocks of the earth's crust might be dislocated into irregular attitudes, we can conceive of many theoretical processes, every one of which is permissible in the presence of our abundant ignorance of the constitution and behavior of the earth's interior. It seems, therefore, unsafe to-day to exclude all other processes than direct-acting gravity from a share in the production of horsts. Forces of uplift are still worthy of consideration. In such a problem it seems better to open the mind as freely as possible to reasonable speculation, rather than to restrain its inventive powers. Deep-seated movements of the earth's core, possibly due to deep-seated compression, may cause local internal up-swelling, over which the heavy-lying crust is broken and irregularly jostled in mountain blocks. It is this supposition that is entertained in Gilbert's suggestion as to the origin of the Basin ranges of Utah and Nevada, above cited; but neither the supposition of local jostling and uplift within a surrounding region of relative stability, nor the counter

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supposition of local stability within a surrounding region of depression, can to-day be regarded as established for the Tian Shan.

It may, however, be pointed out that Suess's view as to the stability of horsts involves extreme measures of the diminution of terrestrial volume. When the highland of the Bural-bas-tau is recognized as a fragment of a central Asiatic peneplain, it must be recognized as having once stood not much above sea level; and if 8,000 or 10,000 feet out of its present total altitude of 12,000 or 13,000 feet result from the depression of the Siberian part of the Asiatic peneplain, then all the oceans and all the continents of the world must have gone down with the Siberian area, except for such highlands, if any, that held their own with the Bural-bas-tau. This seems to call upon a very large mechanism to produce a relatively small result. Not only so. The plateau of northern Arizona, in which the young canyon of the Colorado River is cut, owes its altitude, by Suess's theory, to the depression of the Great Basin region to the west of the plateau; but this plateau is also a peneplain, as Dutton has shown, hence not only the lower land to the west of it went down, but again all the oceans and all the continents as well, and this time the Bural-bas-tau with the rest—unless, indeed, the depressions of the surrounding regions, by which the Bural-bas-tau and the plateaus of northern Arizona were left in relief, both occurred at the same time. In the latter case we have only to consider one of the many other more or less dissected peneplains, that of southern New England, for example; all of these can not possibly have been left standing by a single movement of depression, because their present stage of dissection is so unlike. It thus appears that, according to Suess's theory, the diminution of the the terrestrial radius at any point may be measured (if we neglect the altitude above sea level at which peneplains are formed) by

the sum of all the non-synchronous depressions by which
the horsts of peneplains have been left in relief,
minus the altitude that a peneplain (if one occurs) happens to have
at the point of measurement.

As said above, there may be no evidence by which the theory that leads to this conclusion can be absolutely proved or disproved, but the conclusion is a curious one, and as long as it is based chiefly on our ignorance of the earth's internal mechanism, it can hardly have general acceptance. It does not appear clearly from Suess's work whether he recognizes the necessity of this conclusion or not, for he does not seem to take account of the altitude that the surfaces of horsts had with respect to sea level before they were isolated by dislocation. Indeed, his study of the Face of the Earth takes relatively little account of erosion. One finds, however, an indication of the acceptance of great changes in sea level in such sentences as the following: "I hope to be able to show that there is ground for correcting more than one generally accepted opinion as to the position of the level of the sea at epochs anterior to ours" (1897, i, 782). It will be a matter of interest to see how far problems of this sort are treated in the final volume of Das Antlitz der Erde.

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GLACIAL RECORDS IN THE TIAN SHAN.

Russian explorers of the Tian Shan have discovered many glaciers in its higher ranges and have mentioned the occurrence of abandoned moraines lower down the valleys, but as far as I have read there has been little study given to the subdivisions of the glacial period. To this latter subject, therefore, we gave chief attention while we were in the higher mountains. The strong ranges between Issik Kul and Kasghar contain a much finer development of abandoned moraines than any of the ranges that we saw between Andizhan and Issik Kul. The problem of successive glacial epochs is, therefore, much more fully treated in Mr. Huntington's report than here.

Fig. 49.—The Chalai Range from Kum-ashu Pass in the Kok-tal Range, looking north; a large old Moraine advances to the left, behind the dark spur. The crest of the Chalai Range is dimmed by clouds.

MORAINES NEAR SON KUL.

Although we recognized the occurrence of glacial cirques at a distance in several high ranges, the first moraines that we came upon were in the mountains south and northeast of Son Kul. Those in the north-opening valleys of the Dongus-tau range, south of the lake, were of small size at altitudes about 10,500 feet; the range summits seemed 1,000 or 2,000 feet higher. The glaciated troughs on the southwest side of the Kok-tal range, northeast of the lake, 8 or 10 miles from its outlet, were recognized in the distance. On riding and walking up to them in the afternoon, we found a well-defined moraine, with mounds and bowlders, kettles and ponds, crossed by a cascading stream at about 10,500 feet, in a valley that had received the confluent glaciers from two troughs. The glacier from the larger trough must have been 2 miles long. In the next trough to the west, the glacier seems to have been smaller. No strong moraine was seen there. Further down the valleys there were smooth hills which we did not at the time take for moraines, but in the light of what was seen later, I am now disposed to regard them as weathered and rounded moraines of early origin. It was on the sides of these smooth hills that we saw the old irrigating canals, to be described in a later section. The glacial troughs, higher up the mountain, were of wide open, steep-sided, U-shaped form, eroded in the slanting granite highland already described.

When descending from the Kum-ashu pass in the Kok-tal range, we saw to the north a large moraine beneath a glaciated valley of the Chalai range (Jumgal-tau on Stieler's map, sheet 62), beyond the Tuluk-su (fig. 49). The glacier that made this moraine must have been 3 or 4 miles long, heading in three cirques beneath the sharp peaks and arêtes. On going up to the moraine the next morning, we saw a second and larger one, which Mr. Huntington examined, about 2 miles

Fig. 50.—Moraine in the Tuluk Valley, looking west.

to the west. In both cases the large moraines were of well-rounded forms, with few surface bowlders and without distinct mounds or kettles, and the stream that issued from them had a well-opened valley with something of a graded and flood-planed floor. Moreover, the main valley seemed to have been significantly deepened by the Tuluk-su since the moraine was laid in it; and certainly some of the spurs on the south side of the main valley had lost their ends by the undercutting of the Tuluk, which the moraines had pushed against them, as shown in fig. 50; but the facets thus eroded on the spurs had roughly graded slopes, thus indicating that a considerable time had passed since the undercutting began. The other valley-side spurs showed no such facets, but tapered down to the valley floor. Within each of these large weathered moraines we found smaller moraines of much sharper and fresher form (fig. 51); their irregular mounds and ridges strewn with bowlders, their kettles holding small ponds, and their streams cascading in narrow courses. The youngest moraine ended about in line with the north rock wall of the main valley. This seemed to be a moraine of recession from a larger group of more advanced morainic loops. The time interval of the retreat here indicated must have been short compared to the time that has elapsed since the larger moraine was formed.

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MORAINES IN THE TERSKEI ALA-TAU.

When we reached the southwest shore of Issik Kul (July 14), the snowy summits of the Terskei Ala-tau were seen to the south; so we crossed the outer, lower ranges from the delta to the upper valley of the Ula-khol, and there at once came upon an interesting group of moraines.

The first moraines seen (M, fig. 43) were in a longitudinal valley at the northern base of the Terskei Ala-tau, about 3 miles to the southeast of the head of the Ula-khol gorge in the outer range. They had been formed by a glacier or

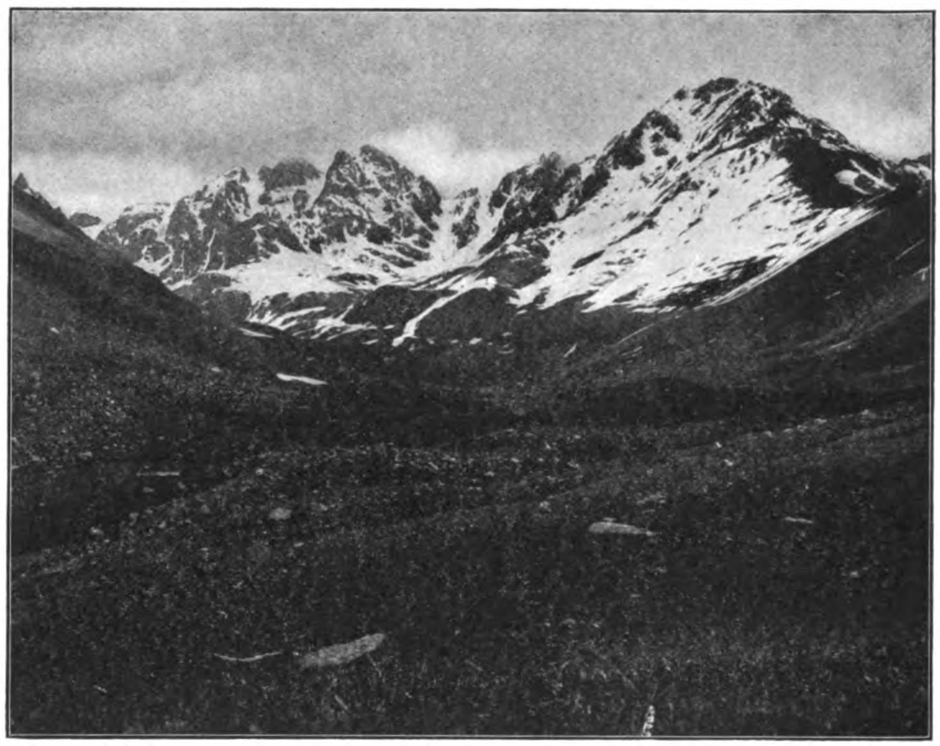

Fig. 51.—A Young Moraine within the Old Moraine in the Chalai Range, looking north.

glaciers that descended northward from the Kashga and Tura side valleys, and stood at an altitude of somewhat over 7,000 feet. Their hills were delicately rounded; the streams had eroded open-floored valleys across the morainic belt; no undrained basins remained; some hillocks were isolated, as if the valley-floor gravels had been aggraded around them. The materials of the moraine were, as a rule, unweathered, but we found in fresh-cut banks a few stones decomposed to a friable condition.

About 2 miles to the south, and at an estimated elevation of between 8,500 and 9,000 feet, another moraine was seen in the Kashga Valley. This was judged to be much younger, as seen in the distance, because the stream had cut only a narrow trench through it.

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In the afternoon of July 16 we went 8 or 10 miles southwest of the head of the Ula-khol gorge, following the main stream west and south into the mountains, and hoping to reach the valleys beneath the highest peak that we had seen from the lake shore; but it proved that we were not far enough west; and that bane of reconnaissance work, the lack of time, prevented our going farther. We found, however, at the mouth of a branch valley from the southeast a large, rounded morainic mass, similar in form and apparent age to those we had seen in the Tuluk Valley. A younger moraine was seen farther up the glaciated trough, in whose steep southern wall two hanging cirques opened. A terrace occurs in the main valley in association with the larger moraine. It was continued upstream as far as we could see, and there it was a hundred or more feet above the stream. It was distinctly traceable for half a mile down the valley, though with rapidly diminishing height in that direction; farther down it was preserved only in small remnants, and no signs of it were found in the longitudinal valley. Aggradation of the terrace seems to have been contemporaneous with the growth of the moraine, and the trenching and removal of the terrace with the weathering and rounding of the moraine. The moraine is thus doubly shown to be of considerable antiquity. This is confirmed by finding that the terrace floor has been aggraded by wash from the mountain sides, so that it now has a distinct slope toward the valley axis, instead of only a slope down the valley, as is habitual with young terraces. Two other old-looking moraines were seen; one of them up the valley to the southwest, the other up a branch valley to the east.

MORAINES IN THE KUNGEI ALA-TAU.

As the Kungei Ala-tau rises eastward along the north side of Issik Kul, the even crest line with which it begins is more and more dissected. Before the middle of the lake is reached the range has gained sharp Alpine forms. A glacier was seen high up among the summits, from near Tur-aigir station; and a few miles north of Choktal station there seemed to be a moraine lying somewhat forward from the mouth of a valley, on the upper part of the piedmont slope, about 1,500 feet over the lake, or at an altitude of 6,700 feet. Further reference will be made to this moraine in connection with Lake Issik Kul. Severtzof mentions what he takes to be a moraine lying on "lake beds" on the south side of Issik Kul (1875, 32).

The ascent from the Russian village of Sazanovka, near the lake shore, northward toward Sutto-bulak pass, in our unsuccessful attempt to cross it, carried us past what seemed to be an old, dissected moraine on the east side of the Ok-su Valley, at an altitude of 7,000 feet. Farther up a branch valley we came to a well-defined moraine whose lower end stands at about 9,000 feet, and whose western lateral ridge is 200 or 300 feet high. It is rather sharply trenched by the valley stream. The glacier that made this moraine must have been at least 3 miles long. We followed the valley nearly to its head in our effort to cross the pass, seeing a number of cirques on either side, inclosed by sharpened arêtes (fig. 52). A small glacier occupied the head of the valley for half a mile or more at a height of about

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11,300 feet. A small recent moraine lay about 300 feet forward from the end of the glacier; a larger one, holding a small frozen lake in its hollow, was a half mile farther forward. There was too much snow on the ground just in front of the glacier to judge whether it was advancing or retreating at the time of our visit.

SUBDIVISION OF THE GLACIAL PERIOD.

The few examples above described of moraines of different ages suffice to suggest, but not to demonstrate, a subdivision of the glacial period, as it affected the Tian Shan Mountains. The many additional examples of more complicated series of moraines in the valleys below the higher ranges south of Issik Kul, afterward

Fig. 52.—Snowfield below Sutto-bulak Pass in the Kungei Ala-tau, looking southwest; a Cirque in the background.

examined by Mr. Huntington, were fortunately more explicit in their testimony, and leave no doubt that the glacial period there, as elsewhere, was not a single climatic epoch, but a succession of epochs, and that the different epochs were of different intensities. It is important, as Mr. Huntington points out in his report, to bear in mind that the actual succession of glacial epochs was in all probability more complicated than the existing records directly indicate. It truly seems possible, in our present ignorance as to the cause of glaciation, that four or five glacial epochs of progressively decreasing intensity and duration might constitute the whole of the glacial period; but it is eminently probable that the first epoch was not the severest one, and that the record of earlier epochs of small intensity might be destroyed by the work of later and more intense glacial epochs. We therefore

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have again a case, like the one already considered in connection with the terraced valleys of the Kopet-Dagh, of a series of decreasing maximum records, before and between which a number of minimum records may have been made, only to be destroyed by the next stronger record. The preservation of four or five records makes it probable that the total number of glacial epochs in the Tian Shan was as many as six, eight, or ten.

We fully concur with earlier observers to the effect that there are no indications of general glaciation in the region that we crossed.

GLACIAL EROSION IN THE HIGHER RANGES.

This excursion across the Tian Shan gave me the first opportunity of seeing high mountains since reading Richter's Geomorphologische Untersuchungen in der Hochalpen (1900). I therefore gave especial attention to the form of the mountains to determine how far Richter's thesis holds good as to the action of glaciers in sharpening the peaks and crests by causing the retreat of cirque walls. There was repeated occasion to test the thesis, and it seemed to hold good in every case.

The Kugart pass, over 10,000 feet in altitude, and with the higher summits of the Fergana range on either side, presented no sign of glaciation. It is possible that some cirques occur not far to the southeast, but clouds covered the mountains too heavily in that direction at the time of our crossing to make sure. All the mountain forms by the pass were the result of the normal processes of erosion. The ridges were all dominated by the down-slope lines of creeping and washing; and all the down-slope lines, decreasing in declivity as they were followed, combined in an elaborate branch-work system, adjacent lines always meeting in accordant grade at their innumerable points of junction. In other words, the ridges were maturely dissected. As seen in profile, the down-slope lines had relatively little variety. Except for a small convexity near and at the crests, they were concave to the sky, and were systematically of decreasing slope downward through all their length, from mountain top far down the valley. This was particularly true for the stream lines of the many ravines which gather water and waste from the sides of their inclosing spurs, and which were prevailingly graded along their courses. It was true, also, to a remarkable degree for the waste-stream lines on the spur slopes, which were broken only by scattered outcrops of the stronger rock masses, and then only to a moderate amount. Here and there patches of hackly, ungraded ledges stood forth, not yet reduced to order; but on the whole the graded down-slope lines were remarkably well developed. The variety of these lines was shown in their plan rather than in their profile, and even in plan their variety is systematic. The stream lines branch over and over again, as they are followed uphill, and the spurs are split repeatedly by the large and small ravines that fork beneath them; but that is all. When the mountains are looked at hastily their variety of form seems confused, but when the forms are more patiently analyzed their variety is seen to result almost entirely from small changes on a simple scheme, and every element of form finds its explanation in the processes of normal erosion carried to a mature stage.

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The crest lines of the normally carved mature ridges are rather sharp and somewhat serrate. The slight convexity of the slope lines as they reach the crest shows that those processes of weathering in which changes of volume act nearly normally outwards from the weathered surface there have a relatively large share, along with gravitative down-slope washing, in the reduction of the mountain mass.

This systematic combination of normally eroded forms was seen not only about Kugart pass, but in various other ranges, and in varying degrees of development; but many of the higher ranges exhibited forms of another kind, imposed, as it were, upon the normal forms of the valley heads; and as these additional forms were, in all cases where they could be closely examined, systematically associated with moraines, they may at once be ascribed to glacial erosion and called glacial forms. The glacial forms are no novelty; they are well known in other mountains. They are described here merely to show how systematically they repeat the features of similar forms seen elsewhere. Their most significant features are as follows: They occur at great altitudes, such as 8,000 feet, in ranges that rise to still greater altitudes, such as 12,000 feet or more. They are independent of rock structures. When considered in profile they involve a double change of slope from that of normal forms. If A B C (fig 53) represents a normal slope, a glaciated slope, D E B, is steeper than normal in the upper part, D E, and less steep than normal in the lower part, E B. The steeper upper slope, D E, may be surmounted by a less steep slope, A D, or it may rise directly to the crest line. When two such slopes meet, back to back, the crest is an unusually sharp and serrate arête. The lower slope, E B, may be hollowed to a basin form.

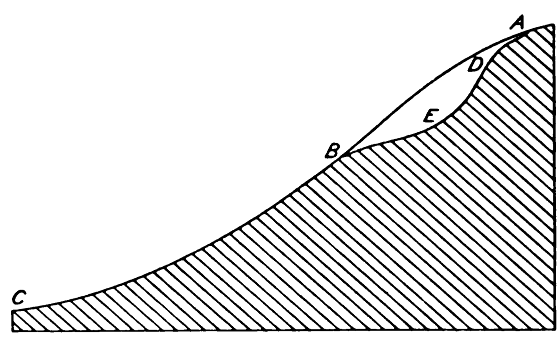

Fig. 53.—Profile of a Cirque at the Head of a normal Valley.

When considered in plan, the glacial forms are simpler than the normal forms that they have replaced, for they involve the substitution of a single broad-floored concave form for a number of interlocking ravines and spurs. When two simple forms of this kind are associated, the smaller one may open its floor in the wall of the larger one, so that the two floors do not join at accordant grade.

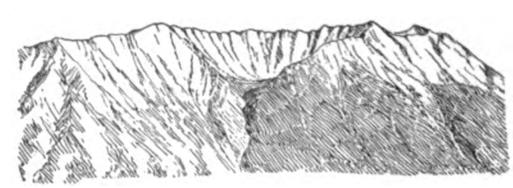

Fig. 54.– Cirque in the Kalkagar-tau.

Glaciated valley heads are so well defined that they have received a special name from mountaineers in different countries—*cirque* and *kar* in the Alps, *botn* in Norway, *cwm* in Wales, *corrie* in Scotland. All these features have been abundantly described by various writers—Böhm, Richter, De Martonne, Harker, Johnson, Gannett, Gilbert, Lawson, to name no more.

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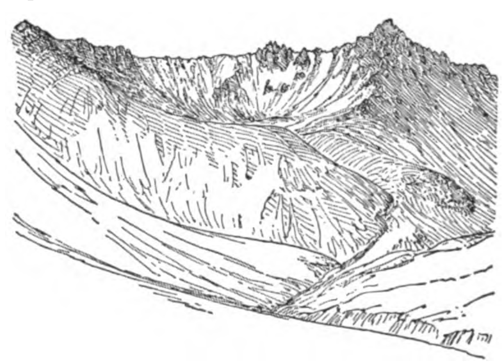
Forms of the kind thus characterized are not to be accounted for by the theory of normal erosion, and are not found where normal erosion has acted alone. They may, however, be accounted for by means of reasonable assumptions as to glacial action, and they occur, so far as is known, only in mountains that are otherwise proved to have been glaciated. Their occurrence may therefore be taken in evidence of the verity of the reasonable assumptions by which they are explained; all the more so because the process of glacial erosion is not open to direct observation, and because there are many different opinions as to its rate, method, and amount. For these very reasons it seems warrantable to determine the process rather by the forms that follow from it than by the little that can be seen of it in actual operation.

The different glacial ranges of the Tian Shan that we saw either close at hand or in the distance afforded repeated examples of nearly every feature above named as characteristic of glacial action. Mention has already been made of the snowy range seen to the south of the Fergana basin, where our field glasses showed numerous cirques crowned with sharp peaks and arêtes, and opening forward into trough-like valleys with over-steepened basal walls. These forms were as typical of strong glacial erosion as any that I have seen in the Alps. It was a surprise that features of this kind could be distinctly recognized at distances of 30 or 40 miles, yet we were persuaded that their identification was safe. We had a similar experience when looking from the Alabuga Valley at the Kalkagar-tau, some 30 miles to the south. Several of the cirques there noted are shown in figs. 54 and 55 as sketched through a field glass. All of these cirques are continued downward by narrow, steep-pitching normal valleys, with respect to which the cirques would have to be explained as the product of an earlier cycle of erosion if they were not admitted to be of glacial origin. But if the open cirques were regarded as of normal origin, the mountain summits above them ought to be rounded forms, while as a matter of fact they are as a rule singularly sharp and serrate. Either form alone might be explained without recourse to glacial erosion, but the combination of the two forms, sharp peaks and open valleys, is believed to find explanation only by the special process of glacial erosion.

Fig. 55.—Cirques in the Kalkagar-tau.



Fg. 56.—Cirque near Sutto-bulak Pass, Kungei Ala-tau.

While we were crossing the low ranges south of Issik Kul on July 16, a number of cirques and troughs were seen high up in the Terskei Ala-tau to the south and southeast. Some of the cirques opened on the walls of the larger troughs in true hanging-valley fashion. One of the troughs showed with remarkable distinctness the significant feature of over-steepened lower walls. All the cirques were associated with sharpened peaks and arêtes. Two cirques, hanging over a glaciated trough, have already been mentioned in connection with the moraines on the headwaters of the Ula-khol. Similar features were seen farther east in the same range when we examined it a few days later through our glasses from the north side of Issik Kul. Cirques, needle peaks, and sharp arêtes were well developed in the Kungei Ala-tau by the Sutto-bulak pass. One of the cirques opened in the side wall of the main valley several hundred feet above its floor, as shown in fig. 56. Its floor must have been at an elevation of about 10,000 feet.

The characteristic association of these various glacial forms in the higher ranges and their striking contrast with forms of normal origin in the lower ranges was a suggestive lesson in mountain sculpture.

THE NARIN TERTIARY BASIN.

After crossing the open pass that separated the basin of the (eastern) Kugart from that of the Makmal, we found ourselves in a basin of partly consolidated conglomerates, sandstones, and clays, which was continued eastward down the Alabuga Valley, and whose end was not reached where we forded the Narin River and crossed the mountains on the way to Son Kul. Although no fossils were found

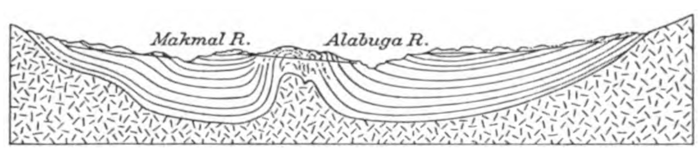


Fig. 57.—General Cross-section of the Narin Formation, looking east.

in the strata of the basin, we regarded them as of Tertiary age from their resemblance to the Tertiaries of the Rocky Mountain region. The most noteworthy features of the Narin formation are as follows.

THE PERIOD OF DEPOSITION.

The basal beds of the formation were seen along the southern border of the Chaar Tash range, at the headwaters of the Makmal. They lay unconformably on granites and limestones. The surface of contact was of small relief, as far as could be judged by the continuity of the outcrops of the basal Narin beds along the mountain side. The formation consists of muddy conglomerates, bright red in color in its lower and marginal part, and of grayish clays, sometimes banded with red, toward the middle of the basin; it includes a series of salt and gypsum beds in the lower members of the central area, as revealed there in a strong anticline. The stratification of the conglomerates and sandstones is variable and irregular, and cross-bedding was common. The stratification of the clays is often remarkably regular; but in many sections of all these beds, toward the center of the basin as well as near the margin, lenses or "channel fillings" were of common occurrence. These

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were taken as evidence of a fluviatile origin of the deposits as a whole, while the salt and gypsum deposits, with their associated clays in the lower central beds, were taken to mark a shallow central depression without outlet, sometimes holding a bitter lake, sometimes sheeted over with playa muds. The thickness of the whole formation must amount to thousands of feet. As in many other basins of heavy deposition, the basin floor, originally a land surface, must have been depressed thousands of feet, so that it in all probability lay below the sea-level. Hence, as far as crustal movements are concerned, the Narin basin is perhaps as noteworthy as the Dsungarian basin, at the east of the Tian Shan, in which the land surface to-day is below sea-level. The unusual feature of the latter basin may not be so much the depth of its depression, but the absence of sufficient waste or water-filling with which to fill it to a more ordinary level for a mid-continental area. The Narin basin was more normal in this respect, for while its area was slowly warped into basin form, centripetal streams carried abundant waste from the elevated margins toward the depressed center, and the latter was aggraded at the expense of the former.

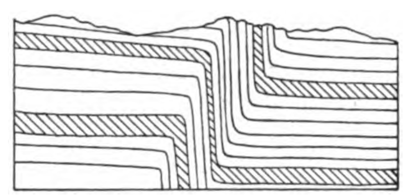

Fig. 58.—A small Monocline in the Narin Formation, looking east.

The lenses or channel fillings in the marginal conglomerates on the upper Makmal were from 30 to 70 feet wide and up to 10 feet thick. They usually showed cross-bedding, and were commonly of different texture from that of the bed in which the channel had been eroded. The lenses in the gray clays, well exposed on the south side of the Alabuga for several miles below the new road bridge, are very numerous. They are from 20 to 100 feet wide and from 1 foot to 10 feet deep. They frequently exhibited a gentle cross-bedding. All the lenses were convex downward and plane upward. There can be little doubt that they represent cross-sections of the shifting channels of the streams by which the basin was aggraded.

THE PERIOD OF DEFORMATION AND EROSION.

The Narin strata have been much deformed on certain lines, but as a whole they have not been greatly disturbed. A generalized cross-section of the basin is given in fig. 57, representing a breadth of 20 or 30 miles. The dip of the basal

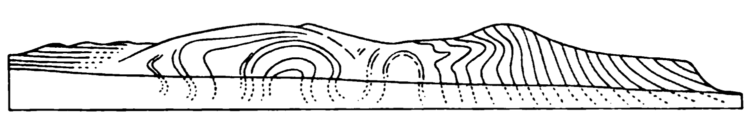

Fig. 59.—Three-mile section through Ulu-tuz Gorge, looking east.

conglomerate along the border of the Chaar Tash is sometimes as much as 50° or 60°, but this measure decreases rapidly as one enters the basin. A well-defined monoclinal flexure, trending about east and west, was crossed as we followed down the Makmal. A small monocline of diagrammatic pattern, with a displacement of about 300 feet, was seen a few miles farther south; it is sketched in fig. 58. The strong and complex anticline, by which the lower beds are brought to light near

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the axis of the basin, runs about parallel to the Alabuga on its north side for some 50 miles west of its junction with the Narin. The trail crossed this anticline in the Ulu-tuz gorge, a few miles west of the new bridge over the Alabuga, and there we saw a section about 3 miles long, given in fig. 59. Beds of salt and gypsum occur in the center, and are greatly deformed. Bad-land clays lie horizontal on the north, and sandstones and clay-beds dip steep to the south on the south. The little stream in the gorge was intensely salt. Some miles farther east, beyond the transverse gorge through which the Makmal comes to the Alabuga, the anti-

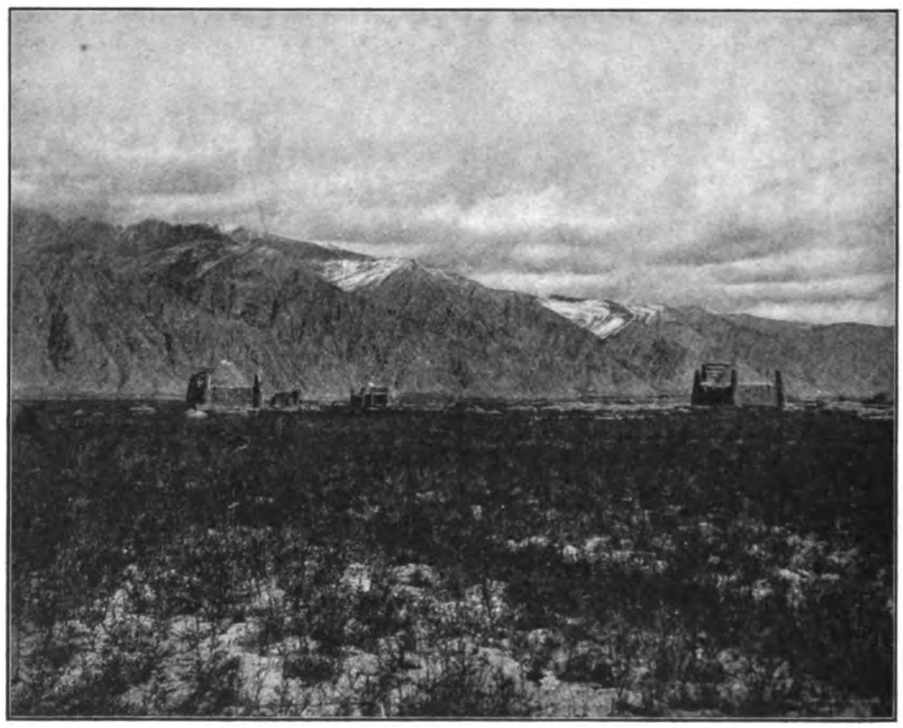

Fig. 60.—The Alabuga Valley, looking north. The east end of the Chaar Tash Range is seen over the dissected anticlinal ridge of the Narin formation; gypseous efflorescence whitens the transverse gorge walls in the anticlinal ridge. Kirghiz Tombs in the foreground.

cline has overturned dips on the south side and rises in a strong ridge, on which the gypseous efflorescence, seen in the distance, was at first mistaken for snow (fig. 60). Where we left the Narin basin on our way to Son Kul, the border of the formation seemed to be determined by a fault, as suggested in fig. 61.

A large part of the Narin formation, where we saw it, has been reduced to a peneplain along the larger streams since its deformation, and this peneplain is now trenched by terraced valleys, further considered below, with much bad-land dissection of the clay beds in the residual uplands and on the valley sides. It was here that we saw that the bad-land forms were developed in sharpest detail on the southwestern slopes, while the closely adjacent slopes to the northeast had a thin cover of herbage and a smoother form, as noted in an earlier paragraph.

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We were led to conclude that the crustal movements during the deposition and the deformation of the Narin strata should be associated with the movements that have given rise to the present relief of the Tian Shan. The red color of the basal beds, seen not only on the south side of the Chaar Tash, but in the southern distance along the north base of the Kalkagar-tau, is consistent with the reduction

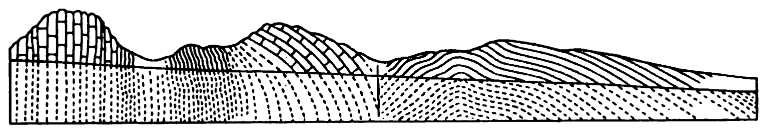

Fig. 61.—Four-mile section across the northern border of the Narin formation, looking east.

of the region to lowland form before the beginning of the deformation by which the Narin deposits were initiated; yet the inclosing ranges to-day have serrate crests without indication of having ever been peneplained. Some smaller valley deposits, probably of Tertiary date, will be described in the next section.

THE RIVERS AND VALLEYS OF THE TIAN SHAN.

If the theoretical considerations presented in the chapter on the Tian Shan are well based, we should expect to find streams of several kinds among the western ranges of this mountain system. Those of the first kind would continue from the former cycle of erosion, but would be revived to renewed activity in consequence of a favoring elevation of the region. The valleys of these revived streams would be seen to-day where the relief of the former cycle remained in greatest strength, or where the new uplifts did not defeat the streams. Streams of a second kind would persist from the antecedent cycle of erosion in spite of an unfavorable elevation of the region. The valleys of these antecedent streams would be expected where the streams were largest and where the unfavorable uplifts were not too strong. Streams of a third kind would be of new establishment, following the slopes produced by the movements which introduced the new cycle. They might be called new consequents, and they would be expected where the movements were strong and the pre-existent streams were weak. A fourth class of streams would include all those developed in the new cycle by headward erosion along belts of weak structures exposed in the valleys of the other class. Such would be called new subsequents.

Examples of revived streams are probably to be found in the central plateau-like region described in Mr. Huntington's report. The gorges cut through some of the ranges suggest an antecedent origin. The gorge by which the Narin cuts through the eastern end of the Chaar Tash, just below the entrance of the Alabuga, the gorge of the Juvan-arik in the Yukok-tau range (fig. 43), and the Buam gorge of the Chu northwest of Issik Kul, all may be of this kind; but the case is not clear. New consequents appear to be numerous on the northern face and on the southern back slope of the Alexander range, and in the longitudinal depressions between the ranges near the west end of Issik Kul. New subsequents of relatively small size are probably of common occurrence as branches of all the other kind of streams.

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RIVERS OF THE ISSIK KUL DISTRICT.

The rivers in the Issik Kul district proclaim their association with new-made ranges by their habit of (until recently) aggrading the longitudinal valleys and of eroding the transverse valleys. This is notably the case in the members of the Chu system. The lower Tuluk Valley contains in its longitudinal portion several hundred feet of yellowish clays, interstratified with lenses and layers of coarse gravels and cobbles, all now dissected. The stream turns abruptly northward from this aggraded and dissected trough to a deep and narrow gorge through the eastern extension of the Chalai range, and then joins the Juvan-arik. The gorge is passable at low water, but at the time of our visit the Tuluk-su was too high to permit us to follow it, and we had to make a detour over a low pass. The upper (western) part of the Tuluk Valley, where we first came to it north of Son Kul, did not present any sure signs of being a valley of recent deformation; its sides were well dissected; its lower spurs were well graded; its present flood plain was eroded 50 feet or more below an earlier valley floor; yet all this is consistent with the origin of the valley by subrecent deformation, followed by dissection of its sides, accumulation in its most depressed part, and erosion of its transverse

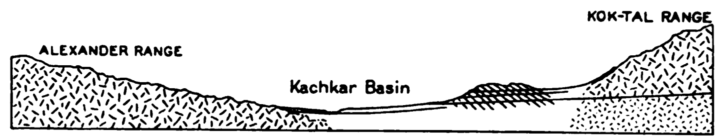

Fig. 62.—Fifteen-mile section across the Kach-kar Basin, looking east.

outlet. The change toward a more arid low-level climate, indicated by an increasing sparseness of vegetation as we rode down the valley, was distinctly noticeable in a distance of 10 or 15 miles.

The Juvan-arik comes from the east in a longitudinal valley on the south side of the Terskei Ala-tau; then turns northward near the junction with the Tuluk-su and follows a deep gorge (fig. 43)—one of the wildest gorges in the Tian Shan, according to Severtzof (1875, 73)—through the range, here called the Yukok-tau (Son Kul Gebirge on Friedrichsen's map), to the Kach-kar basin. The longitudinal valley contains clay deposits of a yellowish or reddish color, but these are now so deeply dissected as to expose the rock floor on which they rest. Since the deep dissection there has been an accumulation of gravels and cobbles, capped with gray silts, but these deposits are also trenched, and the present river flows in an open flood plain below the terrace remnants of the gravels. The transverse gorge has steep, ragged walls of granite, basalt, and diorite, between which the river rushes on a rapidly descending bowlder bed. There are few signs of terracing in the gorge, but where lateral ravines open in the walls, benches of gravel remain.

The Juvan-arik joins the Kach-kar in a longitudinal basin of the same name, and their united waters flow eastward and northward toward Issik Kul, under the name of Urta-takoë. The Kach-kar basin has already been referred to as an aggraded area of depression correlated with the uplifted and dissected block of the

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Alexander range on the north. Near the southern border of the basin are some ridges formed of clay beds, probably Tertiary, tilted to the south and eroded, as in fig. 62, and thus suggesting progressive deformation of the bordering mountain blocks, as in the Narin basin. The passage of the Juvan-arik through the clay ridges is marked by terraces at three levels. Farther on there is a broad plain near the grade of the present rivers. The topography of the district must have been very different when the clays were deposited, for the rapid river is now and has long been washing coarse waste in abundance from its gorge in the Yukok-tau, The clays may, therefore, be provisionally referred to an early period of deformation, before the surrounding region had gained a strong relief. Their deformation and progressive degradation may be associated with the stronger dislocation and dissection of the inclosing ranges.

The Urta-takoë soon leaves the Kach-kar basin by a rather narrow valley, and enters a second basin in the center of which lies Urta-takoë post-station, just south of a superb fan that is washed from the block range on the north. The longitudinal valley here has every appearance of being aggraded, especially to the east, where the waste that is washed in from the higher range on the south has built up a long, slightly convex filling against the middle of the smaller range on the north. Mention of this has already been made in connection with the block mountains of this district. The river runs northward through a gorge and thus reaches the western end of the Issik Kul basin, where a great volume of gravels has been deposited and afterward more or less dissected. Some of these gravels will be mentioned in the section on the lake basin.

The river that we have been following is called the Chu after passing the west end of Issik Kul. For the next 20 miles it follows a rather open valley westward, with an extraordinary exhibition of terraced alluvial deposits, including cream-colored clays and heavy gravels. Then the deep and wild Buam gorge is followed northward. The river here flows at great speed in most tumultuous fashion for miles together. Its descent is so rapid that the road alongside of it was often undesirably steep. The intrenchment of the gorge is evidently still in active progress; yet even here, where the walls are steep and ragged in resistant rocks, and where there is often not even the beginning of a flood plain, some small tributary streams enter the Chu practically at grade. At Kok-muinak station the gorge opens upon a wide basin, where the river has made some fine terraces by cutting down through its former gravels and into the rock beneath.

The persistent alternation of open longitudinal valleys with silts and gravels and of narrow transverse gorges with bare rock walls, taken with the ungraded character of the river in the gorges, gives strong evidence of subrecent displacement of the ranges in the Chu basin, and thus confirms the inferences based on the form of the mountain blocks.

THE KUGART TERRACES.

Terraces occur in all the valleys that we followed. The best examples will be briefly described, beginning with those of the (western) Kugart, where we first entered the mountains. This valley seems to have been eroded to a much greater

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depth than it now possesses and then heavily aggraded, mostly with gravel, but with some silt layers, so that its floor gained a breadth of 3 miles in its lower course. It was during this aggradation that we suppose the loess of the hillsides to have been supplied from the flood plain of the wandering river. Since then the river has returned to its former habit of erosion and valley deepening, as a result of which several terraces have been developed. Those near the mouth of the Karalma (fig. 63), a branch from the north, are drawn in section in figure 64. Here the river is nearly 300 feet below the upper plain. Fans of half-mile radius are built on the plain by streams issuing from the range on the south. The valley is here bordered on the north side by bluffs of bedded conglomerate and silts, which rise several hundred feet above the upper plain, and show a moderate northwesterly dip, thus suggesting that there have been alternations of degradation and aggrada-

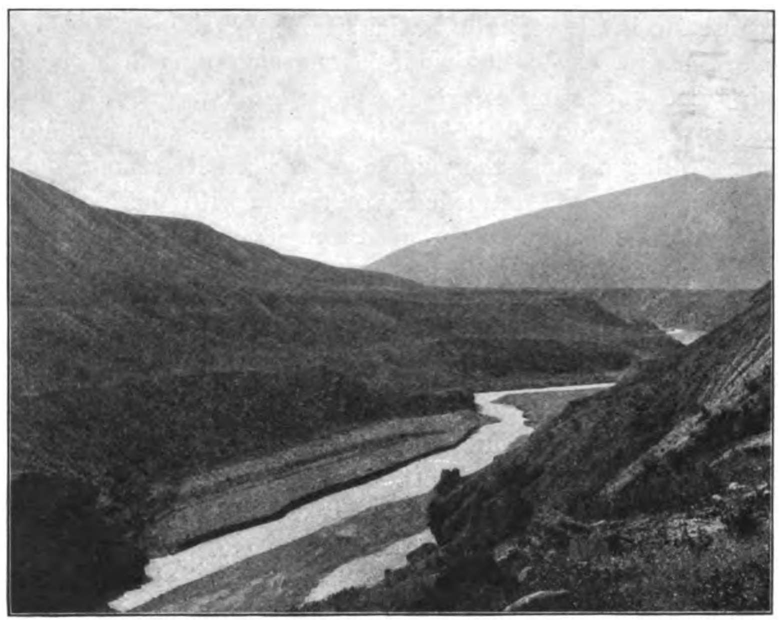

Fig. 63. – Terraces of the (western) Kugart, looking northeast.

tion, associated with slight uplifts, in this district. The stream ran near the north side of its valley for the lower 30 or 40 miles, and the road that is projected to cross Kugart pass followed up the broad terrace plain on the south side; but just above the village of Taran Bazaar the stream lies along the south side of the valley, where it is locally superposed on a belt of limestone to the south of its former course, and a narrow gorge results, as in figs. 65 and 66. We here met one of the engineers in charge of the road construction, who said it was intended to cut a roadway on the southern wall of the gorge, and thus avoid the necessity of bridging the river. In the meantime the Kirghiz ford the river just below the gorge and then follow up the terrace on the north side of the upper valley. We took guides for the ford, and were more fortunate than some wayfarers who had preceded us by a few hours, as one of their pack horses had been drowned in the crossing.

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The terrace plain continues far up the Kugart-su, but it becomes narrowed and the river often cuts through the gravels to the rocks beneath. The rocks are weak red beds for several miles, in which the hills are low and the valley sides are scarred with landslips. Farther on schists and slates set in, the mountains

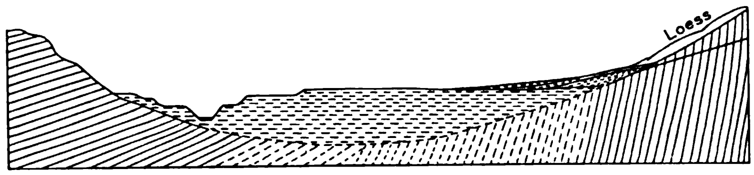

Fig. 64.—Three-mile section across the (western) Kugart Valley, looking northeast.

rise, and the valley narrows. The upper terrace plain is then more built upon by lateral fans and more trenched by lateral streams, so that the trail along it has an uneven grade. At the mouth of the Kizil-su a fine exposure of the terrace conglomerates is seen, several hundred feet in thickness. Above the Kizil-su cobbles and roughly-rounded blocks are found in patches on the mountain side above the terrace plain, as if they marked the remnants of some still earlier valley filling whose terrace form is now lost. Farther on in the mountains the stream rises

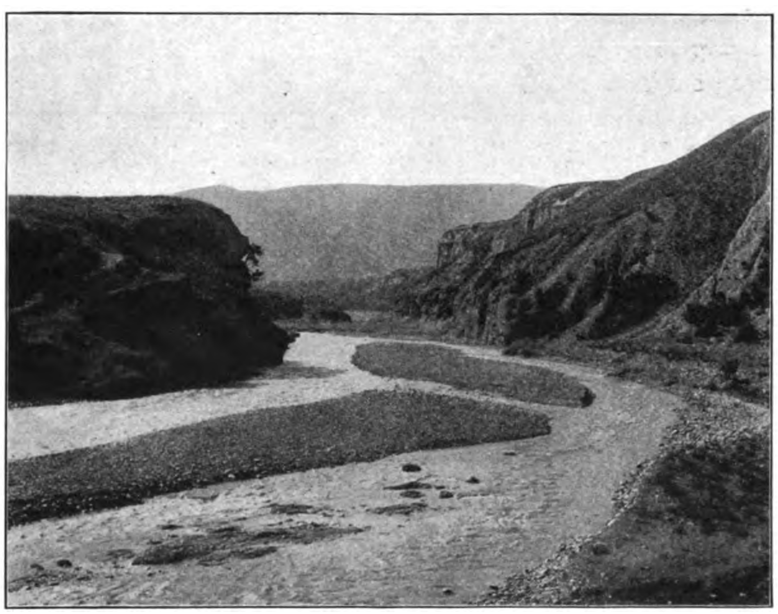

Fig. 65.—Gorge of the (western) Kugart, above Taran Bazaar, looking east.

above the terrace level, and the valley floor is encroached upon by torrent fans from lateral ravines. Here we camped in the rain, about 5 miles below the pass, on June 30. The discomfort of bad weather was removed by the thoughtfulness of our good friend, the Min-bashi, who had given orders to send a party of Kirghiz ahead with yurts. When we reached the camp the yurts were already set up and well furnished for a comfortable night.

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After we had crossed the Kugart pass, in the Fergana range, and descended into the valley of the (eastern) Kugart-su, another finely developed system of terraces was found. The main and branch valleys here, below the torrential head-waters, were eroded in a broad basin of tilted conglomerates that probably belong with the Narin formation. The spurs of the conglomerate hills rose above the highest terrace (fig. 67). Here and elsewhere the hills and spurs were dissected by rather close-spaced ravines, and the slopes were beautifully graded. The terrace plain ascended with a rather strong gradient into the embayments between the spurs. In such a case it is evident that the material of the terrace was derived from the side valleys as well as from the

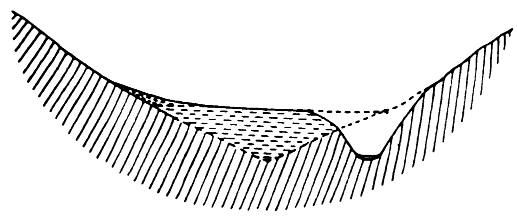

Fig. 66.—One-mile section of Gorge in the (western) Kugart Valley, looking northeast.

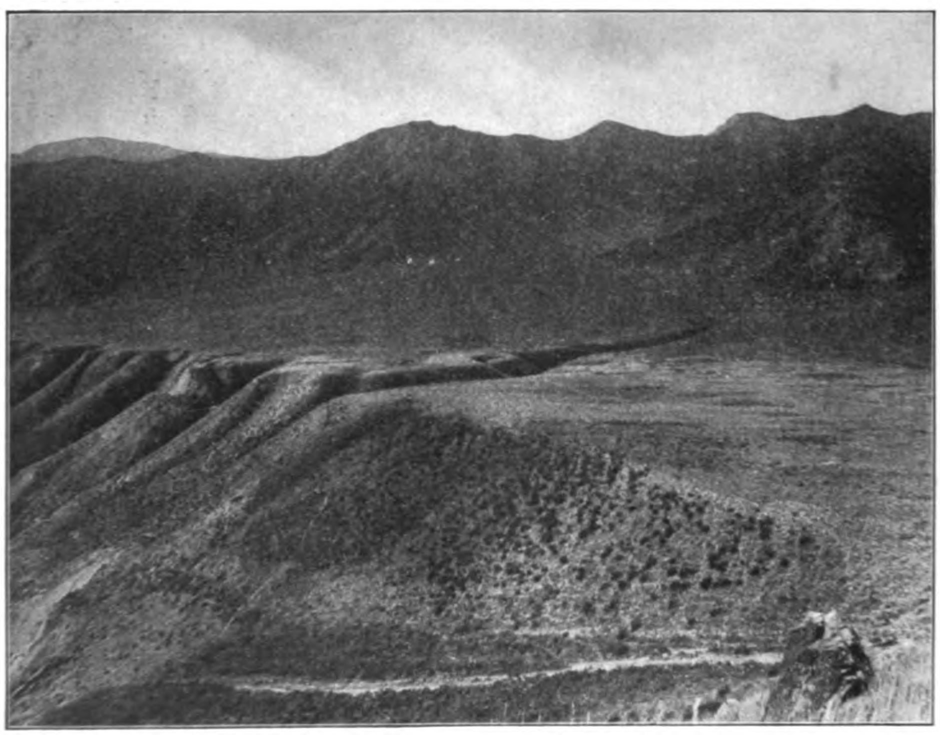

Fig. 67.—Upper Terrace of the (eastern) Kugart, near the Kirghiz Bridge, looking southwest. Dissected hills and spurs of tilted older conglomerates in the background.

main valley. The stream has intrenched itself 225 feet below the upper terrace plain at the Kirghiz bridge, carving several terrace benches in the process. The upper terrace plain and the stronger terrace benches continue for 10 or 12 miles northward toward the Narin Valley. A mile upstream, south, from the rude Kirghiz bridge by which we crossed the river, a westward swing of its course

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undercuts the whole thickness of the valley-filling, up to the upper plain, and shows the half-cemented conglomerate in a fine bluff (fig. 68). Many little terraces occur on the opposite side of the stream.

Several large landslides have invaded this valley from the granitic Chaar Tash range on the southeast. The first one noticed was just below the Kirghiz bridge across the Kugart-su. No very distinct scar was to be seen on the mountain side, but the path of the slide was marked by a wide belt of confused bowlder-strewn knobs and mounds that stretched for 8 or 10 miles northwestward from the mountains down a moderate slope to the terrace plain. Curiously enough, the extremity of the slide lay, 150 feet thick, on the plain on the farther (northwest)

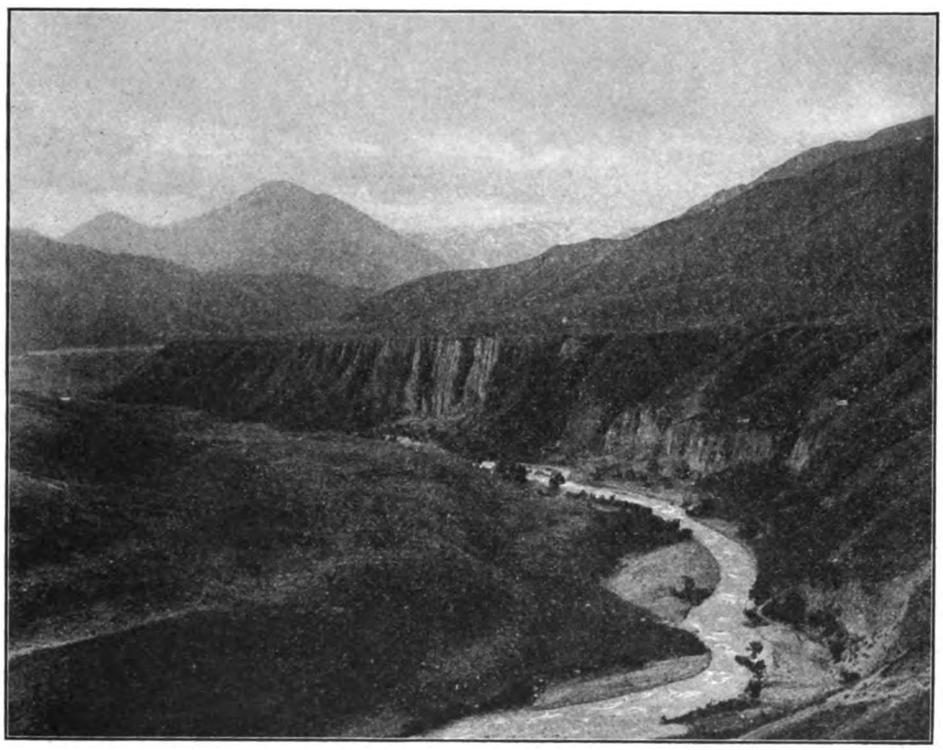

Fig. 68.—Gravel Bluff in the Terraces of the (eastern) Kugart, looking south. Spurs of conglomerate in middle distance; the Fergana Range in the background.

side of the river trench, and rose 100 feet higher there than in the tumult of mounds on the nearer (southeast) side, as in fig. 69. The slide had evidently taken place before the river had deeply intrenched itself beneath the plain, for the walls of the trench gave a good section of the irregular landslide mass resting on the well-stratified conglomerates; and in such a case one might expect the river to have been turned from its former course to a new channel around the end of the slide; but as this did not happen, we may suppose that the river maintained its course by enlarging the leaks and passages through the slide. We had a fine view of the valley from the high terminal mounds of irregular form, composed of angular

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granitic fragments, with many large blocks, 10 or 15 feet through. Some other large slides were crossed farther south. These came from the west end of the Chaar Tash and ran westward into the valley of the Oï-kaïn, a branch of the (eastern) Kugart-su. One of the slides blocked the valley and caused the formation

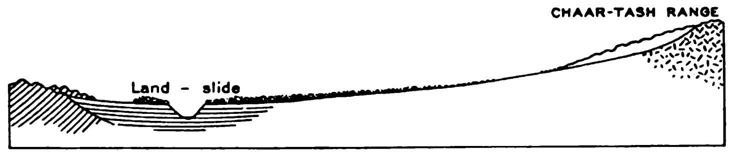

Fig. 69.—Ten-mile section of a Landslide in the (eastern) Kugart Valley, looking north-east. The present river valley is eroded in horizontal gravels that occupy an older and much wider valley eroded in tilted conglomerates.

of a large meadow, now somewhat terraced, next upstream. A little farther south the Oï-kaïn has been superposed on the resistant rocks (apparently limestones) at the southwest end of the range, and has there cut an impassable gorge; hence the trail climbs over the ridge on the southwest and then descends into the open upper valley of the same stream.

THE TERRACES OF THE NARIN BASIN.

The terraces of the Alabuga River in its valley through the Narin formation were among the most interesting that we saw. It has already been stated that the Narin conglomerates and clays had been much eroded after their deformation. The terraces now to be described occur in the valley that has been eroded below the broadly degraded surface—a true plain or a peneplain over large areas—of the Narin strata. The terraces were first seen in the valley of the Makmal, where three or four steps occurred. The uppermost Makmal plain was broadly sheeted over with gravels, even where it truncated the tilted clays. The spurs of the higher terraces,

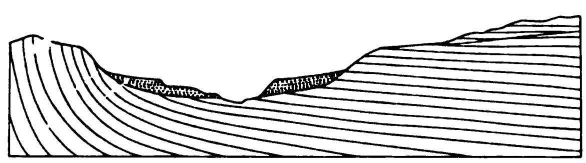

Fig. 70.—Two-mile section of Terraces in Alabuga Valley, looking east.

as well as the residual hills that surmount the highest plain, assume a more and more minute pattern of dissection or bad-land form, as the clayey strata toward the center of the basin are reached. After passing southward through the Ulu-tuz gorge in the salt-bearing anticline, we came out upon a well-defined terrace plain of the Alabuga Valley and crossed it to the trench of this river, which was incised 150 or 200 feet below the plain, as in fig. 70. Here several terraces were seen on the north side of the trench, while a single bluff rose on the south side. The bluff showed a heavy deposit of gravel, capped with 20 or 30 feet of fine gray loess-like silt at the level of the terrace plain. Many springs issue from the bluff at the

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surface of contact of the gravels on the Narin clays. The river is now so rapid that it washes along heavy cobbles. A much gentler current is suggested by the silts that cap the gravel bluff.

As the Alabuga is followed eastward, a graded plain makes its appearance 300 or 400 feet above the terraces just mentioned. It is this higher plain which constitutes the peneplain, worn on the disturbed Narin formation. Bad-land residuals, 100 or 200 feet in height, still surmount it here and there; yet in the district where the road crossed over its remnant spurs, the peneplain must have occupied nine-tenths of the basin floor south of the river before the present valleys were cut below it. The peneplain here is cloaked with from 30 to 50 feet of gravel, which lies unconformably on the beveled surface of the tilted clays. At some points a heavier brown conglomerate is locally developed at the base of the gravels, as if it were the channel fillings of a river. Its outcrops are rather strong, and large blocks from it creep down the clay slopes beneath.

Near the junction of the Alabuga and the Narin, the lower terraces seemed to involve successive alternations from erosion to deposition, as indicated in fig. 71.

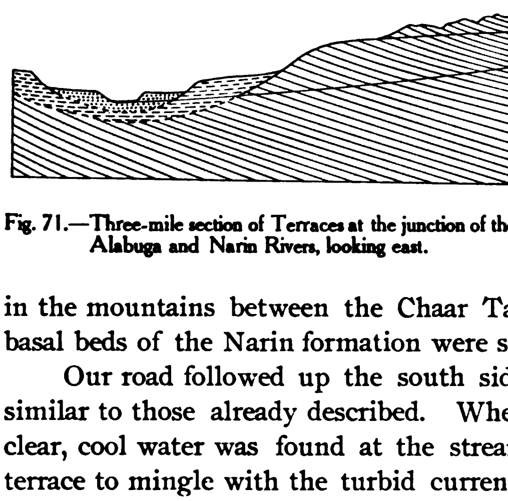

Fig. 71.—Three-mile section of Terraces at the junction of the Alabuga and Narin Rivers, looking east.

A wide, open valley, carved in the tilted Narin clays, was filled to a depth of more than 150 feet with silts. A smaller valley was eroded in the silts, then partly filled with a deposit of gravels. The present river plain is eroded about 30 feet below the gravel plain. The Narin, flowing northwestward, soon enters a narrow gorge that is cut through a sag in the mountains between the Chaar Tash and the Dongus-tau ranges. The red basal beds of the Narin formation were seen in the gorge.

Our road followed up the south side of the Narin, where terraces continued similar to those already described. When we camped on its banks for the night, clear, cool water was found at the stream's edge, issuing from the gravels of the terrace to mingle with the turbid current of the river. The river was said by the Kirghiz to have a daily fluctuation of level, and to be lowest at about 10 o'clock in the morning; hence that time was chosen for fording it the next day, July 7. It was then about a foot lower than when we came to it the evening before.

The terraces of the Juvan-arik have already been mentioned. The Ula-khol, a small river entering the southwestern part of Issik Kul, has several terraces eroded in tilted conglomerates a few miles from the lake.

ORIGIN OF THE TERRACES.

Many more examples of terraces are described in Mr. Huntington's report, where strong reasons are given for ascribing the terracing of the valleys in the Tian Shan to climatic changes. It may be here pointed out that none of the terraces described in the preceding paragraphs resemble the terraces of New England in depending on ledges of resistant rock for their protection. If a Narin terrace

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(B, fig. 72) has not been destroyed by the widening of the valley (Y), this is not because the widening of the valley has been prevented by the lateral encounter of unusually resistant rocks, but because the river spontaneously ceased its destructive work when the lower valley was significantly narrower than the upper valley (V), instead of continuing to widen the lower valley so as to combine the two terraces, A and B, in a single terrace, A′. All the terraces of the two Kugarts and of the Alabuga-Narin Valley, and at least some of those of the Chu system, thus appear to result from successive reductions in the power or in the period of river action. The same holds true in the case of the terraces in the Kopet Dagh, above described. Here, as well as there, it is not likely that the terraces now seen record all of the terrace-making episodes, but only the decreasing maxima in a complicated series. It should also be pointed out that the terraces of New England and of the Tian Shan appear to be of unlike age. Those of New England are eroded in loose sands or clays, and are all of later date than the last glacial epoch. Indeed, their production may have required less than half of post-glacial time, for the valleys in which they were carved were aggraded, after the ice retreated, by the same rivers that are now degrading them; and the existence of the terraces shows that less material has been removed than was previously deposited. The terraces of the Tian Shan, on the other hand, are usually eroded either in rather well knit gravels or conglomerates, as along the two Kugarts, or in partly consolidated sandstones and claystones, as in the Narin formation, while in the Kopet Dagh they are carved in calcareous shales. In all these cases the terrace materials are strong enough to stand up in steep bluffs. None of these terraces are in glaciated valleys. The earlier terracing appears to be much more ancient than the latest moraines in the high mountain valleys. It is therefore quite conceivable that, as Mr. Huntington has concluded, the successive glacial epochs and the successive terracing epochs, each of decreasing intensity, may be synchronous, and may be common results of a series of climatic changes. Whether it is finally proved that the terraces result from climatic changes, or whether the terraces are in part the result of crustal movements, there appears to be good ground for thinking that the time intervals marked by the terraces may be correlated over very considerable distances, and that the time intervals thus established may be eventually placed in the same scale with those indicated by the glacial records; and that thus a good beginning toward the establishment of a Quaternary time scale will have been made.

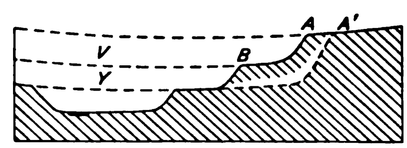

Fig. 72.—Ideal section of Terraces.

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THE ISSIK KUL BASIN.

Issik Kul, or the "Warm Lake," is 115 miles long and from 20 to 35 miles wide. Its surface stands 5,300 feet above sea-level. The bare mountains around it are picturesque, but the barren, stony piedmont slopes, several miles in breadth, greatly lessen the beauty of the scenery. The basin of the lake resembles that of the Narin Tertiary formation, in that both have been produced by the deformation of a previously degraded mountain region and that both have received much waste from their uplifted borders; but they differ in that the deformation of the Narin basin ceased so long ago that its deposits are now well dissected by the trunk and branches of an outflowing river, while the deformation of the Issik Kul basin has been continued into so recent a time that it holds a large lake, from which there is at present no outlet. The lake surface and the surface of the present Narin Valley are of similar altitude, something over 5,000 feet above sea-level. It is very probable that the original floor in each of these basins now stands below sea-level, but as it is concealed beneath a cover of deposits or of water, the depression excites less attention than it would if it were open to observation; yet as far as the mechanics of the earth's crust is concerned, one case is, as has already been pointed out, as remarkable as the other.

Evidence of the previous degradation of the region in which the Narin basin was bent down is found in the relatively even trend of the red basal conglomerates which rose even along the southern side of the Chaar Tash range; for if the surface on which the conglomerates were deposited had been of strong relief, their outcrops and the slopes of the Chaar Tash rocks could not have come together on so even a line. The evidence of previous degradation in the region of the Issik Kul basin is found in the even sky-lines or back slopes of several of the neighboring mountain ranges, as already described. The ranges are now much dissected, and deposits of their waste are found not only in the stony piedmont slopes with which the lake is surrounded, but also in older clays and conglomerates, now more or less deformed and eroded, around the borders of the lake.

THE EARLY BASIN DEPOSITS.

Hills and ridges of eroded conglomerates were seen south of the lake when we ascended the Ula-khol; their total thickness may have been several thousand feet. These uplifted conglomerates fall off northward toward the lake in a rather well defined subrectilinear bluff east of the Ula-khol. A lower bluff, subparallel to the first, stands a little farther forward; then comes the fan of the Ula-khol, in which the stream has now eroded a shallow trench. Not far forward from the second bluff, a third bluff or scarp, from 5 to 15 feet high, crosses the delta, and this one seems to be the result of recent displacement. This scarp can not be considered a high-level shore-mark of the lake, for instead of contouring around the Ula-khol fan in a level line, it passes over the gentle arch of the fan in a relatively straight line. It will be remembered that a similar displacement was noted in the waste fans piedmont to the range at the west end of Issik Kul.

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A point between two bays at the west end of Issik Kul is caused by ridges of dissected conglomerates, bordered north and south by low gravel plains of gentle grade, sloping from the Chu toward the lake, and probably representing former deltas of the Chu when it flowed into Issik Kul. That it had probably once done so was recognized by Severtzof in 1867 (1875, 82). The Chu has now a silt cover on its flood plain near the lake, but shows gravels in its shoals. If the silts were laid over the plain of its former delta, they have been removed. The Kirghiz have led some small canals from the Chu eastward across the southern delta plain toward the lake. The water thus gained is distributed on fields of fine soil not far from the lake shore. A pair of whitish clay belts, about 5 feet apart, vertically, was seen contouring around the slopes that inclose this plain. We took them for shorelines at first, supposing that the clay had accumulated in the presence of reeds or grass, by which wave action was held off, as is now the case on parts of the Son Kul shoreline; but clay belts were not seen eastward along the northern shore. These belts are probably 50 feet higher than the well-determined shorelines traced at and below the 25-foot level; moreover, similar clays in greater volume were seen at the north base of the conglomerate ridges between the two gravel delta plains, and in much greater volume farther down the Chu Valley; so the origin of the clay belts is left in doubt.

On the north side of Issik Kul the piedmont waste slope is rather evenly developed for the first 50 miles eastward from the west end of the lake, although some local varicolored ridges rose through the waste slope at a few points where its breadth was greater than usual. For the next 20 miles, nearly to Sezanovka, the slope was often made very uneven by a succession of irregular ridges of disturbed and dissected basin deposits of variable texture. The finer sandy or silty layers here seen were frequently covered with heavy bowlders up to 8 or 10 feet in diameter. Some of the ridges thus formed are naturally eroded; others have comparatively simple forms, with even scarps 200 or 300 feet high, facing the lake, in which only narrow trenches have been cut. It was evident that these ridges resulted from the recent disturbance of the earlier basin deposits.

THE PIEDMONT SLOPES AND VALLEYS.

Since the disturbance of the earlier basin deposits there has been time enough for the intermittent streams to form the newer piedmont fans and slopes of waste, which now stretch forward for from 3 to 10 miles with moderate declivity from the mountain base to the lake. Trains of heavy bowlders were seen on some of the fans, as if marking the paths of exceptionally heavy floods. Parts of these newer slopes are of coarse surface materials, and the subangular stones there are darkened with "desert varnish." Other parts are more gravelly and of lighter color, as if of somewhat more recent date. On both parts the scanty herbage is not always uniformly distributed, but sometimes occupies interlacing lanes, inclosing barren spaces a few feet in diameter. The delta of the Ula-khol and the abandoned delta plains of the Chu are also seemingly of modern date.

At the east end of the lake Mr. Huntington reports the occurrence of an extensive plain 40 miles broad east and west and about the same north and south,

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of cross-bedded sands and gravels, with occasional silty layers, sloping toward the lake. Here and there low hills rise over the plain. The hills are chiefly made of silt, but contain also certain layers of rough gravel with broken shells of land snails. The body of the plain is about 200 feet above the lake. During the formation of the plain, the local baselevel at the eastern end of the lake may have been relatively higher than now, but whether the strata of the plain are fluviatile or lacustrine does not clearly appear. Semenof noted the marginal conglomerates in 1856, and inferred from them that "the lake in former times occupied a far more extensive basin" (1869, 331). The same explorer states that the mountains on the north of the lake are named from the Kirghiz word "kungei," meaning "toward noon," and those on the south from "terskei," meaning "toward midnight," thus referring to the opposite aspects of the two piedmont slopes (1858, 359). Severtzof noted in his journey of 1867 that the Ak-su, entering Issik Kul at the southeastern corner, had cut its valley through 200 feet of sands and conglomerates, and inferred from this that the lake was once higher than now (1875, 21). Capus (1892, 56) and Schwarz (1900, 581) probably base their statements that Issik Kul once stood 60 meters higher than now on Severtzof's observations. All estimates of the former higher stand of Issik Kul based on the distribution of sands and conglomerates seem untrustworthy, because such deposits are more likely of fluviatile than of lacustrine origin.

The piedmont slopes and the eastern plain are not now in their original condition. They are more or less dissected by open valleys and branching gullies. The valleys are not distinct near the western end of the lake. They are from 50 to 70 feet deep where we crossed many of them on the northern piedmont slope a few miles back from the midlake shore, but they decrease to less and less depth toward the present shoreline. The eastern plain is well dissected by branching terraced valleys with open straths. Even at the shoreline the valleys at the middle, and still more at the eastern end of the lake, are eroded distinctly beneath the piedmont and the eastern plains; and, as will be more fully stated below, the lake waters now invade the valley mouths, the invasion being of increasing measure eastward. It is inferred from this that the sloping plains were not graded with reference to the present level of the lake, but with reference to a lake surface that descended gently eastward with respect to the present lake surface.

The valleys emphasize this conclusion. It has just been mentioned that they increase in depth as one passes from west to east, along the north side of the lake. They were not noticed at the west end. They became serious obstacles in road building near the middle of the lake, and at its eastern end the road winds about on the plain to avoid them; hence it is probable that the cause of the valley erosion should be associated with a tilting of the lake basin, whereby the eastern end was raised more than the western, after the piedmont slopes and the eastern plain had been formed. Climatic change is also to be considered as a cause of the valley erosion, because the depth of the valleys below the piedmont slopes increases toward the mountains. This indicates a change in the règime of the streams, such as a change of climate commonly produces, and such as is commonly associated with

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a change from a glacial to a nonglacial epoch. It would be an aid in the elucidation of these changes if soundings could be made to determine how far the piedmont slopes continue their present declivity under the lake, and how far forward the valleys may be traced. This would be of especial importance in connection with the ruins that are found submerged in the lake, as mentioned below.

The only suggestion that we can make as to the date when the piedmont waste slopes were formed is based on the occurrence of the moraine, already described as standing a little forward from the mouth of a valley in the Kungei Ala-tau, north of Choktal post station, about 1,500 feet over the lake. If one may judge by the relation of moraines and aggraded waste slopes elsewhere in the world, it is probable

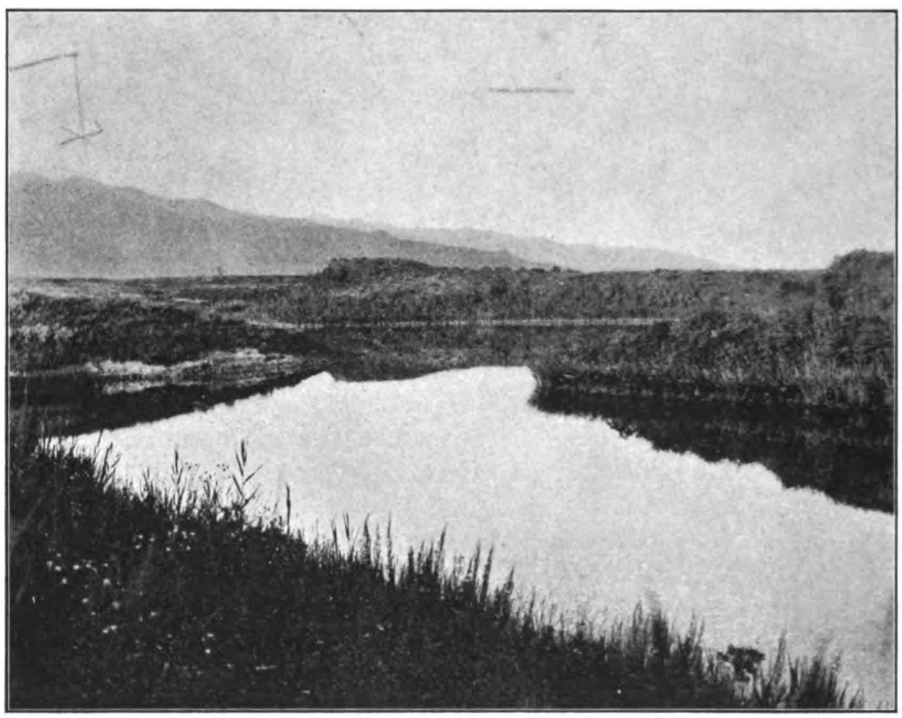

Fig. 73.—A Drowned Valley in the Plain at the east end of Issik Kul, looking northeast.

that the formation of this moraine and the aggradation of the piedmont slopes were contemporaneous; hence the erosion of the valleys is of later date than the glacial epoch in which the moraine was found. Inasmuch as the moraine here referred to was the lowest one that may have been formed in its valley, it apparently belongs to the earliest of the glacial epochs established in Mr. Huntington's report.

It appears from the foregoing that the Issik Kul basin has long been suffering disturbance and receiving waste from the surrounding mountains, and that the latest disturbances of level have been greater at its eastern than at its western end. We have next to consider the more modern history of the lake itself.

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THE RECENT CHANGES OF ISSIK KUL.

The lake was lower and smaller than it is now at a time not long past, as is shown by its recent invasion of the valleys that have been worn in the piedmont slopes. The low-water stand is believed to have been of later date than that of the Choktal moraine above mentioned. The invasion of the valleys was not noticed at the western end of the lake. It was first seen in moderate development in the western quarter of the northern side, and became distinct a little farther east. It is described by Mr. Huntington as a notable feature of the east end of the lake, where the valleys, eroded in the sandy plain, are now drowned so far as to produce long, narrow bays. The scenery of the plain is dull and uninteresting, except for the views of the surrounding mountains; but when one comes unexpectedly upon the drowned valleys, with their long, curving lanes of blue water and their green shores, the view becomes attractive at once (fig. 73). Hence, like the erosion of the valleys, their drowning becomes more pronounced as we go from west to east. The contrast between the shorelines at the northwest end, the middle, and the northeast end of the lake is strikingly shown in the diagrams of fig. 74, which are reduced from the 2-verst map.

The rise of the lake carried it to a higher level than that of to-day, but it remained there only long enough to cut or build a series of moderately developed shorelines, which were first recognized by Semenof in 1856, who said that the lake seemed to have receded from them, as if contracted in its bed (1858, 359). At the southwest corner of the lake, where the bordering plain was low and marshy, we found a well-defined reef of small rounded pebbles, 3 or 4 feet high, 25 feet above the present shoreline, and a smaller sand reef at 10 feet. The present shore was marked by a low sandy beach or reef, often shutting in a narrow lagoon. At the northwestern corner of the lake, low reefs of sand or fine gravel were noted at heights of 2, 3, 5, 10, and 25 feet. At Tur-aigir station, about 15 miles from the west end of the lake, a 4-foot bluff stands about a quarter mile back from the shore, with its base 25 feet over the lake; and a beach was found 5 feet over the lake.

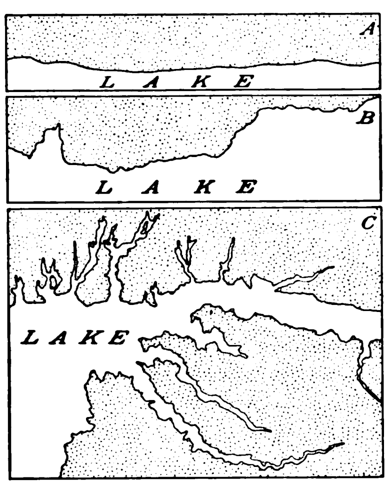

Fig. 74.—Shorelines of Issik Kul at the northwest end (A), the middle (B), and the northeast end (C) of the lake, reduced to 18 versts to an inch from the 2-verst Russian map.

It was near Choktal station that we first noted that the raised beaches are of later date than the valleys. One example from many is illustrated in fig. 75. The surface of the piedmont slope is so smooth that the general shoreline is here notably even; but a small point is made by a trail of coarse bowlders, some of which are 8 or 10 feet in diameter at a distance of 3 or 4 miles from the mountains. The valley here was 6 or 8 feet deep and 70 or 80 feet wide. The stony 25-foot beach or reef was prolonged directly across it, except for a little notch by which a small stream escaped. Several lower shorelines were seen in the valley floor. In another example, a reef 15 or 20 feet high was built across a valley that was 30 or 40 feet deep. In a third example, beds of silt had been laid on a valley floor behind a reef, but at present the reef and silts are both trenched by the stream, which is washing cobbles through them. In this district some trenches of the 25-foot reef were 30 feet wide and 6 feet high on the outer face, with cobbles up to 6 or 8 inches in diameter; and one of the cut bluffs was 8 or 10 feet high. East of Sazanovka Mr. Huntington reports a beach nearly 100 feet wide and a cut bluff 35 feet high. Here and farther east the elevated shoreline is usually indicated on the 2-verst Russian map. The increase in the strength of these features from west to east is probably to be accounted for by the prevalence of waves caused by westerly winds, whose action would be least effective at the west end of the lake.

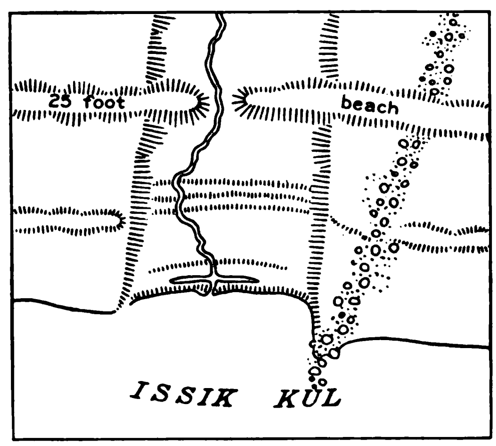

Fig. 75.—Diagram of the relation of a Valley, the raised Beaches, and the present Shoreline of Issik Kul.

The only point where we saw a rocky shoreline was between Chelpan-ata and Kurum-dinskya stations, about 50 miles from the west end of the lake, where a low granite bluff rose at the lake border. It stood in a small embayment, because the piedmont slopes had grown somewhat farther forward on each side of it. Stratified deposits of rather fine texture, covered with bowlders, rested on the lateral slopes of the granite. These seemed to be of earlier date than the modern piedmont slopes. Two elevated beaches have been formed by undercutting the steep slopes of angular waste on the granite bluff, as in fig. 76. The upper beach is the stronger of the two, and is recognized not only by its form, but by the abrupt change from angular blocks above its line to rounded cobbles below. Here only was any direct suggestion found as to the relative date of the two beaches. It seemed that, if the lower one had been made first, it would have been more obscured than it is by waste from the upper one; hence the lake probably rose rapidly to the 25-foot beach and paused during its fall at the 10-foot beach.

At the eastern end of the lake, the highest beach is described by Mr. Huntington as contouring around all the land arms that separate the drowned valleys of the plain. Its height there is given as 30 feet. The 2-verst map shows the shoreline then to have been even more irregular than it is now. The beach is easily distinguished from the valley terraces, for it runs at a level and ends somewhat inland from the bay heads, where the valley floors rise to its level; while the terraces have sloping floors and extend farther up the valleys.

When Issik Kul was first described to us as a lake without an outlet and with abandoned shorelines, we had hopes of finding a record that might compare with that of the Bonneville basin, but there seems to be little likeness between the two. Issik Kul only just fails of having an outlet to-day, and, as will be shown below, its level has probably been regulated by overflow to the river Chu through much of its subrecent

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history. Its abandoned shorelines seemed to be more recent than the glacial epoch, and the variations that they represent are perhaps as well explained by the varying relations between the river and the lake as by climatic changes; but it is evident that the two processes may have worked together.

RELATIONS OF THE RIVER CHU TO ISSIK KUL.

Issik Kul at present has no outlet, and the lake water is very slightly brackish. The Kute-maldy, a short outgoing branch at the elbow of the Chu (K, fig. 43), flows into the lake at its western end. When seen on the map, this stream would naturally be taken for the lake outlet; so indeed Humboldt and Ritter are said to have thought. Various legends are current around the lake as to the origin of the Kute-maldy. A postmaster gave us a very circumstantial story of how a Kirghiz khan, some fifty years ago, tried to drown out his enemies down the valley of the Chu by cutting a canal from the lake to the river, hoping in this way to create a devastating flood; but the lake proved to be lower than the river, instead of higher, as had been expected, and so the water ran the wrong way. Another postmaster told us most explicitly that a canal was cut by the Kirghiz, about thirty years ago, so as to drown out Tokmak and other Russian towns in the lower Chu Valley by a flood from the lake. When the ends of the canal were opened, the water ran in both from the lake and from the river, but the current from the river overcame that from the lake, and since then the flow has been into the lake. He added that the originally straight canal has become winding by the action of the stream. Still a third account is that the Kirghiz found the lake was slowly rising on their fields, and that they cut a canal to the river, hoping thereby to lower the water. It is very doubtful whether there is any truth in these stories. In 1856 Semenof saw a small marsh at the elbow of the Chu, from which a tiny rivulet flowed to the lake (1869, 322). A little later, Venyukof noted the winding course of the Kute-maldy and considered it a natural bifurcation of the Chu (1860, 395). In 1859 Golubef described the Kute-maldy as an artificial canal. "The water in it is nearly stagnant, and barometrical leveling did not show any perceptible difference between the levels of the lake and the Chu" (1861, 369). Osten-Sacken saw the Kute-maldy in 1867 as a shallow, sluggish, winding, muddy stream, with a delta at its mouth (1869, 28). The last description applies to the stream as we found it in 1903. Its channel is said to be left nearly dry when the water in the Chu is low.

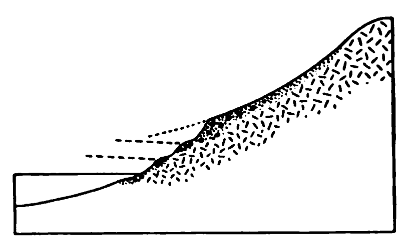

Fig. 76.—Profile of the Issik Kul shorelines on a granitic headland, looking west.

In view of the delta-like form of the gravel plains between the present course of the Chu and the lake, there is no sufficient reason for suspecting that the Kute-maldy is anything but a natural distributary of the main river, from which it can hardly divert more than a twentieth part of its volume.

It is interesting to inquire what effect would be produced on the lake if the whole current of the Chu were turned into it, and for this purpose the following numerical data are pertinent. According to the 40-verst Russian map, Issik Kul occupies about two-fifths of the total area of its catchment basin, the upper Chu basin not included. The surrounding mountains, from which most of the water supply is received, probably occupies as much surface as the lake, leaving one-fifth of the catchment basin as valleys and piedmont slopes. The drainage basin of the upper Chu system, southwest from the lake, is in area about a quarter of the present Issik Kul basin, or roughly a half of the mountain area that drains into the lake. Inasmuch as the chief upper branches of the Chu, the Kach-kar and the Juvan-arik, come from among high ranges, it is evident that their volume must be a considerable fraction of the total water supply that the lake now receives; not, however, so large a fraction as their drainage area would suggest, for the mountains southeast of Issik Kul are lofty, and we were told that many large streams flow from them. If liberal allowance be made for this, the upper Chu might be taken as yielding perhaps a twentieth of the present supply of Issik Kul; hence if the upper Chu were turned into the lake, its surface ought to expand by a twentieth part, if it did not overflow to the lower Chu before such an expansion was accomplished.

On the other hand, when the lake stood at the 25-foot shoreline, its area could hardly have been increased by a twentieth of its present surface. Hence it is probable that if the Chu should now be turned into the lake, its surface would rise to the 25-foot shoreline, if a barrier of that height existed at the outlet; and there might be some water to spare for overflow. It has already been shown that the delta-like plains between the Chu and the western end of Issik Kul indicate that the river has entered the lake. Evidence will now be presented to show that an overflowing outlet has probably generally existed during the subrecent history of the lake. This evidence is found, first, in the eastward increase in the depth of valley erosion, and, second, in the eastward increase in the depth of valley drowning, already stated. To appreciate this curious case, a preliminary statement will be serviceable.

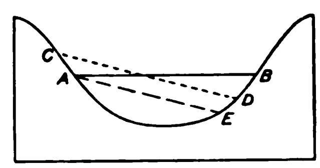

Fig. 77.—Effect of tilting on an inclosed lake; uplift on the right.

The problem before us is to discover the conditions under which a lake, A B, (figs. 77, 78) may preserve its shoreline at A nearly constant, while it sinks from B to D (E) and rises from D to G (H). Let us first inquire how such changes can be produced in a lake without an outlet.

Let the area of the lake, A B, be such as to strike a balance between the rainfall on its entire drainage basin and the evaporation from its surface. If the climate remain constant and regional tilting occur, with uplift on the right, as in fig. 77, the lake will sink from B to D and rise from A to C, thus preserving its area unchanged. In order that the shoreline shall remain at A during uplift, the climate must become just enough more arid to reduce the lake area so that its surface shall be E A, instead of D C. On the other hand, if depression occur on the right, as in fig. 78, the lake will change from A B to F G. In this case the shore can be held at A only by climatic change towards more humidity of just such amount as to expand the surface to H A. It is

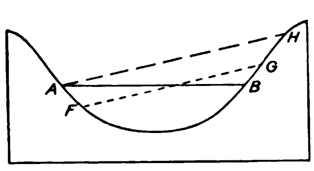

Fig. 78.—Effect of tilting on an inclosed lake; uplift on the left.

evident, then, that the maintenance of the lake shore at A in a lake without outlet involves an extremely improbable correlation of two independent processes—a balancing or tilting of the region and an external climatic change. Hence a lake in which the shoreline remains nearly fixed at A, while it sinks to D (E) and rises to G (H), must in all probability be unlike the lake here postulated; that is, it must be provided with an outlet, instead of being without one.

It is plain enough that an overflowing lake will keep its shoreline fixed at the outlet, however much it may change elsewhere on account of a tilting of its basin. Hence there can be no question that the recent valley erosion and valley drowning around Issik Kul are better accounted for by the example of a lake with, and not without, an outlet; and it therefore seems reasonable to conclude that the present relations of the Chu to Issik Kul is exceptional, and that the river has generally flowed into and out from the lake. Under such conditions it may well be that the overflowing river was a comparatively small one; and it is possible that the heavy valley deposits, now dissected, in the Chu Valley for the first 20 miles west of Issik Kul were accumulated there at a time when the river was too weak to sweep them away, as well as because of the block faulting of the neighboring ranges, as suggested in an earlier section. Indeed, there is a point about 5 miles west of Issik Kul where the fans from the range on the north would close the outlet valley, or raise its floor 100 or 150 feet over the present lake, if their slope were continued forward from their now dissected mass; and it may be that when these fans were formed Issik Kul temporarily had no overflow.

We are thus led to think that Issik Kul has generally had a water supply sufficient to cause overflow during the subrecent time of the erosion and the drowning of the valleys in its surrounding slopes of piedmont waste, and that the Chu has frequently or usually been an affluent of the lake; also, that the fall of the lake from its 25-foot shoreline to its present level may be explained, in good part at least, by the diversion of the Chu past the west end of the lake, as well as by climatic change. It might be possible, by means of soundings, to extend the time to which these inferences apply, so as to include the earlier period in which the piedmont slopes and the eastern plain were aggraded.

It is, on the other hand, probable that the outlet of the lake may often have been of so small a volume that it ceased to overflow during arid epochs of secular duration, as well as during dry seasons. It is quite possible that the present era of desiccation may be of the former character, and in this connection it is noteworthy that, according to Schwarz, the level of Issik Kul was lowered by 2 meters from 1867 to 1877 (1900, 581). It should not, however, be forgotten that the inferences here offered are tentative. The history of the lake is evidently too complicated to be deciphered in a week's visit to part of its shores. It is a most inviting field for further study, and all the more so when its relation to human settlement is considered, as will appear in a later section.

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NOTES ON ARCHEOLOGY.

Brief mention has already been made of the ruins and mounds on the plains. They are further considered in reports by other members of the expedition. The following notes concern localities that were visited on the journey from Andizhan to Issik Kul.

MOUNDS ON THE (EASTERN) KUGART TERRACE.

Near the terminal mass of the great landslide of the (eastern) Kugart, on the high terrace plain over the Kirghiz bridge, we saw 20 to 30 small mounds, from 20 to 25 feet in diameter and from 3 to 5 feet high, made mostly of earth, with cobbles from the terrrace and small angular blocks from the landslide. Smaller mounds, from 5 to 8 feet in diameter and 4 feet in height, were made wholly of stones. No chipped stones were found near them. No such mounds as these were seen in the summer camps of the Kirghiz, and hence we ascribe them to some earlier people.

STONE CIRCLES NEAR SON KUL.

On the gently inclined piedmont slopes that descend to the southeast shore of Son Kul, a mile or more from the lake, we found a row of stone circles. Our guide said they marked the camp of a powerful khan who used to occupy this district, but the Kirghiz are not to be trusted in such matters. The circles were nine in number, unevenly spaced, but set on a nearly north and south line, bearing N. 8° W. magnetic. They are 11 or 12 feet in diameter, each one containing eight stones from 3 to 5 feet in diameter, all of granite from the mountains a mile or more to the south. The fourth and eighth circles have been disturbed. The general arrangement of the stones is indicated in fig. 79, which shows the lateral displacement of the fourth and fifth circles, and indicates the distance between the successive circles, as determined by pacing. A standing stone, rising 4 feet above the ground, is set in a 15-foot circle of small stones, 60 feet east of the ninth circle. North or northeast of the row of circles, 28 small gravel mounds occur within a few hundred feet, and a 5-foot standing stone is seen by the trail 500 or 600 feet to the west. A mile or more to the east there are several earth mounds, 5 or 6 feet high and from 30 to 50 feet in diameter. Four of them are nearly on a N. 12° W. (magnetic) line. The others are placed irregularly. No chipped stones or flakes were found by any of the circles or mounds. Two standing stones on a mound on the plain northeast of Son Kul have human faces rudely carved in outline on a flat surface. Regel makes mention of similar monuments (1879, 414).

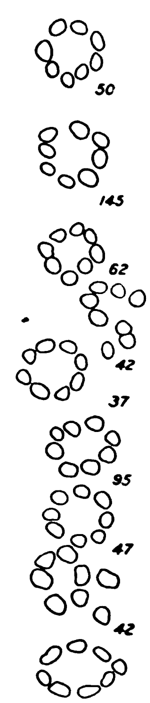

Fig. 79.—Stone Circles near Lake Son Kul. The distance in feet between the circles is indicated in figures on the right.

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OLD CANALS NEAR SON KUL.

The well-grassed foothills of the Kok-tal range north of the Son Kul outlet bore the marks of ancient irrigating canals that gave us much surprise, as the region does not suffer from dryness to-day. The abundant pasture on the foothills and the piedmont slopes is testified to by the great number of cattle driven up there for the summer by the Kirghiz. The canals are now almost obliterated, yet they are indubitably of artificial origin. The Kirghiz seemed to know nothing about them. They have been so far filled by the creeping of waste from the upper slope that they appear as benches 5 or 10 feet wide, instead of as channels. They lead with gentle descent from a stream along a hillside at different levels. Gullies, more or less grassed over, often descend the slope below the canals, marking the paths of accidental overflows.

Similar nearly obliterated canals were seen on one of the northern spurs of the Kok-tal range as we descended from the Kum-ashu Pass into the Tuluk Valley. Their course was observed to better advantage the next day, when we stood on the large moraines on the north side of the valley and looked across to all the spurs on the other side at once. Three canals were then seen on one spur at different levels. The uppermost, estimated to be 700 feet above the Tuluk-su, passed around the ridge line of its spur and turned into the next ravine on the east. Another one on a neighboring spur ran out to the spur ridge, and then followed down the ridge into the main valley. As on the other side of the range, these old canals all started at a stream and led forward on the side of a spur, and down-slope gullies from the canals frequently marked the paths of overflows.

THE ISSIK KUL DISTRICT.

The carved standing stone, shown in fig. 80 was photographed by Mr. Huntington on the plain at the east end of Issik Kul. The following notes are from the same observer. Walls or mounds are found at ten or twelve places on the fertile piedmont plains northeast of the lake. They are generally arranged in lines running roughly north and south. Those that were examined consisted of a circular or oval wall of cobble stones, from 10 to 30 feet high, covered with earth. In the smaller examples the center also was filled with earth, so as to form a mound. In the larger examples the center was unfilled, and formed a hollow within the wall. The only clue as to the age of these monuments in relation to the history of Issik Kul was furnished by a small mound, 14 miles east of Sazanovka. The mound in question stands on the edge of the bluff, the base of which has been cut back by the 30-foot shoreline (the same shoreline is at 25 feet over the lake farther west), and the edge of the mound has thus been cut back so that one-third of its area is undermined and lost. The cobbles and bowlders of which the wall of the mound was made are scattered at the base of the bluff. It would thus appear that the mound-builders lived around Issik Kul before the 30-foot beach line was abandoned by the lake.

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The occurrence of ruins beneath the lake waters was noted by Semenof in his journey in 1857. He was told of the remains of an old city under the lake, about half a verst from its northeast shore (1858, 360). Other travelers make similar reports, but nothing definite seems to be known. We were shown a square brick, about 10 inches on a side and 2 inches thick, that was said to have been dredged from these ruins. Mr. Huntington was told, on the good authority of General Korolkof, at Przhevalsk, that the ruins can now be seen on the lake bottom "in

Fig. 80.—A Carved Stone on the plain at the east end of Issik Kul, looking south.

water of considerable depth." There is no direct evidence to determine the date of the period of low water during which the houses now submerged were built; but Mr. Huntington points out that brick houses are presumably of more modern construction than cobblestone walls, and hence that the submerged houses were probably built during a low-water stand, after the high-water stand recorded in the 30-foot beach. The fact that the bricks can be seen on the lake bottom, not yet buried by silts, points to the same conclusion. The lake ought to be carefully sounded and dredged.

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CONCLUSION.

Many problems that are touched upon in this and the following reports deserve much more study than we have been able to give them thus far. Some of them bear directly upon the objects of our expedition; some are of general interest. Of the first class, the oscillations of the Caspian stand preëminent, and the desert depression, known as the Ungus, seems to be the most important district for next examination in this connection. In view of what is known of climatic variations during Quaternary time in other parts of the world, it is hardly possible that the Aralo-Caspian history is of only one expansion; and whatever complications it experienced would probably have left their record on the bluffs and slopes that border this desert depression. At the same time, the confirmation of our conclusions regarding the complexity of the Glacial period by further study of moraines and terraces, especially in the Alai ranges and the Pamir, is much to be desired. Then would come the connection of these two classes of unlike records—lacustrine and glacial—by any means that can be devised, along the mountains on the south or across the desert plains, thus gaining a correlation of the events of Quaternary time in the three physiographic provinces of the western Asiatic region and bringing the archeological remains of the plains into their place on the geological time-scale. Of subordinate value, but by no means unimportant, are the problems connected with the deposits of loess. Those south of Jizak deserve first attention.

Issik Kul is a problem by itself. Geology, physiography, and archeology are there combined in the most inviting manner. A long season in that field alone would be highly productive.

An outstanding problem of importance in its bearing on theoretical geology is found in the structure of the Tian Shan ranges. For this purpose the region could be entered to advantage from the north, and a deliberate study made of the peneplains and fault-block mountain ranges over which our party had to pass so rapidly. Few finer fields are open to the investigator.

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The following list of authors and articles makes no attempt to include all that has been written on Western Asia, but only to present those essays that bear most directly on the problems here discussed. The list is, however, unfortunately incomplete in many respects, inasmuch as the libraries accessible during the preparation of this report have been found deficient in regard to Russian explorations in Asia.

The names of Russian authors cited are turned into English phonetic spelling. The sch, tsch, and dsch of the German transliteration and the soft ch of the French are avoided, unless the article cited is in German or French; in that case the published transliteration is given in parentheses. The terminal tch, which is so generally used, is continued instead of the English hard ch. English translations of Russian titles of articles are inclosed in parentheses.

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Physiographic Observations Between the Syr Darya and Lake Kara Kul, on the Pamir, in 1903.

By Raphael W. Pumpelly.

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DESCRIPTION OF THE ROUTE.

Fergana forms the southeastern extension of West Turkestan. Its southern half, the Pamir, is, so to speak, the corner stone between the Russian and English possessions and between China and Afghanistan. The district of Fergana is naturally divided into five parts. On the south is the high plateau of the Pamir, with its gray desert steppes and snow-clad mountain ranges, its dark lakes and

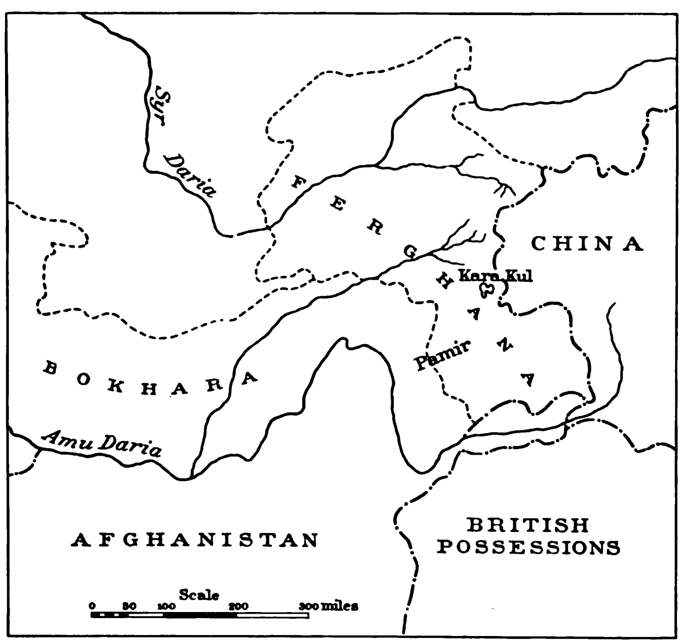

Fig. 81.—A Skeleton Map of Fergana.

its few long, crooked streams. Bordering this plateau on the north is the long, white, east-west range of the Trans-Alai, with the great snow fields and snake-like glaciers of its northern flank, abruptly ending in the broad green lawn of the Alai Valley. Separating this lawn from the lowland plains of the north is the complex mass of the Alai Mountains, with its irregular snow crest running east and west, but its northern flank broken into many flat-topped masses. Lastly are seen the

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broad gray steppes of the northern half of Fergana, patched with a multitude of green oases, and sharply bounded on the south by the high, grassy slopes of the Alai range foothills. (See figs. 81 and 82.)

It had been planned that the reconnaissance trip should extend to Andizhan, at the end of the Trans-Caspian railroad. On June 23 we had left Tashkent, and on the 24th our car was running along the low region just south of the Syr Darya. There the oases were more frequent than farther west, and the landscape correspondingly cheerful. We crossed long stretches of barren, gravelly steppes, but were rarely out of sight of picturesque villages and patches of cultivated land, with their hedges of tall, shaft-like poplars against the sky.

It was decided to follow the ancient Taldic route as far as the core of the Alai range. We drove from Andizhan to Osh, the great starting point for caravans.

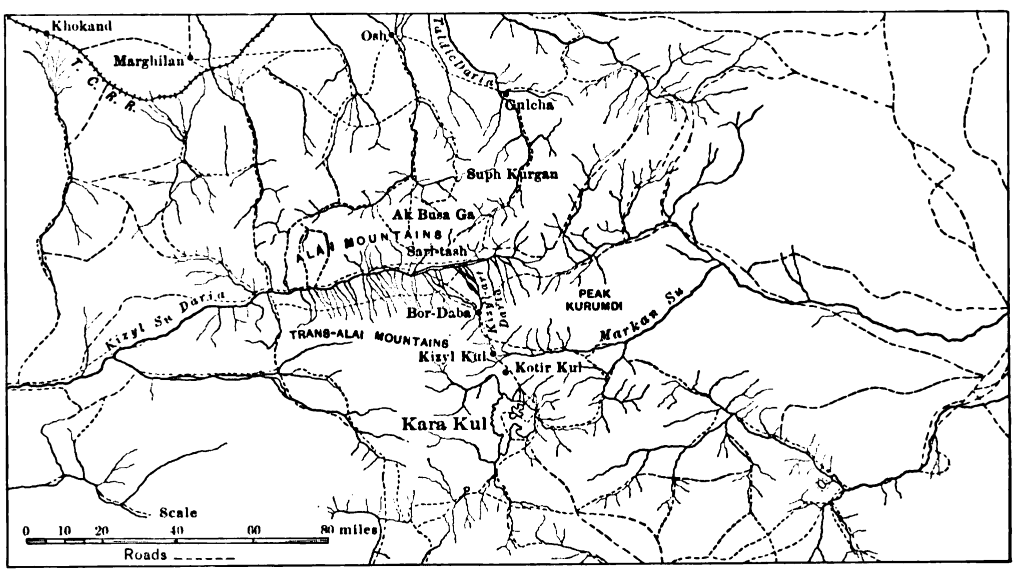

Fig. 82.—Map of the Pamir, taken from Sven Hedin's Map.

There it was decided to go to Lake Kara Kul, on the Pamir. Two or three days were taken in making the preparations necessary for so extended an expedition, and it was the last day of June when our caravan left Osh for the mountains. We were to follow the old route up to the Taldic pass across the Alai Valley, up a stream to Kizil-Art pass, and thence to Kara Kul.

From the lower plains of Fergana (1,200 feet) to the foothills of the Alai range (4,000 feet), there is a gradual ascent and normal progressive increase of natural vegetation. Even at Osh we had begun to miss the striking desert conditions of the regions below, and at Gulcha the hills were covered with rich green grass, small streams rising among them. From Takka pass there was a splendid view over a broad gulf of these green hills and valleys, ending in the snow-clad peaks of the Alai, 40 miles to the south. There were kibitkas (Kirghiz felt tents) here and there on the slopes, and by them herds and flocks. The Kirghiz winter in

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these lowland valleys and in the spring they sow great fields of grain, leaving men to tend and irrigate them, and on their return from the summer pastures reap their crops. We camped over night at Gulcha, July 1–2. It rained heavily during the night, and the temperature stood at 54.5° F. at 6 a. m.

Leaving Gulcha, we fell in with a long Kirghiz caravan, on its way to the Alai Valley. It was very gay, yet full of pomp and dignity. Each group was headed

Fig. 83.—A Kirghiz Caravan on its way to the Alai Valley.

by the men driving their herds of cattle, horses, and camels, and their flocks of goats and sheep. Behind them came the women, all attired in their best, some in cloth of gold or silver, and ornamented with jewels. They rode in single file, each on a stallion draped with brilliant embroideries, and each leading two or more camels laden with the household goods, and draped over all with carpets of rich design. Such is the wealth drawn from the fertile pastures of Fergana. (See fig. 83.)

All day we continued winding up the valley, frequently fording the stream. There were at first no trees on the hillsides, but frequent groups of picturesque mountain willows and crooked poplars along the edge of the stream (fig. 84). No wild animals were seen; only a few vultures and flocks of pigeons very like our domesticated variety. Toward the end of the day we entered a granite gorge and rode a long time above the roaring torrent. Occasional glimpses of the slopes high up above the canyon showed thin forests of bushy cedar trees.

Fig. 84.—A Poplar Tree in the Taldic Valley.

Our camp the night of July 2–3 was at Suph Kurgan, where the trail forks, one branch leading over the Taldic pass, the other over the Terek Davan. During the summer there is but little snow on the Taldic, and that route is used when the Terek is impassable, owing to high flood. In winter the streams are shrunken and the Terek is the best route. That night it rained heavily. Temperature at 6 a. m., 40° F.

The next day we were still winding up the valley, sometimes along the stream-bed, sometimes along the top of the canyon. A new variety of foreground

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was given at every turn, and the ever-changing clouds gave new and more charming effects on the high peaks in the distance. We were in the Alai range, for glistening snow peaks appeared above the green hills on both sides, while in front there rose a chain of gigantic snow-clad pyramids, partially hidden by the clouds that streamed from their summits.

From Suph Kurgan to the Taldic pass the mountain sides are dotted with scrubby cedar trees, which grow smaller, more crooked, and more picturesque as the altitude increases, and below the pass exist as mere stunted spreading bushes hugging the slopes. When about 15 versts below Ak-Busa-Ga we heard, for the first time, the shrill whistle of the marmot, and from there to the border of the Pamir desert this was the characteristic wild animal. At a little after 3 in the afternoon our caravan came to where the valley opened out on the broad, grass-

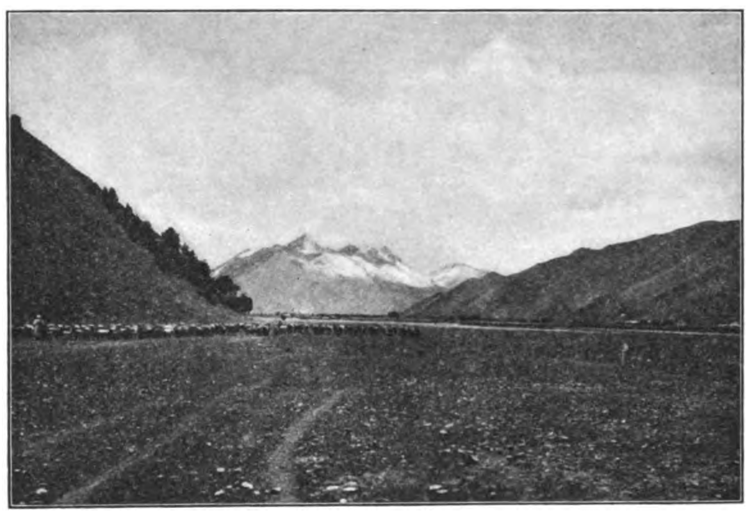

Fig. 85.—Looking up the Taldic Valley at the Entrance to the Broad Plain of Ak-Busa-Ga.

covered flood-plain of Ak-Busa-Ga (figs. 85 and 86). There we camped over night. At 5.30 p. m. the temperature was 40° F. At 9.30 p. m. it had fallen to 32° F., and it was snowing heavily.

The next day, July 4, the caravan made an early start, for we were to cross the Taldic. It was a clear, frosty morning, with the white snow peaks above glistening in the sun. In about a verst the broad valley changed to a torrent canyon. Beyond it opened out again in grassy slopes, where many Kirghiz families had pitched their kibitkas (fig. 88). Flocks of sheep and goats, herds of cattle and horses, and many wandering groups of two-humped camels were grazing by the trail. Above were high peaks, some of craggy rocks and others more heavily covered with great sliding banks of snow. Delicate, steaming clouds trailed from the summits, and others appeared over the ridges, rolling up from the opposite side. One cloud swept down the valley for a moment, its refreshing moisture blowing against our faces. Ahead of us we could see where the trail makes its many zigzags before

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reaching the pass, and our horses were soon struggling up the steep slope past countless skeletons of unlucky pack animals that had fallen in the effort. The clouds gathered so rapidly that the pass, the elevation of which is 11,600 feet, was in a sea of mist when the summit was reached. On the southern side the snow

Fig. 86.—Ak-Busa-Ga.

was much deeper and the drifts so heavy that our guides had difficulty in remaining on the trail, but a short descent led us below the snow-line and down to Sari Tash, on the edge of the Great Alai Valley. There we halted for a day to rest the horses.

The Alai Valley, as it is first seen (fig. 87), looking across from the foothills at Sari Tash, is one vast expanse of smooth green lawn, abruptly bordered on the south by a magnificent wall of snow-clad mountains, and extending east and west nearly as far as the eye can reach. It is 75 miles long, averages 15 miles in width, lies

Fig. 87.—Looking across the Alai Valley to the Trans-Alai Mountains. Taken from a peak north of Sari Tash.

10,000 feet above the sea, and is walled in by the Alai and Trans-Alai mountains, two of the lofty ranges of the world. For nine months of the year snow several feet thick lies upon it. Then it is void of human habitation, and the wolves hunt undisputedly the wild sheep and ibex. By the beginning of July this snow has melted. Like magic the grass turns green, the poppies and buttercups bloom, the marmots come out to sun themselves and call in shrill notes to one another, and

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the Kirghiz, with their vast herds and flocks, are pouring over the passes on to the rich pasture. There are no trees, no bushes, nothing but a world of grass sprinkled with beautiful wild flowers.

It is said that Mount Kaufmann is rarely free from its canopy of clouds, but we had a fine view of it during our first stay in the valley. From over the spur at Sari Tash it came in sight, a long mass of ridges and amphitheaters rising in groups one above the other, and above them great snow-fields mantling the cliffs. Here and there we could see a glacier starting in a group of cirques below the top, and pouring forth its snake-like river of ice to the very edge of the plain. It was a grand sight, this gigantic complex of ridges and snow-banks rising to the top

Fig. 88.—The Kirghiz in the Alai Valley.

peak of all, an ice-capped pyramid so high that it creates the clouds and directs the storms. For a long time we saw the clouds, blowing up from the northwest, split on Mount Kaufmann, part turning back to the northeast, collecting on the Alai range behind us, while the rest formed a horizontal stratum floating just below the high peaks of Mount Kaufmann and disappearing southwest over the Pamir.

By the end of the afternoon it began to thunder and hail on our side of the valley, but during the whole storm the sun shone brightly on the Trans-Alai Mountains, and we could see them sparkling through the hail. Temperature at 7 p. m., 39° F.

On July 6 our caravan crossed to Bor Daba, on the south side of the Alai Valley, and camped there over night. When we arose at 5 a. m. on the 7th it was 35° F., and the stream was sheeted over with ice. The sky was clear, the mountains

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free from clouds, and the rose tints of sunrise were fading away from the snow-fields of Mount Kaufmann. There was a long journey before us over Kizil-Art pass to Kara Kul.

The trail follows along the edge of the Kizil-Art darya to the pass. The snow had melted to its perpetual line, leaving a few masses of white forking down into the ravines. The landscape was everywhere characterized by an extraordinary richness of coloring, especially the deep red of bare gypsum rocks forking into the soft green of grassy slopes, and above them a deep-blue sky, broken here and there by silvery clouds. Always cutting our view in twain was the deep valley of the ever-roaring torrent along which we rode. In places this valley narrowed to a canyon, and the trail led us above, where we looked down into depths from which the sound of roaring water could barely reach us.

When about 12 versts from Bor Daba we sighted a flock of takkan (ibex) grazing on the thin grass of a side fan, and a little farther along, on a distant ridge, five Marco Polo sheep (*Ovis poli*), standing one behind the other, and clearly outlined against the sky. Farther up the valley the green slopes gave way to barren red, streaked here and there with drifts of snow. On all sides rose massive spurs of deep red, sharply carved into parallel ravines running straight down the slopes and crested with dazzling snow outlined above against a sky of turquoise blue.

At about 11 a. m. the caravan reached Kizil-Art pass, 13,721 feet above sea level (by recent Russian leveling), where we stopped to rest the animals. They had carried us 20 versts over a rough trail and up 3,000 feet in four hours, and even the strongest were panting hard from the rarefied atmosphere. Looking back we could see the deep valley out of which we had climbed. Its dark bottom seemed to reach a depth even greater in perspective than the height of the mountain above us.

Here I left the caravan, and while it went on down to Kara Kul I climbed on foot the first peak to the west. This was an excellent position from which to compare the forms established by erosion on the north and south sides of the Trans-Alai crest. On the north the slopes began by sinking into broad amphitheaters, and beyond fell rapidly into deep valleys and dark ravines, separated by high, irregular spurs of soft gypsum and sandstone. On the south, the Pamir side, there seemed to be no great descent; long, straight spurs extended transversely from the main mass, and between them lay flat plains of gravel, starting in the cirques just below the crest and inclining gently toward the south.

We had expected to find the region about Kara Kul like the Alai Valley, green with grass; in reality the two could hardly be more different. From the high slopes of the pass, wet from melting snow, the trail led to a dry steppe of gravel extending nearly as far as the eye could reach. In a few versts the stream wandering on its surface dwindled away, leaving a dry bed. One could perceive nothing living. Here and there projected piles of bowlders hollowed, pitted, and polished by the sand. All along the trail were the bleached bones and skeletons of pack animals that had probably died under loads.

After a seemingly interminable ride along stony steppes, past barren talus-shrouded mountains, and over large, irregular piles of moraine, the desert basin of

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Great Kara Kul came in view (fig. 89), and we reached a point where the trail begins a rapid descent into the basin and a corner of the lake appeared. Far and wide stretched the same monotonous, dazzling gray, unbroken by any sign of life or vegetation. A little way to the right there rose a talus-shrouded mass of rock, and in front were crooked, hollowed bowlders with sharp shadows, while in the distance, far below, was the black-blue sheet of Kara Kul reposing calm and silent, with its deep color contrasting strangely with the monotonous, dazzling gray of the gulf-like desert in which it rested. All around this lifeless waste there rose a continuous chain of snow-clad mountains with their sharp peaks and ridges outlined against a clear blue sky. It seemed like a lake that had lived and died long ago, and now reposed in its desert grave under heaven's ethereal blue and

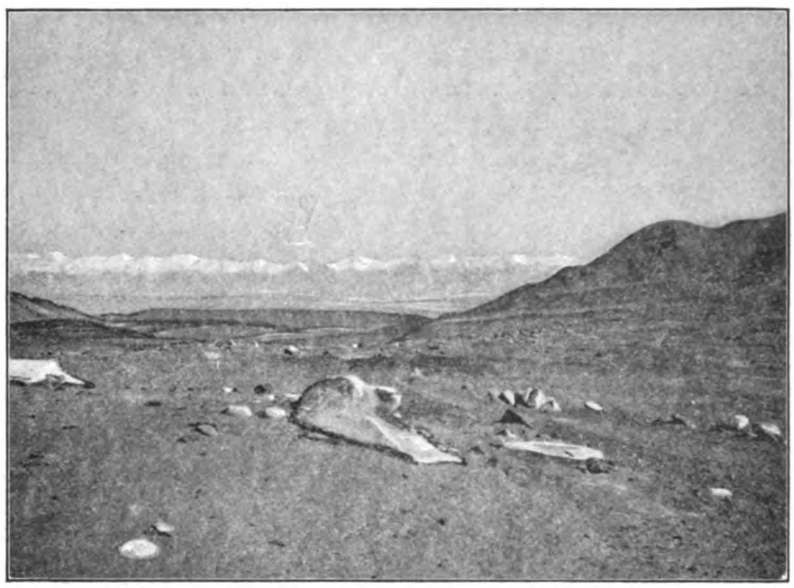

Fig. 89.—Looking down the Kara Kul from Uy Bulak pass.

among the guardian white mountains, ever watching, ever keeping the unbroken silence of space.

From time immemorial this barren desert has been called The Roof of The World, and the name seemed appropriate, for the mountain borders shed their waters to lands of diverse and powerful nations. There, on that eastern crest, was the boundary of China, to the south were the British, to the west the Afghans, and here it was Russian land.

The caravan had camped on the northeastern shore of Kara Kul. There we remained over the next day to study the desert.

Imagine a ground of split and polished stones which stretches away in a seemingly endless waste, the little relief and variety of projecting rock masses near by fading beyond to dreary flatness. That is the Kara Kul desert. There are no trees, no bushes—in fact, no familiar forms by which one's puzzled eye can scale the

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distance. In the distance, a silvery sheet of water reflects and dances on the plain. For a moment there seem to be men and animals moving on the shore, but then the lake slides away into space, the men and animals disappear, and there, instead, is the mocking plain.

A far-off dust column appears on the horizon. At first it seems motionless, but soon there is a visible movement as it approaches, growing denser and taller, and turning, it rapidly crosses the steppe with an irregular motion. It may fade away in the distance; it may disappear suddenly in some unexpected place. These dust storms tell a story. During the warm hours of the day there is nearly always one, often there are two or more in sight. The desert surface here shows a

Fig. 90.—Deflated bowlder of granite.

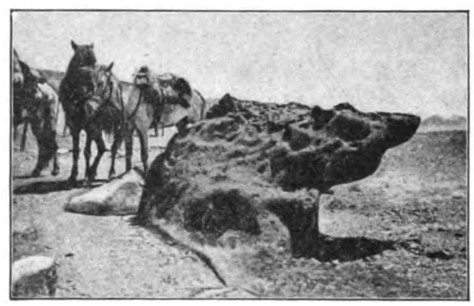

Fig. 91.—Deflated bowlder of granite, hollowed side facing east. Taken at 10.30 a. m.

Fig. 92.—A talus-shrouded mass of crystalline limestone.

Fig. 93.—A glacial bowlder of crystalline limestone cracking from the changes of temperature.

remarkable lack of loose, fine material. But the inclosing mountains are largely made up of rotten gypsum and limestone with earthy surface, from which great quantities of fine stuff are brought down during cloudbursts and left on the fans, always to be carried away by the winds and deposited elsewhere; probably, according to Richthofen's theory, as loess in some neighboring zone of vegetation.

Kara Kul is a lake of bitter salt water. Its sloping shores are white with salt accumulated into low ridges where the brine from each wave-wetting has dried out after the recession. Behind some of these natural dams there are lagoons of brine collected from the overflow of larger waves, and thus, in places, extending the salt belt 100 feet or more from the shore. I could find no shells and saw no fishes.

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There was much dead tape-like grass on the shore, but as there seemed to be none fresh, it may have been washed out of the gray clays deposited at a higher level, which are well matted with a similar grass (p. 139).

Most of the streams rising in the melting snows of the inclosing mountains disappear in broad, stony fans extending from their base. The whole zone bordering the mountains is thus characterized by a topography of interlocking fans, while the foot-hill rock-masses are largely buried in their own talus. For this reason the desert surface consists, for the most part, of bare steppes of small angular or sand-polished stones. In places there are flying sands, and certain areas bordering the mountains are covered with moraine with a surface somewhat modified by the deflation which naturally occurs in this atmosphere of 13,000 feet altitude, where there is so marked a fluctuation of temperature from night to day and between shade and sun. While we were there it went below freezing at night, but during the day our faces were blistered by the dazzling sunlight. Figures 90 to 94 give an idea of the striking forms of desert weathering.

Fig. 94.—Common type of weathered bowlders. The light fragments strewn about it are parts of the former mass.

Except for a few deeply-rooted flowers in bloom and rare clumps of grass on the dry beds of streams, the Kara Kul desert is void of vegetation. No man lives on it, and those who cross it with their caravans have difficulty in finding feed for their animals. The only wild animals seen on the plains were a rabbit, a few ducks and gulls about the lake, and some vultures devouring the carcass of a camel on the trail.

On the slopes of the bordering mountains there was more water and more life. A few marmots burrowed where the grass was thickest, but the characteristic beast was the Marco Polo sheep (*Ovis poli*), the largest of all wild sheep. Of them we saw two or three flocks, one of which numbered over fifty sheep.

After spending four days on the Pamir we recrossed Kizil-Art pass, and returning by our outward route, reached Osh again on July 17.

DETAILED OBSERVATIONS.

From the lowland plains of Fergana we had studied the Alai Mountains through our field-glasses, and recognized in them glacial forms of erosion, such as amphitheaters inclosed by sharp crescent ridges, and above them groups of cirques, and we thought we saw glaciers beneath the higher masses. Unfortunately, the old caravan route led us over a lower part of the range and did not bring us in contact with any records of glacial action until we reached the Alai Valley. It can, however, be stated that the famous Zerafshan glacier lies in a high longitudinal valley of the western extension of the Alai range, and that there are several other glaciers in the high mountains around it. Nowhere did we find any indication of a former regional ice-cap. Glacial remains with which we actually came in contact were confined to the Alai Valley, Trans-Alai Mountains, and Pamir.

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IN THE ALAI VALLEY.

With our field-glasses we had seen from Sari Tash the great glacier on Mount Kaufmann and large grass-covered moraines extending nearly across the plain from all the principal valleys along the Trans-Alai range.

The morainal masses extending transversely across the Alai Valley were each made up of at least two moraines belonging to two distinct, long-separated epochs. The old moraines are broad, smoothed-off lobes made up of large and small semiangular bowlders, usually of rather hard red limestone and mixed with finer till. Their surfaces sloped gently to the plain on each side, and no undrained depressions were seen. The whole was coated with loess usually 2 to 3 feet in thickness. The identification of this loess was at first a little doubtful, owing to the presence of thousands of marmot holes, most of which reached into the till below, thus bringing a quantity of small stones to the surface, but it was well established in exposures on stream cuts. The streams now flowing from the side valleys have

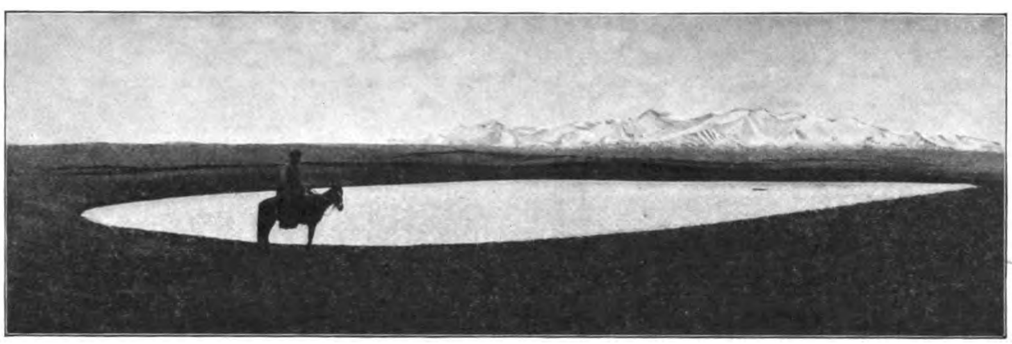

Fig. 95.—A Kettle-hole Lake on the Moraine extending from the Kurumdi Mass transversely into the Alai Valley. The Trans-Alai Mountains rising into the clouds.

in some cases cut broad, flat-bottomed channels in these moraines and in other cases are deflected to one side, cutting a bluff.

Lying on the middle of these old smoothed-off moraines or in the channels there are long, narrower moraines of the second epoch. In topography they are made up of irregular chains of steep mounds with many large blocks on the surface and frequent kettle-hole lakes (fig. 95), and near their origins are cut by sharp V-shaped torrent valleys. They seem to be made up of essentially the same material as the old moraines. They also have loess on their surfaces and are grown over with grass, but, owing to their exceedingly irregular topography, their loess coat varies in thickness even more than that on the old moraines. It did not seem practicable with the little time I had to attempt to get an average measurement, but there appeared to be much more loess on the old moraines than on the new ones. Of course this might be partly due to the more exposed position of the latter. There seemed to be a third series of moraines extending a short distance from the valley mouths, and in cases overriding those of the second epoch (fig. 96). Professor Pumpelly considered them to be of a third epoch.

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Many of the cross-valleys flowing into the Alai Valley from the Trans-Alai range had the form of rounded troughs cut down in the middle by narrower troughs, as in fig. 97. The erosion forms observed low down on the flank of the Trans-Alai, bordering the Alai Valley, are cut mainly in rather soft rocks, especially in partially decomposed gypsiferous series with occasional harder beds of red sandstone.

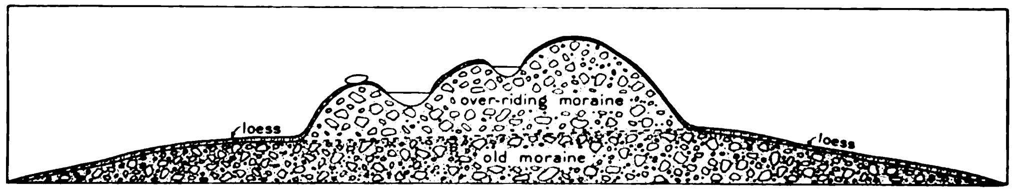

Fig. 96.—Section of Alai Valley Transverse Moraine.

Along the southern border of the Alai Valley there project rather flat-topped, narrow spurs between the valleys coming down from the Trans-Alai. These spurs do not descend to the plains on a gradual slope, but are rather abruptly cut off by one or more steep slopes which may be called terminal facets. These facets appeared to be aligned and to fall into parallel planes or escarpments truncating the base of the range. For convenience let us call the plains of this truncation the Trans-Alai escarpments. The apparent level of the old broad-trough bottoms lies high up on the escarpment. The bottoms of the new lower troughs lie some 50 feet above the plains where they cut the escarpment and emerge into the Alai Valley. In other words, the later troughs cut the escarpment.

Professor Pumpelly discovered that on the slope of the western side of the Kizil-Art Valley, where it leaves the mountains and empties into the Alai Valley, there are high terraces of the older moraines, which bend around to the west at the

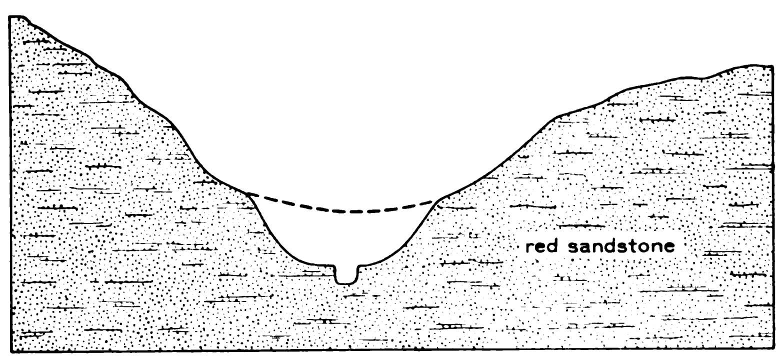

Fig. 97.—Ideal section of a "twice-troughed" valley.

mouth of the valley and form a portion of the spurs mentioned above. The new moraine of the Kizil-Art Valley lies as a long island directly in the middle of the flood plain and splitting the stream (fig. 98). It is partially buried by the stream gravels, but its topography is notably fresh, many little kettle-hole lakes occurring on it nearly to the level of the flood plain.

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It is thus seen that, whatever these Alai Valley escarpments are, and however they were produced, their formation took place during the time of the deposition of the new moraines observed. It is also clear, since they support the bottoms of the old broad-trough valleys and are cut by the new, narrower troughs, that their formation must have taken place between the establishment of the old and of the new trough floors. This places the large, old, worn-down moraines as contemporary with the former broad troughs and the new, fresh, narrower moraines as contemporary with the narrower or present trough bottoms.

The Trans-Alai range is largely carved into cirques. We had an excellent opportunity to study those low down on the northern flank of the range. They may be divided into two classes—the very large and the small cirques. These cirques empty either in groups into a trunk trough or open directly into the Alai Valley. The large cirques emptying directly into the Alai Valley come down on a normal slope to the plain, breaking through the escarpments in which their sections form double curves similar to the sections of the twice-troughed valleys. In and in front of them lie piles of moraine with fresh topography.

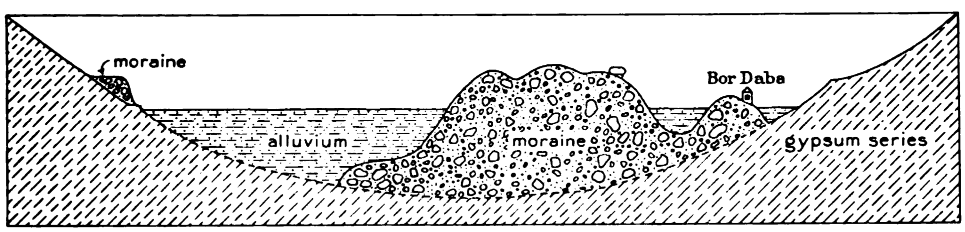

Fig. 98.—Section across Kizil-Art Valley at Bor Daba, looking north.

The bottoms of small cirques opening directly into the Alai Valley lie high up on the escarpments, and the moraines contained by them are worn down to smooth, low masses. There is no double curve in their cross-section. The whole depression with its moraine is, in cases, much dissected.

The absence of the fresh moraines in the small cirques, and the absence of the secondary depression through the escarpments, is good evidence that these small cirques were carved largely during the epoch or epochs predating the escarpments. From this we may reason that only the large cirques of those in question were, to any great extent, glacially active during the epoch following the formation of the escarpment. It seems probable that this difference was because their upper slopes begin several thousand feet above those of the small cirques, and thus accumulated ice when the line of perpetual snow was above the smaller ones. A careful study of cirques at the critical levels might determine the perpetual snow-line of the later glacial epoch.

Of existing glaciers we had, from a short distance, a good view of three in the respective valleys back of the long moraines described. Each appeared to lie on a moraine. Directly in front of the ice this moraine floor was cut by a small rounded

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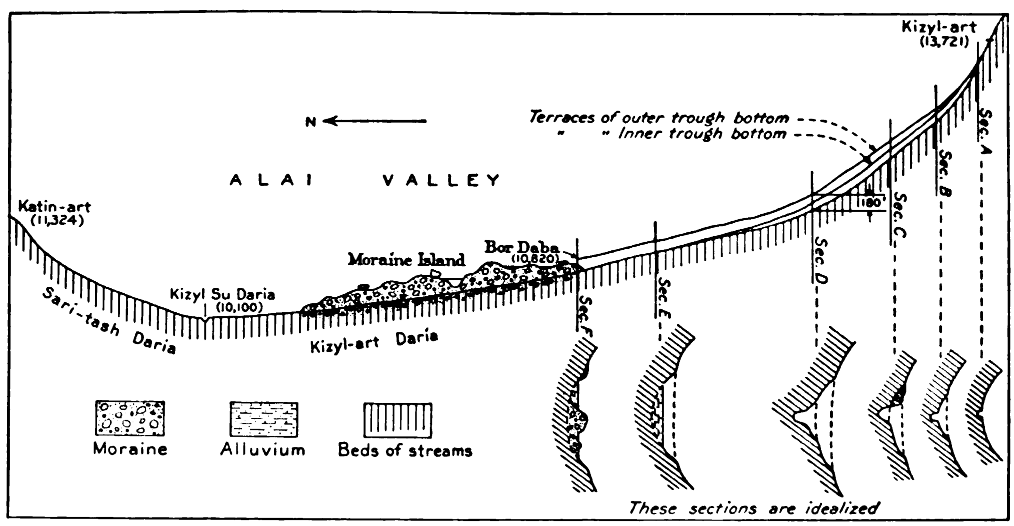
trough, into which the foremost part of the glacier projected. A few hundred feet in front there lay fresh piles of till dropped on the moraine floor and in the small trough. These last moraines were in no case nearer than several hundred feet to to the glacier, which was in all cases terminated by glistening walls of ice. All the ice flows were disproportionately narrow in comparison to the width of the troughs containing them. We also saw, from a greater distance, many smaller glaciers on the Trans-Alai. None of those examined reached lower than about 13,000 feet.

The largest glacier was that coming down from the middle of the Mount Kaufmann mass. The glacier I did not visit, but had a splendid view of it from high up on a moraine some 2 miles in front. It draws its ice from a group of several large amphitheaters, some of which collect ice sliding over their walls from smaller cirques above. Just east of this there is another glacier nearly as large as this and which evidently formed, at one time, a branch of the great one. Both glaciers have



Scale: 1 inch horizontal = 4 versts; 1 inch vertical = 1,000 feet.

Fig. 99.—Profile to show moraines and terraces of the Kizil-Art Valley.

now retreated back of the point of former union. Perhaps the two most striking features of the glacier were, first, the lack of visible débris on its clean white ice flow; second the remarkably free character of its sparkling ice front, the entire depth and breadth of which could be seen by an observer a mile or two in front and several hundred feet below.

IN THE KIZIL-ART VALLEY.

The observations in this valley are best stated in the order beginning with the source of the stream. The valley is, for the most part, carved in highly tilted, soft, partially decomposed red gypsiferous rocks, alternating with medium hard red sandstones and blue-gray slates. No granite or other hard rocks were seen except in

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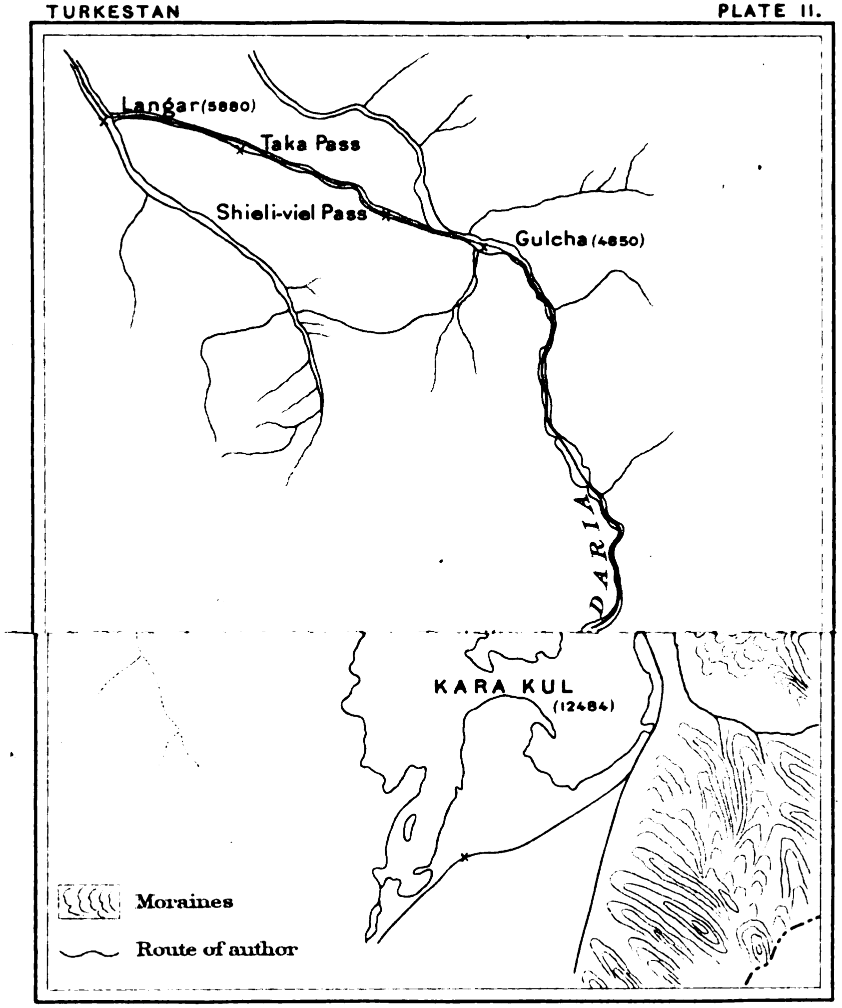
TURKESTAN PLATE II.



MAP SHOWING ROUTE FROM LANGAR TO KARA KUL

Taken from Russian map

Scale

0 10 20 30 versts

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the gravels of branch streams. Kizil-Art pass lies on the middle of a sagging ridge between two diametrically opposite back-to-back cirques. The northern one heads the Kizil-Art Valley, which assumes, below the cirque, the twice-troughed-valley form seen in the Alai Valley tributaries. The bench or change of curve in this valley is but imperfectly preserved, but is occasionally well defined and can be traced to within a few versts of Bor Daba (fig. 99).

The stream rising in the heading cirque of this valley has cut back a gully to within 50 feet of the crest at Kizil-Art pass. This gully is about 10 feet deep and 10 feet wide at the pass, gradually widens downstream, and increases in depth for about 10 versts, where the bottom of the inner trough is about 100 feet above the stream. Here the pitch of the stream suddenly decreases, as a few versts farther down the bottom of the inner trough sinks under the flood plain.

MORAINES.

A few versts below Kizil-Art pass we begin to find portions of moraine left on the inner trough bottom to one side or the other and above the stream. Portions of this moraine occur at rare intervals all the way down to Bor Daba, where the Kizil-Art darya emerges into the Alai Valley. Here begins a moraine island extending over 10 miles transversely into the Alai Valley. It is not surrounded by water except in flood time, when a distributary of the Kizil-Art darya crosses the flood plain to the west and joins the neighboring stream from the Mount Kaufmann mass. The position of this moraine and the precipitous manner in which its unaltered slopes pitch under the stream gravels give it the unmistakable appearance of the mere top of a deeply buried mass beneath.

Thus the stream waste is filling back into the lower part of the Kizil-Art Valley, having partially buried the fresh moraine lying in its mouth and covered the inner trough bottom for some 7 versts upstream, so that, although the base is being raised by filling back of waste, the upper half of the stream has not yet recovered from some previous lowering of base and is still cutting down on rock bottom.

The only tributary amphitheater which I had occasion to examine in this valley was that opposite Bor Daba, 4 versts to the west. It contains grass-covered moraine of fresh topography, with kettle-hole lakes. Its bottom seems to be buried beneath the flood plain where it opens into the Kizil-Art or trunk valley. There appeared to be a mass of ice hanging on the slope some 2,000 feet above.

Two of the branch streams of the Kizil-Art darya were seen to head in glaciers. These branch streams and their valleys appeared to join conformably the Kizil-Art darya and its valley.

The occurrence of moraine in the inner trough of the Kizil-Art Valley and the occurrence of the partially-buried moraine island where the inner trough bottom lies buried at the mouth of the stream show that the glacial occupation of the inner trough was probably contemporary with the deposition of the fresh moraine island.

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ON THE PAMIR.

The region from Kizil-Art pass south through the Great Kara Kul basin is a splendid field for the study of glacial geology. All along the trail one meets with records of past glacial activity. The high mountain sides are, at frequent intervals, sharply carved into large amphitheaters and small cirques, while the plains are dotted with piles of till. From our camp at Kara Kul we could see large moraines spread in front of the principal valleys around the basin, and with our field-glasses we clearly saw the glaciers as they exist to-day, shriveled up, hanging free-ended in their great cirques below the crest.

ANCIENT SHORELINES AND SEDIMENTS OF THE GREAT KARA KUL BASIN.

The glacial geology of the Kara Kul region was found to be so intimately associated with the lacustrine that it has seemed best to begin with a careful description of the ancient shorelines and sediments observed in the Great Kara Kul basin. These shorelines resolve themselves into two classes—those below the 150-foot level and those above the 150-foot level. The first class is in excellent preservation; the second class is largely obliterated.

Fig. 100.—The Northern Peninsula of Kara Kul. The white of the lower portion of the right half of the illustration is salt, probably $CaSO_4$.

The best examples of these shores were seen on the northern peninsula (fig, 100). There are three especially well marked levels at about 60 feet, 120 feet, and 150 feet, respectively, above the present lake surface. Where cut in steep rock-slopes they have the form of narrow, inclining terraces. When followed around to more gradually sloping land they are found to be broader, gently sloping, and covered with deflating fragments of slate. The slopes are marked by miniature bands of briefer action, especially from the 60-foot mark to the present shore. There they occur as delicate contours at remarkably regular intervals of about 6 or 7 feet drop, as though there had taken place a gradual intermittent recession by equal decrements. The remarkable lack of after-erosion and the general freshness of the shorelines can not be too much emphasized.

The second class, or older shores, lie at about 200 feet and 320 feet. On the peninsula they are seen as rounded-off terraces encircling and breaking the slope

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of the higher portions, but entirely worn down in some places. From a distance they were seen to cut the steep slopes coming down to the lake on the west.

From the eastern shore of Lake Kara Kul the land rises with a slope of 1 foot or less in 100, and holds this till it meets the fans from the bordering mountains. whence it rises more and more rapidly and bends up sharply at the mountain's base

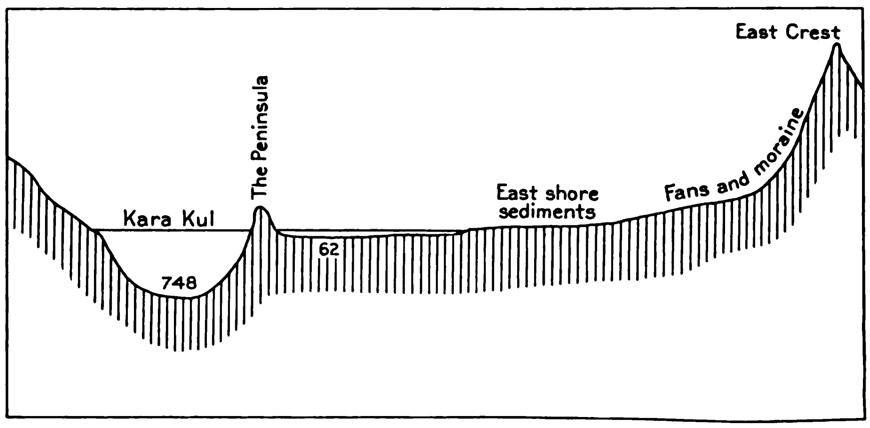

Fig. 101.—An east-west section of the Kara Kul Basin.

(fig. 101). The surface of large areas between the lake and these eastern fans consists of nude, finely stratified, blue-gray clays. A considerable depth of these sediments is well matted with tape-like grass lying flat and varying in width from ⅓ mm. to 3 mm. The roots are about ⅓ mm. in diameter, and spring from the bottom of the wide blade, the fine leaves sprouting just above them. The leaves are light brown and although very thin will bear a tension of one-half ounce and are very pliable. The clays are, as a whole, of the finest flour, but contain minute flakes of

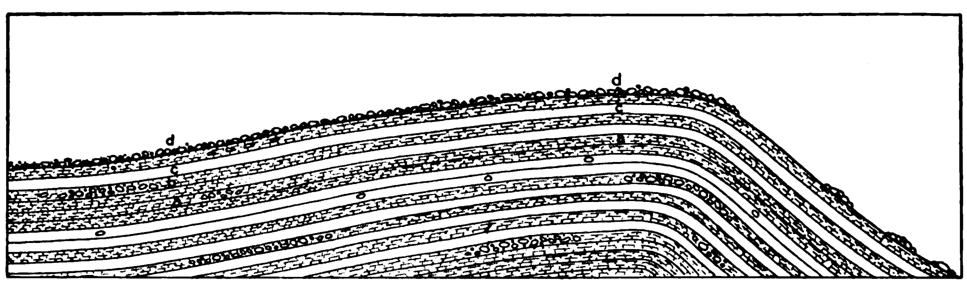

Fig. 102.—Section of Kara Kul sediments exposed in Hillock Bluff about 100 feet above Lake.

mica and here and there a layer with small angular pebbles. The lamination is very perfect; it is easy to split off pieces a foot in area and only half an inch thick, although the same piece can be crumbled between the fingers.

A large proportion of the Kara Kul sediments lie horizontal, but there are also areas of very much disturbed stratification where the surface is broken into irregularly disturbed mounds or little hillocks, among which deflation and wind carving have formed miniature bluffs exposing the structure. The layers seen in

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these bluffs showed a peculiar distortion, being, in most cases, bent into an arch, to which the mound surface is concentric and conformable in vertical section (fig. 102).

While wandering among these hillocks we suddenly came upon an elliptical lake about 1,000 feet by 700 feet, with its long axis pointing directly toward Kara Kul. Its surface was 10 to 30 feet below the level of the plain, the walls everywhere extending vertically down into clear, deep water. At first there seemed to be no reason for its existence, there being no hydrographic relation with the surrounding topography. Professor Pumpelly suggested that "lobes of ice had been buried by the sediments; the slow melting had deprived the sediments of their support, and the roof tumbled in, probably recently, leaving the deep pool." Perhaps a more gradual sinking of the surface, occurring as the buried ice melted, is what has given these areas their hillock topography and distorted stratification. Professor Davis suggested that the solution of the underlying salt deposits could have resulted in the same conditions.

Some versts north of this region there is a moraine sloping under the Kara Kul sediments; this could have pushed its way under water, weighing down the glacial ice that carried it, while the lake depositions covered it with clay sediments. In this way large masses of ice could be buried beneath the sediments.

Fig. 103.—Moraine of the Kara Kul Basin, looking northwest on the Older Moraine. An overriding Moraine seen in the distance on the right.

OBSERVATIONS ON THE GLACIAL GEOLOGY OF THE GREAT KARA KUL BASIN.

The data obtained on the glacial geology of this basin conform very well with the glacial history in the Alai Valley. Here, also, we find evidence of two long-separated glacial epochs and indefinite indications of a third advance of little extent.

The Kara Kul sediments seem to have been largely deposited between the first two epochs established. The older moraines, as seen north of the lake, are in the form of smoothed-off masses rising out of the stratified lake clays, and made up of semi-angular bowlders of crystalline limestone, black slates, red sandstone, gypsum, granite, and greenstone. Where observed they were below the 200-foot level and had clearly been worked over by the lake, which has left numerous bars and beaches of cobbles (fig. 103). A distributary of the Kok-sai darya has cut a very broad, flat-bottomed channel through one of these old moraines.

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Overriding these older moraines there are later ones of fresh topography having many undrained depressions above the 105-foot level, but contoured by shorelines from this level down. No sediments were seen on these later moraines.

About 5 versts northwest of the isthmus joining the north peninsula to the mainland we had the best opportunity to study the relations of the moraines to each other and to the Kara Kul sediments and shorelines. This locality includes a portion of the long, high, frontal bluff of a later moraine overriding the smoothed-off old moraine. The second or later moraine has here reached the Kara Kul sediments overlying the first or older moraine and pushed up a distorted mass of these

Figs. 104 and 105.—Sediment pushed up by an overriding Moraine.

sediments some 50 feet high (figs. 104 and 105). Great masses of the bedded clays lie tilted on others inclining in the opposite direction. Some stand on edge, most of them are bent, and numerous small columns stand where carved out by the wind, their stratifications showing inclinations either towards or from the overriding moraine. These clays are at present very brittle.

Just to the east of this locality the coating of clays becomes thinner and in places æolian carving has exposed the underlying moraine, which, a little farther on, rises to view. On certain undisturbed surfaces of the sediments and in places on the beaches of both the old and the new moraines there are peculiar bushy concretions or growths of calcium sulphate mixed with clay (fig. 106). They stand upright, and are firmly cemented to the ground, which fairly bristles with them over considerable areas. Similar concretions were seen forming in the brine pools on the present lake shore. I am indebted to Professor Palache, of Harvard, for the analysis of these growths.

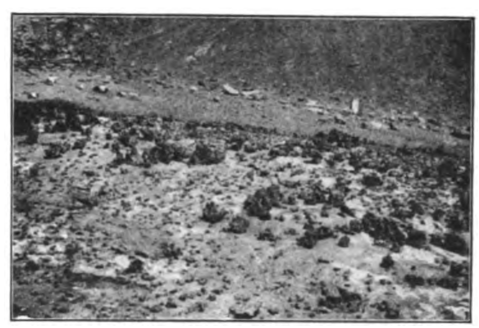

Fig. 106.—Concretionary growths of Calcium Sulphate on Moraine more than 100 feet above Lake.

From these various observations we may reason: (1) that the older moraine predates the Kara Kul sediments at this point; (2) that the deposition of at least

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that thickness of sediments disturbed by the advancing later moraine predates that advance; (3) that the shore of a saline lake has retreated from about the 150-foot level to its present position since the maximum of the overriding moraine; (4) that too little time has elapsed for much alteration either by solution or weathering of the salt growths since the lake-shore existed at that height; (5) that it seems probable that the flexibility exhibited by the pushed-up sediments during the advance was due to their being well soaked under water. This might indicate that the lake was not only there after the overriding moraine had come to rest, but possibly also during the advance, and soaked the otherwise brittle sediments into a flexible state.

We have seen that the Kara Kul sediments consist chiefly of the finest blue-gray clays, containing small flakes of mica and occasional small angular fragments of stone. The light blue-gray color is, in itself, remarkable, for all fine material brought down from the mountains to-day seems to be red. This shows that the old Kara Kul sediments are not oxidized, as are the deposits of to-day, and that

Fig. 107.—Looking north from the front of the Kara Jilga Moraine to the Kizil Kul Steppe.

they are in all probability a product of glacial grinding; their thickness varies with the topography of the underlying old moraine. One minimum estimate gave a thickness of 40 feet where the wall, 30 feet high, of the elliptical lake described was seen through the clear water at least 10 feet below the surface. How much deeper the sediments continued could not be estimated. All this accumulation must have taken place since the maximum advance attained by the old underlying moraine. This, together with the width of the channel established by the Kok-sai darya, is good indication of the antiquity of the underlying moraine.

The kettle-hole topography of the overriding moraines, and the narrow V-shape of valleys cut in them, with the torrent condition of streams contained, show what a relatively short time has elapsed since they were formed.

THE KARA JILGA MORAINE.

It will be seen on the map that the Kara Jilga darya turns an acute angle at about 10 versts upstream from its mouth in Kara Kul, and now remains, partially filling the deep valley between this little lake and the angle of the Kara Jilga. Its surface is indented with frequent kettle-holes, and its topography is, in general, very

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fresh. The moraine front forms an irregular, steep slope rising from the plain some distance below, and about a verst to the north of Kotir Kul. Starting at the base of the moraine, the plain inclines north to Kizil Kul (fig. 107).

OBSERVATIONS IN THE REGION OF KIZIL KUL.

Kizil Kul, as the upper portion of the Markan Su stream is indicated on the Russian 10-verst map, is not really a lake, but simply a sluggish portion of the stream. Here the Markan Su heads in three branch streams, all of which run on broad plains of clear gravel, broken at frequent intervals on their borders by large fans of angular material. These plains join to form the more expansive steppe around the upper portion of Kizil Kul, and in the midst of this steppe a ledge mountain about 500 feet high rises sharply from the waste.

From the midst of the various branch plains there rise numerous island tops of moraines, with apparently unaltered surfaces and slopes pitching sharply under the alluvium, while the valley sides themselves appear to be partially buried by the waste. There are, also, several ledge islands in the midst of the branch flood plain

Fig. 108.—The valley heading a little west of Kizil-Art and joining the Kizil Kul Steppe.

coming down from just west of Kizil-Art pass (fig. 108). Thus this whole region has the appearance of a deeply-carved valley system partially buried in waste, much of which must have accumulated since the dumping of the moraines, probably of the overriding class seen in the Kara Kul basin. There are also traces of low terraces contouring the slopes bordering the Kizil Kul depression, and remnants of an ancient plain to be seen sloping back in a gently rolling topography above the steep valley sides and on the ledge island some 400 feet above Kizil Kul.

On a side excursion about 5 versts to the southeast of this point I came in view of a larger glacier a few versts to the east and flowing south from the Trans-Alai. Unfortunately there was not time to visit it, and the bad sand-storm that came up made it useless to take photographs. Through the field-glasses enough was seen of its long ice-flow to show that it that it might be an important point of attack for the glacial geology of this region.

FLUCTUATIONS OF LAKE LEVEL AND GLACIAL ADVANCES EXPLAINED BY CLIMATIC CHANGES.

With the little time available it was hardly possible to make sufficient observations to definitely pair off the glacial advances with the old shorelines of Kara Kul. It can, however, be stated that during each wet period the lake rose either till its

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surface increase gave enough evaporation to equalize the influx, or till it reached an overflow. Whether these wet periods were or were not coincident with the glacial advances remains to be proved. Since the annual range of temperature is here so low that it freezes nearly every night even on the lowest steppes about Kara Kul, it is natural to feel that a sufficient increase of precipitation is all that is needed for a glacial advance, and that the glacial epochs of the past were brought about by the same wet periods which raised the surface of the lake. The only fallacy here is that there might have been a wet period raising the lake level, but during which the annual temperature was so high that not enough snow would have accumulated to bring about a glacial advance.

Perhaps the most extraordinary circumstance about Kara Kul is that it is said to overflow occasionally, although it is so strongly saline that long stretches of its shores are coated to a thickness of 2 to 3 feet with salt. Severtzoff states that during high northerly storms the water is driven up in the long southern arm, overflows into a branch of the Murg-ab, and thence into the Amu darya.

Fig. 109.—Drowned Valleys on the west side of the North Peninsula. Looking north to the Trans-Alai range.

Unfortunately, we did not have time to visit the southern divide. It seems very likely that it was blocked by moraine during the high expansions of the lake. A moraine during the earlier epoch might have dammed and raised the lake to the high levels marked by old worn-down terraces. During the long time intervening between the two advances it might have been cut down by overflow and other erosion and again raised by the overriding moraine of the later epoch. This reasoning would make the lake expansions coincident with the glacial advances. It is, however, complicated by the lowness of the northern divide over the Kara Jilga moraine, but Kotir Kul is, by Russian leveling, 600 feet above Kara Kul, and the divide at least 200 feet above that. Without the great overriding moraine this divide would be several hundred feet lower, so that Kara Kul may have had two outlets during the earlier glacial epoch, if it was during that epoch that the lake rose to the 200-foot or higher levels of the old terraces. There has, however, been no overflow over this northern divide since the falling into place of the overriding moraine, for its topography is unaltered.

The northern peninsula rises abruptly from deep water on the west, and more gradually from the shallow water and lake sediments on the east. Its western shore is indented with deep bays, from which rise steep spurs of rock as islands. The

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whole has the appearance of a mountain mass formerly normally dissected above water and now flooded in the lower portions. These observations tend to show that when the normal dissection of the flooded part of the peninsula took place the lake stood far below where it is now, and possibly did not exist at all. It was then raised to the old high levels, and must have remained there a long time, for the shores, though now in many cases obliterated, are broad, even where cut in steep ledges. Then it fell again, and a relatively long time afterwards was raised to about the 150-foot level, where it remained some time and then gradually receded, leaving its fresh shores following in and out of the old peninsula valleys. The lake surface appears to have stood at its present height for but a relatively short time, for its shores show very little cutting from wave action (fig. 110).

Considering all facts about the Kara Kul basin, we see that, although there is no absolute proof for associating the old shorelines of the lake with the glacial advances, they naturally group themselves together by probability; for if Kara Kul exists as a result of moraine damming and if, as seems more than likely, ice epochs occurred during times of increased precipitation, the greater fluctuations of lake level were doubly controlled by glacial epochs. Moreover, the ancient 300 to 400-foot shorelines are in their imperfect state of preservation similar in antiquity to the old deeply clay-buried moraines, and the shorelines marked from about the 150-foot level down are similar in their freshness to the overriding moraines with their unaltered surface topography. As further evidence we have the fact that the overriding moraines are cut, where they extended sufficiently low down, by the 150-foot and lower shores, but not cut by the 200 to 320 foot and higher levels. It therefore seems proper to state that the lake surface appears to have risen to a height of 320 feet or more during the first glacial epoch established and to a height of about 150 feet during the second glacial epoch established.

GLACIAL EPOCHS.

It seems only reasonable to suppose that epochs of increased glacial conditions were coincident on both sides of the Trans Alai range and in neighboring regions. In the Great Alai Valley and on the Pamir we have one class of moraines of similar antiquity and extent, another of similar freshness and extent, and indications of a third still later class of little extent. Evidence thus places each class on the Pamir as contemporary with its respective similar class in the Great Alai Valley.

To distinguish the two definitely established glacial epochs we may name the older one the Alai Epoch and the later one the Kurumdi Epoch. It is therefore at present convenient to divide Quaternary time for the field in which I worked into five parts—

Quaternary...... {
- Post Kurumdi.
- Kurumdi Epoch.
- Orogenic Epoch.
- Alai Epoch.
- Pre-Alai.

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FORM OF THE GREAT ALAI VALLEY.

THE VALLEY ITSELF.

Although the dimensions of the Alai Valley have already been given, a repetition seems necessary. It is, except for the flood plains of streams, a smooth, grass-covered plain about 75 miles long, averaging 12 miles in width, and broken by transverse undulations where moraines project from the principal side valleys. It has a longitudinal pitch from 10,500 feet at the pass on the east to 3,200 feet at Darak Kurgan on the west end, and a transverse inclination of about one-half a degree alongside streams from its southern to its northern border. The Kizil Su, or trunk stream, thus flows close to the northern border.

Very few of the side streams coming down from the Trans-Alai, or southern border, reach the Kizil Su, except in high flood. On July 14 we followed the flood plain of the Kizil-Art darya, which is one of the larger streams, from Bor Daba to the Kizil Su. Although there had been three days of rainy weather, all the channels of this stream were dry at 15 versts down from Bor Daba. The lower portions of the flood plains of larger streams from the Trans-Alai are often several versts in width and generally of clean gravel, with certain strips grown over with loess, and rising in the middle to a considerable height above the surrounding plain. These observations, together with the extensive distributary systems as seen on the map, are good evidence of delta accumulation. In the eastern half of the valley the Kizil Su itself is a sluggish stream and incapable of transporting more than a very small proportion of the immense amount of waste supplied by the Alai Valley tributaries. This is shown by the splitting of the stream over long stretches and absence of any permanent channel cut down below the surrounding plain.

We have seen that, in the past, great accumulations of moraine were brought into the Alai Valley, that since the Kurumdi, or later glacial epoch, great depths of moraine of that advance have been buried by later waste, and that the valley is now rapidly filling up with alluvium. A general glance at the valley as a whole would show that it has the character of a formerly deep valley now much filled up with waste. The ledges flanking the mountains on both sides of the valley slope sharply into alluvial and glacial deposits. It would be interesting to know how long this valley has been filling up, what proportion, if any, of this filling took place before the Alai glacial epoch, what proportion between the Alai and Kurumdi epochs, how much since the Kurumdi epoch, and how far down it would be to bedrock in a cross-section. Much light might be thrown on these questions in exposures of the gorge at the outlet to the valley. It seems highly probable that the valley has suffered from morainal blocking. This might explain the existence of the gorge that drains it as a drop-over from the high zone of morainal blocking and consequent alluvial accumulations into lower regions unaffected by glacial action.

SIDE TRIBUTARIES.

The side valleys emptying into the Alai Valley from the Trans-Alai range have already been described in paragraphs on glacial geology. It was shown that there had been a lowering of baselevel of those streams from the south and consequent cutting

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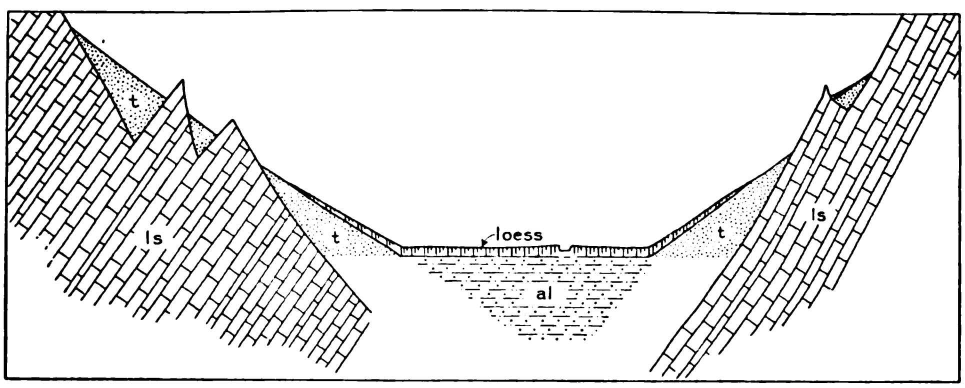
down of their floors since the close of the Alai glacial epoch, and that, although most of this cutting down took place before the close of the Kurumdi glacial epoch, the upper portion of at least the Kizil-Art darya is still cutting down in rock bottom. The valley forms of those side streams coming down from the north, from the Alai range, might well be called a reverse of those from the south or opposite side of the Alai Valley. We had a good general view of many northern tributaries from a distance, and made a detailed study of the Sari Tash Valley, which heads at Katin-Art pass. This belongs to that class of valleys which had in the past the steep V-shape, containing torrent streams, but which have since been largely buried by waste, forming a broad, flat surface over which their now sluggish streams meander. In the Sari Tash Valley only peaks of the rock core rise from the nearly talus-buried mountain sides (figs. 110, 111). There is practically no transportation; the talus is stationary and coated nearly to the top with loess and grass. The stream meanders



(*t*=talus; *ls*=limestone; *al*=alluvium.)

Fig. 110.—Section looking north up the Sari Tash Valley.

between grass banks to within half a mile of the coast, where it winds between interlocking fans of talus. A few versts east of the mouth of this valley there rises an island spur separated from the rest of the range by Alai Valley alluvium.

EXPLANATION OF CONDITIONS.

It is evident that the whole side-valley system of the northern border has been deeply submerged in alluvium, whereas the system opposite, on the southern border, has been cut down. These reverse conditions might be explained by a simple tilt of the region decreasing the grade of southerly flowing streams and increasing that of northerly flowing streams; but, as will be shown later, that would not fit in with what has happened to the Alai Mountains. The simplest explanation seems to be a sinking of the Alai Valley with the region including its northern tributaries. If this took place with a fault on the southern border, it ought to have left a fault cliff which might explain the escarpment at the base of the Trans-Alai range, which escarpment has been described under observations on glacial geology.

Suess states on authority of Ivanof that the Alai Valley is partially surrounded by lake terraces. He considers this valley as orogenically the eastern extension of the Zerafshan and drains the supposed lake through a gorge cut back by a capturing

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branch of the Amu darya, which is the present outlet of the Kizil Su. It seems highly probable that the Alai Valley, with its great transverse moraines, may have held one, or even several, lakes during glacial epochs; but a lake reaching to the height of our escarpment terraces would be high above the lower passes over the Alai range, and, moreover, we observed no lake sediments.

Fig. 111.—The eastern side of the Sari Tash Valley from about 5 versts below Katm-Art Pass.

It seems probable that a sinking of the Alai Valley with the region including the northern side tributaries, accompanied by a fault on the southern border, would have resulted in the observed truncation, lowered the base of, and caused the deepening of, the Trans-Alai side valleys, while the part going down would have been filled up with waste. This fits the present conditions observed.

Fig. 112.—Remnants of Floor A, as seen looking down from just below Taldic Pass.

OBSERVATIONS IN THE TALDIC VALLEY.

Our route led us twice along that part of the Taldic darya between its source at Taldic pass and Gulcha on the southern border of the Fergana lowlands. On the way up a general idea of the valley form was obtained; on the way down more detailed observations were made.

It will be seen on the map that this stream starts with a northeasterly course, but gradually bends toward the west, and finally recrosses the meridian of its source. A straight line from Taldic pass to Gulcha points but a few degrees east of north.

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The Taldic Valley increases in depth from about 500 feet near the source to about 3,000 feet just above Gulcha; a little below Gulcha it emerges into a relatively shallow channel on the lowland plain, and finally joins the Kara darya, a branch of the Syr. It varies greatly in width, according to the hardness of the rock. For about 15 versts, part in black silicious limestone, part in granite and hard slate, it

Fig. 113.—Taldic Valley Terraces, looking up the Taldic Valley from Floor B, about 63 versts above Gulcha. Floor A is high up on the right.

narrows to a deep canyon, where the stream is a roaring torrent running partly on ledge bottom. Where cut in the gypsum series it broadens out, with sides sloping back in successive steps over extensive terraces. Except where in the above-mentioned canyon, the Taldic darya, from about 20 versts below its source to Gulcha, is directly contained in a channel of often rectangular cross-section, averaging some-

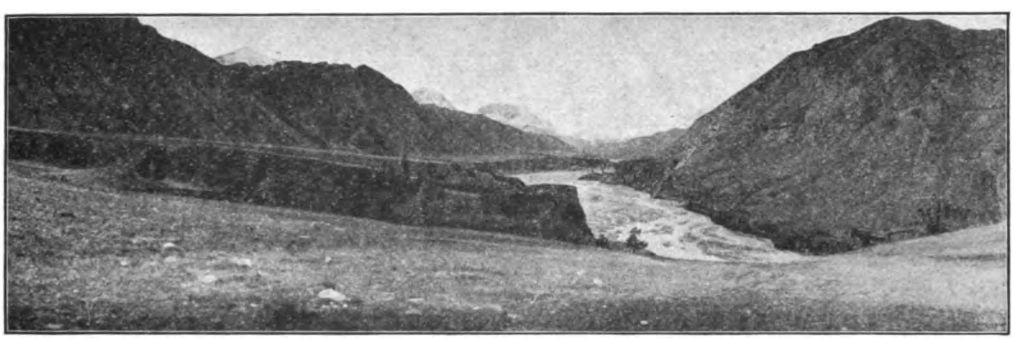

Fig. 114.—Taldic Valley Terraces, looking up the Taldic Valley from Floor C, about 46 versts above Gulcha,

thing like 500 feet in width and 100 feet in depth, and cut in partially cemented alluvial conglomerate. When in high flood the stream covers the whole breadth of the bottom; at other times it is largely split into smaller streams rejoining each other on its irregular gravel flood-plain. The accompanying profile of the stream has been constructed with the aid of Russian leveling notes, and the characteristic terraces have been projected onto it from my approximate measurements. These terraces have been lettered A, B, C (figs. 112–114).

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The first traces of floor A are found as long sloping spurs, projecting transversely into the valley below Taldic pass. Extending down the valley, it rapidly broadens out on alluvium-covered terraces, and appears to have emerged on to a waste-covered piedmont plain, reaching to within 25 versts north of the present Alai range axis. This plain has now been extensively dissected, and remains only in frequent flat-topped hills capped with horizontally lying conglomerate and in the sharper tops of other hills and spurs reaching to the proper height. It will be seen by the profile that it spreads horizontally to the north from the range axis and remains in terraces and alluvium 3,500 feet above stream at Gulcha. There were higher hills that rose as residuals from the alluvium covering portions of the level of floor A (fig. 112).

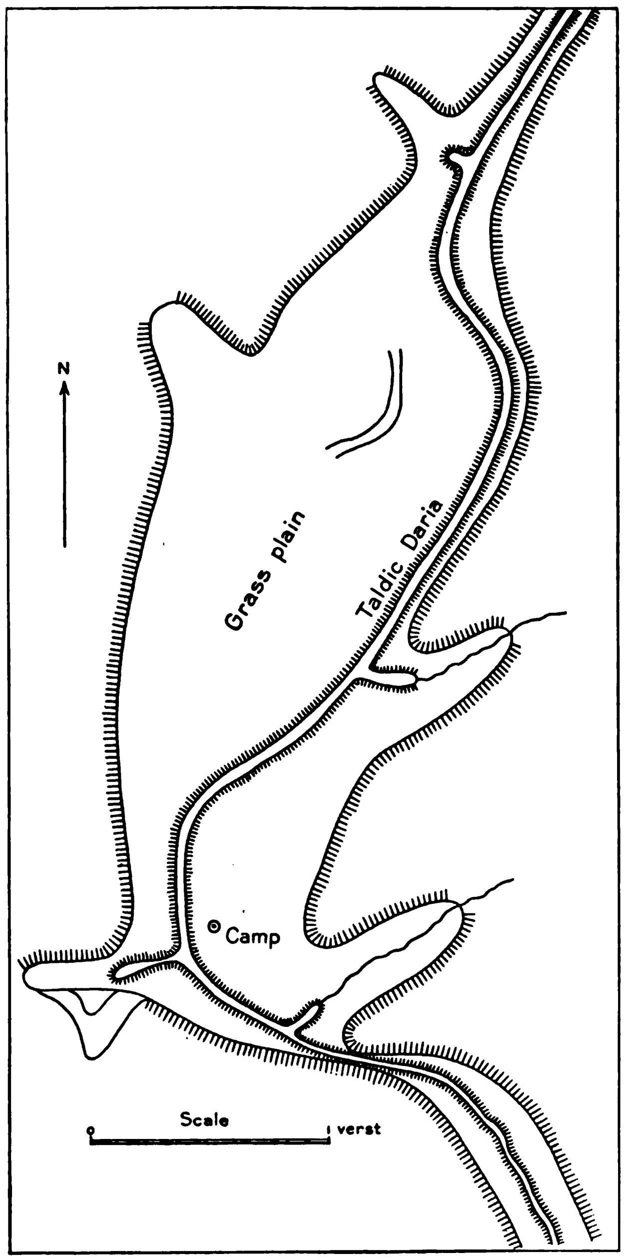
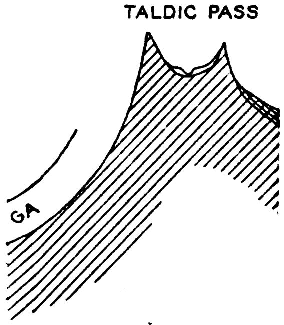
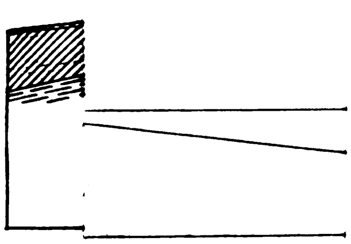


Fig. 115.—Map of the Ak-Busa-Ga grass plain and stream channels.

Reaching a point about 3 versts down the valley from Taldic pass, the stream emerges abruptly from its torrent gorge into the wide valley at Ak-Busa-Ga. The accompanying sketch map (fig. 115) gives a rough idea of the dimensions of the plain of the valley floor and positions of the main stream and tributary channels at Ak-Busa-Ga. Here we find a transitional state. The trunk stream has sunk a channel 15 feet deep through the grass plain and into alluvial conglomerates, while the side tributaries pass over falls into their gullies leading to it. Since these falls are some distance from the plain border, it is evident that these streams have not had time to cut back into their respective valleys since the trunk channel was sunk. Passing down through Ak-Busa-Ga outlet, we find that the grass plain is there higher above





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the stream and forms the beginning of the floor B terraces. These are, at first, narrow, sloping terraces on parallel bedded alluvial conglomerate, but broaden as they are followed down the valley, at the same time increasing in height above the stream at the rate of about 26 feet per verst, and at Gulcha are about 2,000 feet above. Floor B has, however, been much dissected, the tributaries having cut down on a normal grade to the trunk stream, leaving intervening alluvium-capped hills and spurs as portions of the old rock bottom. Its greatest width, of many versts in the lower half of the valley, is evidence of prolonged action and meandering of the stream to an extent well towards maturity at the B stage.

Floor C seems to be the last great characteristic in the records of this valley. It coincides with floor B on the plain of Ak-Busa-Ga, but, having a steeper grade, separates from it a verst or so farther down the valley, soon attains its full height above stream, and continues practically parallel with it all the way to Gulcha, except for a few short stretches missing in the canyons. This floor is remarkably fresh in every respect, and surmounts the present bed of the stream over a large proportion of its course with vertical and often with overhanging walls. The larger branch streams have already cut down to the trunk stream on a normal grade, but small tributaries still fall from floor C in hanging valleys.

Long portions of the valley sides between A and B, and between B and C, are marked with transitional terraces, and where the valley widens there is a series of three, and sometimes more, freshly cut terraces stepping down from floor C to the present stream bed. The striking divergence of terraces is seen by a glance at the profile. The running out of the A and B terraces is a characteristic feature soon recognized in the valley, and it was from that fact that the block tilt described below was first inferred.

OBSERVATIONS ON THE SOUTHERN BORDER OF THE FERGANA LOWLAND PLAINS.

About 30 versts down stream from Gulcha the Taldic darya emerges on to the lowland plains of Fergana. We made a brief study of the southern border of these plains from 20 or 30 versts east of Osh to Jisak, on the railroad, 30 versts northeast of Samarkand. Most of this study was from the railroad train, but there was more detailed work done in the region of Osh, and observations made there projected on to the similar forms along the rest of the border. It was found that the waste from the Alai Mountains, formerly spread in extensive fans on the border of the plains, has been tilted up towards the mountains, dissected in its upper portions, and buried by later waste on its lower portions. It was observed from a distance that, in general, the Alai range foot-hills begin in long flat-topped masses parallel with the range and rising abruptly to a considerable height above the plains.

The stream followed by the route from Langar to Osh crosses the critical zone, including the dissected waste and the line where it inclines under the later waste. The upper part, or that followed between Takka pass and Langar, was found to have cut back a narrow channel increasing in depth to about 60 feet at Langar,

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where a Russian station-house stands on the terrace surmounting it. The side rivulets pass, on their way to the trunk stream, through deep gullies with a sharp double change of slope in their cross-sections, as though there had been an increased rate of cutting down (fig. 116). They are cut in partially cemented conglomerate, interbedded with fine material. The station-house terrace extends down the valley parallel with higher terraces, all of which are cut in apparently horizontally bedded conglomerate.

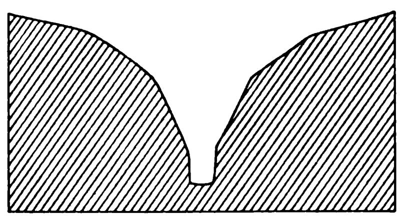

Fig. 116.—Section to show double change of slope in Langar Gullies.

As this conglomerate was followed down the valley, it was found that a larger and larger proportion of it assumed the forms of partings of gravel, filled between with fine pulverous material resembling loess. Throughout the lower portion of the valley the stream resembles the Taldic darya in that it is largely split into separate channels rejoining each other on the irregular flood plain of gravel. There were occasional higher island portions between these channels, which were coated with loess, sometimes pure with vertical cleavage, sometimes interbedded with partings of gravel, and grown over with grass.

About 20 versts from Langar the valley opens out on to the lowland plains. On the way to this point, the terraces seen in the upper portion of the valley had successively disappeared under the flood plain, while here the conglomerates formed

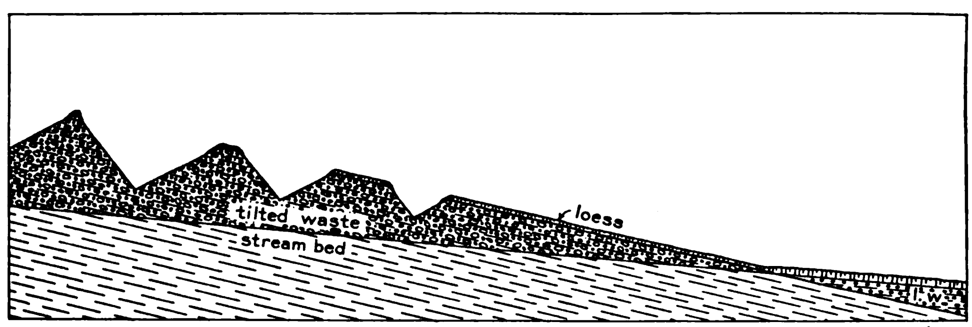

Fig. 117.—Section en route, 20 versts north of Langar, looking 15° south of west. The tilted waste inclines under the later waste.

a low, broad slope inclining gently to the north and sinking under the loess of the lowland plains along a well-defined line, running about 15° south of west. The slope itself was cut by shallow valleys pitching directly with its inclination, running parallel with each other, and with their lower portions apparently submerged in the waste they had spread on the plains. Looking south toward the mountains, we could see that the conglomerate slope extended back on to the flat, inclining surfaces surmounting pyramidal masses dissected from it, and still farther back, over the sharp tops of higher hills (fig. 117).

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ATTEMPT AT CORRELATION OF RECENT GEOLOGY OF THE MOUNTAINS AND PLAINS.

The following suppositions seem to account for the various land forms observed along the route from Kizil-Art pass north to the lowland plains, but it should be added that generalizations, such as block movements, can not be definitely established without a study of several other profiles across the ranges in question.

(1) Floor A of the Taldic Valley profile, the great extent of which was seen from prominent points above the valley, is evidence that in earlier Quaternary time the Alai Mountains had been degraded till a waste-covered piedmont plain had formed on the north side to within 25 versts of the core of the range.

(2) When this stage had been reached, there seems to have taken place a dislocation, essentially parallel to the range axis, and some 75 versts to the north of it, while either the plains to the north sank or the mountains were raised by a block uplift. Whichever happened, it appears that the mountains with a belt some 50 versts in width of the old piedmont to the north were raised at least 1,500 feet relatively to the plains north. As this movement took place, the Taldic darya, as an example, cut down through the raised piedmont and formed a valley increasing in depth from about 500 feet near the crest to 1,500 feet at the dislocation, while its various tributaries dissected the mass on both sides, leaving portions of the old plain, some of which still exist as floor A, recording its former extent. The floor of the trunk valley thus formed is the one lettered B in the profile.

(3) The great width of floor B in the lower half of the Taldic Valley, and the considerable thickness of alluvium on its old ledge bottom there, are evidences of prolonged meandering of the stream and filling back of waste. In other words, there was a decrease, or possibly a cessation, of relative uplift at the B stage.

(4) There seems, then, to have begun a block tilt of the belt lying between the northern base of the Trans-Alai range and the old dislocation zone, about 75 versts to the north of the Alai range axis, the rotation taking place about a line somewhere under the present Alai range axis, raising that part to the north and lowering that to the south. As a result, those streams flowing north in the Alai Mountains cut their way down through that part which was raised, leaving numerous terraces to record the transition. At the same time, the head of the Taldic valley, being south of the rotation axis, was tilted back, decreasing its grade, which explains the preservation of floor B in the broad grass-plain of Ak-Busa-Ga. The lower portions of valley systems south of the crest were being tilted down below their Alai Valley base-level, and consequently choked with waste. Another consequence of this tilting down, suggested by Professor Davis, was the increase of grade of slope from south of of the Alai crest, aiding the transportation of loose material and a rapid sharpening of the peaks which to-day project as pinnacles from the talus slopes (fig. 119). A block tilt seems to be the only way to explain the rapid increase of height above stream of terraces in valleys running north and the deeply filled up character of valley systems running south from the supposed rotation axis. Moreover, the old piedmont, or floor A, now lies horizontal, although it must have formerly inclined to the north.

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How much width of the Great Alai Valley was included in the block tilt is uncertain. It was, however, shown in the discussion on the Alai Valley form that there has been a lowering of base-level and consequent deepening of the valleys emptying into the great valley from the Trans-Alai range, and that this lowering had taken place since the close of the Alai glacial epoch. It was further shown that this took place with a depression of a belt including the side-valley systems from the north and possibly reaching to the very base of the Trans-Alai range. The depression and filling up of the Sari Tash Valley and others running south from the Alai range was probably brought about by a block-tilt. This tilt can explain the observed changes of both the Alai and Trans-Alai ranges, and since the deepening of valleys in the latter took place after the close of the Alai glacial epoch, this tilt probably occurred since that epoch. It is, however, not likely that this one tilt was the only movement that took place; in fact, we have seen that the border of the lowland plains was tilted up, presumably during the block-tilt, and there is no reason to suppose that the Trans-Alai range did not, at the same time, move either up or down a little on the block-tilt dislocation bordering it. If the tilting of the waste on the lowland plains was caused by a drag-up on the block-tilt dislocation there, the tilted waste was deposited largely during and before the Alai epoch, while the deposit overlying its lower portions are, in age, from bottom up, orogenic to present, inclusive.

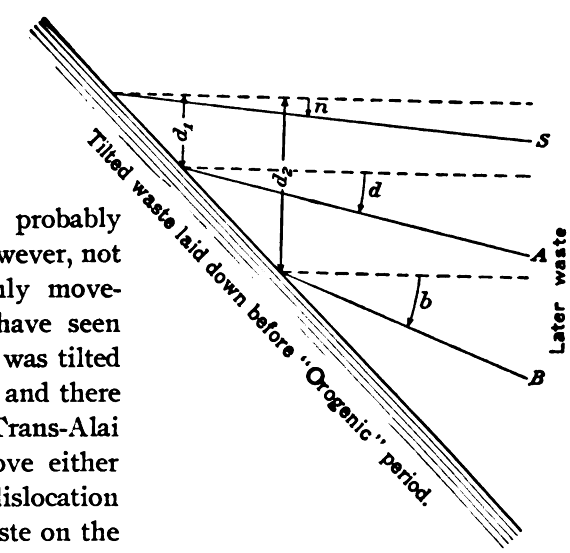

Fig. 118.—Explanatory diagram for example in determining relative antiquity of horizons of the waste on the plains.

The relative antiquity of different horizons might be estimated in two ways: (1) as directly proportional to magnitude of dip less normal surface slope of fans of that coarseness of material; (2) as directly proportional to thickness of overlying accumulations. These methods would, however, be complicated from the fact that the rate of tilting seems to have been accelerated from the beginning, for the transition of valley form was always to the narrow from the broad. This complication might be overcome by careful measurements of terraces and determination of the factor of acceleration.

EXAMPLE.

Let *n* be the present surface with normal slope. Let *A* and *B* be two horizons, the ages of which are to be determined. (See fig. 118.)

Let dA and dB = depths below surface.

Let f = acceleration of tilting, $\frac{\text{age } A}{\text{age } B} = \frac{\angle(A-n)}{\angle(B-n)} \times \frac{l}{f} = \frac{dA}{dB} \times \frac{l}{f}$ as a rough estimate.

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MISCELLANEOUS OBSERVATIONS ON THE LOWLAND PLAINS.

In the region of Osh there are several high, rugged mountains of crystalline limestone rising as monadnocks from the waste of the plain. The Syr Darya, where crossed between Khokan and Schust, was found to flow but a few feet below the level of the plains. The ruins of the ancient town of Ak-si are being cut by the river meandering, but no definite data as to change of level or relations was obtained. The waste of the plains on the northern border has been tilted up toward the mountains, dissected in its upper portions, and buried in its lower portions, in a manner similar to the southern border.

Fig. 119.—The sharp peaks south of the Alai Crest. Taken from a peak some versts east of Katin-Art Pass.

CONCLUSION.

The results of the Pamir expedition have shown that the correlation of the recent geology of the mountains and the plains in the field we covered is not only possible, but practicable, to attempt. We have already found a general connection between magnitude of the valley carving brought about by orogenic movements and distribution of corresponding depositions on the plains, and have, to a certain extent, found the glacial division of time in which these movements took place. When we consider the few days in which all this was found out, it seems that more detailed work on the terraces and dislocating zones ought to yield remarkably analytic results.

If work is to be continued in this field, the following plan is suggested:

1. A detailed study of Sok Darya Valley, which heads in the two large glaciers in the heart of the Alai range and flows north on to the lowland plains of Fergana.

2. Having found the relations of terraces to moraines and to the border of the plains in the Sok Darya Valley, proceed to study the great longitudinal valley of the Zerafshan, where artifacts are extremely abundant. Then, if definite relations of artifacts to alluvium, to terraces, to moraines, are found, time units may be projected to erosion, and deposition units determined in the first valley.

3. It would be of great interest to correlate the old expansion of Great Kara Kul with the glacial advances, and to make volumetric and surface area determinations of each expansion and its sediments. A few approximate profiles would do this.

4. A careful study of the Great Alai Valley, and an attempt to determine the thickness and age of its glacial débris and of the waste filling it. The entrance of the gorge at its outlet might be a good point of attack.

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A Geologic and Physiographic Reconnaissance in Central Turkestan.

By Ellsworth Huntington,
Carnegie Research Assistant.

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ITINERARY.

The following pages present the results of a journey in Central Asia, among the mountains of Russian and Chinese Turkestan, during August and September, 1903, under the auspices of the Carnegie Institution of Washington. The purpose of the journey was specifically the determination of the later geological history of the region, and especially of the changes in the physical conditions of the country with respect to their influence on early human history. In the absence of any general knowledge of the physiography of the region it seemed advisable to undertake a reconnaissance in which the more obvious problems were examined, while those that required prolonged work in one place were deliberately set aside for future study. In pursuance of this plan, two months were spent in following the route shown on the accompanying sketch map (fig. 120), traveling slowly on horseback at the rate of scarcely 25 miles a day, and rarely staying in one locality over two nights. From the town of Przhevalsk, formerly known as Kara Kul, at the eastern end of Issik Kul or Lake Issik, the road led (July 27) southwestward over the lofty Tian Shan plateau to Chadir Kul (August 6), thence southward, still among the mountains, to Shor Kul (August 15), and again southwestward across the border of the interior basin to Kashgar, the capital of Chinese Turkestan (August 21). The return journey led westward across the mountain spur between the Tian Shan and Alai ranges, via the Terek pass, 12,700 feet high, to Osh, in the Fergana basin of Russian Turkestan (September 5); then southwestward to Karategin in the Alai Mountains (September 18); and finally northward again, to Marghilan and the railroad (September 25). Although ten passes were crossed at a height of over 12,000 feet, the road on the whole was not one of great difficulty, and troublesome snow or ice was encountered in only three places. The district traversed measured about 350 miles from east to west, and 225 from north to south.

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PLAN OF REPORT.

Although the main purpose of the reconnaissance was the study of the physiography and Quaternary geology of the country, some attention was given to the records of earlier times. Accordingly, it is proposed to discuss first the Paleozoic geology very briefly, then the Mesozoic and Tertiary geology more at length and with some mention of their relation to formations of similar dates in southwestern United States, and lastly the Quaternary geology, which will be taken up with considerable fullness. Under the last head will be included a discussion of the physiographic provinces into which the region is naturally divided and of the processes which have been instrumental in producing the present land forms. In conclusion, some attention will be devoted to a consideration of the evidence of changes of climate during recent geological times and to an attempt to subdivide the Quaternary era on the basis of these changes.

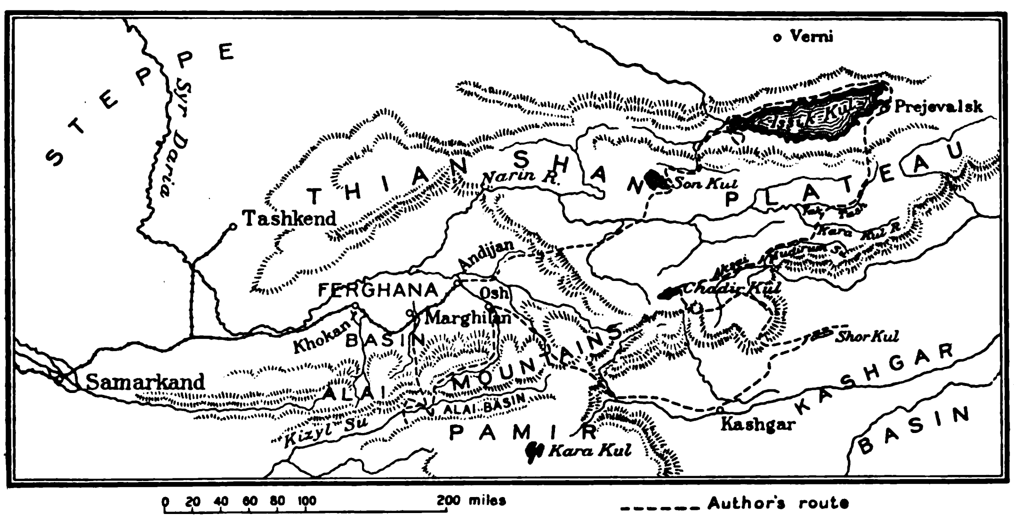

Fig. 120.—Sketch map of Central Turkestan.

THE PALEOZOIC SERIES.

In Central Turkestan a single succession of strata is repeated again and again, with only slight local modifications. The oldest observed formation is an ancient white marble, shot through and through with intrusions of granite. It was noticed only in the Alai Mountains in the neighborhood of Kok Su and Karategin. Its junction with the overlying formation was not seen, but the contact presumably shows an unconformity, as a conglomerate near the base of the covering strata contains pebbles of the marble. The granite which is intruded into the marble is of much later date, for it occurs abundantly in the Paleozoic series in the ridges of the Tian Shan plateau and along the north side of the Alai range. The main body of the Paleozoic series is a great thickness of limestones, many of them slaty, which are stated by Tchernachef to be of Devonian and Carboniferous age. They are greatly folded and have been penetrated not only by granite intrusions, but also by

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some basaltic lavas, as may be seen, for instance, in the Sugun Valley west of Shor Kul. The folding of the Paleozoic strata (see fig. 122) is of the sort which is associated with mountain building, hence at the end of the Paleozoic era or in the early part of the Mesozoic this part of Central Asia must have been highly mountainous. In evidence of this it may be pointed out that the succeeding unconformable conglomerates are so coarse that they could only have been formed

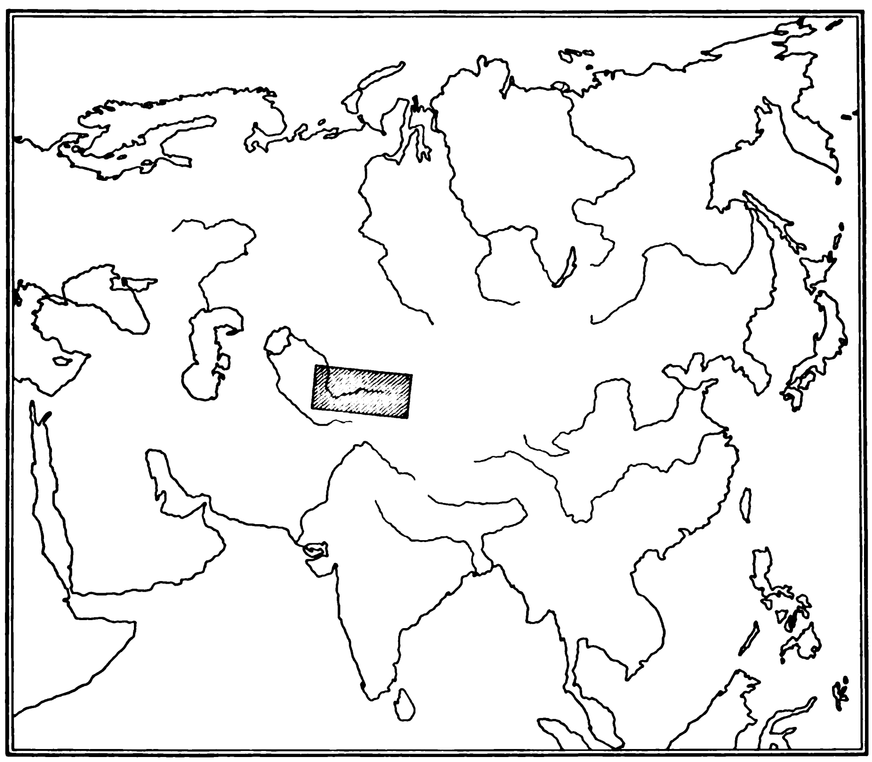

Fig. 121.—Sketch map, showing location of Figure 120.

subaerially in a region of considerable relief, and yet at the time of their deposition the old folds of limestone and slate had already suffered great denudation. As a rule, the hard Paleozoic strata are found in the highlands, while the softer Mesozoic and Tertiary strata occur in basins among the highlands and mountains; but this seems due less to the superior resistance of the older rocks than to the fact that they were bent down where they are covered, and that the younger strata were largely formed in the very basins which they now occupy.

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TABLE I.—*The Geological Series.**

	General section.	Section southeast of Chatar Kul.	Section at Sugun.	Section at Min Yol.	Section at Kuzzil Oi.	Section at Uksalur.	Section at Irkestan.	Section at Guristan.	Section at Kichik Alai.	Section in the Alai Valley.
15	Recent conglomerates and silts.	Do	Do	Do	Do	Do	Do	Do		
Unconformity.										
14	Brown conglomerate	Do	Do	Do	Do		Do	Do		
13	Brown sandstone	Do	Do	Do	Do		Do	Do		
12	Pink sandstone	Do		Do	Do	Do	Do	Do		
11	Red conglomerate and red sandstone.	Do	Do	Do	Do	Variegated marls. Do	Do	Do	Do	
10 Unconf.?	Shale and marl	Clay and calcareous shale.	Sand and calcareous shale.	~~~~~?	~~~~~?	Marls with three limestone bands.	Red and green marl		Buff limestone. Red and yellow marl.	
9	Oyster limestone	Chalk flint limestone.		Do		Do	Do		Do	Do.
8							Marly white limestone.	White limestone		
							Brown limestone		Calcareous brown sandstone.	
	Marls, limestone, and gypsum.				Blue clay marl		Tufaceous limestone	Red and black marl.	Red and blue marl and sandstone.	Marl.
							Gypsum	Limestone		Limestone.
							Red and yellow marl	Red and yellow marl.	Red and green sandstone.	Marl.
							Fossil limestone			Tufaceous limestone.
7	Vermilion sandstone		Do		Do		Do		Do	Do.
6	Coal measures				Clay, shale, and coal.		Blue marl and black shale.			Brown shaly limestone and blue shale.
5	Sandstone and conglomerate.				Do					
4	Coarse conglomerate				Do					
3	Slate and limestone	Do	Do		Do		Do	Do	Do	Do.
2	Marble									
1	Granite								Do.	

* Where the features are the same as in the general section the fact is indicated by "Do." in the table.

THE MESOZOIC-TERTIARY SERIES.

Lying unconformably on the eroded surface of the folded Paleozoic strata is a thick series of Mesozoic and Tertiary formations, the sequence of which at various places is shown in Table I. These begin with very coarse conglomerates, which gradually become finer and are interstratified with sand. Then, by gradual transitions, the sand passes into the shale of a coal-bearing series, which is probably Jurassic. Above these there seems to be a slight unconformity by erosion. When deposition was renewed the first strata were conglomerates of fine texture, and a brick-red or vermilion sandstone, which in some places shows a peculiar cross-

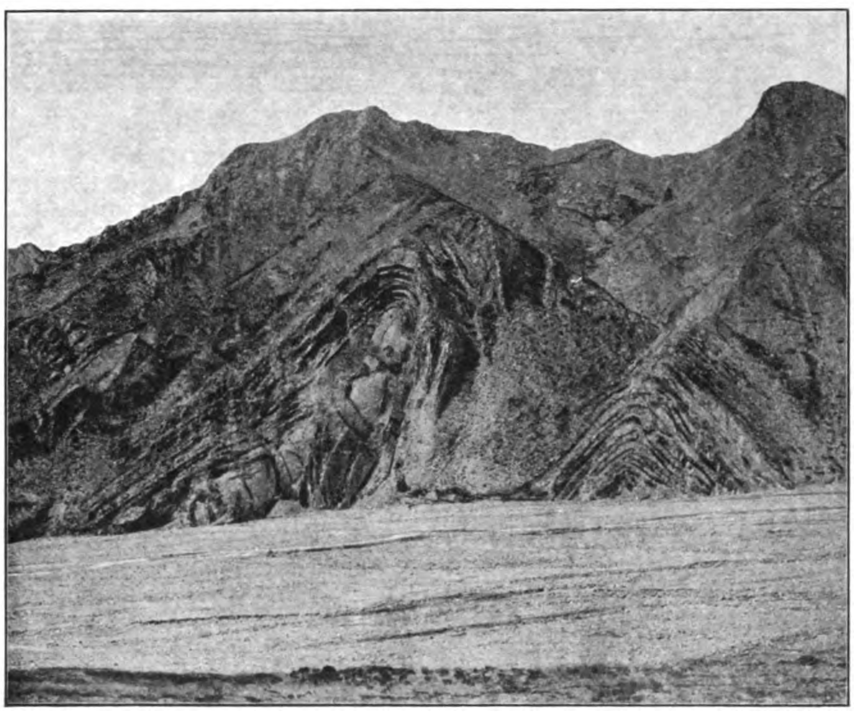

Fig. 122.—Folds in the Limestone in the Sugun Valley west of Shor Kul, looking west.

bedding on a large scale. Everywhere, with one doubtful exception, the vermilion sandstone passes conformably into a series of fossiliferous limestones and marls of Cretaceous and early Tertiary age, which vary considerably from place to place, although the other strata are very uniform over large areas. The overlying Tertiary layers consist of red sandstone, which often forms a bright carmine band one or two hundred feet thick, a heavy pink sandstone, a brown sandstone, and a thick brown conglomerate. These strata form a single series, and pass gradually into one another with no unconformities, except a slight one between the pink and the brown sandstones which was noticed in the fine section near Sungun, west of Shor Kul. The term "sandstones," as applied to all these formations—the red (carmine), the

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pink, and the brown—is not exact, for while certain parts are composed of true sand, small portions are shaly, and large parts are composed of very fine material, which is neither sand nor clay, but a sort of silt which often resembles loess. The bedding is very even at the base, but signs of subaerial deposition make their appearance below the middle of the pink beds. At first there are sun-cracks and ripple-marks, then thin lenses of a slighly different texture from the surrounding rock, and finally in the brown sandstone very distinct stream channels filled with fine gravel. Throughout the Tertiary series, from the limestones upward, the layers are discontinuous; at any given point the bedding seems horizontal and unbroken, yet if individual beds are traced for some distance they gradually die out.

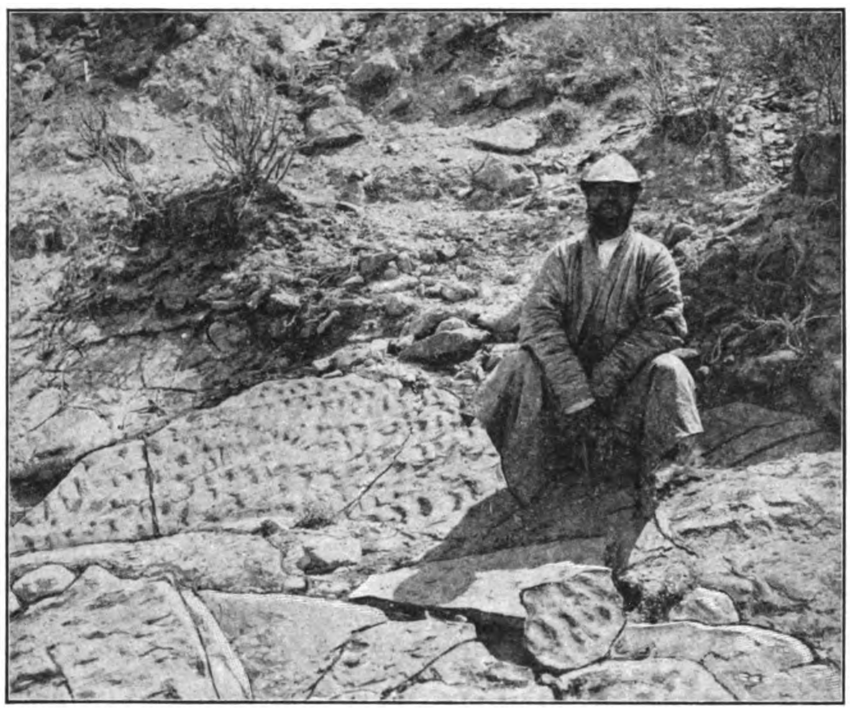

Fig. 123.—Ripple-marks on the lower half of the pink sandstone near Kan Su, west of Kashgar.

The conditions under which the Mesozoic-Tertiary series were deposited seem to have been largely subaerial, or at least non-marine. The coarse conglomerates at the base probably indicate arid or semi-arid conditions in a region of considerable relief. As relief grew less, or as the climate grew moister, the gravel of the conglomerate gave place to sand and that in turn to shale; in the latter are four or five coal seams. The next period, that of the vermilion beds, seems to have opened at a time of subaerial deposition when the conglomerates and the cross-bedded sandstones were formed; but toward the end the encroachment of the sea is indicated by the deposition of the marls and fossiliferous limestones. Elsewhere throughout the whole Mesozoic-Tertiary series fossils seem to be wholly absent, although the deposits are well fitted to preserve the remains of plants and animals if any had

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existed; but here the calcareous strata, which show other evidences of being marine, contain fossils in abundance. Above the limestones the strata are at first red, as though the shallowing of the sea allowed the very highly weathered soil of an old land mass to be washed farther and farther out into the area of deposition. The succeeding formations, the pink and brown sandstone and the brown conglomerate, show a nearer and nearer approach to present conditions. It appears as though, after the retirement of the sea, the land was covered with great playas, on which water first stood in thin sheets, forming ripple-marks in the mud (see fig. 123), and then retired or was evaporated, allowing the surface to become sun-cracked. As time went on streams began to flow across the playas, at first slow and broad and able to cut only shallow channels, which were afterwards filled and covered, assuming the form of very thin lenses of a material slightly different from that of the surrounding playa strata. Then, as the strength of the streams increased, sand was deposited over the whole area, and the channels, now deep and distinct, were filled with gravel. Lastly, gravel was deposited almost everywhere.

Some of these changes may be of climatic origin, some may be due to warping of the crust, and some seem to result from the lessening of relief by erosion. Thus in the earlier Mesozoic times the change from coarse conglomerate to the fine coal shales may be due entirely to the last-named cause, by which, as the mountains were worn away and the intermount basins were filled, relief became less and the size of the transported materials became smaller, until the coal-bearing shales were formed. The next change, from the coal measures to the red conglomerate and the cross-bedded sandstone, is much more sudden and probably indicates a warping and uplift by which previously base-leveled areas were raised and subjected to active erosion. The redness of the strata and the predominance of small pebbles of pure quartz in the gravel indicate that the materials were derived from a region that had long been subject to undisturbed weathering. It is possible, too, that the uplift was of such a nature as to cut off the supply of moisture which had been present during the formation of the coal and to convert the country into a desert, where the wind produced large-scale cross-bedding of the red sandstone. There is no positive evidence on the subject, and we can merely raise the question of the desert origin of this peculiar deposit. From the time of the cross-bedded sandstone to that of the limestones of the Cretaceous there appears to have been a steady sinking of the land or rising of the sea until at last the whole country was inundated. Through the succeeding period to the Tertiary there is no sign of climatic change. Everything points to a steady warping and lifting, by which relief was gradually increased in such a manner as to cause the deposits to change from marine to subaerial, and then gradually to change in texture from the fine silt of playas to coarse conglomerate. The warping seems to have been greatest along the borders of the present basins, for there we find the strata of the whole series considerably folded, while in the centers of the basins they are almost undisturbed. The older strata, too, seem to be more bent than the younger, so that the process seems to have gone on steadily almost from the beginning of deposition.

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COMPARISON WITH AMERICAN FORMATIONS.

Before leaving the Mesozoic-Tertiary series there is another phase of the subject which deserves mention, because of its bearing on the world-relations of the continents. The existing physiographic features of this portion of Asia bear, as has been suggested, a certain resemblance to those of the southwestern portion of the United States, the so-called Basin Range and Plateau provinces. If the rock series and the geological events of the one country be compared with those of the other it is seen that while there is considerable difference in details, there is also a significant resemblance; hence the fundamental features of the past, as well as of the present, are similar. This is set forth in Table II, where American features which are the same as those of Asia are marked "Do." It is not meant to imply that the two series of features were identical in time, but merely in sequence. The similarity seems too great to be accidental; it may be that we have here the normal sequence for an interior desert basin. If this is so we ought to find the same general rock series in other desert regions, such as Arabia and parts of the Sahara, where similar conditions prevail.

TABLE II.—*Comparison table of the Mesozoic-Tertiary rock series and of geological events in the elevated arid regions of Asia and North America.*

	Asia.		North America.	
	Rocks.	Events.	Rocks.	Events.
1	Limestone and shale..	Paleozoic moraine deposition....	....Do	Do.
2	....	Mountain-making and prolonged erosion.	Shales	Estuarine or playa deposition.
3	Conglomerate and sandstone.	Subaerial deposition. Land slowly sinking or stationary.	....Do............	Do.
4	....	....	....	Slight unconformity.
5	Clay shales and coal measures.	Estuarine or swamp conditions...	Blue marls.........	Estuarine conditions.
6	....	Slight unconformity............	....	....
7	Vermilion sandstone, cross-bedded.	Elevation and possibly desert conditions.	....Do............	Do.
8	Limestone and gypsum.	Depression and return to moraine conditions.	White cross-bedded sandstone.	More rigorous desert conditions.
9	Marl and limestone..	Unstable marine conditions......	Cretaceous coal measures.	Estuarine or swamp conditions.
10	Oyster limestone	Marine conditions..............	....Do............	Do.
11	Red and pink beds...	Elevation and eventually a gradual return to subaerial conditions of depositions	....Do............ (Pink beds.)	Do.
12	Brown sandstone and conglomerate.	Complete return to subaerial deposition.	....Do	Do.

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THE TERTIARY PENEPLAIN.

The unity of Central Turkestan is shown not only in the wide extent of the various members of the rock series, but also in the extensive peneplain which truncates them. In all parts of the region there are numerous places where the surface of interstream areas presents a smooth, gentle slope quite out of harmony with the tilted strata which it truncates evenly without regard to whether they are hard or soft, and with the steep-sided valleys that are being cut in it. These areas are therefore regarded as uplifted and more or less dissected parts of a formerly low-lying peneplain of erosion. In the southern part of the Tian Shan plateau, for example, the large plateau basin containing Chadir Kul and the Ak Sai River and lying at a height of from 10,000 to 11,000 feet above the sea is bounded on the south by a broad ridge or swell rising to a height of from 13,000 to 14,000 feet. On the southern slope of the ridge there is a descent of 9,000 feet to the plain of the Kashgar basin in a distance of from 70 to 15 miles—that is, a descent of from 120 to 600 feet per mile. This descent is sufficient to cause active erosion, which in due time will produce the most irregular topography with a maximum of relief; but the valleys of the south slope are not yet profound and the interstream areas, though very rugged, rise everywhere to the height of a nearly smooth imaginary surface ascending from the Kashgar basin to the broad ridge which incloses it on the north. This surface is evident in the hard Paleozoic formations and can be detected even in the soft Tertiaries. A broad ridge with such a slope descending from it must soon become very rugged by reason of the headward erosion of the streams; but here, especially in the eastern portion, the southern ridge of Tian Shan is still quite smooth and level, and its surface is indifferent to rock structure; hence its elevation from the condition of a low-lying peneplain must be comparatively recent. A smooth plain (plateau) of large extent stretches northward from the ridge, sloping at an average rate of about 100 feet per mile toward the Ak Sai basin and truncating the almost vertical slates and limestones of Paleozoic age (see fig. 124, p. 172, southern end). Not far to the west, in the district southeast of Chadir Kul, there are a number of easy passes across the same ridge, which there forms the Chinese boundary. Two of these passes, Kara Kermak and Kuzzil Kur, are in the soft upper members of the Tertiary series, although at an elevation of over 12,000 feet.

It is evident that the smooth imaginary surface to which the tops of the hills rise on the southern slope of the Tian Shan, above described, and its more actual continuation in the plateau, which truncates the Paleozoic strata farther north, could not have been formed by any known process under the present conditions of altitude and drainage; nor could the weak Tertiary strata of the passes farther west have been long preserved in their present form at the elevation at which they now lie. In order to reduce the deformed strata to so smooth a surface the Tian Shan region must have stood many thousand feet lower than now, until it reached a late mature or oldish stage of erosion, deserving to be called a peneplain, over large areas. The present altitude of the region must be due to uplift and warping of the peneplain

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and its residual mountains, and in order that the weak Tertiary strata should still exist in the warped and uplifted plains, its deformation must have been comparatively recent.

Numerous other examples of this kind might be cited, but one will suffice. At Gulcha, about 30 miles southeast of Osh, on the border between the Fergana basin on the north and the Alai Mountains on the south, the Gulcha River flows in a valley 2,000 feet deep. Between this valley and the next there is an upland which in a general view appears to slope smoothly and gently to the north, although it is somewhat notched here and there. The surface of the upland truncates inclined strata which vary in hardness from the resistant oyster-bearing limestone to the soft, shaly sandstones of the Tertiary. It is still well preserved, in spite of the fact that there is in some places a descent of 2,000 feet in 3 miles. The sloping upland plain must have been formed as a peneplain, and must have been given its present inclination at a somewhat recent date. In the western part of the Tian Shan range, where the plateau character is less marked, and in the main range of the Alai Mountains, the old peneplain is shown chiefly in the level crests of the ridges. Even in the lofty Pamir there are certain ranges where the snowy peaks are smoothly truncated, as though by the old peneplain, in spite of the fact that they are from 15,000 to 20,000 feet high. The fragments of old surfaces are indeed so numerous that it seems safe to conclude that much of the country was once reduced to a peneplain, and the rest of it at least to the stage of late maturity. The extent of this degraded region was fully 100,000 square miles—that is, at least 400 miles east and west and 250 miles north and south, and probably much more. Although the age of the peneplain is not closely fixed by the evidence of fossils, it may be referred to the end of the Tertiary, because its erosion was completed after practically the whole Tertiary series of the region had been laid down and warped. For the present we shall consider that the erosion of the peneplain marks the close of the Tertiary era and that the Quaternary is introduced by the succeeding changes of elevation.

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THE QUATERNARY UPLIFT.

The first process which belongs to recent or Quaternary geological history was a vast uplifting of the Tertiary peneplain, the area of the uplift probably extending considerably outside the limits of the region which we are now studying. Coupled with the uplifting of the peneplain as a whole, there was a warping by which it was deformed into basins, large and small, with intervening swells or ridges. As far as was observed, this warping does not seem to have initiated new lines of stress, but to have confirmed old ones of Tertiary age. In the old movements faulting took place abundantly; in the new movements warping was the rule and faulting took place rarely. The Quaternary basins seem to be revivals of former basins, first formed early enough to receive Tertiary deposits, for the Tertiary strata usually appear to have been deposited in basins similar to those which they now occupy, but less deep; that is, the strata are thickest in the center and grow thinner toward the edges, where also they are more warped, as though the edges of the basins had been gradually raised out of the area of deposition. The scale of the Quaternary warping was large, for some of the ridges, such as the main crests of the Tian Shan plateau and of the Alai range, were raised over 10,000 feet above the bottoms of the neighboring basins. The Quaternary uplift gave to the country the general form which it now possesses and divided it into portions which have distinct characteristics and may therefore be treated as natural physiographic provinces.

Consequent Drainage.—Before discussing the provinces separately, a few words should be said about the drainage and the evidence which it gives regarding the condition of the land previous to the Quaternary uplift. Throughout Central Turkestan the drainage is almost universally consequent upon the Quaternary warping, although in some places where the strata are soft the beginnings of a subsequent drainage are seen in process of development. The main streams follow the axes of the basins parallel to the general strike and leave the basins through gorges which seem to be located where the rims of the basins sag. Most of the basins contain Mesozoic and Tertiary strata, and the main streams usually traverse these weaker formations, so that from a mere inspection of a geological map they might seem to be subsequent. It is in the tributaries that the true consequent character is seen, for they flow down the slope of the warped peneplain surface and across the strike of both hard and soft strata. In the old age of the country previous to the Quaternary revival the main streams probably followed somewhat the present lines; for most of the basins, as has already been said, had been formed earlier by the down-faulting or folding of blocks of Mesozoic and Tertiary strata during the previous times of deformation, and at late maturity many streams must of course have searched out the softest formations. The altitude of the peneplain may then have amounted to thousands of feet because of its greatest distance from the ocean, but it must have been far lower than now. The hard rocks, the granite and the Paleozoic limestones, formed the uplands as they had done for ages and as they do to-day. At present there seems to be no sign of an old subsequent drainage in these uplands, a fact which indicates that the country was so far reduced to a peneplain that the streams paid little or no attention to structure.

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LONG CONTINUANCE OF PROCESSES OF DEPOSITION AND UPLIFT.

In the preceding sections the various rock formations and the Tertiary peneplain have been spoken of as though each of them represented a definite space of time rather than a stage of development. That the latter is the truer view is well shown by the phenomena along the borders of the Kashgar basin. South of the village of Artush, about 12 miles northeast of Kashgar, the Quaternary plain is broken by a ridge of interstratified silt and gravel which runs nearly east and west and rises 200 or 300 feet. It is an anticline so recently uplifted that its original form remains almost unchanged, although the material is soft and unlithified. The dip is gentle, about 6° on the north side and less on the south. The greater part of the strata which compose the anticline consists of buff silt, which is like loess in color and texture, although some portions at least are more clayey. It is apparently the same material as that which is now being deposited in the playas of the surrounding plain. Interstratified with the silt are layers of stream gravel, showing old channels with cross-bedding and lateral unconformities. The top of the ridge is covered with gravel from 5 to 20 feet thick. West of Kashgar the silt continues, although with less of the character of loess. The valley followed by the caravan road to Osh leaves the plain through some low hills which seem to be a continuation of those already described near Artush. They consist of the same silts and gravels, which dip greatly toward the plain and are well exposed in the steep sides of the valley. At the top lie several hundred feet of gravel, then come numerous alternations of gravel and silt, with a gradual increase in the thickness of the finer material, and at last very thick yellow silts. The upper part of the latter are full of lenticular stream-channels, which grow broader and less numerous lower down. Although all the strata are very soft, they correspond in position to the formations which have been described above as the brown conglomerate and brown sandstone of the upper Tertiary, and by the rules of ordinary stratigraphy would be reckoned as of the same age. That they are younger is shown by their less degree of consolidation and by the fact that they can hardly be distinguished from the strata now in process of formation. Their folds, too, are younger than those of the sandstones, for although they rise above the level of the old peneplain, they are not beveled by it. Apparently, the Kashgar basin has long been growing smaller by a process of continuous folding along the edges, and as it has grown smaller the locus of deposition of the gravels which accumulate along its edges has gradually been pushed inward.

To make this more concrete, let us take the cross-section at Sugun Karaul, west of Shor Kul (fig. 124). In the Tian Shan plateau, 10 or 15 miles from the edge of the Quaternary plain of the Kashgar basin, the conglomerate at the top of the Tertiary is highly folded and very hard, but as the same stratum is traced southward and westward it becomes softer and less folded, until finally it seems to run into the soft gravel of very recent date which has been described in the preceding paragraph. Moreover, the old resistant conglomerate of the Tian Shan region has been smoothly baseleveled since its severe folding was completed, while the gentle folds of the soft young gravel have only been dissected by narrow valleys which have not yet produced a maximum of relief. This seems to mean that somewhere in Tertiary time

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the border of the Kashgar basin was 15 or 20 miles north of its present location, and was a place of heavy gravel deposition. Then a small fold developed along the border, lifting up part of the gravels and causing the accelerated streams to deposit their load of pebbles farther toward the center of the basin, where playas had formerly deposited silt. Later another fold was developed and the gravels once more advanced, and so on by steps which were perhaps too slow to be noticed. The older gravels were compressed and hardened into conglomerates and their upper portions were worn down to the smooth grade of the Tertiary peneplain. A similar experience befell all the underlying formations. Each of them, and the peneplain as well, represents not a certain time, but a stage in development, and some of the stages are not yet completed.

PHYSIOGRAPHIC PROVINCES.

THE TIAN SHAN PLATEAU.

The part of Central Turkestan traversed by the writer divides itself naturally into four provinces—namely, the Tian Shan plateau, the Alai Mountains, the Kashgar basin, and the Fergana basin. The first of these is generally termed the Tian Shan Mountains, but as far as the province was seen, it is not strictly a mountain range according to a scientific definition, nor is it strictly a plateau. It is a region of mountainous structure, and once of truly mountainous form, but it long ago reached old age, and has since been uplifted to its present height with relatively little renewed folding of the strata. In structure it is still mountainous, but its present form and altitude are due to an uplift of the uniform kind which is usually associated with the formation of plateaus. To-day it may best be described as a plateau; to-morrow, geologically speaking, when all the remnants of the uplifted peneplain surface and the last of the post-Paleozoic strata have been removed and dissection has gone far enough to produce strong relief, it will again become a typical mountain region of highly folded limestones. The general structure is shown in the accompanying section (fig. 124), which is about 200 miles long and extends south-southwest from the mouth of the Juuka Su, 25 miles west of the east end of Issik Kul, to the Kashgar desert at Sugun, 30 miles west of Shor Kul. The section represents the general character of the plateau in its least dissected portion. Farther east and farther west the surface is more deeply trenched by the main streams. Along the section the profile is essentially a very broad anticline of the Uinta type, as defined by Powell, where the sides are monoclines and the top is flat. The fact that the component strata were already highly folded does not alter the character of the last uplift, although it makes it less evident in the cross-section. If the line representing the surface is looked at alone, the true nature of the deformation is evident. The anticline is not strictly flat on top, but undulating. The troughs form broad basins at an altitude of from 10,000 to 12,000 feet, while the crests form broad ridges which reach a height of from 13,000 to 15,000 feet.

On the steep northern slope of the broad anticline the valleys are fairly open at the base where they reach the Tertiary strata of the Issik Kul basin, but they are for the most part narrow canyons with inaccessible walls of naked rocks

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bounding a flood-plain so narrow that in the valley bottom a road with difficulty finds a place among the cedars and must often cross the cascading brook or even climb out of the valley. Between these young valleys the graded northern slopes of the broad anticline are covered with cedars, which form the only forest seen during the whole journey. Far up the stream, where glaciers have been at work, the valleys widen and are better graded, and at the same time the interstream areas become rougher, although they still contrast strongly with the valleys. The youth of the latter is shown not only by the steepness of the walls, but by the relatively moderate depth, 1,000 or 2,000 feet, which seems to be the most that they have as yet attained beneath the interstream highlands, although the streams descend very rapidly and are cutting actively. Another evidence of youth is seen in a normal hanging valley from which a small side stream cascades 40 or 50 feet directly into the Jukuchak Su, whose narrow valley here has no flood-plain whatever.

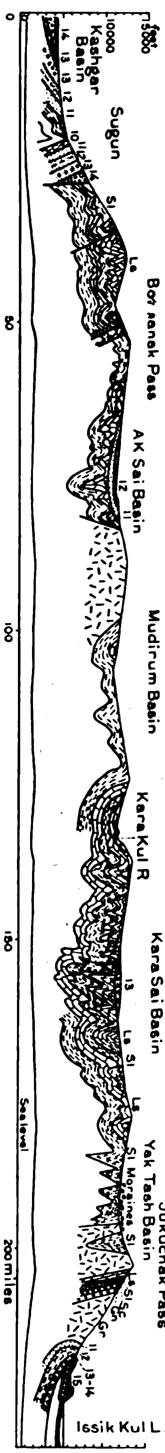

Fig. 124.—Cross-section of the Tian Shan Plateau from Issik Kul southwest to the Kashgar Basin. Vertical exaggeration = 7. The unshaded profile is drawn on the true scale. The numbers attached to formations refer to Table I, p. 162.

The broad ridge which lies along the northern border of the Tian Shan plateau is always covered with snow, and most of its passes are occupied by glaciers. A few of the summits have been sharpened into peaks by glacial action—after the fashion described for Alpine peaks by Richter—and are worth seeing as attractive examples of Alpine scenery, but most of them are mere remnants of the old peneplain, separated by broad, but not very deep, valleys of glacial origin. The uniformity of summit height is illustrated by the excellent topographical map constructed by the Russian general staff on a scale of 2 versts (1½ miles) to the inch. Out of 43 summits, of which the elevation was given on three contiguous sheets at the eastern end of Issik Kul, 32 reached an elevation of from 13,000 to 14,000 feet, and the highest reached 15,069 feet.

As soon as the broad ridge of the northern border is crossed the country assumes an aspect which fully justifies the term "plateau." At Jukuchak pass, for instance, the narrow young valley which one ascends in traveling southward from Issik Kul is exchanged for a broad, open, elevated plain, bounded on all sides by snowy mountains, whose slight dissection causes them to suggest a block of marble on which the sculptor has rudely outlined a form but on which he has as yet carved few details (see fig. 125). The treeless plain with its cover of brown or green grass has the thoroughly graded aspect and subdued slope of a region in late maturity; and such it is in spite of its elevation and potential youth. So far as erosion is concerned it only waits for some stream to cut headward through the surrounding ridges to cause it to enter upon a new cycle at the very beginning of youth. The Yak Tash basin, southwest of the Jukuchak pass, is full of old moraines spread in a broad, uneven sheet and inclosing numerous lifeless ponds and lakes. In other basins the moraines have not advanced so far and the streams have cut slight terraces in the gravel silt or the Tertiary strata which lie on the floor of the depressions and form the plains. Such in general are the basins and ridges of the most typical portion of the Tian Shan plateau.

In the very center of the plateau is a valley of erosion of quite a different character. South of Chakur Korum pass the Kara Kul River, one of the main branches of the Narin, flows in a young valley 1,000 or 2,000 feet deep, with a narrow bottom and steep walls like those which characterize the valleys on the north slope of the plateau. The road descends from the pass to the river by a narrow side valley with walls a thousand or more feet high, and in some places perpendicular

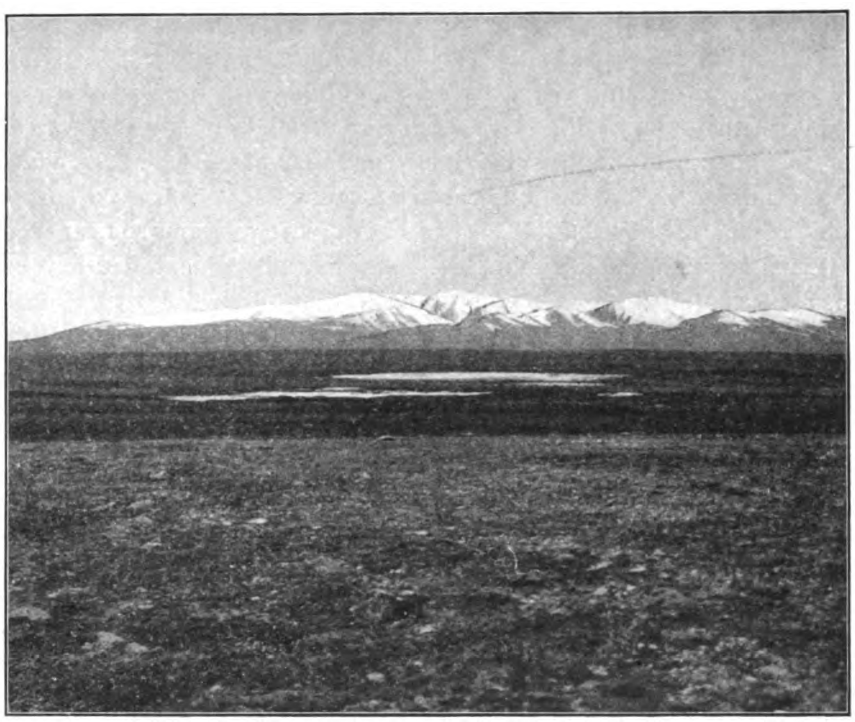

Fig. 125.—Scene in the Yak Tash Basin, in the northern part of the Tian Shan plateau, looking northwest. In the foreground the basin-floor is covered with a flat moraine holding numerous ponds; beyond are smooth-topped mountains cut by glacial valleys.

for several hundred feet. Near its mouth, where the flood-plain widens a little, the valley is suddenly blocked by a barrier nearly 200 feet high, lying directly across the path of the stream. This barrier is the moraine of a little glacier terminating far up on the precipitous side of the valley. The moraine is so porous that the stream flows directly through it with no apparent check, although the gravel flood-plain above the barrier is broader than below.

Among the elevated basins of the Tian Shan plateau one of the largest is that of the Mudirum Su. Its upper portion is a desert of old morainic waste unrelieved by vegetation; the lower portion is also full of moraines, but they are

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well covered with grass and by contrast seem fertile. The mountains on the southern border of the basin reach a height of from 15,000 to 17,000 feet and have been carved into truly Alpine forms by numerous large glaciers. Another basin is that of the Ak Sai and Chadir Kul (Tent Lake), where glaciation has played a relatively small part. The ridge south of this basin forms the Chinese border and has already been described. The valleys descending thence to the Kashgar basin are of the same nature as those on the north slope of the plateau toward Issik Kul. They are cut in somewhat softer strata, however, and hence are wider, and for the same reason the interstream areas are more dissected into sharp hills. Vegetation is almost absent because of the dryness of the climate, and the older contorted limestones and slates stand naked in black and gray, while the later strata are bright with red, pink, and green.

Chadir Kul.—The lake of Chadir Kul, at the head of the Ak Sai basin, near the southern side of the Tian Shan plateau, is a small sheet of water about 16 miles long by 6 wide. It is in the midst of a barren, mountain-girt plain, and does not overflow, in spite of the snowy heights that surround it and of a drainage area which, according to the Russian maps, is five times as large as the lake itself. This has not always been the case, however. The plain of Chadir Kul is composed largely of fine silt which could hardly have been deposited by aggrading streams so near their mountainous headwater area, but which might easily have been deposited in a lake. In one place a cut some 15 feet deep along the side of a brook discloses fine silt full of sphagnum, on which rests a little gravel. The lake formerly had an outlet at the head of the Ak Sai basin, where the plain contracts to a distinct channel about a third of a mile wide, bounded on either side by a terrace 40 or 50 feet high. Across the mouth of this outlet lies a little ridge of sand and gravel 10 or 15 feet high, apparently an abandoned and dissected beach. It does not extend quite to the northern terrace, being separated from it by an open gap of 200 or 300 feet. Apparently the outlet was first stable long enough to allow the cutting of the broad valley and the terraces on either side. Then a change of some sort caused the building of a beach and the partial closing of the outlet, through which, however, a stream still ran for a time before another change caused the lake to retire to its present level. Around Chadir Kul itself nothing was seen to show what these changes were and why they occurred. From the evidence of other places, which will be discussed later, the changes seem referable to alternate expansions and contractions of the lake under the influence of glacial epochs and inter-glacial epochs. The outlet of the lake is later than at least one epoch of glacial action, for while the terrace on the south side of the broad channel is composed of ordinary gravel, the other terrace consists partly of moraine stuff full of bowlders of schistose slate ranging up to 3 or 4 feet in diameter. This must have come from the valleys just to the north, where there are other moraines, and it may have blocked the outlet and caused the lake to expand. The lake as a whole, however, seems to be due to a slight swell or bulge in the basin floor between the Ak Sai basin and its continuation in that of Chadir Kul.

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THE KASHGAR BASIN.

South of the Tian Shan plateau, the second province, the Kashgar basin forms the western part of the vast inner basin of Asia, known as the Takla-Makan and the desert of Gobi. Its flat, barren surface lies at an elevation of from 3,000 to 4,000 feet above the sea and is everywhere surrounded by lofty mountains. Those on the north and west rise from 10,000 to 15,000 feet above it, while to the south-west and south, in the Pamir and Kuen Lun, the heights are even greater. Muz-tagh-ata, one of the world's highest mountain peaks, is plainly in sight from

Fig. 126.—View of the Tertiary strata on the edge of the Kashgar Basin west of Kashgar City. The layers here dip northwest away from the basin, which lies behind the observer. On the left several portions of an old grade plain probably represent the work of an early glacial epoch.

Kashgar, towering above clouds to the tremendous altitude of 25,800 feet. In few other parts of the world can so great a contrast of relief be seen at a single glance, for the parched plain in the foreground lies 21,500 feet below the snowy mountain peak.

The lower part of the slope from the mountains to the plain, where I saw it on the north and west sides of the basin, consists of the upper Tertiary formations (see fig. 126), while farther back toward the mountains lies the Mesozoic series. All the strata are deformed, but on the edges of the plain the outward dips are lessened, and the Tertiaries assume the form of a monocline with decreasing dip, pitching gently under the formations which are now accumulating on the plain itself. If the dip keeps on decreasing under the basin floor, as seems probable, the Tertiary strata must soon become conformable with those of the Quaternary.

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SUBSIDIARY BASINS.

On the border of the great Kashgar basin lie several small basins of similar origin. Three of these were seen, of which the largest and most important, that of Shor Kul, will be treated at length when we come to the consideration of recent climatic changes. For the present it is enough to say that Shor Kul occupies an inclosed basin lying between flat-topped mountains, foot-hills of the Tian Shan plateau. It appears to have been formed by simple warping of the crust without faulting, but this can not be stated definitely, as it was impossible to make a complete circuit of the basin. The floor is a marshy plain, in the center of which is the very shallow salt lake. The other two basins, those of Min Yol and Kuzzil Oi, are traversed by the main caravan route to Fergana, and lie respectively 30 and 50

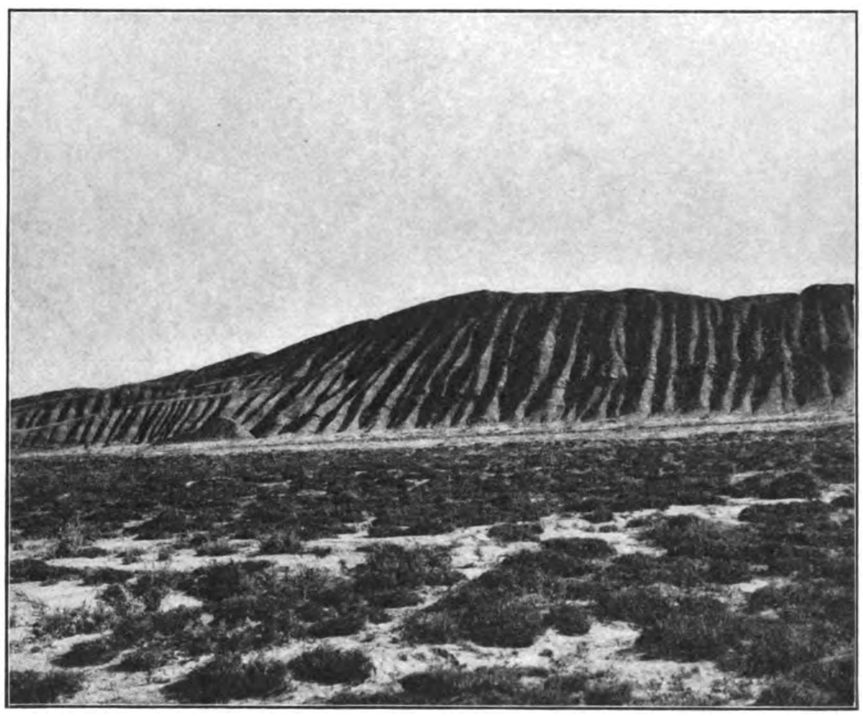

Fig. 127.—Fault scarp on the southern side of the Kuzzil Oi Basin, with a smooth deposit of silt lying in front of it.

miles west by north of Kashgar. They are 8 or 10 miles long and are filled with a smooth fluviatile deposit sloping from north to south. On the north it interlocks with the spurs of the mountains in normal fashion, exhibiting bays of gravel alternating with promontories of rock. On the south, on the contrary, the underlying rock rises suddenly and steeply in a straight-fronted ridge without spurs or bays (fig. 127), through which the outflowing streams have cut steep-sided and narrow gorges. In the case of Min Yol the material that fills the basin is apparently all gravel; the ridge at the south, as observed at a distance, seems to have been produced by folding rather than by faulting. The Kuzzil Oi basin, on the other hand, is filled in the lower part with fine silt, level and swampy (fig. 127), and the

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ridge to the south presents a steep north-facing fault scarp in the central portion, although farther west this merges into a fold.

A peculiar feature of these basins is the drainage, illustrated in fig. 128. In the main, the drainage of the Kashgar region is consequent, with the master stream flowing eastward toward the center of the Kashgar basin and the smaller streams flowing at right angles to it; but along the line of the smaller basins this simple arrangement is interrupted. A continuous valley runs parallel to the main stream and north of it, but instead of being occupied by a single stream it contains three, A, C, and D, and a fourth, B, taking its rise in the western basin, flows across it. The latter stream is easily explained. The fine silts of Kuzzil Oi indicate that the up-faulting of the barrier on the south proceeded rapidly enough to convert the basin into a lake. This was drained by the short stream B, which has only had time to cut a very narrow gorge through the uplifted mass, even though it is composed of

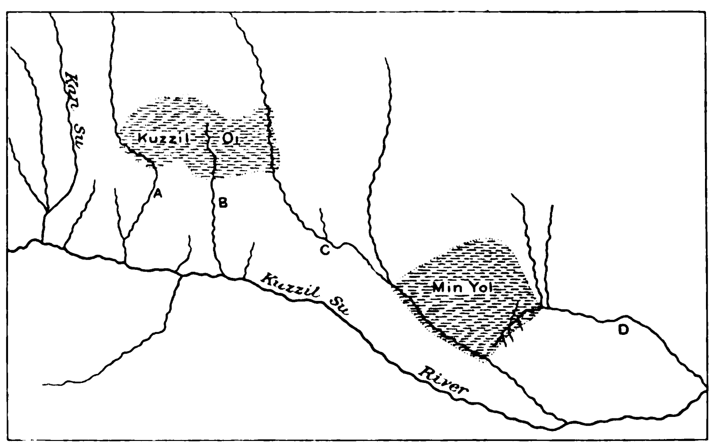

Fig. 128.—Drainage of the Kuzzil Oi and Min Yol basins.

the softest of strata. The further study of these basins and their drainage, together with the very complete geological section exposed near by and the coal mines worked by the Chinese at Kan Su, offers an interesting field of work.

The main portion of the Kashgar basin, as is well known, is a smooth desert plain. On the edges broad slopes of gravel are soon left behind, and the floor of the basin stretches sea-like to the true horizon. It is composed of horizontally stratified sand and silt, entirely free from gravel. The surface is often an immense playa, devoid of vegetation and covered with a deposit of alkali like new-fallen snow. In some districts the surface is thickly strewn with dunes, each topped with small green shrubs a foot or two high. The latter seem to be the cause of the gathering of the silty sand into the dunes, for where the shrubs are dead the dunes are being destroyed, and dunes were seen without shrubs, either living or dead. Elsewhere the plain of the basin floor is less desert and is covered with a low growth of weeds, bushy and tough, from 6 to 24 inches high. The central part of the basin, the real sand desert, lay south of my line of travel. In the peripheral region the muddy streams are incised from 10 to 20 feet between slightly terraced walls, although all but the largest soon leave their valleys and spread out in playas.

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LOESS.

The playas of the Kashgar plain are connected with the interesting geological problem of the origin of loess. The deposits of the playas greatly resemble certain older deposits, having all the typical characteristics of loess; and a comparison of the two at once raises the question whether loess may not be in certain cases an aqueous deposit, formed on the flat floor of basins or aggraded valleys where streams laden with the very finest silt spread out into thin ephemeral sheets. In a previous section mention was made of an anticline of very recent date lying south of the village of Artush, near Kashgar. It was stated that this anticline is composed of gravel interstratified with a light yellow material, which is there termed silt because of its relation to the gravel, but which has all the characteristics of loess. If it occurred without the gravel it would at once be pronounced loess. South of the anticline, near the city of Kashgar, the whole country is composed of what looks like typical loess. It stands in perpendicular walls wherever it is dissected, and deep trenches are worn in it by the roads; everywhere a close examination of the loess walls shows a faint banding; slightly sandy layers and, occasionally, little lenses of fine gravel are found interbedded with the silt. Further west in similar deposits heavy gravel overlies and is interstratified with layers possessing the essential characteristics of loess, although they can hardly be of æolian origin. In two other basins, those of Fergana and Issik Kul, deposits of loess were seen, which included gravel-filled channels. These facts suggest that loess may be a playa formation and that the Kashgar basin may be a place where loess is still in process of deposition.

THE ALAI MOUNTAINS.

Of the two remaining physiographic provinces little need be said, for in essential features they are repetitions of the Tian Shan plateau and the Kashgar basin. The Alai province includes not only the Alai Mountains proper, which run east and west between Fergana and the Pamir, but also the cross-ridge which runs northeast from the Pamir to the Tian Shan plateau, with some peaks rising to a height of 18,000 feet. The Alai range is a portion of the old peneplain uplifted thousands of feet into an arch. It is round on top instead of being somewhat corrugated like the Tian Shan plateau. Its width is much less than that of the latter, and it lacks the broad upland basins of warped peneplain, which are so characteristic of the Tian Shan plateau. The Alai has, to be sure, a series of small valley basins on the north and the great Alai basin on the south, but these are all chiefly due to modern erosion on weak strata that were infolded before the completion of the Tertiary peneplain. Good examples of the small basins are seen on the Terek Su at Guristan, on the Ak Bura at Bopan, and on the Ispairan at Pum. All of the basins appear to be places where soft strata had been faulted down previous to the completion of the Tertiary peneplain; hence, before the uplift of the peneplain, the down-faulted weak strata were inaccessible to the processes of erosion. Since the uplift, deep valleys with broad flood-plains have been eroded in the weak strata, and the surrounding country has been reduced to the stage of mature relief with thoroughly graded slopes. In the more resistant limestone

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areas which constitute most of the northern slope of the Alai range the old peneplain is often well preserved and the valleys are very young in aspect (fig. 129). Some of the rivers flow in magnificent canyons; that of the Ak Bura, which reaches the plain at Osh, is 1,000 to 2,000 feet deep, and so narrow at the bottom that the river runs between walls of solid rock in many places and the trail has to clamber on the side walls on a scaffolding of logs filled with stones (fig. 130). The crest of the range resembles the ridges of the Tian Shan plateau. In the near view, where one looks upward from a valley, the country seems in the highest degree rugged and deeply dissected, but in the large view from a lofty or distant

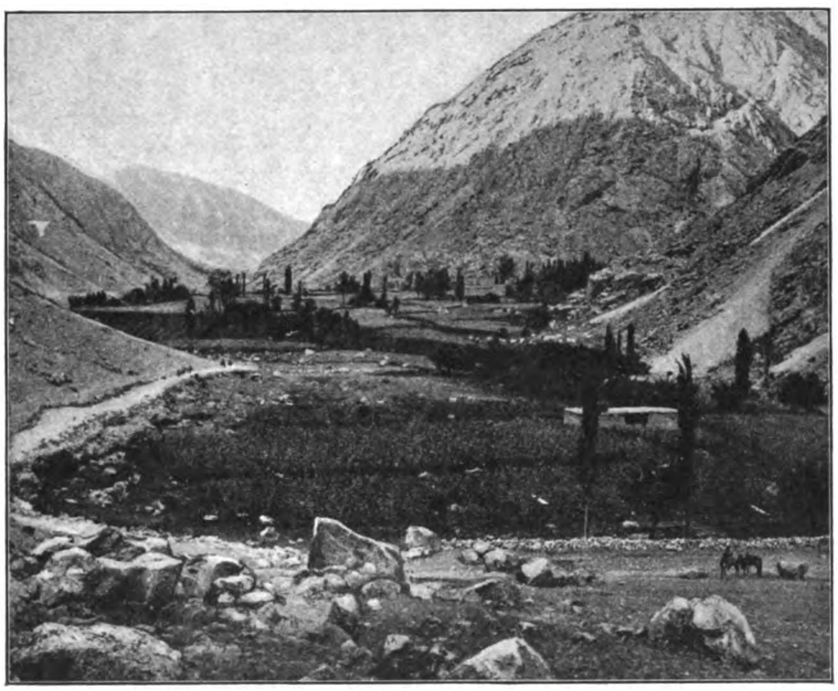

Fig. 129.—Gorge of the Ispairan in its lower portion, where it begins to widen as it flows northward from the Alai Mountains to the Fergana Basin. The valley is filled with gravel, in which the stream has cut terraces.

station it is seen that the mountain crest is very even and that there are large areas where erosion has as yet accomplished but little in dissecting an old surface of moderate relief.

THE ALAI VALLEY.

South of the Alai range lies the Alai Valley, the largest of the minor basins. It seems to be due in part to the warping since the time of the peneplain, but much of its depth is due to Quaternary erosion working on soft Tertiary strata which had previously been faulted down, as in the case of the smaller basins. The drainage is strictly consequent to all appearances. The master stream, the Kuzzil Su,* runs

*The name Kuzzil Su or Red River recurs continually in countries where Turkish languages are spoken. At the moment of writing, I recall seven Kuzzil Sus which I have visited during the journey described in this paper.

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westward near the northern side of a valley 8 or 10 miles wide and 60 miles long. Like most of the streams in the valley basins, whether large or small, it wanders freely over its broad gravel flood-plain in a score of intricately braided channels. At the edge of the flood-plain, on either side, is a terrace 20 or 25 feet high, above which are many miles of gravel sloping smoothly from the base of the mountains to the edge of the terrace. The broader slope is on the south, where lie the higher Trans-Alai Mountains. They form the northern front of the great Pamir plateau,

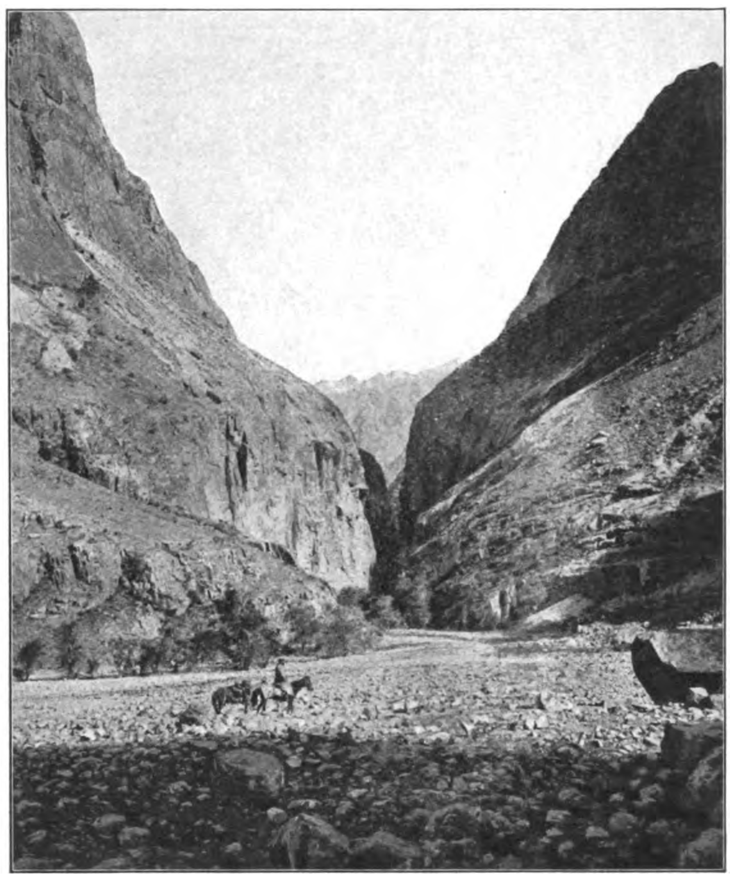

Fig. 130.—Limestone Gorge of the Western Kichik Alai, where it enters the Ispairan River on the north side of the Alai Mountains. Probably the upper portion of the gorge was widened by a glacier, and the narrow slit at the bottom represents post-glacial cutting. The main valley, from the side of which the photograph was taken, is clearly of glacial origin, and the side valley must have borne a hanging relation to that of the master stream.

rising from 15,000 to 23,000 feet above the sea and from 9,000 to 14,000 feet above the valley. On the north also the mountains are by no means low, for the snowy crest lies at a height of about 14,000 feet, and glaciers are numerous. Near the western end of the valley basin, where it narrows before the stream enters the fine gorge which forms the boundary of the khanate of Bokhara, the water wells up from a subterranean course under the heavy gravel deposits and bursts forth in numerous great springs, crystal clear, but very dark. One of these at Mama gives rise to a

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stream so large that it may be truly called a river. Tradition (the tradition found in almost every eastern country) says that this is the outlet of the inclosed lake Kara Kul, lying 75 miles to the southeast, on the Pamir, at an elevation of 12,400 feet.

The chief interest of the Alai basin lies in its old moraines and terraces, which will be discussed in due season. Of the regions seen by the writer in the heart of Asia none is more interesting than the Alai Valley. Its magnificent scenery and splendid climate on the one hand are only less excellent of their kind than are the opportunities for studying the epochs of the glacial period, the moraines and terraces which bear witness to them, and all the phenomena pertaining to glaciation, past and present. Not far to the southwest the salt deposits of Altyn Mazar are of the first importance geologically and economically, and various natural sections present fine opportunities for the study of the rock series; while to the southeast Peak Kaufmann rises 23,000 feet, with Lake Kara Kul on the Pamir beyond it. Moreover, the Alai Valley is inhabited by a peaceable and most interesting folk, the nomadic Kirghiz, with whom it is well worth while to become acquainted. Besides all this, the valley is relatively accessible, as it is only three days' journey from the railroad at Marghilan; and, lastly, it is practically virgin ground.

THE FERGANA BASIN.

In outward appearance the last of the four provinces differs widely from its companion, the Kashgar basin; but the difference is only superficial, resulting from its moister climate. The Fergana basin seems green and prosperous; its many streams are utilized by an irrigation system which sustains populous villages and cities. The Kashgar basin is chiefly a dreary desert. Yet in structure the two basins are so nearly identical that detailed description of the second would involve repetition of much that has been said about the first. The Fergana basin is an aggraded depression, due to local down-warping and burial of the Tertiary peneplain. The mountains inclosing the basin are uplifted and more or less dissected portions of the same peneplain. As in the Kashgar basin, the warping by which the Fergana basin was formed seems to be a late phase of long-continued movements, during which the mountain area has encroached upon the basin area; for the gradually rising mountains around the basin consist of granite and limestone in their higher parts and of weaker Mesozoic and Tertiary strata around the margin next to the basin, all these having been folded and worn down to moderate relief before the present basin was formed. It is therefore quite possible that the down-warped floor, on which the Quaternary deposits of the Fergana basin lie, was not everywhere a peneplain of Tertiary erosion; its central part may well have been an aggraded plain of Tertiary deposition.

The periphery of the Fergana basin is sheeted with gravel which grows gradually finer until it merges into the fine alluvium of the central plain; the area of fine alluvium is much smaller than that of Kashgar and has no playas. Many streams cross the plain, with broad flood-plains of gravel between low terraces, while here and there rise hills more or less carved in masses of interstratified silt and gravel thrust up as folds in recent geological time.

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THE QUATERNARY PERIOD.

In our survey of Central Turkestan we have found that its geological history was long characterized by a remarkable unity. The geological series is uniform in the main, though not in detail. Much of the country in late Tertiary time was reduced to the stage of mature or old topography; and now, after broad deformation, the basins continue to be aggraded plains, and even the mountains retain much of their Tertiary maturity, although exhibiting marked results of revived erosion. When the country was divided into strongly marked provinces by the Quaternary deformation, a considerable diversity was introduced between the mountains or plateaus on the one hand and the basins on the other. Both the pre-Quaternary unity and the Quaternary diversity were due largely to internal causes—to tectonic movements or to lack of movement. In the remainder of this report I shall consider a series of changes of a different character, which seem to have nothing to do with movements of depression or elevation, but appear to depend upon external controls. The changes now considered were climatic and seem to have affected all parts of the country at the same time, although in different ways. As the changes continued to take place through a large part of Quaternary time, they furnish the basis for a definite time-scale of wide application. They involve a series of oscillations between glacial and interglacial epochs. The plan of study outlined by Professor Davis at the beginning of our work in Turkestan directed attention to the evidence of possible climatic changes shown (1) in ancient moraines; (2) in terraces, especially along streams flowing from moraines; (3) in lakes and lake deposits; and (4) in deltas and flood plains of streams which do not reach the sea. In examining evidence of the first three classes it was found not only that climatic changes have occurred, but that there has been a series of changes of decreasing severity; it has, however, not yet been possible to correlate exactly the changes shown by one class of evidence with those shown by another. In the fourth class there should also be indication of climatic changes if the facts elsewhere observed have been rightly interpreted, but as yet this class of evidence has not been detected.

GLACIATION.

DISTRIBUTION OF GLACIERS AND AMOUNT OF EROSION.

During the two months' journey from Issik Kul to Marghilan a considerable number of glaciers, possibly fifty, were seen among mountains ranging from 14,000 to 18,000 feet in height. Most of the glaciers were small and ended close to the base of their cirques. The largest was that of Khoja Ishken* in the Alai Mountains, close to the Bokharan boundary, at the head of one of the innumerable Kok Sus or Blue rivers. It is a small example of the valley type of glaciers commonly associated with the Alps. Its length, so far as can be judged from very incomplete maps, is 5 or 6 miles. None of the glaciers descend to a low elevation,

*On the Russian map, scale 10 versts to the inch, this is called the Adramova glacier, but as the Kirghiz in the neighborhood use the name Khoja Ishken, I have adopted the latter.

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and in the Tian Shan Mountains, where the greater number were seen, the ice rarely descends much below a height of 12,000 feet. Among the Alai Mountains the Khoja Ishken glacier comes down to an altitude of about 11,500 feet, while others stand higher; and even the largest of those on the north side of the Pamir, descending toward the great Alai basin, comes down only to an altitude of 10,500 feet.

In former times, however, these small glaciers were much expanded, so that the Altyn glacier, one of those on the north slope of the Pamir, stretched out 20 miles; those of Yak Tash on the Tian Shan plateau and of Khoja Ishken in the Alai Mountains both reached a length of 30 miles; and the Mudirum glacier on the Tian Shan plateau must have been nearly 50 miles long at the time of its greatest extent. All these Quaternary glaciers were small compared with those of similar mountains in Europe and America. The lowest of them in the steepest valleys was not able to descend to an elevation below 7,500 feet. The large ones on the Tian Shan plateau did not descend below 11,000 feet—that is, only 2,000 feet below the ice of to-day; and of those in ordinary valleys, where the ice was free to advance indefinitely down a steep, narrow trough, not one descends over 3,500 feet below the present glacier. No trace of a general ice-sheet was seen. The significance of this will be discussed later. At present it serves to show that the area of glaciation was very restricted and that its effect on the topography of the region is purely local.

The effects of glacial erosion will not be described here, since they differ in no essential respect from what has been described under similar conditions in other countries. Bold Alpine scenery is found among the arêtes and three-edged peaks of the southeastern Tian Shan, the cirques of the northern Pamir, and the main valleys with over-steepened walls and hanging side valleys in the Alai range. The green moraines not only provide the traveler with an easy road, but furnish fine pasture for the flocks of the nomadic Kirghiz, whose round felt tents one is almost sure to find in summer not far from every old moraine. The most peculiar feature of glacial erosion is the broad troughs cut in the smoothly sloping surface of the warped Tertiary peneplain where it has been uplifted in the Alai Mountains and still more in the Tian Shan plateau. The troughs resemble a series of grooves. They head in cirques in the crest of the ridge and widen and deepen as the branch grooves join the trunk trough during descent, until at the lower end they are typical glacial valleys with over-steepened sides. They may be considered as the elongated form which a cirque takes in an inclined plateau.

THE SUBDIVISION OF THE GLACIAL PERIOD IN ASIA.

In America and Europe geologists as a whole have come to the conclusion that the glacial period included several cold epochs separated by intervals as warm or warmer than the present. Hence, after finding that old moraines abounded in Central Turkestan, it was of the first importance to learn whether they indicated a similar subdivision of glacial time in Asia; for if there were several glacial epochs, not only might it become possible to correlate Quaternary events in Asia with those in the other northern continents, but a definite time-scale might be established which could probably be extended to the lowlands of Western Turkestan. An

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unexpected result was obtained in the study of this question. The moraines were found to indicate glacial epochs so numerous that the writer was very slow to accept the conclusions that they indicated. It was not until a considerable number of glaciated valleys had been examined that credence was given to the occurrence of several glacial epochs separated by warm interglacial epochs. It thus appears that there were certainly two and probably five glacial epochs, separated by long non-glacial intervals of ordinary erosion, during which the climate was relatively warm.

AN OLDER AND A YOUNGER GLACIAL EPOCH.

The less doubtful question of two glacial epochs will be first taken up. The valleys where old moraines were found numbered over twenty, and all but three or four of them were examined up to their heads, or at least up to snow and ice. All, not even excepting the two or three small ones seen at first, show an older and a younger moraine (see Table III), although in some the distinction was but slight.

TABLE III.—*Glacial phenomena of Turkestan, showing the number of moraines in each valley visited and the glacial epoch to which each belongs.*

	Name and location of valley.	Elevation of base of lowest moraine.	Occurrence of moraines. Epoch I.	Epoch II.	Epoch III.	Epoch IV.	Epoch V.	Present VI.	Elevation of foot of present moraine.
1	Nameless valley, south of Son Kul	10,300	X (I–II)		X (III–IV)		......	......	....
2	Nameless valley, northeast of Son Kul....	10,700	X (I–II)		X (III–IV)		......	......	....
3	Tuluk Su (upper), north of Son Kul	10,000	X (I–II)		X	X	......	......	....
4	Tuluk Su (lower), north of Son Kul	10,000	X (I–II)		X	X	......	......	....
5	Kashga Su, south of Issik Kul	7,400	......	X	X (III–IV)		......	......	....
6	Ulakhol, south of Issik Kul............	8,200	X (I–II)		X (III–IV)		......	......	....
*7	Jukuchak, south of Issik Kul...........	8,600	X	X	X	X	X	X	11,600
8	Jukuchak, western tributary	9,300	X (I–II)		X	X	X	......	....
*9	Yak Tash, Tian Shan plateau..........	11,200	X	X	X	X	X	X	12,600
10	Chakur Korum, Tian Shan plateau......	11,200	......	X	X (III–IV)		X	X	12,600
11	Chakur Korum (south), branch of Kara Kul Su.	11,300	......	......	X (III–IV)		......	X	....
*12	Mudirum (Als Sai), Tian Shan plateau.	10,900	X	X	X	X	(?)	X	12,900
13	Kogargun (NE. of Chatar Kul), Tian Shan plateau.	11,600	X	X	X	X	X	(?)	....
14	Nameless valley, west of No. 13	11,800	......	X	X (III–IV)		......	......	....
15	Terek Davan (S. side), Alai Mountains.	10,950	......	(?)	X (III–IV)		......	......	....
16	Terek Davan (N. side), Alai Mountains	10,300	X	X	X	X	X	......	....
17	Kichik Alai, Alai Mountains..........	7,900	X	(?)	X	X	X	......	....
18	Kichik Alai (W. side), Alai Mountains.	7,500	(?)	X	X	X	X	......	....
19	Kauk Bel, Alai Mountains.............	11,500	......	X	X	X	......	......	....
*20	Taka, north slope of Pamir	9,700	X	X	X	X	X	X	11,500
*21	Khoja Ishken (Kok Su), Alai Mountains	8,000	X	X	X	X	X	X	11,400
22	Bursundu, branch of No. 21, Alai Mountains.	9,500	X (I–II)		......	......	......	......	....
*23	Kan Su, north slope of Pamir, in Bokhara.	8,500	X	X	X	X	X	X	10,500
24	Ispairan, Alai Mountains	7,500	(?) (I–II)		X	X	X	......	....

Crosses (X) indicate moraines. Where a cross is on a line the moraine may be of either of the adjacent ages.
Braces (—^—) indicate that though it is possible to distinguish two or more moraines they may be stages of one.
The elevations are taken by aneroid, and are only approximate within five hundred feet.

The simplest case is where a valley contains two moraines, one below the other, as in the valley of Kashga Su, a tributary of the Ulakhol at the southwest end of Issik Kul. Here, at an elevation of 7,400 feet, the lowest altitude at which any evidence of glacial action was seen, the lower portions of an old moraine are buried in valley gravels. The moraine itself consists of bowlders and rock waste of various sizes and kinds, deposited together in the usual glacial fashion. Its higher surface is smooth and rounded to such an extent that the topography peculiar to young moraines is almost obliterated, and the lower portions of the moraine show irregular hillocks and short ridges projecting out of a smooth valley floor of gravel in such a way that a removal of the latter would show the ordinary kettles of a typical morainic topography. Farther up the valley there is another moraine, entirely separated from the first. It has a younger, fresher appearance, and is not at all drowned in gravel; hence it must have been formed at a considerably later date than the other; but so far as the evidence of this valley is concerned the younger moraine might be merely a stage of retreat of the older one.

In other cases the relation is not so simple. The younger moraine lies, as it were, in the arms of the older, and the two appear to have been formed at widely different times, separated by a long period of aqueous erosion during which the ice retreated farther up into the mountains than the position of the younger moraines. One among many examples of this is found in the Tuluk Valley, north of Son Kul. Near the head of this valley and on its north side are two tributary valleys, from each of which projects a large body of morainic material which seems to be of two ages. The older moraine of the western or larger tributary takes the form of a rounded spur with its base at a height of about 10,000 feet. The spur has a long, grassy slope, fairly steep but thoroughly graded, and showing few bowlders. Its morainal character is more distinct on the top at a height of about 10,500 feet, by reason of ridges, imperfect kettle-holes, and other characteristic forms, and also by reason of more numerous bowlders. The topography is not fresh, however; the kettles are all drained, the slopes are gentle, there is a well-developed though circuitous drainage system, and the occasional bowlders are well rounded and decayed. The stream coming from the mountains has cut through the moraine an open flat-floored valley with graded sides. If this open valley is followed up, it comes to a sudden end at an elevation of about 10,000 feet, and above this level it is filled with a moraine that appears to be of much later date. The steep front of the latter has a slope of 30° instead of about 15°, as is the case in the older companion; there are deep, steep-sided kettles, some of them containing pools of water; drainage is but little developed, and the bowlders are mostly subangular. The stream here flows in a narrow V-shaped valley, the sides of which have an average slope of 35°. Yet the same stream, working just below in the other moraine, in what seems to be the same kind of material, has carved out a valley many times as large, with sides that slope at an angle of only 22°. The inner, smaller moraine shows all the signs of youth; the outer and larger all those of age. The two must have been formed at times so far separated that one moraine has had time to be maturely eroded and degraded while the other still remains young. As to what climatic conditions intervened between those times, and as to whether the two moraines represent two

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different ice advances or merely two stages of one advance, the evidence is not so positive, yet it seems to show that the two moraines represent two distinct glacial epochs separated by an epoch of retreat and presumable warmth. The rock floor of the main valley which the older moraine enters seems to have been normally eroded several hundred feet after the deposition of the moraine upon it, and the open valley in the older moraine grades into the newly eroded floor of the main valley. During the normal erosion of the main valley by its stream the glacier of the side valley can not have stood in a position to deposit the younger moraine, for the open valley cut in the old moraine extends farther upstream than that position, and the young moraine lies *in* the open valley worn in its predecessor, which forms a terrace above it. Therefore we seem obliged to conclude that after the first glacial advance the ice retreated above the position of the second moraine and only after a long lapse of time again advanced to deposit the younger moraine.

FIVE GLACIAL EPOCHS.

Let us now examine some of the more complicated cases in which there seems to be evidence of five glacial epochs separated by warmer interglacial epochs. It is only in those valleys where glaciers still persist that we can be certain that the whole series of ancient moraines is or has been represented. Eight examples of this sort were examined, of which two were seen imperfectly. The other six are distinguished by asterisks in Table III, page 184, where the name and locality of the valleys and the number of moraines in each are indicated.

(1) *Moraines of the Jukuchak Valley.*—The simplest case here, as in the previous examples, is one in which the moraines lie in a series one above the other in a narrow valley which has not greatly changed its form since the first glacial epoch. An almost perfect example of this type is found in the Jukuchak Valley (No. 7 of Table III), which may be ascended southward from an elevation of 5,000 feet at Issik Kul to an elevation of over 13,000 feet on the northern edge of the Tian Shan plateau. The lowest moraine lies at a height of about 8,600 feet. At this point the valley ceases to be the narrow steep-sided gorge which can be ascended with difficulty through its lower part, and becomes broad and easy to follow, although there is no accompanying change of rock structure and no apparent cause for the widening unless it be due to glacial erosion. On the floor of the widened valley a strong terrace is composed chiefly of large bowlders of granite, which could have come only from far up the valley and which are of such size that they could have been brought only by a glacier. The terrace is therefore interpreted as the remnant of a moraine so old that all traces of morainic topography have disappeared. Above the terrace the valley is unincumbered for a short distance; then it is clogged by another moraine which is well weathered and worn, but which still preserves in a subdued condition the characteristic glacial hillocks and hollows. Still further upstream a larger space of open valley is floored with gravel, on which the stream wanders somewhat; next comes another fresher moraine and another open space. Twice more these features are repeated before we reach the modern moraine at a height of 11,600 feet. Thus we have five old moraines and five interspaces. The

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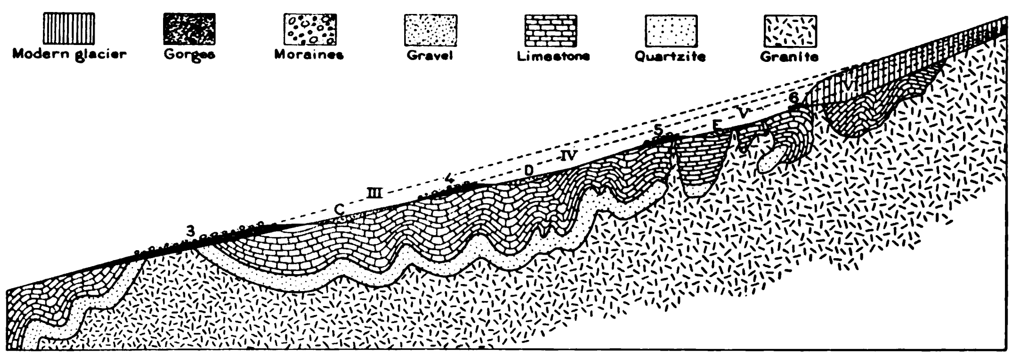
moraines grow fresher and younger in form from the lowest to the highest; and a long interval must have elapsed between the formation of No. 1 and No. 5. From the evidence supplied by other valleys it seems that each moraine represents an advance of the ice after a considerable retreat; so far as the Jukuchak Valley is concerned, however, the ice might simply have retreated by successive steps and the intervals between the steps need not have been of great length.

(2) *Moraines of the eastern Khoja Ishken Valley.*—Another valley, that of the Kok Su, or better, the eastern Khoja Ishken, shows the same succession of five moraines, which might all have been formed by one glacier in its successive retreats; but here erosion has been more active and the difference in age between the successive moraines is more marked. The first moraine lies at an elevation of about 8,000 feet at the mouth of the Kok Su, where it enters the Kuzzil Su of the Alai Valley. Like all the moraines of this earlier age, it has completely lost the original glacial topography and is only to be distinguished by the bowlders it contains. These consist of slate ranging up to 12 or 14 feet in size, which might have been derived



3, 4, 5—moraines of the third, fourth, and fifth glacial epochs. III, IV, V—level of valley floor previous to the third fourth, and fifth glacial epochs. C, D, E—gravel deposited at end of third, fourth, and fifth glacial epochs.

Fig. 131.—Longitudinal section of the Khoja Ishken or Kok Su Valley.

from close at hand, and of granite up to 7 feet in diameter, which must have been transported at least a dozen miles. The moraine is now entirely smoothed off and cut into four terraces. It lies on a thick deposit of river gravel which was probably laid down during the time just preceding the arrival of the ice. The second moraine is much like the first, except that it occasionally shows some of the original relief. If this valley were examined without reference to any others, these two moraines would be considered parts of one. The third, fourth, and fifth moraines are all distinct and are separated by spaces where the valley is open and aggraded. They lie on rock terraces high above the brook, which, as it approaches each moraine, plunges into a gorge. In these gorges may be found a good measure of the length of time that has elapsed since the several moraines were formed.

Before discussing this aspect of the problem, however, it will be well to consider the origin of the gorges themselves. This is best explained by means of the accompanying diagram (fig. 131). The line III represents the valley bottom at the beginning of the third glacial epoch. The advancing glacier came down this slope

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and paused at 3, where it deposited a moraine. Above this point the ice deepened and broadened its channel to the line IV. The erosive action of the glacier ceased where the moraine lay, and the only erosion there was that of the glacial stream which began to cut a narrow gorge that bore the same relation to its volume that the broad valley above bore to the volume of the ice that filled it. Thus the place where the moraine lay became an elevation with reference to the general grade of the valley, and at its upper end there was an actual as well as a relative increase of relief over the upstream portion, where the glacier had been at work. When the ice

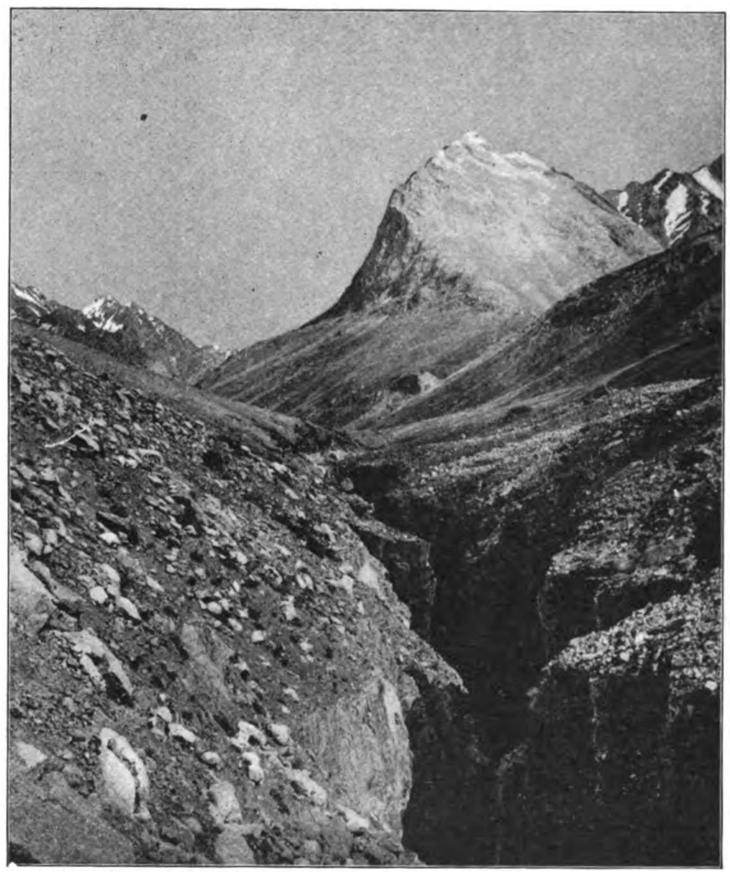

Fig. 132.—Youngest Gorge of the Khoja Ishken, cut in the Bottom of the Main Glacial Valley. The over-steepened sides of the latter show clearly on the right.

retired the stream continued to simplify the slope of its bed by filling the glaciated hollow with gravel (C) and cutting the gorge still deeper. Three repetitions of these events produced three gorges. Further examples of gorges thus formed were seen in the valleys of Ispairan, Kichik Alai, and elsewhere, although they were by no means so perfect as in the Khoja Ishken Valley. The glacial scouring of all these valleys seems to have been closely analogous to but less powerful than that by which the fjords and glacial valley lakes of Europe and America are supposed to have been formed.

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The two upper gorges of the Khoja Ishken Valley and part of the lower are cut in a metamorphic limestone which sometimes becomes marble, and in each the grade is so steep that the stream is still actively cutting downward. Hence the width of the gorges relative to the size of the stream gives a good measure of the time that has elapsed since each gorge was formed. The upper gorge, the one associated with the fifth moraine, is exceedingly young; so young that though it is cut to a depth of over 50 feet in solid rock it has scarcely widened at all, and the top is but slightly wider than the bottom (fig. 132). It is so narrow in one place that it has twice been naturally bridged by bowlders. One of these bridges is utilized by the road; the other is a great granite bowlder, 25 or 30 feet in diameter,

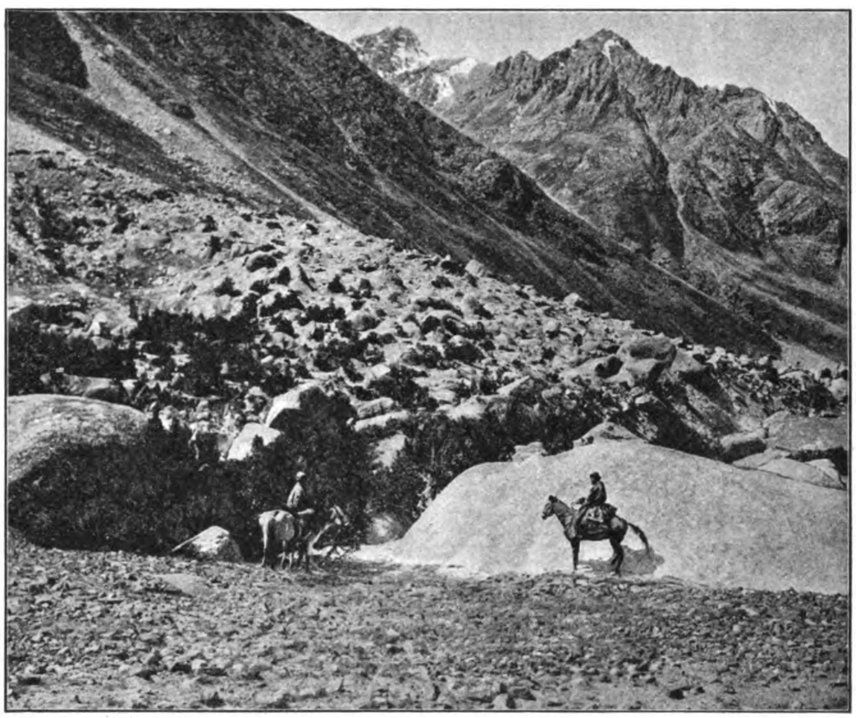

Fig. 133.—Marble Bowlders, and beginning of the Gorge associated with the fourth Khoja Ishken Glacier.

which lies directly across the narrow slit cut by the stream. The next gorge (fig. 133), belonging to the fourth moraine, though not much deeper than the upper one, is decidedly wider both relatively and absolutely, as shown by the accompanying cross-sections (figs. 134, 135). In spite of the fact that it is cut in marble somewhat harder than the limestone of the upper gorge, its sides have a slope of about 45° instead of nearly 90°. In one place it shows a little terrace near the bottom. It seems to be two or three times as old as its successor. The gorge of the third moraine, which is the oldest and the farthest downstream, is so broad that the road runs at or close to the bottom, and the sides have a slope of only 25° or 30° even where it is cut in granite or slaty quartzite. The terrace, which lies 200 or 300 feet above the stream, has been consumed to a mere fringe on the valley-side, and

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the valley floor is choked with waste from the moraine and the underlying rock. The difference in age between this gorge and that associated with the fourth moraine appears greater than between the gorges of the fourth and fifth moraines. This means that between the formation of successive moraines there must have been considerable intervals of erosion. Where the glacier stood during these intervals is not clear. It may have retreated above the position of the next moraine and again advanced; or it may merely have retreated to that position and there remained stationary.

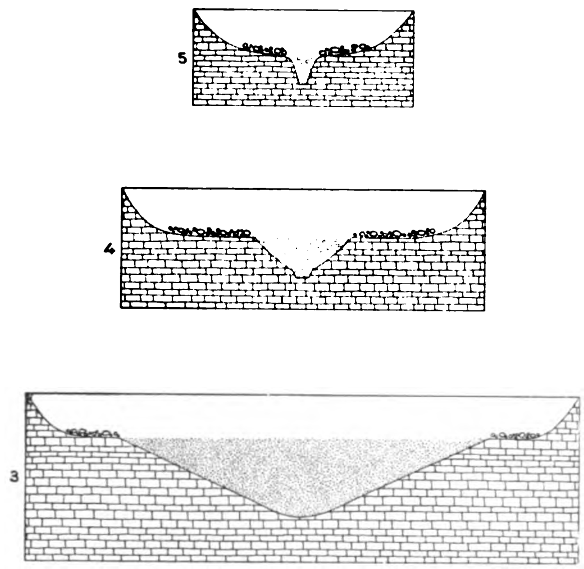

Fig. 134.—Cross-sections of the Khoja Ishken Valley, to show the shape and relative size of the three gorges. Drawn from observation, without measurement. The circles indicate moraines. The lightly shaded portions indicate the amount of erosion since the respective parts of the valley were filled with ice.

(3) *Moraines of the Mudirum Basin.*—A third valley, of broadly open basin form, drained by the Mudirum Su* on the south side of the Tian Shan plateau, shows old moraines of four and probably of five ages lying in regular sequence, without any indication as to what happened during the intervals between their deposition or as to whether there were any intervals when glacial deposition ceased. The glacier of this valley is the largest of all those of which the moraines were studied; it reaches a maximum length of nearly 50 miles. The thickness of the ice was so great that at Jubergenti pass it overflowed toward the north into the valley of the Kara Kul River. It was not possible to follow the Mudirum River to its head, but a side valley was examined as far up as a modern moraine. The relations of the moraines are illustrated in the accompanying sketch map (fig. 136). At the head of the valley are two tiny glaciers, A and B, with little moraines, marked VI. Below these is another moraine, V, which seems to be a little older, but may be merely a stage of VI. In the next valley to the west is a cirque with a very young moraine, V′, but no glacier. There is much snow near by, and these little moraines were not well seen. The next moraine, IV, is 500 or 600 feet lower, and is a large semicircular mass of clearly glacial origin. It is composed of limestone

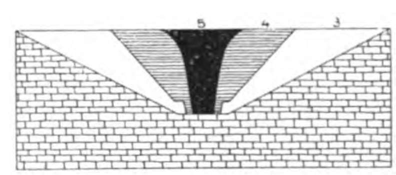

Fig. 135.—Cross-sections of the three gorges of the Khoja Ishken Valley, to show the amount of widening and erosion of the valley in each case relative to the power of the stream and of erosion without reference to the actual size.

*The Kirghiz call most of this stream the Ak Sai or White River, and apply the name Mudirum to the lower part only, but the name Ak Sai is almost as common as Kuzzil Su, and as this Ak Sai empties into another Ak Sai, it seems better to use the less common name.

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and slate, and accordingly is well weathered. The brook cuts through it in a narrow valley with steep sides. In front of IV is a nearly flat plain of silt and fine gravel, due to the obstruction of drainage by the next older moraine, III. This lies 1½ or 2 miles in front of IV and less than 200 feet lower. It is well dissected and graded, with kettle-holes only on the edges near the mountains, where it approaches its successor. The stream flows through it in a broad valley. The next moraine, II, is far larger, as it belongs to the whole valley and not merely to the tributary. It is 4 or 5 miles wide, 10 or 12 long, and several hundred feet thick. Because of its great size and because of its composition of granite, often in large blocks, it is less dissected than its small neighbor, III, but its location shows that it must be older. The stream valley which is cut through it is not of great width, although its sides are well graded. In the downstream half of the moraines the valley is wider and has three terraces. At the very front a moraine of later age, probably corresponding to the third in the above series, comes down from the north and covers the older moraine and its terraces. Below this there is an interval of nearly 9 miles with no moraines except a few small ones which come

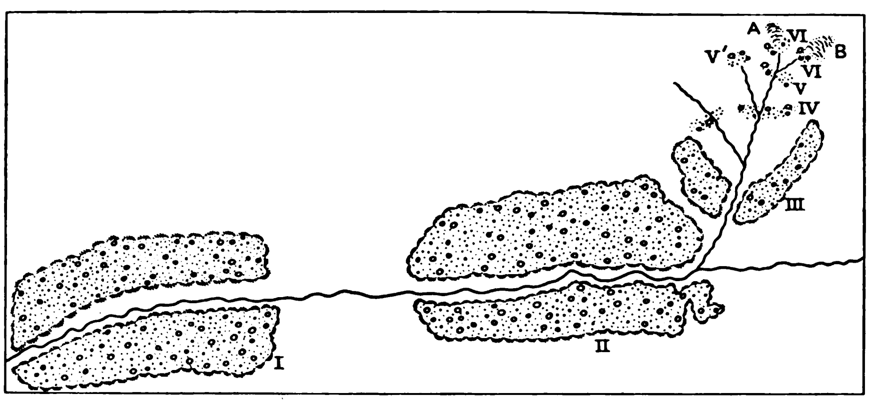

Fig. 136.—Sketch map showing the location of the Mudirum Moraines.

from side valleys and do not extend into the central portion of the main valley basin. Large bowlders of granite, sometimes reaching a diameter of 20 or 30 feet, are scattered here and there. The open valley floor is of gentle descent and falls but 100 feet in the 9 miles. Then begins the lowest and oldest moraine, I. At first it is complicated by a side moraine of later date, coming in from the south, but in its course of 7 or 8 miles farther west it becomes more and more smooth and free from surface bowlders and irregularities. Near its end two subangular masses of granite, from 10 to 15 feet in diameter, were noticed lying in the middle of the flat valley where they could not have been brought by water. Beyond this it is impossible to tell where the moraine ends and the gravel plain at its front begins.

Three examples have been described in the preceding paragraphs where the ancient glaciers have formed moraines at five different points successively farther and farther up-valley. These moraines may represent successive pauses of one retreat, in which the glacier retired quickly for a certain distance and then stood still for a considerable time, or they may represent distinct glacial advances

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separated by warmer intervals of retreat. Three examples will now be described which seem to be explicable only on the latter theory.

(4) *Moraines of the Yak Tash Basin.*—On the northern side of the Tian Shan plateau, south of the eastern end of Issik Kul, lies the broad valley basin of Yak Tash, surrounded by snowy ranges whose side valleys head in little glaciers (fig. 125). Starting from one of these glaciers, that of Jukuchak, which is crossed by the road from Przhevalsk to Chadir Kul, let us examine the moraines in detail, beginning with the youngest and proceeding to the oldest, which we find half inclosing the next to oldest. The present moraine is a tiny affair, perhaps 10 feet high, at the foot of a valley-head glacier scarcely a quarter of a mile long and composed largely of snow. Below this is a little pond, and then the broad, gentle slope of the side valley, which grows wider as it approaches and merges into the the main valley basin. The upper part of the side valley is floored with angular stones, but about 2½ miles from the glacier these give place to a fine horizontally stratified silt, which is now dissected to a depth of 6 or 8 feet. The silt appears to be the deposit of a lake, due to the damming of the stream by a moraine lying half a mile down the valley. This moraine is broad and flat, with few kettle-holes. It represents the last of the glacial epochs, the fifth. Below it is Arabel Lake, a sheet of water 2 or 3 miles long, hemmed in by the next moraine, and lying half in the main basin, half in the side valley. The moraine of the fourth epoch is of large size, extending 7 miles downstream, and spreading out broadly on every side so as to fill most of the Yak Tash basin. Under such circumstances the relief is naturally slight. The moraine is characterized by low bowlder-strewn hills with gentle slopes, and by broad, shallow depressions, of which twelve or fifteen were seen holding ponds from 200 to 2,000 feet in diameter (fig. 125).

The fourth moraine comes to a fairly distinct end near the point where the stream from Juuka pass turns from an eastward to a westward course. Beyond this, however, we encounter a moraine about 7 miles long which seems to be older than IV (fig. 136), but can not be sharply distinguished from it. At first sight it suggests a sand plain washed forward from the ice front, but that can not be, as it contains many bowlders 5 or 6 feet in diameter and some much larger, and in addition to this it increases in height at the lower end. It contains one or two small depressions filled with water, but otherwise its top is quite smooth, and its graded sides stretch evenly down the Jukuchak and Juuka streams, between which it lies as a long tongue. Bowlders crop out but rarely and all are well weathered, with the corners rounded off. Diagonally across the moraine runs what seems to be an abandoned channel of the Jukuchak, 50 feet deep and 400 or 500 feet wide at the top, with a string of ponds at the bottom. The other stream, the Juuka, was so far displaced to the north by the upper part of the moraine that it was caught in a rock-bound channel, where it has now cut for itself a narrow rock gorge.

The third moraine lies largely in the upper part of the typically glacial valley that connects the Yak Tash and Kara Sai valley basins. The hills above, except where they have been acted upon by glaciers, have gentle mature slopes, which form a distinct angle with the steep and often precipitous sides of the valley. The

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floor of the latter is half a mile wide and very flat where it is not cumbered by the third moraine. Many of the smaller valleys tributary to this one are themselves glacial in form and open in the sides of the main valley at heights of 300 or 400 feet, in true hanging-valley arrangement. These features are due to the work of the glaciers of the first and second epochs, and their freshness as compared with the weathering of the moraines is a good witness to the great influence of solid rock as contrasted with rock waste in preserving physiographic forms. About 6 miles below the junction of the Juuka and Jukuchak streams, which unite at the end of the third moraine to form the Yak Tash, the valley loses its glacial form and broadens into a basin 5 or 6 miles wide and 8 or 10 miles long. In this lies the second moraine, forming a great horseshoe. It still retains much of morainal form and has numerous undrained basins, many of them filled with ponds. On account of its breadth and flatness, it has suffered less erosion than has its steeper and narrower successor. The Yak Tash River flows through it in numerous braided channels, which wander freely over a gravel flood-plain a mile or two broad.

So far the moraines of the Yak Tash lie in a linear series like those of all the other valleys that we have considered. The relation of the first and second moraines is quite different. South of the Yak Tash 3 or 4 miles the character of the country changes quite abruptly as one passes from the second moraine to the first. On the north is the second moraine, a flat country studded here and there with bowlders and pitted with numerous little holes and irregular depressions. It is very clearly a moraine, for although the slopes are everywhere well graded, the drainage is irregular and by no means completely established. A belt of country south of this is 100 or 200 feet higher and has a thoroughly established drainage system, to which every part is tributary; the main river has cut a valley several miles wide through this belt. There is not a sign of kettle-holes or other glacial topography and at first sight there is no sign of moraine; here and there, however, large bowlders of slate or oftener of granite from 3 to 6 feet in diameter rise out of the smooth, fine soil, and smaller, angular bits of rock of various kinds are scattered about on the surface. These lie largely on hill tops, where they can have been brought only by glaciers, and are therefore to be regarded as belonging to an ancient moraine. The branch and main valleys are 200 or even 300 feet deep, and are cut through the moraine into an underlying deposit of soft silt. Apparently a glacier flowed into this basin soon after a great deposition of silt had taken place, and because of the flatness of the district the ice spread out broadly and deposited an extensive morainic sheet 10 to 50 feet deep. A period of subaerial erosion ensued, during which the ice retired long enough and far enough to allow the submature dissection of the moraine and of the underlying silts, and to allow the river to cut a valley 5 or 6 miles wide through both deposits. The ice must have stood much farther upstream during this epoch of erosion, and at its close must have again advanced to deposit the second moraine in the valley that had been eroded in the first moraine.

(5) *Moraines of the Kan Su Valley.*—In the Kan Su Valley all five of the old moraines can be detected in addition to the modern one, but the first and second are not well differentiated and do not need to be considered. The third moraine lies at an elevation of about 9,000 feet in the triangle between the two main branches

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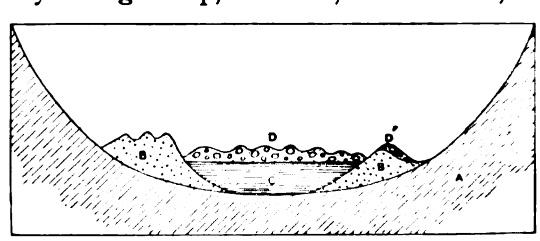
of Kan Su. It shows something of morainic topography, although this is not very marked. The slopes are thoroughly graded and covered with grass, and the moraine as a whole is cut by several subparallel valleys, two of which are occupied by streams and have slightly terraced sides, while the others are abandoned, and seem to be stream channels of glacial times. Their heads are abruptly cut off by the fourth moraine, which lies at an elevation of about 9,500 feet, where there is a sudden rise in the valley floor, and where the main valleys which are not beheaded contract somewhat. At the top of this rise lies the distinct frontal ridge of the fourth moraine, horseshoe-shaped and inclosing a depression. The rest of this moraine has a pronounced glacial topography, although the slopes are perfectly graded. Moraines Nos. 3 and 4 appear to be of different but not widely separated ages. The vegetation of both has reached what may be called the stage of complete occupation; that is, they are covered with a fine growth of grass, except in the valleys, where there are some trees. The fifth and last of the old moraines, on the contrary, has not reached this stage. It begins at an elevation of 10,100 feet, where there is a sudden change to very rough moraine topography, which seems to be of considerably later date than that on which it lies. Instead of the surface being smooth and grassy and almost free from stones, the rough slopes are covered with angular fragments of rock, among which are scattered cedar trees and a growth of thin, weedy grass quite unlike the turf below. The bowlders, too, are larger, more numerous, and more angular than those of the other moraines. The difference between this fifth moraine and its predecessor is more marked than that between the adjacent older moraines. The present moraine at an elevation of 10,500 feet is quite as sharply distinguished from the fifth as the fifth is from the fourth, and the change is of the same sort. The present moraine exhibits in many places a sharp line of division, above which the rock waste is even more angular and fresh than below, and above which there is practically no soil filling the interstices of the rock and hence absolutely no vegetation. Much of the moraine lies as a cover on the ice itself.

In its lower portion the modern moraine spreads out, so that for a short distance it fills the whole width of the valley. Higher up, however, the moraine, or rather the glacier itself with a covering of moraine, lies in an inner valley cut in moraine stuff of an older date. This is represented in the accompanying cross-section through the valley at an elevation of about 11,000 feet (see fig. 137). The portion A represents the rock valley composed of limestone below and purple slate above; B represents an older moraine, either No. 3 or No. 4, which was formed so long ago that its slopes are thoroughly graded and are well covered with grass, and bowlders have almost disappeared. Yet it is not so old but that it still retains signs of a morainic topography, though this is so far destroyed that the



A—rock walls of valley. B—moraine of third or fourth epoch. C—modern glacier. D—modern moraine. D'—bit of modern moraine which has overflowed B.

Fig. 137.—Cross-section of the Kan Su Valley at an elevation of 11,000 feet.

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kettles are drained. On the outer edges are valleys where streams probably flowed along the two sides of the glacier, as they often do. The inner slopes of these two portions of an old moraine are very steep, as they are now being undercut by the ice, C, on which lies part of the present moraine, D. The slopes show that the material of the old moraine is truly glacial in its angularity and irregularity of size, but utterly different from the present moraine in that it is well weathered and that the soil produced by weathering fills all the interstices. In fact, the slopes seem to contain decidedly more soil than rock. At present the modern moraine lies 50 feet more or less below the top of the older ridge, but there are many places where it formerly rose to the top and overflowed, as at D.

These facts seem to lead to the conclusion that between the deposition of moraine No. 3, or 4, as the case may be—it is quite immaterial which—and the deposition of the present moraine, the ice retreated to a position farther up the valley than that which it now occupies, as the following considerations will show. It may, perhaps, be taken as beyond question that a moraine such as B can not have become thoroughly weathered, graded, and covered with grass without long exposure to the air; nor does it require discussion to show that where graded slopes, such as those of B, are being undercut, they must once have extended farther in the direction of the agency which undercuts them. Therefore the ice must for a long time have occupied a smaller space than at present, and since that time it must have widened. But this could not have been possible with a continuously retreating glacier, for it should have suffered a continuous narrowing. Moreover, on the supposition of continuous retreat, with or without pauses, but without readvances, each moraine ought to lie above the one that preceded it, and this seems to be the crux of the whole question. A portion of the third or fourth moraine—let us say the fourth for convenience—lies from 1,000 to 2,000 feet above the rest of that moraine, and from 1½ to 3 miles farther upstream. Between the two portions of the fourth moraine lies the whole of the fifth and most of the sixth moraine. It seems impossible to explain the facts on the theory of one retreat whether at a uniform rate or with pauses.

If, on the other hand, each moraine represents an advance and retreat of the ice, the difficulty disappears. The old glaciers were probably covered with moraine stuff just as the present one is, and as each retreated it would leave a trail of moraine behind it. The glacial stream would carve a valley in the abandoned moraine during the interglacial epoch. The next glacier would follow this valley at first, though it would widen it greatly, and in most cases utterly obliterate it. But each succeeding ice sheet was smaller than its predecessor, and where the valley was wide it might happen that portions of the older moraine would be preserved. This is what appears to have taken place at Kan Su. If this interpretation is correct it means that after the formation of the main portion of the fourth or possibly the third moraine, the ice retreated so far as to end at least 1,200 feet above the level of its moraine, and so reached a point 700 feet above the present level of the glacier front; that is, the fourth glacial epoch was followed by an interglacial epoch decidedly warmer than the present epoch.

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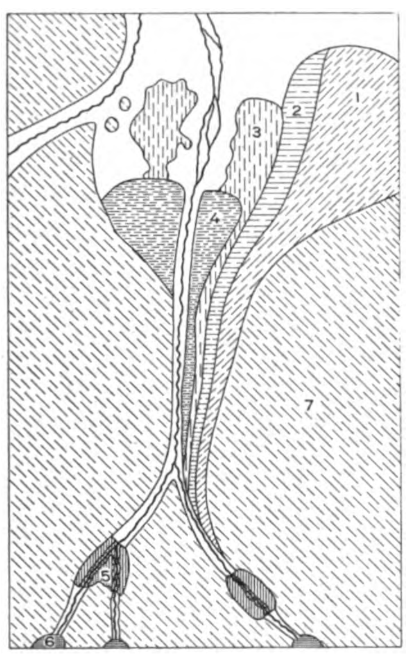
(6) *Moraines of the Taka Valley.*—The last valley to be described, that of Taka Su, on the north side of the Pamir, heads in two large cirques on the north slope of the peak of Khitai Saz, 17,500 feet high. The slope from here to the Alai basin is steep and the stream has been cutting steadily downward all through glacial times and to the present. The cutting has been most active in the soft Mesozoic-Tertiary strata which lie between the basin and the mountains. As this is the place where most of the moraines were deposited, they too have been dissected; but fortunately none have been entirely destroyed, and the dissection furnishes a means of ascertaining what occurred during the interglacial epochs. The moraines number five, in addition to the one now in process of formation, and all are distinctly separated from their neighbors. We will take them up in order of age, beginning with the oldest.

The first moraine is merely a covering of bowlders and finer glacial material lying on the hills east of the Taka Su, at an elevation of from 800 to 1,200 feet above the stream where it debouches on the plain of the Alai basin (fig. 138). The bowlders are chiefly limestone or calcareous slate of the common Paleozoic type, and many are of large size and quite angular. The surface of the moraine is completely graded, and shows only a few traces of glacial topography, such as crooked drainage lines and a few detached hollows. The country rock does not crop out through the moraine itself, but on the sides of the valley cut through the moraine the red beds of Mesozoic or Tertiary age, which extend all along the base of the mountains and must underlie the moraine, are seen up to an altitude of 600 feet above the stream.



Unshaded areas represent gravel. 1-5—old moraine; 6—modern moraine; 7—bed rock.

Fig. 138.—Plan of the Moraines of the Taka Valley.

The next moraine is composed of the same materials as the first. It has clearly the morainal type of topography, although in a subdued and well-graded form. Its relation to the others is shown in the accompanying sketch map and cross-section (figs. 138 and 139), where it is seen that the second moraine lies as a narrow terrace in the valley which was eroded on the western side of the first, about 400 feet above the stream. The first moraine was formed when the valley had been eroded to a depth much less than now and when the glacier was therefore free to spread over a considerable area. The second moraine was formed when the relief was much more like that of to-day, and the glacier was closely hemmed in by a well-defined valley. It seems impossible to explain this relation except by supposing that after the first glacial epoch the ice retreated far upstream above the upper end of the terrace and staid there long

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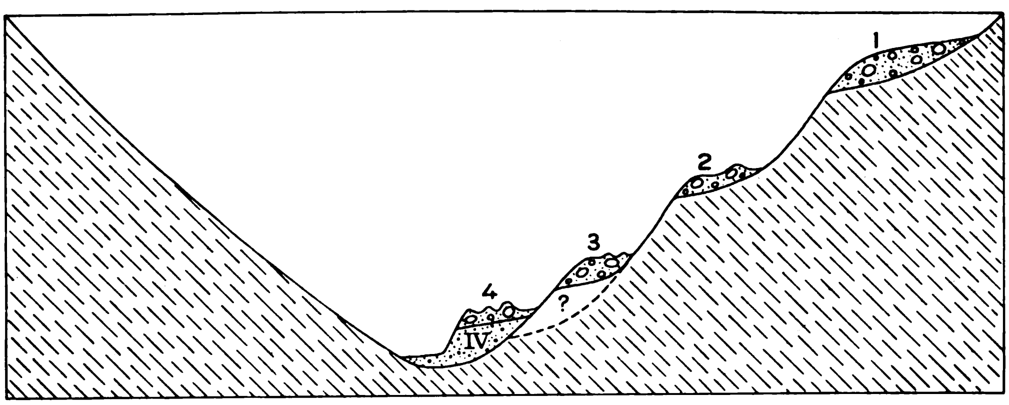
enough for the stream to cut a valley 400 or more feet deep across the soft strata which stretch along the base of the mountains. A second advance of the ice widened this valley and deposited another moraine on its floor.

After this the ice seems to have again retreated, while a second epoch of normal erosion ensued. This was of considerable duration, since it was sufficient not only to account for the considerable differences in amount of weathering between the second and third moraines, but also to allow the cutting of a valley 300 or 400 feet deep through the second moraine. That the second moraine was so deeply eroded is made clear by the fact that the third moraine lies more than 300 feet lower than the second. A glacier can not deepen its valley where it is depositing a moraine; therefore the erosion of the valley must have been performed by water after the ice had retreated. The moraine, the third of the series, which was formed after this epoch of erosion lies in a valley of almost the same form as that of to-day. The moraine itself consists of a broad, rounded lobe which rises abruptly in a smooth, steep slope from the extensive gravel plain of the Alai basin and has



1, 2, 3, 4—moraines of the respective epochs. IV—gravel deposited in the valley as the fourth glacier was advancing.

Fig. 139.—Cross-section of the Taka Valley, looking north.

the characteristic, though slightly subdued, topography of a moraine. Through the middle runs the very broad flood-plain of the Taka Su. The moraine is more complete than either of its predecessors, because the lower parts of the earlier moraines have been cut off by the broadening of the main Alai basin in the soft Tertiaries. Upstream the third moraine is prolonged for 2 or 3 miles in the form of a terrace of the same sort as that of the second moraine below which it lies.

The next interglacial epoch, that between the deposition of the third and fourth moraines, seems to have been shorter than its predecessor; nevertheless there must have been an interval of retreat during which aqueous erosion again deepened the Taka Su Valley. This is shown by the fact that the fourth moraine, like both the second and third, is prolonged far upstream in the form of a terrace covered with glacial débris and having along its inner edge an old stream channel. The terrace is smaller than the one above it, just as that is smaller than its predecessor. The main body of the fourth moraine lies directly upon the third, about a mile

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back from whose front it rises sharply 100 feet or more. It is of the same material as all the others, but is decidedly fresher in form. The hills and hollows are very clearly defined, though all are well covered with grass, and some of the kettles contain water. Where the Taka Su traverses the moraine it has cut a flood-plain about 100 yards wide, on the sides of which are steep, ungraded walls, disclosing the structure of the underlying deposits. Here it is seen that the moraine lies upon a considerable deposit of gravel. The same feature is seen in a number of other cases, where water-laid gravel underlies moraines of various ages. This shows that previous to the formation of such moraines there was a time of aggradation, probably due to the increasing load of the stream which heralded the advance of the ice. As soon as the stream leaves the fourth moraine and enters the third there is a sudden and very marked change in the character of the flood-plain, which expands abruptly to five or six times its former width. This is not due to change in material, for the moraines are alike in composition ; nor is it due to the less thickness of the deposit which is cut through in the older moraine, for if this were the case the broadening would be gradual and funnel-shaped instead of sudden and at right angles. Moreover, in the older moraine the flood-plain is not limited by steep stream-cut walls as it is above, but by gently sloping, sinuous shores rather than banks; for the moraine is half-drowned in flood-plain gravel, so that the kettles form deep bays and the hills form islands and promontories. The gravel which drowns the third moraine seems to belong to the same epoch as that which underlies the fourth, although lack of time made it impossible to trace one into the other. Apparently at the end of the third glacial epoch the ice retreated above the upper limit of the terraces, and normal stream erosion proceeded far enough to cut into the underlying rock along the terraced portion of the valley, and to cut a broad swath through the latest moraine. Then, as the interglacial epoch drew to a close, there seems to have been an increase in the load of the streams. As a result, the whole valley was aggraded, and in the region of the moraine the aggradation was so great that it not only filled the valley eroded in the moraine, but caused the gravel to overflow and cover the adjacent parts of the moraine itself. Meanwhile the glacier was advancing. In its upper course it doubtless widened and deepened the valley, but near the front it ceased to erode and flowed on top of the gravel and the earlier glacial deposits, there forming a new moraine, the fourth of our series.

The youngest of the old moraines is a small one far up the valley, close to that which is now being formed. There is nothing to prove that it does not mark merely a stage in the retreat of the fourth glacier. The other moraines, however, seem to represent epochs and not stages, so that, judging from analogy and even without the evidence of the Kan Su moraine (p. 193) the fifth moraine ought to represent a glacial advance following a retreat. It is noticeable that each moraine is smaller than its predecessor and, except for the older ones, of which the ends are cut off, each moraine extends to a less distance downstream than its predecessor. The amount of erosion in the successsive interglacial epochs also grows less and less.

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SUMMARY OF THE GLACIAL PERIOD.

The facts presented in the preceding sections, together with others of a similar nature not here recorded, show that in Central Turkestan there are many evidences of a Quaternary glacial period, although all records of glaciation are confined to high levels. Wherever old moraines are well developed they indicate that the glacial period is divisible into two or more subdivisions; and where the valleys are large and reach high enough still to contain glaciers the number of these subdivisions is five, marked by successive moraines, each of which is smaller and at a greater altitude than its predecessor. Two theories present themselves as worthy of consideration in explanation of these facts. According to one there was but a single glacial advance and retreat. The retreat was not accomplished uniformly or rapidly, but by successive steps, after each of which there was a long pause that gave opportunity for the accumulation of a moraine; thus five moraines were formed by each glacier and those now in process of deposition belong to the sixth step of the same long retreat. According to the other theory, each moraine represents a distinct glacial epoch, during which the glaciers first advanced and then retreated. Under this theory the intervals of retreat were as warm as or warmer than the present and the ice retreated far into the mountains during each of them.

For fifteen out of the twenty-four glaciated valleys examined the first theory is sufficient, but it will not explain the other nine. In eight of these nine valleys one or more of the older moraines lies upon a topography different from that of to-day, so as to suggest that the moraines and the floor on which they rest have been trenched by a valley of stream erosion. In this valley lie the younger moraines, leaving the older moraines as terraces which extend beyond the later moraines both up-valley and down-valley; the up-valley extension of the morainic terrace gives a minimum measure of the retreat of the glacier during the interglacial epoch. In the ninth valley a detached portion of an older moraine lies far up-valley from its successor and even above the main part of the modern moraine. These facts are to be explained only by supposing a glacial retreat and advance in each interglacial epoch, and hence a warmer interglacial epoch between colder glacial epochs. Another sort of evidence of a warmer interglacial epoch is found where one moraine lies upon its predecessor in an attitude which indicates that before the deposition of the younger moraine the older one was first an area of erosion and later of deposition. All these facts accord with the theory of successive advances and retreats, and thus warrant the division of the glacial period into several glacial and interglacial epochs. In one place or another signs of an interglacial retreat are found between each successive pair of the four earlier moraines, while the fifth moraine stands apart from the others, except at Kan Su, where the time during which there is evidence of retreat may be either between the third and fourth or fourth and fifth advances of the ice. Everywhere the climate of the successive glacial epochs seems to have grown less severe, and the duration of the interglacial epochs seems to have diminished in the same ratio.

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COMPARISON OF GLACIATION OF ASIA WITH THAT OF AMERICA AND EUROPE.

When the glacial history of Asia is compared with that of America and Europe there is found to be an essential agreement of the main facts. In all three continents there seem to have been cold glacial and warm interglacial epochs. American geologists usually recognize three advances of the ice, while many European geologists recognize a larger number, and in Asia, as we have seen, there seem to have been five. In so far as these facts agree, they indicate that the cause of the glacial period must have been of widespread influence, since it has produced similar effects in many parts of the northern hemisphere. The present discrepancy in the number of glacial epochs detected in different regions may yet be reconciled; but there is another discrepancy which can not as yet be explained. It has been already stated that the glaciation of Central Asia was much less severe than that of Europe and America. A specific comparison will make this clearer. The only European mountains that are at all comparable in height to the Alai and the Tian Shan ranges are the Alps; but the Alps lie so much farther north than the Tian Shan and in a region of so much greater precipitation that a direct comparison as to glaciation can not be made between them. In America, however, the Uinta and Wasatch ranges, although somewhat lower than the Asiatic ranges, are in other respects very similar to them. In both cases the mountains lie at a latitude of from 40° to 42° N., in the center of a continent far from the sea, and therefore in a region of slight rainfall. Close by are extensive desert plains, along the border of which are numerous piedmont villages dependent entirely on irrigation by mountain streams. The Asiatic mountains are higher than the American ranges above named by an average of fully 3,000 feet; they seem also to have at present a greater precipitation, if we may draw such a conclusion from the number of summer storms, the height of the snowline, the number of perennial streams, and the amount of vegetation. From these considerations it is clear that if during the glacial period there was an equal climatic change in both countries the Asiatic glaciers ought to have descended lower than the American; but this was not the case. Let us compare the figures in the two regions.

In order to avoid all possibility of exaggerating the unlikeness between the Asiatic and the American ranges, let us say that the average lower limit of permanent snow is 13,000 feet in both cases, although in America it is above this, and in Asia decidedly below. Let us also suppose that the greater height of the Asiatic mountains had no effect on the descent of their more protected northern glaciers. Even with these concessions we find that the Uinta Mountains were covered by glaciers which locally merged into something of an ice sheet near their western end, while those of the Alai and Tian Shan were all confined to the valleys. The average descent of the ice in the twenty-four valleys listed in Table III, from the assumed snow-line of 13,000 feet, places the base of the lowest old moraine at 9,740 feet; while in the Uinta and Wasatch mountains the average altitude of the moraines on the northern slope is 8,055 feet and on the southern slope 7,033 feet, as determined by Dr. W. W. Atwood. If we compare the extreme points to which the lowest glaciers descended below the present snow line in either region it appears

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that in the Wasatch and Uinta ranges there are cases of a descent of 8,000 feet, although in the Alai and Tian Shan mountains the extreme is only about 4,000. In seven Asiatic valleys in which there are still glaciers at the valley head the average descent from the foot of the glacier to the foot of the lowest moraine was 2,150 feet. In four of these cases, where the old moraines lie in sloping valleys and the old glaciers were therefore free to descend without obstruction, the average descent from present glacier to oldest moraine is 2,550 feet; in the three other cases where the old moraines lie in flat basins and the glaciers could not descend to lower levels, it is 1,600 feet. Similar measures can not be given for the American mountains, since no glaciers exist there to-day, but from the other figures already given it is to be inferred that the American measure would be at least twice as great as the Asiatic. It is conceivable that this difference in intensity between the glaciation of Asia and that of the other continents was due to a shifting of the poles; but besides being without assignable explanation, this hypothesis becomes complicated to an untenable extent when it is made to explain the interglacial epochs also. A simpler hypothesis is that during glacial times the sea covered northern Asia and rendered the climate more equable, a theory which has been advanced by several writers. Before this hypothesis can be adequately tested a great array of facts is required not only in regard to the old glaciers themselves, but also in regard to rainfall and evaporation and in regard to the changes of elevation which the land has suffered relative to the sea.

TERRACES.

If during the Quaternary era there were climatic changes of such magnitude and frequency as those demanded in explanation of the old moraines, the changes must have left their traces all over the region. Such traces can be detected in two situations, namely, the terraces of streams and the deposits of lakes. The most striking feature of the terraces in the valleys of Central Turkestan is their wide distribution and uniformity of pattern, without respect to the size or location of the stream along which they occur. They were seen in the valleys of swift mountain torrents and along the sluggish rivers of the plains. They occur not only in the valleys of tributaries of the Syr Darya (Jaxartes) on the north, and of the Amu Darya (Oxus) on the south, but also along the streams that wither to nothing in the Kashgar basin, whether their source be the Tian Shan plateau to the north or the Alai Mountains to the west; and they are found even along the water-courses leading to inclosed lakes. They vary in number from stream to stream as well as in different parts of the same stream. At the very head of a valley there is naturally no terrace, but as the valley is followed downward, first one terrace appears and then another, until in that portion of the valley where erosion has been more active the terraces reach a maximum both in size and number. Farther down-valley they again decrease in both respects until finally, far out on the floor of some basin, a single weak terrace dies out entirely as the stream becomes an agent of deposition rather than of erosion.

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The number of terraces ranges from none to nine, but neither extreme represents the true state of affairs. Where terraces are absent it is either because the slope of the streams is so gentle that there is no erosion or because the slope is so steep and the country rock so resistant that the streams have as yet been able to cut only narrow gorges. Where the number is over five the material is usually unconsolidated gravel, and some of the terraces are usually small and seem to be mere stages of larger ones. Ordinarily there are from three to five terraces. The number of valleys for which the writer has a record is forty-three, and the number of terraces in these valleys is shown in Table IV. The number of valleys with only one or two terraces was really larger than appears from the table; for after the widespread distribution of the terraces had been noticed, valleys where only one or two occurred were not recorded.

Table IV.—*Terraces.*

Valleys with—		Valleys with—	
One terrace	3	Six terraces	4
Two terraces	3	Seven terraces	3
Three terraces	12	Eight terraces	0
Four terraces	8	Nine terraces	1
Five terraces	9		

The terraces are sometimes cut in gravel (fig. 140), and sometimes in rock (fig. 141), but in the latter case there is always a cover of gravel lying over the rock. It may happen in a single valley that the upstream portions of the terraces are almost wholly cut in rock, while the downstream portions are entirely in gravel, as, for instance, along the Kuzzil Su, at the southeast end of Issik Kul. In valleys such as those of the Ispairan Su, flowing to Marghilan, and of the Ak Bura, flowing to Osh, it often happens that the terraces are cut for a certain distance in soft strata, or in gravel that fills a basin where soft strata have been excavated, although farther down the stream flows through a narrow canyon in hard strata, without a trace of terracing; but when the hard strata end and soft ones begin once more, the terraces are resumed as though they had never been interrupted.

Another and perhaps the most characteristic feature of the terraces is the persistence with which the different members of a series preserve the same relative height and width. In terraces due merely to the swinging of the stream from side to side as it cuts steadily downward, one terrace is here or there cut off either at the upper or lower end by another terrace of later date, and a pattern of cusps and bays is thus formed along the valley side. In such cases a single terrace can only be traced a short distance, and the number of terraces is continually changing. In the mountain valleys of Central Turkestan, on the other hand, although it sometimes happens that one terrace truncates another and thus forms a cusp, this is far from being a prevalent condition; each level is, as a rule, distinct and does not interfere with its neighbors. Several terraces often run for many miles side by side without interfering with one another, each one preserving an almost uniform width with remarkable persistency. As a rule, too, the uppermost terrace possesses not only the greatest width, but the greatest height. Such a regular diminution in size can mean only that the cause of the terracing was of steadily decreasing efficiency.

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TERRACES AS A RESULT OF WARPING.

There seem to be but two causes competent to produce terraces of so wide a distribution and so uniform a character. One of these is warping of the earth's crust and the other is change of climate. It is highly probable that terraces resulting from both causes may exist close together, but in the main the terracing in Central Turkestan seems to be due to climatic variations. The reasons for this conclusion are, first, the wide distribution of the terraces, and, second, their relation to the deposition of gravel.

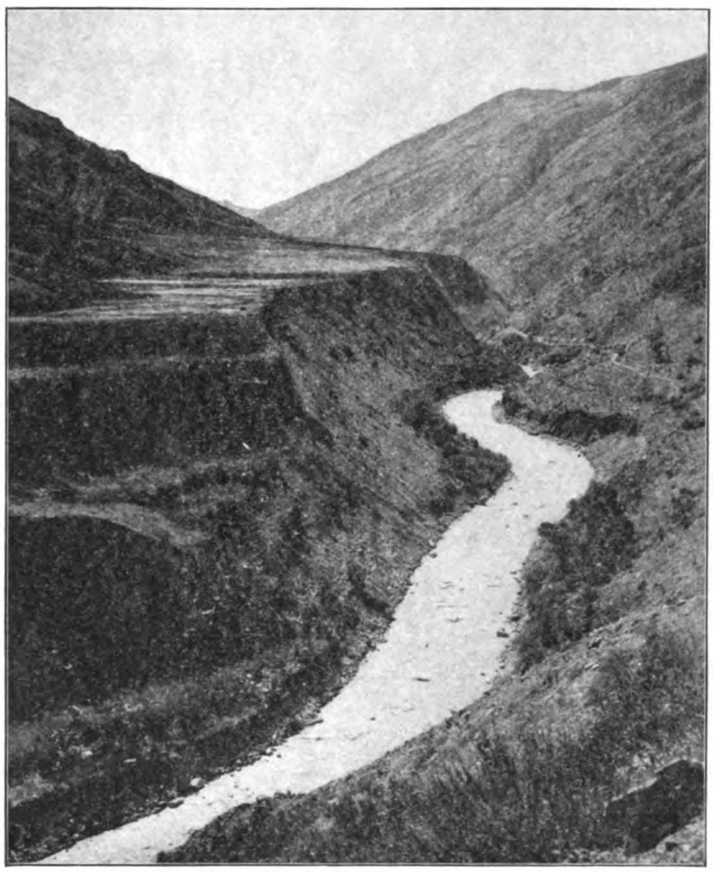

Fig. 140. – View down the Kuzzil Su on the eastern border of Bokhara, showing a gravel-filled valley which has been re-excavated. In the foreground four terraces can be seen on the left.

A phenomenon of so wide an extent and of such uniformity in essential features as are the terraces must have a proportionately extensive and uniform cause. It is possible to imagine a complicated and intermittent bending of the earth's crust so extensive and so systematically related to the streams that all portions of a large area containing four or five distinct and interlocking river basins, with streams flowing in every direction, should be warped so as to cause every stream to cut terraces of the same sort and in the same order. But this would involve a more highly specialized type of bending than is known elsewhere. It would require that

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each of the mountain masses, large or small, should be intermittently elevated or that each of the basins should be intermittently depressed in such a way that all the streams should be intermittently accelerated in their work of erosion. This process involves an alternation of movement and rest from four to six times in each separate drainage area, and at each alternation the amount of uplift and the length of the period of rest must have decreased. All this seems improbable, whatever may be thought of its possibility.

It is, however, not only the erosion of the terraces that has to be accounted for; in most cases each terrace involves an epoch of deposition preceding the epoch of erosion. The gravel deposits in which the terraces are carved occur not only at the mouth of every valley where it opens on the plain, but also along the course of

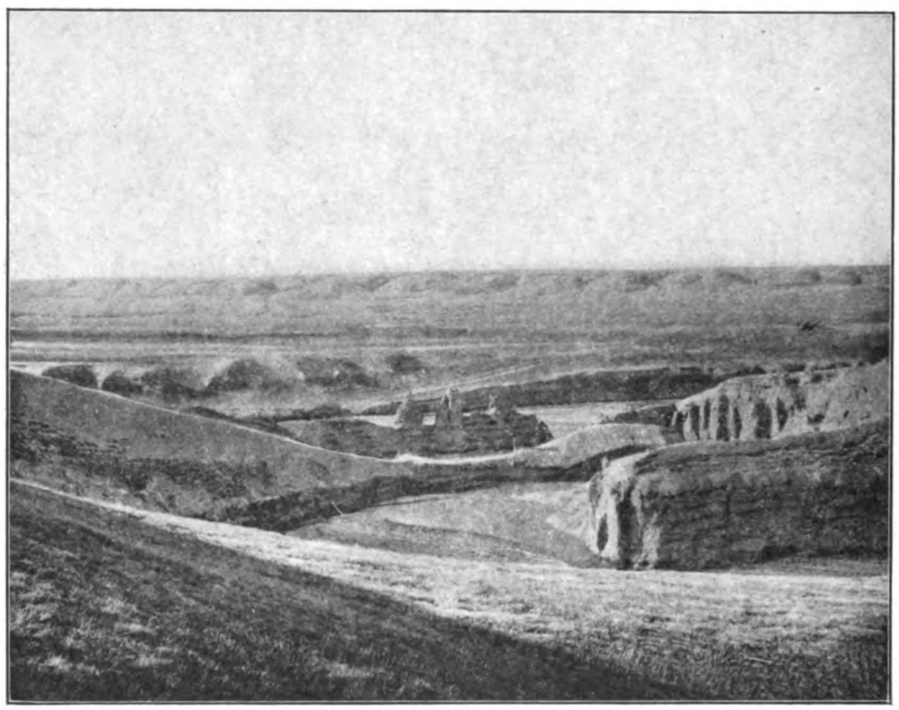

Fig. 141.—Terraces and Meanders of another Kuzzil Su near Chadir Kul, on the Tian Shan Plateau, at an elevation of 11,000 feet. These terraces are cut partly in gravel and partly in red Tertiary limestone.

many streams almost to their heads. Sometimes the gravel lies on rock-cut terraces (fig. 142), where it might have been formed during periods of rest when no uplift was in progress. In other cases, however, the terraces along large portions of the stream course are cut in gravel only, and the rock bottom of the valley is now no deeper than when the first gravel deposits were begun (fig. 143). Where this is true the net result of whatever crustal movements have taken place has been that they have balanced one another in such a way as to bring the region back to essentially the same position that it first occupied. There must have been depression to cause the aggradation of the valleys by gravel deposits, and this must have been followed by periodic and decreasing uplifts of which the sum was equal to the total previous depression;

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nor does this show the full complexity of the problem. In the valley of the Ispairan Su, south of Marghilan, for example, gravels of two and possibly three ages can be detected. The oldest is a very coarse deposit three or four hundred feet thick, which is cemented into solid conglomerate by calcite from the limestone walls. A deep valley was then cut in the conglomerate, so that its remaining portions form a terrace several hundred feet above the stream (fig. 144). This valley was then filled, though to a much less height than before, with gravel of the same sort as the first, except that it is not cemented so firmly into conglomerate. In this second conglomerate another valley has been cut; and there are places where the filling and cutting seems to have been repeated a third time on a still smaller

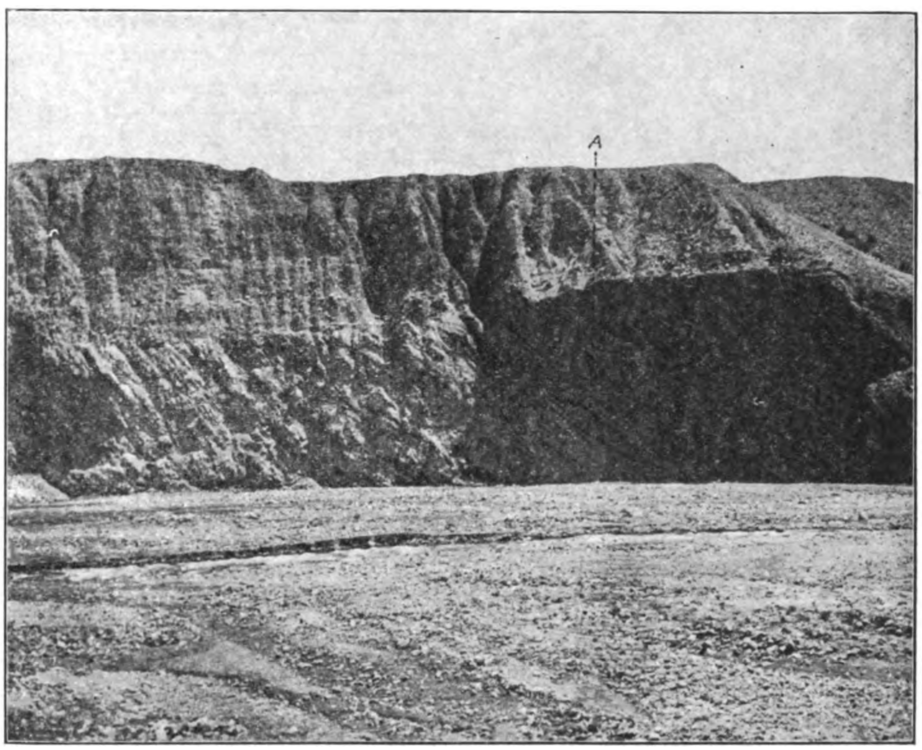

Fig. 142.—Terrace wall of the Kan Su, west of Kashgar, showing horizontal gravel above tilted Mesozoic strata. On the left or north side are the coal measures; on the right are the vermilion-red beds. Between the two can be detected a slight unconformity, A.

scale. If all this is due to deformation it means that there has been an extraordinarily complex series of palpitations—now up, now down—and that while the upward movements have been parallel over large areas, the downward movements have occurred erratically here and there in such a way that the terraces of valleys close beside one another are of different types, or that the upper part of a valley has merely been cut again and again, while the lower part has been both cut and filled an equal number of times. If, then, the theory that the terraces are due to movements of the crust can not be said to be absolutely untenable by reason of the complications that it involves, it certainly matches the facts only indifferently well.

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TERRACES AS A RESULT OF CLIMATIC CHANGES.

Let us see if the other theory, that of climate changes, is more satisfactory. Starting with a climate and topography similar to those of to-day, what would be the effect of successive epochs of glacial and non-glacial climate or of colder and warmer climate? Judging by what has been found true in other parts of the world, the effect would be just what we find in the terraces of Central Turkestan. During the epochs of colder climate aggradation would take place in all the valleys where the streams had already attained a graded condition; and that condition would soon be established in those valleys where the slope was relatively gentle,

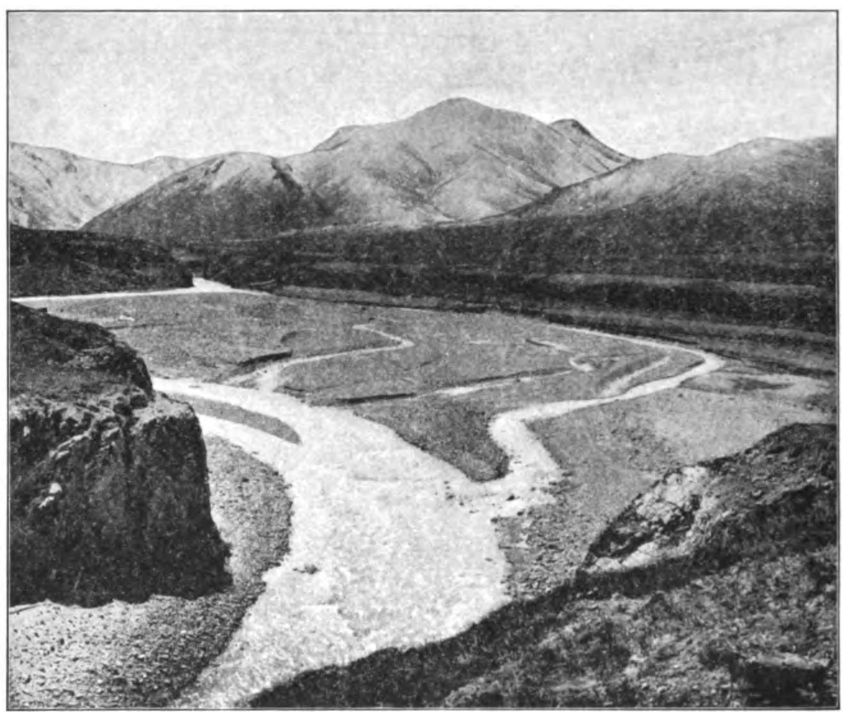

Fig. 143.—Terraces of the Kok Kiya, on the Tian Shan Plateau, at an elevation of 11,500 feet. In the foreground and in the middle distance the stream has been caught upon limestone and has cut merely a narrow gorge, while in the gravel between it has excavated a broad flood-plain with terraced sides.

though the streams were not previously graded. The graded streams would then swing sidewise, and very broad flood-plains would be formed. When warmer conditions again prevailed the streams would once more begin to cut downward; the few streams that had already reached grade previous to the period of aggradation would cut into the gravel till a new grade was reached, and then, if time allowed, they would broaden their flood-plains once more. Of the other streams, the majority would soon cut through the gravel coating of their flood-plains and intrench themselves in the solid rock beneath. If another cold epoch ensued, the previously graded streams would begin to aggrade and would fill their valleys in the same way as before; the others would become graded and would open their valleys and form flood-plains once more. Thus, by a succession of alternations between

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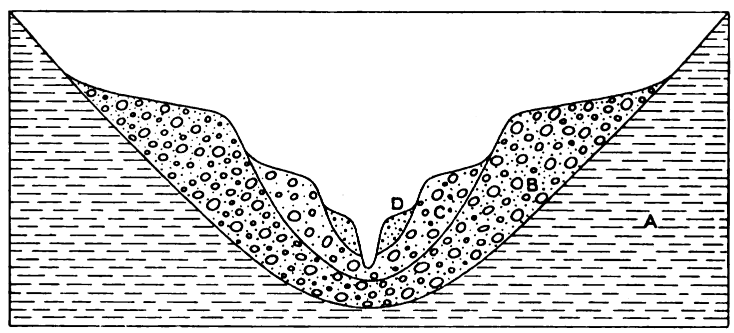
colder and warmer epochs, a series of terraces would be formed closely resembling those found to-day, provided only that the epochs constantly diminished in intensity and duration. Those streams in which a graded condition had been reached before this series of climatic changes began would have their terraces cut entirely in gravel, while the others would have terraces composed partly of gravel and partly of rock. The streams of this class are as a rule deepening rather than widening their valleys.

It is noteworthy that this series of climatic changes corresponds essentially with the series inferred from the old moraines, and the agreement of the two greatly favors the theory that accounts for both. In this connection two points need emphasis. In the first place, it has been shown that the moraines give evidence of interglacial epochs alternating with glacial epochs rather than of a single glacial



A—limestone. B, C, D—successive fillings of gravel.

Fig. 144.—Cross-section of the Ispairan Valley, showing successive periods of cutting and filling.

period which came to an end with a series of partial glacial retreats separated by intervals of glacial rest. The terraces show even stronger evidence of the same conclusion. The deposition of gravel and broadening flood-plains on the one hand and the cutting of narrow trench-like valleys on the other do not represent successive stages of the same kind of climate change; they represent contrasted climatic conditions—namely, the systematic alternation of colder and warmer climates. In the second place, the terraces decrease in width, height, and preservation in the same way that the moraines decrease in size and in the degree of weathering and erosion to which they have been subjected. In both cases the oldest examples are large and well developed, but not very well preserved; the others are successively smaller and better preserved. All these points of agreement increase the probability that the theory of a glacial period consisting of interglacial epochs is correct. One difficulty presents itself—the number of terraces and of moraines does not always agree—the maximum of the one is nine, of the other only five. Part of this discrepancy is due, as has been already explained, to the fact that some of the terrace series are complicated by one or two minor terraces, which seem to be due merely to ordinary swinging of the streams; but even with due allowance for this complication, there seems to be some evidence of a sixth unexplained terrace. It may therefore be suggested that the first of our glacial epochs was not actually the first, but merely the maximum, and was preceded by others which have left no trace save in doubtful terraces. This, however, is at present pure conjecture.

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One of the most important points in a further study of the climatic changes of Turkestan is to establish the correlation between individual moraines of known epoch and individual terraces. This seems to be possible, for in many cases the moraines themselves are terraced, while elsewhere, as in the valleys of the Kara Kul Su and Mudirum Su, moraines have been deposited upon terraces. One of the most promising places to study this relation is in the Alai basin; another, equally good, though less accessible and less beautiful in scenery, is the headwaters of the Narin River.

LAKES.

Evidence of climatic change has also been found about the lakes of Turkestan. One of these, Issik Kul, has been described by Professor Davis in his report on the first month of our journey in Turkestan. Another, Chadir Kul, has been considered in a preceding section on the Tian Shan. Both of these are now without outlets, although a slight rise of the water would cause them to overflow as they have done in the past. A study of their old outlets shows that they have overflowed once or twice at least, probably under conditions of greater rainfall than to-day.

Two other lakes were seen, of which only one, Kaplan Kul, has an outlet. This is an insignificant little sheet of water about a mile long, lying at an elevation of 5,500 feet on the northern slope of the Alai Mountains, 30 miles southeast of Osh. All along the lake margin, especially on the southern side, there is a broad belt of dense reeds, 12 or 15 feet high; the open water in the middle seems to be only a foot or two deep, as herons wade about in all parts of it. The natives say that twenty years ago the lake was much more extensive than now and reached beyond the area where the reeds at present grow—a statement which the appearance of the shores amply supports. At the outlet a fair-sized brook cascades over 3 or 4 feet of hard blue clay, the lake's own deposit, and flows away in a little channel 10 or 15 feet deep, cut in fine gravel and clay. The lake basin is merely a broadening of a stream valley due to the softness of certain red sandstones. Below what is now the outlet of the lake the soft strata are interrupted by a harder band of limestone which has prevented the stream from cutting rapidly downward, and thus gave it an opportunity to widen the valley upstream, while downstream there is a steep descent to another series of soft beds. Where the valley crosses the limestone, and consequently is narrowest, gravel was at some time washed in from the valley sides in such quantities that the slow-moving stream could not carry it all away, and thus a dam was formed, behind which rose the lake. The formation of the dam indicates a time of more intense weathering, and therefore probably corresponds to the last glacial epoch. The barrier which confines the lake has now been almost cut through, and in a few years the basin will again be empty.

Shor Kul.—The fourth lake (fig. 145), is the most important as an indicator of climatic change, as it is completely inclosed by mountains and has never had an outlet. It lies at an altitude of 5,000 feet, 80 miles northeast of Kashgar, in one of the subsidiary basins in the borderland between the Tian Shan plateau and the Kashgar basin. Shor Kul, as it is called, means "Salt Lake," and the name is well deserved, for the lake is a sheet of salt rather than of water. When I saw it

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during an unusually rainy time in August, 1903, it resembled a shallow pond frozen to the bottom and then flooded by a March thaw which covered the ice with water. The shores are composed of black, oozy mud, dipping under the water so gradually that it is impossible to say where the land ends. Close to the edge of the water begins a sheet of salt resembling rotten ice. At first it consists of a loose mass of cubical crystals of pure transparent salt, but farther out this becomes thicker and more solid. The natives say that in dry weather the whole lake is a mere sheet of salt on which one can walk, although with some danger of breaking through. In the latter event one finds pure salt as deep as to the knee and then half-liquid muck. The salt is collected by the people and is carried as far as Kashgar. It is used just as it occurs, without cleansing.

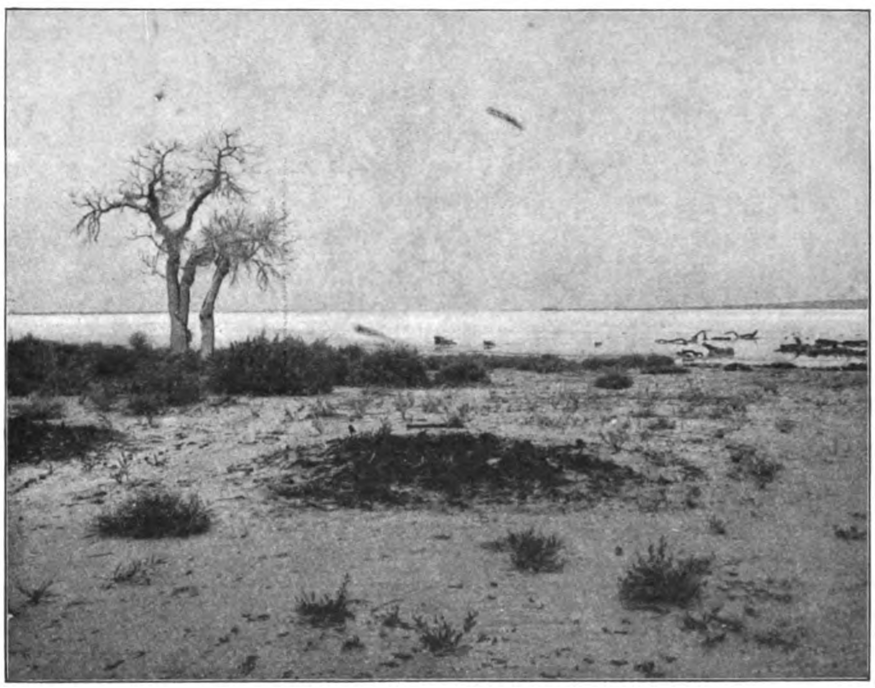

Fig. 145.—Shor Kul, looking south.

A smooth plain about 40 miles long and 10 miles wide surrounds the lake. Much of it is so level that it forms a sort of swamp with a thick growth of tamarisks and tall sword-edged marsh-grass. The surface of the swamp is dry, except in rainy weather, although in many places there is a bog below the dry surface crust. The material of the plain is everywhere a fine silt of lacustrine origin and full of salt. Toward the edges, where the plain begins to rise, the swamp gradually gives place to a desert. Still nearer to the mountains a deposit of rough gravel is encroaching on the fine lake deposit. The gravel is the front of a large number of broad, flat fans which drown the foot of the naked mountains and have converted some of the lower spurs into islands. Usually the ascent from the lake to the mountains across the belts of swamp, dry lake deposit, and gravel forms a smooth

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curve without a trace of terracing or any indication of old lake shorelines. Here and there, however, the smooth stretches of the swamp are broken by low, rounded hills or by broad, flat tables, 20 to 40 feet high and several miles wide, which are distinguished by a sparse growth of knotted poplar trees. On the soft slopes of these elevations are found most of the springs that make it possible for the poor Kirghiz to inhabit the wretched swamp. Jai Tebeh (Devil Hill), at the western end of the lake, is one of the best examples. Here on the sides of a small rounded hill five small springs bubble gently up at heights of from 10 to 40 feet above the green swamp which stretches for 3 or 4 miles on every side. The material of the hill and of the swamp seems to be identical, although possibly that of the hill is a little more sandy. In neither is there the least sign of gravel. A few miles west of Jai Tebeh a formation of apparently the same sort as that of the hill assumes the shape which has above been called a table, although it might better be described as a low and very broad promontory. It rises from the swamp as a rude terrace with an irregularly dissected front, on which there is a suggestion of smaller terraces. Near the borders the top is somewhat rough, but it soon becomes very even and stretches back smoothly toward the mountains, near the base of which it merges into the slope that rises more steeply, although still very gently, toward the mountains from the edge of the adjacent swamp. On this low promontory are two or three springs like those of Jai Tebeh. A few miles farther to the west, at Dongjigdeh, another hill stands in the middle of the portion of the swampy plain lying west of the lake. The hill is about 40 feet high and has a spring near the top. Like Jai Tebeh, it appears to be mostly made of silt, but there are gravel and some sand scattered here and there. Six other streams were seen in different parts of the basin, welling up on small hills at a height of from 20 to 30 feet above the surrounding swamp or neighboring lake. In all the springs the water was sweet, and the material from which they flowed was the same silt as that of the swamp, so far as the eye could detect.

It seems hardly possible, however, that the underlying part of these hills can be composed of this same silt. The one hill where sand and gravel occur seems to furnish the key to their structure, and the suggestion afforded by this one is borne out by evidence which will be presented after the statement of the conclusion to which it leads. Shor Kul appears to have been twice expanded to a size much greater than that of to-day. At the first of these expansions it reached a height of about 350 feet above the present water level. It then retired, so that the lake deposits were first covered with sand and gravel and later were well dissected. It next rose again, although to a less extent, and covered some of the remnants of the old lake deposits with a new layer of silt (fig. 146). The remnants of the old deposits are the hills and tables which have already been described, and which are now left exposed by a second retreat. The springs occur on them because the layer of sand and gravel on top of the earlier lake beds is easily pervious to water, while the silts above and below are impervious. Consequently water from the base of the mountain beyond the end of the silts gathers in the sand or gravel and percolates gently downward toward the lake. In the little hills the upper layer

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of silt is thinner than elsewhere and has often been broken through by erosion. Accordingly at these points the water finds a ready exit and bubbles upward because it is under pressure. It is, however, possible that the deposits of which the hills are the remnants may belong to an earlier time than that mentioned above. This point and others had to be left unsettled on account of the short time allowed for the writer's journey and of the peculiarly unfavorable conditions of unseasonable rain and mud experienced at Shor Kul.

Let us now turn to the more direct evidence of the double rise of the lake. During the first expansion, when the lake reached its maximum size, the water seems to have stood about 350 feet above the present level. On the north side of the plain, a little below this height, there is a sudden transition from coarse, angular gravel to the finest silt without a trace of pebbles. The gravel is subaerial waste of the normal type for an arid mountain region, and is now being slowly pushed forward over the silt. The silt could hardly have been deposited anywhere except in a lake, for under almost any conditions of climate some gravel would be included in a deposit so close to the base of the mountains, unless it was laid down a little offshore in standing water. At the west end of the plain, southwest of Kirk Bulak, there is at the same 350-foot level a small bench and cliff, cut for about half a mile in the silty gravel which there cloaks the mountain flanks. At the opposite end, near Pchan, a large compound fan of gravel has cloaked the lake silts smoothly as high as 130 feet above the present lake level; but at an elevation nearly 400 feet from the water the gravel has a different form. At the lower level the gravel cloak is spread smoothly and the streams wander across it in numerous shallow and ever-changing channels. Above a height of 400 feet the gravel is well dissected, and each stream has a single, definite terraced valley.

On the south side of the lake the plain rises more rapidly and the old lacustrine deposits are considerably dissected, perhaps because of a slight warping. Nevertheless there are the same lacustrine silts and subaerial gravels as on the north side, and the silts end at about the same height, that is, a little over 350 feet above the lake. Elsewhere old lake silts are found up to a height of 200 or 300 feet above the water, where they begin to be covered with gravel. It seems quite clear that the lake once stood 300 or 400 feet higher than to-day.

At a place called Dungsugot,* on the south side of the plain, 4 or 5 miles from the western end of the lake, there is good evidence of a second rise of the lake separated from the first rise by a period when the water retreated nearly or quite to the present level. Here the older lake deposit is considerably dissected (fig. 148), probably because the slope of its surface is much steeper than elsewhere. The valleys carved in the deposits show three terraces which extend out to the fronts of the spurs, and even around them, from valley to valley. The spurs are flat-topped and for the most part are made of lacustrine silt. On the top, however, is a layer of gravel only a few inches thick at first, but gradually increasing in

*There is a spring at Dungsugot where a camp could be made from which the terraces and lake deposits could be minutely studied. Fodder for horses would probably have to be brought from one of the villages 6 or 8 miles away.

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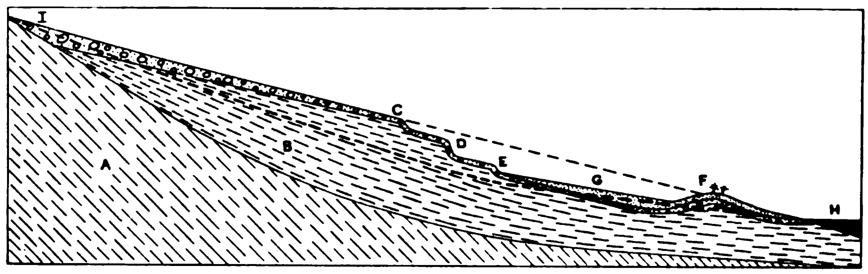
thickness toward the mountains. The gravel extends down the slopes of the terraces (fig. 146), but at the bottom it is abruptly covered by another deposit of lacustrine silt. On the latter there is nowhere any gravel except in places where it is now creeping down from the terraces, or where a stream comes out from the mountains and is now covering its broad flood-plain with a thin coating of pebbles.



A=bed-rock. B—lake silt of 350-foot level. C—first terrace and layer of gravel covering silt. D—second terrace. E—third terrace. F—hill with springs. G—lake silt of 100-foot level. H—lake. I—edge of mountains.

Fig. 146.—North and south section of the plain of Shor Kul from the lake to the mountains at Dungsugot.

In the valleys the lower terraces are not cut in silt, as is the case on the fronts of the spurs toward the lake, but in gravel deposited in the valley after it had been cut below its present depth (fig. 147). The reader will at once perceive that fig. 147 is almost identical with the cross-section of the Ispairan Valley (fig. 144), and will doubtless infer, as the writer does, that both are the effect of a similar series of climatic changes.

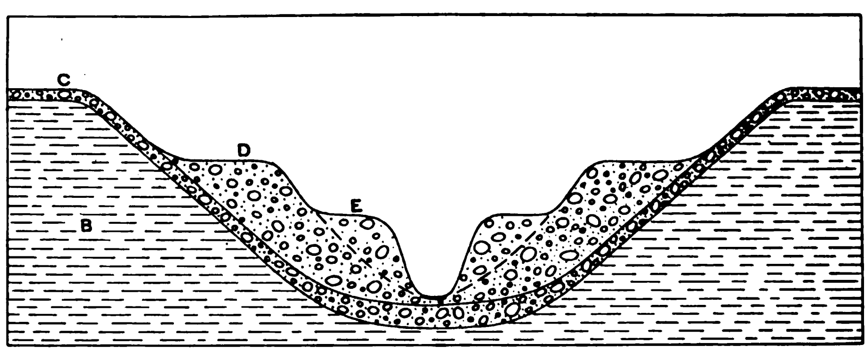


Fig. 147.—Cross-section of a Valley cut in the silt at Dungsugot. For explanation see fig. 146.

All the phenomena of Shor Kul are satisfactorily accounted for by the same theory which explains the old moraines and the terraces. The earliest record of the lake was at the stage of greatest expansion; the silts of the 350-foot level were then laid down. Later the climatic conditions changed, so that the lake shrunk almost, if not quite, to its present size. Gravel at once began to creep forward over the silt, and, as the surface was very smooth, the streams wandered widely and covered the whole lacustrine plain with a layer of pebbles. In time, however, the amount of waste from the mountains grew less under the influence of the changed

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climate. The load of the streams was correspondingly decreased, and they cut downward until the relief was like that which is represented by the outer valley cut in the silt (B, fig. 147). At the same time the front of the old silts was being gnawed back and the slope was being prepared on which the terraces (fig. 146) were later cut. The surface of the old lake deposit must originally have presented an unbroken slope (I H in fig. 146). The bed of the stream, the lower dotted line, I B H, must have presented an equally smooth although more concave slope. The two must have met at the lake shore when the water was at its lowest level. Even the most cursory inspection of the valleys and spurs shows that this point of meeting must have been far out in the swamp close to the present shoreline. Therefore the lake must have been small and shallow, and the climate must have been similar to that of to-day or possibly even drier.

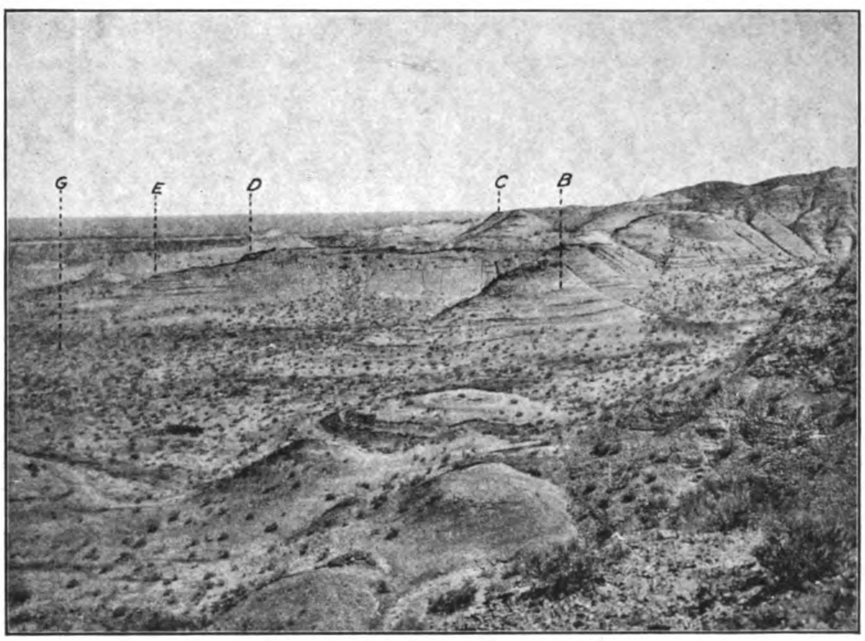

Fig. 148.—The gravel-covered lacustrine deposits at Dungsugot, illustrating the same features as the preceding diagrams. For explanation see fig. 146.

The next changes were those recorded in the terraces and in the gravel which fills the valleys represented in fig. 147. It is easy to infer that the lake must have risen and fallen twice, and that each rise was associated with the formation of a terrace and with the partial filling of the valleys with gravel, but of this we have as yet no direct evidence. The next rise of the lake of which we have positive proof was probably also the last. It deposited the recent silts (G, figs. 146 and 148), which rise to a height of 100 feet and bury not only the foot of the terraces, but also the isolated hills on which well up the springs of sweet water in the midst of the salt swamp. Now a last change of climate has again reduced the lake to very small proportions.

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Although we do not find in the history of Shor Kul a complete series of records to match all the changes of climate inferred from the study of the old moraines, we find no records inconsistent with such changes and many confirmatory of them. The essential features of our glacial theory are that a number of cold or glacial epochs were separated by warmer interglacial epochs, when the climate was approximately like that of to-day, and that these epochs decreased in severity and length from first to last. The retreat of the lake between the two epochs of unequal expansion supports this most clearly. Further study will probably show that the past oscillations of the lake agree even more perfectly with those of the glaciers. At present only a tentative correlation of lacustrine and glacial epochs is possible. The silts of the upper lake level may represent either or both of the first two glacial epochs; the cutting of the deepest valley in them represents the succeeding warmer interglacial epoch; the third and fourth epochs, glacial and interglacial, are perhaps represented by the gravel filling and the terraces, respectively, which lie in the deep valley. The fifth glacial epoch seems to correspond to the rise of the lake to the 100-foot level, and the present retreat of the ice to the present retreat of the water.

SUMMARY.

In our review of the history of Central Turkestan, from Paleozoic times down to the present, we have found that the greater changes have on the whole affected the entire country rather than small areas. Uniformity has been the rule. During the Paleozoic era the entire region was submerged beneath the sea and the deposition of calcareous strata was long-continued. After the latter had attained a great thickness tectonic movements began on a large scale and continued until the limestones had been closely folded and mountains had been formed, which were worn away during the first part of the succeeding era. The Mesozoic and Tertiary eras are not sharply separated and must be considered together. Throughout the greater part of these eras terrestrial conditions prevailed, with the deposition of strata characteristic of interior basins, namely, conglomerates, cross-bedded sandstones, and silts, which appear to be vast playa deposits. Most of the strata are without fossils, and in this and other ways suggest that the climate was dry and that desert conditions prevailed more or less extensively. Only once during this long period did the sea encroach on the land. This was at the end of the Mesozoic era, when limestones and marls were laid down in what seems to have been a sea of somewhat fluctuating depth. It is not impossible that between the Mesozoic and Tertiary eras there were world-wide movements which elsewhere caused uplift and erosion, followed by unconformable deposition; but here the movements of this time caused encroachment of the sea and deposition. In the basin region of America the Mesozoic and Tertiary eras present a succession of strata notably similar to those of Central Asia. The resemblance is so marked and extends so far into details that it can scarcely be the result of chance. It suggests that interior arid basins which to-day resemble one another have long resembled one another and have passed through a similar succession of changes.

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By the end of the Tertiary era erosion and deposition had so far lowered the mountains and filled the basins that the country was in a stage of late maturity or even of old age. Considerable warping had taken place during the preceding period, and perhaps was still going on, but the rate was so slow that even the languid erosion of late maturity was able to keep pace with it. At the beginning of the Quaternary era, however, there was a revival of internal activity which manifested itself chiefly along the lines of movement of earlier times. Warping and some faulting then took place so rapidly and so recently that the forms to which they gave rise still dominate the topography, and the effects of erosion are chiefly noticeable in the young valleys. By these movements Central Turkestan was divided into its present physiographic provinces. One province, the Tian Shan plateau, is essentially a broad, flattened arch, on the top of which a number of minor warpings give rise to lofty plateau-like ridges surrounding elevated basins. A second province, the Alai Mountains, is a similar arch, except that it is narrower and lacks the minor corrugations on the top. Both of these provinces are characterized by very precipitous young valleys, between which are tilted and well-preserved portions of the Tertiary peneplain. The two other provinces are basins, those of Kashgar and Fergana, the flat floors of which have for ages been regions of deposition. In the Fergana basin deposition has for the present ceased, but in the Kashgar basin it is still progressing actively.

The recent geological history of Central Asia has been controlled by a series of climatic oscillations between conditions of relative warmth to those of relative frigidity. Evidence of these changes is found in phenomena of three distinct types associated with the headwaters, the trunks, and the lower ends of the rivers. In the high mountains many headwater streams flow from glaciers which in ancient times were much expanded so as to deposit moraines at considerable distances down the valleys. The moraines show that the ice advanced five times during as many glacial epochs, and that between the advances there were epochs of retreat which must have been almost as warm as the present, if not warmer. The moraines further show that the glacial epochs steadily decreased in intensity from first to last, and, although less clearly, that the interglacial epochs correspondingly decreased in length. Along their middle course the streams, almost without exception, flow in terraced valleys. The only adequate explanation for these seems to be a series of decreasing climatic oscillations from cold epochs on the one hand, when increased weathering overloaded the streams and caused them to aggrade and broaden their valleys, to warm epochs on the other hand, when the streams cut narrow canyons in the bottoms of the previously formed flood-plains, thus producing terraces. The number of the terraces does not agree precisely with the number of the old moraines, but the disagreement is easily explicable by a simple expansion of the theory of climatic changes so that it shall include a series of increasingly severe glacial epochs preceding the epochs of the decreasing series. In other respects the agreement of the terraces and the moraines seems very close. The former as well as the latter indicate not only that there were oscillations from one extreme of climate to the other, but that in intensity as well as in length each succeeding period was less than its predecessor, for the terraces decrease steadily in breadth and

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height. Where lakes are found at the lower ends of rivers, they show changes of level that are only explicable on the theory of climatic oscillations of decreasing intensity. Only two of these have been clearly identified, but there is some indication of a larger number, and it is entirely possible that further observation will show that the lakes changed as often as the glaciers and the rivers. When the glaciers advanced and built their moraines, the rivers swung laterally, aggrading and broadening their valleys, and the lakes expanded and spread their silts. When the glaciers retired the streams cut gorges and the lakes contracted.

The essential point in our study of the recent geological history of Turkestan is this: From three separate lines of reasoning, based on the allied yet distinct phenomena of glaciation, terracing, and lake expansion, we arrive at the same conclusion, namely, that during the Quaternary era there have been a number of colder or glacial epochs, five or more, separated by warmer interglacial epochs when the climate was similar to that of to-day; and further, that these epochs progressively decreased in length and intensity.

When a single theory fits all the facts of a single series of phenomena, it becomes probable; when it fits the facts of three distinct series of phenomena, it becomes highly probable; and when it fits the facts of several continents, it becomes in a very high degree probable. Much confidence is therefore felt in the theory above announced. It is yet to be applied to the basins of the Caspian and Aral seas on the west. A most interesting additional step would be to see if the theory is capable of explaining the great basin deposits of Central Asia which lie to the east of the region here described.

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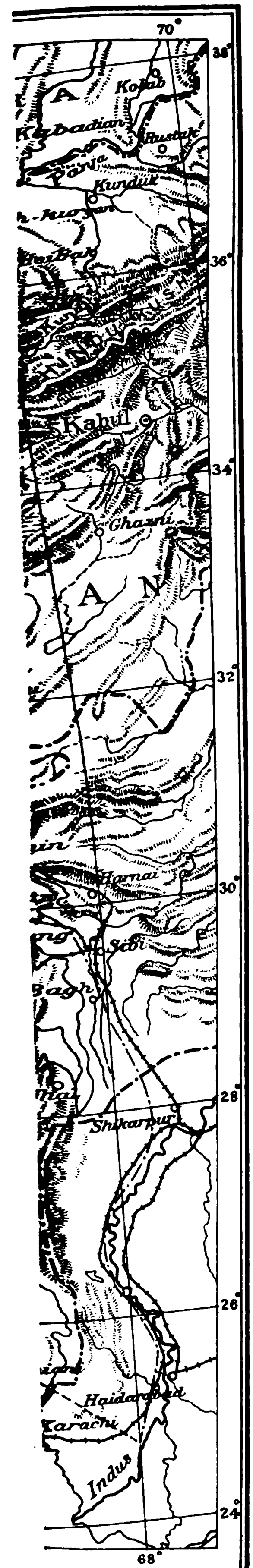

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of Alexanders army

The Basin of Eastern Persia and Sistan.

By ELLSWORTH HUNTINGTON,

Carnegie Research Assistant.

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THE BASIN OF EASTERN PERSIA AND SISTAN.

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INTRODUCTION.

At the beginning of the work of our expedition in Central Asia it became evident that the problem of the physical changes which have taken place in the Caspian basin since the advent of man is so complicated as to require the work of many years for its solution. It also became evident that if the history of the chief changes could be ascertained in smaller neighboring basins where there was reason to suppose that a similar series of events has taken place, the elucidation of the Caspian problem would be greatly facilitated. Accordingly, during the summer of 1903 our attention was turned to Issik Kul and the mountains of Turkestan; and later, on the approach of winter, I was dispatched southward to the remarkable basin of Sistan, in Eastern Persia. Not only the basin, but the country traversed in reaching it, proved to be full of evidences of very recent changes in physical conditions, and the time-scale established by their means is applicable in a large degree to the Caspian region, for the main line of evidence, the terraced character of mountain valleys, is found abundantly in both the Sistan and Caspian basins.

The records of antiquity and the work of previous explorers make it certain that both basins have long been inhabited and that their present sparsely populated condition is essentially different from that of the past. The question to be answered is whether this condition is due to purely human causes, such as the decay of races, wars, famine, deforestation, and the exhaustion of the soil by prolonged cultivation on the one hand, or whether it is due to physical causes, such as changes of climate, the warping of the earth's crust into higher mountains and deeper basins, the natural changes of the course and volume of rivers, and the encroachment of sand-dunes on the other. Before this can be answered the human history of the country must be more carefully elucidated by archeological work and the physical history by geographic work.

In the pursuit of the latter object, under the direction of Professor Davis, the problem resolved itself into two parts, namely, the physical history of Central Asia in recent times as influenced by internal or terrestrial causes, such as the warping of mountains and the deepening of basins, and the history as influenced by external causes, such as changes of climate. The studies of a year and a half have led me to think that while numerous crustal movements furnish abundant evidences of the earth's internal activity during very recent geological times, most of the movements are too ancient to be connected with human history and too local to have produced

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uniform changes over broad areas. Nevertheless, the purpose of our expedition can not be achieved until we possess such a knowledge of the movements of the earth's crust in Asia during recent geological times as shall enable us with certainty to estimate their possible effect upon early man. I have therefore recorded all the data on this subject which came under my observation. Moreover, as my journey led through an unknown country, I have thought it advisable to record certain geological facts relating to earlier times.

In Asia, as in Europe and North America, the main events of that part of recent geological time which immediately precedes and includes early man seem to have been due to changes of climate. Evidences of this are found abundantly in Persia, Transcaspia, and Turkestan. It is therefore of first importance to ascertain the exact sequence and degree of each change and the dates of the later changes in relation to the origin of man, and accordingly the main portion of this report is concerned with the evidences of climatic change in Persia, and with an attempt to form a tentative scheme of the physical history of the country during Quaternary times. The influence of climate, and especially the physiographic results of climatic changes in nonglaciated regions, are so little known that it has seemed necessary to devote some attention to a theoretical examination of these questions. Accordingly this report is in the main a study of the influence of climate and of climatic change in Persia. When this influence is understood, and when the sequence of events shall have been clearly made out, we shall be in a position to determine the relation of physiography to climate in Persia and to apply our results to the larger problem of Western and Central Asia.

ROUTE.

Between the high mountains of Central Afghanistan on the east and the fearful salt wastes of Eastern Persia on the west lies a dreary region of naked mountain range, huge fans of rough gravel, and level basins floored with fine silt. At the northern end of this region the Heri Rud, the river of Herat, furnishes life to the towns and villages of Herat, Serakhs, and Tejen, while to the south the half-mythical Helmund, before losing itself in the immense swamp of the Hamun-i-Sistan, supports the numerous villages of the province of Sistan. Between these two rivers the lowlands are absolute deserts, while the uplands above an altitude of 4,000 feet are sparsely studded with villages located at the bases of the higher mountains, where water can be procured.

Across this inhospitable region lies the route from Transcaspia to Sistan. (See map.) Through the courtesy of General Ussakovsky, governor of the Russian province of Transcaspia, to whom our expedition is indebted for many favors, I was allowed to follow the Russo-Persian frontier and to stop at military posts to which foreigners are not usually given access. Starting from Askhabad, the capital of Transcaspia, November 23, 1903, I proceeded eastward along the southern border of the province to Serakhs, at the northeastern corner of Persia. There I was joined by Mr. V. G. Yanchevetzki, secretary for special affairs to the governor of Transcaspia, and the rest of the journey was made in his company. To him, in

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large measure, is due the success of our three months' journey in a country where travel is not only difficult, but sometimes dangerous. His presence was especially acceptable because of his unfailing good humor under trying circumstances and his kindness in conforming his plans to the whims of a geographer. Leaving Serakhs December 4, we crossed into Persia and spent the next month, till January 1, in traveling as nearly as possible straight southward along the Afghan-Persian boundary, past the playa of Khaf to the oasis and swamp of Sistan. At the latter place we remained till February 5, much of the time as the guests of Dr. A. J. Miller, the Russian consul, to whom my heartiest thanks are due. Not only did he entertain us most hospitably, but through his help it was possible to see in a short time the most important parts of the interesting region of Sistan. From the Russian consulate as a center, trips of from four to eleven days' length were made in all directions. During a part of our stay in Sistan I was the guest of the British officers connected with the Sistan Arbitration Commission, and the time so spent was as valuable scientifically as it was pleasant socially. In spite of his pressing political and military duties, Col. G. H. McMahon, the British commissioner who is settling the disputed boundary between Persia and Afghanistan, finds time for an enthusiastic study of the physiography of the new region to which his work brings him. To him and to his assistants, Mr. G. P. Tate, topographer, and Mr. T. R. J. Ward, irrigation officer, I am indebted for information and suggestions of the greatest value, to which I shall have occasion to refer later. Our return journey from Sistan to Transcaspia lasted from February 5 to March 13. It was made in a northwesterly direction, by way of Birjand, Tun, Turbat-i-Haideri, and Meshed, to Askhabad. Everywhere we received the most hearty hospitality and ready help from both British and Russian consular officials, to all of whom thanks are due.

LITERATURE.

Few travelers have penetrated eastern Persia, partly because of its remoteness and partly because it offers few attractions in the way of scenery, historic cities, game for the hunter, or people with picturesque dress and manners. Most of the foreigners who traverse the country are bound on business, usually official, and follow the easiest and most frequented route through the mountains, where villages are numerous. This route, which leads from Meshed, by way of Birjand or Khaf, to Sistan, is, indeed, the only important road that leads far south in Eastern Persia. Other routes have been followed chiefly by British officers who were studying the country from a military point of view either as surveyors or consuls, or as members of the various boundary commissions whose thankless task has been the demarcation of the boundaries of Persia, Afghanistan, and Baluchistan. These officers and a few venturesome travelers have written almost the only accounts of Eastern Persia which we possess. The majority of the accounts are geographic in the sense that they describe the country and people with great accuracy of detail, but all of them fall short of the modern geographic ideal in that they contain little save empirical accounts of isolated facts encountered along the line of the author's route without reference to any underlying scheme of geographic classification. The best of these

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books, and also the most recent, is that of Major Sykes, "Ten Thousand Miles in Persia," a work which embodies a vast amount of careful observation and record, supplemented by most painstaking research. To it and to others of the same class which are noted in the bibliography at the end of this report, I shall have more or less occasion to refer. Lord Curzon's "Persia" stands easily first among books on the country as a whole, but unfortunately it deals but briefly with the eastern part of the Shah's dominion, and hence will be referred to but little. Of books by professional geographers or geologists, there is, so far as I know, not one which deals with Sistan and the most important parts of Eastern Persia. Blanford, however, over thirty years ago, traversed the neighboring regions to the south and west, and has given us the result of his observations and studies in a valuable review of the geology of Persia as a whole, and in a masterly essay on that most striking of Persian physiographic phenomena, the huge gravel fans at the base of the mountains. More recently Vredenburg has written a geological account of the portions of Baluchistan to the south and east of Sistan. His facts are valuable, although some of his conclusions are open to question. In addition to the classes of books already named there are several accounts of Eastern Persia which are mere travelers' tales of the most ephemeral interest. The books of all classes, so far as I have consulted them, are mentioned in the bibliography at the end of this report, although not all are referred to in the text. As an aid to future students a brief comment on the nature of the work is appended to each title in the bibliography.

OUTLINE OF THE FOLLOWING REPORT.

Eastern Persia is one of the most desolate lands in the world. The chief cause of its desolation is aridity, due in the first place to the country's continental position and in the second to its basin character. As a result of Persia's continental position the prevailing northwest winds which blow across it have not only already traversed wide stretches of land and been deprived of most of their moisture, but they are continually advancing into more heated regions and thus becoming warmer and less ready to part with moisture. The basin character of the country tends to increase the dryness of the interior; for the mountains which surround the basin are for the most part lofty and cause the precipitation of whatever moisture the winds may still contain after their long journey from the sea, so that almost nothing is left for the inner regions.

Eastern Persia, northwestern Baluchistan, and southwestern Afghanistan are all included in the basin which has just been mentioned. Close to the eastern border of Persia this basin of Iran, as it is called, is divided into two subsidiary basins by a range of mountains running north and south. (See sketch map, fig. 152.) East of the range, and complementary to it, lies a remarkable depression containing the Heri Rud River and four large hollows containing playas or saline swamps. (See map at end of volume.) Although the geological history of the country is imperfectly known, the unconformability between Tertiary deposits of continental or estuarine origin and Cretaceous deposits of marine origin shows that Iran began to assume its present basin form far back in the Tertiary era. Since

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that time minor basins have been produced within the greater basins. Throughout the Tertiary era and perhaps even during Quaternary times the basins have been the receptacle of the waste from the mountains, which has now deeply filled their lower portions. The waste thus deposited lies horizontal in the centers of the basins, but is warped along the edges, the older strata being more warped than the younger. Apparently the basins have been subjected to a gradual process of intensification by which they have become deeper, while their edges have been folded and uplifted.

The large basin of Iran, with its rim of lofty mountains, is a typical example of long-continued erosion and deposition in a mountainous plateau under arid conditions. The traveler is wearied by an endless repetition of naked mountains rising on the edges, or even in the midst of smoothly-floored basins, in which the streams have for ages deposited waste from the mountains. In the centers of many basins stretch vast playas, whose smooth expanse is often covered with salt. Where water is more scarce fields of drifting sand move slowly forward, while between the barren mountains and the plains gently sloping fans of gravel merge into level sand and silt on the one hand, while on the other they mantle the flanks of the ridges, and even overtop the passes, uniting one basin to another. What few streams there are flow toward the basin centers in terraced valleys, and often the shores of the playas and lakes are also terraced.

No one, however unobservant, can fail to be struck by the contrast between the physical features of Persia and those of the well-watered countries of Europe and America. The only competent cause for this difference seems to be that the climate in the two regions is different. It is often assumed that the presence of inclosed basins, such as those of Persia, is due to some special variety of warping of the earth's crust. That the basins are due to warping can hardly be doubted, but there seems to be no reason for thinking that the warping is of a peculiar sort. The mountain building of the Alps and the Himalayas must have given rise to basins just as did the mountain-building of Persia and of the basin region of North America. The present differences are due to differences in climate. In the Alps one of two things happened: First, the streams may have eroded so fast that when tectonic forces began to uplift the mountains and form basins, erosion kept pace with the uplift, and the streams which crossed the rims of the basins preserved uninterrupted channels from the interior to the exterior. Second, a newly formed basin may have been filled by a lake, the overflow of which soon cut a channel so deep as to drain off all the water, or at least all that stood at any great elevation above sea-level. In either case the basins were quickly converted into valleys opening freely toward the sea. In Persia, where the climate is dry, on the contrary, the erosion of the scanty streams was insufficient to keep pace with the movements of warping, and inclosed basins were produced in which the streams still terminate in salt lakes, playas, or gravel fans, where all the material that comes from the mountains is preserved. A peculiar topography was produced, which consists of inclosed basins within which are huge gravel slopes, broad plains of silt, buried mountains, salt lakes, and fields of sand-dunes. In brief, basins are the universal accompaniment of mountain-building, but their preservation is dependent on a dry climate. Such a climate, it is true, is often due in large

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measure to the presence of mountain barriers which shut out the moisture-laden air of the oceans from the basins which they inclose. Thus the formation of basins tends to produce a dry climate, and the dry climate tends to preserve the basins and at the same time to produce a peculiar topography.

It is not simply with aridity of climate that we have to deal in Eastern Persia. During Quaternary times there appear to have been changes of climate, and as some of the changes took place very recently, probably since the occupation of the country by man, their careful study is of great importance for the purpose of our expedition The chief evidences of climatic changes take the form of numerous lacustrine and fluviatile terraces. The former, like the terraces of Lake Bonneville, are due to changes in the water-level of lakes or playas, while the fluviatile terraces appear to have been formed where one type of climate caused the deposition of gravel, and another type, probably either drier or warmer, caused this to be channeled. The physiographic effect of changes of climate is so important that its exemplification in Persia demands the most careful consideration. The uniformity of the terrace phenomena throughout the semi-arid countries of the western half of Asia seems to be explicable only on the theory of a succession of epochs of changing climate corresponding to the glacial epochs of more northern countries.

The lake and district of Sistan afford unusually clear evidence as to the subdivision of Quaternary time. During the latter part of the Quaternary era volcanoes broke out within the area of the lake, and in the course of their eruptions large portions of the lake bottom were uplifted and covered in part with caps of lava. Subsequent erosion has produced cliffs from 50 to 600 feet high, which expose large portions of the ancient lake deposits. The history of the Quaternary era and of the forms assumed in Persia by the period which corresponds to the glacial period of other lands is here laid bare without the concealment of earlier phases and without undue emphasis on later events.

The record of the climatic changes of the Quaternary era is almost everywhere incomplete, whether preserved in moraines, in terraces, or in aqueous deposits. One formation is placed upon another, and unless each successive epoch happens to be less severe than its predecessor, the traces of earlier epochs are almost sure to be effaced. The records of climatic change are preserved most perfectly in the bottoms of shallow lakes without outlets, where a diminution in rainfall or an increase in evaporation produces a great diminution in the size of the body of water and consequently in the character of the sediments deposited. Naturally the bottoms of such lakes are of little use to the geologist, because of his inability to study them. Hence the importance of Sistan, where so large a part of the record is exposed. It affords a key which may serve to unlock the history of the neighboring Caspian basin and of still larger regions.

The deposits uplifted at the time of the Sistan volcanoes and exposed to view by the erosion of the lake consist of layers of reddish clayey silt varied with bands of sand and gravel on the one hand, systematically alternating with remarkably uniform unbroken layers of hard, greenish clay on the other. The reddish layers contain lateral unconformities, discontinuous layers of coarser material and raindrop prints, which indicate that they are of subaerial origin and were laid down by

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running water or in playas when the lake floor was almost free from permanent water, and hence during epochs of aridity. The green clays on the other hand are so fine-grained and uniform in texture and so free from changes of structure that they appear to be lacustrine deposits, laid down at a time when the lake was full of water, and hence during epochs of more abundant moisture. The entire formation of alternating reddish and green strata is most satisfactorily explained on the theory that it is the product of a series of climatic oscillations during which the lake was first dry and then full. The history of the region after the volcanic eruptions is recorded in gravel deposits which overlie the strata just described and alternate with fine gravel and in terraces which dissect all the strata. The gravels and terraces appear to indicate a continuation of the climatic oscillation down to very recent times. The total number of oscillations amounts to fourteen or fifteen, and may have been more.

As one ascends from the bottom to the top of the deposits, the greenish layers increase in frequency and to a less extent in thickness up to a certain point, while the red layers become correspondingly thinner. After the green beds have reached their maximum development there is again a decrease in thickness which can be traced only through a few stages because the clays soon give place to gravels. The thickness of the layers is probably proportional to the length of time consumed in their accumulation. Therefore where the red layers are thin, epochs of desiccation must have been short, and epochs of lake expansion must have prevailed for relatively long periods. Where the red layers are thick, on the contrary, the epochs of desiccation must have been longer and more important, and those of lake expansion must have been short. The meaning of the clays, the overlying gravels, and the terraces seems to be that the Quaternary era in Persia consisted of a long series of *increasingly* strong climatic oscillations, followed by a nearly equal series of *decreasingly* strong oscillations. The latter appear to correspond to the series of oscillations which we know as the glacial period in more northern countries. Furthermore, there is evidence, based on physiographic, archeological, and historical observations, which indicates that the last of the climatic oscillations may have been in progress during historical times.

THE PHYSIOGRAPHY OF EASTERN PERSIA.

Eastern Persia is a land of gravel and nakedness, of huge desert basins and desolate, interminable slopes, of tantalizing mirages and bare mountains. Springs and fountains are things to dream of, except directly among the mountains, and the traveler and his tired animals must be content with the brackish water of rare wells or the poor brine of an ever-diminishing salt stream. Day after day one sees the same sad monotony of parched plains and lifeless mountains. At long intervals nomads pitch their black tents beside wretched wells and feed their sheep and camels on the sparse brown grass which springs up for a brief month at the end of winter. The mountains are naked masses of rough, jagged rock, rising as islands in the midst of their own waste. Drought and aridity are everywhere written large in the dearth of vegetation and in the very forms that the earth itself

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assumes. The whole country is sad and desolate—a region to be shunned by those who have dwelt in a happier land.

"So far as the surface of the Persian plateau has been surveyed," wrote Blanford, thirty years ago, "it consists of a number of isolated plains of varying extent and elevation above the sea, all without any outlet, and separated from each other by ranges of hills, frequently of considerable height. The lowest portion of each of these plains is generally a salt lake or marsh. If there be a lake its level often fluctuates, and one or two seasons of deficient rainfall suffice to lay bare the greater portion of its bed, or to convert it into a marsh. Rivers are few in number and singularly small in volume; in fact, not the least striking feature of the country consists in their paucity or absence. The whole of Persia, except near the shores of the Caspian and on the western slopes of the Zagros, is, in fact, a desert, and all cultivated oases owe their fertility to irrigation from springs or from the small streams fed by the rain or snow of winter." Such streams are so rare, however, that Colonel Gore, as Sykes relates (p. 40), rode 400 miles from the Heri Rud to Hur, near Kirman, without seeing a single stream of flowing water.

Yet even in Eastern Persia, the worst part of the country, there is another side to the picture. Among the mountains which border the basins, springs and little streams support small villages, where green fields and flourishing orchards drive away the thought of the desert for a while. Sad experience has taught the people to utilize the underground water by means of "kanats," long underground channels, which start deep underground at the foot of the mountains and gradually approach the surface, bringing water far out into the plains. Where the mountains are high and provide water for numerous "kanats" the plains are well dotted with villages, and even support cities. All of the few rivers are utilized for irrigation, and in Sistan the waters of the Helmund support scores and perhaps hundreds of villages.

In such a country the conditions of life are extremely hard. Strange as it may seem, when the average population is less than 10 to the square mile the country is overpopulated. There are thousands upon thousands of square miles of fine-soiled plain which would be highly fertile if only they could be supplied with water. Everywhere the cry goes up for water, and there is no water. In Western Persia conditions are better, but throughout the basin region of the center and east every drop of water from above ground and below is utilized, and a scarcity of winter snow to stock the mountains means gaunt famine. The distribution of population illustrates this. Harbors, trade routes, facilities for manufacturing, and the like are of secondary importance in determining the location of cities. The primary consideration is water. Where water is abundant large cities are almost sure to grow up, if other conditions are in the least favorable. Accordingly the large cities of Persia are situated close to lofty mountains. As a rule, the density of population is in direct proportion to the height of the mountains. Sistan appears to be an exception, but, after all, its abundant population is a response to the tremendous mountains of Hindu Kush. The response is far from the cause, because the intervening space can not be cultivated.

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CLIMATE: THE CAUSE OF THE DESOLATION OF PERSIA.

The main cause of the desert condition of Persia is its climate. The rainfall of the country as a whole is estimated as averaging not over 10 inches a year. Throughout the greater portion of central and southeastern Persia and the adjoining portions of Afghanistan and Baluchistan the annual rainfall can not be much more than 5 inches. (St. John, p. 7.) The extreme paucity of this will be realized when it is remembered that when the rainfall is less than 12 inches a year the region is reduced to a desert and the water supply is too small to be of service in irrigation, except in small areas or on the banks of large rivers. The scanty rainfall is usually divided as follows, according to St. John (p. 7): "A little rain is hoped for, but not always expected, in November, to sow the early crops. In December there is generally a tolerably heavy fall of snow, and another in February, followed by showers in March and the beginning of April, after which there is nothing but an occasional thunder storm in the mountains till the next winter."

This woful aridity is due partly to Persia's continental position and partly to the high mountains which hem it in. Although 36 per cent of the Persian frontier is bordered by salt water, the country is distinctly continental in climate and in the character of its people. Only the 7 per cent of seacoast in the southeast corner along the Indian Ocean is exposed to the open sea, while the remaining 29 per cent faces the inclosed Caspian Sea and the Persian Gulf, which have little influence in producing a marine climate or people. Moreover, the high mountains which border Persia on every side shut out the moisture of the sea and shut in the people.

The prevailing winds of Eastern Persia bring very little rain, as they come from the north and northwest, from a continental region. They flow into districts of increasing warmth, where their capacity for holding and absorbing moisture is continually increased and the tendency to furnish rain correspondingly decreased. The moisture picked up in crossing the Black and Caspian seas is deposited in the lofty Armenian highland and Elburz range, and little is left for the thirsty lands beyond. In summer the northward prolongation of the trade winds combines with the spirally inflowing winds which circle round the Asiatic center of low barometric pressure far to the northeast, and guided by the north-northwest trend of the mountains of Eastern Persia produces dry winds of the most extraordinary strength and constancy. Holdich (pp. 145, 334) describes their occurrence in northwestern Afghanistan and northwestern Baluchistan, but they are most violent at Sistan, halfway between the two. According to the British members of the Sistan Arbitration Commission, this wind, called the "Wind of One Hundred and Twenty Days," blows almost continuously day and night during the four hottest months of the year, much of the time at the hurricane rate of from 60 to 80 miles per hour. Dust and sand fill the air. The double-pegged tents which withstand the blast make a noise like that of the rigging of a ship in the wildest storm. The continual hum, flap, clatter, rattle, bang, make mental work almost impossible.

Yet the wind has its beneficial aspect. In the houses of the rich an open doorway in the north side is stuffed with small brush. Upon this a servant throws

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water, the evaporation of which cools the air that whistles through and renders the interior comfortable. When the wind dies down for a day or two, as happens occasionally, the houses become insufferably hot and myriads of flies and mosquitoes at once swarm everywhere.

The strength and uniform direction of the wind allow windmills to be constructed with simplicity and ease. The wheel is shaped like an old-fashioned water-wheel, 6 or 8 feet long, and is set vertically on the roof of the mill, directly over the stone which

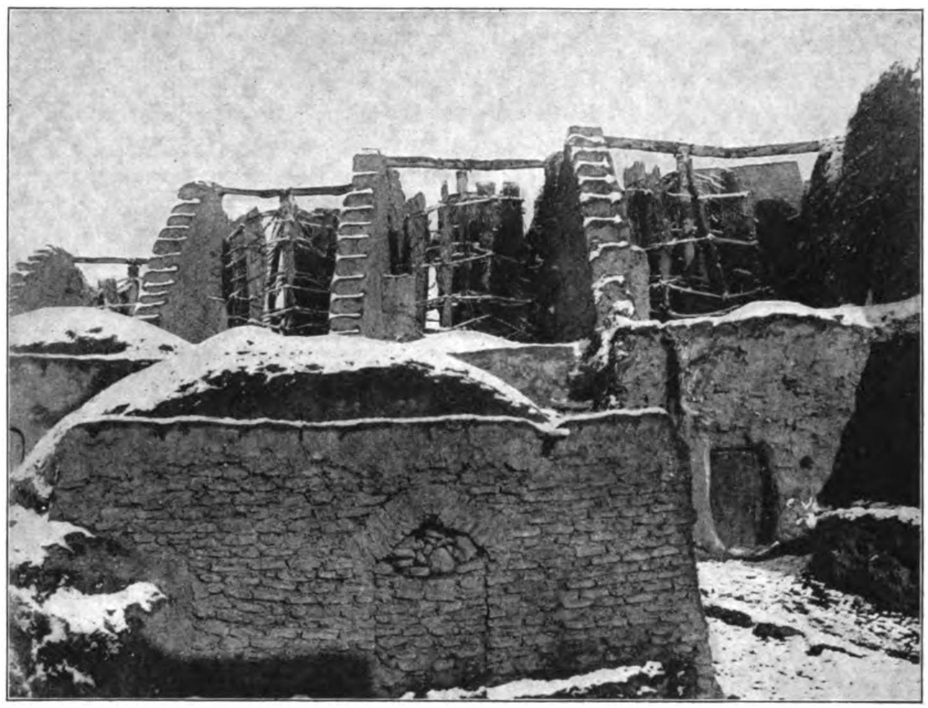

Fig. 149.—Windmills at Tabas.

it is to turn (fig. 149). About the wheel is built a high mud wall, which is left open on the south side and on the western half of the north side (fig. 150). The wind enters through the slit at the north, turns the wheel, and finds an exit to the south. Often ten or twelve mills are set in a row, east and west, and at Neh, northwest of Sistan, I saw fifty. One unfortunate effect of the wind is that in Sistan no fruit can be raised upon trees, and in certain places even melons can not thrive. The wild watermelon, which matures its beautiful but intensely acrid little green and yellow fruits in the dry "nullah" beds, has learned to withstand the wind. Normally, the vine spreads in all directions, but under the influence of the wind the branches are bent to the south, and lie in a long bunch so exactly oriented that the plants might almost serve as a compass. Three that I measured were directed S. 3° E., S. 17° E., and S. 11° E.

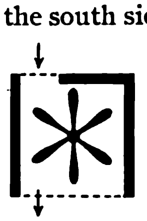

Fig. 150 Horizontal section of a Persian windmill.

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Evidences of the strength of the wind and the paucity of rain abound everywhere. In many parts of the Helmund delta the fierce "Wind of One Hundred and Twenty Days" has scooped in the smooth plain great hollows 6 or 8 feet deep, 20 or 30 feet wide, and hundreds of feet long. Universally the long axis is directed to the north-northwest. At first sight these hollows appear to have been formed by running water, but the testimony of the natives, the location of the depressions where no water could come, the uniform orientation, and the known force and direction of the wind unite to make it certain that they are of æolian origin. In this same region a peculiar effect was called to my notice by Mr. G. P. Tate, topographer of the Sistan Arbitration Commission. Sistan abounds in ruins made of sun-dried brick. Wherever the old walls stand in a north-and-south direction, parallel to the prevailing course of the wind, they remain standing indefinitely,

Fig. 151.—Ruins at the Mil-i-Kasimabad, near Zahidan. These mud walls are at least five hundred years old. Only those in a north-and-south direction remain standing.

although gradually worn very thin by attrition. Wherever the walls stand in the other direction, and are exposed to the full power of the wind, they are speedily blown away and disappear entirely. Thus it happens that the ruins often present the appearance shown in the illustration (fig. 151), where numerous north-and-south walls stand intact, with almost no east-and-west walls to connect them. Besides these more unusual results, the wind plays its well-known part in beveling pebbles and bricks and in etching out and carrying away the softer parts of the rocks.

In winter the winds, although prevailingly from the northwest, are less severe and less regular than in summer. Occasional cyclonic storms are accompanied by southeast winds (St. John, p. 7), which bring the scant rainfall of the country. At its best the rainfall is sufficient to tinge the mountains with green for a few weeks in spring and to support a scanty population of villagers and nomads; at its worst, it supports nothing but a few prickly bushes, and famine destroys unnumbered people and animals. The curse of Persia is the aridity due to the continental position of the country and to its rim of high mountains.

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THE BASIN REGION OF IRAN.

Before proceeding to a more detailed study of the influence of an arid climate upon the physiography of Eastern Persia, I shall describe the main features of the mountain rim and of the diversified basin which it incloses. Among geographical writers it is customary to speak of Persia, Afghanistan, and Baluchistan as composing the plateau of Iran. It is well to use the name Iran for the portion of the three countries included within the mountain border, but the term "plateau" is misleading. The region is essentially a basin, not a plateau. From the central knot of the Pamirs, a genuine plateau, two mountain passes diverge westward. One, the more northerly, runs west by south under the name of Hindu Kush, and then, as the Paropamisus, turns directly westward and traverses Northern Afghanistan. From a height of 25,000 feet in the Pamirs it descends until in Western Afghanistan the highest peaks rise but 5,000 or 6,000 feet above the sea, and the main range is traversed from south to north by the Heri Rud, the river of Herat. Westward in Persia the mountains incline to the north, and in Kopet Dagh and the mountains of Khorasan reach an altitude of 10,000 feet. Then, inclining once more to the south, they take the name of Elburz, south of the Caspian Sea, and rise to an extreme height of 19,400 feet in Demavend. Lastly, still at tremendous heights, the range swings to the northwest and loses itself in a second mountain knot, the plateau of Armenia. The other mountain mass starts from the Pamir as part of the Hindu Kush, but soon diverges to the south, and running south-southwest traverses the eastern part of Afghanistan and Baluchistan under the name of the Suliman Mountains, rising often to heights of 12,000 feet. As it approaches the Arabian Sea it turns westward, and at decreasing heights follows the seacoast until Persia is reached. Here, as in the corresponding portion of the northern range, the mountains are but 5,000 or 6,000 feet high. Farther west in Persia, however, the mountains soon regain their height, and swinging to the northwest run straight through the center of the country at heights from 8,000 to 14,000 feet, and finally in the highlands of Armenia coalesce with the northern of the two mountain chains which start from Hindu Kush. Between these two chains, and completely inclosed by them, lies the basin region of Iran, which is roughly shaped like a segment of a circle, 1,200 miles long from east to west, and 600 miles broad. This region, most of which is absolute desert, contains an area of over 500,000 square miles, and is as large as the twenty of the United States which lie east of the Mississippi River and north of Tennessee and North Carolina; or, to compare it with a region where physiographic conditions are more similar, as large as the five semi-arid states of Colorado, Utah, Nevada, Arizona, and New Mexico.

THE TWO BASINS OF IRAN.

The basin region of Iran contains two chief basins divided into many smaller basins (fig. 152). The largest basin, embracing about three-fifths of all Iran, lies wholly in Persia and may properly be called the Persian basin. The other chief basin, embracing the greater part of the remaining two-fifths of Iran, about 200,000 square miles, contains parts of Persia, Afghanistan, and Baluchistan. It

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is sometimes called the Helmund basin, from the main river, but a better name is the Sistan basin, from the lake and swamp into which all the rivers would finally discharge if they did not dry up on the way. The main portion of this report is concerned with the Sistan basin, but certain features of the Persian basin will also be described, and there will be frequent occasions to refer to Iran as a whole, and also to Turan or Turkestan, as the region farther north is termed.

The border region between the basins of Persia and Sistan is important because it represents a line of earth movements extending north and south across the middle of Iran transverse to the main orographic lines. West of this line the Persian basin was uplifted, while to the east the Sistan basin, together with that of the Heri Rud, was depressed. The region of maximum depression forms a long north-and-south strip, the Afghan depression, in which are grouped a number of

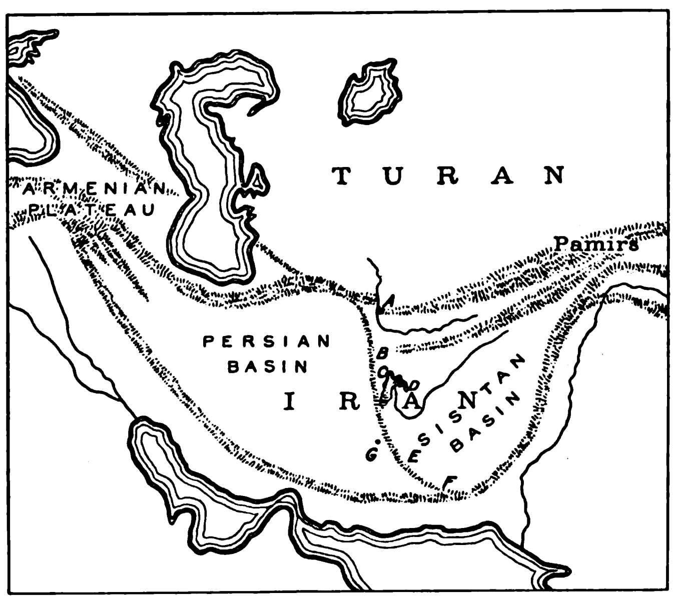

Fig. 152.—Sketch map of the double basin of Iran.

notable physiographic phenomena. At the north the low mountains, close to what is now the boundary between Persia and Afghanistan, afford a ready passage between the deserts of the south and those of the north. Elsewhere, for more than 1,500 miles from the Pamirs to the Armenian plateau, a giant wall of mountains separates Iran and Turan. Here, however (A, fig. 152), the low, rounded mountains afford an easy passage which has been utilized by army after army, from the time of Alexander through the days of Timur and Jenghis Khan to the present century, when Russia sees in it her easiest road to the south. Here, too, the Heri Rud breaks through the main mountain range and emerges upon the desert of Transcaspia, the only instance where a river escapes from the basin of Iran. South of the Heri Rud the east-and-west ranges of Afghan mountains come to a sudden end, while those that front them on the Persian side run in the opposite direction nearly north and south. Between the opposing mountains lies the "Nemeksar" or "salt

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playa" of Khaf (B, fig. 152), at the center of an important subsidiary basin. Farther south a steep east-facing escarpment, which suggests a fault scarp, limits the Persian basin, which stretches away in normal fashion westward from the summit, while on the east, at the foot of the escarpment, the smooth "Desert of Despair" (C, fig. 152), strangely broken by buried mountains, spreads its harsh gravels far southward to the lake and swamp of Sistan (D, fig. 152). Onward in the same direction the desert continues to the swamp of Mashkel (E, fig. 152), still bounded by the escarpment which swings somewhat eastward south of Sistan and bears upon its top the cone of Kuh-i-Taftan (G, fig. 152), the only active volcano of Western Asia. South of all these features the low mountains of southwestern Baluchistan bring the depression to an end (F, fig. 152). The streams flowing into the depression from the east are long and large; those from the west are so short as to be little more than mountain torrents.

GEOLOGICAL HISTORY OF THE BASIN.

The age of the basins of Iran can only be determined by a study of the geology of the country, but of this, unfortunately, we know merely the bare outlines. Not only is the country remote and difficult of access, but the aridity obliges the traveler to hold closely to the roads which usually traverse the gravel-strewn plains. If he makes detours to the mountains, his caravan may be obliged to spend the night without water. Geological study is at a disadvantage. The work of Blanford (A, p. 468) and the geographical map of Mushketoff show that the mountains bordering the Persian portion of Iran consist for the most part of a main mass of Cretaceous limestone bordered on the inside by a smaller amount of Paleozoic or ancient crystalline strata, and on the outside by concentric bands of Tertiary strata, each of which is less warped than the one below it. The inference is that at the end of the Cretaceous era the mountain borders of western Iran began to rise and have continued to be uplifted throughout a large part of Tertiary time. Throughout the Eocene period the sea (Blanford, A, p. 468, and Vredenburg, p. 168) covered the region which is now occupied by the low mountains of Baluchistan, and also much of the interior, judging from the nummulitic limestone which Blanford mentions as being reported from Yezd and Kohrud, and which I found abundantly in the mountains northwest of Sistan. It also probably covered the northwestern corner of Afghanistan, for the mountains there consist largely of Tertiary formations which seem to be of rather late date. Apparently there was oceanic connection between the Arabian Sea and the Samartian Sea which covered the Caspian region, and the interior of the Iran basin was covered by a marine embayment. When or how the sea retreated or when the eastern borders of Iran were uplifted we do not know. It is clear, however, that during the latter half of the Tertiary era Iran had been divided into basins in which subaerial deposition took place, as is shown by the silty and sandy strata of a prevailingly red color which overlie more uniformly bedded shales of marine or estuarine origin.

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ILLUSTRATIONS OF THE GEOLOGICAL HISTORY OF NORTHEASTERN PERSIA.

Although the portion of Iran which I traversed embraces but a small part of the entire basin, it affords illustrations of many phenomena characteristic of the entire region. These fall into groups illustrating, respectively, (1) the non-climatic or more strictly geological history of Iran during the Tertiary and Quaternary eras; (2) the physiographic results produced by an arid climate during the same time; and (3) the effects produced by climatic changes during the Quaternary era. Each of these groups will be considered in its relation to certain theoretical generalizations, and in relation to the geographic aspect of the country. The following illustrations of the geological history pertain first to the character and conditions of uplift of the mountains on the northeastern border of Persia; second, to the nature and appearance of the north-and-south break which separates the Persian and Sistan basins; and, third, to the conditions of warping and deposition in the numerous subsidiary basins.

THE MOUNTAINS OF KHORASAN.

The term Khorasan is applied administratively to all northeastern Persia from Astrabad to the northwestern corner of Baluchistan. In a more restricted sense it is the name of the mountainous northeastern corner of the country centering about Meshed as a capital. As thus limited Khorasan is one of the most prosperous provinces of Persia, thanks to the considerable number of mountains which rise to the height of 10,000 feet or more; yet the prevailing aspect is one of sterility. The mountains are very scantily covered with soil, and support merely a few weeds and bushes and an ephemeral growth of grass in spring. Cultivation is almost confined to the valley bottoms and is dependent entirely on irrigation. Each village is an oasis in the midst of a desert, but compared with other parts of Persia the oases are large and numerous, and are often of great beauty, with their fringes of poplars and orchards.

This favored province of Persia consists of four parts. On the north lies the broad mountain mass of Kopet Dagh, running northwest and southeast, and forming the boundary between Persia and the Russian province of Transcaspia. South of Kopet Dagh lies the so-called valley of Meshed, a narrow cigar-shaped basin or depression. This is bounded on the south by the Binalud range, which runs from the Afghan border northwestward parallel to Kopet Dagh as far as Kuchan, and then turns southwestward until it joins the Elburz Mountains southeast of the Caspian Sea. Within the great arch of the Binalud range lies the fourth division of Khorasan, the little-known basins of Isferayin, Jaga-tai, and Nishapur, together with the mountains which hem them in. South of all stretches the fearful desert of the Dasht-i-Kavir or Dasht-i-Lut.

KOPET DAGH.

If the line of the Caucasus Mountains be projected across the Caspian Sea it reappears in the low, isolated, and half-buried ranges of the Great and Little Balkhans. Toward the southeast these mountains become broader and higher, and rise into the distinct range of Kopet Dagh, or Kopet Mountain, which, with an

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average breadth of 40 or 50 miles, extends for 350 miles to the Afghan frontier. My own knowledge of the range is based on three caravan journeys—one into the high mountains south of Askhabad; another around the eastern end of the range from Dushak, where the railroad turns away from the mountains, to Serakhs and up the Heri Rud; and a third from Meshed, via Kuchan, to Askhabad.

Kopet Dagh appears to be a fairly mature mountain mass which has recently been faulted and strongly uplifted, and thus rejuvenated. The highest portion, near Askhabad, has been described by Professor Davis (ante, p. 46). Farther to the east the mountains present the same flat-topped appearance, with young valleys cut sharply into structural slopes which must have assumed their present smooth character during Tertiary times, when the mountains stood lower. This is well illustrated in the back slope of the Gaoudan block, which is without difficulty reached from Anau, 6 miles east of Askhabad. The faulted face of this block, as seen from the Meshed road, is a precipitous escarpment of naked rock. The back slope, on the contrary, is a long, smooth descent, covered with soil, and closely corresponding to the dip of the limestone strata. In this are cut five or six black gashes, the parallel gorges of young consequent streams which have cut so deeply into the uplifted mountain mass that their sides appear from a distance to be perpendicular. East of Dushak, where the railroad leaves the base of the mountains, the strata of Kopet Dagh become softer and are more thoroughly dissected, but the hilltops still retain a flat aspect and the valleys are steep-sided and narrow.

On the southern side of the mountains there is clearer evidence of recent uplift. Looking northward from Meshed toward Kopet Dagh, the plain is bounded by a line of steep bluffs, which rise a thousand feet in one or two great jumps, and continue northwestward scores of miles. They are cut in strata, apparently Cretaceous limestone, which lie nearly horizontal, with a slight roll from northwest to southeast. The steepness and straightness of the mountain front, its slight dissection, and the absence of a stream competent to produce such effects suggest that the escarpment is the result of recent faulting by which the mountains were uplifted and subjected to renewed dissection. Between the top of the bluffs and the remarkably smooth crest of the range the uplands are rounded and mature in form. These same features continue far to the northwest, but in the neighborhood of Kuchan the bluffs decrease in height and the escarpment comes to an end. Apparently the fault gradually decreases in amplitude, and near Kuchan, after a course of about a hundred miles, is transformed into a simple flexure where the strata of the mountains dip southwestward and pass under the plain. In the neighborhood of the flexure the aspect of the mountains is more mature than in the regions which have been uplifted by faulting. This great displacement along the southern border of the mountains is parallel to the smaller displacements on the north side near Askhabad and seems to be of about the same age.

The youthful character of the valleys in the uplifted block of Kopet Dagh agrees with the steep fault face in indicating that the uplift is of very recent date. For instance, in the mountains north and northwest of Meshed, Curzon (I, pp. 122, 123, 141) describes frequent instances of magnificent gorges from 1,000 to 1,500 feet

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deep and so narrow that there is only room for a single horseman to pass between the walls. Northeast of Radkan his party "plunged into a deep and narrow gorge that cut straight into the heart of the rock wall as though some Titan's axe had slashed a savage gash in the solid stone. Its walls were absolutely perpendicular and shaped in parts by the storms of centuries into windy buttresses and towers, while at the bottom brawled a stream which had hollowed pools in the rocks, and up and across the bed of which it was with difficulty that our horses could be persuaded to climb. The formation and scenery of this magnificent gorge, whose walls are in receding terraces, are a precise reproduction on a miniature scale of the unequaled canyon of the Colorado in Utah." This comparison is very appropriate, for just as the horizontal strata of the Colorado plateau were uplifted at the time of the formation of the Grand Wash fault and have for a short time been exposed to dissection, so, at a correspondingly recent date, the slightly tilted strata of Kopet Dagh were uplifted at the time of the formation of the Meshed fault and are now in process of rapid dissection.

The drainage of Kopet Dagh appears complex. In part, as at Anau, it is clearly consequent, depending entirely on the attitude assumed by the mountains in consequence of recent earth movements. The streams follow relatively straight courses in steep-sided young gorges, and the crests of the ridges form the main divides. Oftener, however, as Curzon (I, p. 144) points out, the streams flow along the main valleys parallel to the axis of the mountains for a certain distance, and then, without warning, turn suddenly at right angles and pierce the mountain ranges at almost their highest points, cutting gorges of almost incredible depth and grandeur. "The base of these defiles seldom admits more than a torrent bed blocked with enormous bowlders, and the walls are frequently vertical to a height of from 500 to 1,000 feet. The main divides are seldom the highest ranges or crests. The streams start on one side of the main ranges, and after running parallel to them for a while, break through to the other side, and perhaps run in an opposite direction for a time." Apparently, though the data are very scanty, the drainage of Kopet Dagh was originally like that of the Appalachians, subsequent for the most part, but with antecedent remnants of a former consequent drainage. This has been further complicated by the recent uplifts, which in some places have caused the previous drainage channels to become more deeply intrenched, while elsewhere they have given rise to a new consequent drainage.

THE MESHED BASIN.

The so-called Meshed Valley south of Kopet Dagh is in reality a narrow, cigar-shaped basin or depression, 10 or 15 miles wide, and at least 150 miles long from northwest to southeast. On the north it is bounded by the Meshed fault; on the south it seems to be separated from the mountains of Binalud by a simple flexure. At Kuchan, in the western half of the basin, its floor is arched where the Meshed fault becomes a flexure. As a result, the basin is occupied by two streams, probably consequent, one of which, the Atrek, flows northwest to the Caspian Sea, while the other, the Meshed River, or Keshef Rud, flows southeast to the Heri Rud;

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both traverse the open plain at first, but later enter gorges, one of which, along the Atrek, is said to be so deep and narrow as to afford magnificent scenery and to be impassable for caravans.

THE KUCHAN EARTHQUAKE.

In connection with the earth-movements by which the Meshed basin has been differentiated from Kopet Dagh and Binalud Kuh it is interesting to note that earthquakes are still common in this region, and are most violent at Kuchan, where the Meshed fault ends in a flexure. In November, 1893, an unusually severe shock destroyed Kuchan, and is said to have killed from 5,000 to 7,000 people. So complete was the destruction that in 1904 the place had almost lost the semblance of a town and was fast becoming a mere shapeless mass of ruins. The surviving inhab-

Fig. 153.—The ruins of Old Kuchan.

itants moved to a location about 10 miles farther east and have there built a new town, modeled after the Russian pattern, with broad streets shaded with numerous trees. Earthquakes still occur very frequently, but are reported to be much less violent at New Kuchan than at the old city. A few of the people of Old Kuchan refused to leave the ruins after the great earthquake of 1893. Digging among the shattered houses, they pulled out old timbers and set them up to form houses which should be both rain-proof and earthquake-proof. At first the timbers were merely set up A-shape against a ridge-pole, like roofs without walls, and the interstices were filled with bushes and the whole plastered with mud. When a more pretentious house was desired, a second structure of the same sort was erected parallel to the first, and the intervening space was walled in and bridged with a flat roof. Old Kuchan consists to-day of a heap of ruins on which are irregularly scattered earthquake-proof houses containing from one to three rooms (fig. 153).

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THE BINALUD RANGE AND THE NEIGHBORING BASINS.

Little is known of the third and fourth divisions of Khorasan. I have seen nothing of the basins and shall not attempt to describe them. The Binalud Mountains, as seen from the north, present somewhat the same youthful appearance as Kopet Dagh, though to a less degree. I was told by Mr. Clemenson, of Meshed, that some of the valleys are as deep and narrow as those of the northern range. Farther south, however, the youthful outlines are lost and the mountains assume a mature appearance. The component rocks also change in character and become largely igneous or of Paleozoic age. It appears that the uplifting of the mountains of Eastern Persia has proceeded gradually from south to north. On the edge of the Dasht-i-Kavir the mountains are mature, farther north in the Binalud range they are young, while still farther north in Kopet Dagh many features are exceedingly young. In Central Asia the same thing seems to be taking place. Step by step the ranges are gaining in area at the expense of the basins, and the mountainous areas of the central massif of Asia seem to be encroaching northward upon the great plains.

THE AFGHAN DEPRESSION.

THE HERI RUD VALLEY.

The Afghan depression is bounded on the north by the low mountains through which the Heri Rud has cut its way out from the basin of Iran. Gathering its waters from the snowy heights of Hindu Kush, in the most inaccessible portion of northern Afghanistan, the Heri Rud flows westward for 300 miles between towering mountain ranges which gradually decrease in height and finally come to an end at the edge of the Afghan depression. Here the Heri Rud turns abruptly north, and after threading its way through a gorge emerges upon the plain of Transcaspia. There, after receiving the waters of the Keshef Rud from Meshed, it takes the name of Tejen River, and soon loses itself in the swamps and sands of the Turkoman desert.

Where the Heri Rud crosses the mountains, the eastern portion of the northern border of Iran appears to be offset to the south. The Paropamisus appears to be the continuation of Kopet Dagh, and the mountains south of Herat the continuation of the Binalud range. The eastern mountains lie roughly 50 miles south of their Persian counterparts. This break between the ranges of Persia and Afghanistan causes the depression through which the Heri Rud escapes to the north. Little is known of the mountains which border the depression. Those on the west at the end of Kopet Dagh, according to Mushketoff, consist for the most part of Cretaceous limestone, but I saw several large basins and other areas where the prevailing formations are of Tertiary age. The topography on the whole is mature; it probably corresponds to that which would exist farther west in the neighborhood of Meshed and Askhabad if no recent uplift had taken place. East of the river the topography is still more mature. Holdich (p. 113), whose opportunities for observation were extensive, describes the country north of Herat as so mature that, although the passes rise to a height of 4,800 feet, wagons can be driven across the mountains in spite of the absence of roads. In the region about 60 miles north of Herat, which Mushketoff erroneously, I think, marks as Triassic, Holdich

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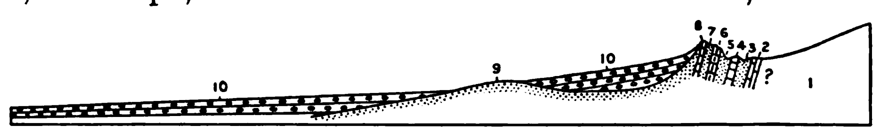
(pp. 133-134) speaks of the "soft-sided" hills as being worn away so fast that "the mountains ran down to the plains in rivulets of mud." Because of this rapid process of degradation the mountains north of Herat "are certainly not such as were described by classical writers two thousand years ago." The wonderful rapidity of erosion is illustrated by a story related by Holdich (p. 135) of a place in this region where the hilltops consisted of a stratified, somewhat loess-like formation of recent date. In descending from the top of a hill during "quite an ordinary hailstorm . . . I was up to my knees in a moving mass of liquid mud. . . . By evening that mud had spread out in a thin but very measurable sheet of surface soil far over the plains all around the hill; and the hill was definitely smaller and the plains definitely higher than they had been the day previous." It is possible that the region is as young in years as Kopet Dagh, although the topography is mature by reason of the softness of the strata.

A section along the Heri Rud from Serakhs southward leads to the same conclusion. At first the stream flows in a terraced valley intrenched some 20 or 30 feet below the alluvial plain which stretches indefinitely northward. Toward the south, however, it traverses a region of low hills composed of an alluvial deposit, which seems to be of the same character as the plain and as the deposits which are now being laid down by the river, although older than either. Where exposed in section by the undercutting of the river, as at Nauruzabad, 25 miles south of Serakhs, for example, the alluvium consists of fine stratified silt, brown in color,



1—Cretaceous limestone; 2—Tertiary brown limestone; 3—Tertiary brown sandstone; 4—Tertiary thin clayey limestone; 5—Tertiary soft sandstone; 6—Tertiary impure yellow limestone; 7—Tertiary reddish-brown sandstone; 8—Tertiary white limestone.

Fig. 154.—North and south section along the Heri Rud at Pul-i-Khatun.

and, in some layers, with a texture much like typical loess. Overlying this is thick gravel, and interstratified with it are bands of gravel lenticular in shape and sometimes reaching a thickness of 5 or 10 feet. This deposit, formed apparently by the ancient Heri Rud, covers most of this corner of Transcaspia from the Afghan border northward. Often it is concealed by drifted sand or loess; sometimes it is interrupted by projecting bits of an older sandstone, presumably of Tertiary age, which dips gently northward where I saw it at Pul-i-Khatun salt lake. Back from the river, east of Pul-i-Khatun (Ladies' Bridge), the soft alluvium assumes the form of low, rolling hills, well graded and mature, which toward the southeast gradually increase to a height ot 4,000 feet. The main valleys are bordered by terraces cut for the most part in gravel.

At Pul-i-Khatun the alluvium comes to an end where the Heri Rud emerges from the mountains through a narrow gorge composed of the Tertiary strata shown in the accompanying section (fig. 154). These strata form a smoothly truncated ridge, in which the river has cut a sharp notch. South of this Tertiary ridge lies a great body of calcareous Cretaceous strata forming the main mass of the moun-

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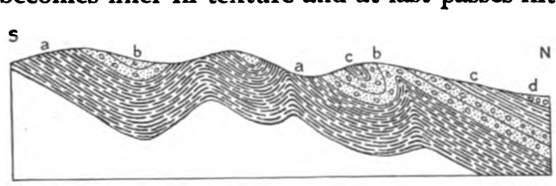
tains. The mountain tops are smoothly rounded; the streams, which seem to be in process of becoming subsequent, sometimes follow the strike of the strata, but often break away, and there are a number of young gorges such as that of the Heri Rud.

The history of the mountains around the Heri Rud seems to have been similar to that of the more western parts of Kopet Dagh. After the Tertiary era was well under way, the Cretaceous formation and the older Tertiary strata were uplifted and the softer strata, at least, were highly folded. Erosion then reduced the country to the rounded character which the mountain tops now show and to the flat condition which is seen in the flat-topped Tertiary ridge at Pul-i-Khatun. The waste from the mountains formed the vast alluvial or piedmont deposits through which the Heri Rud had now cut its way below the ridge. At length another uplift occurred corresponding to that of the Meshed fault, though on a much smaller scale, and possibly at a different time. The land was raised to approximately its present height, and the work of cutting the Pul-i-Khatun gorge and other young valleys was inaugurated. Since the completion of that work, or during the latter part of its accomplishment, gravel terraces were formed. The topography of to-day consists of three portions—the mature topography of the mountains, remaining as an inheritance from a preceding cycle, the young topography of the gorges, and the mature topography of the uplifted piedmont deposits, which is as young as the gorges in years, although mature in form.

THE EXTINCT LAKE OF ZORABAD.

Along the Heri Rud, within the area of Cretaceous limestone south of Pul-i-Khatun, lies the basin of Zorabad. On the Persian side of the river it extends northwest and southeast parallel to the mountains for a distance of about 20 miles, with a width of from 6 to 8 miles. On the Afghan side the limits are not known, but they are probably not extensive. This basin formerly contained a lake, as is shown by an extensive deposit of pure, bluish-white clay or marl, very homogeneous and almost unbanded, into which the terraced streams have cut to a depth of at least 100 feet. Upon the clay, and sharply contrasting with it, lies a hard cap of from 5 to 20 feet of coarse gravel. Near the Heri Rud, in the deepest portion of the basin, both formations increase in thickness. The clay, as would naturally be the case with a lacustrine deposit, preserves the same character. The conglomerate becomes finer in texture and at last passes into silt. Near the edge of the basin, on the south side at least, the clays and the overlying gravel are slightly warped and have been beveled by a grade plain formed at the beginning of the cycle, during which the present valleys were incised in the lake deposits after the draining of the lake. Here it is seen that under the clays, and apparently conformable with them, lies a thick series of sediments, consisting of sandstone and conglomerate in the upper portion and the thick shale



a—shale; *b*—sandstone and conglomerate; *c*—lacustrine clay; *d*—recent gravel.

Fig. 155.—Section near Khitayi, on the southern border of the Zorabad basin.

below (fig. 155). The whole series has been much folded along the edge, but appears to lie more nearly in its original position out toward the center of the basin.

The known facts in regard to Zorabad are too few to warrant any hard and fast conclusions as to its history. The most probable hypothesis is that in early Tertiary times apparently a body of shales was deposited under what were presumably marine conditions. At length the water retired and heavy conglomerates and sandstones were deposited either subaerially or in very shallow water of fluctuating depth. Toward the close, or perhaps during the progress of this deposition, earth-movements were in progress which diminished the size of the basin and uplifted its sides, as is shown by the crumpling of the strata along the edge. Eventually the northern border was raised so high that the Heri Rud was checked and the basin was converted into a lake where clayey marls were deposited. It is probable that these movements were contemporaneous with those which uplifted the alluvial deposits southeast of Serakhs and inaugurated the present cycle of erosion, for the cutting of the gorge at Pul-i-Khatun must have proceeded *pari passu* with the draining of the lake which now ensued. After the lake had disappeared the lacustrine deposits were covered with the subaerial gravels which are so common in arid regions. To-day the deepening of the gorge of the Heri Rud has permitted the dissection of both the clays and the gravels. The most notable fact in regard to Zorabad is that we have here on a small scale the same phenomenon which will presently be described in other basins of Persia, and which seems to have taken place in some of the basins of Turkestan. The area of deposition along the edges of the basin is continually in process of folding, and the folding progresses gradually inward.

THE AFGHAN DEPRESSION SOUTH OF THE RUSSO-AFGHAN BOUNDARY.

On the southern rim of the Zorabad basin the Heri Rud enters the ancient lake bed through a deep gorge cut in Cretaceous limestone and probably of nearly the same age as the corresponding gorge of Pul-i-Khatun on the north side. Upstream the river flows through a broad open valley, which is in reality another large basin extending northwest for 60 miles past Turbat-i-Sheikh Jam. The immediate river valley is bounded by the broad terraces cut in gravel and in an underlying deposit of unconsolidated silts. The silts are slightly warped and are truncated by the terraces. They will be described later. Opposite the southeastern corner of the Jam basin, and offset to the south from it, just as the mountain ranges on the two sides of the Heri Rud are offset from one another, lies the basin of Herat, broad at first, but gradually contracting into the stupendous gorge of the upper river. The Jam-Herat basin is bordered on the south by low hills, chiefly of sandstone, beyond which the smooth, white sheet of the "Nemeksar," or playa of Khaf, and the smaller sheets of its neighbors fill the bottom of a depression which is chiefly remarkable for the large number of half-buried mountains which rise on every hand like islands in an archipelago. It seems as though a once mountainous region had been depressed to form a hollow, in which the mountains still stand as of old, although some have been buried in detritus to the waist, others to the neck, and some are doubtless wholly hidden.

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Thus far, for a distance of 250 miles from Serakhs on the north to the farther side of the basin of "Nemeksar" on the south, the Afghan depression presents the appearance of an undulating hollow with nearly equal slopes from east and west. Farther south, however, the west side of the hollow becomes short and steep, and there seems to have been faulting as well as warping. Near Meliki, at the southern end of the Nemeksar basin, the western boundary of the depression consists of a long line of mountains running nearly north and south, with a remarkably straight front. They are not dissected by the deep re-entrant valleys filled with gravel which are so characteristic a feature of most of the mountains in the basin of Iran. The spurs between the valleys end abruptly and steepen toward the front as though they were the remnants of the facets of a fault scarp (Davis, *c*, p. 148–154). Apparently this steep escarpment marks a relatively recent fault with a heave of many hundred feet on the west side. This is borne out by the appearance of the top of the upheaved block. From a study of the map and from the appearance of the escarpment from below one expects to ascend to the top of the ridge and enter a region of ridges and valleys like the ordinary mountain districts of America and Europe. The top of the escarpment fulfills this expectation, for it is a distinct ridge, at an elevation of 5,000 to 7,000 feet.* Toward the west the ridge descends much less steeply than toward the east, and at a height of about 4,000 feet merges into plains of gravel and silt of the same sort as those on the down-faulted side, except that they stand some 2,000 feet higher and the mountains surrounding them are less deeply buried in gravel. In other words, the country on either side of the fault appears to have been originally of the same type, the ordinary mountain-girt basin type of Eastern Persia. One side was uplifted and exposed to somewhat greater rainfall and erosion; the other was depressed and exposed to diminished rainfall and increased deposition. Hence the upland is a mountainous region containing basins floored with gravel; the lowland is a basin, almost filled with gravel, from which project mountain tops.

Between the hollow of Nemeksar and the much larger hollow of Sistan lies the Dasht-i-Naumad, or Desert of Despair, the central portion of which can not be crossed for lack of water. It does not appear to differ essentially from the lifeless desert wastes of silt and gravel which floor the hollow of Nemeksar. On the edges, at least, it contains the usual complement of buried mountains. Everywhere dreariness and desolation are the rule. The Desert of Despair is a place where men and animals die of hunger and thirst and their companions have no pity. A caravan of Afghans which crossed our track was about to return across the northern edge of the desert with salt from Nemeksar to be sold at Sebzavar in Afghanistan. They reported that on the outward journey they had been delayed and several of their number had died of hunger.

"But had the rest of you no bread?" "Yes, we had enough, but we could not give any to them, for we might have suffered from hunger ourselves."

The desert makes men lose every sentiment except the desire to get safely to the other side.

*The ridge consists of a cap of limestone lying unconformably on a complex of igneous rocks composed chiefly of dark traps shot through with dykes and masses of light-colored felsite, and occasionally interspersed with bodies of highly metamorphosed slate.

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The remainder of the Afghan depression may be summed up briefly. In the southwestern corner of Afghanistan lies the hollow of Sistan, bounded to the west by the unknown, and probably unknowable, escarpment of Palan Kuh (Panther Mountain). Then comes the God-i-Zirrah in Baluchistan, a part of the Sistan hollow; and lastly, to the southeast, the hollow of Mashkel, west of which, near the edge of the escarpment, lies the active volcano of Kuh-i-Taftan. From north to south the Afghan depression, varied as it is in character, forms a continuous whole. So, too, from the Jam basin southward, does the escarpment which forms the western edge and divides the basin of Sistan from that of Persia. It is not by accident that the boundary between Afghanistan and Persia is located along this line. The Heri Rud, so long as it flows in a gorge, forms an unmistakable frontier which can not easily be crossed. The deserts of Nemeksar and the Desert of Despair form an even more effectual barrier. In two places the frontier is weak. One is where the Heri Rud turns northward and the plains of Jam and Herat coalesce. At this point there is no natural barrier, although the land southwest of the bend of the river is so nearly desert and of so little value that it affords small provocation for quarrels. The other weakness is at Sistan, where the boundary arbitrarily bends eastward to the Helmund River, leaving the incomparable natural boundary afforded by the absolute desert at the base of Palan Kuh. Geographically, the whole of Sistan belongs to Afghanistan. Until the political boundary coincides with the natural boundary it is not to be expected that Persia and Afghanistan can avoid quarrels.

THE TERTIARY HISTORY OF THE BASINS OF EASTERN PERSIA.

In a preceding paragraph an outline has been given of the history of one of the minor basins of northeastern Persia.

The Zorabad Basin.—Apparently the Zorabad basin was first occupied by the sea and later became dry land. Then, by the warping of the earth's crust, it was converted into a lake, which in time was drained by the cutting of a gorge. As the water of the lake receded gravel was washed in from the sides and covered the lake deposits. Since that time the gorge at the outlet has been cut deeper, the various deposits have all been more or less dissected, and terraces have been formed. At intervals during the progress of these events warping has gone on in such a fashion that the size of the basin has continually diminished and all the deposits except the most recent gravels have been warped along the edges, although apparently remaining horizontal in the center of the basin. Most of this history probably belongs to Tertiary times, although the dissection of the lake deposits and the formation of the terraces almost certainly belong to the present geological era.

In order to understand the geological history of Persia it will be necessary to ascertain to what extent a similar series of events has occurred in other basins. What few facts are known indicate that the history of all the basins is similar to that of Zorabad, with the exception of the lake episode. The only lakes of which we have record in the other basins occurred at a later time and were due to changes of climate rather than to warping of the crust.

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The Jam Basin.—The deposits of the Jam basin south of Zorabad are disclosed in a number of terraces along the Heri Rud and its tributaries. They consist of fine-grained brown silts, neither sand nor clay, but between the two. Most of the silts are reddish-brown in color, others are brown, brownish-purple, or green. They contain gypsum in thin and very pure transparent layers, which are sometimes so abundant that the ground is white with fragments. Often the strata lie horizontal, but there are many places where warping has taken place. For instance, south of Danidue a terrace 180 feet high consists of a cap of coarse slaty gravel lying unconformably on silts dipping 6° N. The edges of the Jam basin were not seen, and we can not be sure whether the amount of warping increases from the center outward.

An interesting point in regard to the Jam deposits is that as a whole they much resemble the Moencopie beds which occupy so large an area in the plateau region of the United States (Goldthwait, pp. 203, 205, 210). Not only is the general character of the two formations similar, but the brilliant color and peculiar form of the cliffs are strikingly alike, while in each case a gravel cap protects the soft underlying silts. Even the terraces present the same appearance, although those of America are structural, while those of Persia are fluviatile.

The Nemeksar Basin.—In the Nemeksar basin, 75 miles south of the Jam River, many of the phenomena of the Jam basin are repeated. The gravel-capped terraces bordering the playa consist of a soft, fine silt, mostly red, but sometimes slightly green, in which are numerous thin layers of transparent crystalline gypsum. No warping of the silts was here observed, but they were seen only near the center of the basin.

The Chau Bineh Basin.—At Chau Bineh, near Durukh, about 90 miles southeast of Birjand, thick warped clays were noted, purple, red, and green, like those of the Jam basin. They lie unconformably against a mass of ancient volcanic rocks full of serpentine and iron pyrites. The Durukh basin, on the edge of which they lie, is tributary to Sistan.

The Chahak Basin.—This basin and the following one lie on the edge of the main basin of Persia, the Dasht-i-Lut, and would discharge into it if supplied with sufficient water. Yet each possesses its own individuality and is a separate basin with its own "kavir" or salt playa occupying the lowest portion. The basin of Chahak lies two days' journey, 40 or 50 miles, northwest of Birjand, on the road to Tun. Around the playa at the bottom of the basin the waves of a former lake, have cut bluffs of considerable height. For the most part these are composed of a hard clay shale, partly green and partly red, which usually lies horizontal, although in some places it is much folded. Three or four miles northwest of the village of Chahak the bluffs, about 100 feet high, are capped with lava and disclose the following section, beginning from the top:

	Feet.
Dark volcanic trap	20
Green clay shale	40
Pink shale	10
Yellow clay shale	5
Green clay shale	20

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The lava cap lies horizontal; the shales dip about 20° to the north or northwest. The shales are but slightly consolidated, and do not appear to be of great age. Their resemblance to the formations of Sistan, to be described later, is so close that it may be significant.

Twenty miles southeast of the above section, at a point a few miles west of Husseinabad, on the main tributary of the Chahak basin, the valley walls consist of highly folded green clay shales of much the same composition as those of the section just given, although more indurated. It is probable that they form the lower members of the same series, for similar shales are seen at intervals between the two sections. The Husseinabad shales show a strong overthrust from east to west; that is, out from the mountains toward the great basin of the Dasht-i-Lut (fig. 160). It should be noted that these beds, like the older shales at Zorabad, must have been deposited in water of at least moderate depth, which preserved nearly the same conditions for a long period. The recent strata at Chahak, on the other hand, like those at Sistan, seem to have been deposited under changing conditions, which favored first the deposition of green and then of pink clays. In the next basin we shall come to pink beds deposited entirely under subaerial conditions.

The Bajistan Basin.—Bajistan, 40 miles north of Tun, lies on the southern margin of a large "kavir," or salt playa, which, according to Curzon's map, extends some 75 miles northeast and southwest, and from 10 to 30 in the other direction. The playa, at most times, contains a very small amount of standing water surrounded by a broad white plain of salt mixed with silt, muddy in winter, dry and powdery in summer. About 25 miles northeast of the edge of the playa and 20 miles southwest of Turbat-i-Haideri, the gently sloping plain of Bajistan rises into a low line of hills a thousand feet above the "kavir." These hills are composed for the most part of reddish or pink silts which attain a thickness of several hundred feet. At intervals the silts are interrupted by layers of sand from 10 to 20 feet thick and of a reddish-brown color. These strata of alternating silt and sand are soft and unconsolidated; they are folded to such an extent that dips of 15° are not uncommon, and they extend around the edge of the basin and along its sides for some miles. Apparently they were deposited in the basin at a time when it was larger. They have since been uplifted and warped, while the central deposits into which they merge have remained undisturbed. In structure, color, and texture the Bajistan strata suggest the more sandy portions of the pink strata at Sistan. They bear a stronger resemblance to the pink deposits of the Tertiary in Central Turkestan and the Kashgar basin. To a less degree they resemble the deposits of the Jam and Nemeksar basins, although at Bajistan no gypsum was noticed. It is probable that all these red and pink strata are of subaerial origin or were deposited in very shallow saline playas or estuaries. No other explanation seems to account for the absence of fossils, the presence of gypsum, the red color, and the alternations between sand and finer silt.

OTHER LOCALITIES.

Blanford cites a few instances of deposits which apparently belong to the same class as those mentioned above. Near Abarik (*a*, p. 485), on the edge of the Dasht-i-Lut between Bam and Kirman, "are some high cliffs of shales and con-

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glomerates, very slightly consolidated, and to all appearance of comparatively recent origin. The shales are rather brightly colored, greenish-white, red, etc. . . . The beds near the river are contorted and sometimes vertical; farther away they become more horizontal and appear to pass up into the alluvial beds of the great plain to the northward."

Elsewhere (*b*, pp. 493–494) Blanford speaks of red shales, or ferruginous shales and sandy beds, sometimes banded red and white, and often much decomposed, which lie in tilted positions against the limestone of the mountains on the edge of the basins west of Kirman and seem to have been brought to their present positions by faulting and folding. From the description it seems as though these beds must closely resemble those of Bajistan.

SUMMARY.

The facts set forth above, so far as they warrant any conclusion, suggest that in Eastern Persia the lower strata of the basins are generally greenish shales, which are now exposed along the edges of the basins where they have been extensively warped and compressed. Above them occur reddish silts containing more or less sand and gypsum and warped like the underlying shales, although to a less extent. In certain places toward the top of the series the red strata alternate with green clays. Above all lie the deposits of silt and gravel which are to-day accumulating. Although these different strata show varying degrees of warping along the edges of the basins, it is noticeable that toward the centers they approach the horizontal position. It is probable that in the centers of many of the basins an uninterrupted series of strata has been deposited from the time of the post-Cretaceous uplift of the country until now. At first a shallow sea or large lakes probably occupied the central portions of Iran and allowed the deposition of the green shales. Later, as the great basin was broken into smaller basins, the larger bodies of water gave place to smaller ones, and these, under the influence of a dry climate, gave place to playas or shallow salt lakes where the prevailing deposits were reddish silts. Still the process of deepening the basins and decreasing their area went on, with the result that the green shales were more highly warped and the red deposits were also uplifted along the borders of the basin and were exposed to erosion. Meanwhile the superficial deposits which now cover the plains were laid down and the country assumed its present form. It is not to be supposed that every basin has gone through exactly the same process, or that a single process has everywhere taken place at the same time. Accidents have intervened. At Zorabad the damming of the Heri Rud formed a lake and greatly altered the course of events. At Sistan, and probably elsewhere, a series of lakes appears to have occupied the basin during the glacial period. Nevertheless the general course of events was a gradual progress from larger basins to smaller basins, and from subaqueous to subaerial deposition.

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PERSIA AS A TYPICAL EXAMPLE OF AN ARID COUNTRY.

Eastern Persia is in the stage of physiographic development where the influence of aridity is most prominent. The climate of the world as a whole is such that soil is abundant, lakes have outlets, rivers discharge into the sea, and agriculture can be carried on without irrigation. Such conditions are so common that it is hard to realize that they are merely the effects of one special variety of climate. In Persia, however, where the whole aspect of nature is different from that to which we are accustomed, it becomes easy to appreciate the influence of climate. The fundamental difference between the topography of Persia and that of a well-watered country like the eastern United States is that in the latter the main forms are determined by the forces of erosion acting under the guidance of rock-structure and rock-texture, while in Persia a large proportion of the main forms are determined by deposition, which tends to conceal and nullify the influence of rock structure and texture. This can best be illustrated by considering the life history of Persia.

THE CYCLE OF EROSION AND DEPOSITION IN PERSIA.

YOUTH.

The changes through which Persia has passed in the earlier stages of its development, and also those of the future, must in part be inferred, for, so far as I am aware, no part of the country is in the stages of extreme youth or old age, and no typical examples of these stages have been described elsewhere. The present cycle of erosion in Persia was introduced by the formation of inclosed basins, the most striking topographic feature of the country. As we have already seen, the basins are not due to any peculiar form of warping, but rather to the arid climate which has long prevailed. This is well exemplified in the three basins of Zorabad, Jam, and Meshed, in the northeastern corner of the country, which receive an abundant supply of water from high mountains, and hence are provided with outlets and are fast being transformed into valleys of erosion. During the youth of the country these three basins, like their neighbors, such as Pul-i-Khatun, to be described later, Nemeksar, Bajistan, and others, were completely closed and in one case at least contained a lake. During early youth it is probable that all the basins were completely closed. At first their development must have proceeded in much the same way as that of the lake-filled basins of moister regions. The mountains also appear to have developed in the same way as in lands of greater rainfall. Kopet Dagh is the best Persian example which I have seen of young mountains developed under conditions of aridity. Here, however, much of the topography is mature, and the altitude of the mountains has increased the rainfall so that the erosion is not greatly different from that of America and Europe. A better example of young mountains in an arid region is furnished by the southern border of the Tian Shan plateau on the edge of the Kashgar basin. As there exemplified, the chief characteristic of such mountains is extreme sharpness of form and utter nakedness.

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MATURITY.

As youth advances toward maturity the difference between the physiographic forms of a moist country and of a dry country increases apace. At the beginning of maturity in a land of sufficient rainfall the lakes have for the most part been drained, and the topographic forms are almost universally due to erosion guided by the structure and texture of the rocks. In Persia, the typical dry country, on the other hand, almost none of the lakes have been drained, and the proportion of the surface where topographic forms produced by erosion prevail, has reached and passed a maximum. Indeed, the process of decreasing the area subject to erosion goes on from early youth until old age, and is perhaps the most prominent characteristic of the activities controlled by an arid climate. The streams which come from the mountains laden with detritus are compelled to deposit much of their load on reaching the foot of the mountains and changing from a steep to a gentle grade. Even a small stream can flow a long distance in a very arid region, provided it is confined to a small rock channel where there is little opportunity for evaporation. As soon, however, as a region of deposition is reached, the stream begins to spread into many channels, which reduces the already diminished velocity and causes further deposition. Moreover, the stream itself quickly comes to an end, for much water is lost by reason of the larger area exposed to evaporation in the many channels, and even more sinks into the thirsty gravel. For this reason the small running streams of Persia are almost entirely confined to the higher mountains and are continually growing shorter Each new addition of gravel to the fan of a stream represents a decrease in the height of the mountains which in the course of ages is sufficient to cause a decrease in rainfall. It also raises the height of the fan itself, and compels the stream to divide and to lose itself in the gravel at a higher elevation than formerly. Both these processes tend to shorten the streams and cause them to deposit their loads higher and higher, building up the fans indefinitely. Everything tends to increase the areas of deposition until finally basin coalesces with basin; the lower hills are buried out of sight; those of greater height rise as islands in vast expanses of gravel; and even the highest mountains are half-buried in great fans of the same material. Thus in full maturity only the mountains present forms due to erosion, and even of the mountains the lower portions are buried by constantly increasing products of deposition.

This is the condition which has been reached in Eastern Persia south of Binalud Kuh. One of its prominent characteristics is the isolation of the mountains, which is well seen in the basin of Nemeksar. One of the most striking examples is in the playa of Kulberenj, south of the main playa of Nemeksar. From the very floor of the playa rise several small, dark islands, whose roots seem to descend beneath the plain as though these were the pointed tops of what once were high hills or mountains.

The erosion of the mountains.—Another prominent characteristic of the mature mountains of Persia is their nakedness, roughness, and sterility. In a young country it is to be expected that there shall be large areas of naked rock, but in a mature country, if the rainfall is abundant, most of the surface, except the imme-

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diate valley-sides, is graded, and thus covered more or less deeply with soil. Eastern Persia, however, is so arid that the ordinary state of affairs is reversed. All the mountains, whether young or mature, are characterized by nakedness. In the mountains between Neh and Sistan, for instance, which are now passing from youth to maturity, the aridity is so great that the growth of plants is prevented, and free play is allowed to the activity of the wind. The result is that the hills are almost absolutely free from soil and present a remarkable degree of roughness. On one small mountain near Aliabad, for instance, the highly tilted shale of which it is composed stands entirely naked, and even the cracks between the fragments are free from bits of soil. In structure, although not in color or texture, the mountain suggests a great mass of small quartz crystals tied loosely into enormous bundles, with the points up. Another good example of the influence of aridity is found in the neighborhood of Birjand. Here the mountains are composed of dark volcanic rocks, and their main outlines are not sharp and steep in outline like those among the regions of stratified rock to the south, which have just been described. They lie rather in long ridges with rolling crests, rising to a nearly even height, but yet with considerable variation. The sides rise with a steep but by no means abrupt slope, and the drainage is completely established and seems to have become subsequent. In a well-watered country such mountains would be wholly covered with soil and vegetation, and their rounded outlines and graded slopes would leave no doubt that they were in the stage of maturity. In the arid region of Birjand, on the other hand, but few of the slopes are graded, vegetation is very rare, naked rock is as prominent as soil, and many of the small valleys have precipitous sides. Everywhere the same phenomena appear. Most of the mountains are rocky and jagged, with numerous small, sharp peaks and little points; and very often a small hill, which forms but a tiny island in a plain of gravel, still retains the ruggedness and sharpness of outline of an Alpine peak. Graded slopes are not a feature of maturity in an arid climate, for the mountains may be much reduced in height, the drainage may become completely adjusted to the strata, and all the other characteristics of maturity may be developed before the graded condition makes its appearance.

Mature basins.—In the maturity of an arid mountain region the basins are the most important and characteristic feature. In the Persian basins the rock floors are hidden far from sight; the deposits of Tertiary age which were first laid down in them are also invisible for the most part. Only the deposits which are now in process of formation contribute largely to the geographic appearance of the country as it exists to-day. In Eastern Persia these modern deposits are in part aqueous and in part æolian. The latter vary little in texture, and consist largely of fine sand, covering the drier plains and sometimes mantling the leeward side of the hills. Their most remarkable development is at Sistan (Plate 4 and fig. 169), where the violent winds move the sand with phenomenal celerity and heap it into dunes of great height, which are to-day fast encroaching on areas of gravel and silt. The aqueous deposits, on the other hand, vary from the finest clays of lacustrine deposits, through the silts and sands of playas, to coarse gravel and bowlders in the huge piedmont fans and in the mountain valleys. The basin deposits seem to occur almost invariably in one

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order of superposition, namely, silts or other fine materials at the bottom, then gravel, and lastly wind-blown sand on top. It is probable that this order of superposition represents the ordinary sequence of events in a country where basin-making and desiccation are both in progress.

The aqueous series of basin deposits.—The general appearance of the basin deposits is well described by Blanford (*a*, pp. 495–496):

In the smaller plains, and in the larger deserts at a short distance from their margins, the surface usually consists of very fine, pale-colored rather sandy earth, which, although barren in general, is fertile wherever irrigation is practised, unless, as is not unfrequently the case, it is strongly impregnated with salts. . . . The margins of the desert plains . . . usually consist of a long slope covered with gravel and bowlders, and with a surface inclination of from one to three degrees. Such slopes often extend for a distance of from 5 to 10 miles from the base of the hills bounding the plains, the difference in level between the top and the bottom of the incline being frequently from 1,000 to 2,000 feet or even more. What proportion of this depth consists of detritus it is impossible to say, but depth of the deposit must be great, because hills of solid rock but rarely emerge from it. The greater part of such slopes consists of sand and pebbles, the latter more or less angular and mixed with large blocks, all derived from the adjacent hills. . . . Fragments 2 or 3 feet in diameter are not uncommon, even at a distance of a mile or two from the base of the hills; but I only observed them near places where small streams issue from the higher ranges. At such spots the gravel deposits are naturally very often raised into a fan-shaped slope. Such a phenomenon is common enough in all countries, and so are strong slopes at the base of steep hills; but the peculiarity of these slopes in Persia consists in their great breadth, and in the enormous mass of detrital deposits which they contain.

From many of the desert plains of Persia valleys of great width extend far into the more hilly regions. These valleys have, along their sides, precisely such long slopes of gravel as I have just described. The presence of a stream in the midst of the valley is by no means constant; but occasionally small rivulets coming from the sides run for miles along the slopes without descending to the bottom of the valley, and are finally absorbed by the soil, if not exhausted by being diverted for irrigation.

Even at great elevations (p. 497) up to 9,000 feet, similar immense accumulations of loose material occur in many places, and the higher peaks and ranges rise out of them. Among certain of the higher mountains, for example, near Shiraz (p. 498), where the rainfall is greater than usual and the streams flow perennially, the valleys present quite a different appearance, being flat-floored and having no gravel slopes along the sides. The reason for this peculiarity, as Blanford infers, is that the perennial streams are able to carry away the waste that is brought into the valley, whereas, if the streams come to an end at the base of the hills, it is inevitable that the detritus which they carry should be deposited at once and fans should be built up indefinitely.

Blanford describes many fine examples of superficial deposits, especially of gravel slopes, and there are numerous others which might be mentioned. A small but typical example is the basin of Tabas, 60 miles east of Birjand, among the mountains, at an elevation of about 4,000 feet. The center of the plain, which is about 15 miles in diameter, is composed of the finest silt, and as water is relatively abundant, most of it is cultivated. Outside the cultivated area is a broad rim of fine gravel, difficult of cultivation, but very useful to the traveler, as we found during the melting of one of the occasional winter snows. The center of the plain was so muddy and slippery that it was utterly impassable for camels, which are the most helpless of beasts of burden when removed from their proper environ-

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ment. On the fine gravel, however, they had no difficulty. The junction between the gravel and the silt is very indefinite, and the two formations appear to merge into one another in many places. Elsewhere, however, the gravel lies over the silt, and we noted here and at Sistan that certain streams were engaged in the process of bringing small gravel and spreading it out in a smooth and very thin sheet upon the silt. Outside the band of finer gravel, the borders of the plain of Tabas are formed of coarser gravel, which increases in size and in the angle of slope of the surface as the mountains are approached. On the very edge the gravel becomes a mere mass of rough, angular fragments of all sizes up to a foot or more in diameter, and it is hard to say where the coalescing fans of the basin deposit come to an end and the creep from the mountain slopes begins.

The basin of Selabad, 60 miles southeast of Birjand, is of much the same character. The center of this basin is not occupied by fields, but by a salt playa 6 or 8 miles in diameter. On the edges of this are broad deposits of silt, some of which are cultivated. Outside of these are the usual gravel slopes.

The surfaces of these tiresome, gently sloping expanses of gravel do not lie in one plane, as appears at first sight. Although they owe their origin to a sheet of waste which descends evenly from all parts of the mountains, this waste must first be gathered into valleys. Thus the immediate origin of the gravels which skirt the mountains is the innumerable fans which head in every valley, large or small, and expand outward until they coalesce with their neighbors on either side and merge into the plain of silt at the lower end. Each fan, no matter how flat it may seem, is really part of a cone; hence the union of many fans must form a series of low swells and faint hollows. In only one way can this rolling quality be brought to the notice of the eye, at least in the larger basins, without the aid of instruments of precision. This is well illustrated in the northern portion of the Desert of Despair. In looking across a piedmont slope at right angles to the mountains, it often happens that the lower half of some far-away mountain is hidden from view by the seemingly level plain as by a hill. For a mile, or even five, the mountain may be approached without apparent change in its appearance, but at last, slowly and almost imperceptibly, the whole of the distant blue mass is exposed to view, and one realizes that he has reached the arch of a huge flat cone of detritus. Beyond the arch the mountain again half disappears, and then reappears on the next cone, and so on indefinitely. The traveler feels that he is traversing a smooth plain, although his reason tells him that he is crossing a series of broad swells made by the coalescing of great fan-shaped cones of detritus. His aneroid may show that the arch of a fan is one or two hundred feet higher than the hollows on either side.

Almost every writer on Persia speaks of the astonishing abundance of gravel. The largest gravel plain which I saw was on the northwestern border of the lake of Sistan. From Bendun to Bering a smooth plain extends toward the southeast with a uniform slope so gentle that in 30 miles it amounts to but little more than 800 feet. From mountains to lake the plain is composed of pebbles of dark limestone and slate, coarse and angular near the mountains, well-rounded and small near the lake. It is hard to understand how gravel, even though fine-grained, can

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be transported and spread in a sheet on so gentle a slope. East of Sistan the wonder becomes greater. According to Colonel McMahon, the dreary expanse of the Dasht-i-Margo extends eastward 150 miles without change and without interruption from the top of the bluffs of Sistan to the first mountain, Malik-Dokhand in Baluchistan. In this distance the plain rises 2,500 feet—less than 17 feet per mile—and yet gravel has been smoothly distributed everywhere. It is noteworthy that in the driest regions the accumulation of gravel is most extensive, provided the relief of the neighboring mountains is great.

Proceeding now from the coarser to the finer deposits, we find that the center of each basin usually holds a salt lake or playa, bordered by an area of fine silts. Playas and salt lakes are so abundant and various that the Persians have different names for different sorts. The names are used loosely and often overlap, but there seems to be some system. Thus "darya" signifies simply a lake or any large body of water; "hamun," which is often translated "swamp," is used for a body of water which is partly open and partly filled with reeds; next comes "nemeksar," a salt lake which is dry part of the year, but contains water during the rainy season, and, on drying up, deposits salt which can be used commercially. Still drier than the nemeksar is the "kavir," a salt playa or swamp which may sometimes be covered with water for a brief period, but never forms a real lake in which salt of economic value is deposited. Its deposits are always mixed somewhat with sand and silt. The Persian naturally looks upon the utilitarian side of physiography, but his classification is exact enough to be of scientific value. In all these forms of lake, swamp, or playa the deposits which are not composed of salt present much the same appearance, being usually fine-grained saline clays or silts.

OLD AGE.

In the absence of observational knowledge of any country which has grown old under arid conditions, we are obliged to fall back upon deduction in order to discover the ultimate fate of Persia if the present conditions of climate and elevation remain unchanged. In youth and maturity the elevation of the floors of the basins above sea-level is of small importance. In old age it plays an important part. If the floor of a basin is below the level that would be occupied by a peneplain at the same distance from the sea, it will never be affected by aqueous erosion and, unless otherwise influenced, will preserve the forms due to deposition as long as the continent continues to exist. If the center of the basin is considerably above sea-level, on the other hand, the basin form and the features due to deposition will eventually disappear. In every region where there is any aqueous erosion the divides between different drainage areas must shift continually until the slope on the two sides is equal. In a basin region such a state of equilibrium can never be attained so long as the streams on one side flow to the ocean and those on the other to a basin; for the local base-level of the basin rises indefinitely by reason of deposition, and the slope of the streams flowing inward is continually diminished. The ocean base-level, on the contrary, remains fixed, and the slope of the streams reaching it is diminished only by the lowering of the divide which affects the streams on both sides to an equal extent. Accordingly the ocean streams will always have a slightly perhaps imperceptibly, steeper slope than their opponents, and the divide

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must shift inward until the center of the basin is reached and the basin is destroyed. This must happen in every country, provided the streams are strong enough to reach the sea. The divide, in its migration, will come into regions deeply buried in gravel and silt, but the streams must cut through this in time and reach bed rock. When this happens the topography will lose the characteristic forms due to deposition and assume forms determined by erosion along lines indicated by rock structure and rock texture. The whole country will doubtless be deeply shrouded in gravel, the residue of decomposition left after the wind has swept away the finer material, but the main topographic forms will be determined by the character of the rocks, and will so continue until all relief disappears. Therefore, if the center of a basin region is sufficiently elevated above the sea, and if the rainfall is great enough so that some streams reach the sea, the basin character will eventually be destroyed, the major forms due to deposition will disappear, and in old age the arid country will present a topography similar to that of a moist country. The chief difference will be that the moist region will be reduced to a peneplain deeply shrouded in fine soil and densely covered with vegetation, while the arid country will be reduced to a peneplain deeply shrouded in wind-swept gravel and almost void of vegetation.

Under still drier conditions another state of affairs is possible in old age. Suppose that the country is so arid that no stream is able to reach the sea. The divides will migrate until the streams on the two sides have the same grade, and then will sink steadily, though exceedingly slowly, in one position. While this is in progress, the rainfall will still further diminish because of the lowering of the mountains, the streams will grow even shorter, and the heads of the gravel fans will rise nearly or quite to the divides. At last there will come a time when the land forms produced by deposition will dominate the topography of practically the whole country. Gravel fans, extinct playas, and deserts will everywhere prevail, and the little rain which falls will so soon be evaporated or sink into the ever-deepening gravel that running streams will be practically unknown. Whatever transportation of solid matter toward the sea takes place by means of water will be almost infinitesimally small, and the whole result will be an immeasurably slow melting away of the country which will not materially affect the surface. If this were the end we might conclude that in an extremely arid country all the topographic forms of old age are due to deposition, with the single exception of the divides, which to a certain extent survive as the last remnant of forms due to erosion.

There is still one factor, however, which we have disregarded. As the power of aqueous erosion decreases that of æolian erosion increases. In a country which had reached the stage of old age which has just been described, the wind would play an exceedingly important part. It would comminute and strip off the gravels on the surface, and then would begin to erode the underlying rock. The forms produced would be very different from those of aqueous erosion in detail, but they would follow the same guidance of rock-structure and rock-texture. Thus in extreme old age the driest country must be reduced to a peneplain, parts of which may lie below sea-level where the strata are very soft, and all of which will follow the lines of the rock structure. The surface of the peneplain will be strewn with fragments of waste which will increase in size in proportion to the aridity.

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SUMMARY.

In early youth the main forms of Persia probably differed but little from those of a moist country. There was more nakedness, roughness, and sharpness, but this was confined to the minor details. From youth onward, however, through maturity the land forms of Persia increasingly diverge from the forms of moister regions. Those of the latter are shaped by erosion; those of Persia largely by deposition. In the one case basins are destroyed; in the other they are preserved. The divergence between the two types is at a maximum during mid-maturity, when, in a moist country such as the southern Appalachian region of the United States, inclosed basins have wholly disappeared, a subsequent drainage follows implicitly the lines of rock structure, and the slopes of the mountains are completely graded; while in an arid country, such as Eastern Persia, inclosed basins are the rule. The drainage is largely interfered with by immense areas of deposition which have no connection with the underlying rocks, and the slopes of even the lower mountains are rough and naked. From mid-maturity onward the main topographic forms of moist and of arid lands again approach one another somewhat, until in old age both are reduced to peneplains. If the wind is active, however, the arid peneplain will continue to develop and may be eroded below sea-level.

PERSIA AS AN EXAMPLE OF THE INFLUENCE OF CHANGES OF CLIMATE.

Although as a whole the basin deposits of Eastern Persia indicate the long prevalence of an arid climate, there are certain phenomena which suggest a departure from the present condition during relatively recent times. These consist, in the first place, of fine deposits of silt and clay which seem to be of lacustrine or playa origin, although they lie in regions which are never inundated under the present climatic conditions. Associated with these are shore terraces of the kind which are usually characteristic of lakes. These are best explained by supposing either that the rainfall of former times was greater than to-day, or that the climate was colder, evaporation was less, and a greater accumulation of water was possible in the basins.

Another class of facts seems to have some connection with the lakes, but is by no means so well understood. Numerous valleys in all parts of Eastern Persia contain a series of terraces ranging up to five in number, and closely similar to the terraces of Turkestan. Sometimes the terraces are cut partly in rock and partly in stream-laid gravel, sometimes wholly in stream-laid gravel, and sometimes in stream-laid gravel which lies with a slight unconformity upon finer deposits of silt. Such unconformities are common on the edges of the ancient lakes, and in almost every case coarse material lies above and finer material below, while the transition in the reverse order from coarse below to fine above seems to be gradual, without any sudden change. As the terraces and the associated phenomena represent the most recent physiographic changes which have taken place in Persia, it is not impossible that some of them originated since the advent of man, and they must be carefully explained.

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THEORIES OF TERRACE FORMATION.

There are three generally accepted theories of terrace formation. (1) The best-known theory explains terraces as the result of tectonic movements of the earth's crust. The uplift of a given region accelerates the streams and causes them to deepen their channels. A period of rest allows the streams to cut down to grade and to broaden their flood-plains. A repetition of this process produces terraces, provided the broadening of the flood-plains during each successive period of rest is less than during the preceding period. For brevity I shall refer to this as the tectonic theory of terrace formation. (2) A second theory explains a large number of terraces as due to the growth of stream-laid deposits in the valleys downstream from the foot of glaciers during successive glacial epochs and the dissection of the deposits by the streams during interglacial epochs. (3) Other terraces have been explained by Davis (*d*) as the result of the normal swinging of rivers in alluvial deposits during a single phase of downcutting. Under this supposition a river cuts laterally until it reaches the rock wall of the valley, where it is stopped by the rock. At its next swing in the same direction the stream is at a lower level, and, because of the narrowing of the valley downward in vertical section, reaches the valley wall before swinging so far as before. Thus it is not able to cut so far laterally, and a terrace is formed. (4) In addition to these three theories there is a fourth, which has been but little discussed. It has been outlined in the preceding report on Turkestan, where the conclusion is reached that the terraces of that country are due to the alternations of climate which occurred during the glacial period in regions where no glaciation took place. I shall refer to this as the climatic theory of terrace formation.

Of the four theories mentioned, the second and third can not possibly apply to Eastern Persia, for no trace of glaciation has been detected there, and the terraces frequently continue for many miles without approaching the rock walls of their valleys. The explanation of the Persian terraces seems to lie either in the first or the fourth theory—the tectonic or the climatic. In the following pages the terraces of Eastern Persia and the neighboring portion of Transcaspia are described and an attempt is made to ascertain which theory best fits the facts. To avoid confusion I shall use the terms "fluvial" and "interfluvial," or "lacustral" and "interlacustral," when speaking of the climatic equivalent of the glacial period in non-glacial regions. These terms must not be understood as bearing any implication as to the cause of the glacial period. Either an increase in cold or an increase in precipitation would cause the lengthening of the rivers and the expansion of the lakes. Hence the climatic equivalent of a glacial epoch is appropriately termed a fluvial epoch when we are considering river action, and a lacustral epoch when we are considering lake action.

EXAMPLES OF TERRACES.

THE NORTHERN SLOPE OF KOPET DAGH.

In his report on Transcaspia Professor Davis has described the terraces of Kizil Arvat, at the western end of the Kopet range, 140 miles northwest of Askhabad, and also those of the portion of Kopet Dagh immediately to the west and south

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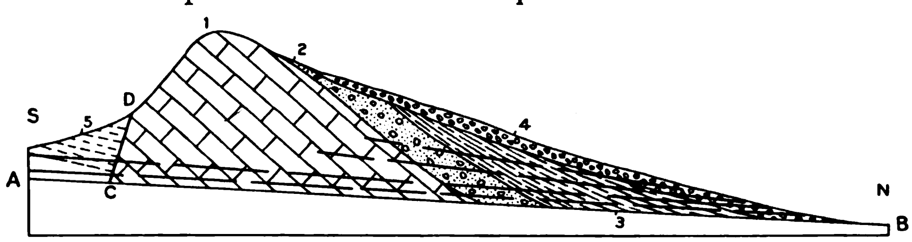
of Askhabad. In both these regions there were well-marked series of terraces, indicating a succession of decreasingly severe impulses toward valley deepening. Whether the cause of these terraces was to be found in crustal movements or in changes of climate could not be determined because of the small number of examples, either cause seeming to be competent to explain all the phenomena. Farther east along the northern slope of Kopet Dagh the same state of affairs continues indefinitely. At Anau, 6 miles east of Askhabad, a small stream breaks through a gorge in the front range of Kopet Dagh and debouches upon the piedmont plain, where its waters are diverted for irrigation. In its upper course the Anau stream flows northwestward through a broad valley of soft strata, which were depressed to their present level by the fault which uplifted the small Anau ridge on the northeast side of the valley. This Anau ridge appears to be a fault block of the same sort as that of Suru-Muzdar, which lies on the southwestern side of the valley and has been described by Professor Davis. In both of these parallel blocks the southwest side presents a precipitous escarpment, the battered successor of the original fault scarp, while the northeastern face presents a smoothly-graded slope in which are incised the deep trenches of small consequent streams. In the Suru-Muzdar



a, b—course of brook; *c, d*—fault; 1—limestone; 2—conglomerate; 3—red silt; 4—gravel; 5—soft Tertiary formation.

Fig. 156.—North and south section along the Anau Brook, across the Anau fault block. Dash lines indicate terraces.

block, so far as could be judged from a distance, the back slope appears to be wholly structural, following the bedding of the hard Cretaceous limestone. In the Anau block, on the other hand, the upper part of the back slope is determined by the structure of the limestone, while the lower part is quite independent of structure and truncates the underlying warped Tertiary strata (fig. 156). Where the Anau stream turns to the north and passes out of the trough between the two fault blocks it has cut a deep gorge in the Anau block. The sides of this gorge are steep, but even at the narrowest point the bottom is flat-floored and has a width of several hundred feet, so that although the gorge is young there must nevertheless have been a considerable lapse of time since its cutting was begun, and even since it was cut to its present level and the work of broadening the bottom began.

The Anau gorge is important because of the terraces which it contains. As is seen in the cross-section (fig. 156) the stream, on leaving the soft strata south of the Anau fault block, first traverses a hard limestone forming the narrowest portion of the gorge, and then a coarse conglomerate, and lastly a red silt already described as like the silts of Kashgar and Bajistan. Overlying the conglomerate and silt, both of which have been warped and dip northward, extends a recent conglomerate or,

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better, gravel, forming an unconsolidated sheet some 40 or 50 feet thick, which lies unconformably on the beveled edges of the other strata and shows almost no sign of warping. It seems probable, however, that the gravel sheet has been uplifted and tilted somewhat, and that it represents the old piedmont deposit of a time previous to the faulting and uplift of the Anau and Suru-Muzdar blocks. On the east this conglomerate or, better, gravel, forms a smooth though sloping plain, in which are incised young valleys; on the west it has been dissected into low, rolling hills.

Thus far there can be but little question as to the true nature and origin of the phenomena of the gorge; it is when we come to the terraces that the difficulty begins. In its more open portions to the north of the hard limestone the sides of the gorge are marked by well-defined gravel terraces to the number of five, which gradually converge downstream until they, as well as the upper grade plain, merge into the general slope of the present piedmont plain in the vicinity of Anau, where the stream comes to an end. The heights of the terraces above the stream, as measured at a point well within the gorge a little below the so-called "Old Mills," are approximately as follows:

	Feet.
First terrace, narrow and insignificant	3
Second terrace, rather broad and strong	6
Third terrace, broad plain of main valley floor	20
Fourth terrace, narrow, often missing	50
Fifth terrace, broad and flat	100
Grade plain, uplifted piedmont deposit	300

The whole number of terraces is not always present, sometimes one and sometimes another being undercut; nor does it appear as though they all merged into the plain at the same point.

If all the terraces were cut in the solid rock, and came to an end in the Anau fault block, it would be easy to explain them as the product of the same faulting which produced the block and which uplifted the old piedmont plain. As a matter of fact, however, the lower terraces at least, so far as their structure could be made out, seem to be composed entirely of stream-laid gravel. In other words, the gorge was cut to nearly its present form and then was subjected to a series of changes by which it was first filled with gravel and then cut out again. Moreover, although the terraces disappear in the narrowest portion of the gorge, three of them reappear in the more open portion of the valley farther upstream—another evidence that the younger ones are of later date than the gorge. The importance of the relative ages of the gorge and the terraces lies in the fact that the fault which caused the cutting of the gorge represents the last movement of uplift of which we have any unmistakable record. It is not impossible that the terraces are due to earth movements of a kind which first caused deposition and then erosion, this alternation being repeated as many times as there are separate gravel deposits, an unknown quantity which may number from one to five. The Anau terraces, like those described by Professor Davis, are unsatisfactory, because, so far as can be seen, they may be either tectonic or climatic in origin.

At Anau, and elsewhere along the base of the mountains as far as Dushak, where the railroad turns to the northeast, the hasty view of the country obtained

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from passing trains shows that almost universally the "ateck," or "skirt" of the mountains, as the Turkomans term the piedmont slopes, has been subjected to a slight dissection. The numerous coalescent fans are intersected by small dry valleys, the peculiar feature of which is that they are not fresh, but are everywhere grassed over, while the sides are reduced to a very gentle angle and the bottoms appear to be half filled with sediment. They are certainly not channels which are now being eroded, and they seem to extend farther than the farthest floods of to-day. It is possible that they belong to a rather recent time when the streams flowed farther out into the desert than they do to-day. The largest stream of the district is at Lutfabad, where the railroad crosses the lower waters of the stream whose terraced upper portions have been described by Professor Davis. Here, where the stream spreads out upon its fan shortly before coming to an end, it is bordered by two distinct terraces.

From Dushak southeastward for 80 miles to Serakhs, at the northeastern corner of Persia, on the Heri Rud, or Tejen River, I traveled by caravan and was able to examine the country more closely. Few new features were seen, however. Near the mountains the fans are naturally more arched and more gravelly than farther out toward the plain. Curiously enough, the old stream channels do not take the form of depressions, but appear as incipient ridges topped with a belt of cobble stones, some of which are 6 or 8 inches in diameter. Apparently at some previous time the streams deposited cobbles along the floors of their channels. Since that time the fans have been so far degraded that the channels have disappeared and their floors have been converted into ridges. The present streams are incised below the plain to depths of from 10 to 15 feet, or even more. All that were seen were small dry channels, with the exception of the flowing streams at Meana.

THE MURG-AB RIVER.

Omitting for the present the Heri Rud (river), which comes from the interior of the Iran basin, one more stream must be described, which flows from the northern side of the mountains. The Murg-ab, *i. e.*, Murg-water, rises in the Paropamisus Mountains in northwestern Afghanistan, and flows northward into the desert of Transcaspia, where it finally loses itself in the reed-beds of a swamp after watering the flat oasis of Merv. At Merv itself and throughout the oasis the main stream flows practically on the surface of the delta, although some of the irrigation canals are incised 10 or more feet. Upstream, however, the delta is bounded by cliffs of silt, which gradually converge and grow higher until at the dam of Hindu Kush, 30 miles above Merv, the river flows in a well-defined valley. At the dam the sides of the river show two terraces, one of them 10 feet above the level of the water in June and the other 30 feet above that level. The banks of both terraces appear very young and freshly cut, as indeed they ought, since the lower is merely the border of the channel and the upper is occasionally undercut by the river when an unusually high flood causes the stream to overflow. It is interesting to note that the channel seems to be growing deeper at an appreciable rate. The dam is located just below the divergence of an old river channel which was abandoned something over a hundred years ago, and into which the new dam, completed about 1895, now

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diverts a part of the river. According to Mr. Nikrashevich, superintendent of the dam, the inner terrace at the bottom of the old channel had a height of 2 feet before conditions were changed by the building of the dam, while the inner channel, where the stream to-day runs, has a depth of about 16 feet. That is, the bottom of the river to-day is 14 feet lower than it was at the time of the abandonment of the old channel a hundred years ago. Part of this difference, however, may be accounted for by filling of the latter subsequent to its abandonment.

Since the building of the dam the river has so filled up its channel above the artificial obstruction that the lower terrace has entirely disappeared and the stream has no proper channel, but wanders this way and that over its own deposits. This wandering is causing the widening of the flood-plain, and there is great danger that in time a sudden change in the course of the main stream will cause it to cut into the banks close to the dam and finally to break a way around the end of the latter. Such a catastrophe took place at Sultan Bend, a few miles up the river, where a dam was built about 1890 and was abandoned a few years later. Retaining walls were built in all directions, but nothing could prevent the river from cutting laterally when it was prevented from accomplishing its normal work of vertical erosion.

The material which is now being deposited by the Murg-ab seems to be the same as that which is exposed in the bluffs of the terraces. It consists of a very fine clayey sand well stratified and with a consistency like loess. It stands for years in nearly perpendicular bluffs, and preserves the marks of the pick indefinitely. It is said that as far as Tash Kupri, nearly a hundred miles upstream, the same fine sandy deposit continues, and only at that place does it become gravelly.

The terraces also continue far upstream. At Tash Kupri there are said to be two, one of them close to the river and the other 70 feet above it. At Sultan Bend, 15 miles above the dam at Hindu Kush, there are three terraces. At the top lies the great sand-covered alluvial plain, 70 feet above the river; then comes a broad terrace covered with tamarisk and other bushes, and lying about half as high; and lastly there is a small young terrace only 10 feet above the water. Here, again, as in so many other cases, there is no positive indication as to whether the terracing is due to climatic or tectonic causes. There are archeological indications that the flow of the Murg-ab one or two thousand years ago was more abundant than at present, and it is not impossible that the decrease in the size of the stream is connected with the building of the lower terraces.

THE HERI RUD.

The Heri Rud, or Tejen River, as it is called after it enters Russian territory, when taken by itself is no more conclusive as to the cause of the terraces than are the other rivers. To be sure, it flows directly across the northern mountain rim of the basin of Iran, and thereby differs from the other streams which we have considered. If the terraces are due to an extensive uplift of Kopet Dagh and the Paropamisus, the main axis of that uplift must have passed directly athwart the Heri Rud not far from what is now the Afghan border, accelerating the lower or northern portion of the stream and retarding the upper portion. The process of terrace-making under such circumstances would differ materially from that in cases

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where the whole stream was tilted in one direction, but the resulting forms would be similar in appearance. They could be distinguished from climatic terraces only by means of a careful study of their height at many places and of the irrelation to uplifted areas and to the mountains along the course of the stream. There is, however, one respect in which the Heri Rud affords a valuable clue to the origin of the terraces. Closely associated with the river, and in one case forming part of its system, are some small lakes showing phenomena which it seems impossible to explain on any hypothesis except that of climatic change. If a study of these shall show the terraces of the Heri Rud to be of climatic origin, there is a strong presumption that the terraces of the neighboring streams are due to the same cause.

In its lower course the Heri Rud closely resembles the Murg-ab. At Tejen it flows upon the surface of the plain and is also liable to the extraordinary floods described in Professor Davis's report. At Serakhs the cross-section is much like that of the Murg-ab at Hindu Kush, with the river flowing in a deep channel about 10 feet below what may be termed either a lower terrace or an elevated flood-plain, and with a second terrace 20 feet high rising to a broad alluvial plain. Fifty miles farther upstream, at Pul-i-Khatun, below the lower gorge, there are four terraces. The lower one is small, as usual; the second forms a broad plain half a mile wide, on which is located a Russian military post to guard the only bridge in this part of the country; the third is narrow, though distinct; and the fourth is the rather flat tops of the surrounding hills of old alluvium. But little was seen of the 35 miles of the river between Pul-i-Khatun and Zulfagar (Zulfikar) at the northwestern corner of Afghanistan. Most of the way the river flows in a narrow gorge, and whatever terraces may have existed are naturally destroyed for the most part. Just south of Pul-i-Khatun, in a relatively open stretch, two were noted, composed of gravel which had clearly been brought in as a filling after the work of valley-making had reached practically its present stage.

At Zulfagar, in the ancient lake basin of Zorabad, the valley of the Heri Rud again widens, and at once the number of terraces increases. In one side valley five terraces were noted cut in the ancient lake clays; in two or three others the number is four, while in many cases there has been so much undercutting or change of some sort that only the minimum number of two is preserved. Along the main river the terraces, where best preserved, number five, of which the first, third, and fifth are usually strong, while the second and fourth are weak or missing. Some 10 miles south of the Afghan boundary and a little upstream from the dam of Dat Mehemet Khan, a very significant section is seen on the right bank of the river as one looks downstream from the cultivated fields east of Khatayi, on the left side of the river (fig. 157). Here the gravel remnants of what seem to be the third and fourth terraces, counting from below upward, are seen to lie on a slope of westward-dipping shales which must have been subjected to erosion. They indicate that before the formation of each terrace the valley must have been cut well below the level of that terrace, though not necessarily to the present depth, and then filled with gravel. This is not absolutely inconsistent with a tectonic origin of the terraces, but inasmuch as this section lies close to what must have been the axis of any supposed

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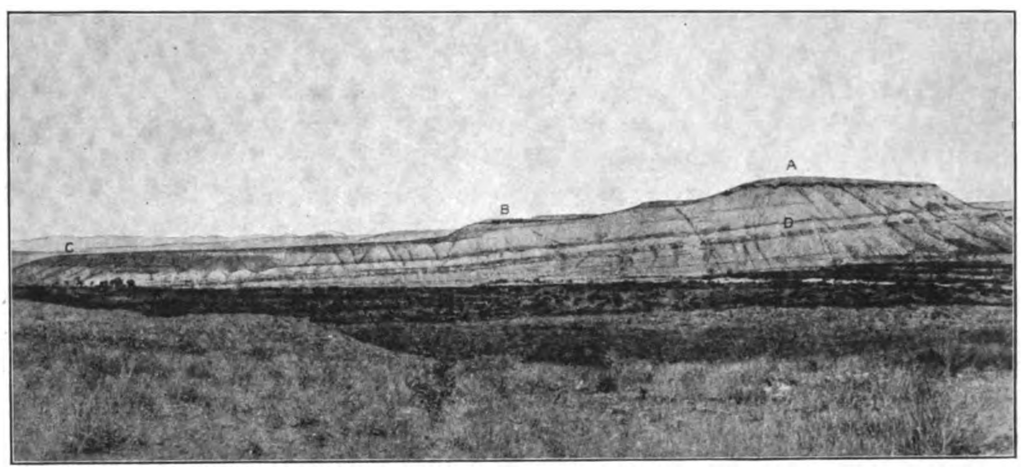
uplift, it would demand that for the production of each individual terrace there must have been an uplift to cause dissection and a depression to cause deposition. If the terraces are of climatic origin no such complicated and highly specialized wavering of the earth's crust is required.

Upstream from the Khitayi section the Heri Rud traverses a narrow limestone gorge through which there is at present no caravan trail, and where, so far as could be seen, there are no terraces. Twenty-five miles farther south, at the mouth of the Jam River, where the valley again widens, terraces appear once more to the number of four, with the remnants of what seems to be a fifth farther back. They are cut in the brownish and reddish shales described previously and are characterized by a heavy stratum of gravel from 5 to 20 feet thick lying upon the soft shales or silts, unconformably as a rule. Owing to the softness of the material, all the terraces are very broad. Upstream the lower terrace grows continually wider, apparently



A, B, and C—terraces of horizontal gravel. D—tilted shale. E F—course of river from right to left.
Fig. 157.—Terraces of the Heri Rud, near Khatayi. View northeast across the river into Afghanistan.

because the silts become softer, until, at the point where the Heri Rud turns from a westward to a northward course, it forms a plain, 10 or even 20 miles wide, and the upper terraces are entirely consumed.

THE LAKE OF KOGNEH NEMEKSAR.

The salt lake of Kogneh is situated near the mouth of the Jam River, in the northwestern angle between that stream and the Heri Rud, close to where the latter passes out of the open region of terraces which has just been described (see fig. 158). The lake is of insignificant size, only a mile long from northwest to southeast, and three-quarters of a mile in the other direction. It has no outlet at any season. When we saw it in December a small stream flowed into it from the northwest, and there was a little water in pools here and there. The amount of water may have been more than appeared at first sight, as the surface of the lake was covered with a sheet of salt, and the shores were composed of thick, black mud, so wet that it was impossible to approach the open water. On all sides except the northwest the lake

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is bounded by steep bluffs, 35 feet high, which on the north and northeast are composed of a rather solid formation which appears to be a portion of the half-lithified basin silts of Tertiary age. On the southeast and south the bluff consists entirely of stream-laid gravel. On the northwest side, whence the lake receives its water supply, a plain, at first marshy, rises gently to the great basin plain of silt bordered by gravel, in which are located Kalagak and Turbat-i-Sheik Jam. The rise from the lake to Kalagak, however, is not perfectly smooth, for beyond the marshy border it is broken by two small terraces, the lower of which is very slight, while the upper, perhaps 15 feet above the water-level, is also slight, although it is clearly marked. Around the lake itself, at the foot of the bluffs and about 10 feet above the water-level, is a beach which extends downward 4 or 5 feet. It may represent the extreme high-water level of to-day, although I could get no information on this point. It

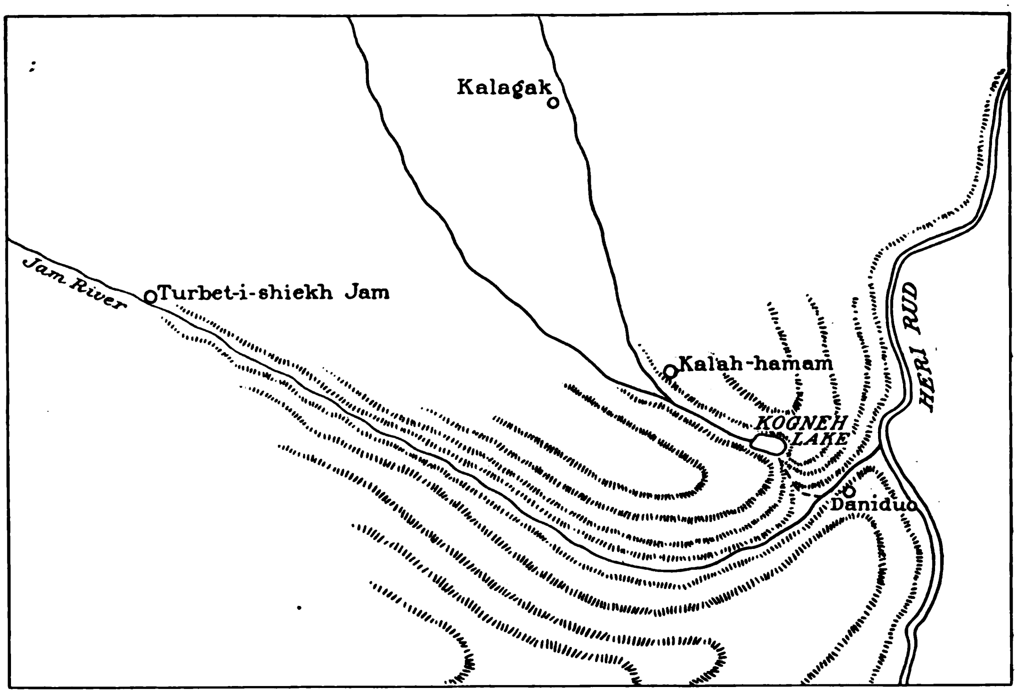

Fig. 158.—Sketch-map of Kogneh Lake and the Jam Basin.

probably corresponds to the lower terrace. The bluff which surrounds the lake is very flat-topped and is unbroken except at one point on the southeast side, where there is a notch, broadly flat-floored and some 12 or 15 feet deep. This notch opens into the head of a well-defined valley which discharges to the Jam River, as shown in the sketch. It is evidently not occupied by water even during the highest floods, and there can be no doubt that it is an abandoned channel, representing a former higher stand of the lake. It probably corresponds to the upper of the two small terraces on the northwest, but the latter seemed to be lower than the notch, and as no exact measurements could be taken the matter must be left unsettled. The phenomena immediately about the lake indicate that the water must at various times have stood at three, or possibly four different levels. First, the level of the top of

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the gravel bluff; second, the level of the old outlet; third, the level of the upper terrace, although this may be the same as the old outlet; and fourth, the level of the lower terrace and the beach which may be reached to-day in time of flood.

At a little distance from the lake we find evidence of still other changes in the behavior of the water-courses. If the level top of the gravel bluff south of the lake be followed northwestward, it will be found that it merges smoothly into the plain of Kalagak. In the plain the streams have incised themselves to a depth of from 4 to 10 feet, in response apparently to the changes in lake level indicated by the little terraces. On the edges of the plain two terraces of quite a different kind present strong escarpments heavily capped with gravel. These correspond to the uppermost of the terraces of the Heri Rud, as appears by following them to the south, where they are well displayed. Along the Jam River seven terraces can be seen in certain places, but as two of them, near the bottom of the series, do not seem to be permanent, we shall consider them as adventitious and leave them out of account. The third terrace, counting the upper and oldest as the first, corresponds to the Kalagak plain and to the top of the bluff south of the lake. The fourth terrace, that is, the one next to the bottom, if it be traced toward the lake, is found to coincide with the bottom of the old outlet. A little tributary of the Jam is now gnawing back into the soft gravel in which the former outlet is trenched, and will in time cut through the bluff and drain the lake. The fourth and fifth terraces along the Jam seem to correspond to the low terraces northwest of the lake and to the slight channeling of the Kalagak plain. The terraces along the Jam are strong while the others are weak, because the main river was able to continually deepen its channel, while the lake furnished a but slightly changeable base-level and prevented its tributaries from cutting deeply.

Turning now from a mere statement of facts to a consideration of causes, we must first sum up the history of the lake of Kogneh and the neighboring rivers. Originally an uninterrupted stream must have flowed from Kalagak to Daniduo, where, after passing what is now the site of Kogneh Lake, it joined the Jam River, and the combined streams emptied into the Heri Rud. For some reason this whole river system was subjected to certain systematic changes by which the streams were at first induced to deposit abundant gravel and to wander widely from side to side. Then other conditions ensued under which the streams acted in exactly the opposite fashion and cut deeply into their beds, carrying away much of the gravel, cutting even into the underlying rock and forming high terraces. Just how many such alternations took place we are unable to say, but there were at least two before the formation of Kogneh Lake. During the third time of gravel deposition and river wandering, the large Jam River deposited its load so rapidly across the mouth of the Kalagak stream that the latter could not keep an outlet clear. Thus a bar was formed across the mouth of the Kalagak Valley, and behind this the brook spread out into the lake of Kogneh, finding an outlet to the main stream as best it could among the gravels of its bigger neighbors. Up to this point the history of the region is explicable either on the tectonic or the climatic theory; from this time onward only the climatic theory seems competent to account for all the facts.

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When the third period of degradation and valley deepening set in, the volume of the streams, according to the tectonic theory, was unaffected, and Kogneh Lake must have remained full. Supposing this to be the case, the lake continued to overflow to the Jam River throughout the third period of degradation and the fourth period of aggradation. At the beginning of the fourth period of degradation the flow of the Kalagak stream was somehow so diminished that the lake no longer flowed, and the abandoned outlet was left at the level of the fourth terrace. The cause of the sudden desiccation of the lake, no marked change of climate being admitted, can only have been a diversion of some of the tributaries of the Kalagak brook. I saw no sign of any such diversion and it is not likely that it took place, but without detailed study of the region this can not be asserted positively. The last change in the lake, by which the lower terrace was formed, will have to be explained by the same gratuitous assumption that a tributary of the Kalagak was again diverted, this time toward instead of away from the lake. It can not have been the same tributary as on the earlier occasion, because it only sufficed to half fill the lake. Lastly, this second tributary must have been again diverted in order to bring the lake to its present condition. These changes must have taken place at the same time that the lower terraces were being formed along the Jam and the Heri Rud. It is possible to explain the phenomena of Kogneh Lake on the tectonic hypothesis, but it involves several assumptions for which there is no basis in facts of observation.

The climatic hypothesis is simpler and involves no assumption beyond the facts of observation. At the end of the third period of aggradation, after the lake had been formed, it is supposed that an interfluvial epoch ensued. The lake was desiccated to such a degree that it no longer overflowed; the neighboring rivers eroded their channels and formed a third terrace. Another change of climate with an increase in the size of the streams filled the lake to overflowing and caused the rivers to aggrade. When this came to an end the outlet had been cut to a depth which corresponded with the fourth terrace of the Jam, at which level the river was then flowing. Another interfluvial epoch left the lake empty and allowed the cutting of the fourth terrace. During the last fluvial epoch the increase in the volume of the streams was so moderate that the lake was not filled to overflowing, but merely to the level of the lower terrace, while in the river valleys slight deposits of gravel were laid down. Lastly, the present dry epoch leaves the lake almost empty and has allowed the cutting of the lowest terrace along the streams. Theory and fact seem to agree perfectly. If the climatic theory is the true explanation of the phenomena of Kogneh Lake, it must apply also to the terrace of the Heri Rud, for the two are inextricably connected.

THE SALT LAKE OF PUL-I-KHATUN.

The other salt lake to which reference has been made lies back upon our line of march in Russian territory about 7 miles east of the gorge of the Heri Rud at Pul-i-Khatun. Shor Kul, or Salt Lake, as it is called, is really a playa, a perfectly smooth expanse of salt-covered mud, 3 or 4 miles long and half as wide, and lying at a height of about 2,000 feet above the sea. It was so dry in November, 1903,

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that in riding almost across the middle of it my horse's hoofs sank in only about an inch. The whole expanse is covered with a beautifully crystalline deposit of salt, thinner on the edges and thicker toward the middle, where it crackles like snow under the horse's hoofs. The smooth playa floor is divided into broad concentric bands which grow successively whiter and more thickly covered with salt toward the center. They appear to mark stages to which the water had risen during the last season, and have the irregular boundaries characteristic of water which stands on an almost level surface. To the eye the surface of the playa seems perfectly level, but there is a slight slope, as is shown by a beach marking the high-water level of spring. At the south end this can hardly be distinguished from the floor of the playa, but a mile or two farther north it lies distinctly 8 or 10 feet above the floor. No lacustrine terraces could be detected, although the bluffs, which are cut in soft sandstone, dipping gently northeastward, and which sometimes reach a height of a hundred feet, seem to have been undercut during a former higher stand of the water. The tributary valleys, however, show terraces to the number of three, cut partly in rock and partly in a filling of gravel. Away from the lake these gradually die out in the course of a few miles. They might easily be due to an intermittent warping by which the basin was deepened, although that would demand a rather complex system of movements by which a minor basin warping should be superposed upon the main warping demanded for the Heri Rud. A climatic origin is simpler, but the terraces are too poorly developed to be of great importance.

NEMEKSAR OR THE PLAYA OF KHAF.

Beyond the great northward bend of the Heri Rud, in the southward continuation of the Afghan depression, the playa of Khaf—the Nemeksar par excellence—and its basin continue the terrace phenomena of the more northern districts, though the maximum number of terraces is less. At the northeasten corner of the basin we passed three valleys, all of which show two strong terraces of the usual type, with heavy gravel beds covering the horizontal portions and with the vertical portions cut partly in the gravel and partly in the underlying rock. Besides these there were two minor terraces, scarcely worth mentioning, one between the two strong ones and one below.

In the higher valleys of the pass near Chani Well, 8 or 10 miles north of the northeast corner of the playa, a phenomenon was noticed which is rather common in the mountains of this part of the world. The steeper valleys are filled with coarse gravel firmly consolidated by a calcareous cement, and now dissected into rude terraces. The deposit is closely analogous to the gravel of the ordinary terraces, but differs in being found in very steep ungraded valleys and in being well consolidated. Apparently these two features belong together, since only a well-consolidated deposit could retain its position under present conditions on so steep a slope. The gravel and terraces appear to be due to changes of climate, since they are found in ungraded valleys which would be wholly uninfluenced by any movement of uplift or warping which did not directly affect their own grade. It is highly improbable that earth movements, determined as they must be by broadly acting and largely subterranean causes, should so adjust themselves as to accelerate all the

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chief ungraded streams of several neighboring mountain ridges. Yet such must necessarily be the case, if the gravels and their terracing are due to a tectonic cause. The most probable explanation is that they occur in valleys which are ordinarily ungraded and hence subject to erosion, but which became graded during one of the fluvial epochs, perhaps not the latest, when the climate was so altered that even these valleys assumed a graded condition and were floored with flood-plains of gravel.

The Nemeksar, or playa of Khaf, is a broad, almost waterlesss expanse of salt, much like the Pul-i-Khatun salt lake. In the late winter it is said to be entirely covered with water, although in mid-December we saw but a few detached bits of open water and were able to ride out nearly a mile before the mud became disagreeably deep. On the northern edge of the playa, where high mountains rise within a few miles, huge fans of coarse, angular gravel terminate close to the edge of the playa floor. Where they approach this most nearly they end in a distinct bluff, which is from 6 to 10 feet high and has its base 10 or 12 feet above the edge of the area that seems now to be subject to inundation. Between this latter limit and the foot of the little bluff there is either no gravel or else a little very fine grit that has been brought in recently. The greater part of the formation here is a very fine silt, crusted thickly with salt. Where the fans do not extend as far as the line at the base of the bluffs, they die out gradually and irregularly on a deposit of silt of the kind just described. In their upper courses these fans are dissected by channels which at first grow deeper until they reach a maximum of 12 or 15 feet near the middle of the fans, and then decrease toward the playa. They appear to be channels cut during a fluvial epoch through a zone of maximum deposition formed at a previous time of greater desiccation. The phenomena along the edge of the playa seem to indicate a somewhat higher stand of the water at no very distant day. The high-water level of the present is indicated by an ill-defined beach a few feet below the base of the little bluffs. Along the east side of the playa, as to the north, the main tributary valleys show two strong terraces which sometimes reach a combined height of 100 feet. They are of the usual type, deeply covered with gravel. Where the formations surrounding the lake consist of soft Tertiary formations, there is some indication of ancient undercutting by the waves at higher levels. This feature is much better shown in the playa of Kulberenj, which lies in the Khaf basin a little to the south of the main playa.

KULBERENJ.

At Kulberenj the whole playa is surrounded by two strong lacustrine terraces, one of which rises from 20 to 25 feet above the playa floor, and the other over 50. Below these there is in places a faint third terrace which would be too indefinite to mention if it were not that in other places similar traces of a last faint terrace-making epoch are evident. The two larger terraces consist of fine silt, on which is a cover of gravel 4 or 5 feet thick. Whether or not the silts are the deposits of an ancient lake of great size is not certain, although it is probable. The cutting of the terraces is clearly the work of three different lakes, or of one lake working at three different levels. Naturally the tributary valleys are terraced to correspond to the lake. The phenomena of Kulberenj, Khaf, Pul-i-Khatun, and Shor Kul in Chinese Turkestan (see the report on Turkestan), all agree in showing that two or three times in

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the recent past the lakes of Central and Western Asia have been more extensive than at present. The length of the epochs of high water was so short that no beaches or bluffs were cut upon hard rocks, although very distinct ones were cut in soft silts and gravels. In the lake of Kogneh, also, three probable periods of high water are indicated, and these are seen to be connected with river terraces of apparently the same date, and also with older ones.

TERRACES AMONG THE MOUNTAINS FROM MESHED TO BIRJAND.

From the basin of Khaf our route led westward into the mountains to the east of Birjand, thence southeastward to Sistan, and finally back by another route northwestward to Meshed. Sistan is so important that it will be reserved for fuller treatment later. The mountains from the border of the Sistan basin, near Birjand,

Fig. 159.—A slightly terraced Valley in the Mountains of Binalud Kuh, 30 miles north of Turbat-i-Haideri, March 3, 1904.

to the vicinity of Binalud Kuh, near Meshed, present so many features in common and withal so few of special importance, that they may be described in general terms without the tedium of particulars. As a rule, the parts of the mountainous districts of which the traveler in Persia sees most are the areas of deposition, the basins. In these it is not to be expected that terraces either of tectonic or climatic origin should be found, for the streams oftentimes come to an end in gravel, even though the form of the mountains round about shows that they might find ready outlet from the basins, as they probably have done in the past, if only they were provided with sufficient water. A significant feature of the basins is that almost universally gravel is encroaching upon finer sediments of a silty or sandy character.

Wherever valleys were seen in which water sometimes flows, they were found to be terraced almost without exception. The terraces are for the most part cut in

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a valley filling of gravel and are of small size. In many places they number but one, although farther north, around Turbat-i-Haideri, and among the mountains south of Meshed, two was the usual number. Most of the valleys in which the terraces were found drain either to the Heri Rud or to the Khaf playa, or at least belong to the systems of which the river and the playa are the final gathering-grounds. If the tributaries all reached the main streams it would be fair to infer that the diminutive terraces of the branches might be the reflection of the large terraces of the trunks, and were possibly due to a cause acting at some distant point downstream. Inasmuch, however, as many of the branches never reach the trunks at any time, and as some of them are separated from the trunks by ungraded stretches over which the influence of a downstream displacement would not be felt, it becomes almost necessary to refer these minor terraces to some local cause. If this is done, crustal movements are out of the question, since an impossible complexity and conformity with the minor surface features would be required. The only other possible explanation seems to be climatic change.

THE TERRACES ON THE BORDERS OF THE DASHT-I-LUT.

Along the borders of the Dasht-i-Lut, where the streams run with greater strength than they do among the gravel-clogged uplands, there is again a considerable development of terraces. In the valley of Haji Hussein Beg, a day's journey northwest of Birjand on the road to Tun, there are four good terraces of the old familiar type, gravel, more or less cemented by calcite, above, and rock below (fig. 160). These terraces are highest along the steeper part of the stream's course, and die out as it approaches the smooth salt playa of Mehemetabad. Therefore they can not be due to any change in the playa whereby it became a lake. Indeed such a change would be impossible, since if the water of the playa rose ever so little it would overflow to the Dasht-i-Lut, and the playa could not be permanently covered with water unless the whole of Central Persia were converted into a vast lake. The terraces of Haji Hussein Beg may be due to warping which, for some peculiar reason, assumed such a form as to produce the same number and sort of terraces here in this detached locality which it had produced at approximately the same time in a score of other distant places. Or these terraces may be due to climatic changes, in which case their likeness to those of other regions is a necessary part of the theory.

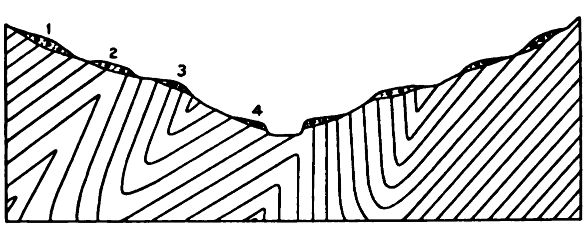

Fig. 160.—Terraces in the Valley of Haji Hussein Beg in the Chahak Basin.

From Mehemetabad nearly to Bajistan, 35 miles north of Tun, there are no good series of terraces, and the scenery is much like that of the mountains to the east—gravel fans, buried mountains, and valleys with a single or occasionally a double terrace. At Bajistan three small valleys come together, each of which has one terrace cut in stratified gravel and brown silt. The town lies on what seems to be an older terrace, which has been half-buried by the later deposit of gravel, in

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which the younger terraces are cut (fig. 161). This is a good illustration of the way in which older terraces disappear, and explains why, in regions of gravel deposition, it frequently happens that only one terrace exists where we should expect to find more.

The upper terrace at Bajistan consists of fine silt with a cover of gravel from 1 to 3 feet thick. It is the same phenomenon of gravel lying with a slight unconformity on fine silt, which is so noticeable throughout the whole of Central Asia from Kashgar to Sistan. On the tectonic hypothesis it can only be explained by supposing that the times of the deposition of the valley fillings lasted so long that the processes of erosion and weathering reduced the slopes of the mountains to a well-graded condition, which allowed them to furnish the streams with nothing but finely comminuted detritus. Times of uplift then ensued and at first caused

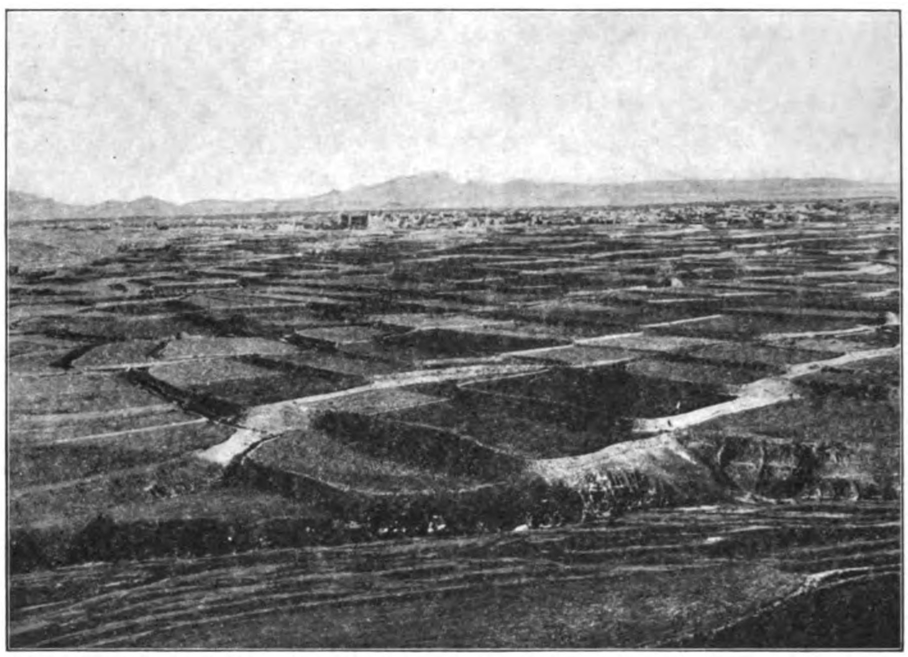

Fig. 161.—The Town of Bajistan, looking east. In the Middle Foreground the Fields are Terraced for Cultivation. In the immediate foreground lies a fluviatile terrace cut in silt and gravel.

rapid erosion and a flooding of the valleys with gravel. Soon, however, the accumulations upon the graded slopes were all washed away, and the streams relied merely upon the products of contemporary weathering, which naturally furnished a much lighter load than the sudden carrying away of the accumulated product of many years' weathering. When the streams were thus more lightly loaded, they at once began to deepen their channels and form the terraces. Such an explanation is quite possible in the case of a single terrace, but it fails entirely when we come to two or more. If the interval between the formation of two successive terraces was so long as to allow the mountain slopes to be reduced from an ungraded to a graded condition, it is inconceivable that so slight a thing as an unconsolidated terrace should be preserved from one cycle to the next.

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According to the climatic hypothesis this difficulty disappears. During a fluvial epoch a decrease in evaporation or, still more, an increase in precipitation, would cause ungraded mountain slopes to become graded and covered with vegetation. The material washed down from such graded slopes and deposited in the valleys and plains would be relatively fine, whether it happened to be deposited in valley bottoms, in playas, or in lakes. When an interfluvial epoch ensued, vegetation would become scarce, floods would be more frequent and violent, and it would be but a short time before the slopes would assume their present ungraded condition. During this process the streams would at first be heavily loaded with the products of previous weathering, which they would deposit in widespread beds of gravel; but ere long the supply would fail, and the streams would begin to deepen their channels and form terraces. This process might be repeated a number of times in rapid succession and thus a series of terraces would be formed. In parts of its flood-plain where a stream happened to be flowing at the time of a change from wet to dry conditions, the transition from silt to gravel would be gradual and there would be no unconformity. Elsewhere the change would be marked by a sharp unconformity. Both of these conditions are found, but, as might be expected, unconformability is the rule.

At the northeastern end of the basin of Bajistan, not far from the city of Turbat-i-Haideri, there are again four terraces, which must be due to a highly specialized warping of that particular basin, unless they are due to changes of climate. The tops of the reddish silts, previously described, are beveled by an old grade plain covered with from 5 to 15 feet of gravel (fig. 162). Below this are traces of a second grade plain forming a second terrace which is almost consumed. At the base of the second terrace lies the broad plain of Bajistan, in which are cut two more terraces. There are thus four gravel-covered terraces separated into two groups. The same phenomenon is noticeable at Kogneh Lake and elsewhere. There seems to have been a long interval between the formation of two groups of terraces. The fact that this division is observed in widely separated places makes it probable that the cause of the terracing was of such widespread application as to affect enormous areas in precisely the same way. This would be true of climate, but not of warping.

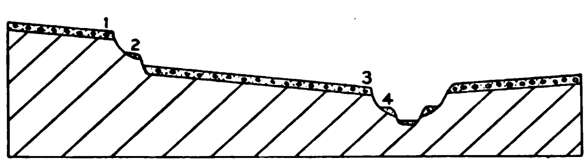

Fig. 162.—Terraces at the Northeastern Corner of the Bajistan Basin.

SUMMARY.

The part of Central Asia touched upon in this report and in the preceding report on Turkestan embraces 22 degrees of longitude and 12 degrees of latitude in the heart of the arid portion of the continent. Between the extreme limits of Kizil Arvat on the west and Issik Kul Lake on the east the distance is 1,200 miles, while from north to south the distance is 800 miles. Throughout this large area, wherever young or mature mountains have been observed, the valleys contain terraces composed in whole or in part of gravel which must have been brought into them after they had reached nearly their present condition.

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There are two hypotheses in explanation of the terraces—either the terraces are due to warping of the earth's crust or they are due to the changes of climate which in colder regions caused the successive epochs of the glacial period. The terraces of each valley, taken by themselves, can be explained on the first of these theories as due to warping of the earth's crust. Such warping is essentially a local manifestation. The force which produces it may act simultaneously over large areas, but the manner of manifestation is almost sure to vary in details from place to place. Moreover, the force is an internal agency, and its manifestations can not be expected to coincide universally with such puny surface features as individual valleys. When we examine the scores of valleys in which terraces have been noticed, it appears that the cause of the terraces has acted in just the way that tectonic forces can not act. The same phenomena occur everywhere with the same details as to the number of terraces, the method of filling and then re-excavating the valleys, and the grouping of the successive changes. The incidence of the cause, moreover, must be taken to be that of an exterior, not an interior agency, because it has so acted as to produce the same effect upon all similar external features, whether they be remote from one another or whether they be closely and intricately interlocked. The more broadly the terraces are viewed the more unlikely does it become that they are the product of warping.

The theory of climatic changes is of directly the opposite character in these respects, and seems to fit all the facts. It is not local, but almost universal in its application, since a change of climate in one place implies a corresponding change in other places. In a region such as we are discussing the details of climatic change, and hence the manifestation of those changes, would be almost identical everywhere. In the next place, climate is external in its origin, and so may be expected to adapt itself to the minute details of mountain and valley, and to produce the same effect upon all similar parts, whether they be remote or whether they be closely interlocked.

In addition to these more general reasons for adopting the climatic rather than the tectonic theory of the origin of the terraces, there are others of a more specific character. At the heads of some of the valleys are old moraines, whose relation to the terraces proves that the two forms were in process of construction at the same time. At the lower ends of certain valleys are inclosed lakes whose old shorelines show that while the terraces in the surrounding valleys were being formed the lakes were subject to pronounced changes of level. One such lake is so closely connected with the terraces of the Heri Rud as to make it almost certain that the changes in the lake took place simultaneously with the terracing of the river. Both moraines and ancient shorelines are well known to indicate changes of climate. It is highly improbable that at the very time when climatic changes were taking place and were producing certain sets of fluviatile terraces any other agency should be at work which would produce the same type of terraces in almost the same region. Still another reason for accepting the climatic theory is that it alone seems competent to explain the habitual superposition of coarser deposits upon finer deposits in the filling of the valley bottoms. Lastly, the phenomena of Eastern Persia agree exactly with what we should theoretically expect to find if the climatic changes of the glacial period

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extended to that country, and if those changes are competent to produce recognizable physiographic forms. The cause of the abundant terraces of Western Asia demands much further investigation, but it is at least a fair working hypothesis that the terraces are due to a series of climatic oscillations, and that those oscillations were contemporaneous with the successive epochs which in other lands composed the glacial period. If this theory proves worthy of acceptation it will probably furnish the necessary clue to the elucidation of the recent physical history of the Caspian basin and of other parts of the earth's surface immediately before and perhaps after the advent of man.

TERRACES IN TURKEY.

If the conclusions which have been reached in the preceding pages of this report are correct, terraces of climatic origin ought to preserve a record of some of the epochs of the glacial period in other parts of the world, especially where the conditions resemble those of Persia, that is, among unglaciated mountains in the stages of youth and early maturity in regions of slight precipitation. Several years ago, in Eastern Turkey, a thousand miles west of the part of Persia which we have been considering, I observed numerous terraces which I could not then satisfactorily explain. Almost invariably the bottoms of the valleys of Eastern Turkey are filled with gravel in which the streams have incised newer valleys, often to a considerable depth. Thus along the Euphrates River in its upper course, where it flows westward before turning southward and eastward on its long course through Mesopotamia, there is a strong gravel terrace almost everywhere except in the narrow canyons. In the Malatia plain, for instance, this terrace ranges from 30 to 60 feet in height. Farther upstream, along the eastern branch, or Murad Su, a few miles east of Pertag, there is a half-consolidated gravel which evidently was deposited in the valley after it had attained nearly its present form, and there are also two terraces, one about 50 feet high and the other nearly 100. In the small tributary valleys of Pekanik and Kurdemlik, which here descend steeply northward from the Harput Mountains, there is a dissected valley deposit of alluvium which reaches a thickness of 100 feet. The deposit is for the most part composed of silt and very fine gravel, quite different from the cobbles and coarse gravel which now fill the stream-bed. In these deposits and in many others there are marked unconformities like those of Bajistan, where relatively coarse material suddenly succeeds fine silt. Still farther up the Euphrates, and along some of its main branches, as for instance, in the Harput and Peri plains, there are extensive gravel deposits in which the streams have deeply intrenched themselves. As the higher mountains of Dersim are approached along the Peri and Muzur rivers the terraces become more distinct. In my notes on a number of the smaller streams there are references to "alluvial terraces," "terraced valleys," "a series of terraces," or "several terraces," most if not all of which are cut in gravel. The number of terraces is not stated, for their possible significance was not then appreciated, and most of them are small features, easy to overlook.

Terraces are found in other parts of Turkey in addition to the Euphrates Valley. My notes contain references to similar phenomena along the Tigris in its upper course southeast of Gyuljuk, along the Kizil Irmak or ancient Halys, along the

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tributaries of the Yeshil Irmak or Iris, and along the steep mountain torrent which flows from the lofty Pontic range northward to the Black Sea at Trebizond. These phenomena are probably due to the same cause as the similar phenomena farther east in Persia and Turkestan.

TERRACES IN NORTH AMERICA.

The southwestern part of the United States is not unlike large portions of Central Asia, and among its higher mountains we should naturally look for gravel terraces if our conclusions concerning climatic changes are correct. As a suggestion of the sort of phenomena to be looked for, I shall cite a few examples which I saw in Utah and Arizona during the summer of 1902.

The first example is the Kanab Canyon, in Southern Utah, which has been described by Professor Davis (*b*, pp. 10–11). This steep-sided young canyon contains "two terraces of well-stratified alluvium, usually of fine texture and containing lateral unconformities such as are to be expected in the deposits of aggrading streams. The higher terrace is 80 or 100 feet over the stream-bed. It is less continuous than the lower one, which stands from 40 to 75 feet over the stream. The channel below the lower terrace is the work of a series of floods, beginning in the summer of 1883. A great part of the alluvium then accumulated along the valley was swept rapidly away." In external appearance and scale these terraces are like many of those found in Persia aud Turkestan, and the character of the surrounding mountains is the same in both parts of the world. The sudden sweeping away of the alluvium from the canyon and the formation of the lower terrace in the course of a few years may be compared with similar action taking place in Asia. At Nauruzabad, a few miles south of Serakhs on the Heri Rud (Tejan River), my guide pointed out a place where, during the great flood of the preceding spring, whose appearance at Tejan has been described by Professor Davis, a mass of alluvium half a mile long and nearly a thousand feet wide was washed away, leaving a bluff a hundred feet high. Among the mountains of Persia it frequently happens that if a terraced valley be followed toward its head, points will be found where the terraces, one after another, come to an end. Often this ending, especially in the case of the lowest terrace, is very sudden, and it is manifest that in every great flood the inner channel cuts headward and the terraces are prolonged upstream.

A less marked, though distinct, example of the same process of valley-filling and terracing is found along Le Verkin Creek, near Toquerville, 50 miles west of Kanab. The bottom of the young valley of the creek is filled with from 10 to 20 feet of alluvial gravel, which the stream has now dissected, forming a rude terrace.

These few examples of terraces in Turkey and North America are not supposed to lead to any definite conclusion, but are presented merely with the purpose of showing that if our conclusions as to the terraces of Central Asia are correct, these features in other lands are what we should expect. Prolonged study is necessary before we can correlate facts so widely separated. The glacial period was a world-wide phenomenon, and to understand it fully we must take a world-wide view.

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THE NATURE AND THE METHOD OF ACTION OF THE QUATERNARY CLIMATIC CHANGES OF EASTERN PERSIA.

If we admit that the terraces of Eastern Persia are due to climatic changes, we are at once confronted by the question of the nature of the changes and the method of their action. It seems reasonable to suppose that the nature of the changes was the same as that of the changes which took place in glaciated countries at the same time, although differing in degree. Till recently it has generally been assumed that the glacial period was characterized by increased precipitation accompanied by greater cold. Penck and Bruckner have shown, however, that certain phenomena in the Alps can only be explained on the supposition that the precipitation remained nearly constant, while the degree of cold increased and evaporation therefor diminished to such an extent that glaciers and inclosed lakes expanded greatly. Our knowledge of Persia is too slight to justify any conclusion as to whether the climate of the fluvial and lacustral epochs was characterized chiefly by greater cold or by greater precipitation. The question can not be wholly neglected in this report, however, for if, as seems probable, the last of the fluvial epochs occurred since the occupation of the country by man, the character of the change must have had an important bearing on human development.

A little light may be shed on the question by considering the conditions which must have prevailed during the formation of the terraces. The most important and universal condition for the production of climatic terraces seems to be that during an interfluvial epoch like the present the slopes of the mountains shall be ungraded, and during a fluvial epoch graded. A general view of Western Asia from Chinese Turkestan to Turkey shows that terraces are well developed among young mountains such as the Tian Shan range in Turkestan and the eastern part of the Taurus range in Turkey, where ungraded slopes are the rule. They are also numerous among mature mountains, provided the region is so arid that ungraded slopes are characteristic of maturity. Such a condition, as we have seen, is well illustrated in Eastern Persia. Among mountains which have reached the stage of maturity, and are not so arid as to remain ungraded, on the contrary, terraces are poorly developed, as is shown among many of the lower mountains of Turkey and to a less extent of Turkestan. The cause of the prevalence of terraces in regions where the slopes are to-day ungraded seems to be that in such regions a change of climate is able to produce marked effects upon the character of the slopes, either by causing more rapid weathering or by causing the slopes to assume a graded condition.

Another condition of terrace formation is that terraces do not occur to any great extent in regions of deposition such as fans. When found upon fans they almost always soon die out downstream, showing that they owe their origin to impulses derived from farther upstream among the mountains. Accordingly, in considering the process of terrace-making we may confine our attention to the mountains and to those parts of the mountains where erosion is actively at work upon ungraded slopes.

It is difficult to estimate the effect which an increased degree of cold with unchanged precipitation would produce upon ungraded slopes; for among the mountains as they stand to-day the colder, more elevated portions are also subject to

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greater precipitation. And in the same way a comparison of winter and summer conditions affords no assistance, for the colder winters are also times of relatively large precipitation. Nor does it help us if we compare different years, the colder with the warmer; for we have no statistics as to the growth of vegetation, the length of rivers, and the other factors which affect the problem. If we suppose, however, that the precipitation remains constant and the degree of cold increases, the amount of evaporation must decrease and the size of rivers and lakes correspondingly increase. It would probably require a great decrease in temperature to bring the lakes to the dimensions of even the more recent lacustral epochs. Another effect of increased cold would be an increase in vegetation and perhaps in the rate of weathering of the rocks by reason of the greater amount of moisture which would remain in the ground. Here again we have no means of measuring the effect of any possible increase in cold, and so can not feel any assurance as to the adequacy of this cause to produce the observed effects upon the erosion and deposition of streams.

The influence of an increase of rainfall upon the ungraded slopes of mountains such as those of Turkestan and Persia can be more easily estimated. In the case of young mountains with slopes so steep that they can not possibly become graded, the whole effect of increased precipitation would be to accelerate weathering and thus to increase the load of the streams. In the case of streams which were approaching grade, but were not yet graded, the result of the increased load would be that it would no longer be possible for the streams to cut downward, because they would be so heavily loaded as to cover their beds with débris. Hence they would cut laterally and form flood-pains covered with gravel. Upon the advent of a drier time the load of the streams would decrease, but their carrying power would remain almost the same; for the carrying power of a stream depends upon its maximum size, and the maximum of flood size of streams in arid regions is almost as great as in moister regions. With lessened loads and unlessened capacity the streams would begin to cut downward once more, and terraces would be formed which would show a capping of gravel with solid rock beneath, as is common among the lofty and arid young mountains of the southern border of the Tian Shan range on the northern side of the Kashgar basin.

Among young mountains, where the main streams are graded, the result of increased rainfall and increased load would probably be that streams would build up their flood-plains and the valley bottoms would become filled with alluvium, most of which would be gravel. A drier epoch would allow this to be dissected and terraces composed wholly of gravel would be formed, like those found in the moister parts of the Tian Shan Mountains, and to a certain extent in Persia. Thus among young mountains oscillations between an arid and a moister climate would apparently produce two kinds of terraces; first, ungraded valleys would contain terraces cut partly in rock and partly in stream-laid gravel; second, graded valleys would contain terraces cut wholly in stream-laid gravel.

In these two cases the terraces of young mountains are the result of a *changed* climate, that is, the maximum effects of deposition and of erosion are produced under the extreme conditions of moisture or of drought. Among mature but ungraded

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mountains, on the other hand, terraces seem to be the result of a *changing* climate, that is, the maximum effect, of deposition at least, is produced during the change from moist to dry conditions. A large number of the terraces of Persia, it will be remembered, are cut in stream-laid gravel which lies with a slight unconformity upon finer deposits of silt. It may be that these can be explained as the product of epochs of increased cold alternating with epochs of relative warmth, but data are as yet insufficient. It is also possible to explain them as the product of epochs of increased precipitation alternating with epochs of relative aridity, but this theory does not necessarily exclude the other.

In Persia, as has frequently come to our notice, the rock slopes of mature mountains are ungraded because of the aridity of the climate. If the climate were to become moister the process of grading the slopes and covering them with vegetation would at once begin. So long as solid rock lay near the surface the increased moisture and the increased number of decaying plants would accelerate the process of weathering. Whether this increased weathering would increase the load of the streams depends on whether the increased vegetation is able to hold back the larger amount of waste which is now supplied by the decaying rocks. However this may be, it is certain that the load of the streams would become finer as the process of grading the slopes went on, and ultimately the flood-plains would be covered with fine material, usually silt, no matter whether the streams were aggrading or degrading their beds.

When the climate once more becomes arid the graded character of the mountain slopes will soon disappear and the old conditions will reign once more. The process of grading the slopes must of necessity be slow and lag long after the change of climate which gives rise to it, for much time is required to convert solid rock into soil. The process of ungrading the slopes, on the contrary, is rapid, and scarcely lags behind the change of climate which causes it. As soon as vegetation begins to dry up because of decreased rainfall, the streams will begin to carry off the soil and weathered fragments which cloak the mountain sides. The carrying power of the streams will remain approximately the same, but their load will be so greatly increased that they will be obliged to deposit the coarser portions upon the silts of the valley flood-plains. This process of building up deposits can not last indefinitely, however, for the supply of weathered material is limited, and when once it is exhausted the weakened forces of weathering can furnish new supplies very slowly. Therefore it will continue while the climate is *changing*. When the change is finished and the climate has become arid, the streams will no longer act as heavily loaded agents of deposition, but will be insufficiently loaded and will act as agents of erosion.

Other more striking examples of terraces exist in the semiarid regions of North America, but little attention has been paid to them. It must not be understood that these few examples of terraces in Turkey and North America are supposed to lead to any definite conclusion. They are presented merely with the purpose of showing that if our conclusion as to the climatic origin of the terraces of Central Asia is correct, these features in other lands are what we should expect. Prolonged study is necessary before correlating facts so widely separated. The glacial period was a world-wide phenomenon, and to understand it fully demands a world-wide view.

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SISTAN.

The basin of Sistan is unique. Its streams, at least during floods, focus in a fresh-water lake, exceedingly flat-bottomed and shallow, and without an outlet to the sea. About this circles a broad band of reedy swamp, the home of innumerable wild fowl and of the strange Sayids who gain a livelihood by netting them. Next comes a band of smooth, rich plain, splendidly fertile and capable of supporting a dense population, but bounded suddenly and even encroached upon by the grim belt of the surrounding desert. Wastes of blown sand, dry pools of glistening salt, and vast expanses of dark, lifeless gravel form the desert which comprises half the area of the basin and completely cuts off the inner, more hospitable regions from the surrounding mountains and the rest of the world. In its sterile wastes all the streams except the Helmund wither to nothing and are wasted, except when the floods of spring carry them clear to the central lake. Outside of these four belts—the lake, the swamp, the plain, and the desert—the basin is everywhere bounded by mountains. On the west and south, where they lie close to the lowest depression, the mountains are low and arid. The streams which rise in them are mere wet-weather torrents, which lose themselves in the piedmont gravel a few miles from their source. To the east, however, and even more to the north, the mountains are among the grandest in the world. From the northeast angle of the basin, near Kabul, the continuation of the Hindu Kush Mountains stretches westward for a distance of 400 miles to the Afghan depression. Of this slightly explored region, larger than New England, we know almost nothing, except that magnificent mountains, from 10,000 to 17,000 feet in height, pour their melted snows into the tremendous gorges of rushing rivers, the Harud, the Farah, the Khash, and the many branches of the Helmund. Where these streams reach the lower mountains, their valleys widen and are filled with fields, orchards, and prosperous villages, and a strip of green abundance intervenes between the sterile mountains and the sterile plain. (See plate 6, opposite p. 288.)

THE HELMUND RIVER.

The main features of all the larger rivers of the Sistan basin may be illustrated by a single example. The Helmund of the Afghans, the Etymander of the ancients, is the only large river between the Tigris and the Indus. Rising among great mountain peaks which tower to heights of over 15,000 feet, the Helmund flows through the land of the Hazara Mongols (Holdich, *a*, p. 42), "a wild mountainous country of which no European has seen much more than the outside edge. It is a high, bleak, and intensely inhospitable country, where the snow lies for most months of the year, where little or no fuel is to be found, and cultivation is confined to the narrow banks of the Helmund and its tributaries." Farther downstream, near the edge of the mountains, Zamindawar, northwest of Kandahar "is a beautiful country, stretching up in picturesque valleys and sweeping curves from the Helmund, and filled with a swarming population of well-to-do cultivators" (p. 43). From Zamindawar the river flows southward, and not far below Girishk enters the desert, through which it flows for 300 miles to Sistan, first southward, then westward, and lastly northward. On the left lie the deserts of Registan and northern Baluchistan, which McMahon (*a*, pp. 13, 14, 16; *b*, p. 290) and Holdich (*a*, p. 104-105) describe

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as consisting of flat plains of fine alluvium and dark gravel over which the fierce north winds drive fields of sand-dunes. On the southern edges of the desert the dunes often attain a height of 200 feet, and enormous drifts of sand bury the volcanic mountains of northern Baluchistan to depths of one or two thousand feet, or even more (McMahon, *b*, p. 290). North of the Helmund River the Dasht-i-Margo, or Desert of Margo, which was crossed by Ferrier (*a*, p. 400), appears to be of much the same character, although the sand-hills are not so high apparently, and the area of fine silt exceeds that of gravel.

The river itself flows in a distinct valley of erosion, which Colonel McMahon described to me as being broadly open, with three or four persistent terraces of gravel, like those which will be described later as occurring along other streams nearer to the Hamun-i-Sistan. Between these receding terraces lies what Holdich (*a*, p. 106) calls "the curious green ribbon of Helmund cultivation which divides the great untraversed wastes of the Dasht-i-Margo from the somewhat less formidable sand deserts to the south." "Here in a narrow little space of a mile or so in width we found the great river shut in with a green abundance, infinitely refreshing and delightful." Jungles of tamarisks border the river, and here and there nomad Baluchis feed their flocks, or even cultivate fields of grain. Far more impressive than the modern villages, however, are the innumerable evidences of a far greater population which finally disappeared not many hundred years ago. Every writer on the region dwells on the "cities of the dead, spreading out like gigantic cemeteries for miles on either side of the river, gaunt relics of palaces and mosques and houses, upright and bleached, scattered over acres of débris, masses of broken pottery, mounds of ancient mud ruins. . . . The extent of these Kaiani ruins (dating their final destruction from a century and a half ago) would be incomprehensible were it not for the extent of the indications of that canal system which was developed from the Helmund to assist in supporting the crowd of humanity which must have dwelt in the Helmund Valley" (Holdich, *a*, p. 107).

The other main affluents of the Hamun-i-Sistan repeat the features of the Helmund on a smaller scale. Rising in the mountains south of the Heri Rud, they run southwestward to the desert. Through this they flow in intrenched valleys which are probably like that of the Helmund. Along their courses through the plains, ruins replace the settled villages of the upper valleys, while at the heads of the deltas not far from the lake of Sistan the remains of ancient cities, such as Peshawaran, cover the plain for miles. Except for the distributaries which traverse the western half of the delta of the Helmund, all the important streams of the Sistan basin are located in Afghan territory, where exploration has always been exceedingly difficult. To-day it is practically impossible for a European to enter the country, and we must perforce rest content with the scanty accounts contained in the works of a handful of adventurous explorers half a century ago.

DESCRIPTION OF SISTAN.

The district of Sistan occupies a shallow depression on the southwestern edge of the Sistan basin. It comprises the lake, the swampy belt of reeds, and the low arable plain. Along the western border for a distance of 50 miles or more the

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plain and the swamp are absent, and the lake at high water meets the gravel desert. In approaching Sistan on this side by the ordinary route from the northwest, the traveler must pass through the Gate of Bendan, a gorge cut across a low ridge of limestone. The bottom of the gorge is filled with fine alluvium, chiefly silt, which is rapidly being cut away by the stream (cf. the Kanab canyon in Utah, ante p. 272). The latter has intrenched itself to a depth of 20 feet. This gate is remarkable for its large grove of date palms, which flourish here in the shelter of the mountains, although alsewhere in Sistan the violent wind prevents their growth.

Southwest of Bendan the alluvium of the gorge broadens into the gravel-covered desert of Sistan. As far as the eye can reach it encounters a smooth expanse of small dark pebbles, clean swept by the wind, and devoid of vegetation except for a small bunchy weed every two or three hundred feet (fig. 164). Valleys are incised in this plain, but are so sharply depressed as not to break the lifeless monotony of the gravel, which is only interrupted by islands of buried mountains. The valleys are

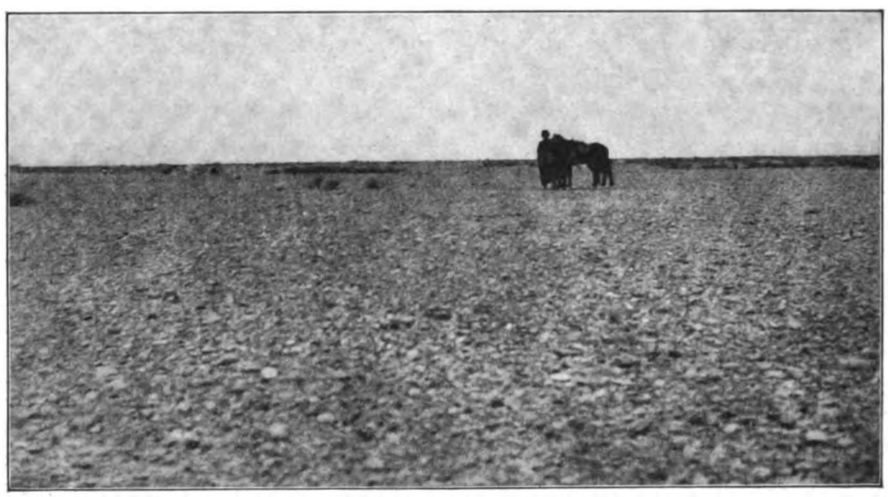

Fig. 164.—A Typical Portion of the Gravel Desert northeast of Sistan.

universally terraced. Along the Bendan stream a second terrace soon develops below that at the gate. These two continue to the mouth of the valley, varying in height, but very persistent. In many places a third small terrace appears below these, but it is not persistent. All along the west shore of the lake the same thing seems to be true; the main streams are bordered by two good terraces and there are traces of a third. In the side valleys the two lower terraces soon disappear.

East of Bendan the gravel desert suddenly comes to an end in the steep bluffs which border the lake on the northwest. At Bereng, where the road to Sistan crosses the "hamun" (swamp) the bluffs are only 20 or 30 feet high, and stand somewhat back from the water. Farther north, however, they approach the water until they are undercut by it and form almost perpendicular cliffs 100 feet high. Still farther north, near Kharikha and Kuh-i-Chaku, the total height of the bluffs becomes 300 or 400 feet, although they stand farther from the lake and are not to-day being undercut. Just how far these bluffs extend is not known. I followed them for 40 miles from Bereng to the northwest corner of the lake, and saw them

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stretching eastward along the northern shore for at least another 25 miles. On the opposite side of the lake, south of the delta of the Helmund, I followed them again for 30 miles, and saw them extending indefinitely farther in both directions. On this eastern side of the lake they lie far from the present shore, and must have been cut when the lake stood higher than now. So far as I can gather from the chance remarks of travelers who have approached Sistan from various directions, the whole of Sistan, including the lake, the swamp, and the arable plain, is surrounded by these wave-cut bluffs (Bellew, p. 263, 264). Sometimes the bluffs stand close to the lake and attain a height of hundreds of feet, while sometimes, especially on the east side, they are distant 20 or 30 miles from the shore and attain a height of only about 25 feet. Everywhere the cliffs are composed of alternating pink silt and white or greenish clays, capped with gravel.

Fig. 165.—A Raft of Reeds poled by a Sayid, or "Fowler," on the Edge of the Swamp of Sistan.

The district surrounded by these lake bluffs is the real Sistan. It has a breadth of about 60 miles from east to west and a length of 100 from north to south. When the traveler, arriving by the main road from the northwest, first views Sistan from the bluffs back of Bereng, he is impressed by the monotonous uniformity and flatness. In front, if the lake level be high, lies a broad sheet of water, blue sometimes, but oftener a dull gray to match the hazy sky. Here and there, (figs. 165 and 166) surrounded by the water, or fringing it, stretch miles upon miles of "naizar" or reedy swamp, green in summer, but in winter sadly brown or blackened by fire, where the inhabitants of the swamp have burned the reeds in order to facilitate the growth of the young shoots on which the cattle grow fat. Bordering the reed-beds, and blending imperceptibly into them, come the fertile fields, green, flat, and treeless, except where the rivers flood the land in spring and allow the growth of graceful tamarisk jungles. In all the view there is nothing to

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break the unmitigated flatness except the dark tabular mass of the volcanic mesa of Kuh-i-Khoja, rising as a black island from among the brown reeds and gray water.

The lake of Sistan has been a cause of wonder to most of the writers on the region because of the fluctuations of its level. Their wonder is perhaps natural, although the changes differ only in degree, not in kind, from those to which every inclosed lake is subject. A single example will illustrate the matter. Early in the year 1903, when the British Arbitration Commission arrived at Sistan, there was no lake at all, and the very lowest hollow in the northwest corner was dry. At the very time when the commission arrived, however, the spring floods from Hindu Kush were beginning to come down in great force. The lake was rapidly filled, and within a few weeks had assumed the extreme dimensions shown on the map. It was at this time larger than at any period for many years. Such sudden and

Fig. 166.—An Arm of the Lake of Sistan. In the foreground are beds of reeds; in the background, the lacustrine plain.

widespread changes in the distribution of land and water have taken place again and again in the past. They are naturally impressive, even though they are nothing but the normal behavior of an inclosed desert lake fed by streams from lofty mountains. The hollow of Sistan has been so largely filled with silt that the bottom of the lake is exceedingly flat. Even at high water the Sayids pole their reed rafts almost everywhere. The people say that in the deepest places the water is "as deep as a man with upstretched arms." Where I examined the lake bottom it consisted of fine greenish or white clay which clung tenaciously to the poles of the raftsmen. Near the edges of the lake and on the plains round about, the material is the same clay mixed with more or less sand. At present fine sand seems to be the coarsest material brought down by the streams, and all of this is deposited immediately in the deltas. The main body of the lake is free from visible sediment and the water is clear and drinkable.

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The drinkable quality of the water of Sistan is another of the qualities which many writers have deemed remarkable. At times of very high water, perhaps once in a dozen years, the lake possesses an outlet to the south which will presently be described. The amount of water passing through this, however, is a most minute fraction of the total which reaches the lake, and as it passes out at the time of high water, when the percentage of salt dissolved in the water is least, the amount of salt carried by it must be very small compared with the total amount brought in by all the tributaries. The amount thus brought to Sistan in a single year, or in a score of years, may be insignificant, but it must be large compared with that carried by streams in moist countries. Ferrier (pp. 400 ff.) describes the Dasht-i-Margo, through which the Helmund flows, as full of salt pools. Bellew (pp. 166, 168, 172, *et al.*) found the soil of the Helmund Valley highly charged with saline matter. In one place close to the river, a region some 10 miles long contained several thousand pits from which the people extract salt for commercial purposes. On the opposite side of Sistan, to the northwest, many of the tributary streams are strongly impregnated with salt. The Shor Rud (Salt River) of Durukh proved so saline that we could not drink it. The Gisha stream was drinkable in December, although our guide said that in summer, when the brook is reduced to a few pools, not even camels can drink the water. In the same way the Bendan stream and the other seeping brooklets which I saw along the northwest shore of the lake are all bordered by incrustations of salt; and lastly, the unconsolidated strata of the bluffs and of the lacustrine plain on all sides of Sistan are frequently white with saline matter. Clearly the water of the lake is not fresh by reason of any lack of salt in the surrounding basin. The amount of saline matter brought in each year by the streams must be large.

It is possible that the freshness of the lake is due to its occasional overflow. If we suppose that a flood occurs every tenth year and carries out of the lake a tenth of the water which is that year discharged into it, the maximum salinity of the water would be one hundred times that of the tributary rivers. Under such conditions the water might be apparently fresh, although as to this we have no data. It is probable that the amount of water escaping from the lake is less than a tenth every tenth year, and the salinity should be two or three times as great as we have estimated. Another explanation of the lack of salt is that in comparatively recent times the lake stood so much higher than now that it overflowed permanently, and was flushed clean. Other lines of evidence, as we shall see, point to this conclusion. It is mentioned here to show that while the freshness of the lake proves nothing, it is strictly in accordance with the theory which will be considered later.

THE DELTA OF THE HELMUND.

The most important part of Sistan from a human standpoint is the arable plains which lie outside the central expanses of the lake and swamp. In certain places these represent a shore platform cut by the waves when the lake stood higher. Elsewhere they represent a portion of the general lake bottom, now laid bare by the

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retreat of the waters. The most important plains, however, are the deltas of the larger streams on the northern and eastern sides of the "hamun." Most of these lie in Afghanistan and are almost unknown, but the largest, that of the Helmund, is partly in Persia and has been frequently described. To the eye the delta seems to be a flat plain, merging into the reed-beds on the one hand and ending abruptly at the foot of the bluffs on the other. Toward the lake the soil is clayey like the lake bottom, and is exceedingly slippery and sticky in wet weather. Toward the head of the delta it gradually changes to very fine sand, in which there is a considerable proportion of clay. Everywhere the soil is fertile if properly irrigated. Where cultivation is carried on, the whole country is often half under water. Deep and

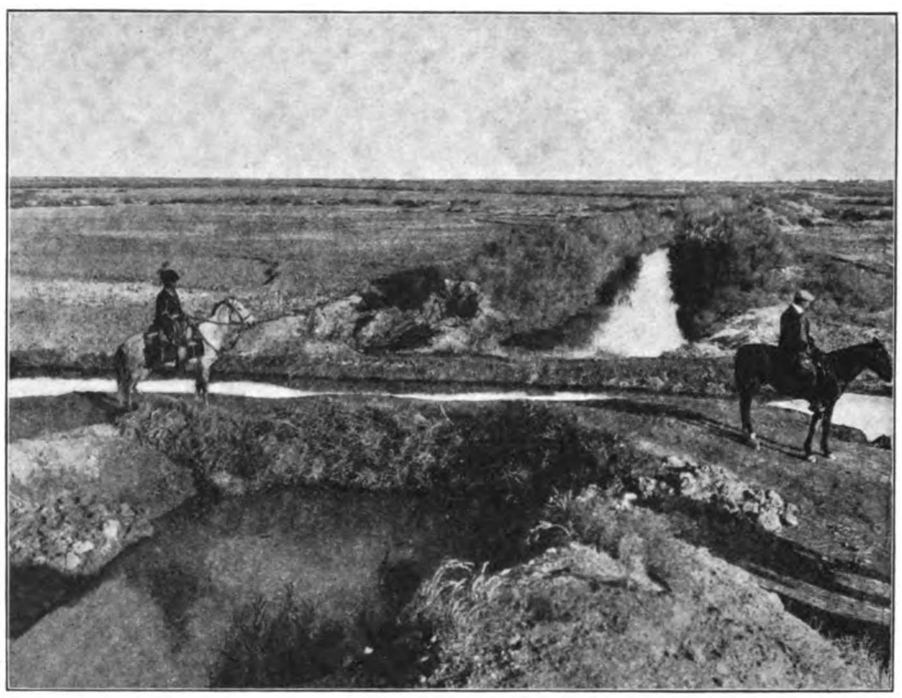

Fig. 167.—Canals in the Delta of the Helmund at Sistan. One canal crosses the other upon a bridge of weeds.

rarely bridged canals wander here and there, and even cross one another on bridges, which are nothing but dried weeds packed into the water and covered with clayey soil (fig. 167). Grain and melons grow luxuriantly, but other crops are rare and fruit can not be raised because of the wind. At present large tracts are not under cultivation and are covered with a spiny growth of camel thorn bearing purple-pink flowers, or with a dense growth of tall tamarisks forming an almost impenetrable jungle 20 feet high, the home of innumerable wild boars and jackals. In still other places, as at Zahidan, the delta is being invaded and buried by sand. At first sight there appears to be no special reason why certain areas should be cultivated, others should be left to camel thorn, still others should be covered with tamarisks, while the most unfortunate parts are being destroyed by sand. The explanation is

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easily found, however. The delta of the Helmund, like every other delta, not only slopes from apex to front, but consists of a number of broad, almost imperceptible ridges separated by hollows equally broad. The ridges indicate the location of the main stream in former times when it built up the inner edge of its flood-plain and left slight depressions on either side. To-day the ridges are largely abandoned to the encroaching sand, although in the not far distant past they were the most populous parts of the country. Their slight elevation of 5 or 10 feet adds to the difficulty of bringing water to them, although this is of relatively slight importance. The main reason for abandoning them seems to be that they lie above the level where perennial underground water can be reached by the roots of the crops. Therefore a greater amount of water is required for irrigation, and a drought does much more damage than in the regions a few feet lower. In proof of this it is only necessary to examine the distribution of vegetation. The ridges and the upper parts are for the most part, though by no means universally, abandoned to the prickly camel thorn where they are not being overwhelmed by sand. The troughs, on the other hand, are occupied by the tamarisk jungle wherever they are liable to inundation, and are thickly studded with villages. The larger part of the cultivated land, however, lies in the low, flat regions along the borders of the delta, where the level of permanent underground water is but a few feet below the surface and can be easily reached by the crops. Lovett (*b*, p. 146) cites a good example of the rapidity with which changes in cultivation take place in response to changes in the water level, although he himself ascribes the change to an improvement in the government and a temporary sense of greater security. Arriving in Sistan in 1872, at the end of a six years' drought, during which the lake had practically disappeared, he found that the country around Kuh-i-Khoja was dry and was covered in part with tamarisks and in part with fields, although Connolly in 1842 described it as under water. "Now, however," says Lovett, "cultivation has advanced to within two miles or so of the island (Kuh-i-Khoja); in fact, has been developed *pari passu* with the retreat of the waters which has been assigned as the cause." To-day the villagers endeavor to plant their fields as close to the lake as possible. In February I saw men ploughing in deep mud on the very edge of the water, and rode across old fields which went under the lake and had evidently been cultivated a few years before during some drier season. At present, ruins, camel thorn, and sand occupy the higher portions of the delta, while villages, fields, and tamarisks occupy the lower portions. Strangely enough, the latter contain no ruins of any considerable age, although if conditions in the past were the same as to-day these must have been the most desirable parts of the country. The only adequate explanation of this phenomenon seems to be that the lake stood at a higher level during a past not far remote.

THE SHILA AND THE GOD-I-ZIRRAH.

In times of heavy flood the lake of Sistan overflows and sends a stream of water down the Shila 40 miles to the south and then 50 to the southeast, to the God-i-Zirrah. The Shila, where Sykes (*a*, p. 364) crossed it on the road from Kirman, is "a watercourse 350 yards wide, with banks 50 feet high." It lies in a "great

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trough—at least 100 miles in length by 30 in width—which appears to have received either the whole of the present water-supply [of Sistan] or the overflow of the old and greater flood; otherwise it is impossible to account for its vast area. The Shila runs in a briny stream when there is a large accession to the lake." Yate, writing of a journey made about 1894, speaks of the Shila (p. 98) as being from 150 to 200 yards wide, with precipitous banks 30 to 40 feet high, where he first saw it. There was no sign of a running stream, but merely pools of bitterly salt water. Thirty miles farther downstream he found (*a*, p. 99) the Shila "150 yards in width, with sloping banks some 20 feet high and full of sand, there having been no flood-waters down for the last five years." Below this point (p. 102) the banks of the Shila gradually decrease in height and finally die out on approaching the God-i-Zirrah. From these two descriptions the outlet appears to be through a broad, deep channel, which could only be cut by a strong, vigorous stream far different from the trickling overflow of the rare floods which now traverse it. Smith, however (*a*, p. 254), describes the Shila in very different terms as "a low, shallow sort of ditch or canal, about thirty yards wide, and quite dry." As he crossed the channel near the places seen by Sykes and Yate, there seems to be no way to reconcile the opposing statements except by supposing that the outlet, like the tributaries, is terraced, and preserves the record of two periods of overflow corresponding to the two elevated shorelines which will presently be described.

The lowest portion of the basin of Sistan and the final resting-place of the waters which escape via the Shila is the God-i-Zirrah, or Hollow of Zirrah. McMahon (*a*, p. 19) describes it as "a large lake of clear, deep-blue water, some 25 miles long and 5 miles wide, standing in the midst of a wide margin of solid salt. It used to be fed by flood-water from the Helmund, but it now seldom receives any replenishment. The last time it received any water from the Helmund is, so far as I can ascertain, as long ago as 1880, *i. e.*, seventeen years ago. [Yate, p. 105, says 1885.] All the drainage which, in the natural course of events, should flow into it from the mountain ranges south of it is intercepted and swallowed up by the wide barriers of sand lying in the way and thus never reaches it. Its water is now so salt that even water-fowl avoid it."

A glance at the map shows that the Shila and the God-i-Zirrah form an arc parallel to the arc of the Helmund and sloping in the opposite direction. In ancient times, according to Ishtakhri, who wrote in the tenth century (quoted by Sykes, *a*, p. 365), the Helmund was diverted so as to flow across the neck between the two arcs and discharged directly into the Shila. The lake of Zirrah was 100 miles long and covered an area ten times as great as to-day. It was filled to overflowing, apparently, and the direction of the Shila was reversed, for the people of Sistan have a legend that in former times the supply of the Hamun-i-Sistan entered at the southern end of the lake instead of the northern. Part of the water of the Helmund, however, still flowed to Sistan along the present course and watered the numerous villages the ruins of which crowd the upper part of the Helmund delta. In course of time this main channel regained all the water, perhaps, as McMahon (*a*, p. 20) suggests, because the Helmund deepened its bed below the mouth of the canal which leads to the Shila. To-day that canal still exists, and until a hundred years ago

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carried water to the town of Hauzdar. Even now extreme floods of the Helmund rise high enough to trickle into it on rare occasions. All along the Shila and at the head of the God-i-Zirrah are abundant ruins, all of which seem to date from Mohammedan times. It is evident that the lakes of Sistan and Zirrah and the rivers of Helmund and Shila have undergone a series of changes intimately associated with the human history of the region. These changes seem to be explicable only on the theory that the climate of Eastern Persia has been growing gradually drier during historical times. Before considering this question further we will examine certain phenomena which seem to indicate extensive climatic changes in earlier times. Having examined these, we shall be in a position to judge whether there is an adequate basis for the working hypothesis that the last pulsations of the series of climatic changes known as the glacial period are still in progress.

THE QUATERNARY ERA IN SISTAN.

THE DEPOSITS OF THE LAKE OF SISTAN.

In the preceding pages the conclusion has been reached that while the more northern countries of the world were passing through a glacial period, Persia was passing through a fluvial period due to the same causes and characterized by a similar series of climatic oscillations. The record of the dry and wet or warm and cold epochs composing this fluvial period seems to be preserved in a series of terraces, lacustrine and fluviatile, which occur in all parts of the country. These terraces are unsatisfactory, because the record which they preserve is incomplete, and a single, strong, terrace-making impulse may destroy the record of all that have gone before. The best possible record would be one preserved in the bottom of a basin which contained a lake during pluvial epochs, but was dry or contained merely a playa during interpluvial epochs. Such basins abound in Persia, but the bottoms of most of them are not exposed for study. In Sistan, however, several volcanoes broke out during the latter part of the fluvial period, and parts of the lake bottom were warped upward to a maximum height of over 600 feet above the present lake level. These have since been undercut by the waves and form the bluffs which surround the lake. A proper interpretation of the sections exposed will disclose the history of the lake far back toward the beginning of the Quaternary era.

From a scenic point of view the most notable feature in Sistan is the lava-capped mesa of Kuh-i-Khoja (Mountain of the Teacher). From whatever direction one approaches Sistan he sees a flat-topped hill, low and black, and nearly a mile in diameter. From the encircling reeds and water, steep slopes of dark talus mantling red clay rise 200 feet to the base of cliffs of basaltic lava, over 200 feet high. The uneven upper surface of the lava is covered with many-chambered tombs, or is roughened with great pits, dug as reservoirs perhaps, or for some other unknown purpose. On the edges the lava is being undermined by the retreat of soft underlying clays, and huge blocks are continually falling off, thus preserving the steepness of the cliffs and hiding the strata below. Enough of the latter are seen to show that they are for the most part red, with some bands of green, and belong to the lacustrine series so well exposed elsewhere. At its contact with the lava the clay

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is broken into a breccia, and is baked, so that the upper portions resemble a mass of finely broken bricks cemented with brick dust. Kuh-i-Khoja is the remnant of a volcano (see fig. 168) which broke out under the lake, and in its efforts to find exit elevated the sediments of the lake bottom into a dome, which it covered with lava. Around the island thus formed the waves at once set to work, and have now undermined and carried away all the dome except the central mass. Soon all the clays will be removed and merely a volcanic neck will remain.

Similar volcanic outbursts are described by Vredenburg as having taken place in other parts of Sistan and throughout Baluchistan. Smith (*a*, p. 315) describes "a flat-topped, irregularly-shaped hill, called Kuh-i-Kuchah, somewhat smaller than but resembling the Kuh-i-Khoja." It lies between the Farah and Harud rivers, 8 miles west-northwest of the ruins of Peshawaran. (See plate 6, opposite p. 288.) This hill and others like it will doubtless repay close study when it shall be possible to travel freely in Afghanistan.

Meanwhile there is one mountain, the Kuh-i-Chaku, on the northwestern shore of the Hamun-i-Sistan, which can be studied. It lies in the desert close to the Afghan border and is difficult of access, but it presents such wonderful sections that

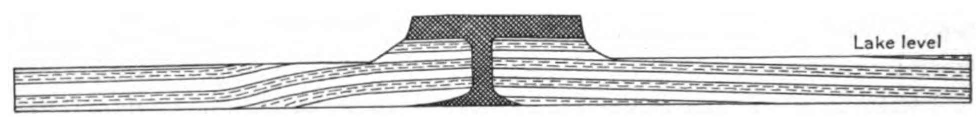

Fig. 168.—Ideal cross-section of the Mesa of Kuh-i-Khoja. Heavily shaded portions = lava; lightly shaded portions = pink silt; unshaded portions = green clay.

it deserves months of study rather than the short week which I was able to give to it and to the surrounding country. The mountain of Kuh-i-Chaku is a mesa like Kuh-i-Khoja, although much larger. The clays reach a thickness of 650 feet, and the lava cap 400. The broad top of the mesa presents a relief of from 100 to 200 feet, and two breached craters inclosing hills of scoria can be made out. The upper layers of clay are baked, as at Kuh-i-Khoja, and most of the lower slopes are covered with talus, so that good sections are difficult to obtain directly on the side of the mountain. At the time of the volcanic eruptions which produced the mountain, however, the whole region was uplifted. South of Kuh-i-Chaku a slightly rolling monocline of uplifted clays descends gently for 30 or 40 miles to Bereng, and has been dissected by the waves to form the bluffs which have been described. Fine sections are exposed between Kuh-i-Chaku and Kharakha, where the bluffs reach a height of over 400 feet.

LAKE DEPOSITS VERSUS PLAYA DEPOSITS.

The accompanying diagram (plate 5) illustrates sections of lake deposits from various locations along the northwestern shore of the lake in the region of the Kuh-i-Chaku uplift, and from the southeastern bluffs along the edge of the Helmund delta in the district affected by the Kuh-i-Khoja uplift. The sections are arranged according to location. The position of each is marked on the map of Sistan by the appropriate letter, A being in the northwest corner, close to Kuh-i-Chaku. With the possible

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exception of two on the Helmund River, each section contains three distinct parts. At the top, lying unconformably on the other strata, are beds of gravel from one to a hundred or more feet thick. Below these are numerous alternations between thick pinkish strata and thinner strata of a greenish or whitish color.

The pink beds consist largely of clays and very fine silts, but often pass into layers of fine brown sand. Viewed as a whole, the pink layers are very continuous, and preserve the same character for mile after mile. In detail, however, they vary considerably, even in short distances. For instance, a layer of clay is often interrupted by a band of fine sand which continues a few hundred feet and then dies out. More rarely a layer of grit or gravel occurs and, rarest of all, a distinct fossil stream-bed of gravel is exposed. Again, in certain places slight unconformities are discernible, as though a brief period of erosion had taken place between the deposition of one layer and the next. Among the more sandy layers there are further evidences of exposure to the air. In one place, for instance, the sand shows ripple-marks, worm-casts, and rain-drop prints. Lastly, the layers of this formation are everywhere of a reddish tint, varying from pink to brown. The only exception is found in some of the sandier, more quartzose layers, which are gray for a few inches. Everywhere the materials seem to have been exposed to oxidization for a considerable period. They bear the marks of having been deposited subaerially by widely spreading floods or in temporary playas.

The white or, more exactly, the greenish clays, on the other hand, present a very different appearance. On the edges they are mixed with fine sand or are more or less banded. Occasionally a purple layer occurs, or a band of yellow clay, in which are what appear to be fossil leaves and reeds. The main mass of each stratum however, consists of solid, unbroken layers of pure clay, uniform in texture and color, and showing none of the slight variations which characterize the pink beds. The color indicates that the materials were brought rapidly from their place of origin in the mountains and were not long exposed to oxidization on the way. The green strata as a whole show no sign of subaerial origin, and appear to be typically lacustrine.

The pink beds and the green beds differ from one another chiefly in manner of deposition. The material of the clayey portions of the pink is identical with the green, except that it is more weathered, and it is reasonably certain that they were derived from the same source. The discontinuous, highly-weathered pink layers, however, appear to have been deposited subaerially after long exposure to the atmosphere, while the uniform, slightly-weathered green layers appear to have been deposited subaqueously after a relatively short exposure to the atmosphere. Such alternations of subaerial and subaqueous conditions indicate that the lake of Sistan has been subjected to changes whereby a portion of its bed has been alternately exposed as dry land and submerged under water. The duration of each epoch of submergence or exposure must have been considerable, for the accumulation of from 5 to 20 feet of the finest clay, or of a greater thickness of clayey silt and sand, is a slow process measured in our small unit of years. This is especially true if in former times deposition was as slow as at present. Mr. Tate told me that during

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the year of his stay in Sistan the lake was always clear and deposition proceeded very slowly. Even during the great flood of 1903 the water was muddy only off the river mouths, although everywhere covered with the wreckage of reeds and tamarisks. The transition from submergence to exposure must also have been comparatively slow, for the change from pink to green deposits is frequently gradual, although always distinct. The sandy layers mixed with the upper and lower portions of the lacustrine clay seem to indicate shore conditions, and the layers of purple and yellow clay, with the included fossil plants, probably point to the existence of marshes during the disappearance of the lakes. In brief, an examination of the sections exposed in the bluffs of Sistan suggests that in very recent geological times the basin of Sistan has been subjected to a long series of slow and gradual changes by which large portions of the floor of the basin became alternately areas of subaerial and of lacustrine deposition. In other words, the predecessor of the present lake of Sistan has either again and again passed from conditions of extreme expansion to those of great diminution or else has repeatedly and systematically shifted its position.

THE CAUSE OF THE ALTERNATIONS OF THE SISTAN STRATA.

When we attempt to explain these variations in the lake, four plausible theories present themselves. (*a*) The lake may have had an outlet which was repeatedly dammed by volcanic eruptions or otherwise, and as frequently swept clear. (*b*) Some large tributary may have been diverted alternately to and from the lake, first filling it and then leaving it diminished. (*c*) The basin of Sistan may have been subjected to rhythmic earth-movements by which the lake was poured alternately from one side to the other. (*d*) The fluvial period may have consisted of a greater number of epochs than has been supposed, and each epoch may have caused an expansion of the lake.

(*a*) *Outlet Theory.*—If the lake had an outlet as recently as the time of deposition of the clays, traces of it must still remain. The Shila can not be considered in this connection, because the Hamun-i-Sistan and the God-i-Zirrah are on nearly the same level and form parts of a single lake so far as the present problem is concerned. The entire border of the basin of Sistan has not been explored, but it is certain that even the lower passes stand at least 1,500 or 2,000 feet above the lake of Sistan. Any outlet which may have existed in former geological times must have ceased to do duty ages before the formation of the modern clays which now concern us.

(*b*) *Diversion Theory.*—In the case of the lakes of Sistan and Zirrah we have seen that the diversion of the Helmund caused great changes in the area subject to inundation. If a similar change could have taken place repeatedly in earlier times it might have caused the deposition of alternating lacustrine and subaerial strata. The diversion, if such there was, must have taken place much nearer the mountains. This theory can not be absolutely excluded, because our knowledge of the rivers in Afghanistan is exceedingly limited. The extreme improbability that a river should be diverted back and forth eight or ten times at regular intervals is a strong *a priori* argument against it. Moreover, if such diversions did take place, it is still necessary to explain why. Such behavior on the part of a river could only be due to some systematic cause, such as repeated warping of the crust or climatic changes.

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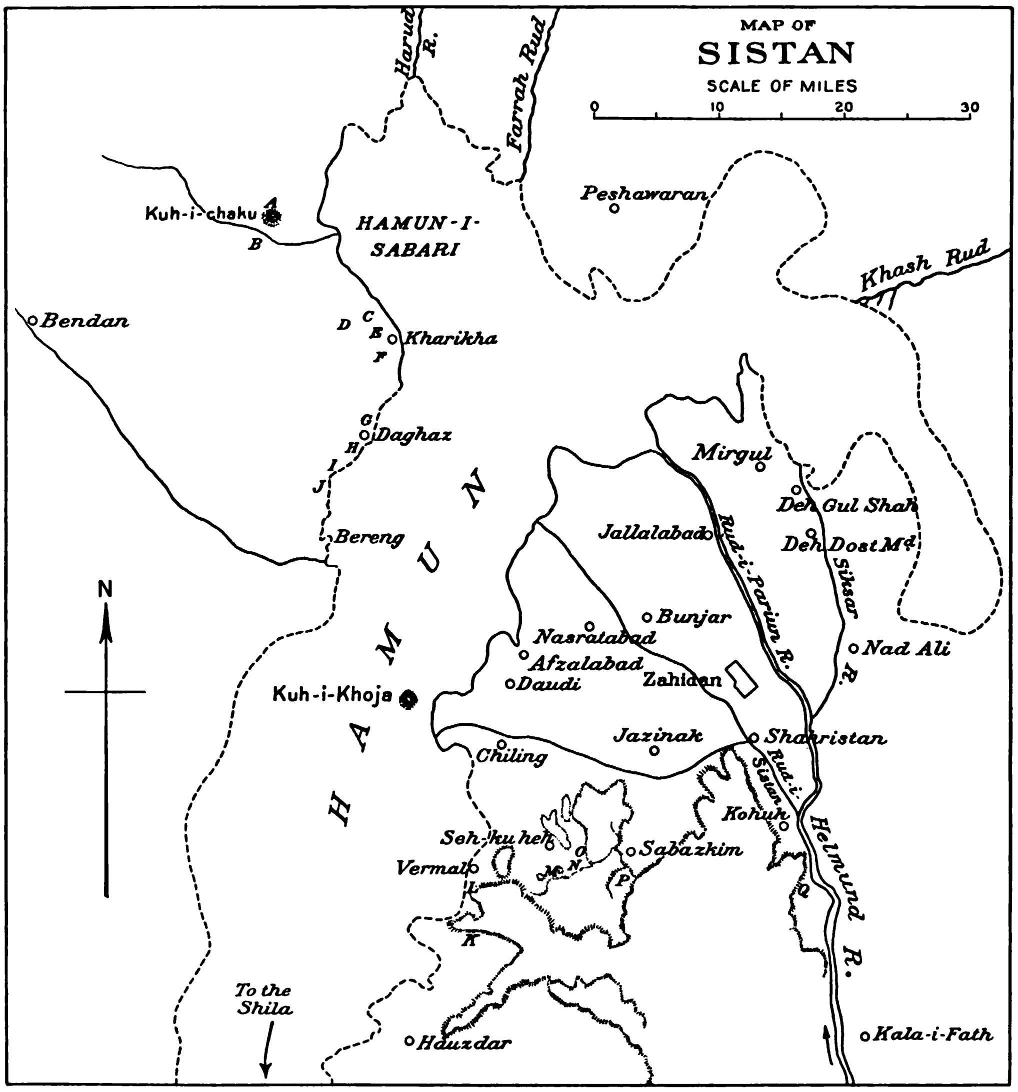

MAP OF SISTAN.

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(*c*) *Rhythmic Warping Theory.*—The third possible explanation of the stratigraphic series at Sistan is a warping of the crust, whereby the lake was again and again poured from one side of the basin to the other or, what amounts to the same thing, the streams were deflected and a lake accumulated first on one side and then on the other. This theory possesses one inherent though not insurmountable difficulty. It demands a form of warping of which we have no proved examples elsewhere, and which is radically different from that which has taken place in neighboring basins and in the world at large. The progress of geology has led to two conclusions which are not in harmony with the theory of warping as applied to Sistan. In the first place, earth-movements are characterized by irregularity rather than regularity. They occur spasmodically, now a great movement, now a minor one; now a short interval of rest, now a long interval. The phenomena of Sistan demand an opposite character, approximately equal movements occurring at approximately equal intervals. In the second place, earth-movements are cumulative; that is, the main changes of a given period consist of repeated impulses in the same direction. For instance, if the world as a whole be taken as an example, the old idea that the oceans have become continents and the continents oceans is abandoned. Almost everyone now believes that the continents and oceans were differentiated far back in early eras, and that in spite of temporary depressions the continents have steadily increased in height and area and the seas have grown deeper. The same holds true in smaller areas. For example, in the faulted basin region of the western United States, it has been shown by Gilbert, Russell, Davis, and others that there has been continued movement along the same fault lines, and during a given epoch that movement has been uniformly in one direction. If there have been reversals, they have only occurred after a long lapse of time, during which the internal forces suffered an entire readjustment. Or lastly, to take an example close to Sistan, the basins of Eastern Persia, as has been shown above, have gradually grown smaller through Tertiary and perhaps Quaternary times, by the progressive warping and elevation of the strata along their edges. In not a single instance has evidence been found to show that a basin has alternately grown smaller and then larger. To put it briefly, the movements have been cumulative, not undulatory. If the red and green clays of Sistan, however, are to be explained by movements of the crust, those movements must have been preëminently undulatory—rhythmic pulsations as regular almost as the beating of the heart; and the final result of a long series must have been to leave the country in the same condition as at the beginning. These objections do not prove that the theory of warping is untenable. They merely show that a warping of a peculiar sort is demanded different from anything of which we have knowledge elsewhere.

Granting, then, the possibility of rhythmic crustal movements by which the lake and rivers of Sistan may have been deflected first to this side of their basin and then to that, do the red and green clays show all the expectable features? In all but one respect they do. The amount of warping demanded by the theory is so slight and may have taken place so slowly that the streams encroaching upon the abandoned lake bed would spread into broad sheets and would lay down subaerial

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or fluviatile deposits which would merge imperceptibly into those of the lake. Rapid movements would involve unconformities between the lacustrine and fluviatile deposits, but slow movements would involve just such transitions as actually exist. The structure and texture of the clays agree with the demands of the theory of warping.

The weakness of this theory is that it does not explain the difference between the red color of the fluviatile strata and the green of the lacustrine layers. The transition from red to green must mean that the grains of waste at the bottom of a red layer were exposed to different conditions of weathering from those of the green grains a few inches lower. An important and widespread change must have taken place in a short time. It is quite impossible that such a change should take place merely because the border of the lake has been shifted a few miles. Whether the lake shore is a mile or two this side or that of a given point, the deposits must have come from approximately the same mountains and must have been subjected to the same journey under precisely the same conditions, except for the last mile or two. If the pink grains have had time to become highly oxidized, it is inconceivable that the green grains, brought by the same stream, have scarcely had time to become weathered at all. This might indeed happen in the case of two individual grains, one of which was brought from the mountains in a single year by a flood, while the other spent many years upon the way, but it could not possibly happen with an infinite number of grains. The color of the clays seems to be an insurmountable obstacle to the acceptance of the theory of rhythmic warping.

(*d*) *Fluvial or Lacustral Theory.*—The theory which explains the phenomena of Sistan by a succession of fluvial and interfluvial epochs is an expansion of the principles which have become so well established in the study of the glacial phenomena of Europe and North America. During fluvial or lacustral epochs the increased rainfall or decreased evaporation would cause a large lake in the basin of Sistan; the streams from the surrounding mountains would become fuller and more perennial, vegetation would become more abundant, and the mountain slopes would tend to become graded. As a result of all this the load of the stream would be fine in texture and would be carried quickly to the lake, where it would be deposited without having an opportunity to become highly weathered. The lake bottom would be covered with unoxidized clays of fine texture and light color. On the advent of an interfluvial epoch, the lake would decrease in size, and marshes would encroach upon its edges; the rivers would dwindle and become intermittent, and at the same time would become subject to fiercer floods; vegetation would everywhere decrease; and the slopes would become ungraded. These changes would allow coarser materials, such as sand and even gravel, to be washed in over the exposed portions of the old lake bed. The total amount of material might be greater than during the moister period, for the flood torrents would be loaded to the utmost; but the journey of a given particle would be much slower, for the laden floods would quickly spread into a sheet and deposit their loads, and many short journeys separated by long periods of exposure would be required to bring the waste of the mountains to its final resting place. During this protracted journey the redness which characterizes the fluviatile

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strata would be acquired through oxidization. A succession of ten fluvial and inter-fluvial epochs would account for all the observed facts of the clays of Sistan. There is therefore reasonable ground for the working hypothesis that Sistan, and presumably the Iran basin, has passed through at least ten fluvial epochs during the Quaternary era. The number of these epochs is surprising and adds interest to the question of their relation to the glacial epochs of other countries.

THE GRAVELS OF SISTAN.

Before we can consider the question of the relation of the fluvial period of Persia and the glacial period of other lands, it will be necessary to ascertain the history of Sistan since the volcanic outbreaks which elevated the clays. The first part of this history is recorded in gravel deposits, and the later part in terraces. A reference to the diagrams of the sections (plate 5) exposed in the lake bluffs shows that at the top of each a stratum of gravel lies uncomformably on the clays. In sections C to F the gravel is greatly developed and reaches a thickness of from 100 to 150 feet. These sections are located a few miles south of Kuh-i-Chaku, in a region which received the full force of the uplift due to the volcano, but was not covered with lava like A. Their situation is most advantageous for the preservation of a record of all the non-volcanic events since the eruption of Kuh-i-Chaku.

The eruption took place during a time of gravel deposition, as appears from the gravel under the lava in section A and the much greater thickness of gravel which accumulated nearby outside the lava-covered area. The change from the deposition of silt to that of gravel was probably due to an uplift of the borders of the basin, whereby the slope of the streams was steepened and opportunity given them to carry away the material which had accumulated upon the graded slopes of the mountains a few miles to the west, or in the small basins scattered among them. Evidence of such an uplift is found in the stage of dissection of the mountain range on the western border of Sistan, and in certain lava sheets. West of Bendan, on the road to Neh, a large sheet of dark lava, from one to three hundred feet thick, forms a high mesa, like Kuh-i-Khoja and Kuh-i-Chaku. The lava does not rest upon clays, however, but upon a broad, smooth expanse of relatively soft limestone and shale, both of which are evenly truncated by a surface of erosion. This surface could only have been reduced to such smoothness by long erosion at a lower level, for the strata vary much in hardness and are highly folded. Most of the mountains round about are young in appearance, although few of them stand higher than the mesa. The peaks are sharp and well defined, even though some of them consist of the softer strata. The slopes are naked and steep, and the valleys, which to a large extent follow subsequent courses along the softer strata, are narrow, with ungraded sides. Rising above the mesa and the lower peaks are a number of large, flat-topped mountains, most, if not all, of which are composed of more resistant limestone. Apparently at the time of the eruption which formed the lava-sheet capping the mesa, the country stood lower than now and consisted of hills of gentle relief, from among which rose residual mountains of limestone. Such a mature country is exactly what might be expected at the end of the long, quiet period during which the alternating pink and green clays of Sistan were deposited.

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While there is no direct evidence as to the time of the uplift, it seems safe to associate its inception with the first accumulation of gravel around the lake of Sistan. Judging from the appearance of the lava cap of the mesa, it must be of approximately the same age as Kuh-i-Chaku.

How long the process of uplifting the mountains continued or how widely it extended we do not know. The distorted shorelines which I shall presently describe show that warping continued till very recent times. To-day earthquakes seem to be unknown in Sistan, but Mr. Tate informed me that either Iben-i-Haukl or Iben-i-Batuta record the occurrence of one in the eleventh century. On the edges of the Sistan basin, however, earthquakes still persist. Two hundred miles to the south the smouldering volcano of Kuh-i-Taftan proves that the forces of vulcanism are still active; while 300 miles to the eastward McMahon (*a*, p. 10) reports that earthquakes are common along a remarkable fault-crack which extends north and south for 120 miles along the Afghan frontier between Kandahar and Quetta. It is highly probable that the basin of Sistan, like so many of the other basins of Persia, is being uplifted along the edges. The invasion of gravel in a thin sheet on every portion of the basin floor may be due in part to these movements.

A detailed study of the thick gravels near Kuh-i-Chaku is difficult because of the extent to which the deposits are hidden by their own talus. Sections E and F, however, show that the gravels are interstratified with finer beds of silt, red for the most part. The alternating beds seem to be related in the same manner as the alternating clays below; the gravels seem to occupy a place corresponding to the pink clays, while the silts correspond to the green lacustrine clays. The problem of accounting for the alternations in the upper strata is the same as in the clays, and the same reasoning applies. If our conclusions are correct, earth-movements, of which the volcanoes were one manifestation, elevated the northwestern corner of Sistan, reviving erosion among the mountains and raising part of the bottom of the lake beyond the reach of the water. The clays of the lake bottom were exposed to erosion and certain layers were carried away, forming an unconformity, but soon abundant gravel was brought down from the renewed mountains and the whole country was buried in it. This must have happened during an interfluvial epoch, as appears from the gravels. A fluvial epoch then ensued, and, to use a word not recognized by lexicographers, the ungradation of the mountains was checked. The conditions of the fluvial epoch favored the preservation of the graded slopes of the mature topography of the uplifted mountains, and the stripping which had progressed rapidly during the interfluvial epoch was retarded. Accordingly the materials brought down by the streams were fine-grained, and silts accumulated upon the gravels. Thus it seems probable the changes went on until three more were added to the ten fluvial epochs that had gone before. The evidence for these last three is not so abundant or conclusive as for their predecessors; but three strong strata of gravel separated by finer material cap the bluffs in many places where no sections were obtained, and it is difficult to explain them otherwise. We rebel at the thought of adding epoch to epoch in such wholesale fashion, yet thirteen or a hundred epochs of climatic change are as reasonable as two.

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THE TERRACES OF SISTAN.

NORTHWEST SIDE OF THE LAKE.

In Sistan lacustrine and fluviatile terraces merge into one another, but cause no confusion, as they both tell the same story. Scattered among them and often parallel to them are numerous structural terraces, due to the hardness of the gravel among the upper and of the green clay among the lower strata. Most careful work is needed to avoid confusing them with their neighbors. A fourth class of terraces is due to warping. None of these has been detected, but the older lacustrine terrace has been warped, and the corresponding stream terraces must have been similarly affected.

The lacustrine terraces agree with those of fluviatile origin; two are well developed, and a third is now in process of formation. They indicate that since the last heavy gravels were deposited on the smooth plain which caps the upper terrace (fig. 169) the lake has stood at three different levels, at two of which it has cut high bluffs in the soft clays or formed large beaches where the shore is less steep. The bluffs are best developed on the northwest side of the lake. At Bereng, where there has been no warping, the two upper levels are about 15 and 25 feet above the level occupied by the lake surface of January, 1904, which was perhaps 5 feet lower than the extreme high level of floods. Just north of Bereng all the space between the 15-foot beach and the present beach is covered with beach material, and the same is true wherever the shores of the lake are fairly steep. Where the shores are flat, on the contrary, the two beaches are sharply separated. The 15-foot beach appears to be parallel to the present shoreline. The 25-foot beach, on the contrary, has been warped up to a height of 300 feet. At no time, apparently, did the lake level reach any great height, for even a rise to the 15-foot level would mean that the lake of Sistan must permanently overflow to that of Zirrah, and a rise to 25 feet would cause the two lakes to coalesce into one and would involve an immense increase in area.

The recent history of the lake resolves itself into a few simple changes. At the time of the volcanic eruptions of Chaku the lacustrine deposits at the northwest corner of the Hamun-i-Sistan and along the western side had been uplifted and covered with layers of gravel and silt. The gravel layers appear to have numbered two before the eruptions began and one during their progress or after their completion. When the deposition of gravel came to an end a vast and very smooth gravel plain (I, fig. 169) surrounded the Hamun and concealed a series of lacustrine deposits, very complete at the north, but worn away by the Bendan stream at the south. At Chaku the plain stood several hundred feet higher than the lake, although not so high as at present; at Bereng it stood at the level of to-day. When matters were in this state the lake stood at the 25-foot level (A, fig. 169), and remained there long enough to form bluffs on all sides of the lake. Near Chaku these are 500 to 600 feet high and are capped with lava; toward the south they gradually descend till at Bereng they are but 20 or 30 feet high. At Daghaz the bluffs still border the lake and are being actively undercut. They present an almost perpendicular cliff 100 feet high. From here northward they gradually retreat, and at the same time grow higher, till at Chaku they are 3 miles from the water. Where

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there is no lava cap the upper portion of the bluffs is broken into three smaller terraces (*x*, *y*, *z*, fig. 169), due to the alternate strata of gravel and silt, while lower down the hardness of the green clays causes minor benches. As viewed from below the crest of the higher bluffs sometimes shows its true flat-topped character, but oftener it appears like a jagged range of high hills. Below the ragged terraces of the dark gravel cap the softly outlined but steep slopes of the beautifully tinted clays spread into fine sprawling spurs, separated by cleft-like gorges and buttressed with round greenish bastions where the harder, unweathered lacustrine clays form terraces. At the base of the cliffs outstanding portions of clay form graceful pyramids or domes, soft in outline and banded with harmonious colors—pale-pink, green, yellow, and purple, which blend insensibly one into another.

After the cutting of the first shoreline, the lake fell and perhaps became dry during an interfluvial period. When next we have a record the water stood at B (fig. 169), and again cut a bluff, low and insignificant where it stood below its predecessor at Bereng, for example, but higher where it completely undercut the latter,

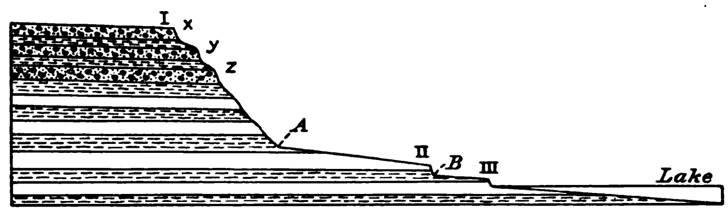

Fig. 169.—Ideal Cross-section of the Lake Terraces and Bluffs on the Northwest Shore of the Lake of Sistan.

as at Daghaz. North of this latter point a great change had taken place since the formation of the earlier bluffs. The whole country had been uplifted to a height which reached a maximum of 300 feet at Chaku, as shown by the height of the older shoreline. Probably the elevation was in progress during the earlier fluvial as well as during the interfluvial epoch, for the terrace-top below Chaku slopes more steeply than would be the case if it had all been produced by water standing at a single level. At present the lake is cutting insignificant bluffs or depositing beaches. Thus, on the northwestern shore of the Hamun-i-Sistan, we have a record of two fluvial or lacustral epochs and two interfluvial epochs. During the first the water stood approximately 25 feet higher than now, and remained there long enough to cut very far back into the surrounding country. Toward the end of this epoch the region around Chaku began to rise. Then came a time of falling water, and, by inference, an interfluvial epoch, when the lake became almost dry. When the water again rose in the succeeding fluvial epoch the movements of uplift had almost come to an end and the land stood in practically its present position. For a second time bluffs were cut. The level of the water was but little higher than to-day, but the area and hence the volume of the lake must have been vastly larger; lastly, the water fell to its present level, and is now forming an insignificant strand. This strand, however, lies higher than the level where most of the lake's erosive action takes place at present, and it seems probable that the level of the water is now falling.

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SOUTHEAST SIDE OF THE LAKE.

On the diametrically opposite side of the lake, along the southern border of the Helmund delta, a number of beaches and bluffs confirm these conclusions. Certain features stand out clearly, and may be classified according to age: (*a*) Modern shorelines; (*b*) younger abandoned shorelines closely connected with fresh bluffs; (*c*) older abandoned shorelines with weathered bluffs.

Modern shorelines.—The modern shorelines are everywhere weak, and in many places where the shore is flat and marshy they are quite indistinguishable. The lake can not have stood long at the present level, for if it had the present shorelines would be more pronounced. The water appears to have fallen gradually to its present position, as is shown by the character of the beaches which intervene between the present water-level and the 15-foot level. Where the shores are somewhat steep the weak modern beach appears as the lower member of a series of small beach ridges which culminate in the well-developed 15-foot beach. Where the shores are flat and are not closely bordered by bluffs the older beaches diverge from the present lake shore, and are more clearly differentiated.

Younger abandoned shorelines.—(*1*) *Lutuck.*—Three older beaches were seen which clearly belong to a time when the lake stood higher than now. Their exact level in reference to the water could not be ascertained, but it is certain that they lie beyond the reach of the lake to-day. In the first place, many cultivated fields, and even villages, lie between the beaches and the lake; and, in the second place, the beaches are covered in part with large sand-dunes which could only accumulate after the water had retired. The beach which lies nearest the lake was seen at Lutuck, half-way from Devletabad to Vermal. Here the delta plain ends in low east-and-west bluffs of the the usual banded clays capped with gravel. From the foot of the bluffs what appears to be an old beach diverges northward. It has now been transformed into a strip of low sand-dunes which cover a breadth of from 25 to 50 feet, and rise to a height of 5 feet. No pebbles or fossils were found. Farther south along the base of the cliffs this beach could not be distinguished. Beyond Vermal, however, there is a strip of sand which has the character of a beach without the relief. Where an irrigation canal has been dug through this the sand was found to be full of small bivalve shells like those found in the beaches next to be described.

(*2*) *The Seh-Kuheh beach and bluffs.*—Two or three miles southeast of Seh-Kuheh and from 5 to 7 miles from the lake, there is a much better example of a shoreline of the same kind as that at Lutuck. It consists of the line of fresh bluffs from which sections M, N, and O, plate 5, were taken. At their foot lies a ridge of huge sand-dunes (fig. 170), half concealing a beach composed of sand, fine gravel, and bivalve shells like those of Vermal. About 2 miles from Seh-Kuheh the beach leaves the foot of the bluffs and runs northwestward between Seh-Kuheh and the lake. It takes the same form as the beach at Lutuck—a long line of sand blown into dunes by the wind. It is not impossible that the two beaches are of the same age, although I am inclined to believe that the Lutuck beach belongs to a slightly later stage of the lake's history.

The exact age of the Seh-Kuheh beach can not be determined by physiographic evidence, but it is at least evident that the water stood upon it very recently. This

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is shown by the bluffs (fig. 170). Wherever they are fronted by a beach they are extremely fresh, as though the waves had been at work on them but yesterday. Their tops present a clean, sharp angle and are little dissected, and their slope is almost perpendicular. Yet the material of which they are composed is by no means resistant and contains many sandy or silty portions which are subject to rapid degradation. Moreover, the beach is also fresh and is not concealed by talus from above. Where the beach and the bluffs diverge the character of the latter at once changes. They become rounded and well dissected, a sloping body of talus lies at their base, and the cliffs slope so gently that they are covered with gravel and waste derived from the battered tops. The beaches and the fresh bluffs can not be old. The accumulation of sand at the base of the latter is of very recent date. The large

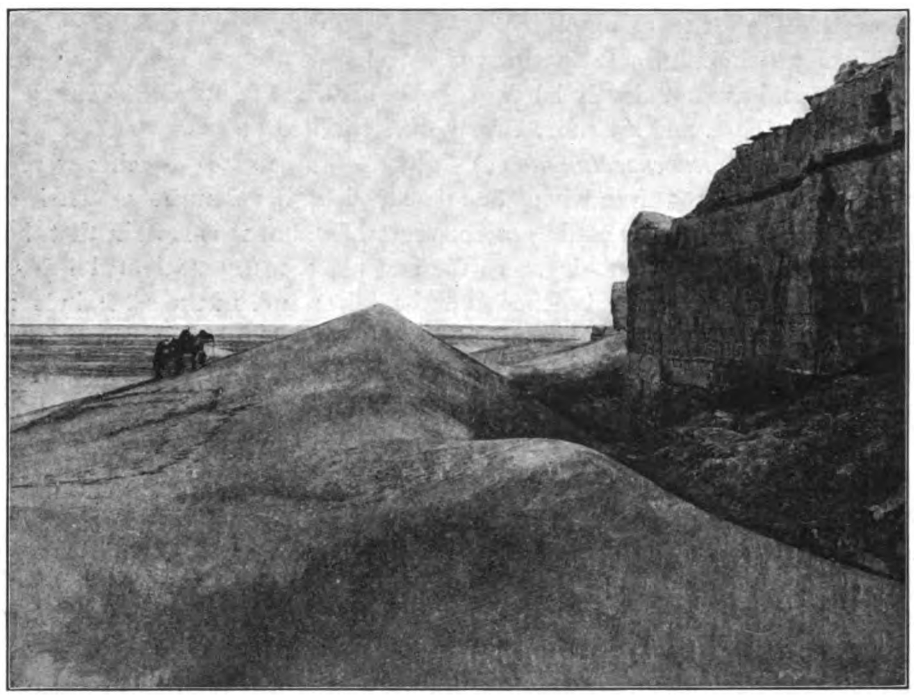

Fig. 170.—Lacustrine Bluffs and Recent Sand-dunes near Seh-Kuheh. View to the northeast.

dune shown in the illustration (fig. 170) is said by the natives to have accumulated in three years. Under it are seen the cross-bedded remains of older dunes which have been repeatedly formed and swept away. Under the lowest of them, and resting upon the old beach, I saw the ruined mud walls of an ancient garden. This is said to have belonged to a certain Rustum Khan, who died a hundred years ago. It is clear that the accumulation of the dunes is the work of a comparatively short time, probably not more than two or three hundred years. Moreover, it is probable that the accumulation of the dunes would begin within a relatively short time after the retirement of the water. Accordingly, from the recency of the sand-dunes and the freshness of the beach and bluffs, I am inclined to believe that the lake stood at the level of the Seh-Kuheh beach at a date which is to be measured in hundreds

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rather than thousands of years, and which falls well within historical times. It is probable, as will be shown later, that the lake has stood twice at this level, but this inference is based on historical rather than physiographic evidence. This level seems to be that at which the lake would permanently discharge to the God-i-Zirrah through the Shila. Therefore the lake might be expected to return to this position whenever it was abundantly supplied with water.

(3) *The Sabazkim beach and bluffs.*—The most remarkable of the old beaches of Sistan lies in the northward-facing bay of Sabazkim, a mile and a half south of Aliabad, on the road from Seh-Kuheh to Kohuk. It is situated 12 miles from the lake, and is elevated but little above it, standing probably at the 15-foot level. When the water filled Sabazkim Bay it must have covered most of that part of the Helmund delta which is to-day most thickly populated, although the ridges occupied

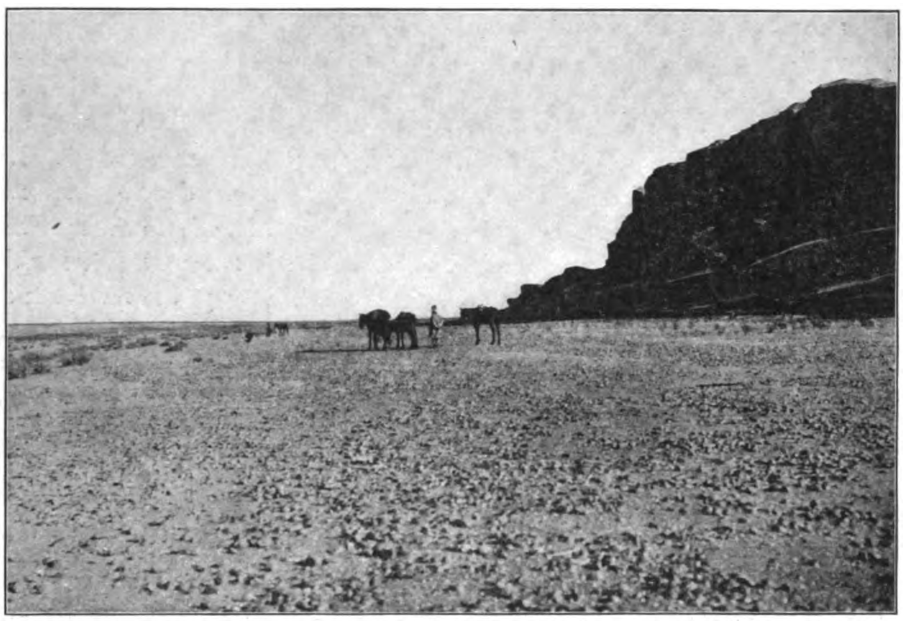

Fig. 171.—Abandoned Beach and Lacustrine Bluffs at Sabazkim. At the base of the bluffs sand-dunes are accumulating.

by Zahidan and most of the other ancient ruins were probably out of water. The shape and position of the bay exposed it to the full force of the waves and currents generated by the fierce north-northwest "Wind of One Hundred and Twenty Days," and the result is seen in the size of the beaches. At the base of the highest of the Sabazkim bluffs, where the British Arbitration Commission has set up a monument, there is a beach, over 500 feet broad, with a rise of 20 feet (fig. 171). At the top of the beach rise large sand-dunes like those at Seh-Kuheh, and behind these a very freshly eroded cliff rises almost perpendicularly to a height of 110 feet (see section P, plate 5). The upper part of the beach is composed of fine gravel, the middle part of small cobble-stones and sand, and the part far out toward the lake of sand. Everywhere the beach is crowded with shells of four or five kinds, of which

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two, a clam and the pink mussel already mentioned, are said by the natives to still live in the lake. The others may also exist, but are too small to be noticed, except by the scientist. At present, however, the amount of life in the lake is so small that I did not once see any living creatures or even any shells of those that had recently died. This decrease in life is the natural result of the drying up of the lake. When the water stood at the higher levels and was always abundant, conditions were favorable for plentiful lacustrine life; when the water decreased and actually dried up, as in 1872, most of the animals perished.

Fig. 172.—Old Lake Beach at Sabazkim, looking West. The lake stood on the right of the beach and a lagoon on the left.

Near the middle of the bay of Sabazkim the beach and the bluff part company. The cliff bends southward and at once loses its steep, freshly-cut appearance and becomes like the corresponding cliff at Seh-Kuheh. The beach assumes the form of a gravel ridge from 10 to 15 feet high and as level as a railway embankment (see fig. 172). It continues unbroken for a distance of 4 or 5 miles and possibly

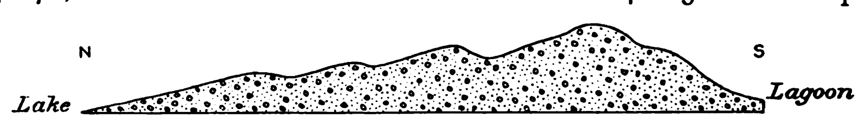

Fig. 173.—Ideal cross-section of the old Lacustrine Beach at Sabazkim.

farther. In cross-section (fig. 173) it shows several ridges thrown up when the waves were at different heights. Everywhere, even in the coarse gravel, shells abound. Between the beach and the cliffs to the south there is a broad lagoon. This is bordered by worn, battered cliffs, at the base of which lies a small beach which was probably formed before the waves had built the larger beach which now cuts off the lagoon.

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Older abandoned shorelines.—Traces of the older lake level were not found in great abundance on the southeast side of the lake, although there were enough to prove that they exist. At Lutuck the lower bluffs are capped by a narrow plain or terrace about 15 feet, possibly more, above the 15-foot beach. From this rises a second line of bluffs much more worn than any of the lower ones and well sheeted over with gravel, so that they present a slope which a horse or even a camel can ascend. At Seh-Kuheh and Sabazkim there are similar old bluffs. Those at Sabazkim are shown in the sketch (fig. 174). From either side of the central bluff

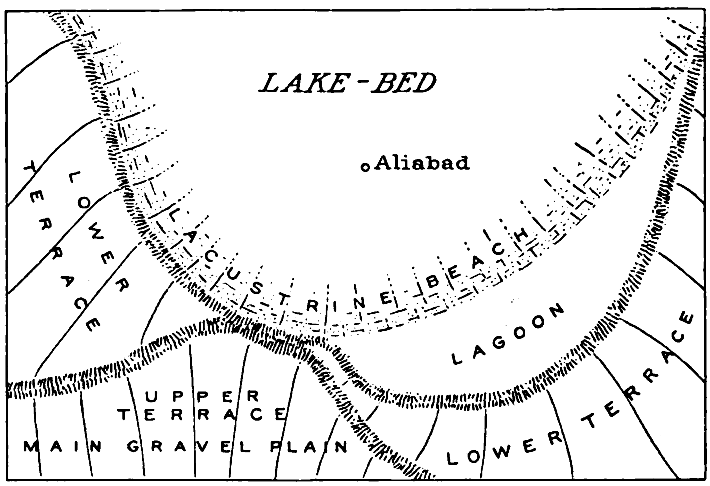

Fig. 174.—Sketch Map of the Ancient Shore features in the Bay of Sabazkim.

a wing of terrace branches off at a height of about 30 feet above the 15-foot beach. The foot of the upper terrace seems to represent the position of the lake at the time when the 25-foot beach was formed in the neighborhood of Bereng. Apparently here, as at Kuh-i-Chaku, warping took place between the last two fluvial epochs.

COMPARISONS.

A comparison of the lacustrine terraces of Sistan with those of other regions described in this volume shows that in each case there were two epochs of high water preceding the present epoch of low or medium water. At Shor Kul, in Chinese Turkestan, at the playas of Khaf and of Kulberenj and at Sistan precisely the same phenomena are repeated. In the latter case we should not expect more than two lacustrine terraces, because of the movements of the crust which have interfered with possible records of older lake levels. In the other cases, however, a greater number would be expected to agree with the number of glacial or fluvial epochs of which there is evidence in neighboring mountains or valleys. It seems probable that the interfluvial epoch preceding the formation of the first terrace was of unusual length, or of unusual character in some respect, so that traces of earlier lacustrine action were destroyed. Such a supposition is supported by the great gap which we have seen to exist at Kogneh and at Bajistan between the two lower terraces and those above them.

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Extinct lakes are a feature of many of the chief playas of the Iran basin. At Mashkel, south-southeast of Sistan, in the continuation of the Afghan depression, the playa seems to be surrounded by terraces in the same way as the playa of Khaf, so far as can be judged from the brief notes of MacGregor (pp. 128, 129, 134) and others. Farther to the east, in the center of northern Baluchistan, the Lora Hamun, as described by Vredenburg (pp. 210-211), "is now a large playa entirely dry most of the time. In it are islands of lava rising to a height of 50 feet, more or less. They are surrounded and even covered by pale-yellow silt of just the same sort as that which forms the floor of the playa. The lower portion of these mud deposits, though ravined by the rain, still presents a terraced outline, and denudation has exposed sections in which strings of angular pebbles from the tuffs of the hills rest upon strata of the buff-colored mud. It is quite evident that this mud, washed down in former times by rivers, was deposited in the still water of a lake, just as the deposit of the same nature which covers the dried-up floor. Moreover, as they are found at all heights along the slopes of the hill, it shows that these were at that time entirely submerged; further, that a large sheet of water then existed whose surface rose to a height of 50 feet or more above the floor of the dried-up lake, and that the Lora Hamun covered a surface three or four times as extensive as the plain which now bears that name."

In the same connection Vredenburg (p. 210) says that throughout all the confusion of the volcanic mountains, interrupted drainage, and smooth playas of northern Baluchistan "there are some curiously regular features. Such are the long lines of terraces formed by the conglomerates (*i. e.*, gravels) stretching over wide areas. It frequently happens that the traveler following the narrow camel-track beaten out of the stone-strewn 'dasht' (*i. e.*, naked gravel slopes), along what seems an interminable plain, suddenly finds himself on the edge of an escarpment and sees another plain below him some 30 or 40 feet lower. This lower ground may again slope gently down to another step-like escarpment, and there may be thus three or four of these superposed terraces. If the country had been more thoroughly examined it would have been found probably that these lines of terraces form concentric belts surrounding at a distance some of the larger lake basins. They admit of only one explanation—they represent ancient shorelines of great lakes, which now have either dried up entirely or are reduced to insignificant shallow marshes or salt swamps." It is not impossible that these gravel terraces of Vredenburg are of fluviatile rather than lacustrine origin, and resemble those which I have described along the Bendan stream, for example. Nevertheless, the facts stated in regard to these and to the Lora Hamun are enough to show that the phenomena of Sistan are not isolated, but form part of a record of changes which have affected all the neighboring regions.

SUMMARY.

On the basis of the facts and conclusions set forth in the preceding review of Sistan and of the confirmatory evidence from surrounding districts, we are prepared to sum up the history of this part of Eastern Persia during recent geological times. Changes of climate have been the keynote of that history, although there has been

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no lack of other activities. Earth-movements have taken place, mountains have been uplifted, plateaus have been carved into mountain ridges, basins have been intensified, and volcanoes have poured forth sheets of lava, but all these actions have been more or less local in their application. On the whole, their action in Eastern Persia during Tertiary and Quaternary times has tended steadily in the one direction of elevating the mountains and increasing their area, while at the same time the basins have grown steadily smaller by the folding up of their edges. Nevertheless, this action has not gone on simultaneously over the whole country, and there are many parts of Persia where as yet we have found no evidence of tectonic action since the end of the Tertiary era.

With climatic changes the case is different. Their action is uniform over broad areas, and if our interpretation of the phenomena of Eastern Persia is correct, they have been extraordinarily active throughout the whole of Quaternary time. Thus interpreted the recent geological history of Persia begins with an arid climate at the end of the Tertiary era, after which ensued a fluvial period composed of some fifteen fluvial epochs of prolonged rivers and expanded lakes, separated by inter-fluvial epochs of shortened rivers and diminished lakes. The fluvial epochs increased in frequency and possibly in length and intensity from the beginning up to about the middle, after which they decreased. The evidence for these many epochs is of varying degrees of validity, and increases in certainty from first to last. The two lacustrine terraces of the various lakes and playas indicate two recent fluvial epochs. The kind of evidence and the method of study are of a sort which is everywhere familiar and which has been successfully tested in many cases. The three preceding epochs rest on less effective evidence. The evidence for them in the three gravel strata at Sistan is not in itself conclusive, since it consists of but two or three sections; and the warping and volcanic action which are known to have been taking place at the same time may have influenced the deposition of the gravels. Nevertheless, the widespread occurrence of a series of five terraces in other localities, and the impossibility of explaining these except on the climatic theory, give a fair degree of reliability to the conclusion that three more severe fluvial epochs preceded the two recorded in the lake shores. The test of this conclusion lies in a further study of those regions where, according to theoretically deduced consequences, similar terraces ought to be found.

The remaining ten epochs rest confessedly on a small basis of fact. It has been surmised that the glacial period may have consisted of an increasing series of climatic changes preceding a decreasing series, and there is evidence that the extension of the ice during what is commonly known as the second glacial epoch was greater than during its predecessor. Further than this, however, so far as I am aware, no one has ever gone. The facts of Sistan seem explicable only on the theory of a large number of increasingly severe fluvial epochs followed by an approximately equal series of decreasing epochs. This is at least a fair working hypothesis. To test the theory is difficult in the very nature of the case. Yet it can be done. In the first place, a far more extensive study of the abundant deposits of Sistan is practicable to-day, and it is only a matter of time when it will be possible to enter Afghanistan and study the lacustrine clays which are reported to lie far up the Helmund. It is not impossible that other localities may be discovered where the bottoms have been lifted up and exposed to view (*e. g.*, Chahek, p. 267), but none is likely to be found where a greater harvest of facts can be gathered than at Sistan. There is also a way in which the theory can be tested nearer home. If the glacial period in all parts of the world consisted of an increasing and a decreasing series of changes, the bottoms of such lakes as Bonneville and Lahontan must preserve the record. Some day it will be possible to investigate the dry beds of these lakes by borings, and the theory can be adequately tested.

CLIMATE AND HISTORY.

In the concluding section of this report I shall deal briefly with the main object of our expedition, to which the preceding sections have been tributary. Iran is one of the countries which will most readily furnish an answer to the question of the relation of history and physiography, for the country has been inhabited by man from remote antiquity. If man inhabited the earth during the later glacial or fluvial epochs, Iran would probably have been peculiarly favorable to his development by reason of the relatively warm climate and moderate degree of rainfall which it appears to have enjoyed. A few facts bearing on this subject may indicate the line along which a solution of the problem will perhaps be found. History, archeology, and tradition all present certain features which seem to point to a greater rainfall in antiquity than at present. Physiographic evidence points in the same direction. The question is: Do the two sets of facts show points of contact, and does the same theory explain them all?

THE ANCIENT CLIMATE OF IRAN.

Many writers on Iran have referred to the possibility that in antiquity the rainfall of the country was greater than now. For instance, Blanford (*a*, p. 500) states that "from the accounts given by ancient writers it appears highly probable that the population of Persia was much greater and the cultivated land far more extensive 2,000 years ago than at present, and this may have been due to the country being more fertile in consequence of the rainfall being greater. Some alteration may be due to the extirpation of trees and bushes, the consequent destruction of soil, and increased evaporation; but this alone will scarcely account for the change which has taken place." Sykes (p. 364) expresses the same opinion: "Alexander's march with a large army and a huge camp tends to show that Asia was, in his day, not so arid as at present, and it would seem possible that in a sense my observations in Sistan support this contention." In various places he elaborates this view and presents other evidence. The Rakshan Valley, for instance (pp. 234–235), in western Baluchistan, 300 miles southeast of Sistan, is a stream of exceedingly salt water flowing in a wide, shallow valley and discharging into the Mashkel River. The marches up this valley were "intensely monotonous, day succeeding day without a sign of life being anywhere visible, yet we could interest ourselves by speculating on the causes that had swept away the population from this valley, which for mile

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after mile was carefully terraced, while here and there were mounds littered with pottery. War, no doubt, has had much to do with it, but even more probably ruthless deforestation in this and adjacent districts had decreased the rainfall, after which the springs dried up and the population was driven away."

Holdich, speaking of the swamp of Mashkel, which lies in the same part of Baluchistan, but a hundred miles nearer to Sistan, remarks:

> This extraordinary abundance of water locally is difficult to explain. It appears to be a survival of a far more extended condition of water-supply in southern Baluchistan than now exists. There is widespread evidence of former cultivation by an elaborate system of irrigation in so many parts of southern Baluchistan, where it is vain to hope that such cultivation will ever exist again, that it seems as if some mighty change must have come over the land thus to render so much of it waterless. It may be due to forest denudation and cessation of rainfall, but, more likely, it is due to the gradual exhaustion of those subterranean sources which seem to be still prevalent in more northern districts.

In speaking of the mountains of Kharan, 100 or 200 miles east of Mashkel, in the center of northern Baluchistan, Vredenburg (p. 213) comes to a similar conclusion:

> In all the valleys round Zara there are to be seen hundreds of stone walls which are called "gorband," or "dams of the infidels." Sometimes they stretch right across the flat, pebbly floors of the great valleys, which, for want of a better name, are termed "rivers." They also occur across the entrance to most of the tributary ravines and at various heights above the main valley. The country is quite uninhabitable for want of water, and yet there is no doubt about the nature of these walls, which are similar to works erected to the present day in many regions of Baluchistan and Persia, being, in fact, nothing but terraced fields. In many cases they still hold back the soil, formerly cultivated, which has been heaped up against them. . . . The absence of any canals, the great height to which the walls are found up the tributary ravines, show that the fields were not watered by means of some general scheme of irrigation with canals deriving their supply from some reservoirs placed at a greater altitude. Perennial springs, now everywhere dried up, must have existed in all the ravines where these remains are found, which shows how much greater the rainfall must have been formerly.

From the evidence of certain tombs Vredenburg thinks that the fields were in use even down to Mohammedan times.

ALEXANDER'S MARCH.

The march of Alexander from Mesopotamia across Persia to Samarkand and the Jaxartes River, and thence via Bactria to India and back through Baluchistan to Persepolis and Babylon, is justly regarded as one of the most remarkable feats in history. There have been innumerable discussions of the subject, and the general tendency, especially of those writers who have actually traversed the more remote routes followed by the conquerer, is to think that under present conditions the march would have been impossible. This is not the place to discuss the whole question, but a few remarks upon the portion of the journey nearest Sistan may not be out of place. When Alexander left India he divided his army of 110,000 men into two parts, one of which, including the elephants, the invalids, and the heavy baggage, was put under the command of Krateros, and followed a route through southern Afghanistan and Sistan. Alexander himself, as Sykes says (p. 169), "faced the horrors of the desert by the route along the coast of Baluchistan in order to supply his fleet by means of his army," although Arrian says it was because of his wish to rival the journeys of Semiramis and Cyrus along the same road to India.

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The route which he followed is exceedingly difficult even for a small and quickly moving caravan; and for an army such as that of Alexander, which is stated to have been accompanied by women and children, the hardship must have been incredible. St. John (*a*, p. 75) is of the opinion that "in the early part of his march through Baluchistan, Alexander must . . . . have been deceived by his guides, who seem to have kept him at exactly that distance from the coast where there is least water." Farther west, in southeastern Persia, conditions were scarcely better. Sykes, who is the latest authority on this region, speaks of it as follows: "During my journey from Chahbar to Ceh, in October, 1893, which was also the time that the Greek army traversed Makran (*i. e.*, southeastern Persia and southwestern Baluchistan), the temperature in the shade was generally about 100 degrees, while water was almost nonexistent, and what little there was we could hardly drink (because of the salinity)." (P. 171.) "Throughout the journey (from Chahbar to Kirman during the months from October to June, 1893–94) forage was our chief anxiety (although the caravan numbered only from a dozen to twenty men)." (P. 112.) Among the higher mountains of this corner of Persia water can usually be found by digging in the water-courses, although it is very poor and scarce (p. 113). Forage, however, is always hard to obtain, and (p. 123) the governors-general of the province practically never visit the district because of the scarcity of supplies. Yet Alexander must have crossed it with a large army. Northeast of Bampur, even in March, when vegetation is at its best, forage was so scarce that the governor-general, whose guest Sykes was, had had a supply stored at every stage (p. 144). "This desert stretch of more than 150 miles" along the north side of the Jaz Morian swamp was once thickly populated, as is shown by numerous ruins, and by the remnants of kanats or underground canals, to the reported number of 200, which are now dry. Many of these canals have probably been abandoned because of wars, but that does not explain how Alexander procured water for an army where there are now merely salt pools, nor how he procured forage for all his baggage animals where to-day a few score can barely subsist. (See plate 4.)

The division of Alexander's army which marched through Afghanistan under Krateros appears to have had no special difficulties, for Arrian, the historian of the expedition, merely remarks that "when Alexander arrived in Kirman, Krateros joined him, bringing the rest of the army and the elephants." (Quoted by Sykes, page 174.) Apparently Krateros went via Quetta to Kandahar, and thence his route is agreed to have been down the Helmund to Sistan. So far the line of march would present no insuperable difficulties even to-day, although Bellew (p. 182), who followed the same route, relates that where the road made a detour to get around an impassable portion of the river valley, some of his men nearly died of thirst on the hot gravel plain. Beyond Sistan Krateros's route led across the southern end of the Dasht-i-Lut to Narmashir. As St. John says (*a*, p. 75), "it would certainly puzzle a Krateros nowadays to march his elephants and heavy baggage from the Helmund to Narmashir; but there is every reason to suppose that part of Persia to have been far better populated and better watered than it is at present." The greater part of the distance of 180 miles from the borders of Sistan to Narmashir is the most absolute desert, either waterless or supplied with the most brackish wells.

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Nasratabad, the one village, could hardly give supplies for a hundred men, and everything for an army would have to be brought from Sistan. Yet the route was once so important that strong fortifications, caravanserais, and other ancient ruins occur at frequent intervals, as do also kanats or canals. Of the last 90 miles Smith (p. 248) says that at both of the two possible stopping-places "water was obtainable by digging wells 5 feet deep, but it was brackish and bad; and at the latter place there is a stream so salt and bitter that none of our animals would even touch it." Sykes (*a*, p. 417) describes the same route in equally uncomplimentary terms:

> Gurg (the first stage) is generally considered to be the worst stage in this part of the desert, the pools of water being quite undrinkable. . . . In summer, owing to the heat, Gurg is little better than a death-trap, and here, more than elsewhere, the abomination of desolation is realized. . . . At Shurgaz (the next stage) the water was just a little better, but so scanty that there was none for the camels.

At the end of the third day, after marching over a hundred miles through the worst part of the desert, a better region was reached. "A day's halt was imperative, as our camels could hardly move." That a large army could cross such a desert is hardly credible; that such an army should have no hardships worthy of mention by the historian is less credible; and that they could bring elephants with them is least credible.

The elephants of Krateros are not the only ones mentioned in history. Malcolm (I, p. 35) speaks of them as abundant in antiquity in the kingdom of Persia, as is shown by both the ancient history and the sculpture of the country. Mazanderan is the only part of the country that could now support them, but they are spoken of in other places.

Another interesting commentary on the climate of antiquity is afforded by a comparison of a description of the province of Kirman as it is to-day, by Sykes (p. 44), and as it was in the past by Strabo (quoted by Sykes, p. 48). The modern description runs: "The whole province can best be described as partly desert, pure and simple, and partly desert tempered by oasis. . . . As may be supposed, the rivers are unimportant." The ancient description is scarcely longer, but conveys a wholly different impression: "Kirman . . . lies more to the north than Gedrosia. This is indicated by its fertility, for it not only produces everything, but the trees are of large size. . . . It is also watered by rivers. . . . It includes also a desert tract which is contiguous to Parthia." Even since the twelfth century there has been deterioration, for in numerous cases ancient Mohammedan towns are abandoned and can not be restored because no water can be procured.

THE DESICCATION OF ANCIENT RUINS.

The ruins of Eastern Persia and the neighboring countries are incredibly abundant. The mighty cities of the dead crowding the shores of the lake of Sistan in the center, and the abundant vestiges of a former population much denser than the present in Kirman to the west, Baluchistan to the south, and the Helmund Valley to the east, have already been mentioned. Examples might be multiplied indefinitely, for the tale of every traveler is full of them. North of Sistan the same is true. Half-way from Herat to Kandahar the plain of Dasht-i-Bakwa, where, according to

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an Afghan prophecy, a great battle will some day take place between the English and the Russians, is now inhabited only by nomads, although this has by no means always been the case. Yate (p. 11) "found the plain covered with the marks of old karezes, or underground water-channels, and it had evidently been thickly populated by a cultivating class at some time, while water was said to be obtained all over it. When I passed it was all a waste." Ferrier, in the same region, describes the ruins of city after city. To a certain extent these might be restored to prosperity under good government, but there are certain places which no amount of government, good or bad, could affect.

NEH.

The ruins of Neh, called Kala Shah Duzd, or the Castle of King Thief, illustrate this point admirably. They are located 60 miles west of the northern end of the lake of Sistan. They have been described by Sykes (p. 413), who says:

"Neh . . . is undoubtedly a site of great antiquity, and must have been a place of importance. . . . At the present time nine routes radiate from the town. Ancient Neh . . . three miles to the east of the more modern fort, is built on a hill only accessible on the west side, and is carefully guarded by . . . a line of bastioned wall. . . . Lying up the steep hillside are thousands of houses, built of unhewn stone fitted together with mortar the summit being some six hundred feet above the plain. The other faces are perpendicular, but the water supply seemed insufficient, there being only tanks, so far as could be seen. The area covered was quite four acres, and these are certainly the most important ruins which I have examined in Eastern Persia."

It seems to me that Sykes, who is usually very accurate, has overestimated the size and importance of the ruins. I estimated that there were at least 300 houses still standing, possibly 500, and there may have been as many more which have fallen. As to the paucity of the water-supply, these questions seem to be not whether there are cisterns enough, but how the cisterns were filled. I counted five large cisterns, all of them located near the top of the hill. One was located in the mouth of a small valley, where it might possibly be filled several times in the year if the drainage from among the surrounding houses were allowed to pour into it. The others were placed at the very crest of the hill, where they were not only surrounded by houses, but had only the most limited drainage areas, so that the rainfall of a whole year under present conditions would hardly fill them, even if the drainage from the streets were allowed to come in. If the place were simply a fortress we might suppose that water was laboriously carried up the steep hill from the plain 600 or 700 feet below and stored for time of need, although there is now no source of water within 2 or 3 miles. The number and permanence of the houses and the fact that many of them lie outside the fortifications, even though there are open spaces inside, indicate that the place was a permanent town. If the inhabitants were agriculturists their fields must have been far away; if they were artisans and tradesmen their number is surprisingly large in proportion to the present possibilities of the surrounding country. If the rainfall were greater there would be no difficulty in understanding the location of Kala Shah Duzd, for the cisterns could be filled, fields could be cultivated nearby, and the surrounding plains could support villages which would warrant the building of a large fortress and town. It is not absolutely impossible that such a place should grow up under

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existing conditions, but it is highly improbable. Ancient Neh is one of many places which are hard to understand unless we suppose that some radical change of conditions has taken place.

THE MERV OASIS.

In this connection two other places farther north in Transcaspia deserve mention. One of these is the ancient city and oasis of Merv, which I have described in a short report which will be published among the archeological reports of the Pumpelly Expedition to Turkestan for the year 1904. A study of the distribution and extent of the ruins which cover the oasis indicates that in antiquity the extent of land under cultivation and the number of inhabitants were not only greater than at present, but were greater than would at present be possible, even if all the water of the Murg-ab River, which sustains the oasis, were utilized with as much care as is employed upon the experiment station of the Imperial Domain. It is difficult to account for this unless the water-supply was formerly greater.

BAL KUWI AND ANAU.

The other Transcaspian example is at Anau, near Askhabad. The main features of this place, both modern and ancient, will be described in the forthcoming archeological reports of the Pumpelly Expedition. At Bal Kuwi, in the desert about 10 miles north-northwest of Anau, lie the ruins of an ancient mud village. The main site consists of a mound perhaps 15 feet high, very broad and flat, and covered with bits of pottery. Where not buried in sand-dunes the surface of the mound shows the rectangular outlines of houses, the roofs of which have disappeared, while the walls have been buried to the top in the pink sand of the desert, and are thus preserved with their tops flush with the surface. Excavation shows that these houses are built without a trace of wood. On the floor of each room is a foot or two of loose clay, half of it in the form of sun-dried bricks, which appears to be the débris of the roof. Apparently the houses were made entirely of mud, with domed roofs, like those of modern Persia. The total number of houses in the main village may be estimated at from 75 to 150, while half a mile away, at Telbeng Berkoh, are 20 more of the same kind. The date of the ruins is unknown, and so far as the style of architecture and the kinds of pottery which are found in the houses are concerned, they may belong to any epoch within the last two thousand years. The Turkoman gray-beards have no tradition on the subject and merely say that when they came to the country fifty years ago the ruins presented the same appearance as now. The inhabitants of the ruins were probably tillers of the soil, for the houses are permanent structures, and their number, at least 75, is so great that they can hardly have been occupied by a pastoral people. At present there are three wells at Bal Kuwi, and 20 families of Turkomans camp there for three months in the spring. They say that there is grass enough for nine months, but as it gets dry they move away. Even allowing for understatement by the Turkomans, it is hardly probable that 75 and probably more families could be permanently supported by flocks in a region which the present inhabitants consider only sufficient to support 20 families nine months out of each year. If the inhabitants of Bal Kuwi were not pastoral, they

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must have been agricultural, but agriculture is to-day impossible in the neighborhood of their village. In the first place, more than half the region round about is covered with sand-dunes. In the second place, irrigation is impossible, and without irrigation agriculture is utterly impossible, as the Turkomans know to their cost. Bal Kuwi lies in the course which the Anau stream would pursue if it should be prolonged. At present, however, even in the greatest floods, when no water is taken off upstream for irrigation, the floods are lost in the desert before coming half-way from Anau to Bal Kuwi. Between their point of disappearance and Bal Kuwi lie some miles of sand-dunes, through which it is evident that water never passes. In brief, Bal Kuwi appears to have been an agricultural village, but under present conditions that would be impossible. If in some way the Anau stream could be caused to increase its volume so as to flow farther out into the desert, the old condition might be restored. Bal Kuwi seems to be a parallel case to Shah Duzd and Merv, and to many other ruins in this part of the world.

THE NORTHERN BORDER OF THE DASHT-I-LUT.

One more illustration will suffice to show the uniformity with which depopulation has gone on over the whole of Eastern Persia and its neighbors. Lord Curzon (p. 255) made a rapid journey along the high-road from Meshed to Teheran, which skirts the northern border of the great Persian desert.

> For the entire distance of 560 miles there is frequent and abundant evidence that the country traversed was once more densely or less sparsely populated, and for that reason more carefully tended, than it is at present. The traveler passes towns which have been entirely abandoned, and display only a melancholy confusion of tottering walls and fallen towers. He observes citadels and fortified posts which have crumbled into irretrievable decay and are now little more than shapeless heaps of mud. He sees long lines of choked and disused kanats, the shafts of the underground wells by which water was once brought to the lands from the mountains. The walls of the cities are in ruins and exhibit yawning gaps; the few public buildings of any note are falling to pieces; rows of former dwellings have been abandoned to dust-heaps and dogs.

From other more detailed accounts of this same region it appears that the ruins are of all ages, from two thousand to twenty years, and that the country has been subjected to a gradual process of ruin and depopulation. Practically all writers on Persia agree that in the time of Darius and as late as early Mohammedan times the country was decidedly more prosperous and more populous than now; and the area of cultivation and the visible supply of water in canals and kanats, or underground channels, were much greater.

THE CAUSE OF THE DEPOPULATION OF IRAN.

Several theories have been advanced in explanation of the gradual ruin of Persia and its neighbors, but all of them can be summed up under two. According to one school, in which Curzon is the most prominent writer, the climate of Persia has remained practically unaltered throughout historical time. The decay of the country is due to wars and massacres and the frightful misgovernment which has prevailed century after century. If a strong, just government were established the former conditions of prosperity would be restored. The progress which has been made under British rule in the arid portions of India and under Russian rule in

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Transcaspia shows what can be done. The other school, of which Blanford is the best-known representative, holds that during the last two thousand years the climate must have changed. Wars and misgovernment have been a fearful curse, but their influence is not sufficient to account for the location of large towns in places where to-day a caravan can with difficulty find a pool of brackish water. The just rule of a European power may do much in favored localities, and it would be an immense blessing everywhere; but it can not restore the ancient prosperity.

It is not my purpose to enter into an exhaustive discussion of these two opposing views, for that would lead into a consideration of the causes of wars and migrations, the reasons for the fall of nations, and the philosophy of history. I shall merely state a few salient facts which may be put in the form of answers to the following questions: (*a*) Do wars and misgovernment necessarily cause permanent depopulation? (*b*) Are Eastern Persia and its neighbors able to support a much larger population than that which now occupies them? (*c*) Is there any independent evidence that the climate either has or has not changed during historical times?

(*a*) *The influence of wars.*—The depopulation caused by wars is one of the best-known facts of history. The question now before us is whether, other conditions remaining unchanged, frequent wars *must* cause permanent and progressive depopulation. Examples from many lands might be quoted, but Persia itself furnishes an answer. The province of Astrabad is one of the few in Persia which are blessed with an abundant rainfall and great natural advantages. For centuries its inhabitants have been exposed to the terrible raids of the fierce Turkomans and have also had the disadvantage of a very unhealthful climate. Their condition as described by Vambery in the early sixties was most pitiable. Even as late as 1880, when conditions had much improved, owing to the proximity of Russia, O'Donovan (p. 190) relates that murderous affrays were frequent even in the immediate vicinity of Astrabad. Yet in almost the same paragraph the author enlarges on the density of the population, Persian villages of from 20 to 30 houses being scattered every 500 or 600 yards. The fertility of the region is so great that the people persisted in coming into it, in spite of the fact that their numbers were frequently decimated by the Turkomans.

Azerbaijan, the northwestern province of Persia, furnishes a more striking example of the same sort. This, according to Curzon (p. 514), "is the province which, excepting only Khorasan, has more often been violated by foreign invasion than any other part of Persia. . . . Its fertility of resources entitle it to be called the granary of Northern Iran." Tabriz, the capital (p. 518) "has fallen the first victim to invading armies, and has been successively held by Arabs, Seljuks, Ottomans, Persians, and Russians. What the rage of conquest has spared, nature has interfered to destroy. The city has been desolated by frequent and calamitous earthquakes. Twice we hear of its being leveled to the ground before, in 1392, it was sacked by Timur, whose path was strewn with ruins that vied with the convulsions of nature. Five times during the last two centuries has it again been laid low. A reliable historian tells us that 80,000 persons perished in the earthquake of 1721, and we hear from another source that half that number were claimed for the death-roll by its successor in 1780." Yet in spite of wars and calamities the fertility of

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the province is such that the city of Tabriz (p. 521) now numbers a population of nearly 200,000 and is the commercial metropolis of Persia, while the province (p. 517) contains 2,000,000 inhabitants, or from 25 to 40 per square mile, according to the estimate which is put upon its area. Ruins are found in many parts of Azerbaijan, but they do not give the impression of a country whose population and resources have steadily declined, but rather of a country which has suffered and recovered. If war and calamity are the chief causes of depopulation and the fall of nations, why has Tabriz lasted so steadily, and why is Azerbaijan so prosperous and populous?

A comparison of the four provinces of Khorasan, Azerbaijan, Kirman, and Sistan is suggestive. Khorasan (Curzon, pp. 180, 514) has suffered from war more severely than any other province of Persia. Its northern portion, where the rainfall is greatest and where also the greatest amount of fighting has taken place, is to-day one of the most prosperous portions of Persia. It contains abundant ruins, but they are by no means the impressive features which they are farther south. The southern and drier part of the province is full of ruins and has suffered great depopulation. Azerbaijan, which (Curzon, p. 514) has suffered from war more than any province except Khorasan, is the most prosperous and thickly populated part of Persia. The relative abundance of its water-supply renders its future hopeful. Sistan has suffered from wars, but less severely than the two preceding provinces. Nevertheless, it has been depopulated to a far greater extent. Its extreme aridity renders recovery well-nigh impossible, except along the Helmund. Kirman (Sykes, p. 60) lies so remote behind its barrier of deserts and mountains that it has suffered from war much less than any of the three preceding provinces. Yet its ruined cities and its appearance of hopeless depopulation are almost as great as in Sistan. If war and misgovernment are the cause of the depopulation of Persia, it is remarkable that the two provinces which have suffered most from war and not less from misgovernment should now be most prosperous and least depopulated; while the two which suffered less from war and no more from misgovernment have been fearfully and, it would seem, irreparably depopulated. It is also significant that the regions which have suffered the greatest ruin are those where water is least abundant and a decrease in the supply would most quickly be felt. Wars and misgovernment do not seem to necessarily cause depopulation, nor has that process gone on most rapidly where war has been most prevalent.

(*b*) *The density of the population of Iran.*—It is often asserted that with proper methods of irrigation Persia might support a much larger population, and the Persians are taken to task for not utilizing their resources. The Persians, as Holdich (p. 374) says of the Afghans, "have from time immemorial been great practical irrigation engineers. Every acre of rich soil is made to yield its abundance by means of every drop of water that can be extracted from overground or underground sources. It would be rash to say that the cultivable area of Afghanistan could be *largely* increased." Goldsmid, who knew Persia from end to end, was of the same opinion in regard to that country, as he shows (*c*, p. 186) when he speaks of "the precariousness of cultivation (in Persia as a whole), even where to many travelers fertility has appeared undeniable and of considerable extent."

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The mistake of overestimating the possibilities of Persia is very common among travelers. For instance, O'Donovan (I, pp. 426-427) describes the country between Abasabad and Mazinan, a few miles west of Sabzawar, on the road from Meshed to Teheran, as "a dreary flat, entirely uncultivated, though plentifully supplied with water from the Kal Mura River, which has left marks of extensive inundations in numerous white deposits of salt. This plain would undoubtedly produce abundant crops of rice if properly cultivated." After passing numerous ruins of fortifications, reservoirs, tanks, and other structures, "we crossed the Kal Mura, a river about 40 yards wide here and tolerably deep, though on the maps it is usually marked as dry in summer. The country around was once extensively cultivated, as the traces of the irrigating ditches show. . . . Nowadays, cultivation is only attempted immediately around the towns, and even there . . . the crops are miserably poor." In June, 1880, when O'Donovan traversed this region, the Kal Mura River must have been phenomenally high, for when Smith (p. 376) passed this way in May, 1872, a year of very fair rainfall, with unusually good crops, he found the Kal Mura at the same place "a narrow rivulet of salt water." Apparently it was lack of water, not lack of energy, which prevented the Persians from raising O'Donovan's "abundant crops of rice."

Only a year previous to Smith's journey this very region suffered from a famine of such frightful severity that he found (p. 367ff.) skeletons of men along the road where they had died of hunger, skulls of children in the very houses, 450 out of 600 shops in Nishapur closed and the others barely able to subsist. Sebzewar (p. 373) was reduced from a population of 30,000 to scarcely 10,000. Everywhere death ran riot and frequently half the people of a village perished. The famine extended with great severity over all Persia except the northwest, and is described by Goldsmid, Bellew, Smith, and St. John. For six years the rainfall was scanty and there was much suffering. Then came a season when the crops in many places failed almost entirely, and thousands of people perished in every province. In view of the periodic return of such famines it does not seem probable that Persia is capable of supporting permanently a population greatly in excess of that of to-day.

(*c*) *Independent evidence as to the climate of antiquity.*—Independent evidence as to the climate of antiquity is hard to find. It must be looked for chiefly in the forms of historical or written record, archeological record, legend, and physiographic record. The written accounts which afford evidence as to the ancient climate are scattered in numerous inaccessible volumes and have not been investigated. A few of the more prominent, such as Alexander's march and the statement of Istakhri that in the tenth century the God-i-Zirrah was 100 miles long, have been mentioned. In general it is well known that ancient authors down to Mohammedan times speak of Persia in a way which implies a much greater productiveness and beauty and a much more abundant growth of trees than at present, but their statements lack the quantitative element which is necessary for a convincing solution of the question. Archeological evidence is more abundant and exact. The dams of Baluchistan, the ancient fort of Shah Duzd, the oasis of Merv, and the village of Bal Kuwi are cases where it seems as though there had been more water in earlier times. Probably a more complete study of Persian archeology will go far toward solving the problem.

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LEGENDS.

Legends are proverbially untrustworthy, but there is usually a solid kernel of truth in their center. Smith (p. 350) relates an ancient tradition common among the natives of Bajistan to the effect that the whole country around Bajistan was once covered by the sea, and that the place derives its name from two words signifying "to take toll," alluding to the toll at the ferry paid by travelers for boat-hire when the waters had partly receded. Farther east along the borders of the same playa which lies near Bajistan, "Yunsi (the Persian form of Jonah) is marked by local tradition as the spot on which the prophet Jonah was cast by the whale, and where he lay for many days concealed under a pumpkin plant." Sykes (p. 93) mentions these traditions and adds: "Again, further east, on the Herat road, is the village of Langar, signifying an anchor, and so a port, and according to M. Khanikoff, there is an ancient tradition that Langar was a harbor on the great inland sea. Although legends are as a rule far from trustworthy, yet in the two instances given it is hard to understand how they came to exist, unless there had been an inland sea at some not very remote period." Smith (p. 367) relates another legend which does not fit quite so well. Ja-i-Gharak is a village 20 miles south of Meshed, on the direct road to Nishapur. It is located in a mountain valley, 1,200 feet above Meshed. The name means "place of drowning," and is derived from an old tradition that the country here was once covered by the sea, and that a ship foundered here. Although Smith mentions a small lake which has been artificially dammed below the village, it is hardly possible that a large lake could ever have existed here, as it may possibly have done near Bajistan, Yunsi, and Langar. It may be that the name has been transferred a few miles across the mountains from the borders of the Dasht-i-Lut, which must have been a lake if the rainfall was ever greatly in excess of that of to-day.

THE LEGENDARY HISTORY OF SISTAN.

Sistan has its own crop of legends. The village of Deh Abbas Khan lies on the shore of the lake 2 or 3 miles east of Kuh-i-Khoja, and is inhabited by Sayids, who are supposed to be one of the oldest and purest Persian stocks in existence. According to their own traditions, they have inhabited the country from time immemorial, and are the descendants of the ancient Zoroastrian population. The chief of the village possesses an ancient book which has been handed down to him from many generations of ancestors, and is now his dearest treasure. From this book he partly read, but mostly related to me the following traditions:

> Long, long ago all Sistan was occupied by water, a great lake, which covered not only the swamp and the site of the modern villages, but the site of Zahidan and the other ruins as well. King Suliman (Solomon) saw the lake and perceived that if it were free from water the bottom would be very good for grain and melons and all sorts of fruit. At that time there was no more rain than now, but the rivers, which came from springs in the mountains, were very much larger. Desiring to benefit mankind, King Suliman sent for his "dhus," huge giants, each with a single eye looking upward from the top of his head, and ordered them to reclaim the lake. Swifter than man can imagine they went to work, and digging up earth from this side and from that, carried it on their shoulders in bags, and filled the lake. By noon the work was completed, and hence the country is sometimes called "Nim-ruz," or "Half day." When the work was finished the "dhus" went to the springs in the mountains and covered them, so that the water no longer came out. Since that time there has been some water in the lake, but far less than formerly.

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My ancestors, whose record is in this book, came to Sistan from Persia a thousand and forty-three years ago (A. D. 860). At that time all the villages were around Zahidan, where the ruins now are. The site of this village, Deh Abbas Khan, was under water, and only became habitable ninety years ago. It is now but very little above high-water level, and in the phenomenal flood of May, 1903, it was under water for a time.

Later I visited the ruins on the mesa of Kuh-i-Khoja with Mehemet Bey of Afzelabad, the "arbab" or chief of the antique race of Sayids, who told me the same story with less detail. He added a few points which are worth recording. In his boyhood, sixty years ago, the water about Kuh-i-Khoja was more abundant than now, and came from the south from the Shila instead of from the north, as it does to-day. The ruins of Kuh-i-Khoja are those of structures built by a king called Kaha-Kaha, by whose name they are still called. They belong to the same period as the ruins of Sabari, which are built of burned brick and lie at the bottom of what is now the main northwest bay of the lake. At that time, before the building of Zahidan, there was no water in the lake of Sistan.

As we approached the top of Kuh-i-Khoja the "arbab" stopped me and, pointing to two small holes in the rock beside the path, remarked, "There was a spring here once, but it was closed by the Holy Man, Hazret Mehemet Ali (one of the immediate successors of Mohammed). He stepped on the spring and caused it to dry up. His heels made these holes." When I asked if there were other springs of the same sort, the "arbab" replied that he knew of another on the north side of Kuh-i-Khoja, a second at Bendan, called Sum-i-Duldul, and a third at Malik-Siah-Kuh, in the corner where Persia, Afghanistan, and Baluchistan meet. All three were closed in the same way by Hazret Mehemet Ali or by his horse. At Malik-Siah-Kuh, the "arbab" added, there was formerly a kanat or underground water channel, but now it is dry.

From what has just been related it appears that the history of the lake of Sistan, as preserved in the traditions and written records of the ancient race of Sayids, consists of the following periods: (1) A time when water covered the area now occupied by the lake, the swamp, and the cultivated plain. (2) A time when the lake diminished in size and its shores were occupied by man. Meanwhile the size of the rivers decreased and springs dried up. At last the lake had so entirely disappeared that the town of Sabari was built in one of the lowest parts of its bed, and Kaha-Kaha was built on what is now an island, but was then dry land. (3) Then the water returned to the lake, although the springs still continued to dry up. The city of Zahidan was built. During the days of its prosperity the lake was larger than now, and probably received its water via the Shila. (4) Last comes the modern period, the last few centuries, during which the lake has shrunk to its present size and receives all its water-supply via the delta of the Helmund.

AGREEMENT OF LEGEND, HISTORY, AND PHYSIOGRAPHY.

The manner in which this traditional history agrees with the history already inferred from physiographic evidence deserves careful attention. That inferred history may be recapitulated as follows:

(1) During one of later fluvial epochs the upper or 25-foot beach was formed and the lake probably covered the whole of the swamp and plain of Sistan and also the God-i-Zirrah.

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(2) A decrease in the size of the lake ensued because of decreased rainfall or increased warmth.

(3) Next, the lake stood at the level of the lower beach, with an area greatly diminished from that of the time of the upper beach. As this is the level at which the lake overflows permanently to the God-i-Zirrah, the water may have stood here twice. The last time was probably very recent, because the bluffs left by it are so fresh that they can scarcely have existed more than a few hundred years.

(4) From this time of relatively high water the lake appears to have shrunk gradually to its present condition, as is shown by the transition from the lower of the old beaches to the present shoreline. Colonel McMahon believes that the condition of the reed-beds proves this decrease in size to be still in progress.

The agreement between the traditional and the physiographic history of Sistan is so close as to amount almost to identity. If we assume that they are identical, and put them together, we find that they match a third set of facts, the historical, which have already been mentioned, and a reasonable sequence of events presents itself. In this we begin with what was probably the last fluvial epoch, either when the lakes of Sistan and Zirrah were united and stood at the 25-foot beach, or more probably when the lake of Sistan stood for the first time at the 15-foot level and overflowed to Zirrah. As the fluvial epoch began to wane, springs dried up, the rivers decreased in volume, and the level of the lake fell. As the water retired the abandoned shores were occupied by human inhabitants, who we may suppose began to practice irrigation at an early date. At first the largest tract of irrigable land lay along the relatively elevated neck through which runs the Shila. Accordingly the largest canals were dug in this direction. Thus it happened that the God-i-Zirrah, which was now separated from the Hamun-i-Sistan, received the greater share of water. Indeed, it is probable that practically the whole stream of the Helmund flowed to Zirrah, for Smith (p. 285) says that in prehistoric ages the Helmund is reported to have flowed from the dam of Kamal, where it now turns north, in a southwest direction to the lake of Zirrah, and tradition has it that Khai Khusru sailed down it in a vessel. Sykes (p. 365) quotes Istakhri to the effect that in his day, the tenth century, the river flowed in the same way. Earlier classical writers speak of only one lake in this part of the world. It is probable that at this time Sistan was entirely dry, and the towns of Sabari, watered presumably by the Harud or Farah River, and of Kaha-Kaha, watered from the Shila, were built in what is now the lake. It is not to be supposed that the absence of water in the lake of Sistan indicates extreme aridity, for at this time not only was the lake of Zirrah a hundred miles long, according to Istakhri, but Sistan was in its glory. At the height of its prosperity a region which, as Curzon (I, p. 227) puts it, "contains more ruined cities and habitations than are perhaps to be found within a similar space of ground anywhere in the world," must have consumed an immense amount of water in the irrigation of its fields. To furnish this and at the same time fill the great lake of Zirrah, the rivers must have been larger than now. The limits of this period of prosperity and of abundant water-supply can not be stated, but they seem to have included Alexander, 300 B. C., and Istakhri, 900 A. D.

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Again there was a change. The bed of the lake of Sistan was once more filled with water to a height greater than that which is now reached, but less than in the previous epoch of high water, for Zahidan was not covered as it had been before. Between the time of Istakhri and the present the Helmund was diverted from a southwestward to a northward course, and this was probably the cause of the increase in the size of the lake. This is the more probable because from historical and archeological evidence it is known that Zahidan was built soon after the time of Istakhri. To supply so large a city with water a large amount must have been withdrawn from the Helmund before it reached the God-i-Zirrah and turned in the direction of Sistan. For some centuries, until its destruction by Timur at the end of the fourteenth century, Zahidan continued to flourish. It is probable that the lake stood at a high level for a considerable portion of this time, for it was able to form, or at least to rejuvenate, a well-defined shoreline, with broad beaches and high bluffs. During the last five centuries, since the fall of Zahidan, there has been a gradual decrease in the size of the lake and in the density of the population that surrounds it. How this could take place without a dimunition in the water supply it is hard to understand. The history of Sistan, so far as it can be made out, seems to indicate a gradual desiccation of the country from early historical times down even to the present. The evidence of archeology, history, and tradition in the surrounding countries points in the same direction. At Sistan history and physiography appear to join hands, for the change from the conditions of greater water-supply during antiquity to the desiccation of to-day is apparently the change from the last fluvial epoch to the present interfluvial epoch.

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