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## Article II—Geological Studies in the Northwest Himalaya between the Kashmir and Indus Valleys

BY

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# ARTICLE II

# GEOLOGICAL STUDIES IN THE NORTHWEST HIMALAYA BETWEEN THE KASHMIR AND INDUS VALLEYS

BY HELLMUT DE TERRA

WITH 1 MAP AND 21 TEXT-FIGURES

## INTRODUCTION

The geological cross-section described in the present contribution leads from the "Vale of Kashmir" northeastward over the main Himalayan range to the upper Indus valley in Indian Tibet, covering a distance of 180 miles. It traverses for the most part the main structural elements of the Himalaya at right angles to the strike and thus permits insight into the geology of this most elevated of mountain ranges.

The author has crossed this region four times. In 1927 he accompanied Dr. E. Trinkler on his journey from Kashmir to Indian Tibet on the "High Treaty Road" and returned the following year on the same route. With the Yale North India Expedition in 1932, he used the same caravan road between Srinagar and Leh and returned to Kashmir in the fall of that year. This fourfold opportunity to study one of the more accessible portions of the Himalaya naturally led to a better understanding of its geological history, the section revealing the general outlines of mountain history in the Northwest Himalaya. The limitations imposed by caravan travel and the hasty circumstances under which each of these trips had to be carried out explain why these studies represent a general reconnaissance rather than a detailed survey. Notwithstanding the incompleteness of the observations, it appeared that the structural relations of the Tethyan formations are much more complicated than previous investigators, particularly Stolitzka (1866) and Lydekker (1883), had thought them to be. This was indeed to be expected, for Wadia (1928) has recently proved that the Pir Panjal range in the southern Himalaya is characterized by southward thrusting on a large scale, and that even subrecent strata within the Punjab foredeep have become involved in the more recent crustal movements. Pleistocene and subrecent diastrophism have left their traces in the neighboring Kashmir valley, and such traces appear also in the topographic relief of the mountain sector under discussion which presents a most remarkable picture of such crustal deformations as followed the Tertiary folding.

The sedimentary and morphological record of the Pleistocene epoch in this region has previously been studied by Oestreich (1906), Dainelli (1922), and Norin (1925). In the present report special attention is paid to the Pleistocene only when the author's observations are more complete than those of previous investigators.

The writer feels greatly indebted to Professor H. Gerth of Amsterdam and to Professor H. Kühn of Vienna for the paleontological descriptions of Triassic fossils which will eventually be published in Volume IX of the Memoirs of the Connecticut Academy of Arts and Sciences. He feels equally obliged to Doctors H. Schulz and Kunitz who very kindly undertook the microscopic study of a number of rock specimens.

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# I. GENERAL GEOGRAPHICAL ASPECT OF THE REGION

The geological cross-section here presented begins in the Sind valley, one of the numerous transverse valleys that drain the southern slope of the central Himalayan range. One enters it from the Kashmir valley plain across a large delta over which the Sind river discharges its swift glacier-fed waters into the quiet swampy lakes of Kashmir. Rice fields border on the barren fluvial soil of the delta which is surmounted by gravel terraces of Pleistocene age on which one proceeds upstream into the valley. From the boulder-strewn banks of the river one looks across cultivated flats, fields of maize, barley and rice, and glades shaded by planes, walnut, mulberry and wild fruit trees. Talus-covered mountain slopes appear at a somewhat higher level and are overgrown with deciduous trees and shrubs which merge with the darker belt of coniferous forest. Long rows of pine and cedar, of silver fir and spruce cover the steep and dissected slopes. The upper limit of the forest belt lies at 11,500 feet and from there alpine meadows spread over the gentle rolling surface which in places has the aspect of a high plateau. This is the "marg-level," the pre-Pleistocene mature land form where the "gujars," or Kashmir herdsmen, have their summer camps with flocks of sheep and goat. The valley is densely populated, and the villages are built on the higher terraces so as to secure sufficient protection from floods and avalanches.

Between Gandarbal and Gund the valley width shrinks from three miles at Gandarbal to half a mile at Gund, and at Gagangijer it narrows down to an impressive gorge some five miles long. It is here that the Sind breaks through what farther northwest has been named the "Sogput Range." This is a minor range, 14,000 to 15,700 feet high, of a resistant trap rock with its strike parallel to that of the central Himalaya. In the gorge snowbeds from avalanches block the caravan path until June, and the caravan people then use snow-buried débris of pine, birch and spruce as a welcome supply of firewood. The bottom of the gorge is choked with coarse boulders over which the green glacier-water cascades into whirlpools and foaming torrents. Quite unexpectedly the gorge opens towards a wider terraced valley, which two miles northwest of Sonamarg swings from a transverse course into the longitudinal strike of the surrounding mountains. The landscape becomes more alpine, the pine forest is thinner, here and there destroyed by long streamers of talus which mark the trails of avalanches (Text-figure 1). The hamlet of Sonamarg was almost completely destroyed in May, 1928, by a large avalanche, but in 1930 had already been rebuilt. Avalanches and frost-weathering readily furnish débris from the limestone and shales producing the thick accumulation of coarse talus on the present valley floor. Ample precipitation causes frequent outwash of finer particles which spring and summer floods carry into the river. The residual soil is therefore coarse and devoid of clay components.

The gorge through which the winter route of the caravans leads to the Zoji La is cut transversely through the rocks. At places it attains the aspect of a canyon, 1000 feet deep, with almost vertical walls. The erosive force required to make such a cleft can be fully appreciated only when one considers the great thickness of snow which the avalanches deposit each year during the months of April and May, since the steep southern flank of the range receives the bulk of the moisture carried by the southern winds and the monsoon towards the high glaciated range. Birch and fir thrive on the slopes above the ravine up to a thousand feet below the pass-level. The Zoji La (11,200), on the crest of the central Himalayan range, marks a sharp geographic boundary between the Kashmir catchment basin and the drier highlands drained by the tributaries of the Indus. Here the traveller from Central Asia hails the long-expected end of his troubles encountered on the journey across the barren alpine desert of the northern Himalaya and Karakoram. The trader from the south, on the other hand, is aware that from now on firewood and grazing will become increasingly scarce. No wonder that this pass has been the political boundary of the west Tibetan kingdom for hundreds of years. Today telegraph poles and stone huts for mail runners mark this trail across the ancient barrier.

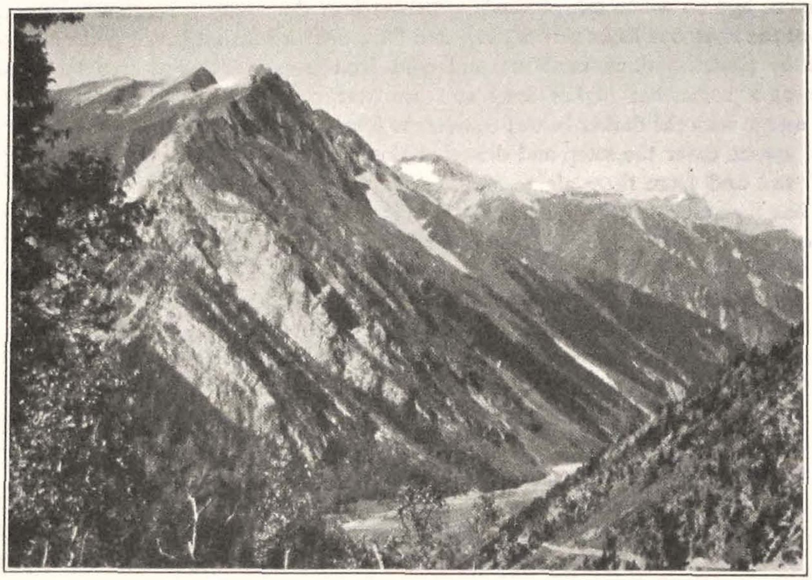

FIGURE 1. THE UPPER SIND VALLEY NEAR BALTAL.

View from the summer road to the Zoji La towards the Triassic limestone range. Birch and pine forest in foreground. The high spurs in the background are just above 12,000 feet.

The descent from the pass is gentle compared with the steep southern slope, and the level of the Gamru valley between Matayan and Dras never falls below 10,000 feet. The only physical feature which it has in common with the Sind valley is its Pleistocene glacial morphology, viz., the composite slopes and the glacial trough. The shape of the latter, however, is not as perfect as along the Sind for, due to the drier air and the more rapid temperature changes, weathering is here more intense. The green verdure of coniferous forests is replaced by barren mountain-slopes and flat talus-covered valleys. The latter expand at Dras to form a narrow basin one to two miles wide. The barren rounded hills north of Dras contrast markedly with the precipitous snowy range in the south (Text-figure 8), the former consisting of volcanic rock which yields more easily to erosion than the harder Triassic limestone. Geographically this higher range still belongs to the Central Himalaya.

At Dras a little irrigation is possible and the valley is scantily cultivated, but farther downstream towards Kargil it becomes more barren. The path follows across morainic débris and talus fans. A few remnants of fluvio-glacial terraces are cultivated by the natives, who grow the native barley called "grim." Here and there small oases of poplar and willow trees appear and along the river wild roses, pencil cedar and *Myricaria* bushes occasionally grow. The valley-slopes, which are barren except for a few xerophytic and alpine flowering plants and mosses, rise steeply 6000-9000 feet above the river bed. On approach-

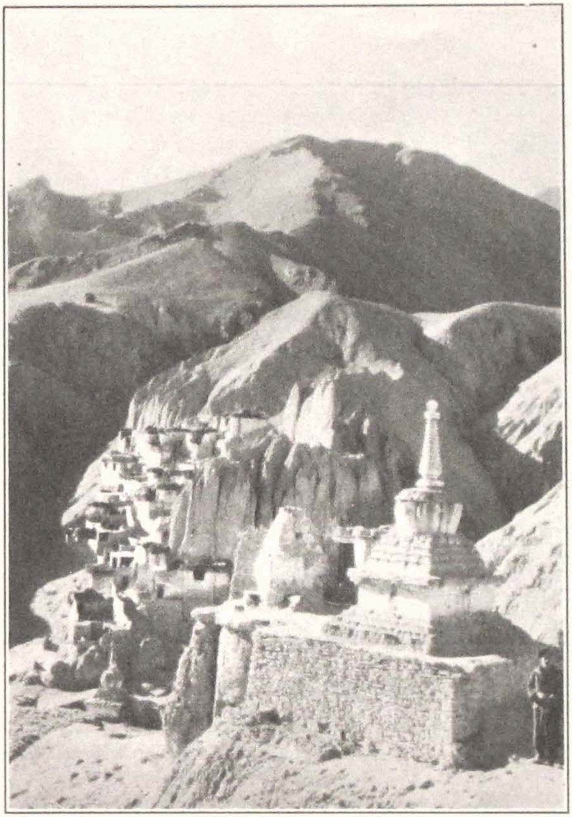

FIGURE 2. THE VILLAGE OF LAMAYURU IN LADAK.

Deeply dissected Pleistocene lake beds on Dras Volcanics determine the architecture of this Tibetan village which is typical for the monastic-agricultural type of community. The religious monument in the foreground is a "chorten." Note how the badland-topography is restricted to the lake beds.

ing the confluence of the Dras and Suru rivers northwest of Kargil, the stream becomes entrenched over 100 feet deep in the granite rock. At Chanigund, ancient whirlpools can be seen in the granite 100 feet above the present stream level. They correspond with the level of a post-glacial terrace on the opposite bank and hence indicate the rate of vertical cutting since the last glacial retreat.

As the road turns from the Shingo into the lower Suru valley, the view opens unexpectedly towards a broad depression. The rugged granite mountains give place to sloping hills and ridges, and before one reaches the junction of the Suru and Wakka streams a wide terraced basin appears. The town of Kargil lies surrounded by barley fields and poplar groves. On entering its narrow bazaar street one notices that merchandise is here as varied as the merchants who retail it. Hindus from the Indian plains and Kashmiris deal with people from Indian Tibet and Baltistan, for it is here that the trade route from Kashmir branches into two caravan routes. One road follows the Suru valley to Skardu in Baltistan while the other turns southeastward to Mulbek and to Leh, the capital of Indian Tibet. This junction of trade routes at Kargil is determined by the successive confluence of the three rivers mentioned above, for the Suru valley affords easy access to the province of Baltistan while the other permits a gradual ascent towards Ladak or Indian Tibet. The sand and

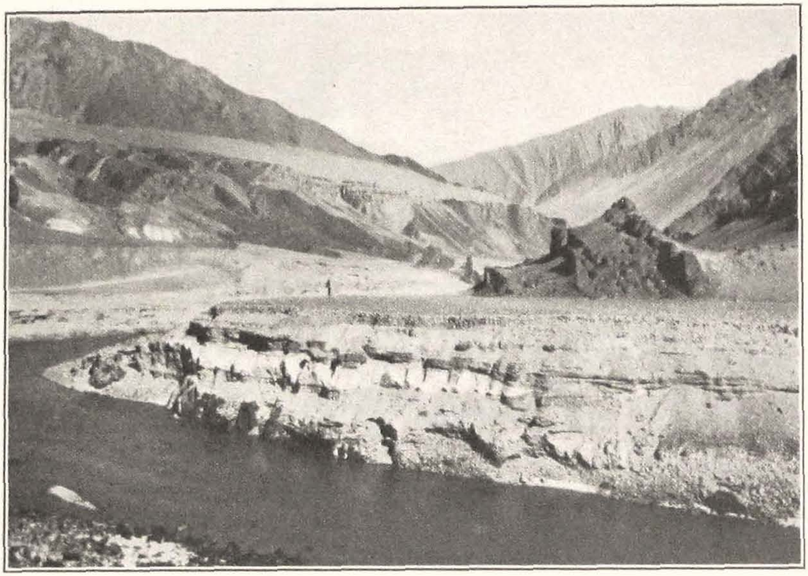

FIGURE 3. THE INDUS VALLEY AT THE CONFLUENCE OF THE HANGRU BELOW KALATSE.

The valley is cut into an anticline of flysch beds and the river entrenched into Pleistocene coarse fluvio-glacial and finer lake deposits. The higher terrace is of fluvio-glacial origin and probably mid-Pleistocene in age.

gravel soils of the broad river terraces in the vicinity of the junction also permit cultivation and provide an inviting site for settlement. The geographical position of Kargil as a gateway to Indian Tibet is therefore determined by geological and physiographic factors alike.

The river fork thus determined the ground pattern of the Kargil basin. A triangular depression has been carved out of the mountains which lie between the Zanskar range and the northeastern slope of the central Himalayas. Its southern base is about 4 miles broad, its apex lies 1 mile north of the junction between the Suru and Wakka streams. The depression is thus but an enlarged valley fork and therefore of erosional origin.

The trade route from Kargil to Leh in Indian Tibet follows first the Wakka stream and then crosses a tract of mountainous country which is reminiscent of the topography north of Draz. Rounded hilltops and gentler mountain slopes here characterize the higher relief unit, and not until one reaches Shargol does the landscape regain its alpine aspect. Again the limestone range appears, as at Dras, like a buttress some 19,000 feet high, and the valley widens, permitting agriculture. Wherever the political frontiers of Tibet may have been in former times, here at Shargol one enters the present spiritual domain of the Buddhistic empire of Tibet. Its monastic hierarchy has impressed a certain style of living and of architecture on the people, quite distinct from that found in Kashmir. No longer are the villages solely agricultural or mercantile settlements, but they are grouped around a lamasery quite reminiscent of the mediaeval pattern of certain ancient European communities. Means of communication also cease to be purely utilitarian and become also channels for spiritual intercourse. The caravan route is flanked with religious monuments and peopled with travelling monks, a picture which in itself expresses the mystic powers that dominate the life of the natives (Text-figure 2). Opposite Kangral one notices a ruined village which was obviously deserted after torrential floods had destroyed and partially buried most of the dwellings. At Bod Karbu, on the other hand, a larger fortified settlement on the hilltop was left in ruins after Kashmir troops had conquered the city in the Dogra war of 1846. The ascent from the Sangeluma valley to the Fotu La is steep because the interstream divide is greatly trenched on the northeastern flank, where the erosive influence of the nearby Indus river is felt. But of all these divides only the one immediately south of the Indus deserves special attention for it is as distinct an orographic unit as its northern neighbor, the Ladakh range. Its mean elevation is about 19,000 feet and locally, for example southeast of the Hangru gorge, and again near Leh, it bears single peaks of 21,000 feet altitude. Hence it is not surprising that the transverse valley through which one crosses the range should have the steepest slope of all the valleys on this route. It drops over a distance of eight miles at the rate of 200 feet per mile to the 9600 feet level of the Indus river. The Hangru valley is a typical example of an overflow and subsequent capture of a late Pleistocene lake basin which was drained off by a small tributary of the Indus. The yellow silt and clay beds at Lamayuru with their bad-land topography make a most striking picture as their remnants hang like natural fortifications above the deep gorge (Text-figure 2). The geological section closes here at the outlet of the Hangru valley and the trade route turns upstream and uses forthwith the main longitudinal valley of the Indus into Ladakh (Text-figure 3).

# II. DESCRIPTION OF GEOLOGICAL CROSS SECTIONS

## FROM THE OPENING OF THE SIND VALLEY TO THE MAIN HIMALAYAN RANGE[1]

On leaving the Kashmir valley at Gandarbal, a village situated at the outlet of the Sind valley, one notices on the eastern slope Panjal trap appearing beneath the Pleistocene gravel fill. The outcrop is at least three-quarters of a mile wide and is followed abruptly by slates and phyllites, which continue from here upstream forming most of the area drained by the lower Sind river. The boundary between trap and the metamorphic rocks is a major dislocation, the former is shattered and heavily infiltrated with calcite veins and the grey slaty greywacke is full of slickensides and minor faults. Before reaching Margund grey hard greywacke, greenish phyllites and slates are exposed on both slopes of the valley. The slates bear rusty spots on the schistplanes, reminiscent of the middle Cambrian slates of Handawara in the northwestern part of the Kashmir valley which they resemble in every respect. Closer inspection reveals that the slate in the Sind valley is more metamorphic than the fossil-bearing Handawara horizon; it is sheared and crumpled and clearly shows a secondary foliation. At Margund granite has intruded the slates and forms an elliptical outcrop one mile long and about half a mile wide. Its shape is that of a neck or chonolith rather than that of a laccolith as Middlemiss (1911, p. 139)[2] had assumed, for it cuts across the northwest strike of the slate which is closely folded. Quartzite and pyritiferous schist form a contact halo, some two hundred feet wide, thus indicating that the intrusion is younger than the ?Cambrian series and their folding.

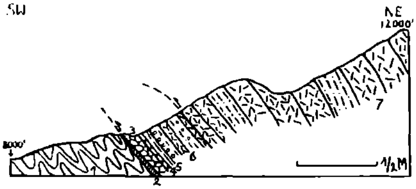

FIGURE 4. CROSS SECTION THROUGH THE NORTHWESTERN CONTINUATION OF THE BASMAI ANTICLINE ABOVE GAGANGIJER IN THE SIND VALLEY.

1 = Cambrian-Silurian slates; 5 = Fenestella shales. Other numbers refer to signatures given in Figure 7.

At Reyil, two miles beyond Gund, the strike in these rocks is N 80° W, 65° NNE,

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[1] Topographic references are to be found on the following Survey of India maps: Nos. 43 J15, 43 J16, 43 N 3, 43 N 7, on a scale of 1 inch to 1 mile; and Nos. 43 N, 52 B on a scale of 1 inch to 4 miles.

[2] The larger outcrop of trap, southwest of Kangan, was not actually observed but taken over from Bion's sketch map (1928).

while four miles above Kangan the slates strike N 60° W, 40° NE. Near Rezan conglomeratic and brecciose layers appear in the purplish slate. They are intraformational and consist of well rounded pebbles of quartz, flint, and greywacke. The intense folding led to repetition and to a closely packed mass of folds whose thickness must exceed 3000 feet.

The greywacke and slate series give place at Gagangjir to the Devonian Muth quartzite. The latter is exposed 1000 feet above the path which leads from that place towards the Sind gorge below Sonamarg. It is a silicified coarse sandstone, of light yellow speckled appearance, somewhat slaty and sheared and with N 50-60° W strike and 65° NE dip. Its contact with the slate seems at first sight normal, but the boundary is marked by shearing and the slate is completely squeezed into a mass of slickensided lenses (Text-figure 4). At one place, about 500 feet higher and just above milestone 43, slices of phyllitic slate and chloritized trap appear squeezed in between the slates and the Muth quartzite. Bion's and Middlemiss' map (1928, Pl. VIII) reveals that here narrow strips of Devonian, Lower Carboniferous and Permian rocks disappear successively between the Panjal trap of the Sogput range and the Cambro-Silurian slate series (see map). This must be because portions of the northern limb of the Basmai anticline have been squeezed out between two thrust planes of which one lies at the base of the Muth quartzite while the other is situated below the Panjal trap sheet. Half a mile south of peak 14341 both thrusts seem to join in order to form the major dislocation which follows the base of the Sogput range. North of Gagangijer the second thrust plane is indicated by the chloritized and sheared variety of trap which follows the agglomeratic slate in the section. In places the slate has turned into phyllonite and is intensely slickensided. From these relationships it may be inferred that the contact between the trap and the younger Paleozoic rocks is largely of a tectonic nature and not solely due to unconformity with overlap as Middlemiss and Bion had assumed. It may, of course, be that the subsequent thrust-movement utilized planes of unconformity, but in this section the sudden southward advance of the trap has clearly led to profound deformation of the adjoining rocks which cannot be due to normal magmatic overflow.

Under such conditions one would expect the trap to acquire its normal non-metamorphic aspect as one proceeds northeastward into the trap ridge and this is precisely what one observes. On entering the Sind gorge at the first bend of the river, the epimetamorphic facies of trap merges into a fine-grained or dense rock of light greenish color. The texture varies in different layers. Some are dense and intercalated with banded tuff, and others are amygdaloidal. There is a platy jointing all through the trap and quite commonly larger sheer planes with moderately steep northeasterly dip. Locally one may observe a progressive displacement of trap layers in an ascending fashion from northeast to southwest.

The total thickness of the trap must exceed 4000 feet, but, as the map shows, the trap thins out where the northern thrust plane makes a re-entrance. This indicates that the thickness of the trap varies with the degree of tectonic deformation.

Petrologically the rock differs from the normal Panjal trap, which is an augite-andesite, by a greater amount of epipodite, zoisite and chlorite. This mineral combination signifies the strong epi-metamorphism due to intense pressure of folding. Chloritization accordingly has especially developed along major sheer planes. So far as the exposures along the river permit one to judge, the trap consists of a number of individual flows or sheets frequently separated from each other by jasper-like bands of tuff. The thickness of some of these sheets is only 20-100 feet which suggests a highly liquid lava that welled up in intermittent eruptions. As all of these characteristics are shared by the normal Panjal trap and as its stratigraphic position above the agglomeratic slate is normal, it is safe to consider this trap as a metamorphic variety of the Panjal extrusive of Lower Permian age (see Text-figure 7).

At the outlet of the gorge, 1½ furlongs before reaching milestone 48, the trap is seen to form precipitous cliffs which plunge into a small ravine opposite Tramkagan. The trap is faulted against a series of carbonaceous phyllite and graphitic schist which dip 80 NE (Text-figure 5). The rocks are strongly sheared along the contact, the trap is partly converted into chlorite schist, while the phyllite is infiltrated with quartzose veins. A larger quartz vein displays a N 80° W strike. The phyllitic rock is a few hundred feet thick and merges into a hard, dark, limy slate, which in turn is followed by slaty grey limestones. The carbonaceous content of the phyllite may indicate that it is derived from a member of the Gondwana series of Kashmir for which a high carbon and bitumine content is very characteristic. Therefore, it is probable that part of the Permian *Gangamopteris* beds appear here, though in metamorphosed condition. This formation, which near Srinagar bears the remains of *Archegosaurus*, *Actinodon*, and *Amblypterus*, is an old Gondwana land deposit, and if this carbonaceous phyllite can be regarded as of equal age, it is only logical to conclude that the Gondwana land mass extended during some of the Permian time about 30 miles north of the Kashmir valley and about 80 miles north of the present southernmost limit of Mesozoic Tethys formations.

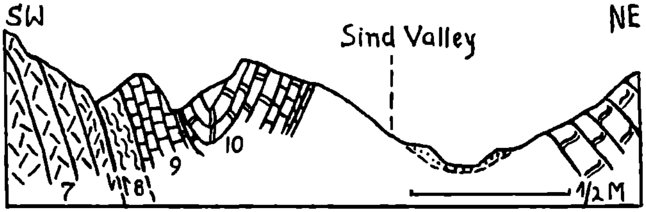

FIGURE 5. SCHEMATIC SECTION THROUGH THE SHEARED NORTHEASTERN LIMB AND ANTICLINE IN UPPER SIND VALLEY BELOW SONAMARG.

8 = Permian shales; 9 = lower to middle Triassic; 10 = middle to upper Triassic limestone and shales.

The Triassic age of the succeeding limestone had previously been ascertained by Stolitzka who found *Ptychites geradi* at a locality called Tajiwaz. Middlemiss (1911, p. 142) also found fragmentary Muschelkalk ammonites. Diener (1899) confirmed the Muschelkalk age (*Ceratites thuillieri*) for the sequence of phyllitic to slaty, ochre-colored layers of limestone which overlie the slates on the slope opposite Tajiwaz. Middlemiss determined this series to be 200 feet thick as compared with 900 feet in the Kashmir valley. The Lower Triassic then is doubtless represented by the dark slaty limestone, but its metamorphic condition did not permit the preservation of fossils. The black shales which, according to Middlemiss (1911) follow the slaty limestones, are different from the carbonaceous (Permian?) shales mentioned above. They are limy shales alternating with thin-bedded limestone. In these I found slabs from which bryozoa, corals and algae had weathered out. The fauna is being determined by Professor Kühn in Vienna and is evidently of middle Triassic age.

In the upper portion of this Triassic exposure the beds dip 70° SW but they bend abruptly to a syncline and near the sheared contact with the phyllite the dip is 50° NE. The limestones and shales continue in a normal NW-SE strike and the sheared contact with the trap can be followed on the southern flank of the Darnar valley. The apparently normal succession of ?Permian to Upper Triassic suggests a tightly squeezed syncline whose southern limb was sheared against trap. Between the river bend and Baltal, this structure becomes more clear. All along the northern flank of the Sind valley the dip of the Triassic limestones is northeast and it generally exceeds 50°, whereas the southern flank exposes a thick southwest-dipping series of thin-bedded dark and light grey limestones. The Sind river therefore follows an anticline in Triassic limestones. About a quarter of a mile east of Sonamarg there appears a sequence of cherty grey limestones quite unlike any of the Triassic rocks heretofore mentioned. They form a picturesque, sharply serrated spur of banded limestones which are vertically upturned as if they had been faulted. They contain grey cherty limestones full of sponge spicules, small gastropods and crinoids, and the northernmost portion of the sequence exposes a reddish cherty limestone. In this I found the fragment of an ammonite operculum. This limestone resembles certain *Aptychus* limestones of the Alpine Jurassic, and it may possibly belong to that system. As one follows the road towards Baltal, these rocks disappear and give place to dark limy shales which occupy the northern flank of the valley. They reappear 8 miles to the southeast along the summer road of the trade route which leads from Baltal to the Zoja Pass.

The geological section from Baltal (9450 feet) to Matayan (10,430 feet) across the orographic axes of the main Himalayan range is full of tectonic complications. First there appears a thick series of dark, bluish-gray pyritiferous shales with intercalated siliceous limestone beds, all intensely folded and sheared and partly transformed into calcareous schists. It was here that Middlemiss[3] came across some badly crushed fragments of belemnites which induced him to ascribe this shale to the Jurassic, possibly to the Liassic. The strike is here about N 65° W with an irregular dip that changes northeastward from 80° SW to 75° NE. The Sonamarg anticline evidently is followed a mile and a half to the northeast by a steeply infolded syncline in which the Jurassic shales have been tightly compressed. Towards the pass a perpendicular dip prevails and here grey ochreous phyllites and calcareous slates with limestone beds seem to represent the Triassic of Kashmir facies. In this northwestern limb are enfolded schists and granitic gneiss, the latter steeply thrusted against calcareous schists. Local mylonitisation and the general metamorphism of biotite into chlorite indicate that this granite has undergone intense post-crystalline deformation. West of the pass the granite is followed by a thick series of sericite and chiastolite schists, phyllite and green schist which dip steeply northeast. The structural relationships of these rocks are sketched on the map. It appears that the granite-gneiss and upper Triassic limestone were thrust upon the syncline which contains the Jurassic shales. The contact-metamorphic schists of unknown age were strongly compressed on the northeastern limb of a sheared anticline. As to the age of the granite-gneiss, it should be considered that the neighboring Jurassic shales are metamor-

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[3] Personal communication to the author in 1927.

phosed to pyritiferous schists but it would necessitate special studies to decide whether this was due to contact-metamorphism of the granite or to thrusting. Schist and phyllite predominate between the telegraph hut and Machhoi, and from the latter place on they alternate with beds of hard dark limestone. The latter may belong to an older formation but on descending from Machhoi towards the upper Gamru valley the Triassic limestone reappears.

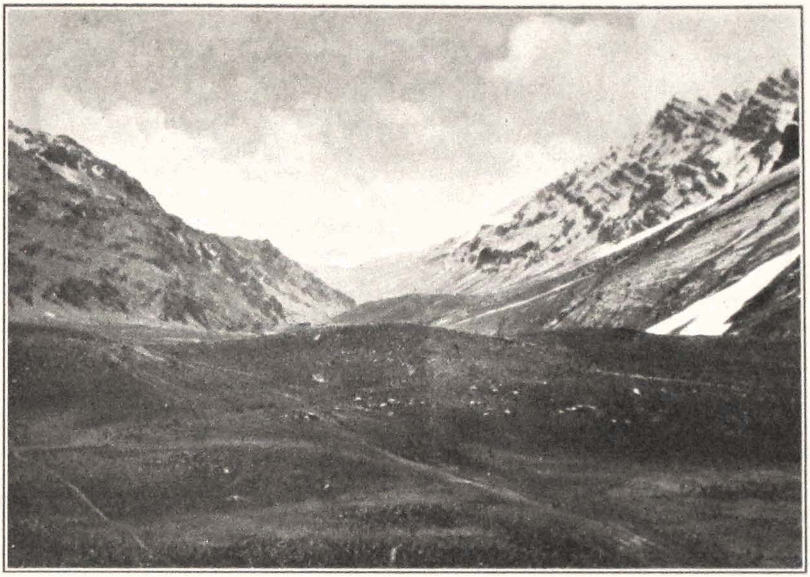

FIGURE 6. THE GAMRU VALLEY AT PINDRAS.

View taken from two miles west of Pindras looking east. In foreground ground-moraines of last Pleistocene glaciation. To the right Triassic limestone and shales faulted against Dras Volcanics which build the left valley flank.

## THE GAMRU AND DRAS VALLEY SECTIONS

The desert aspect of the region accentuates the sinister looking color of the steep limestone walls through which the Gamru river flows towards Dras. On approaching Matayan the steep dip which near Machhoi is northeast turns southwest. The Triassic forms a syncline whose axis strikes N 70° W. Its thickness at Matayan must be at least 7000 feet. In the lower part of the mountain slopes the dark grey limestone is banded by layers of shale while higher up it appears more massive and of lighter color. Fossils were collected from a dark grey, somewhat dolomitic rock in the lower portion of the exposure at Matayan. Among the fossil fragments which permitted identification were: *Megalodon ladakhensis* Bittner, *Thamnastraea* sp. and *Rhynchonella* sp. The most common fossil found in this rock is the large marine clam, *Megalodon*, which according to Bittner (1901) is a guide fossil for

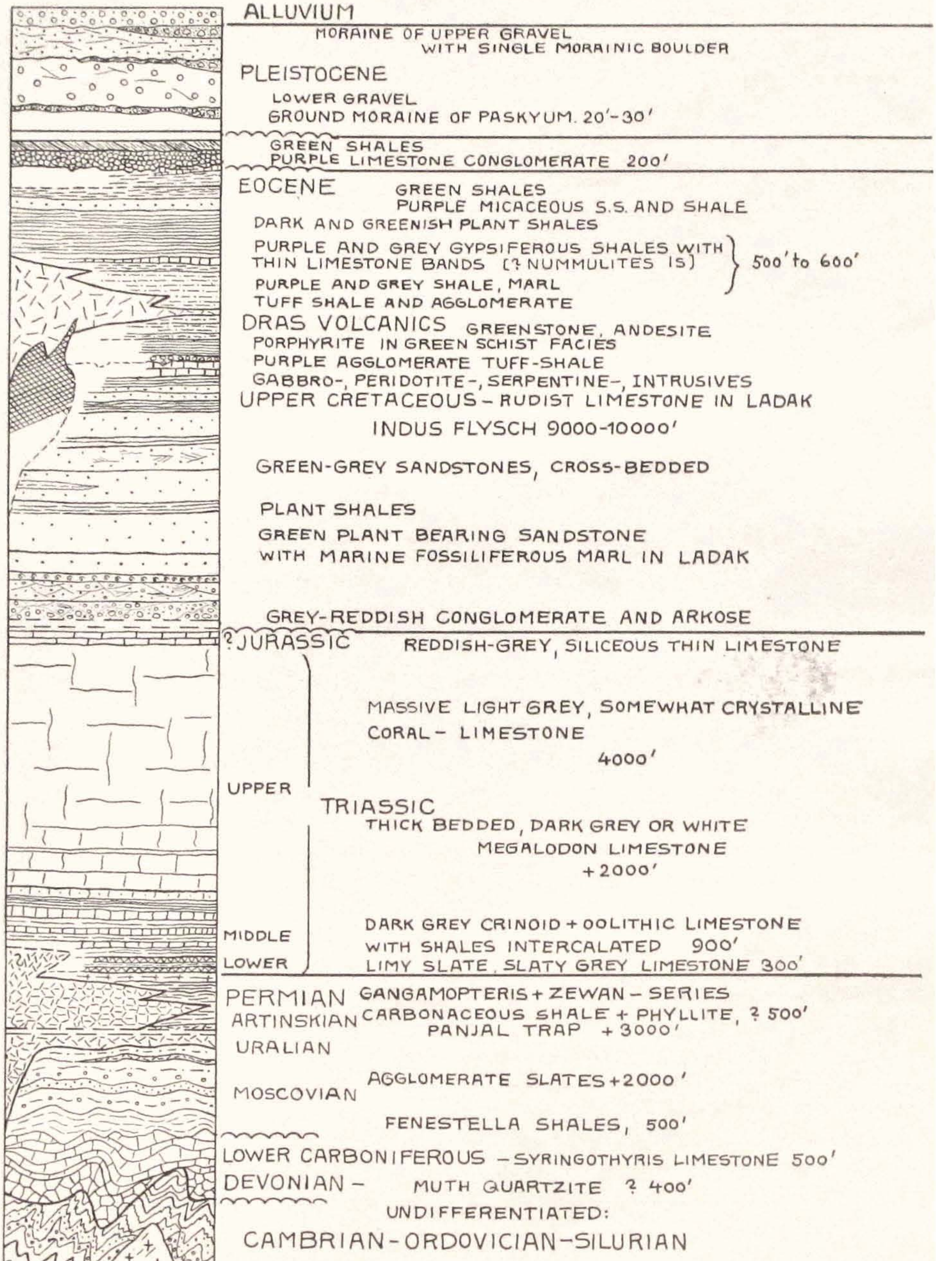

FIGURE 7. STRATIGRAPHIC SEQUENCE OF ROCK FORMATIONS AS OBSERVED IN THE SECTION. Thicknesses not true to scale. The arched line indicates an angular unconformity.

the Noric and Rhaetic stages of the upper Triassic in Spiti and in Kashmir. The great thickness and massiveness of the light grey limestones make this Triassic sequence resemble the upper Triassic of Spiti to such a degree that it is fairly safe to say that the Triassic in the Gamru valley at Matayan represents a northwestern outlier of the great Triassic syncline of Spiti. It is quite possible that the thin-bedded limestone and shales which appear below the massive rocks represent the Middle Triassic or Muschelkalk. Between Matayan and Pindras the limestone is sharply compressed into recumbent folds such as those exposed in the neighboring peaks 17,881 feet and 16,478 feet where the fold axis can be seen to dip southwest. This structure prevails only in the highest portions of the exposures, whereas 3000 feet lower the folds become more normal. Here the structure seems more determined by the incompetence of the shaly limestones.

At Pindras and about 1500 feet south of the sharp bend of the Gamru valley, dark-bedded limestone abruptly meets a series of tuffaceous and agglomeratic rocks and greenstones. As these are less resistant to erosion, they give rise to softer land forms and to a greater accumulation of débris which is strikingly exemplified on the northern slope of the Gamru valley towards Dras. Here the Triassic limestone occupies the upper portion of the southern flank, rising like a buttress above a sequence of green and purple shales, agglomerates and greenstones which dip towards the Triassic (Text-figure 6). North of the river the volcanic rocks are seen to dip 30-50 north. Thus the Gamru river flows on an anticline with a west-east strike. At P. 16,210 feet west of Pindras, the tuffaceous slates and agglomerates dip 40° SSW towards the lower portion of the Triassic sequence. Seven miles eastward the Megalodon limestone is seen to be faulted against greenstone. Slickensides, brecciation and crystalline structure within the limestone indicate here a great dislocation. From Pindras on eastward, the fault plane crosses the river and can be followed as a sharp dividing line between the cliff-forming Triassic and the softer tuff-shales. The true fault character of this contact was first clearly observed in a few exposures on the southern flank of the Dras basin. Tuffaceous slates of green and purple color are here separated from sandy, calcareous shales and overlying Triassic limestones by mylonite, 10-20 feet thick. The latter consists of angular pieces of Triassic limestone and slate which are cemented by ochreous, limy matter. The tectonic breccia is locally penetrated by quartz veins and is otherwise completely silicified. The fault plane itself is tilted and changes its dip within a quarter of a mile from 50° to 70° SSW. The fault runs along the base of the Triassic limestone ridge and can be seen half a mile north of P. 14,850, continuing eastward along the northern slope of the range.

We may now consider the age relationships of the thrusted formations. The older investigators such as Stolitzka (1869) and Lydekker (1883, p. 147 ff.) believed that the volcanic series near Dras represented Panjal trap and agglomeratic slate (Text-figure 7). It must be admitted that the greenstone of Dras outwardly resembles the chloritized facies of the Panjal trap, but the differences are more significant than their superficial resemblance. In the first place a large portion of the greenstone is derived from an augite porphyrite or from diabase, and its tuffaceous derivatives, as will be pointed out later, are intimately mixed up with Mesozoic limestones. There is at Dras also evidence for intrusive phases represented by masses of ultra-basic rocks such as gabbro, pyroxenite, peridotite and serpentine which

FIGURE 8. THE SOUTHERN FLANK OF THE DRAS VALLEY AT DRAS.

Pleistocene gravel terraces over faulted Dras Volcanics. The snowy range in the background is composed of Triassic limestone, dipping south. The broad high valley on the left is a remnant of the "Deosai-level," see Figure 20.

are clearly connected with the volcanic series. The tuffaceous shales are purple and bright green in color and bear little resemblance to the greyish agglomeratic slate of Kashmir. They lack fossils and alternate in adjoining regions, such as in Ladak, with marine Cretaceous limestones. The agglomerates of the Dras Volcanics are generally purplish or reddish and consist of angular fragments of older metamorphic rocks, such as phyllites, but more commonly of tuff, greenstone and shale. The latter is micaceous and sandy and frequently forms layers 200 feet thick in the green-schist complex. The agglomerates and tuffs are cut by dark, basic dikes (2 miles west of Dras) which seem to come from the intrusive masses. The latter build up great portions of the northern frame of the Dras basin where they give rise to reddish brown undulating hills which contrast remarkably with the grey precipitous limestone ridges to the south (Text-figure 8). According to Aloisi (1933, p. 226) the gabbros north of Dras have been greatly altered under the influence of heavy folding. The serpentine rocks he considers to be derived from a dillag-gabbro which is exposed a few miles north of Dras. All along the northern slope of the basin, between Dras and the great bend of the river towards Kargil, there appears a massive complex of dark green rocks which may be followed for a distance of over 30 miles. It consists of diabase in green schist facies and of augite-porphyrite. Locally these rocks are cut by dikes and the whole mass presents a network of irregular thrust slices which generally dip northeast. The greenstones and green schists which flank the basic intrusives alter with green and purple colored laminated tuff shales and slates. These latter are of two-fold origin. Aloisi (1933, p. 232) found a schistose diabase at Tasgam in the Dras valley while at Dras the denser and laminated green schists are derived from metamorphic rock of diabase-tuff origin. The close affinity which exists between these tuffaceous schists and similar ones near Lamayuru in Ladak is very illuminating as to the geological age of the Dras Volcanics. In Ladak they are intercalated with the Upper Cretaceous flysch, while near Dras, as everywhere else along the Indus river, these green schists appear closely associated with porphyrite and diabase lava sheets (Text-figure 7). In the eastern part of the neighboring Kargil basin at Pashkyum the same diabase and augite-porphyrite are found in close association with purple and green tuffs and agglomerates. As regards the Dras Volcanics, Lydekker (1883, p. 115) also remarked on the close resemblance of these igneous rocks to the greenstone and its associated red shales that appear in the Kargil region. It seems, however, as if the information which he obtained in the field was too scanty to permit him to recognize that the Dras Volcanics are not of the same age as the Panjal trap. Moreover, these tuffaceous shales and greenstones are locally associated with thrust slices of Eocene limestone, which points to a close age relationship with the older Tertiary.

The origin of the ultrabasic rocks and their structural position within the Himalayan geosyncline will be discussed in a later chapter.

Between Dras and Kargil one has occasion to see more of the volcanic series. Augite-porphyrite and diabase, the latter varying from a dense to a coarser texture, are here cut by black lamprophyre dikes which appear opposite the hamlet of Djas-Gund. For five miles one crosses this complex of diabase and greenstones along the Dras river until at Tasgam gabbro and amphibolite appear. These rocks evidently form smaller intrusive masses within the diabase greenstone complex. All along the road one notices the effects of intense deformation. The more massive serpentines and gabbros are shattered and cut by numerous shear planes and appear generally strongly jointed. The green schists are locally turned into chlorite schist. The gabbro complex crosses the valley with a north-northeast strike and is associated at Shimsu with agglomerates and thin lenses of dark limestone. The latter appears in the form of thrust slices, 150 feet thick, on a major dislocation which subsequently will be described as the Kargil thrust. Middlemiss determined this limestone to be of Eocene age. The small inthrusted portion of this limestone seems to occur some 1200 feet northwest of the bridge below Tasgam where a slaty, much altered and unfossiliferous rock of this type is exposed. Opposite Karbu (or Shimsha Karbu) this limestone is associated with sandy micaceous and pyritiferous slates very similar to those which make the syncline south of Zoji pass. The strike is here N 55° E, the dip 40° SW. Slaty agglomerates of the Dras volcanics are found folded in between limestone and greenstone. A thrust plane appears to be responsible for the much sheared condition of these rocks.

In the section along the Dras river there also appear local intrusions of granite. Aloisi (1933, pp. 30, 33) determined it as an amphibolite granite with quartz diorite association. He described the rock as being sericitized and chloritized, evidently representing an epi-metamorphic facies. Similar smaller outcrops of granite are to be found southwest of Tololing mountain north of Dras, where they form larger lenses in the greenstone complex. The origin of these small granite intrusions is still obscure. Benson (1926, p. 70) states that the diabase-serpentine rocks in the Italian Alps and in the Sierra Nevada of California contain veins of granite which he believes to have been derived from acid residual fluids of a basic magma. It is quite conceivable that the local granite intrusions around Dras are derived from the same parent magma which was the source of the Tertiary Himalayan granites such as occur in the eastern Himalaya.

About one mile north of Shimsha Karbu a small boss of granite may be seen on the right side of the Dras river. Granite also forms the heights north of Soman peak (16,957 feet) and the divide between the Dras river and the Suru river west of Kargil. It continues northwestward towards the Deosai plateau and forms the northern frame of the Kargil basin. As to the nature of the contact between the granite and the Dras Volcanics, it appears that about one mile downstream from Karbu the chloritized green schists and porphyrites terminate abruptly. The schists are slickensided and badly crushed along their boundary with the granite. The latter rises steeply above the valley floor and a side glen exposes the contact for a few miles in a southeasterly direction. West of Soman and of Station 14,114 chlorite schist and chloritized porphyrite are seen to form a kind of embayment in the granite which southeast of Karbu is replaced by a salient of the schists. Here lenses of porphyrite appear in the form of thin thrust slices within the granite, and here also granite emerges from below porphyrite along the eastern slope of the valley. On the right side of the stream and almost continuous with the former rocks there appears the thrusted slice of limestone and agglomerate mentioned above. This rock forms an almost unbroken thin belt which extends from south of Tasgam eastward to the southern flank of the Kargil basin. From here it can be traced farther east to Pashkyum where the flysch formation and the overlying Eocene-series plunge beneath the Dras volcanics. The limestone is associated with agglomerates and bordered by major dislocations. The abrupt fault contact between granite and Dras volcanics on the one hand, and the appearance of thrust slices south of the granite on the other, indicate a fault- and possibly thrust-structure.

## THE GEOLOGY OF THE KARGIL BASIN

The erosion of this basin was clearly determined by two geological factors: the softness of the sandy and shaly strata which underlie the region where the confluence of two pre-Pleistocene rivers occurred, and the subsequent filling of the depression with loose, fluvio-glacial and interglacial deposits. The geological structure of the basin is composed of three main elements: igneous rocks, sedimentary Cretaceous flysch, and Eocene and Pleistocene strata.

The igneous rocks form the highlands to the south, west and north. Most of them belong to the granite massive which displays a variety of granitic rocks ranging from hyperstendiorite to an acidic granite. The former is particularly prevalent on the western and northern flanks of the basin where the diorite emerges from under the basal strata of the Upper Cretaceous flysch. Just before one enters the Kargil basin, the granite, exposed on the left side of the Suru river, displays its normal petrologic composition. Biotite, oligoclase, quartz, and occasionally amphibole, are its main components, with zircon and apatite as accessory minerals.[4] The structure of this granite is schistose throughout, which is due to recrystallization under stress, as indicated by the linear arrangement of granular mica particles and by the absence of larger quartz grains which have been transformed into smaller aggregates. Dr. Fischer's analysis[5] points to a deformation during and immediately subsequent to the intrusion. The granite is also characterized by an abundance of resorbed schist material especially in its southwestern portion near the confluence of the Suru and Shingo rivers. At Chunagund an aplitic variety dominates and the texture becomes holocrystalline to porphyritic. Aplite and pegmatite veins are cut by a few lamprophyre dikes which have a N 45° E strike. As to the age of this major granite intrusion, it must be pointed out that the Kargil granite is but part of a larger intrusive mass which extends from near Karbu down the Shingo river to the Indus valley some thirty miles north of Kargil. Here Dainelli observed a normal contact between granite and the late Mesozoic flysch formation. The Kargil granite, then, is but an outlier of the Ladak granite which builds the core of the Ladak range north of the Indus valley. The granite is locally rich in resorbed schists which belong to an older formation that crops out as a resistant hillock at the resthouse opposite Kargil (Text-figures 9 and 10). The Pleistocene gravel lies here directly upon amphibolitic schist which has a NW-SE strike. It is probable that the great differentiation of the granitic magma around Kargil is due to the resorption of older schist material. Apart from granodiorite rocks there appears south of the basin near Pashkyum a thick complex of greenstone and serpentine. The latter appears as the continuation of the Dras Volcanics. At Pashkyum the greenstone is greatly shattered and broken up into smaller complexes. At its base lies a phyllite some thirty feet thick below which appears a major thrust plane separating the greenstone complex from the purplish conglomerates and shales that dip beneath the volcanic series.

At first sight these purple conglomerates seem to be part of the upper portion of the great sedimentary formation into which the Kargil basin has been carved. On the southern border the conglomerate forms the last and uppermost layer of this sedimentary complex which overlaps the granitic rocks southwest of Kargil. Its high stratigraphic position in the

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[4] For further description see H. de Terra (1932, p. 191), and Aloisi (1933, p. 33).

[5] In H. de Terra (1932, p. 191).

FIGURE 9. THE KARGIL BASIN AS SEEN FROM ABOVE THE RESTHOUSE TOWARDS SOUTHEAST.

In foreground outcrop of amphibolitic schist. Four of the lower terraces can be seen into which the Suru river is entrenched. In the left background is the opening of the Wakka valley with the flysch sandstone hills of P. 10214 in front.

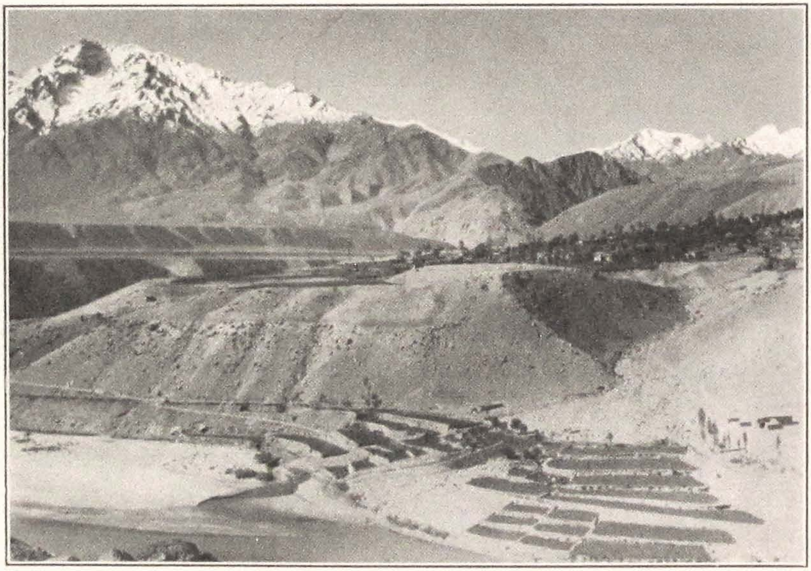

FIGURE 10. THE KARGIL BASIN LOOKING SOUTHWEST FROM THE HILLOCK ABOVE THE RESTHOUSE.

Suru river in foreground with cultivated subrecent fan. Leveled moraine (M4) with coarse boulder weathering out along the slope. Terraces 2-4 in background and ravine of Suru river.

sedimentary sequence is indicated by the peculiar pebble composition. Nummulitic and Triassic limestone, greenstone, purple sandstone, shale, and quartz are the most common constituents. The Nummulitic limestone varies from a light to a dark grey color and is one of the most frequent pebble components. It makes large subangular fragments from one to three inches in size, full of *Nummulites* and *Alveolina*. The fossil content and lithologic character alike make it certain that these pebbles were derived from the Eocene limestone age (Loudovian-Lutetian) which overlies Cretaceous flysch in Ladak.[6] The conglomerate must therefore be post-Middle Eocene in age. Its normal thickness cannot be determined on account of its tectonic contact with the greenstone. Lydekker (1893, p. 47) mentions that it is associated with purple shales and overlain by grey shales and slates. The pebble composition of this layer suggests erosion in a neighboring region where newly uplifted strata of the latest Tethys sea and volcanic rocks had been exposed. It is known that late or post-Eocene uplift, preceded by basic intrusions and by lava flows, occurred extensively in the Himalayas and it is therefore possible that the purple limestone conglomerate also reappears in adjoining regions. In Ladak, such post-Lutetian limestone conglomerates are found in the upper portion of the Eocene as at Skiu in Zanskar from where Lydekker (1883, p. 108 ff.) described a post-Nummulitic sequence with several hundred feet of conglomerates at its base. These beds resemble the Eocene "Laki-series" of the southern Himalayas in Kashmir as described by Wadia (1928, p. 262). I propose to call them the "Skiu-series" from the locality in Ladak where they appear to be perfectly exposed.

The sedimentary break between this horizon and the underlying shale and sandstone formation, is not exposed at Pashkyum, but it should be remembered that the observations are too localized to permit a true recognition of this relationship. Furthermore, the contact may have been altered by later thrust-movements such as at Pashkyum where the thrust was transmitted locally along a bedding plane in the conglomerate (Text-figure 11). A thrust could have flattened an underlying angular contact to such a degree as to lead to local tectonic coördination ("Einregelung" of Sander) between bedding and thrust plane. Tectonically concealed breaks such as these are not uncommon in the Alps where the major thrusting on the southern flank of the central massifs has changed many a stratigraphical break into a plane of major movement. This possibility should, therefore, always be kept in mind, a final judgment being possible only when the contact has been studied over a wider area.

The strata underlying the conglomerate are purple sandstone and shales, both being of a harder consistency in the neighborhood of the thrust than farther north. The sandstone is fine and micaceous, with intercalated shales. The exposures along the Wakka river above Pashkyum show the purple sandstone underlain by purple and green shales with thinner bands of dark carbonaceous shales (Text-figure 11). The former are gypsiferous and very friable, hence the tight local folding which has led to crumpled and fan folds. One mile north of the thrust contact the dip has flattened to 40°. The green shales appear in the lower portion of the purplish sequence and locally contain thin beds of dark limestone, one and a half feet thick. These might either belong to the "*Conulites* limestone" mentioned before, or to the *Nummulites* horizon of Lutetian age. Oldham (1893, p. 341) mentions similar limestones from the Indus valley between Nurla and Kalatze. The thickness of the dominantly purplish sequence between this calcareous layer and the red limestone conglomerate at Pashkyum is at least 1500 feet.

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[6] E. Fossa Mancini (1928).

Shortly below Pashkyum the purple and green shales are followed conformably by a thick sequence of dark grey and green marly and sandy shales. Certain layers are micaceous and others more carbonaceous. The latter contain plant fragments, usually lacerated leaves of *Populus* and *Sabal.* These fossils do not permit stratigraphic dating but it must be mentioned that they do not occur in the fossil flora of pre-Nummulitic age found at Hemis in Ladak.[7] It is evidently from these beds at Pashkyum that Drew (in Lydekker 1883, p. 100) collected *Melania* and *Unio* which are found also in the *Potamides* marl of the Eocene sequence near Jurutse in Ladak. Here the marl is interbedded with sandy plant-bearing shales and seems to underlie the *Nummulites* limestone. The gastropod fauna in the marl of Jurutse is according to Fossa Mancini (1928, p. 227) of lower Eocene, perhaps even Paleocene age. Although the localities are sixty-five miles apart, there is every reason to believe that the two sequences can be correlated on both fossil and petrological grounds. This makes it highly probable that the shale below Pashkyum is of very early Eocene age. Its total thickness is 500-600 feet.

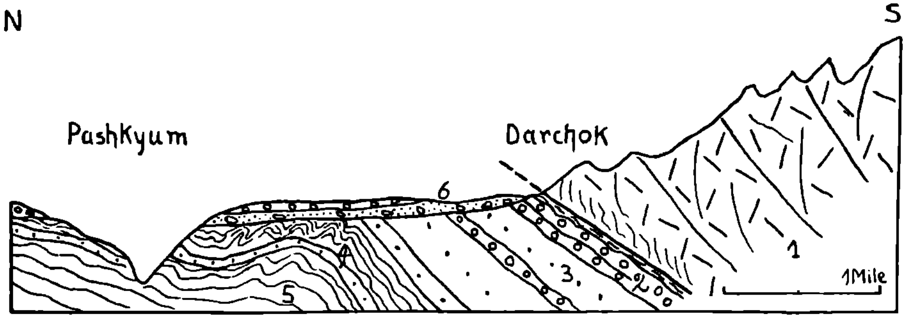

FIGURE 11. SHORT OVERTHRUST OF DRAS VOLCANICS ON POST-EOCENE STRATA AT PASHKYUM.

1 = greenstone, serpentine; 2 = purple limestone conglomerate; 3 = purple sandstone; 4 = purple shale and thinly bedded sandstone; 5 = green shale; 6 = Pleistocene till and gravel.

The apparent absence of the *Nummulites* limestone in this section is probably due to the incompleteness of observations rather than to a stratigraphic break, because a few miles westward from Pashkyum Eocene limestone appears with marl-bearing shales. The outcrop here is, however, too poor to permit recognition of its geological relationships. The stratigraphic position of the *Nummulites* limestone in the formational sequence as indicated on Text-figure 7 must therefore remain uncertain.

Below the shale there appears a yellowish-grey, fine-grained sandstone which after eighty feet changes into greenish-grey sandstone of coarser texture. This sandstone forms the entire ridge towards the Hamboting La and some of the hillocks which surmount the upper terrace of the Kargil basin (Station 10,214 feet). Across the basin the total exposure of

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[7] This information was obtained from Professor R. W. Chaney who very kindly undertook the determination of the Hemis flora.

this sandstone group is two miles and the average angle of dip is 40° SSE. Its thickness must amount at least to 6000 feet. The lithologic facies is clearly that of a delta deposit. Changes from sandy to conglomeratic or shaly layers are common and rather sudden. The pebble layers consist of well-rounded quartz and harder porphyric rocks and of black flint. No Eocene limestone could be detected. The bedding planes in the sandstone show layers of mica and occasionally ochreous plant fragments, mainly rushes. Viewed from a greater distance the outcrops of this group seem more evenly stratified. Greenish-grey colors prevail in the lower portion but there are intercalated many purplish and some red shales. The strike in these beds is N 60-70° E. This sandstone can be correlated with the Indus flysch, particularly with its lower portion such as is exposed on the slopes of the Indus valley in Ladak. Here the age of the sandstone group can definitely be fixed as Upper Cretaceous. I found at the Yaye Tso north of Mahe a calcareous marl which yielded a small marine gastropod fauna of Senonian (?Maestrichtian) age.[8] This fossiliferous layer appears at the base of the sandstone group which here, as near Kargil, is followed by a thick series of dark grey shales, and underlain by coarser conglomeratic beds and arkose. Such being the sequence in the adjoining Indus valley, we should anticipate a similar increase in coarseness in the basal layers of the flysch at Kargil. Here the sandstone not only turns into arkose and finally into coarse basal conglomerates but its grey color is replaced by purplish-red. Both west and east of the town the basal conglomerates are seen to overlap the Kargil granite and its various derivatives. False-bedding indicates fluvial agencies of deposition (Text-figure 12). These basal beds attain a thickness of 500-600 feet. Here the plane of overlap appears rather even, but over greater distances it is very irregular, suggesting some sort of relief at the time when this rock waste accumulated. This old undulating relief can be detected by the irregular occurrence of metamorphic schists, granitic and dioritic rocks which form irregularly shaped patches of subfloor rising from below the basal flysch sandstone. The height of this buried relief must have amounted locally to several hundred feet as is shown southwest of Kargil where a granite ridge some 1100 feet broad emerges from beneath a

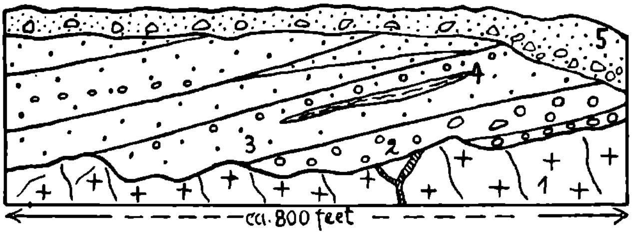

FIGURE 12. OVERLAP OF BASAL FLYSCH BEDS ON GRANITE FLOOR ON THE WESTERN SLOPE OF THE KARGIL BASIN.

1 = biotite granite; 2 = arkose and conglomerate 110′; 3 = grey coarse sandstone 160′; 4 = silt-stone with plant remains 11′; 5 = Pleistocene till (M2).

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[8] Professor C. F. Parona very kindly undertook the determination of this pigmy fauna. He believes that this horizon might be correlated with the *Omphalocyclus* beds of H. Douvillé in Louristan, Persia.

600 feet sequence of arkose and sandstone. In accordance with the depositional nature of this overlap, the basal strata flatten their dip along the contact to 10°. The ravine of the Wakka river south of Kargil follows the plane of overlap for two miles, purplish arkose forming the southern and syenite the northern wall of the ravine. Here the steep slope of the igneous rock almost suggests a fault contact but no sure traces of such abnormal relationship could be found. The last tributary of the Wakka river must originally have followed the flysch contact eastward, for the present river runs only one mile south and about parallel to the flysch boundary. The nature of the basal beds which rest upon crystalline rocks also reflects the ancient geography of this region. A fair number of the pebbles are water-worn but subangular fragments prevail throughout. These are of diorite, granite, aplite, pegmatite, amphibolite, basic dike-rock, and quartz. The feldspar in these rocks is kaolinized and the biotite is rusty. The reddish clay component in the matrix also indicates such weathering agencies are are typical of a humid climate. The fluvial type of bedding and above all the abundance of lacerated plant remains in lenses of shale and sandstone are equally suggestive of a wet climate and rich vegetation in the surrounding highlands. The pebbles are badly assorted and mostly derived from the underlying crystalline rock. There is no indication of glacial origin in any of these basal beds and Lydekker's suggestion (1883, p. 104) that they might have been derived from glacial boulders has no foundation.

Obviously this overlap is an important datum line in the geological history of this region. It indicates that the Kargil granite is of pre-Upper Cretaceous age and that a long denudation of its rock mantle took place before the basal flysch was laid down. The unconformity, therefore, conceals not only a time break but a structural event of importance, for the granite and the crystalline schists associated with it are part of the Tethyan subfloor which was obviously converted into land. Elsewhere (1934a) I have already called attention to a variety of evidence for such diastrophism in the late Mesozoic of the northwest Himalaya and Karakoram. I compared this uplift with the Middle Cretaceous phase of folding in the Alps and pointed out that the Indus flysch can be interpreted as the filling of a foredeep which resulted from the uplift of the Karakoram region. The foregoing discussion tends to confirm this view and widens its application to the northwestern portion of the Himalayas which at that time evidently were but part of the newly uplifted land. After the denudation, renewed sinking set in. It is probable that only the basal portion of the flysch represents continental deposits, whereas the overlying sandstones and shales are of marine or brackish water origin. The great thickness of the dark and purple Eocene shale series signifies deposition in deep, relatively quiet water with occasional sedimentation of fine clastic material.

Earlier observers have noticed the lack of younger Tertiaries in this part of the Himalayas, a fact which is not surprising if one considers the uplift and folding that occurred after the Eocene. The region under consideration must have been a mountainous upland during the time when the late Miocene to Pliocene Murree- and Siwalik formations accumulated on the southern slope of the Himalaya. But the question arises whether the rock waste in the upland was immediately removed by erosion or whether it first accumulated and then was subjected to erosion which owing to the capturing of the longitudinal drainage by transverse streams must have been very effective during Siwalik times. The latter alternative appears to be the more plausible. The adjoining Indus valley doubtless existed during the Tertiary and, as Dainelli (1922) has shown, was connected with the Kargil basin through the Suru valley. The basin at that time, as today, was drained by a tributary of the Indus and this old Indus, during the younger Tertiary, presumably flowed eastward instead of westward (deTerra, 1934, p. 39). This pre-glacial tributary then joined the headwater portion of the Indus river which at that time could not have been as powerful a stream as now, nor as it presumably was during the close of the Tertiary. From such intermontane depressions as the Kargil-Zanskar basins, the quickly accumulating rock waste could hardly have been removed instantly. But once the Indus was converted into a powerful westward-flowing river the tributaries began rapidly to erode the basins, until finally the relief was deepened, the rock waste denuded and the rivers started cutting into the underlying older rocks. This pre-glacial relief at the close of the Tertiary was, as has previously been pointed out, greatly dissected. The drainage pattern was generally established, the glaciers of the following Ice Age utilizing its valleys time after time. These inferences must suffice to fill the gap in the incomplete record of events which followed the deposition of the post-Eocene rocks. Theoretically, the Pleistocene deposits can therefore be expected to rest in a youthful relief of late Tertiary origin. Dainelli (1922) has shown this to be true. Not only did he demonstrate the pre-glacial existence of the deeply incised junction of the Suru and Wakka rivers but he also showed that the basin floor at one time continued into the Wakka valley which rose eastward towards Mulbek, thus indicating the existence of an early Pleistocene Wakka valley. There is, however, widespread evidence for a reshaping of the pre-glacial relief by ice action and this feature invites a more thorough discussion of the Pleistocene history of the Kargil basin.

## THE PLEISTOCENE AT KARGIL

The block diagram (Text-figure 13) indicates that the Kargil basin contains a number of Pleistocene terraces which contrast strangely with the rugged and barren relief of the surrounding mountains. An ancient basin filling made of gravel and sand with intercalated clay layers is seen to occupy most of the river floor between the Suru and Wakka streams. These appear deeply incised and expose the underlying irregular rock floor. The picture suggests a complex record of Pleistocene history and obviously promises to shed light on the problem of the glacial cycles in High Asia. Thanks to Dainelli's (1922) extensive studies we have well substantiated evidence of four mountain glaciations in the Northwest Himalaya. I believe that in this respect my observations confirm Dainelli's ideas in principles. In cases where my views differ from his, as for instance in the interpretation of the Kargil terraces and the nature of the basin filling, the difference may be attributed to better opportunities for observation which I enjoyed around Kargil. When Dainelli travelled through that place in 1914 the landscape was still snowbound and actual rock exposures must have been rare. Later Trinkler (1932) added some valuable information which I was able to confirm on my second journey. Dainelli, however, had a rich fund of experience derived from the adjoining regions, especially from Skardu, and his interpretation of the Kargil Pleistocene therefore deserves careful consideration.

Dainelli's deductions are based on two principal assumptions: firstly, that the ground-moraines at Pashkyum belong to the second glaciation, and secondly, that the overlying gravel filling of the basin is a fluvio-glacial deposit resulting from the third ice-advance. The first assumption appears to be correct, for in the neighboring Wakka valley there are remnants of a composite slope profile which clearly indicate a glacial stage earlier than the groundmoraines at Pashkyum. At Lotsun the upper bench of the composite slope corresponds to the striated rock terrace which I observed above the Wakka ravine near Pashkyum. The terrace is well marked and bears the ruins of an old fort. In the following interglacial period the melt-waters cut into the floor of the first glacial trough and made a gorge which was somewhat remodelled by a glacier of the second ice-advance (Text-figure 14). This latter event is demonstrated by the close correspondence of level between the groundmoraines on striated rock floor at the outlet of the gorge and the base of the lower gravel at its entrance (Text-figure 15).

The groundmoraines at Pashkyum are exposed above the hamlet where they overlie the Eocene formation horizontally. They are 20-30 feet thick and consist of unassorted till with striated boulders. Altimetrically they seem to correspond to a second outcrop of glacial till in the lower Wakka ravine, about half a mile east of its junction with the Suru. In both places the till fills a steeply eroded and partly scoured relief in bed rock. This relief must have been very irregular, and clearly indicates active erosion before the second ice-advance. The first interglacial period was evidently one of intense erosion and river action, to which the earlier relief and its deposits were subjected. This widespread erosion may account for the lack of earlier interglacial or preglacial deposits.

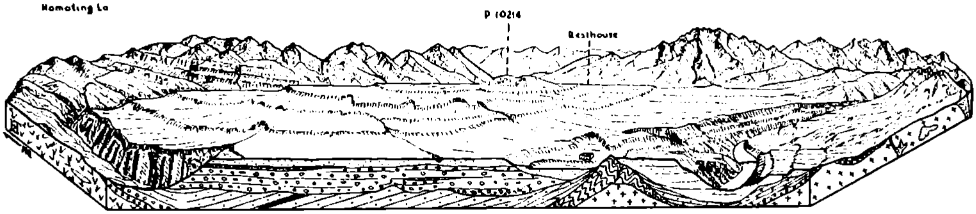

FIGURE 13. BLOCKDIAGRAMMATIC SKETCH OF THE KARGIL BASIN.

For explanation see Figure 7.

A third occurrence of these moraines was found by me a mile due southwest of the Edward bridge at Kargil across the Suru river on the higher slope of a side glen. It is of a very coarse nature with boulders up to six feet in diameter embedded in a somewhat reddish sandy clay, capping the basal conglomerates of the flysch formation. On all these places the till is directly overlain by what Dainelli has called the "fluvio-glacial filling" of the basin which he attributes to the third glaciation. The following observations tend to show that Dainelli's interpretation is altogether too generalized and only partially supported by my stratigraphic studies. The strata overlying the groundmoraines represent a composite sequence of fluvial and lake deposits. Text-figure 15 shows the lower boulder gravel stratified and overlying the bevelled edges of the basal flysch strata. The lower groundmoraine seems to be missing here; it certainly was not clearly exposed, but the flysch sandstone is smoothed by ice, proving a glaciation before the gravel was laid down. Dainelli himself has brought forward extensive evidence of an interglacial period following the second Himalayan ice-advance. The fluviatile nature of the gravel indicates that the ice had become replaced by rivers. The coarseness and the water-worn shape of the pebbles and boulders signify a period of rapid erosion in the surrounding mountains and of rapid filling up in the basin. Such action could only have occurred during a period when normal drainage was reëstablished and the highlands more or less freed from their ice cover. If the boulder gravel represented a fluvio-glacial deposit, one would at least expect to find some striated pebbles and, moreover, nearer the mountains glacial till or morainic boulder should replace the gravel. Evidence for such a relationship was not found.

The boulder gravel which varies in thickness from 80 to 110 feet corresponds, as Dainelli pointed out, to the cemented conglomerate in the upper Wakka and Suru valleys.

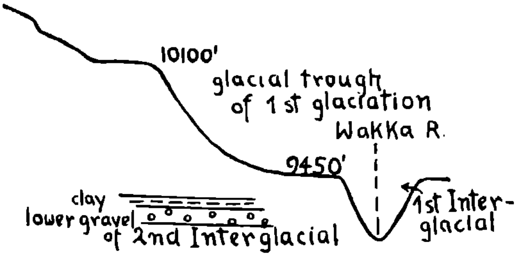

Figure 14. The Early Glacial and Interglacial Records in the Gorge of the Wakka River Between Pashkyum and Lotsun.

Trinkler (1932, p. 58) observed that these conglomerates are striated on their surface and that they are overlain by morainic boulder where the Wakka terrace merges into the upper terrace of the basin. This relationship caused Trinkler to correlate the lower gravel with a period of ice-retreat, or, in other words, with an interglacial which followed the second glaciation of Dainelli and which was ultimately succeeded by another ice-advance. In the Wakka valley, as well as in the basin, the lower gravel is overlain by clay and silt of varying thickness which in Text-figure 15 can be seen to increase towards the center of the basin (ten feet or more). Its nature, especially the regional distribution and fine lamination, points to a lake period during which the waters were ponded, presumably by a choking of the lower outlet in the Suru valley below Kargil. The sedimentary break is so sudden that we must assume a catastrophic event, perhaps a large landslide, which led to a blocking of the melt waters derived from the dissipating glaciers. The lake period consequently also occurred during the second Interglacial.

Furthermore, Text-figure 15 demonstrates that the whitish clay stratum is overlain by a younger gravel. The contact between the deposits is one of disconformity, marked locally by a gravelly boulder bed of obscure origin. But around the edges of the basin, especially at the outlets of the Suru and Wakka rivers, there are morainic boulders and glacial striae on the surface of the cemented conglomerates. The former are missing in the basin, a fact which would indicate that the new ice advance (third of Dainelli) was not so pronounced as the preceding one and that the glaciers presumably did not fill the entire basin. Trinkler (1932, Fig. 19, $S_2$) also came to this conclusion and pictured roughly the succession of events in the Suru valley. From his description it appears that he considered the less consolidated top gravels to be deposits of a glacial recession. An altimetric comparison proves that these cannot be identified with the upper sandy gravel of the basin filling, for the latter directly overlies the second Interglacial, and although they seem to cover its somewhat irregular surface they never appear at a much lower level. Therefore the upper sandy gravel seems to belong to the Third Interglacial. It was on this sandy gravel that Mr. G. E. Hutchinson, biologist of the expedition, collected an artifact of presumably pre-Mousterian make which shows signs of later retouching.[9] This implement was crusted with a ferruginous patina which indicates that it had lain a long time on the surface, and the fact that it was not waterworn, though reworked, makes it probable that it was derived from the upper gravel. This indicates that since that time there was no river on the upper terrace but that the lower terraces were cut into it. If, then, the upper gravel terrace was the habitat of the maker of so ancient a type of implement, it is obvious that the formation of the terrace cannot be younger than the Third Himalayan Interglacial, a confirmation which is tempting enough were it not for the fact that one single artifact does not permit an accurate dating since correlations of Stone Age cultures between Europe and this region cannot as yet be established.

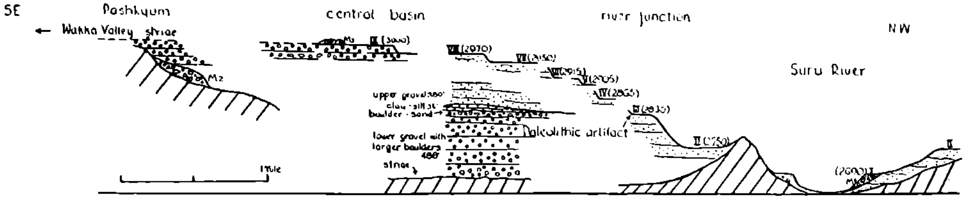

FIGURE 15. THE RECORD OF THE ICE AGE IN THE KARGIL BASIN (COMPOSITE CROSS SECTION).

M2-4 = moraines of the second, third and fourth ice advances. Lower gravel = Second Interglacial; upper gravel = Third Interglacial. Terrace levels are given in meters.

The Suru valley contains, as already mentioned by Trinkler, along the upper third of its slope, a terrace bench which exposes coarse boulders and faintly stratified sand. The nature of this deposit suggests a fluvio-glacial origin, such as might have been brought about by either a receding small valley glacier or by glacial outwash redistributed by melt waters in the vicinity of receding ice. It makes an ancient valley filling and lies 50 miles above the present river bed and some 25 miles below the upper larger terraces. A relief was evidently cut into the latter before this boulder was laid down. The relief-making processes therefore

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[9] See Article I, Memoirs of the Connecticut Academy of Arts and Sciences, Vol. VIII, New Haven, 1934, p. 14. Here it was pointed out that this artifact had undergone a secondary flaking of much later, perhaps late Paleolithic, date.

fall either into the later part of the Third Interglacial or into the last glaciation. Dainelli (1922, p. 225 and Fig. 24) held that the larger terraces, Nos. 1-3, were formed during his fourth glaciation. In view of the fact that there are no signs of ice action within their area it is more likely that the younger boulder gravel in the Suru valley represents glacial outwash of a small glacier belonging to the last period of ice advance.

Subsequent to the last glacial retreat there has evidently occurred intermittent cutting, for the rivers are deeply entrenched into the higher terraces, leaving terraced fans on the outlet of larger tributaries. These lowermost river terraces must therefore be of post-Pleistocene age.

The foregoing discussion of the nature of the basin filling obviously must lead to an interpretation of the terraces quite different from that given by Dainelli. The terraces cannot be lacustrine for the majority represent former levels of erosion which evidently developed in successive stages on the interglacial fluvial gravel filling of the basin. Their erosive origin becomes particularly evident firstly through the winding outline of their respective slopes, and secondly on account of the fact that their slope is occasionally determined by that of the underlying hard rock, either bed rock or cemented lower gravel. The latter feature is probably much more common in nature than the schematic Text-figure 15 indicates where terraces II and IX are seen to abut on the resistant rock which must have checked the swinging motion of the streams as they cut laterally. Terrace IX was evidently an erosion level before the third ice-advance occurred, but it must subsequently have been altered by the ice. Therefore it is distinctly older than the lower ones, as indeed Dainelli pointed out. Terrace I, on the other hand, shows the original level of deposition, which was cut into by the younger Suru river in post-glacial time.

The spacing of the terraces, which is so conspicuous a feature in this landscape, was obviously determined by the increasing ability of the streams to erode. Such intermittent erosive action is to be expected during a period of ice retreat for, at such time, the snow waters become less and less hindered by their load, so that they can renew their cutting activities at certain stages, and are then led successively to lower levels. Processes of this kind are well known in other mountain regions where stages of Pleistocene ice retreat have been connected with terrace making in adjoining basins. The development of these terraces may be taken as indicative of widespread erosion which could have occurred only during the later part of the last Interglacial. From Text-figure 13 it can be seen that the present streams are deeply entrenched and that their courses follow approximately the borders of the basin where the resistant subfloor rises from beneath the flysch formation. This vertical cutting must have preceded the last glacial advance which deposited morainic boulder (M4), in the deeply incised Suru valley. This entrenching of the river system at Kargil probably falls into the late third Interglacial which, as Dainelli has shown, was characterized by mountain uplift in Kashmir and Ladak. The vertical erosion which preceded the last glaciation doubtless was due to this mountain-making event.

The fact that the morainic deposits (Text-figure 13) were cut into by the Suru river clearly indicates that vertical erosion predominated since the last glacial advance. The lower terraces which can be seen along the younger fans should mark intermittent stages of river filling and cutting belonging to late glacial climatic oscillations for which both Norin (1925, p. 194) and Dainelli (1922, 569 ff.) have given evidence.

If we summarize the observations on the glacial geology of the Kargil basin, it becomes clear that they principally support the theory of Dainelli according to which the Himalayas witnessed four glacial and three interglacial periods. The first two ice advances actually reached the basin while the succeeding ones confined their ice tongues to the edge of the basin or to the upper course of the adjoining valleys. The first and the third Interglacial were periods of intense erosion which was due to mountain uplift.

On this occasion it should be noticed that Dainelli compared the four Himalayan periods of valley glaciation with the Mindel-, Riss-, Würm- and Bühl advances in the Alps (1922, p. 635). This geological equation of Pleistocene events tends to throw additional light on the recency of Himalayan mountain uplift for which I shall present more evidence in the following chapters.

## THE STRUCTURE IN THE UPPER WAKKA VALLEY

On leaving the Kargil basin at Pashkyum one enters the belt of the "Dras Volcanics" across which the Wakka river has cut excellent exposures. In the ravine towards Lotsun the greenstone is locally stratified with layers of dense olive-green and laminated slaty material alternating with diabase and chlorite schist. The latter appears to occur more frequently than near Dras, and the diabase also is much more sheared and metamorphosed. The laminated slates are tuffs which seem to occur mainly at the base of the greenstone complex. Frequently along the road one meets with purplish and reddish shales into which the diabase magma has intruded as shown by many inclusions of the shales in diabase or serpentine. The explosive stage at the beginning of the diabase eruptions is amply illustrated by coarse agglomerates near Shargol. Half a mile before one reaches this place, one can study numerous exposures on the right slope of the valley where a shaly greenstone contains large limestone blocks, two feet in diameter, and fragments of phyllite and slate. A microscopic investigation of the greenstone shows that it is derived from a fine tuff in which the limestone blocks lie scattered. These fragments are of two kinds, one is identical with the upper Triassic limestone of the adjoining range to the south, the other belongs to a dark and siliceous rock strongly reminiscent of the Upper Cretaceous limestone of Ladak facies. The Triassic fragments fix the age of the agglomerate as post-Triassic and hence they give additional proof of the post-Paleozoic origin of the "Dras Volcanics." Above the tuff lie augite-porphyrite and serpentine both attaining a thickness of at least 1500 feet.

The stratigraphic position of the "Dras Volcanics" at Shargol is determined by a thick series of multi-colored shales and conglomerates which form the northern slope of the Wakka valley towards Mulbek. This formation is characterized by dark carbonaceous shales some 150 feet thick which are found interbedded with greenish shales and phyllitic slates. Tight folding has caused minute crumpling and sericitization in the shales while some of the carbonaceous layers attain a graphitic aspect. These beds crop out along the lower part of the northern slope with which they share a west-east strike. As one proceeds eastward towards Mulbek the underlying agglomerates disappear beneath the Pleistocene gravel filling, and as the caravan path winds up the dissected mountain front one crosses higher horizons such as gypsiferous purple shales and overlying sandstones. The slopes are covered by a reddish loamy soil from which white salts effloresce, locally forming a hard surface deposit of soda. Above, the gypsiferous layers are followed by sandstone and phyllitic shale of greenish and purple color. The crest of the ridge appears to be formed of greenstone. The entire sequence of variegated shales and sandstones measures at least 600-800 feet. Their dip is 40-60° north. The resemblance between this formation and the lower portion of the Eocene at Pashkyum is most striking. It permits but one conclusion, namely, that the Eocene reappears here eleven miles southeast of the Kargil basin. This fact is of some structural significance, for the contact of the "Dras Volcanics" with the Eocene is a major thrust plane. The thrust contact is exposed on the northern flank of the lower Poka valley between Kutchi and Shargol, from where it crosses the Wakka valley about one-quarter of a mile south of their confluence. From this point eastward the thrust plane seems to continue some two miles north of the valley and crosses the Zanskar range into the Sangeluma valley. In the exposures west of Shargol the "Dras Volcanics" are represented on the thrust contact by chlorite schist and shattered serpentine. Below, the gypsiferous purple shales are tightly squeezed and give rise to a brightly colored banding in zigzag pattern on the slope surface. The grey shales are turned into phyllites and sericitic slates which are crumpled and infiltrated with vein quartz. The main greenstone complex is always restricted to the north of the valley, but in the vicinity east of Shargol some members of the greenstone complex, such as serpentine and chlorite schist, have been tightly folded together with such shales as form the lowest slopes south of the river. The section shown in Text-figure 16, which was taken eight miles upstream at Mulbek, proves that Eocene shales and "Dras Volcanics" are greatly faulted. A limestone rock, some 900 feet thick, rises here abruptly from the valley floor, providing a solid foundation for a picturesque Tibetan monastery called Mulbek-gonpa. In this massive limestone of light grey color were found a number of fragmentary fossils amongst which *Megalodon* is the most common type. The rock therefore is a member of the Upper Triassic which also forms the higher slopes of the great range that rises one and one-half miles to the south of Mulbek. The walls of the rock, polished by Pleistocene ice, are ornamented with the cleanly cut sections of this clam and of single corals. The rock itself is

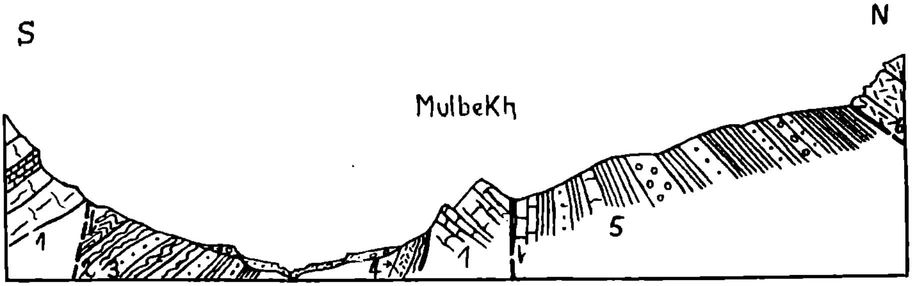

FIGURE 16. STRUCTURE SECTION THROUGH THE UPPER WAKKA VALLEY AT MULBEK.

1 = Triassic limestone; 2 = green schists; 3 = sandstone and shales; 4 = shaly serpentine and chlorite schist; 5 = agglomerates and gypsiferous shales; 6 = greenstone.

partly brecciated and cut by an infinite number of joints and slickensides. Its crystalline structure also indicates the intense strain of deformation to which it was subjected. That faulting and not volcanic action is responsible for this shattered condition is indicated by two faults, one of which borders the southern and the other the northern wall. Here there are slickensides on a large scale, their grooves and striae pointing to vertical movement of the adjoining rocks. The slate, phyllite and serpentine which appear in this section are completely shattered along the contact. The fault planes dip steeply away from the limestone as if the schistose rocks had been compressed from both sides against it. The normal northerly dip of the Eocene becomes vertical and it is only south of the river that the strata regain a flatter inclination.

Further evidence of a major fault along the Wakka river was found at the Namika pass. This section will be described below but it must be mentioned that the Triassic reef limestone is here also faulted against Eocene rocks.

The much crushed appearance of the schistose and shaly members of the Eocene and "Dras Volcanics" is corroborative proof of a fault zone in the upper Wakka valley. This phenomenon cannot be fully understood unless some consideration be given to the structure south of the valley.

Although my field observations are here too imperfect to permit clear insight into the complete sequence of rock formations, the general exposures allow one to recognize the following relationships. A series of partly metamorphosed members of the "Dras Volcanics" and of Eocene rocks dips 40-50° S. At about 1500 feet above the valley floor I noticed a steepening of the dip to 65°. The contact with the Triassic limestone was not observed here. Viewed from the Namika La (12,200 feet) the schists seem to dip beneath the Triassic, but as pointed out below, the contact appears to be rather that of a tilted fault or of a short overthrust. The massive limestones contain only sections of *Megalodon*, but there can be no doubt that they are Upper Triassic since more abundant fossil evidence was obtained from near Bod Karbu (see p. 52).

## PLEISTOCENE AND SUBRECENT FORMATIONS IN THE WAKKA VALLEY

It has already been mentioned that the lower gravel of the Kargil basin continues into the Wakka valley where it forms local remnants along the slopes. Here also it is overlain by fine silt and yellowish clay which may represent the same period of ponding as near Kargil, where it was interpreted as a lake deposit of the Second Interglacial phase. Dainelli (1922, p. 220-221) has shown that the thickness of the lower gravel diminishes gradually as one proceeds upstream from Kargil to Mulbek. In the same manner the overlying clay lake deposits thin out slowly until near Shargol they disappear altogether. From here on one would expect the upper cemented level of the Kargil basin to rest directly on the lower cemented gravel. Trinkler (1932, p. 56) pointed out that the upper looser gravel makes a younger valley filling within the older deposit, such as is illustrated by Text-figure 17. The lower gravel is coarse and contains fragments up to ten inches in diameter, most of which are waterworn. The angular fragments are derived from slates and greenstones which lend themselves easily to disintegration. The matrix is sandy and locally loamy. There is not a pebble whose origin could not be traced to the native rocks. This short description may suffice to show that this older deposit is not a fanglomerate as Trinkler maintained, but that it is rather of fluvial origin and the lack of glaciated or faceted pebbles clearly indicates its non-glacial nature. It must however at one time have been under ice cover as local occurrences of glacial striae on the higher terraces indicate. It was subsequently cut into by a stream which deposited the loose gravel after the valley glacier had receded. The Pleistocene near Mulbeck reflects, therefore, the main stages of Pleistocene history for which the Kargil basin has furnished a more complete evidence: it represents two interglacial periods which I am inclined to relate to the second and third period of ice retreat.

It is true that there are no distinct traces of a later glaciation in this part of the Wakka valley, but there may be good reasons which account for their absence. The Survey map shows that only one of the southern tributaries carries a short valley glacier which is about two miles long. The last twenty-five miles of the upper course of the Wakka stream are also devoid of any recent glaciation. This scantiness of glaciers contrasts markedly with the rich glaciation found in the headwaters of the neighboring Sangeluma valley and there is every reason to believe that similar differences in the degree of glaciation existed during the Pleistocene. If the Pleistocene glacier advanced after the loose gravel had been laid down it is most probable that it never reached the region at Mulbek but that it confined itself to the upper twenty-five miles of the headwater region. The middle and lower course of the Wakka valley therefore never contained any glaciers during the later Pleistocene. In this respect its history recalls the case of the Suru valley near Kargil where traces of a later ice advance point to a limited valley glaciation which never reached the Kargil basin. This last and rather feeble glaciation may have been responsible for the deposition of coarse boulder-bearing gravel which one occasionally finds above the upper gravel. Such single boulders occur three-quarters of a mile upstream from Mulbek where they lie scattered on the second lowest of the terraces. The lowermost of the terraces must be of post-glacial origin and should correspond to one of the lower benches found along the terraced fans of the Suru tributaries near Kargil.

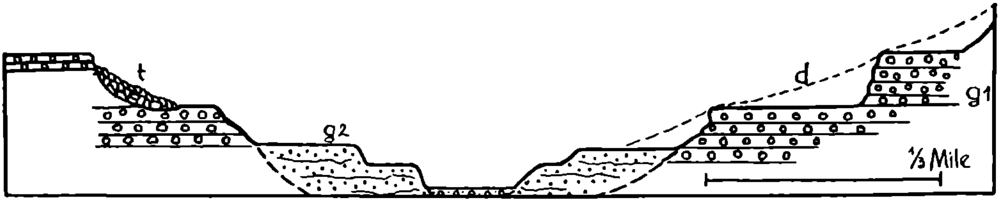

FIGURE 17. PLEISTOCENE AND SUBRECENT FORMATIONS IN THE UPPER WAKKA VALLEY.
gl = coarse cemented gravel; g2 = loose gravel; t = talus cone; d = delta deposit of tributary stream.

The alluvium of the Wakka valley at Mulbek presents some striking features which owing to their frequency elsewhere deserve brief discussion. On both slopes, particularly on the southern flank, there occur large fans and talus cones which frequently alternate with each other. Dainelli (1922, Tav. 78, Fig. 2; Tav. 79, Fig. 1) has figured some of these in his recent publication. The former are restricted to the outlets of side streams and it can be readily seen that the fans are disproportionately large for the volume of water which today, during the seasonal melting, discharges into the main river. Frequently the fan is without any stream, yet its waterworn pebbles clearly bear witness of former stream deposition. The relation of these fans to the higher Pleistocene terraces, as illustrated on Text-figure 17, indicates that they could only have been deposited at a period of stream aggradation subsequent to the formation of the lower gravel and consequently following the third ice advance the larger fans are cut into by a set of terraces which, owing to their low position, must either be late Pleistocene or post-glacial (Text-figure 17). Their relation to the upper gravel is unknown but it looks as if they would merge into each other. The fans, of which some have meanwhile been dissected by streams, are presumably deposits of the last Interglacial for they clearly represent a time of rapid filling of the valley which was the period of the waning third ice cover. The formation of talus cones is due to quite different agencies. On closer inspection they were found to consist of disintegrated broken-up pebbles derived from the lower gravel. This cemented older valley filling gives rise to the formation of steep cliffs in front of which talus rapidly accumulates. The prevailing angularity of its pebble components and the irregular shape of the cones suggest their having been deposited under climatic conditions such as at present give rise to the peculiar block- or coarse landslide deposits in western Tibet. Their formation is mainly determined by frost-weathering, nivation, insolation, and temporary saturation with melt-water. Their appearance in the Wakka valley at 11,000 feet clearly reflects the weathering agencies of the present semi-arid alpine type of climate.

## ACROSS THE ZANSKAR RANGE TO THE INDUS VALLEY

From Mulbek eastward the caravan path follows a tributary of the upper Wakka river. The valley which leads to the Namika pass was completely dry during May and September, but intermittent rivulets have trenched the slopes sufficiently to give the relief a rather youthful appearance. Along the steep slopes are exposed gypsum-bearing shales of the Eocene series (Text-figure 18). These form strongly compressed, recumbent folds, their axial planes dipping about 40° N but gaining in steepness towards the pass. Here green ochreous slates and marl-bearing phyllites strike N 77° E with 78° S or SW dip. An isolated cliff of Triassic rock rises like a watchtower about one mile south of the Namika pass. It is bordered by steeply dipping faults which have given rise to considerable slickensiding along the limestone walls. This structure recalls the situation at Mulbek and it is tempting to interpret such isolated occurrences of Triassic limestone as downfaulted portions of the adjoining Triassic sequence. Be that as it may, the Triassic at the Namika pass is in itself proof of the eastern continuation of the Wakka fault. The structure of the adjoining rocks also indicates intense tectonic strain. The strong compression makes recognition of the normal stratigraphic sequence very difficult. Locally there appear thin layers of grey silicified limestone which are distinctly different from either the Triassic or Eocene rocks. The path follows in the strike of these formations until the junction with the Sangeluma valley is reached. Here, at the hamlet Kangral, the phyllite and green slates are overlain to the north by a thick complex of greenstone and purple shale. In these one recognizes instantly the "Dras Volcanics" and their sedimentary associates. The augite-porphyrite from

Shargol reappears and so do the banded tuffaceous slates. The contact between the shale and the volcanic series is conspicuously apparent on the right side of the valley where purple shales dip 50° beneath the greenstone. There can be little doubt that the greenstone of Dras and Kargil continues from Shargol eastward to Dachi for about eleven miles.[10] From here on downstream via Chiklitan (Chiktan) the section was studied by Dainelli (1922, p. 228) who mentions that the Eocene and the flysch formation which prevail between Talmadu and Chiktan are followed by greenstones. Farther downstream the flysch rests on the granite of the Ladak range. Hence it appears that the section along the lower Sangeluma river exposes the same type of structure as the Wakka stream does eighteen miles to the west.

FIGURE 18. VIEW FROM CARAVAN PATH WEST OF NAMIKA LA INTO THE UPPER WAKKA VALLEY.

Gentle slopes in foreground Eocene shales and agglomerate series. Range in background shows the southward-dipping Triassic limestone.

The greenstone and underlying purple shales strike across the valley and then continue on its northeastern slope. Similarly a Triassic limestone ridge bends towards the southeast and from here on accompanies the caravan path on the left side of the valley. The map clearly shows this bend in the strike which reëstablishes the prevailing NW-SE trend of the formations. Upstream at Bod Karbu the slope of the limestone range borders the path.

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[10] See Hayden's (1908) geological map where the "Tertiary trap" is seen to form a similar belt north of Mulbek ("The Geology of the Himalaya Mountains," etc., Calcutta, 1908).

About half a mile north of the latter place a coral fauna was found in loose limestone blocks which had tumbled from the precipitous rocks above. The following genera are represented: *Thecosmilia, Rhabdophyllia*, and *Lovcenipora*. The last is a guide fossil for the upper Triassic of the Karakoram and other Tethys regions in Europe and in the Malay Archipelago.[11] The mountain slope is here covered with coarse limestone breccia in which two types of rock, a dark and a light greyish limestone, occur. This breccia is somewhat schistose and the rock fragments are occasionally compressed. The limestone walls above consist of dark grey bedded rock overlain by some 2500 feet of light yellowish-weathering limestone and dolomite. Here as elsewhere near Dras the Triassic makes the highest and steepest range which can clearly be seen to continue from Bod Karbu southeast toward the group of towering snow-covered peaks. The fragments contained in the breccia therefore are all derived from the range above and their position at the foot of the cliffs excludes their being of the same age as the Triassic rock. The breccia could not be a schistose coral reef detritus for it was nowhere observed to replace any of the upper Triassic strata. The total lack of sandy components or of proper stratification makes it very improbable that they represent such detritus as might have accumulated on the slope of an uplifted mass of rock. On the other hand, their distribution along the contact with the Eocene and volcanic series points to a tectonic origin. There is a variety of other evidence in support of this view. On the right bank of the river, just opposite Bod Karbu, upper Triassic limestones dip 80° NE. Hardly 800 feet, or less than one-third of the normal thickness of the upper Triassic, is represented in this section. On the slope the limestone is abruptly overlain by purple and green shale and greenstone representing the "Dras Volcanics." Downhill, across the river, the limestone is bordered by phyllitic shale and calcareous slate which appear to underlie the reef limestone on the left valley flank. The coral limestone is brecciated and slickensided, and faulted against the purple shale. The fault plane must be rather flat as it is little inclined towards the valley floor. The low angle thrust contrasts remarkably with the perpendicular dip of the Triassic and makes one suspect that the steep dip of the latter is due to normal faulting which preceded the thrust movement. The structure on both flanks of the valley warrants the assumption that there is a normal fault along the river, which caused the drop of the major portion of the reef limestone towards the northeast. This relationship recalls the structure near Mulbek where the Dras thrust has moved the greenstone complex over Eocene shale while the Triassic has been downfaulted some two miles southwest of the thrust contact. Here at Bod Karbu it becomes evident that the purple shales are part of the thrusted volcanic sequence which was moved over faulted Triassic limestone.

As one follows the valley upstream, one passes numerous outcrops of dark grey coral reef limestone which is greatly folded with phyllites and sericite slates. These rocks continue in a WNW-ESE strike towards the Fotu La (13,432 feet), and as one crosses the strike obliquely the Eocene purplish shales and green schists of the Mulbek section reappear. These dip 60-80° NE and are intensely crumpled. Infolded with these shales appear dark grey oolite limestone with foraminifera.[12] A limestone bearing foraminifera in such quantities is unknown in the Triassic rocks of Kashmir facies and hence these limestones should be referred either to the Upper Cretaceous or the Eocene. Their petrologic resemblance to

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[11] This information and the preliminary identification of the fossils was received from Professor H. Gerth in Amsterdam to whom the author is greatly obliged for his coöperation.

[12] H. de Terra, 1932, p. 185.

the Upper Cretaceous in the neighboring Indus valley is very close indeed, particularly the dark cherty variety which recalls the Upper Senonian *Hippurites* limestones near Kalatse (Parona, 1928, p. 112). The association with purple shales also suggests that Upper Cretaceous to Lower Eocene formations are represented in this section. This view contrasts with interpretations that have previously been given by Stolitzka and Lydekker (1883, p. 165, and Hayden, 1908). The latter recognized that the Fotu La rocks resemble the lower "Indus Tertiaries" but was evidently misled by Stolitzka who saw in them younger Paleozoic formations. Stolitzka had probably noticed that these series dip towards the Triassic limestone range in the southwest but his hurried traverse had not allowed him to study the fault contact of the two series at Mulbek and Bod Karbu. The finding of an ill-preserved fossil, which Stolitzka took for a trilobite, must have strengthened his belief in the Paleozoic age of the slaty sequence. The association of this limestone with purple shale makes it almost certain that these rocks belong to the Indus flysch series of Ladak. Half a mile south of the pass Triassic reef limestone rises abruptly above the softer shales. The contact was not observed and the formations that occur over this distance are not known. It is possible that Paleozoic rocks underlie the limestone range but it seems rather improbable that this narrow exposure should contain sufficient space for the entire Triassic sequence, not to speak of the younger Paleozoic.

The Pleistocene of the Sangeluma valley is almost identical with that of the upper Wakka in that two kinds of terrace gravels occur, of which the lower is thicker and more cemented than the upper. As in the Kargil basin the lower gravel contains in its upper portion a clay stratum, thirty-two feet thick, which indicates that the ponding of glacial waters during the second Interglacial was of regional extent. The high position of this ancient valley filling between Bod Karbu and the Fotu La and the 400-feet thickness of cemented gravel indicate rapid filling of the depression and its tributaries. This aggradation must have followed the second glacial advance. Trinkler (1932, p. 56) interpreted these gravels as fanglomerates but here, as at Mulbek, the subangular shape of the pebbles, the clay matrix, and the stratification of the entire deposit rather indicate fluvial deposition. These deposits resemble to such a degree the pseudo-glacial talus found on the Tibetan highland, that these valley fillings easily may have originated from snow mud-flows, which were later reworked by river action. This type of sediment is in fact restricted to the plateau region of Tibet so that it may be taken as an indicator soil for an alpine subarctic climate and it is obvious that such a colder climate existed during the Pleistocene in the NW-Himalaya.

In the absence of morphological evidence, Dainelli concluded that this valley had never been glaciated. The regional extent of the second ice-advance, however, makes such an assumption rather improbable, and moreover erosion could have in post-glacial time erased the traces of the preceding glaciation. Dainelli himself states that the slates and phyllites connected with the Eocene series lend themselves to rapid weathering which leads to very fast evolution of a mature relief. Such a process adequately accounts for the lack of glacial features common elsewhere.

The slate and schistose limestone series continue with a N 40-50° W strike towards Lamayuru. The dark slates are somewhat sericitic and often contain indistinct ochreous plant remains which are frequently drawn out in the plane of schistosity. These shales resemble the "schistes lustrés" of the western Alps both in respect of their lithology and thickness. No fossil that would indicate their age could, however, be found. Their mode of weathering, and particularly the efflorescence of white salts, make me believe that they are identical with the Eocene shale of the upper Wakka valley.

At Lamayuru these shales appear to overlie the greenstone and chlorite schist of the "Dras Volcanics." The mountain slope on which the picturesque lamasery is built exposes these dark slates and grey thin-bedded limestones, metamorphosed into slaty crystalline rocks. The contact of this formation with the wide belt of greenstone and flysch strata of the Indus region is here largely concealed by a thick filling of Pleistocene lake deposits. The much sheared and contorted condition of the limestone-bearing slates and the confused structure seem to indicate that the contact is determined by a major dislocation. No exposure which gave conclusive evidence on this point was studied. A quarter of a mile east of Lamayuru bright green jasper-bearing tuffaceous slates emerge from beneath the dark schists. Eastward and almost at the entrance of the Hangru river gorge dark slaty breccias or agglomerates appear which resemble those of the "Dras Volcanics." These strata merge into green fine sandstone and finally into a thick complex of tuffite, sandstone and shale of dominantly green, but also of purple and reddish color. As one descends through the sinister gorge towards the Indus valley one has ocasion to observe the intense folding in this complex. The structure clearly varies with the competency of the rocks. The purple and dark grey colored shales, being the competent layers, lend themselves to composite folds of different types, such as isoclinal-, chevron-, and fan-folds. The green sandstone and tuffite, on the other hand, display simple asymmetric folds. This variety of structure makes it quite impossible to estimate the thickness of the formation, especially as the difficult passage through the gorge forbids any detailed observation. The exposed thickness of this zone is five miles measured along the flank of the valley from the entrance of the upper gorge below Lamayuru downstream to a place 300 feet below the bridge at Hangru. In this zone the northern two miles are entirely composed of greenstones, tuffites and fine-grained volcanic breccias with a general N 80° W strike. Here the more simple folding permits one to estimate the thickness of the volcanic series as at least 6000 feet.

Petrologic investigations of the green volcanic and clastic rocks show that the entire complex was somewhat metamorphosed in the epizone with formation of chlorite, epidote, sericite and carbonates. This re-mineralization within the incompetent strata took place without having been much influenced by differential movements in the rock fabric. However, the shales and thinner units suffered from slipping and crumpling movements which were greatly facilitated by the formation of chlorite and sericite aggregates. The greenstone in this section is a massive or coarsely bedded rock of green color in which fine granular mineral aggregates become visible (de Terra, 1932, p. 187). The felsitic ground mass contains sharp angular fragments of porphric rocks which consist mainly of mid-basic plagioclase, titanite, augite, and a few rounded fused quartz grains. Its origin is either that of a fine volcanic breccia or of a tuffite. These greenstones include fine banded jasper-bearing greenish slates, consisting of very fine aggregates of augite and felsite which are clearly fine volcanic ashes, deposited in a quiet aqueous medium on top of the coarser breccia. Locally the greenstone attains the character of greywacke with quartz, feldspar and augite as dominant constituents.

Below Hangru greenstone and chlorite schists are seen to form an anticline in the core of which grey cherty limestone appears. The latter weathers out from the softer volcanic rocks and makes a conspicuous ridge which can be followed for miles along the southern flank of the Indus valley. This limestone is 180 feet thick and it resembles in every respect the *Radiolites* limestone of Balukar in the Indus valley, exposed about five miles eastward from the outlet of the Hangru gorge (Parona, 1928, p. 111). This limestone dips steeply northeast and at the outlet of the gorge is abruptly followed by a layer of coarse conglomerate. This rock is composed of well rounded pebbles of greenstone, schist, amphibolite, grey cherty limestone, granite, and quartz porphyrite. Some of these pebbles are from six to eight inches in diameter but most usually measure two or three inches. Such a composition indicates a denudation process which followed deposition of the Senonian *Radiolites* limestone, affecting both the granite of the neighboring Ladak range and the "Dras Volcanics" south of it. On the southern flank of the Indus valley the Cretaceous limestone is underlain by green and purplish colored shales and overlain by greenstone, above which lie the conglomerates of the Hangru gorge.

From this relationship it may be concluded that the main portion of the "Dras Volcanics" is younger than Senonian (Maestrichtian, according to Parona's report). The volcanic activity evidently took place during the marine submergence at the close of the Cretaceous or during the earliest Eocene period. Presumably it was a submarine eruption of predominantly middle basic magma which led to thick accumulation of explosive products such as agglomerates, tuffites and shales. Most of the detrital material was reworked and mixed with very fine clastic sediment which was swept in from the crystalline highlands in the north. Since the Eocene marls and *Nummulites* limestones appear to be uninfluenced by this volcanic action, it is evident that the volcanic phase could not have continued into the Middle Eocene. From a subsequent description of the Upper Cretaceous in the Indus valley, it will be seen that the first eruptions preceded the deposition of the Senonian *Radiolites* limestone so that it is possible to trace the origin of the "Dras Volcanics" back into at least the first part of the Upper Cretaceous. These first eruptions caused rather thin outflows of lava over marine sediments, whereas during the later period volcanicity must have proceeded on a much grander scale, as the thickness of the "Dras Volcanics" implies.

# III. GENERAL OBSERVATIONS UPON SALIENT GEOLOGICAL FEATURES

## PALEOZOIC STRUCTURES OF THE TETHYAN SUBFLOOR

In so far as one can judge from the foregoing observations, there are revealed in the geological section under discussion several major time periods and rock units, each having a history of its own. In the lower Sind valley there is a metamorphic complex of phyllites, slates and greywacke which obviously antedates all of the known younger Paleozoic rocks. Its slaty members, inasmuch as they resemble the Middle Cambrian of Handawara,[13] must be of marine origin. The greywacke and phyllites contain thin bands of yellowish limestone which resemble the Silurian rocks of the Lidar valley section as described by Middlemiss (1910, p. 215). This Cambro-Silurian complex evidently is largely a marine deposit which must have accumulated in a fairly stable trough of long duration, as is implied by the great thickness and the time range of formations. A study of a geological map of India reveals that this belt of older rocks continues southeastward into the Spiti district, thus forming a long, NW-SE-striking belt of old Paleozoic strata. The general agreement of strike between the fold axis and the outlines of this zone suggests perhaps that the Cambro-Silurian geosyncline once extended in a direction similar to that of the present mountain ranges. Hence it appears that the present strike of these older formations is of very ancient origin which presumably antedates all subsequent structures. Of this the cleavage and tight folding give ample evidence. The slates generally show flow cleavage with superimposed fracture cleavage, the strike of which makes an acute angle with the general NE-SE strike of the entire complex. The few measurements of strike are insufficient to throw more light on this structural discordance but it is quite obvious that the compression of these rocks was a differential one in which at least two deformations were involved. Bion's (1928, Pl. VII) studies tend to show that the Cambro-Silurian rocks are unconformably overlain by Muth quartzite which presumably is of late Silurian and Devonian age. On the other hand, the thrust movement of the younger Paleozoic rocks suggests that the sudden overlap of Panjal trap over the older slates may in part be due to the southward advance of the thrust mass. Whatever their relationship today, the thinness of the Muth quartzite and its petrology contrast so remarkably with the thick Cambro-Silurian schists that only an effective upheaval and a subsequent shallowing of the old Paleozoic geosyncline can account for its deposition. Hence it is highly probable that this region underwent folding during Silurian or late Ordovician time.

In the Lower Carboniferous the region once more became submerged, and about 500 feet of *Syringothyris* limestone was deposited (Text-figure 7). Then followed a period of great crustal unrest. The granites and their associated metamorphic rocks very likely originated after the limestone had been deposited. The basal slates of the agglomerate slate series contain pebbles of granite and pegmatite (Bion, 1928, p. 4), and hence it is reasonable to assume that the granite of Margund is a Middle or Upper Carboniferous intrusion. The outlier of the Ladak granite between Kargil and the Indus river should be of similar age. In a previous publication of mine (1932, pp. 113-114) I discussed the evidence for the pre-Mesozoic origin of the main granite massifs. The relation of the Kargil granite outlier to the flysch shows that the intrusion was at least pre-Upper Cretaceous. Mesozoic granites in

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[13] T. Kobayashi, "Middle Cambrian Fossils from Kashmir," Amer. Jour. Sci., vol. 27, 1934, pp. 295-302.

the northwest Himalaya are unknown and it therefore seems reasonable to conclude that with the exception of minor occurrences of granite at Dras and possibly in the Zoji La region, they are of post-Lower Carboniferous and pre-Permian date. In a recent publication Auden (1933) has presented evidence for the Carboniferous age of the granites in the Central Himalaya, from which it appears that such intrusions belong to the Tethyan subfloor and are therefore unconnected with the post-Paleozoic folding.

The crystalline schists and other igneous rocks which appear near Kargil in association with granite should therefore be considered as part of the older Paleozoic structure. Bion recognized the overlap of the Agglomerate slate series over *Syringothyris* limestone and as the *Fenestella* shales appear to be contemporaneous with the lower volcanic slates it is evident that this folding was of pre-Moscovian date. The Himalaya then shares with the rest of the earth this record of world-wide mountain-building during the Carboniferous. (Asturian phase of Stille). Evidences for this folding can also be found in the neighboring Karakoram and K'un-lun mountains (de Terra, 1932, pp. 80-81, 114) and in the Salt Range to the south. This mountain-making must have welded the Indian Gondwana mass to the enlarged Angara mass lying to the north, in what is now Central Asia. With this view in mind, it becomes clear that the origin of the Tethys sea followed this folding and that the Tethyan geosyncline, here as well as in Alpine Europe, marks the disintegration of a previous land mass for which Born (1933), by analogy with European structures, has employed the term "Meso-Eurasia." This connection of previously separated land masses broke down in Permian time. Whether it was this event or the preceding folding which led to the vast eruptions of the Panjal andesitic rocks and tuffs, we do not know. Volcanism continued over a long period for the trap sheets and sills appear both below and above the *Gangamopteris* series of Kashmir. If any folding took place contemporaneously with the eruptions, its records are hidden under the great thickness of volcanic rocks.

The Permian strata at Sonamarg are sheared against trap and therefore one feels hesitant in accepting Bion's (1928, p. 13) idea that the Panjal trap normally underlies here the ?Middle Permian rocks. The Kashmir valley sections prove that at that time general subsidence began, so that at the close of the Paleozoic the region under discussion was once more submerged under the sea. The fact that no Permian strata occur in the northeastern portion of the section has a definite bearing on the structure and can only be understood after due consideration has been given to the progressive sinking of the Tethyan geosyncline in Mesozoic times.

## TRIASSIC SINKING AND CRETACEOUS EMERGENCE

The Permian apparently is conformably overlain by the Triassic shale and limestone series. Whereas its lower beds still contain a great deal of sandy and micaceous shales, the Middle Triassic or "Muschelkalk" is for its greatest part devoid of land detritus. In the uppermost portion only, at about the base of the massive Upper Triassic limestone, there appear quartzitic layers of unknown thickness which may correspond to the arenaceous *Ptychites* horizon of the Triassic in Kashmir. The sandy shales and limestones in this portion stand out as a foreign element from the otherwise limy or dolomitic sequence of the Triassic, which induces one to believe that this change of sedimentation was brought about by alterations in the border of, or within, the geosyncline. Evidence for an unconformable contact between Muschelkalk and Upper Triassic is wanting, but south of the Himalaya, in the Salt Range, there appears a great hiatus, with the Middle Triassic directly overlain by Cretaceous beds. This break has been taken as a sure sign of a general regression of the Triassic sea from the Salt Range area and it is this event which seems to be reflected in the sandy layers of the late Middle Triassic in Kashmir. Here, however, the tendency to crustal yielding was so dominant that during the subsequent period basining progressed rapidly. The great thickness of the Upper Triassic coral-reef limestone and dolomite appears to be normal for the Tethyan sequence and indicates its progressive sinking. This movement may have continued into the Jurassic but, as previously pointed out, very little is as yet known of strata belonging to this period.

To the Upper Cretaceous must belong in part the very thick pile of detrital sediments which appear in the vicinity of Kargil. The exposed unconformity with the Paleozoic igneous and metamorphic rocks on the one hand, and the total lack of any normal contact or sedimentary relation to the Triassic formations on the other, are outstanding features. The former implies a reversion from subsidence and sedimentation to uplift and denudation. The fact that hardly any of the flysch pebbles are derived from the Triassic would indicate that the recent formational boundaries between the flysch and the Triassic cannot reflect their original contacts. Considering that the Paleozoic rocks must have been greatly submerged below the Triassic sea, the denudation preceding the deposition of the basal flysch beds must have been enormous. In fact it is impossible to imagine such an event without taking into account extensive uplift of the Tethyan rocks so far deposited and a very effective erosion which levelled the newly folded strata down to the subfloor of the geosyncline. This denudation clearly was restricted to anticlinal ridges in which one may see the forerunners of recent anticlinoria. It is obvious that events such as these must have required a long period of time and one stage of the Upper or Middle Cretaceous could have hardly been sufficient to bring about such profound changes. As Lower Cretaceous and Jurassic formations were not observed, it is impossible to say when these intra-Mesozoic movements began, but it should be recalled that Middlemiss (1896) found evidence for Jurassic folding in the neighboring Hazara district. Besides, we know from the Alpine region in Europe that the so-called "Tertiary folding" must in reality have been a long process of intermittent yet progressive crustal deformation which can be traced far back into the Mesozoic and presumably even into the younger Paleozoic. Due consideration should therefore be given to the considerable antiquity of Himalayan mountain-making. Its influence upon the Tethyan sedimentation should be found in the facies differentiation of the rocks.

The Indus flysch fulfills all the requirements of a foredeep deposit. The coarse basal conglomerate indicates the steepness of the former mountain slope. The sandy-shaly character of its plant-bearing beds and the extraordinary thickness of the flysch implies constant basining with filling and widening of the trough, until the time when marine calcareous deposits were laid down. The intimate blend of these basin sediments with basic igneous rocks as revealed by the "Dras Volcanics" is in accordance with the conception of foredeep formation in the mountain belts of Europe and North America.[14] Important inferences as to the structure of orogenic belts have been drawn from this close association of

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[14] The Jurassic and Tertiary ophiolites of the Alps are directly to be compared with the "Dras Volcanics" as Aloisi (1933) pointed out. In the central Appalachians the Wissahickon schists of the Algonkian Glenarm series and the greenstones in the Franciscan formation of the Pacific coast ranges are similar illustrations.

"ophiolites" or greenstones with the strata of geosynclines. Ed. Suess interpreted them as abyssal magma which was intruded during the first stages of folding. This view is greatly supported by Staub's analysis of Alpine structures, particularly by the contemporaneousness of the Jurassic orogeny and ophiolitic intrusions. The Himalayan ophiolites or "Dras Volcanics" appear for the first time in the Upper Cretaceous but the fact that the flysch sandstone is largely derived from rock waste of green basic rocks points to an earlier existence of freshly exposed lava flows. This makes it highly probable that the initial eruptions of porphyrite and andesite were contemporaneous with the Middle Cretaceous folding. The obvious connection between the thrusts and the greenstone belt should, however, be considered as a different phenomenon which manifested itself long after the flysch had been laid down. The fact that this intrusion of basic magma into the geosyncline lasted into the Eocene indicates that this event was not restricted to an orogenic phase but that it continued all through the basining stage of the flysch period. Bucher (1934, pp. 268-273) in discussing this same problem, contended that the upwelling of basic magma in mobile belts results from tension in a subcrustal mobile region which is equivalent to the tensional force acting in the resisting upper crust. The example of the "Dras Volcanics" will satisfy both views inasmuch as the magma appears to have originated during an early phase of geosynclinal compression subsequent to which the lava welled up over a wider area during the tensional phase of foredeep basining.

This idea permits another inference as to the general structure of the northwest Himalaya. Ophiolites tend to occur in association either with deep water deposits or with such strata as accumulated rapidly in sinking belts, and in almost every case they mark the axis of greatest basining in the geosyncline. Their present location, then, would approximately coincide with the region of greatest subsidence, provided that no great thrust movements had considerably displaced them. As subsequent discussion will show, the structures on the southern flank of the Karakoram do not permit the assumption that the "Dras Volcanics" have been displaced very far from their original position.

The geophysical data, as computed on Chart 7 of the Geodetic Report 8 (1933) of the Survey of India, characterize this particular region as one of high position gravity anomalies. Their distribution coincides rather closely with the belt of "Dras Volcanics" which in parts consists of igneous rocks of high specific gravity such as gabbro and magnetite-bearing peridotite. This relationship illustrates how locally the Himalayan region, like peninsular India, follows the law cited in Glennie's (1932, p. 9) recent study, according to which the anomalies are positive over igneous and negative over sedimentary rocks. The fact that large portions of the northwest Himalaya are made up of either Paleozoic or Mesozoic to Tertiary basic igneous rocks should be considered as a factor which contributes to the general positive anomaly of the northwest Himalaya.

## THE EOCENE MARINE REGRESSION, SUBSEQUENT FOLDING, AND RESULTING STRUCTURES

Judging from the exposures of flysch in the Kargil basin, it seems probable that the Eocene plant-bearing shales and marine marls lie conformably on the Upper Cretaceous. In the adjoining Karakoram mountains and in the plateau region of western Tibet, however, there is an angular unconformity between *Hippurites* limestones and continental Tertiaries which indicates general uplift of the northern area in late Cretaceous time. Possibly it was this emergence which caused deposition of limestone conglomerates such as appear at the outlet of the Hangru gorge near Kalatse. Here the contact of the conglomerate is faulted and the proper relationships are therefore unknown. If there were any break in the sequence, one would suspect it to be a disconformity as the early Eocene continues the shaly facies of the flysch. This contrast in the character of the boundary of the Cretaceous Eocene between the Himalayan and Karakoram regions is highly significant for it shows that the northern region emerged from the Tethyan waters while the southern region continued its marine history. Fossa Mancini (1928, pp. 236-237), commenting on the lithology of the *Nummulites* limestone and *Potamides* marls of Ladak, pointed out that this Eocene sea must have been a very shallow body of water in which estuarine conditions temporarily led to the evolution of brackish-water life. This same picture holds good for part of the sandstone flysch in Ladak and it would thus appear that the thick mass of over 10,000 feet of sediment accumulated between the Upper Cretaceous and the Middle Eocene required a steadily sinking crust. In view of the fact that this same region had previously undergone considerable sinking during the early Mesozoic and that this sinking continued into the early Tertiary, it is remarkable that in spite of intervening phases of folding the Indus basin should have resumed crustal yielding even in modern times (p. 67).

The folding which followed this relatively quiet period resulted in a total change of Himalayan geography. Evidence of this folding is given by the total lack of any marine post-Eocene formation, by the post-nummulitic conglomerates, and by the intense folding and thrust structure illustrated in the section. Apart from these facts, corroborative proof for a post-Middle Eocene folding is found in adjoining territories, such as Poonch, where Wadia (1928, p. 29) observed the effects of the intense deformation to which Eocene and older rocks had been subjected. The map reveals that not only "Dras Volcanics" and Eocene have been strongly folded but that the post-nummulitic beds at Pashkyum are involved in the deformation. The latter phenomenon makes one inclined to believe that the main folding is of post-Eocene date, but it is questionable whether the structures originated entirely during one orogenic phase. A solution of such an intricate problem evidently cannot be expected from this general survey, but a brief review of the structural outlines may contribute to a general understanding of the tectonic forces involved.

So far as my own observations and those of earlier investigators go, the section may be divided tectonically into the following units: (1) an autochthonous zone consisting of the Basmai anticline and a somewhat displaced syncline of Permian and Triassic rocks; (2) a thrust zone of crystalline and metamorphic rocks as exposed in the Zoji La region; (3) an intermediate syncline of Triassic strata, faulted and partially overthrusted by (4) a synclinal belt of Indus flysch, Eocene and "Dras Volcanics" which overlap in the north, and (5) an autochthonous crystalline complex of granite and diorite.

In addition to what has previously been said about the structure of the first of these units, it would appear as if the axis of the Basmai anticline makes an acute angle with the NW-SE strike of the Permian-Triassic belt as exposed in the upper Sind valley syncline. Along the northern limb the Paleozoic formations are sheared against Cambro-Silurian rocks and the thrust contact of the Panjal trap also indicates that pressure from the northeast was exerted on what appears to be a perfectly normal syncline. The shearing forces naturally acted on planes of least resistance, that is, between the more resistant trap and the adjoining slate or Permian shales. The much more massive Triassic sequence reacted to the folding by the formation of a steep anticline which is about one mile broad and is followed by an incompletely exposed syncline. Hence the older (Permian-Lower Triassic) rocks are brought to an almost equal elevation with the much younger Upper Triassic and Liassic strata. This relationship would indicate that the syncline was first folded and then again subjected to compression which carried the southwestern limb upward against the more resistant trap which in itself transmitted the movement farther southwest, thereby causing a slight overthrust against the older Basmai anticline. This in turn presumably led to a slight diversion of such structures as are inherent in the older Paleozoic complex.

The Zoji La region presents a complexly built zone of tightly compressed formations in which Triassic, gneiss-granite and green schists of unknown age take part. Each formation appears to be separated from the next by a major shear plane, and even the Triassic of the Gamru syncline seems to be somewhat sheared towards the belt of undetermined schists. The dip of the shear planes flattens northeastward until it is parallel to the normal dip of the Gamru syncline. This progressive steepening of the shear planes towards the southwest, and the successive appearance of apparently older rocks in the same direction, suggest that an older anticline was moved southwestward upon the autochthonous syncline of the upper Sind. As the thrust contact is at present practically vertical it is evident that the shear planes must have been either steepened by continued pressure of folding from the northeast or by subsequent faulting. Whether the Zoji La sequence really presents an upthrusted portion of the Tethyan subfloor, or whether it is a metamorphic unit of younger rocks belonging to the Cretaceous-Eocene series, cannot yet be decided.[15] But in view of the fact that there is little evidence in support of the latter view, it seems probable that this structure in the main reflects the process of deformation previously described; that is, pressure of folding from the northeast leading to folding and shearing until the various formations came to rest like a row of shingles bent against a flat wall.

The Gamru synclinorium is almost entirely occupied by the thick marine Triassic sequence. It can be traced from the Gamru valley eastward across the headwaters of the Suru river into the upper Wakka valley where its strike changes from W-E to NW-SE. Between Machhoi and Pindras one recognizes at least three synclines and one anticline. Besides, there is a variety of secondary structures which, in case of the anticline, are piled above each other so as to form a mass of recumbent folds with their open limbs pointed northward. Such recumbent folds were observed mainly in the northern part of the Triassic belt and always in the upper portions of the exposures. These facts would seem to indicate that the main force of folding pressure was applied from the north and that the compression of the Triassic rocks was here as great as in the Zoji La region. It is significant in this connection that the Triassic limestones in the north are abruptly cut off by a major fault. The exact nature of this "Dras-fault" could not be ascertained for the limited number of exposures visited revealed a great variety of structures. West of Pindras the fault contact apparently dips under the Triassic; eastward and south of Dras the fault dips 80° N or is perpendicular. South of the Wakka valley the Eocene and "Dras Volcanics" dip again towards the range of Triassic limestone but the contact is clearly one of faulting rather than thrusting. The Wakka fault near Mulbek and the valley fault at Bod Karbu with their downfaulted patches of Triassic limestone give evidence of these vertical displacements.

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[15] This view was adopted by the writer in a previous publication, op. cit. 1934a.

Wherever this fault plane was deflected towards the south, the Triassic is slightly moved over "Dras Volcanics" or shales. It seems as if such local rotations are due to a slight tilting of the massive Trias complex over the adjoining weaker shales and tuff-slates. The fact that Upper Cretaceous to Eocene rocks abut on the fault line indicates that the northern limb of the Gamru syncline was downfaulted in post-Eocene time. It is, however, possible that the "Dras-fault" represents a complex system of displacements and that the faulting began at an earlier date when the Karakoram foredeep was formed. In this connection it is interesting to note that the fault itself marks the southern boundary of the flysch basin and that there are indications of faulting previous to the thrust-movement (see p. 52).

The fourth structural element, the Indus flysch and "Dras Volcanics," has preserved its normal overlap contact with the granite subfloor near Kargil. The oldest flysch beds dip southeastward towards the place where the ancient foredeep must have been located. Farther south, however, this normal relationship does not prevail any longer for the "Dras Volcanics" are here moved northward upon Eocene and post-Eocene strata. The thrust fault at Pashkyum (Text-figure 11) shows that the movement towards the north could not have been very great. This fault apparently continues westward where it offsets greenstone from granite. It was also traced at Karbu where Eocene slates are faulted against "Dras Volcanics." Whether it is this same fault which displaces the greenstones north of Dras from granite cannot be stated with any certainty. In contrast to this northern fault, there is a thrust plane which borders the main greenstone complex on the south. This thrust is best observed near Shargol and can be traced from there north of the Wakka valley to the Sangeluma river. Farther southeast it has not been sufficiently studied but presumably continues east of Lamayuru towards the Yapola valley. At Dras few observations that indicate the trend of the main thrust are available. The appearance of a thin band of Eocene limestone surrounded by greenstone and agglomerate might indicate a thrust relationship. On the other hand, the greenstone on the northern flank of the Gamru river east of Pindras appears to overlie the purple shale and agglomerate series. Here the reduced width of the shale belt, much narrower than that in the Mulbek section, suggests a greater southward advance of the greenstone complex. This thrusting apparently was an outward movement, directed from the flysch foredeep, which affected the massive volcanic rocks more than the underlying rocks or the younger shales so that the "Dras Volcanics" were thrust independently over the basin filling towards the south.

Previous investigators such as Lydekker (1883) and Oldham (1898) have drawn attention to the northwestern terminal of the Indus flysch along the crystalline rocks near Kargil. Formerly it was stated that the granite-diorite mass with its associated metamorphic schist should be regarded as part of the uplifted subfloor which is intimately connected with the crystalline axis of the Ladak range northeast of the Indus. It is in this fifth structural unit that the influence of the pre-Tertiary uplift manifests itself most clearly. The fault contact of the granite with the greenstones would indicate that this sudden termination of the flysch basin does not actually represent the original border of the flysch, particularly if one recalls that only the basal layers are in normal contact with older rocks. The great thickness of this formation and its relative petrologic uniformity would rather point to a much greater extension of these strata in Upper Cretaceous and Eocene time. This consideration induces one to believe that the present flysch boundary is due to post-Eocene movements which brought about upheaval of the axis of the flysch trough. Such a structure is in accordance with the general tectonics of the adjoining Karakoram ranges where the Paleozoic formations and crystalline rocks emerge progressively from southeast to northwest from under the intensely folded Mesozoic rocks. An axial uplift towards the northwest therefore is common to both the Karakoram and the northwest Himalaya, and it is obvious that this movement could have taken place only in post-Eocene time.

The present general reconnaissance permits one to draw but limited conclusions as to the general tendencies of tectonic deformation. Naturally these were determined by two main elements: the geosyncline on the one hand, and its subfloor or borders, made of older rocks, on the other. The latter at present makes a frame for the fold- and thrust-structure prevailing in the central portion of the section, for it is flanked by an autochthonous complex of igneous rocks in the north and an older Paleozoic sedimentary one in the south. Evidently the former came into existence through Cretaceous uplift, and after temporary subsidence gained prominence when a general folding occurred in post-Eocene time. These compressive forces transmitted themselves within the rock sequence in such a way as to give rise to an offshearing of the northern part of the geosyncline. This was moved southward, thereby causing extensive shearing along the contact with the southern unit and with the older Paleozoic rocks. The northern portion underwent strong compression especially along the contact with the "Dras Volcanics," which, as an individual thrust mass, had been moved from a more central position in the flysch basin to the south. It is here that the thrust movement evidently attained its greatest force. It is rather improbable that the autochthonous complex in the north was ever displaced to any appreciable distance. The southward movement of the Tethyan folds, as exemplified by this structure, appears to have originated from the same orogenic force that gave rise to the thrust structure in the neighboring Pir Panjal range, as described by Wadia (1928, p. 198).

# IV. PHYSIOGRAPHIC OBSERVATIONS AND THEIR STRUCTURAL SIGNIFICANCE

The relief model of the northwest Himalaya, if such could be constructed along the geological section, would in the vertical dimension present a four-fold arrangement of physiographic units. The uppermost floor of this towering structure would show single high massifs and glaciated ranges at an altitude between 16,000 and 26,000 feet above sea level. A second floor between 11,000 and 16,000 feet would reveal widely extended mature land forms with wide valleys, isolated plains and sharp-wedged interstream divides molded by Pleistocene glaciation. The latter completely dominates in the formation of the next floor which merges into the youngest relief unit through deeply dissected, glacially shaped, but more recently excavated valleys. The boundary of the lowest and fourth unit becomes clearly visible wherever glacial troughs have been cut into by younger streams, as in the Sind or Hangru valleys (Text-figures 1 and 3).

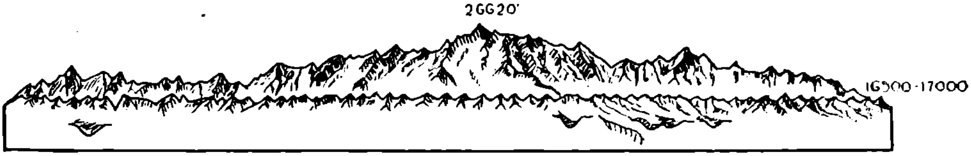

FIGURE 19. THE HIGH MASSIVE OF NANGA PARBAT ABOVE THE SUMMIT LEVEL.

Sketched after a photograph taken by A. and R. von Leyden from Haramuk peak near Srinagar.

The highest floor is buried under snow and ice and is greatly scoured by a lasting glaciation. It lies more than two miles above the structures described in the previous chapter. Its formational composition is as yet little known and can only locally be inferred from the underlying ground plan. But its outlines, from a bird's-eye view, reveal an orderly arrangement of topographic forms, which becomes particularly striking in the neighborhood of the high massifs. Such great mountain groups are Nanga Parbat and Nun-Kun. The former lies seventy miles northwest of the Sind valley and the latter about thirty miles southwest of the Wakka valley.

From an alpine meadow near Gulmarg above the Kashmir valley I saw Nanga Parbat rise above the summit level of the Kashmir Himalaya. Like a giant group of islands it lifts itself above an approximately even line of single peaks and serrated ridges that lie in an accordant level at a height of about 16,500-17,000 feet (Text-figure 19). Here and there a somewhat higher peak rises out of the uniform alignment of crests and interstream divides. No plateau remnants can be seen, nor are there any other signs to indicate that this level originated from an ancient dissected peneplain. On the contrary, the youthfulness of the innumerable sharp-edged crests, summits, and divides which are so perfectly dissected by active weathering and erosion, seems to imply an ever-changing state. Albrecht Penck (1919, p. 264) has demonstrated that such summit levels in the Alps may actually mark a balance of topographic relief between mountain upheaval and erosion. There, as in the Himalayas, the summit level is constantly in the making, and Penck's conclusion was that it could never therefore be a land form directly inherited from an older peneplain. The alpine summit level, according to Penck, is the result of rapid weathering in snow-covered heights and of constant cutting of an evenly spaced river system which continues to cut ever more deeply in the attempt to keep pace with the mountain uplift.

As in the Alps this summit-level of the Kashmir-Himalaya is surmounted by higher mountain groups, such as Nanga Parbat. Nanga Parbat consists of resistant metamorphic as well as non-resistant rocks and these also take part in the structural composition of the underlying region. Its boundaries do not coincide with the outcrops of the harder rock element and it is therefore improbable that Nanga Parbat represents a group of monadnocks. This conclusion can also be drawn from the observation that the accordance of level is due to an even spacing of the river system which originated at a time previous to the general uplift. As long as there existed a state of balance between the deeper cutting of this drainage system and the mountain upheaval, the alpine summit-level dominated the entire relief. But when this balance was upset by a quicker uplift of certain portions of the structure, the rivers in the quicker-rising portion were unable to establish an equally dissected relief. Higher massifs began to appear above the summit-level. Such an event must be responsible for the extraordinary prominence which the Nanga Parbat massif attains above the summit level. But we ask ourselves what forces controlled these accelerated uplifts? Are they dependent on those earth movements which are manifested in the deeper structure of the section, or do they belong to an entirely different order?

## WARPING OF FOLD STRUCTURES

The assumption that young crustal deformation is largely responsible for axial elevations in the summit level region is justified if one accepts a variety of evidence which goes to prove the youthful character of the diastrophism. Text-figure 20 shows that the longitudinal valley profile along the Sind presents a steep slope on the southern flank of the central Himalayan range. The same steepness of grade is reflected in the relative levels of Pleistocene terraces. At Woyil near the outlet of the Sind valley the main terrace lies at 5500 feet and at Sonamarg thirty miles upstream its level is at 9000 feet. Considering that the Sind valley suffered repeatedly from glacial erosion which must have lowered the grade and smoothed the slope, it is surprising to notice how steep the ascent of these Pleistocene terrace levels is at present. Moreover, there is evidence to prove that the Pleistocene waters were temporarily ponded in the valley and that the interglacial lake deposits between Gandarbal and Gund rise over a distance of twenty-three miles by at least 800 feet without gaining in thickness (Dainelli, 1922, p. 510). This situation reveals a progressive tilting of the Pleistocene from southwest to northeast, from the Kashmir basin towards the higher range. In the Kashmir basin, which is the local base level of erosion for the Sind and neighboring rivers, the Pleistocene Karewa formation is folded and faulted (Text-figure 20). Along the northern rim the upper Karewa clays and sands are slightly tilted with a southwest dip. The upper bench mark of the Karewa lake at Takht-i-Suleiman near Srinagar is tilted. Between

Gandarbal and Woyil a set of lake terraces shows slight tilting towards the southwest. Dainelli (1922, p. 554) also has given indisputable proof for very recent, old and young Pleistocene uplifts of the Pir Panjal range. These observations permit only one conclusion, namely, that a relatively recent rise occurred in the surroundings of the Kashmir valley and that considerable changes of level took place in the Karewa lake basin.

Physiographic studies lead to a further recognition of the nature of this diastrophism. The summit level slopes rather quickly towards the Kashmir depression and, on the north flank of the Pir Panjal range, plateau levels appear at lower elevation which can only be remnants of a fully matured relief. Here it is possible to date the mature land forms as late Tertiary or early Pleistocene as the folded Karewa clays rest upon the graded slopes of the range. Towards the northeast the summit level of the central Himalayan range is replaced by maturer land forms and intermediate basins. The Kargil and Zanskar basins form in conjunction with the broad Indus valley a great depression which follows the NW-SE strike of the mountain axis. The Pleistocene terraces in the Kargil basin evidently are not tilted, but, as I described previously (1934, Fig. 22), there is subrecent tilting in lake beds of the Rupshu district in the southeastern continuation of the Zanskar range. It cannot be fortuitous that the topographic depressions coincide with regions of Pleistocene or subrecent deformation. Hence one is rather driven to the conclusion that the uppermost topographic relief has suffered from gentle warping, long after the Tertiary orogeny, and subsequent even to the intra-Pleistocene folding. If this is so, we would expect to find that the mature land forms were developed independently from underlying structure. That this is indeed the case will subsequently be demonstrated. The sketch map (Text-figure 21) shows such a phenomenon rather clearly. On it two anticlines appear, occupying respectively the Pir Panjal range in Kashmir and the main Himalayan range. The axes of the synclines on this map approximately follow the greatest thickness of the Pleistocene, mainly consisting of lake deposits, so far as it is known. Their position permits an estimate of the amount of basining during the Pleistocene. In case of the Kashmir valley it amounted to at least 4000 feet (the minimum thickness of the Karewa formations) and in the Kargil-Indus depression to over 1500 feet. The total amplitude of this gentle crustal folding can here be determined to be 7000 or 8000 feet. The "wave length" or distance between the two crests of the anticlines is forty-five miles, but the asymmetric position of the intermediate syncline would rather indicate a flexible and asymmetric shape of these warped structures. Their origin certainly dates back to the Pleistocene but a more accurate dating will become possible only after the stratigraphy of the Karewa formations has been fully studied. Suffice it to state that the uppermost relief unit gives evidence of gentle crustal warping. Its characteristics coincide with those described from other crustal folds such as the Alps, the ranges of central Celebes or the Andes where "Grossfaltung" has been a dominant factor in the relief and mountain-making process since the close of the Tertiary folding.[16] It is not surprising that the Himalaya, as the mightiest of the great crustal folds, presents deformations similar to those observable elsewhere, and it may be said that it shares this morphologic phenomenon with almost all of the younger mountain ranges of the world. Its presence in other parts of the Himalayan mountain belt can readily be deduced from similar morphologic evidence. The basins of Hundes and Nepal, for instance, repeat the depression of the southern Himalaya

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[16] See E. C. Abendanon, "Die Grossfalten der Erdrinde," Leiden, 1914, and W. Penck, "Die Morphologische Analyse," Stuttgart, 1924.

in Kashmir while the Brahmaputra (Tsang Po) valley, north of the central range, likewise forms the depression corresponding to the upper Indus region. Outside of the Himalayas but in a closely related tectonic unit, namely in the Alps of Chinese Tibet, Abendanon and more recently Arnold Heim (1933) have shown how young crustal movements continue to determine the morphology. Once more the question arises whether these deformations are related to older structures and if so, whether they are manifestations of the same forces which led to thrusting and folding of older rocks?

From the picture presented it would appear as if there were a very definite relationship between axial elevations in the highest relief and the axes of older uplift on the one hand and between depressions and zones of crustal basining on the other. The Indus depression in the north coincides largely with the flysch area south of the Karakoram. This region, as has already been pointed out (Text-figure 7), has a long record of crustal basining. The Kashmir valley, on the other hand, was at one time part of the Siwalik foredeep for there are certain bottom layers of the basin filling which resemble certain younger Siwalik beds. Middlemiss (1911) as well as Dainelli have drawn attention to the much lower elevation of the Pir Panjal range in old Pleistocene times. Dainelli (1922, p. 533 ff.) could prove that this range was uplifted in the first and especially during the third interglacial period. He also demonstrated the close correspondence between the topography of this range and the uplift of the Karewa lake beds. The axial uplifts possess either anticlinal structure, as in the Pir Panjal and around the Zoji pass, or represent elevated zones of strong thrust movement in which tangential and radial components shared alike. Hence it becomes obvious that this gentle crustal warping is nothing but a different manifestation of the same forces of folding which previously led to much more intricate rock structure. The Tethys formations were rendered inflexible by tight compression but they yielded once more to younger deformation which may be characterized as a broad crustal bulging accompanied by differential gentle warping of its upper structure.

## REMNANTS OF OLDER LAND FORMS AND THEIR RELATIONSHIPS WITH OTHERS FOUND IN THE EASTERN KARAKORAM

Previously it was mentioned that summit level and high massifs are locally replaced by a more or less extended mature topography. Of what nature is this relationship between the most youthful and the older land forms?

The more mature relief in the northwest Himalaya generally lies a few thousand feet below the summit level and as Text-figure 20 shows, there are at least two, locally even three, surface levels present, one between 11,000 and 12,200 feet and a second around 13,200 feet. The former may be called the "Marg-level" for it takes the form of rolling alpine meadows which the Kashmiris call "marg." Such an alpine meadow can be found at Mohandmarg above the entrance of the Sind valley. Topographic sheet No. 43 J 15 of the Indian Atlas shows beautfully how the glacial and post-glacial erosion has dissected this relief except for narrow flats on interstream divides. If we connect the two southernmost of the elevated mature relief remnants in Text-figure 20 with each other, it appears that this level slopes steeply towards the Pleistocene and sub-recent syncline of the Kashmir valley, whereas it ascends northward towards the Zoji La anticline.

North of the central range there is a higher surface level at 13,200 feet and it is this level which is represented south of Dras by highly elevated broad valley floors and flat slopes below the snow-covered limestone range (Text-figure 8). This panorama shows that the Pleistocene terraces of Dras lie about two thousand feet below that level. In its most perfect state of preservation it is encountered some twenty miles north of Dras, where it constitutes an extended plateau remnant called "Deosai." Oestreich (1906, p. 83) described its flat land forms as the remnant of an uplifted peneplain. Its width is about sixteen miles and the undulating surface cuts across schists and gneissic rocks alike. Its pre-glacial origin as a highly elevated surface becomes evident through the fact that it was thoroughly glaciated during the Pleistocene and that already then it must have been much raised above the now greatly depressed pre-glacial floor of the Kargil basin (Text-figure 20). It was noted previously that pre-glacial erosion had caused denudation of the flysch rocks near Kargil, and it seems therefore reasonable to assume that previous uplifts had already raised the "Deosai" plain. This "Deosai" level extends into our section where it appears near Mulbek and around the Fotu pass. Here it can be recognized in the form of top level spurs and generally flatter land forms (Text-figure 20). South of the Indus it is clearly represented by level terraces at 13,400 feet which project boldly from the flanks of the range. There can be little doubt that this level extends regionally over a still greater distance and that its gentle southward slope reveals the mature stage of erosion which the Himalayan upland had acquired after the folding. Here in the northeasternmost sector, between the Fotu La and the Indus valley, a still higher surface is found (Text-figure 20). It makes a terrace about 2000 feet above the "Deosai" level and very often its level coincides with a distinct line of cirques. The latter are now abandoned and are therefore of Pleistocene rather than of recent origin. Wherever these cirques appear they merge into widened valley floors and gentle slopes, into which the Pleistocene glaciers had carved their troughs. Post-glacial erosion has in such cases not been

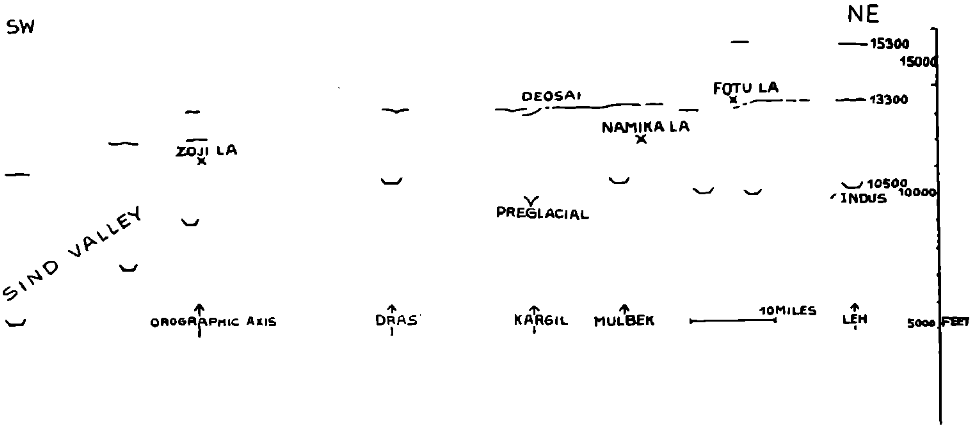

FIGURE 20. OLD SURFACE LEVELS AND RECENT VALLEY FLOORS BETWEEN THE SIND AND INDUS VALLEYS.

strong enough to destroy entirely the older land forms, but the interstream divides always appear sharp-edged owing to intense Pleistocene glaciation. The slope down to the lower "Deosai" level is rather abrupt but concave and in the longitudinal valley profiles this slope can be recognized in the form of a step. Quite unlike the "Deosai" level, this surface does not give rise to extensive plateau remnants, but further eastward in Rupshu and southeast of Leh, it forms highly elevated plains. The latter extend across resistant Cretaceous limestone and granite, but also across less resistant greenstones and shales. Hence it cannot be said that the maturity of land forms is due to advanced erosion in less resistant rocks. Neither is its occurrence restricted to the main river courses.

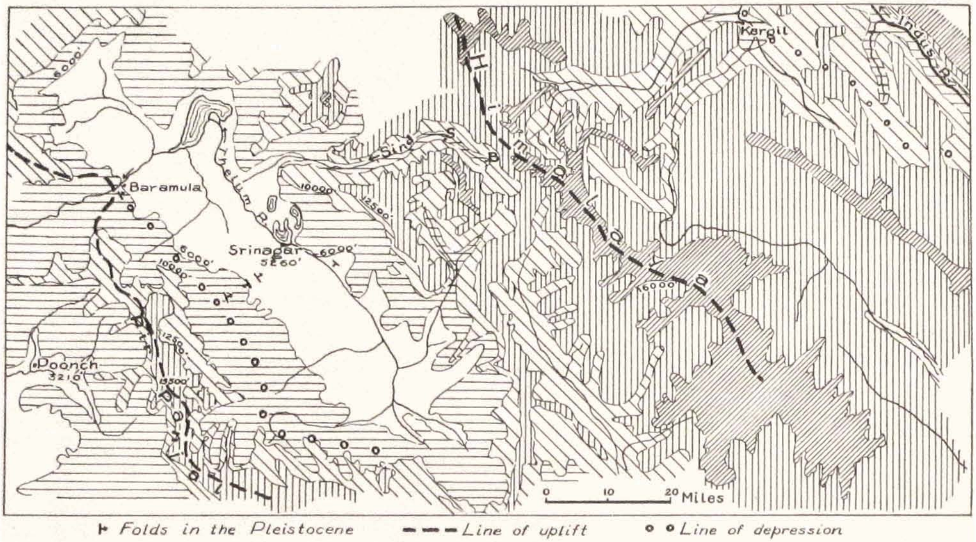

FIGURE 21. GENERAL RELIEF MAP OF THE REGION BETWEEN THE KASHMIR AND INDUS VALLEYS.

The shaded area is at an elevation over 16,000 feet and partially glaciated.

From the existence of at least three terraces and of their step-like arrangement, it would appear as if this Himalayan mountain sector had undergone a fate similar to that of the neighboring Karakoram. Here I (1934) found three separate uplifts of which one has been assigned to a pre-glacial period. This geomorphological relationship between Karakoram and Himalaya might suggest an identical history, were it not for the fact that the latter has an alpine summit level and a warped relief. Such phenomena seem to be lacking in the easternmost Karakoram for wherever a summit level appears it is derived from a late mature or old land surface of pre-glacial date (de Terra, 1934, Fig. 7). The higher massifs which surmount this surface must here be considered as monadnocks. Such land forms are clearly inherited from an older relief. Plateau remnants of this kind actually occur in the Himalaya but as was pointed out they do not correspond to summit levels. The higher massifs are here entirely restricted to the zones of young anticlinal uplift along the main mountain axis, and the mature forms of erosion escaped destruction only in intermediate zones which experienced downwarping.

This physiographic contrast between the northwest Himalaya and the easternmost Karakoram apparently reveals two different types of post-Tertiary diastrophism. The Himalayan sector is characterized by uplifts and gentle warping of older structures; the eastern Karakoram, on the other hand, suffered broad uplift without further warping. This does not mean that the entire Karakoram is free from warped land forms, but, so far as its eastern border region is concerned, it certainly does not show any signs of young differential movements. The effect of gentle warping on Himalayan structures possibly extends over the high Karakoram north of the Nubra valley, for here again the central tectonic axis bears high massifs which alternate in the geological strike with longitudinal zones in which, as in the Shaksgam valley, mature land forms appear.

In regard to the origin of this gentle warping, it should be noted that the upwarps continue the rising anticlines of earlier date and that the downwarps are in no way caused by strike faults. This independence from faults becomes especially clear in the Kashmir valley where the Pleistocene is folded only along the rising flank of the Pir Panjal range. This type of warping is then clearly an orogenic process and a continued phase of Tertiary folding. Tectonic pattern and rock structure are due to successive phases of folding but the final relief- and mountain-making process is one in which a new type of crustal deformation combines orogenic with epeirogenic movements. It remains to be seen whether this is an intermediate or a final stage in the mountain-making process.

## V. GENERAL CONCLUSIONS

So far as my studies of structure and relief permit an analysis of this mountain sector, it appears that the geological history of the Himalaya, like that of the Alps, was determined by crustal movements of deep-seated origin. This is revealed by the breaking down of the Paleozoic structure, its progressive sinking in Mesozoic time, and the ability of the Cretaceous and Tertiary folding to mobilize rocks of Tethyan and pre-Tethyan age in the formation of one great crustal fold. Its structures are mainly due to compressive forces which were applied from the north. Here thrust structures are connected with a belt of basic igneous rocks which intruded the geosyncline during a stage of deep crustal subsidence. This thrusting is directed towards the south and reflects the crustal movement against the foreland of Gondwana. The amount of horizontal displacement cannot as yet be estimated and it must therefore remain an open question whether the structure of the entire northwest Himalaya was caused by nappe-movements. As the structure of the neighboring Karakoram ranges is characterized by much steeper folding and northward movement, it is evident that the intermediate Indus valley approximately marks the boundary between two fold systems. Of these the Himalaya must be considered as the more active unit which still continues to grow in height as well as in breadth.

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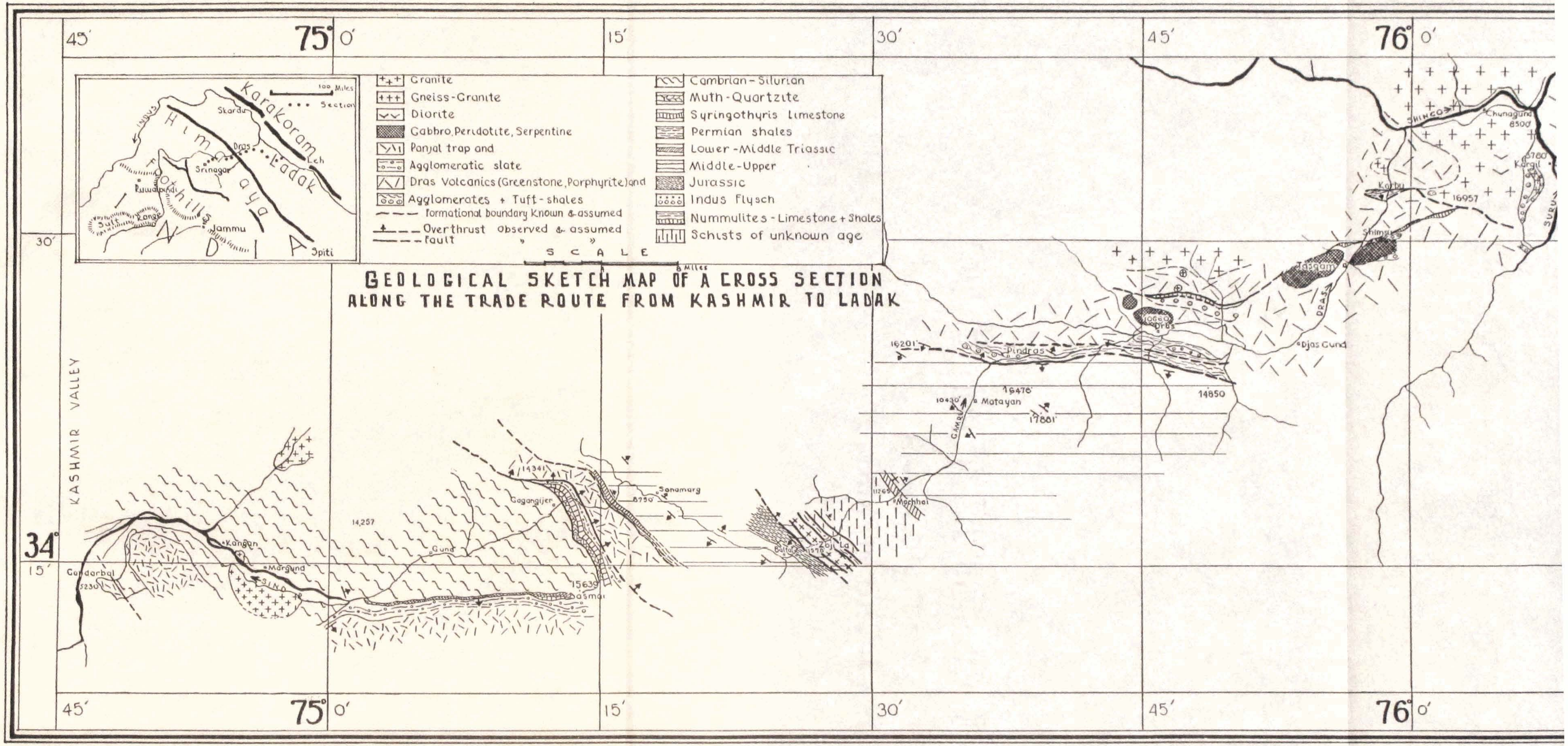
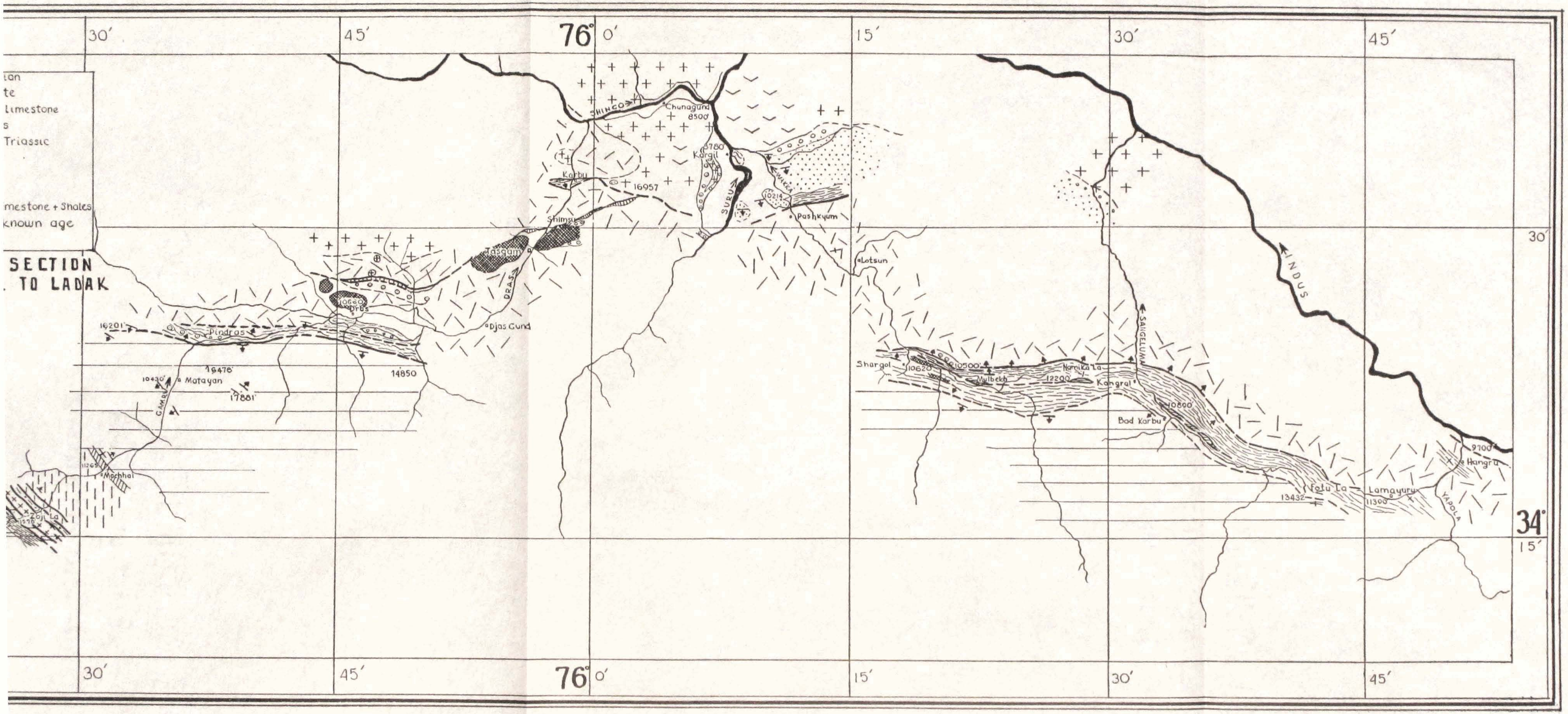


GEOLOGICAL SKETCH MAP OF A CROSS SECTION ALONG THE TRADE ROUTE FROM KASHMIR TO LADAK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s
Triassic
mestone + Shales
known age
SECTION
TO LADAK
30′
45′
76° 0′
15′
30′
45′
30′
34° 15′
SHINGO
Chunagund
8500′
8780′
Kargil
Karbu
16957
SURU
WAKKA
10214
Pashkyum
Shimsu
Tasgam
DRAS
10660
Dras
Djas Gund
16201′
Pindras
16478′
14850
10430′
Matayan
17881′
GAMRU
11265
Machhai
Zoji La
Lotsun
INDUS
SANGELUMA
Shargol
10620
10500′
Mulbekh
Namika La
12200′
Kangral
10890′
Bad Karbu
9700′
Hangru
Fotu La
13432
Lamayuru
11300′
YAPOLA