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The relationships between the Tibetan Platform and the Tarim Basin

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A review is given of the principal tectonic-stratigraphic features of the Russian Pamirs mainly according to Soviet investigations and the author's researches in the farther easterly extension in K'unlun and Karakoram (Tibetan Pamirs) in the years 1930—1932. The development during the Late Cretaceous was dominated by persistent subsidence with deposition of mainly marine calcareous sediments of Aksaichin facies, terminating in the Paleogene with heavy volcanism of monzonitic magma type, and subsequent uplift of the Tibetan Platform relative to the Tarim Basin.

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Introduction

In 1962 V. N. Krestnikov published a synthesis of all stratigraphical data available at the time on the Pamirs and the adjacent regions showing how since the earliest Paleozoic the distribution of land and sea through the ages had been determined primarily by the large median massifs of Kurama (Fergana), the South Tadzhik massif, and the Tarim massif, to which he added a fourth, viz. the Pamirs-Karakoram median massif. During the Paleozoic orogenetic cycles a K'unlun-Transalai megaanticlinorium gradually developed between the Tarim massif and the Pamirs-Karakoram median massif. With the growth of this megaanticlinorium, depressions formed along its flanks, viz. the North Pamirs depression on its northern side and the South Pamirs depression along the southern side.

At about the same time, V. P. Barkhatov (1963) published his important monograph on the tectonics of the Pamirs with a tectonic map 1:1 000 000 on which four principal tectonic units were distinguished, viz. A) the Northern Zone of the Pamirs, B) the Central Zone, C) the Southeastern Zone and D) the Southwestern Zone, these units being separated from each other by deep rifts. N. G. Vlasov 1969, however, emphasized that the geological structure of the Northern Zone of the Pamirs is much more diversified than that of the Central, the Southeastern and the Southwestern Pamirs, so much so that a combination of the latter three zones into one major unit under the general term of the Southern Pamirs might seem motivated. Yet, according to V. I. Dronov & E. Ya. Leven (1963), the Central and the Southeastern Pamirs cannot be regarded as belonging to the same structural zone because of the differences in facies and thicknesses of their contemporaneous deposits, differences in their tectonics and magmatic phenomena etc. All these circumstances led them to regard the Central Zone of the Pamirs as separate from the Southeastern Pamirs, and constituting an independent unit. This conclusion was confirmed by the discovery by S. V. Ruzhentzev (1962) that the autochthonous fundament of the Central Pamirs largely consists of Proterozoic and Early Paleozoic rocks, usually more or less strongly metamorphosed, overlaid locally by autochthonous Late Paleozoic littoral and continental sediments, but locally also by large younger thrust-sheets from the south.

The Southeastern and Southwestern Zones of the Pamirs, on the other hand, are evidently very closely related genetically. Passing from the usually only slightly metamorphosed black "Sarikol shales" in the Southeastern Pamirs westwards into the Southwestern Pamirs a progressive increase of the metamorphism is in evidence as noted already by Hayden (1916), and later confirmed in various parts of the Southwestern Pamirs by int. al. N. A. Khorev (1956) and A. G. Davydčenko (1966). It may be suggested tentatively that a large part of the very thick Pre-Kimmeridgian paragneisses in the Southwestern Pamirs (about 15 km thick) represent originally sequences of shales, marls, limestone, and associated basic volcanics of Precambrian age, similar lithologically to the younger Paleozoic sequences in the Southeastern Pamirs and their extension far eastwards into western Tibet. In this belt, the Southwestern Pamirs may constitute an axial culmination soached at depth by the migmatitic front; the Karakoram ranges proper may represent an axial depression with greatest amplitude around longitude 77°E, where during the Kimmeridgian orogenesis the migmatitic front ascended highest; another axial culmination may be represented by the ancient crystalline rocks in the Mawang Kangri in the Tibetan Karakoram.

A very great improvement concerning the geotectonics of High Asia is embodied in the sketch-map presented by Peive, Ruzhentzev et al. to the IGC in India 1964. The most important feature on this map is the recognition of the affinity of the Central Pamirs Zone to the so-called K'unlun Plains in western Tibet, now separated by the huge Pamirs-Karakoram strike-slip fault. Along this fault, the Central Zone of the Pamirs has been displaced as a block at least 200 km to the north relatively to the K'unlun Plains.

The fundamental deep rifts within the Pamirs seem to be those marked 23, 24 and 27 on the tectonic diagram (Fig. 1). The deep rift 23, the Akbaital deep rift and overthrust to the north, separates the Central Zone from the Northern Zone of the Pamirs and probably extends eastwards along the southern side of Karanghutagh in the K'unlun. The deep rift 24, the Rushan Pshart-Uprang-Lokzung deep rift, separates the Central Zone of the Pamirs from the Southern Pamirs. The deep rift 27 or the Upper Indus boundary zone separates the Pamirs from the Himalayan Zone, constituting the northern boundary of the Gondwana realm. Younger than all these deep rifts and associated overthrusts is, in the east, the huge Pamirs-Karakoram strike-slip rift 25 striking NNW and its extension, the Talas-Fergana deep rift striking in the same direction with a total length of more than 1300 km; it crosses all the structural-facies zones in High Asia, displacing its western parts several hundred km northwards in relation to its eastern parts. This enormous zone of fracture has its counterpart along the western border of the Indian peninsula and along the western border of the Hazara wedge where the "Petrushevskiy Line" in a similar way delimits the Pamirs to the west. To these young great fractures is to be added the K'unlun frontal deep rift 20, topographically the most conspicuous and still highly active, which extends from the westernmost end of the Tarim basin eastwards to continue along the Kansu Corridor and the northern frontier of the Tsing-ling Shan to the Pacific.

The Paleotethys

In northeastern Afghanistan, a remarkable stratigraphical record is preserved in the Nauwar Geosyncline as revealed by int. al. Fesefeldt during the German Afghanistan expeditions in the 1960s. Even in its present folded state, this geosynclinal belt attains a width of about 50 km, exhibiting a subdivision into troughs and swellings that determined the facies of the sediments. There is in the whole Paleozoic sequence no trace of neither Caledonian nor Variscan folding, nor are there any traces of initial volcanism; the ultrabasic rocks and serpentinites occurring outside the border of the anticlinorium are probably of Cretaceous or Tertiary age. The sedimentation processes seem to have proceeded in rather uniform facies without any major breaks from the Ordovician into the Lower Permian, i.e. during a space of time of some 200 mill. years.

To this geosynclinal system belong also the Southeastern Pamirs. This complex of mainly black slates (the Sarikol Slates) with an aggregate thickness of several km records the sedimentation in distal marine facies from the Lower Carboniferous to the Lower Jurassic, the base not being known. The stratigraphy has been investigated in great detail especially by S. V. Ruzhentzev whose works of 1968 and 1971 I have dealt with in my paper of 1976. In Ruzhentzev's general transverse section (Fig. 2), three stratigraphic main divisions are distinguished. The lower division, the Bazardar Suite, consists of very uniform black and dark gray, laminated silty and fine-sandy argillaceous sediments of distal marine facies with an exposed thickness of 1,5—2 km, representing a space of time from the Early Carboniferous to the Early Artinskian. There is a gradual transition from the Lower into the Middle Division comprising the Kuberganda ($P_{1a}-P_{2kb}$), the Gana ($Pm-P_2pm$), the Karabeles (P_2pm), and the Kobrigen (T_1-T_3k) Suites, being composed mainly of carbonatic, silexitic and hydrated ferruginous deposits and radiolarites with only a slight influx of terrigeneous material. The total thickness of this division which represents the greater part of the Permian and the Triassic, fluctuates between a few hundreds and a few tens of metres. Upon these sediments of deep-sea facies then follows abruptly the Upper Division of the geosynclinal sequence, the Istyk Suite, a formation of very uniform black and dark gray fine-grained silty-argillaceous sediments of Norian-Rhaetian age, very similar lithologically to those of the Bazardar Suite and of similar thickness (locally $>$ 1000 m). The Carboniferous-Triassic sedimentary cycle was concluded in the Early

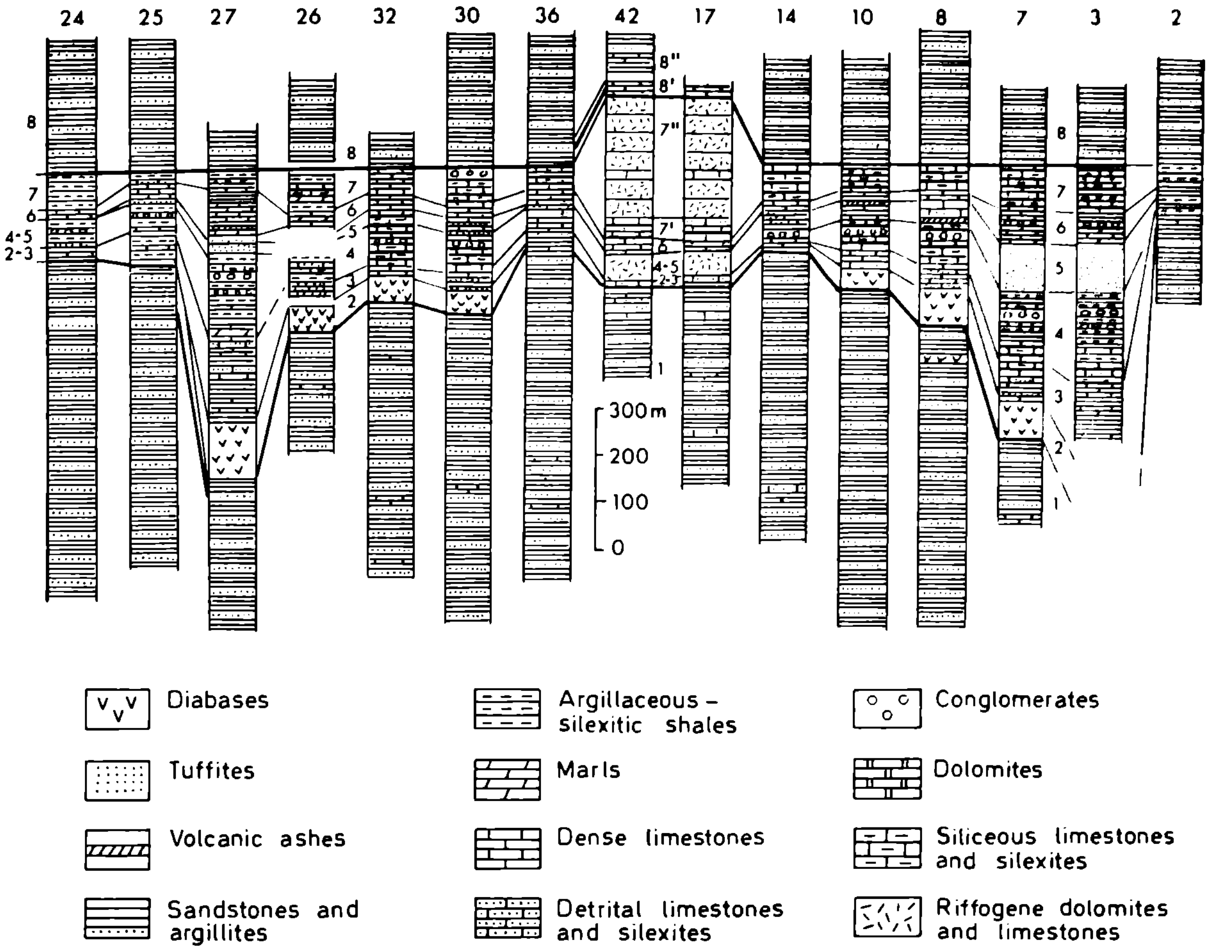

Fig. 2. Stratigraphy of the "Black Slates" Series in the Southeastern Pamirs (Ruzhentzev 1968). 1 — Bazardar Suite (C_1—P_{1a}); 2 — Shindi Suite (P_{1a}); 3 — Kuberganda Suite (P_{1a}—P_{2kb}); 4 — Gana Suite (Pm—P_2pm); 5 — Karabeles Suite (P_2pm); 6 — Lower Kobrigen Subsuite (T_{1-2}an); 7 — Upper Kobrigen Subsuite (T_2l—T_3k); 7′ — Ladinian; 7″ — Carnian; 8 — Istyk Suite (T_3n-r); 8′ — Lower Norian; 8″ — Norian and Rhaetian.

Jurassic by the first stage of Kimmeridgian tectogenesis, expressed by the unconformable superposition of Bajocian basal conglomerate and Red Beds upon the eroded older formations.

From the Southeastern Pamirs, this sedimentary complex extends with uniform facies eastwards in the Hunza (Hu) and the Baltoro Karakoram (K) ranges and farther in the Changlung Karakoram into western Tibet where Norin (1946 p. 60) named it the Horpatso Series (H). Here the intensity of the folding decreases to form ultimately the huge fractured high-level plateau of Mawang Kangri where the sediments extend almost horizontally over wide regions.

Common to these more or less strictly homotaxial sediments are their usually very uniform lithology over an enormous region; they are composed predominantly of silty and fine-sandy argillites of great thickness with frequent intercalations of turbidite sandstones, thin limestone beds and laminae of silexites, whereas true conglomerates or gravellites are very rare or absent; characteristic is also contemporaneous simatic volcanism. In the central parts of the geosyncline in the Southeastern Pamirs and the western Karakoram, long chains of reefs attaining locally a thickness of a thousand metres developed along subsiding longitudinal swellings. However, there is a general gradual increase of the grain-size of the terrigeneous material in a south-easterly direction on approaching the Transhimalaya, suggesting a source region of the coarser material here.

Whereas in the Southeastern Pamirs the "Black Slates facies" continues without a break throughout the Upper Paleozoic into the Lower Jurassic, in western Tibet, on the other hand, the "Black Slates facies" continues only into the Upper Carboniferous or earliest Permian, where it becomes overlaid disconformably by the basal orthoquartzite and the richly fossiliferous calcareous sediments of the Tashlikköl Series of Karachatirian age, and which exhibit distinctly different facies of sedimentation. In my opinion, there is, here, contrary to the Southeastern Pamirs, a pronounced break in the facies development of these two regions. This facies boundary can also be traced along the Shaksgam valley and associated deep rift in the Baltoro Karakoram along the northern margin of the Southeastern Pamirs (Desio & Martina 1972).

The Upper Cretaceous deposits of Aksaichin facies

In the Lower Cretaceous, an epoch of orogenesis occurred along the Pamirs-Karakoram Mountain system and its extension into Western Tibet. This orogenesis seems, however, not to have resulted in the formation of high mountain ranges, but a comparatively low relief seems to have prevailed in large parts of the folded region also after this revolution.

It has been observed in many places in the Loqzung Mountains and all along the southern border of the K'unlun Plains in western Tibet that the ubiquitous red sandstones at the base of the transgressive marine calcareous Cenomanian rest upon a deeply weathered fundament of folded and peneplained Paleozoic and Mesozoic rocks, including Lower Cretaceous beds, often without any basal conglomerate; it is only at some height above the base that fluvial conglomerate or gravelly beds usually make their appearance in the sandstones. Thus, the sea transgressed here over a very flat land-surface of detrital rocks and soil which, when reworked by the sea, resulted in a fine-grained, usually reddish sandstone, rich in quartz. Elsewhere, e.g. in the Khökhö Shili ranges in eastern Chang T'ang (Central Asia Atlas NI 45), basal conglomerate and salt deposits occur in the sequences. The morphology of the country (broken locally by uplifts) was probably similar over large areas in the Central Pamirs.

Owing to this peneplanation of the landsurface, the Upper Cretaceous sea covered an enormous area during the maximal transgressions in the Senonian. This sea was bounded on the south by the northern slope of the Hindu Kush swelling and its western extension into Central Afghanistan; to the north a very irregular shore extended with many bays and deltas along the Middle T'ien Shan. The interior of the basin was dominated by a long, comparatively narrow swelling from the present western K'unlun over the Northern Pamirs, tapering out in the Amu Darya depression in the neighbourhood of Kulyab.

In western Tibet, where the Tibetan platform widens between Transhimalaya and K'unlun, the Paleozoic, Triassic and Jurassic formations have usually been subjected to much less intense deformation than in the west, and over large regions the sequence is only slightly disturbed.

An apparently complete record of the whole Upper Cretaceous sequence of strata has been described by Norin (1946) in the Eastern Loqzung Mountains along the southern shore of Lake Lighten. Here, the basal red sandstone (Hor. A) rests upon a flat land surface of crystalline schists, overlaid by light grey, yellowish and reddish limestones (Hor. B) with an estimated thickness of about 400 m. The fossils collected in the lower part of the sequence indicate Cenomanian age, but as no fossils have been found in the upper part, the age of that part is not known.

Next follow conformably calcareous shales and dark bituminous sediments with plant fragments and gastropod shells (Hor. C) of no great thickness, passing higher into light grey calcareous sandstone and a coarse limestone conglomerate with a light grey matrix and a total thickness exceeding 200 m (Hor. D). This "Loqzung Conglomerate" (Norin 1974) is probably identical with a similar limestone conglomerate of Post-Turonian age discovered by De Terra 120 km to the WSW in the same range north of Sarigh Yilganing Köl (De Terra 1932 p. 100). At Lake Lighten, the Loqzung Conglomerate is overlaid by grey fine-grained sandstone (Hor. E) and then follow the deposits of a second major transgression represented by black (Hor. F) and light grey dense limestone (Hor. G), together a hundred metres thick. A horizon (H) of red-brown, fine-grained sandstone, about 50 m thick, with intercalations of greenish, completely chloritized mafic tuff, separates this limestone from another formation of massive grey limestone (Hor. I), more than 100 m thick, recording continued subsidence in a marine environment.

The next member of the sequence, following conformably upon the limestone Hor. I, is a very thick formation of red conglomerates of medium coarseness, gravellites and sandstones (Hor. J), with low northerly dip. It is evidently a piedmont formation deposited by shifting streams upon a wide plain. These conglomerates are very different from the grey bouldery Loqzung Conglomerate. Also here the pebbles consist mainly of various limestones, but the general colour is reddish brown owing to abundant matrix of that colour. This formation is the highest horizon of the Upper Cretaceous sequence exposed on the southern side of the depression of Lake Lighten.

So far, all these horizons with an aggregate thickness, estimated to be at least 1 km, occur in primary conformable succession throughout with low or moderately low northerly dip. The red upper conglomerate, Hor. J, of piedmont facies crops out with low northerly dip at many places in the broad valley or tala that unites the basin of Lake Lighten with that of Yeshil Köl to the east. The northern slope of this tala is outlined by a steep mountain frontier of dark limestone overlaid by red sandstones with low northerly dip which can be traced, albeit with interruptions all the way to Yeshil Köl forming its steep northern shore. In the field, this was interpreted as representing the normal succession of higher strata of the sequence along the southern side of Lake Lighten. A chain of hot springs along the foot of the escarpment, partially sublacustrine, shows that a zone of fracturing here cuts the depression.

This autumn (1977) I received an interesting paper by V. A. Shvol'man (1977) on the tectonics of the Pamirs during Cretaceous and Paleogene time in which special attention has been paid to the volcanic development. This induced me to investigate anew the volcanic rocks contained in the corresponding sediments in western Tibet from the petrographical point of view.

In Fig. 3, my section across the Late Cretaceous sequence in the escarpment of the plateau north of Yeshil Köl, described in 1946, is reproduced

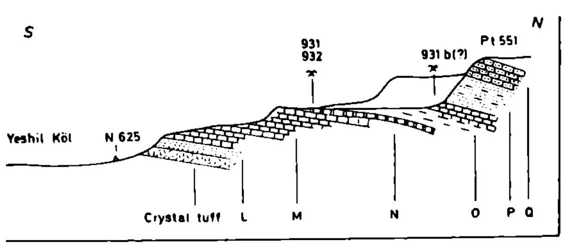

Fig.3. Section at Camp N625 on the northern shore of Yeshil Köl (Legend and scale, see Norin 1946 pp. 43—44).

with some additional data (cf. map and section 1946 pp. 33 and 43). According to my diary, the lowest outcrop visible here is a bed of red brown porphyry (spec. 929) with an exposed thickness of about 10 m and very low northerly dip. The base is not exposed, being hidden by young alluvials. Actually, the "porphyry" is a trachytic-dacitic crystal tuff composed by broken fragments of large phenocrysts of slightly turbid orthoclase, several mm in size together with solitary minor phenocrysts of corroded quartz, embedded in a very hard crypto-crystalline groundmass of undefined composition, probably fine silicified ash. The quartz phenocrysts do not exhibit any traces of strain shadows. The tuff seems to have been subjected to weathering.

Fine-grained red sandstone (Hor. L) rests conformably upon the tuff without any basal transitional sediment; it grades higher into yellowish white shaly calcareous sandstone, altogether 10—20 m thick, and followed with a rather sharp contact by light grey and nearly white, very fine-grained limestone (spec. 930) with partly brecciated layers of black chert (930b) and with a thickness about 100 m (Hor. M). Next follows grayish black bituminous limestone of slightly coarser grain-size (Hor. N) about 10 m thick, with layers filled with small *Ostrea*, gastropods and a few foraminifers of the genus *Globigerina*. It is overlaid by light grey calcareous shales passing into light grey, very fine-grained limestone (Hor. O) about 30 m thick. From here originates Spec. 931b, collected in the detritus below the outcrop. In this rock F. Brotzen identified *Quinqueloculina*, *Globigerina*, *Guembelina*, *Haplophragmoides* or closely allied forms. Upon this horizon then follows yellowish grey and red brown clayey fine-grained sandstone (Hor. P), about 30 m thick, followed conformably by still another horizon of light grey, thinly stratified clayey limestone (Hor. Q) probably about 50 m thick. This horizon becomes shaly in the upper part, where some small shells were collected by my travelling companion Dr. Liu Ch'eng Ngo.

The total thickness of the Yeshil Köl section above the basal tuff amounts to 200—300 m. There is probably a disconformity of some size at the top of the tuff. The sequence contrasts conspicuously with the Cretaceous sequence south of Lake Lighten by the absence of red conglomerates and by the predominance of light grey or nearly white limestones and shales. Comparing the stratigraphic development of these two sequences, the data available distinctly indicate that the stratigraphic sequence of the Yeshilköl Series is younger than the upper red conglomerates, Hor. J, in the section south of Lake Lighten. The few fossils collected in Hor. N and Hor. O in the Yeshilköl Series may indicate, according to Brotzen, that also these horizons still belong to the Upper Cretaceous and possibly to its uppermost stages. This suggestion is supported by Shvol'man's investigation of the equivalent formations in the Pamirs.

Summing up, we have found that the Upper Cretaceous sedimentary sequence with an aggregate thickness estimated to about 2 km exhibits progressive rhythmic subsidence of this part of the earth's crust, whose surface, levelled to a peneplain by intense chemical weathering, only temporarily rose above the level of the ocean throughout Upper Cretaceous time. During the submergences only small quantitites of fine-grained sandy terrigenous material was therefore deposited along the shallow coasts whereas thick formations of limestones, generally of light colours, are markedly predominant. In this huge sequence of mainly marine strata, very thick conglomerates appear at two horizons, viz. the thick bouldery "Loqzung Conglomerate", Hor. D, which is followed by eruptions of highly mafic tuffs, Hor. H, and the thick beds of red conglomerates of piedmont facies, Hor. J. Assuming that the Yeshilköl Series represents stratigraphically the higher continuation of the Lake Lighten Series it follows that the formation of the red piedmont conglomerates, Hor. J, was succeeded by a stage of trachytic-dacitic volcanism, Hor. K, and subsequently by a stage of denudation.

The following sequence, viz. Hor. L—Q, records a new marine transgression with submergence and deposition of very uniform light coloured calcareous silts and limestones several hundred metres thick, and with only a thin basal sandstone bed resembling the one above the disconformity at the base of the Cenomanian in Aksai Chin, and proving the flatness of the land surface. The only feature interrupting the uniformity of the calcareous sediments at Yeshil Köl is the appearance of partially brecciated layers of black or brownish chert, until finally above the uppermost limestone, Hor. Q, sediments of entirely different flysch-like facies follow, terminating the marine regime.

At Ak Tagh on the Kushku Maidan plateau, between the Karakoram Pass and the crest of the Suget range, a thick, very young series of light coloured sediments only slightly disturbed and without any traces of metamorphism, was discovered by F. Stoliczka in the 1870s. These beds are unlike everything else known on the heights of the K'unlun. This peculiar series, exposed along the Karakoram main trade route, was investigated in the 1940s by N. A. Belyayevskiy who describes it as follows (1966 p. 132): "On the northern borders of the Karakoram (lower reaches of the Karakoram river and the Saryk-Darvaz landmark) the Tertiary deposits have a completely different stratigraphic section, which starts with red and red-brown conglomerates bedded on the eroded surface of lower Paleozoic Kunlun schists at the head. A higher position is occupied by gravelly coarse-grained and medium-grained sandstones, which gradually change colour from orange-red to yellow. Among these sandstones are lenses of quartzose-siliceous conglomerates. This part of the section reaches a thickness of 300 m. Above it lie brownish, cavernous Eocene limestones with poorly preserved *Nummulites*, to a thickness of 15—20 m, above which lie reddish-gray, compact, obliquely laminated sandstones, presumably of Oligocene-Miocene age. The section terminates in a group of gray, coarse conglomerate strata greatly resembling the Pliocene-Pleistocene conglomerates in the Kunlun foothills."

In this description I may draw attention to the appearance of "quartzose-siliceous conglomerates" in the middle part of the sequence. The nature of these "conglomerates" is not discussed by Belyayevskiy. They recall, however, to me the occurrence of certain sedimentary quartz-chert-coal breccias in similar sediments in the Middle K'unlun (cf. p. 30 below and the occurrence of layers of partially brecciated chert in Hor. M of the Yeshilköl Series. A closer investigation of the Aktagh siliceous conglomerate is therefore of great interest. The stratigraphy of the Kushkumaidan transgression resembles the one recorded in the Yeshilköl section which probably also lasted into the beginning of Tertiary time although the disconformity at the base of the series is not so conspicuously in evidence because of more distal situation relatively to the watershed of that time.

In the basins of the upper reaches of the Raskam Darya and Shaksgam Darya, the Upper Cretaceous is represented by Cenomanian and Turonian limestones associated with red marls and calcareous sandstones more than 400 m in thickness. The principal difference of the stratigraphy of the Upper Cretaceous in the Pamirs compared to Western Tibet is that Cenomanian marine limestones of considerable size are rarely found in the former region. Instead we find in the Pamirs abundant evidence of intense denudation prior to the Senonian transgression. We have seen above that in Western Tibet, the Loqzung Conglomerate records a stage of intense erosion posterior to the deposition of the higher post-Turonian limestones in the Pamirs.

The easterly termination of the Western K'unlun ranges

East of long. 81°1/2, there is a most remarkable, sudden change in the orography of Northern Tibet (Fig. 4). Until now we have seen to the north the tremendous snowy frontier of the Southern K'unlun, the rather flat crest of which extends at an average altitude of about 6500 m, one huge block behind the other, separated by narrow, straight, abyssal valleys. Seen from the pass 5554 at long. 82° (Fig. 5), we are now facing to the north and north-east a different landscape: it is a terrace landscape on a gigantic scale, where the terraces are the edges of mountain plateaus sloping softly to the north. The first terrace edge rises above the basin of Yeshil Köl and extends far to the east (I). The next one is at the pass upon which we are standing (II), being fringed to the south by a fracture extending in a straight line to ENE along the northern shore of Hedin Tsho, gradually verging into due east about long. 83°. The third terrace edge rises with a straight and steep frontier 10 km north of the latter, extending ENE and then dwindling eastwards in the plain. It constitutes the southern margin of a flat swelling covered with young latitic lava beds, culminating in the large dôme-shaped volcano 5891; another zone of fracturing (IV) delimits this swelling to the north, converging towards the west. The fifth terrace edge (V) is the steep, straight frontier of the snowy range of Koramlik Tupe Tagh that rises isolated out of the plain to a height of 6000 m, trending N65°E, verging into due east at long. 83°, and merging farther east into the rocky plain, where the range disappears as an orographical feature. The Koramlik Tupe Tagh has the appearance of a tilted flat block sloping gently northwards and wedging out at both ends.

North of this step rises the next block called Koramlik Muztagh, the highest in the K'unlun System with several peaks about 7000 m, trending north-east. The granitic core of this range is fringed by huge, very young black lava beds upon its northern slope along the Keriya Darya. This huge block ends at lat. 35°43′, then it suddenly dwindles, the direction verges into ENE and E, where the last exposures of its granitic core are found in the narrow range Pt. 5895. Farther east, this dwindling outlier of the mighty K'unlun can no more be distinguished on the rocky plateau, the northern rim of which, called Ustan Tagh, towers steeply along the rift valley of Sarigh Tuz. This is seen clearly on the ERTS photo (Fig. 5). Neither did N. P. Ambolt, in 1932, find any traces referrable to a reappearance of the range during this topographical survey at long. 85°1/2 E. Also here the same flat hilly plain expands with a few solitary residual plateaus and massifs, the lowest point measured here (Camp A 505) descending to 5028 m.

The great zone of fracturing that extends along the upper Keriya Darya separating Koramlik Muztagh from the next high K'unlun block to the west, called Aksu Muztagh, passes over the pass of Keriya Davan (Keriya Kotel Davan), which is the main K'unlun watershed. This zone of fracturing extends along a straight line in N52°E and continues with exactly the same direction along the lower Sarigh Tuz Jilga, cutting across the Ak Kar Chakil Tagh, the total length amounting to about 240 km. In the south-west, this fracture ends at the great depression marked by Lake Lighten and Yeshil Köl.

This peculiar "terrace topography", characteristic of the Middle K'unlun, is due to the fact that the region, like other parts of the Tibetan plateau, originally constituted a part of the Sub-Cenomanian surface of denudation which subsequently became split and dismembered by dislocations during the general upheaval at a late stage of the geographical development. The remains of ancient surfaces of degradation that can still be traced by toplevel constancy upon many K'unlun blocks, evidently belong to the same system of surfaces of denudation as found elsewhere on the Tibetan plateau.

Part of this region (map Fig. 4) was surveyed by myself and the Chinese botanist Dr. Liu Ch'eng Ngo in the summer of 1932. The flatness of the larger part of the country which nowhere descends below 4900 m.a.s.l., the nearly daily blasts of westerly violent wind and the frequent snowstorms even in the height of the summer, were extremely trying for man and beast. Out of our 33 transport animals, only one donkey and one mule, but fortunately all men, finally reached the gold field at Kan Bulak in the sheltered Sarigh Tuz Jilga. So far no report has been published because the very scanty fossil material did not allow accurate dating of the various formations. However, the region being of outstanding interest geologically, I find it motivated to present here the data available.

Stratigraphy of the Sarightuz Complex

In 1973, Professor N. A. Belyayevskiy drew my attention to a new geological map of China on the scale of 1:4 000 000, published by the Chinese Petroleum Corporation, Taiwan, in 1970. On this map, which includes also the region reconnoitred by myself, a broad belt of Jurassic-Cretaceous formations extends along the valley of Sarigh Tuz, associated to the north with Neogene sediments which ascend to the very summit of the frontier range. South of the Sarigh Tuz, the greater part of the high plateau land consists of supposedly Paleozoic formations, but for a large outlier from the northern Mesozoic-Neogene belt. This is a similar zonal distribution of the rocks as shown also on my map, the principal difference being that the age of the supposedly Paleozoic sediments, which dominate the central part of the Chinese map, was referred by me tentatively to the Upper Cretaceous-Paleogene.

The fundament of this complex is excellently exposed in the upper Sarigh Tuz Valley along the southern slope of Aq Kar Chakil Tagh. It is a series of dark calcareous shales and limestones, passing at the top into, and terminating with, a huge horizon of black chert at least 50 m thick, an excellent index horizon which could be traced 30 km down the valley to Kan Bulak. Then the basal division of the Sarightuz Complex follows conformably, beginning with coarse, well waterworn, polymict conglomerates interstratified with gravel beds and mainly reddish sandstones several hundred metres thick and locally with streaks of coal. These sandstones merge by interstratification into Division B ("Yellow Series") of mainly yellowish and light greenish, fine-grained calcareous sandstones and silts, interstratified with black shales with an aggregate thickness of about 1 km. The stratigraphic relationship between the "Yellow Series" and the younger part of the sequence, Division C, is not definitely established. This series of very peculiar lithofacies consists mainly of black shales, aleurolites, dark fine-grained graywackes, siliceous sediments, sandy marls, coarse sedimentary chert-quartz-coal breccias and — in the lower part — one or two thin intercalations of marine fossil-bearing, bluish gray limestone. The total thickness is of similar magnitude as that of Division B. North of Muztagh, several sills and probably also effusive beds of altered basaltic-porphyritic rocks occur in the boundary zone between Divisions B and C.

Thus, apart from the elevated horst-blocks, the whole area of hilly plains on the map seems to be built up of one coherent sequence of mainly fine-grained sediments, representing a more or less continuous process of sedimentation of great thickness, without any apparent major breaks. So far, the only true conglomeratic formation observed along the three sections traversed during our reconnaissance is the basal conglomerate of Division A. The only fossil-bearing marine limestones encountered are the thin intercalations of "crinoidal limestone". Coaly fragments of plants and silicified twigs of wood were found at several places in the graywackes. In order to emphasize the peculiar geographical milieu, about 120 km wide, in which these sediments were studied, the region may be distinguished as the Cenozoic K'unlun syneclise.

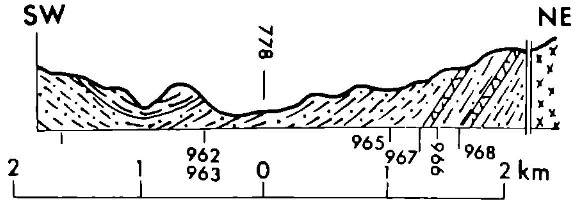

Fig. 6. Section of the transverse synclinal graben below Kan Bulak. Figures indicate specimens collected.

The basal red conglomerate-sandstone, Division A, begins with thick beds of well waterworn, coarse, polymict conglomerates with numerous large boulders int. al. of granite, interstratified with medium-grained gray sandstones, followed by red and greenish gray shales, gravelly gray (spec. 958) and red sandstones (957) with a total thickness of several hundred metres. The sandstones are fairly even-grained (0,2—0,5 mm), the sand partly well rounded and closely packed, consisting mainly of quartz, limestone, chert and feldspars. The sequence is then cut by a fault passing south of Khangit Köl, and then the strike of the strata changes abruptly to N 56°, 5 E. At the gold pits of Kan Bulak, the red sandstones and the subjacent horizons of black chert and calcareous shales still form the slope of Aq Kar Chakil Tagh. Below Kan Bulak a synclinal graben, composed exclusively of sediments of the "Yellow Series", cuts obliquely right across the range, the axis trending west-north-west (Fig. 6). The northerly limb gradually becomes schistose and phyllitic with sills of much altered gabbroid rock with moderately steep southerly dip, bordering on only slightly deformed granite; the southerly limb is delimited by large steeply dipping quartz breccias with the same trend.

From Camp N648, the gray coarse granite (spec. 997) continues 2 km down the valley where it borders on red quartzitic sandstone (998), rather similar to spec. 957 and 958, apart from somewhat larger grain size and better roundness. The sandstone is overlaid by golden yellow sericitic slate of the Yellow Series, both with moderate southerly dip. Higher up the slope, the granite passes into gneisses and crystalline schists. Ten km below Camp N648, where a large tributary enters from the north, the red sandstones extend to the very watershed. Now, numerous boulders of red conglomeratic quartzitic sandstone begin to appear in the valley, together with boulders of strongly wrinkled phyllites and mylonitized granite. The well rounded pebbles in the conglomerate which seem to consist mainly of quartz and quartzite in a red matrix, are intensely deformed with transitions from only slightly compressed oval pebbles and pebbles deformed into long narrow lenses tapering out at the ends.

The Yellow Series and the subjacent red sandstones extend with moderate southerly dip all the way from Camp N669 to a point 5 km below Camp N670. At first we have the Yellow Series mostly in the shape of sericitic phyllites interstratified with dark slates, wedging out to ESE; then red quartzitic sandstones and much distorted slates and sheets of granite-mylonite follow, wedging out to ESE; finally at Camp N670 the red quartzitic conglomerate with its squeezed pebbles reaches the bottom of the valley, exposing beautifully the zone of overthrust upon crushed or mylonitized granite. The magnitude of this overthrust must be quite considerable. Judging by the stratigraphic succession, it seems very likely that the deformed conglomerate at the crest of Aq Kar Chakil Tagh represents the remains of the basal conglomerate of the Sarightuz Complex as exposed in the upper reaches of the Sarigh Tuz Valley.

The Yellow Series B is composed of fine-grained yellowish calcareous sandstones and silty sediments more or less densely interstratified with black shale throughout its great thickness without any definable lower and upper boundary. There seems to be a gradual transition everywhere by interstratification into the adjacent formations. The Yellow Series attains its greatest thickness in Ustan Tagh and in the transverse synclinal graben between Kan Bulak and Camp N648 where the thickness may amount to about 1 km. In the southern belt, north of Hedin Tsho, the thickness is probably less.

In the northern belt, the subjacent Red Sandstone Series often contains streaks of coal and plant fragments, but even in this boundary zone, black shales begin to appear. At Ustan Tagh, the yellow calcareous silt or fine-sandstone is densely interstratified with beds of gray and black shales, 1—3 feet thick. The sediment is always more or less calcareous, the content of $CaCO_3$ varying between 9,1 and 28,9 % in five samples. The grain size mostly fluctuates between 0,06 and 0,2 mm, the grains usually being subangular and seldom well rounded. The principal mineral constituents are quartz which greatly predominates, acid plagioclase and potash feldspar, chert and sparingly minute flakes of sericite and altered biotite, usually in a carbonatic and/or limonitic matrix. In some specimens (978, 990), grains of chert or silexite are quite common but it is often difficult to decide whether they represent individual sand grains or a siliceous matrix. Some coarser varieties (978) are conspicuously equigranular (about 0,5 mm) with closely packed grains. Gravelly or conglomeratic beds have nowhere been observed in the series.

Higher, the facies changes into greenish gray and dark gray fine-grained sandstones and shales, and also beds of red shales appear occasionally, besides the black ones. The structure of the formation as conceived during my quick reconnaissance is shown in Sections I and II (Fig. 7).

Westwards the Yellow Series occupies a broad zone on the Ustan Tagh plateau with similar facies and apparently synclinal structure as shown in the northern part of Section II. Here, the occurrence of several distinct strings of detritus of altered basaltic or porphyritic (spec. 956) rocks indicate the presence of sills of volcanics in the series. The position of the strata is here uncertain because of the absence of observations on rocks in situ. However, at km 28 (north) grayish green paper-shales and sandstone are recorded dipping 80°NW, bounded probably by a fault a short distance farther south.

The flat massif between km 24 and 20 is composed of very uniform beds of fine-grained grayish green siliceous graywackes (spec. 955) and sandy shales dipping 10—15°N. On the plain between the lake (km 21) and Camp N644, there are numerous boulders and fragments of altered basaltic rocks (954) carrying large porphyroblasts of pea-sized red garnet, which make the rocks resemble eclogite in hand specimens. They probably represent sills in undulating position at a shallow depth, as indicated by the position of spec. 954 and the sill, spec. 975, at km 14.

In a small ridge at km 13, a narrow syncline is sharply outlined by a thin bed of a bluish black, dense, siliceous and slightly calcareous pelit (spec. 952) intercalated in fine-grained dark graywacke and black aleurolitic sediments. Below then follows, at km 11, a bed of coarse detrital, sedimentary chert-quartz microbreccia, a few feet thick, underlaid by a thin bed of bluish gray limestone and below this one another bed of marl weathering with conspicuous brownish colour, the whole sequence with moderate northerly dip. Below the marl, yellowish calcareous silt and sandstone inter-

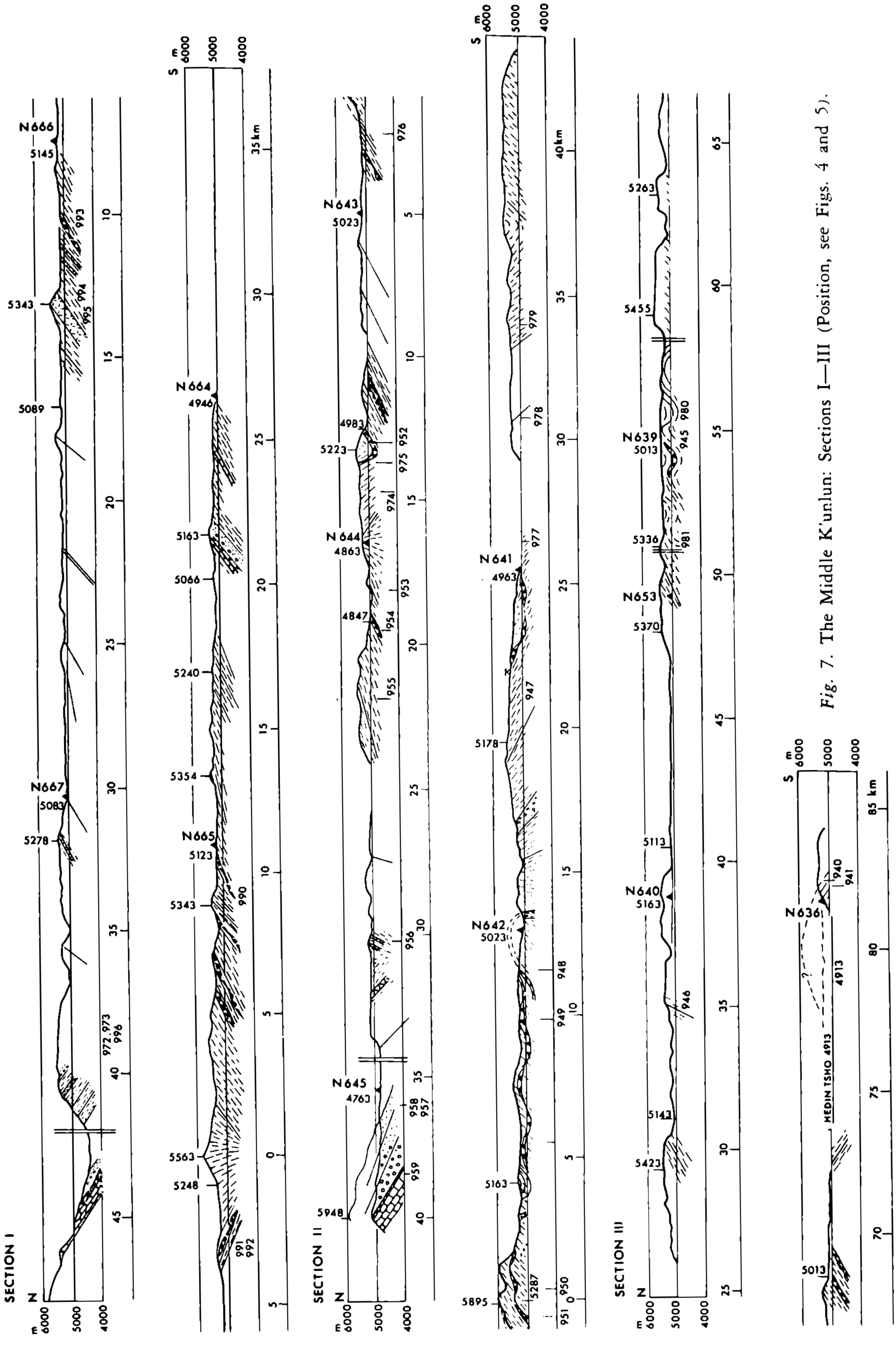

Fig. 7. The Middle K'unlun: Sections I—III (Position, see Figs. 4 and 5).

stratified with several beds of bluish black pelite crop out over a distance of about 1 km on the gravelly plain. Between Camp N643 and the foot of Muztagh my diary records a succession of grayish green sandstones of varying grain size, containing coaly plant fragments, aleurolites, black shales, and at least one horizon of chert-quartz sedimentary microbreccia. At km 2,5 (north), a belt of numerous large boulders of fine-grained granodiorite (spec. 976) and dacitic quartz porphyry (951) extends along the mountain frontier, derived from sills in the northern slope of the ridge 5895, on the top of which a bed of quartz porphyry rests in horizontal position. This is the only place where intrusive granitic rocks were observed in situ in the sedimentary complex (cf. p. 30 below). It should be noted that no trace of strain-shadows occur in the large quartz phenocrysts in the porphyry.

I crossed the Muztagh pass (5283 m) twice, once on the way north and again on the way south. We have here similar dark grayish and greenish sandstones or graywackes as before, viz. black partially coaly shales, and calcareous sediments amongst which one or two very persistent thin beds of dark bluish gray sandy marl (spec. 950) stand out very distinctly in the terrain by the brown weathering, showing a very flat undulating position of the strata. It is a fairly evengrained, fine sandy marl (9,84 % CO_2) containing about 20 % of detrital grains of limestone, quartz, plagioclase and chert in a cryptocrystalline matrix. Below the marl, a bed of sedimentary chert-quartz breccia, a few feet thick crops out. At km 3 (south) a thin bed of bluish gray limestone is exposed.

All the way from the Muztagh pass to Camp N642, we passed a flat hilly plateau where the marly horizon 950 or closely associated strata extend in undulating position. At Camp N651 on the large plain, fine-grained sandstones crop out interstratified with beds of black shales or aleurolites, thin beds of dark siliceous marls, and coarse-grained sedimentary chert-quartz breccias dipping 10—15° to N 15°W. This plateau ends at km 12 (south) with an escarpment, exposing the subjacent sequence of graywackes, calcareous shales and beds of sandy or silty siliceous marls, which are underlaid at the foot of the cliff by a thick bed of bluish gray "crinoidal limestone" with moderate northerly dip. A few fragments of "crinoid stems" and a fragment of a coral were collected here (coll. 948). Between this point and Camp N642 the strata form a dôme-shaped structure, the center coinciding with the broad stream bed. There are here numerous low outcrops of grayish brown calcareous graywackes with beds of "impure marl" and coarse-grained sedimentary chert- quartz breccias in undulating position. In a ridge closely south of Camp N642, the "crinoidal limestone" crops out again with steep southwesterly dip, due to a fault. The limestone is here at least 5 m thick and is overlaid conformably by two beds of coarse sedimentary chert-quartz breccia, each about 1 m thick, separated by marly sediments.

South of Camp N642, another flat plateau with low ridges extends to Camp N641 (km 27, south). It is the easterly extension of the Koramlik Tupe Tagh block. Here is exposed, at km 15, grayish green brittle sandstone dipping 60° to S 15°W, bordering about 1 km farther south on reddish sandstone and shale dipping 30° S. This red horizon can be traced along the margin of the plateau far to the east. Then the same succession of dark greenish gray calcareous sandstones, sandy calcareous shales and solitary beds of dark pelite follow with persistent southerly dip of about 20° to km 22, where the typical bluish gray "crinoidal limestone" crops out again in flat undulating position, being exposed for a distance of about 5 km. The bed is here only about 1 m thick. Some fragments of "crinoid stems" were collected at Camp N641 (coll. 947). The limestone bed is overlaid at many places by coarse sedimentary chert-quartz breccia, and then by marly argillaceous sediments and calcareous sandstone. At the margin of the plateau the "crinoidal" limestone is underlaid by calcareous graywacke with a thin bed of bluish black pelite and — lowest — dark gray, fine sandy marl (spec. 977) with about 40 % detrital grains mainly of quartz, fresh acid plagioclase and some grains of opaque substances in a calcareous matrix (9,08 % CO_2). The sparseness of grains of chert or silexite is noteworthy.

It is seen in Section II that, all the way from Camp N644 on the northern side of the Muztagh pass to Camp N641, a distance of 44 km, we have been passing over a comparatively thin blanket of consanguineous sediments, only slightly deformed, in which the "crinoidal limestone" and beds closely associated with it constitute characteristic marker levels. The thickness of this evidently limnic sedimentary sequence may be estimated to, perhaps, a few hundred metres only. Unfortunately I did not realize in the field the peculiar petrographic composition of these sediments which usually were recorded in my diary as "argillaceous limestone", "impure limestone", "argillite", "sedimentary breccia", etc. of which too few typical specimens were collected. An adequate description of the mutual relationships of the different types requires much more material for comparative study than was collected during my reconnaissance.

Some of the index horizons in Section II were recognized readily in Section I that extends about 25 km farther east in the same direction. Thus, near Camp N664 the 'crinoidal limestone' crops out, dipping 30°NNW. The dark bluish gray limestone is here about 10 m thick and is underlaid conformably to brownish weathering, sandy gray shales, darker paper-shales and calcareous sandstone. At km 22,5 (south) red fine-grained schistose sandstone and shales with about 30° northerly dip follow, forming the southern slope of the ridge 5163. From its crest, the red beds can be traced westwards along the margin of the plateau to the similar outcrops south of Camp N642. In the northern slope of the ridge 5163, the 'crinoidal limestone' crops out striking N60° E; the dip is here uncertain because of the strong disintegration of the rock, but is probably steep, due to a fault. The limestone is, however, identical with that one at km 25.

Between this place and Camp N665 I have only few observations on the rocks in the mostly flat gravelly terrain. At Pt. 5114, I have noted calcareous sandstone and brownish "impure limestone" dipping 20—30° north. Then, mostly calcareous sandstones and sandy shales were the principal sediment to Camp N665 where a northerly dip of 5—10° could be measured. Because of the generally low, disconnected and strongly disintegrated outcrops in the plain, the dip is difficult to ascertain and may often appear steeper than is actually the case. My impression was that the strata rest with rather flat undulating position, the axis of folding trending nearly due east, and that therefore deeper horizons were not exposed.

North of Camp N665 ridge 5343 rises; it is the main watershed in this part of the Middle K'unlun, although situated about 10 km south of the eastern extension of the Muztagh main range that is marked by the elevations 5513 and 5583. In the flat southern slope of the ridge 5343, beds of "impure brown marl" crop out with a low northerly dip, overlaid at the pass by medium-grained brownish gray marly sandstone (spec. 990) with rather steep northerly dip. In the depression on the northern side, calcareous shales and brown "impure marl" follow, associated by an horizon of coarse chert-quartz breccia. In the next ridge to the north, similar coarse detrital sandstone appears again with a moderate dip to the NNW, and 1 km farther north, gray sandstone and sandy shales with another bed of brown "impure marl". At the entrance of the transverse valley through Muztagh, grayish green schistose sandstones and shales were recorded dipping 30—45° NNW.

At the western end of the ridge Pt. "1035" in the northern forehills of Muztagh, 5 km south of Camp N666, the division with sedimentary chert breccias is well exposed. Here, gray and reddish sandstones of greatly varying coarseness are interstratified with beds of black shales with thin cleavage and brownish shales with a southerly dip. This is the same kind of sedimentary breccia as observed at many places along Section II associated with marly and silexitic sediments. In the low hills at Camp N666, schistose grayish green argillaceous sandstones are recorded with low dip to NNW. A few km farther north, black shales and beds of nearly black sandy marl (spec. 993) predominate. The coarseness of the sandy component of the latter (about 20 %) averages about 0.2 mm and consists mainly of quartz, chert and acid plagioclase in an abundant carbonate matrix.

North of Camp N666, sills of more or less strongly altered mafic rocks begin to appear, followed 5 km north of the camp by a thick, massive body of diabase (spec. 994) with apparently moderate northerly dip, which forms the high ridge 5343. The lower part of this formation consists of much altered basalt (spec. 994) with idiomorphic, more or less saussuritized plagioclases, chloritized or uralitized pyriboles, ore grains and interstitial quartz, but no garnet. The upper part (spec. 995) has the appearence of an originally probably hypocrystalline andesitic lava with large idiomorphic phenocrysts of plagioclase and hornblende. The plagioclase is in part clear, untwinned and albitic, in part entirely decomposed into turbid, cryptocrystalline masses and calcite. The hornblende, often developed as long, slender prisms, is entirely chloritized. The groundmass is altered into microcrystalline substances. In addition solitary large porphyroblasts of rounded crystals of red garnet occur, some ones several mm in size. The lava is overlaid by gray phyllitic shales and fine-grained graywackes.

This ridge constitutes one of a string of isolated ridges in the plain which extend far eastwards, and which westwards is represented in the direction of the strike by the ridge 5288 and its outliers of mafic garnet-bearing sills in the neighbourhood of Camp N644 and farther south.

At km 24, the plateau terminates with a steep escarpment, 120 m high, below which a broad stream bed runs slightly south of west, draining ultimately into the lake north of Camp N644. This fracture is evidently tectonically outlined. North of it, a wide gravelly plain extends with only a few scattered low outcrops. At km 25, the sediments consist of fine-grained, greenish sandstones and sandy shales with about 30° northerly dip which, a short distance farther north, decreases to 5—10°. These sediments much resemble those occurring west and north of Camp N644. Still farther north, at Camp N667, the typical yellow calcareous sandstones and dark shales of Division B crop out with northerly dip.

The intimate consanguinity of the yellow calcareous sandstone-silt sediments and the black shales is apparent in the frequent interstratification throughout the Yellow Series, although the former greatly predominate. Besides black shales also beds of red sandstones and shales enter subordinately in the Yellow Series, especially in its lower part. The appearance of the thick, main body of black shales upon the Yellow Series is, however, associated with the first appearance of one or two thin beds of marine limestone, the "crinoidal limestone" in the lower part of the Black Series, proving a temporary transgression of the sea of wide extension over the flat delta deposits. The thickness of this limestone varies between about 1 m and 10 m at the localities investigated. Its persistence, in spite of its thinness, shows the flatness of the region invaded by the sea. The fossils collected in the limestone, viz. "crinoidal stems" and a single fragment of a coral, have been studied by several prominent specialists who, however, did not venture a determination even as to the genus, but all agreed upon the marine nature of the sediment. This is the only horizon of fossil-bearing marine limestone encountered, so far, in the Saghtuz Complex.

The strata associated with the marine horizon above as well as below it, usually contain levels, one or a few metres thick, of marly and siliceous sediments with much varying composition and structure as described above. Among these sediments the coarse chert-quartz-coal breccias are very conspicuous being the only more coarse-grained sediment in the whole sequence above the basal red sandstone series. These detrital sediments consist of angular or more or less rounded fragments, several cm in size, of black, brownish and gray chert together with varying amounts of milky quartz and fragments of coal, and sometimes also fragments of limestone, scattered in finer sand of the same material or a marly or siliceous base. The horizons of spec. 991 and 992 in Section I are most instructive. The former consists mainly of large irregular pieces of black, brownish and gray chert, and only a few fragments of "milky quartz" with sparse interstitial material of quartz and chert. The large angular fragments of chert are usually only slightly rounded at the corners as if slightly water-worn, but have not been subjected to considerable transport after disintegration. The breccia resembles a broken solid sheet of chert of various colouring, mainly gray with streaks of black and brownish silexite, the cracks and interstices being filled with fine sand of quartz and chert.

The neighbouring horizon, spec. 992, is a medium-grained to coarse sandstone with numerous angular and rounded fragments of cm-size of black and brownish coaly chert and large pieces of coal, embedded in sand of medium coarseness (0,6 mm), consisting mainly of better rounded grains of similar chert and quartz. Some large fragments consist of black coaly chert with streaky, apparently organic structure like that of silicified mouldering wood. The fragments of coal are sometimes difficult to distinguish from the black chert when not recognized by the softness and the black streak. One fragment in spec. 992, that was subjected to partial analysis contained 60,24 % C + H_2O^+ and 13,35 % SiO_2. Most of the larger irregular fragments of quartz is of pegmatitic type or "milk quartz", probably derived from quartz veins. Most of the mineral components of Hor. 992 are clearly water-worn and may have been derived mainly from disintegrated beds of chert, the material of which has been subjected to transport by water.

Closely associated with the sedimentary breccias on the one hand and with the "crinoidal limestone" on the other is the rather coarse-grained marly horizon of spec. 949 at km 10 (south) in Section II. It is composed mainly of irregular fragments of chert and quartz, and more subordinately feldspar in a calcareous matrix (8,32 % CO_2) with much opaque dust. To the same association belongs also the horizon of spec. 950 at the Muztagh pass, a fairly even-grained (0,2 mm) sandy marl (0,84 % CO_2) with detrital quartz, limestone, chert and feldspar. A frequent, more purely silexitic variety is represented by the slightly hornfelsic, sandy silexite, spec. 952 (Section II, km 13). It is a bed of bluish black, hard pelite, a few feet thick, consisting mainly of crypto-crystalline silexite and sparingly calcite (1,87 % CO_2) containing for the rest about 10 % of fine-grained detrital material, mainly quartz and plagioclase. Another variety closely associated with the sedimentary brecccias in Section I is the horizon of spec. 990, a light brownish gray, calcareous sandstone (7,58 % CO_2) consisting of angular grains of quartz, better rounded grains of chert, limestone and a little plagioclase.

In the usually greenish and grayish graywackes between Camp N664 and N665, slender, sandy, cylindrical formations resembling twigs of wood were often observed and also fragments of coal. Other fine-grained graywackes exhibit distinct cross-bedding.

The thin beds of marls, silexites and sedimentary chert-quartz-coal breccias are apparently closely associated with the marine sediments. Their lithology suggest that these sediments were deposited in a limnic milieu of low relief with abundant vegetation where coarser fluvial sediments were not deposited. The great thickness of the previously deposited sediments of the Yellow Series, the facies of which frequently merges into black shales facies as shown by the interstratification, suggests persistent subsidence of the sedimentary basin.

The peculiar facies and wide distribution of these limnic sediments is, in my experience, unique in Central Asia and Tibet. The only sedimentary formation presenting certain resemblances are the siliceous delta sediments of Cenomanian-Turonian age in the Kyzyl Kum (Aralo-Kyzylkum Series) along the northern marginal region of the Cretaceous Sea in Soviet Tadzhikistan, described by S. S. Shul'tz Jr. (1972). It is a sequence of delta deposits, 300—500 m thick, with brackish ingressions of the sea and coarser deposits of ancient rivers as well as variegated clays and sandstones. Some of these beds contain remains of turtles and crocodiles, others an abundance of silicified wood (genus *Cupressinoxylon* Goeppert). According to Shul'tz, this type of riverine delta may have resembled certain mangrove deltas of today (Shul'tz 1972 p. 95).

The relationship between the Yellow Series and the thick formation of black shales in the southern belt of the Yellow Series in the region between Hedin Tsho and Koramlik Muztagh, is rather peculiar, the boundary being often associated with a broad belt of white quartzy gravel or detritus (Ak Sai or White Plain). It is a very conspicuous feature in the landscape between Pul Tsho and Hedin Tsho. Travelling from Camp N657 (4912) towards the north-north-east, the first outcrops of solid rock north of the river were observed in the wide plain 4 km south of Camp N659. Here calcareous shales crop out with a bed of black crystalline argillaceous limestone (spec. 983) that exhibits typical "cone-in-cone" structure, underlaid by black slightly phyllitic shales dipping 20° to S5°W. Below the black shales grayish green shales and calcareous sandstones then follow with the same dip. These light greenish and yellowish sediments are exposed in shallow outcrops all over the plain between Camp N659 and the steep margin of the western basalt plateau forming the fundament to basal basaltic tuff and the lava beds. They represent the upper part of the Yellow Series of the Sarigh Tuz region.

Near the boundary to the black shales, the Yellow Series is here intensely impregnated with veinlets and sills of pegmatitic quartz, as much as a foot thick, parallel to the bedding. No veinlets of quartz were found in the Black Shale Formation nor in the basaltic rocks, neither do they occur in deeper horizons of the Yellow Series but are confined to a rather narrow zone in the upper part of the latter. From this zone, the abundance of white quartz is derived which is the principal component of the gravelly sai, the abundance being due to the flat orientation of the strata of the Yellow Series.

In a gravelly low ridge extending along the western side of the stream bed at Camp N659, there occur numerous large boulders, half a meter in diameter, of fine-grained, pink quartz-muscovite porphyry (spec. 984), microcrystalline yellowish gray quartz-porphyry (986) with phenocrysts of idiomorphic albite, potash feldspar, biotite and subidiomorphic quartz. Other boulders consist of clearly hybridic rocks, viz. spec. 985, a fine-grained, partially microcrystalline rock of quartz, feldspar and biotite with large diffusely delimited spots of untwinned oligoclase stained with minute clear droplets of zoisite and enclosing solitary idiomorphic crystals of twinned plagioclase. Another common variety is a fine-grained orthoclase-amphibole rock. Strain shadows were not noticed in the large quartz phenocrysts. The rocks exhibit certain resemblances to the porphyritic rocks of eastern Koramlik Muztagh (spec. 951 and 976). In spite of the large size and the abundance of these boulders of granitic rocks, which suggest the closeness of their source of origin, no veins or loose pebbles of them were found in the neighbouring hills, although searched for. The rocks seem to be confined to the depression around Camp N659 and farther north. Thus, similar boulders were noticed also in the large valley coming from Koramlik Tupe Tagh and opening near Camp N640.

The quartz-impregnated sediments of the Yellow Series are overlaid by the young basal tuffs and lava beds along the eastern border of the large shield volcano 5891 as well as below the small basalt-plateau remnant 5265 south of the larger one 5455, proving that the quartz impregnation as well as the folding are older than the eruption of the basalts. The quartz injection is therefore probably related genetically rather to the granitic volcanism, possibly in connection with translatory tectonic movements along the boundary between the Yellow Series and the Black Shales Series. This zone of translatory movements may possibly be correlated with the greater overthrusts at Ak Kar Chakil Tagh and the Sarigh Tuz Valley.

The mountain frontier south of Camp N659 is built up entirely by black shales with beds of schistose sandstones or graywackes dipping 15—20° south. In the southerly part, a few thin beds of bluish gray and black limestones are intercalated, probably the easterly extension of the limestone spec. 983 mentioned above. The same calcareous zone forms also the marginal part of the deeply dissected plateau that rises north-west of Hedin Tsho, here with shallow anticlinal structure outlined by one or two thin beds of bluish gray limestone. Eastwards this plateau-like highland ends in the wide gravelly plain that extends from the eastern part of Hedin Tsho northwards around Camp N638, but 5 km ENE of this camp an isolated large shallow outcrop of the Black Series indicates its farther extension below the alluvials in this direction.

This dissected plateauland north of Hedin Tsho is delimited to the north by an escarpment trending slightly north of east and marked on the map by the point 5333. The escarpment is outlined by a fault, the eastern extension passing between the two isolated remnants of the basalt plateau 5455 and 5265; farther east it passes along the northern front of the tilted plate, the warped edge of which is marked by 5313 and the pass north of Camp N661. This large fracture is numbered III on the ERTS photo Fig. 5.

In the west, in the escarpment below Pt. 5333, the sediments of the Yellow Series impregnated with quartz veinlets crop out with low southerly dip, overlaid conformably by the Black Shale Series. The Black Series seems to form all the neighbouring part of the highland visible to the south. The Yellow Series was traced eastwards along the escarpment to the basalt massif 5265 and then disappears below the alluvials. The Yellow Series appears, however, again in the steep escarpment Pt. 5313 that rises about 150 m high above the valley bottom on its northern side. It is the same fine-grained yellowish, calcareous sandstones and silt with apparently southerly dip as before. From the crest a flat gravelly sai descends to the south with low gradient of slope. Judging by the nature and the distinctly zonal distribution of the coarser gravel material, solid rocks extend at a shallow depth. At first, boulders and pebbles derived from the Yellow Series predominate down to Camp N661. Between this place and Camp 638, the plain is locally white due to quartz detritus showing that the horizon impregnated with quartz extends near the surface. Five km ENE of Camp N638, pebbles of bluish gray limestone begin to appear, increasing in frequency and size outside an extensive low outcrop of the Black Series close by, from which they are evidently derived. Pebbles of sedimentary chert-quartz breccia were also recorded here. These observations are in accordance with the assumption that the Yellow Series constitutes the warped edge of a plate sloping south, overlaid southwards successively by the zone injected by quartz veinlets, and then by the Black Series with intercalations of limestones and sedimentary chert breccias, i.e. the same stratigraphic sequence as in the western part of the same belt.

Also the next step in the "terrace orography" marked by the fracture IV that passes south of the large lake south of Koramlik Tupe Tagh and the large salt pan at long. 83°30'E, is distinctly reflected in the geological structure by the reappearance of the Yellow Series at this boundary, as seen on the map Fig. 4 and the sections. Also this block, about 20 km wide, is built up mainly by the sediments of the Black Shale Series, here more strongly folded than in the southern block, the axis of folding generally trending ENE. To this block belongs also the wide region of black shales which culminates in Pt. 5463 (Section II, km 30—45, south). Along its northern margin, the Yellow Series crops out with moderate southerly dip but the boundary to the Black Series was not investigated during our passage in a violent snowstorm. The boundary is, however, well exposed in the northern part of Section III (Fig. 7), not far to the west. Here, the Black Series, with a bed of marine limestone near the bottom, rests conformably upon calcareous gray sandstones and sandy shales of the Yellow Series, densely permeated by veinlets of quartz parallel to the stratification. This is the most northerly locality where this impregnation with quartz has been observed, and shows the wide extension northwards of this phenomenon.

The structure of the block of black shales between the fractures III and IV is shown schematically in Section III, km 47—58. In the plateau-like highland west and north-west of Camp N639, the dip of the strata varies irregularly at often high angle within a radius of a few hundred metres, showing the presence of superficial local structures. This is clearly seen along the valley running southwards down from Pt. 5336 to the lake at Camp N639. At 5336 there is a massive grayish green fine-grained siliceous graywacke (spec. 981), a hundred metres thick, with beds of "calcareous argillite" and shales in vertical position striking W—E, bordering to the south on the same graywacke in flat undulating position, where the amplitude of the folding is so shallow that the subjacent black shales reach the surface only locally. Petrographically the graywackes 981 (Section III) and 979 (Section II, km 34, south) are nearly identical with the thick Horizon 955 at km 22, Section II, on the northern side of the Koramlik Muztagh. Like the latter, they are composed mainly of closely packed sand grains (0,5—0,05 mm) of quartz and subordinately twinned acid plagioclase, but only a few grains of chert, with sparse interstitial silexite and opaque dust. In the bottom of the valley, this horizon rests upon black shales and thin beds of "calcareous argillite" in flat undulating position. In a synclinal fold at Camp N639, a horizon of coarse sandstone enters (spec. 980) composed of quartz and chert, in part coaly, very little feldspar and a silexitic matrix, probably a more fine-grained variety of the chert breccias. It is associated with grayish black silty sandstone (945). At 1,5 km south of Camp N639, argillaceous sandstone and black shales, dipping 45° to N30°E, form the northern limb of an anticlinal fold, the southern limb of which gradually becomes steeper and finally vertical at the foot of the basalt plateau 5455, the lava beds resting upon the truncated surface of the folded shales.

Concluding remarks

The Sarightuz Complex of Astin (Altyn) Tagh and the Middle K'unlun is here assumed provisionally to correspond to the Cretaceous sequence in the Yarkand depression, including part of the Paleocene. Accordingly, the thick formation of "red beds" conglomerates and sandstones of Division A in Sarigh Tuz Jilga should correspond to the thick basal Cretaceous conglomerates and associated "red beds" in the Yarkand and the Kucha depressions. The age of the succeeding Yellow Series (B) and the Black Series (C) of partially limnic sediments have not been dated by means of fossils. The volcanic history in adjoining parts of Aksai Chin and the Pamirs during the Cenozoic may, however, allow some conclusions in this respect.

The acid volcanics, the presence of which is revealed by numerous large boulders occurring north and east of the present border of the great "basalt" (latite) plateau (5891) in the south-western part of the map, exhibit distinctly monzonitic affinity or hybridic magmatic facies. To this assembly belongs also the dacitic quartz-porphyry (spec. 951) and the granodioritic rocks of Koramlik Muztagh and the sill of altered hornblende andesite (975) 14 km north of the latter in Section II. This stage of volcanism is also represented by the horizon of trachytic-dacitic crystal tuff (929) in the Cretaceous beds on the northern side of Yeshil Köl (Norin 1946 p. 43) and by sills of monzonite and monzonite porphyry in the Loqzung Series in the Aksai Chin region at long. 79°10′ (op. cit. p. 118). This type of magmatism occurs again strongly expressed in the Teshiktash Suite in the basin of Kyzyl Rabat in Southeastern Pamir. Here, the volcanic sequence with a thickness of about 1 km rests transgressively upon the Upper Jurassic with coarse "red beds" conglomerates associated with andesitic-dacitic volcanics, followed, in the middle part, by beds of red dacites, andesites and quartz porphyries of dioritic-monzonitic affinity, terminating with tuffaceous beds. The age determinations vary between 95—130 mill. years, corresponding to parts of the Lower and Upper Cretaceous (Baratov et al. 1976 pp. 149, 232).

To this magmatic cycle I also refer tentatively the series of strongly altered "mafic hypabyssal volcanics" which enters in the Sarightuz Complex at the boundary between the Yellow Series and the Black Series north of Koramlik Muztagh, represented in Section II by spec. 954, 956, 975 and in Section I by spec. 994 and 995. Among these rocks, which illustrate only incompletely the great variety of types present, spec. 956, 954 and 994 are medium-grained hypabyssal basaltic rocks. Spec. 995 is an originally probably hyalopilitic hornblende-andesitic lava with close affinity to the subjacent basaltic "greenstone". Also the sill spec. 975 is an altered hornblende andesite. Characteristic to all these volcanics is that they have all been subjected to postvolcanic diaphthoritic processes, resulting int. al. in the common formation of porphyroblastic garnet, which sometimes give the altered rocks an eclogitic appearance in the hand specimen.

A close analogy to this peculiar volcanic sequence is found in the Bartang Series in the Central Pamirs. It is a sequence, 1—2,5 km thick, of various volcanics of mafic to intermediate composition, viz. albitophyres, andesites, andesitic basalts, basalts, trachybasalts, and sodium liparites which erupted in "red beds" environment. The series rests conformably upon rudistid limestones of Late Cretaceous age which gives the lower dating limit. According to K/Ar determinations on andesitic-basaltic lavas in the basal part of the Badzhudarin Suite its age amounts to 70 ± 5 mill. years; two determinations on granitoid Sokhčarv intrusives gave the values 44 ± 5 and 50 ± 5 mill.

years. The series is placed provisionally in the Paleogene by Baratov et al. (op. cit. p. 170). A conspicuous feature of the Bartang volcanics is the extensive alteration of the rocks into "greenstones". A comparative petrographic study of this post-volcanic diaphthoresis with that of the garnet-bearing Sarightuz volcanics should be of much interest. It should be noted, however, that the Sarightuz volcanics erupted in a limnic environment, whereas the Bartang volcanics erupted in "red beds" milieu.

The above tentative correlations of certain stratigraphic and petrological features of the volcanic formations concerned, strengthen the supposition of mainly Late Cretaceous age of the Sarightuz Complex.

Apart from external volcanic phenomena, not accompanied by the extrusion of lavas, the latest eruption of lava flows in the northern parts of the Tibetan plateau known at present, took place probably in the Early Pleistocene. These young lavas are widely distributed in northern Tibet, mainly east of long. 82°. They cover large areas especially along the slopes of the Khökhö Shile Uula and its southern foreland and have been more closely investigated in the area covered by the flows from the large shield volcano 5891 rising north-west of Hedin Tsho. Four of the flows subjected to chemical analysis were all latitic lavas of monzonitic magma type, the principal norm minerals being — in order of frequency — andesine, anorthoclase, augite or hypersthene, and a few percent of quartz. Thus, also this youngest volcanism on the Tibetan plateau is of monzonitic affinity like the Late Cretaceous magmatism.

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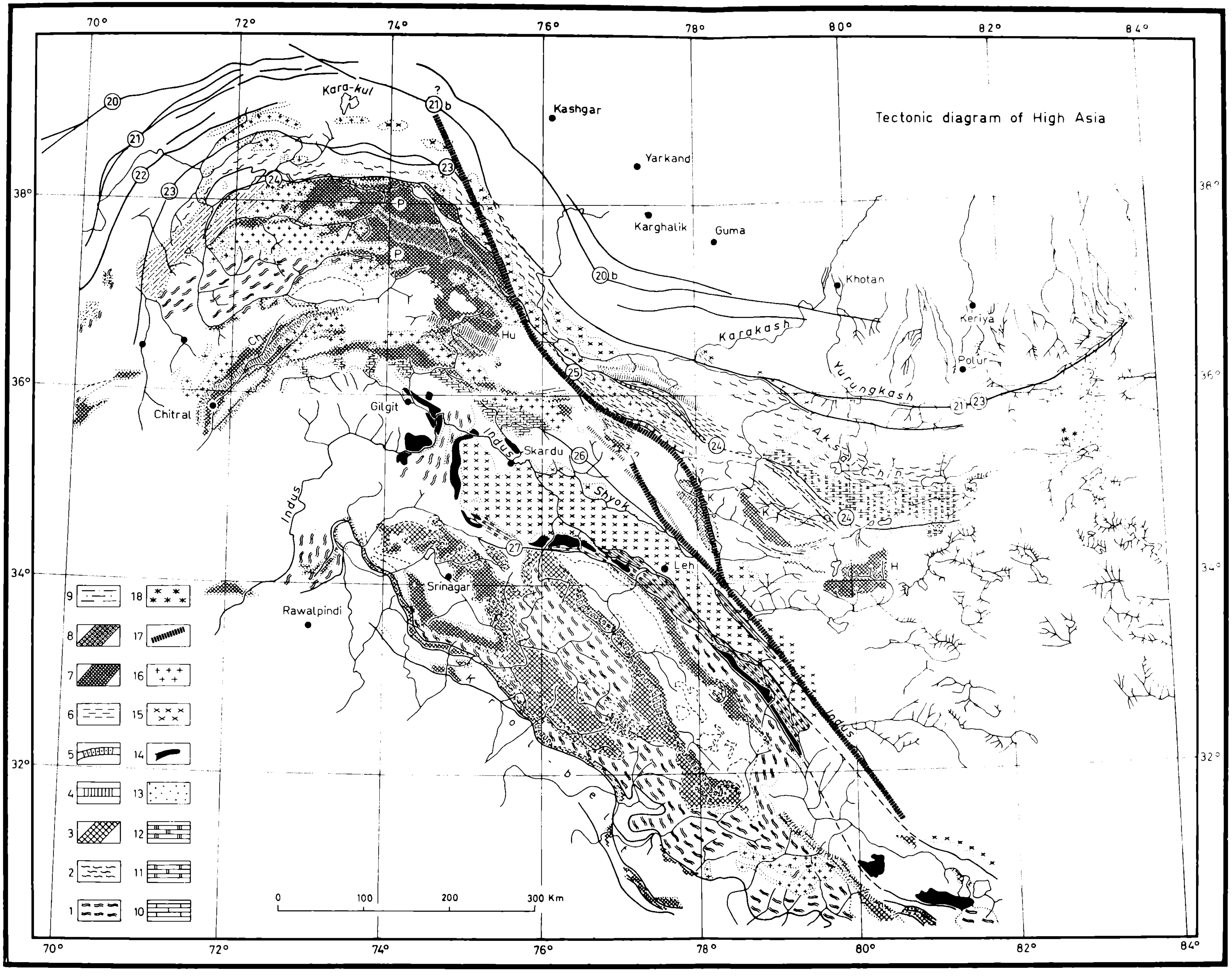

Fig. 1. Tectonic diagram of High Asia.
1 — Basement gneisses; 2 — Proterozoic and Lower Paleozoic crystalline schists; 3 — Dogra, Attok, Simla "Black Slates"; 4 — Devonian; 5 — Upper Devonian of Muth facies; 6 — Late Paleozoic of Loqzung facies; 7 — Late Paleozoic and Triassic "Black Slates"; H= Horpatso facies $(C+P_1)$; K-Hu-Ch=Karakoram facies $(C+P)$; P=Southeastern Pamir facies $(C+P+T)$; 8 — reef facies (P_2+T); 9 — Triassic, Jurassic and Lower Cretaceous of Loqzung facies; 10 — Lower Cretaceous (?) flysch and mainly acid volcanics; 11 — Upper Cretaceous mainly limestones; 12 — Indus flysch; 13 — Sarightuz Complex; 14 — Indus ophiolites; 15 — pre-Jurassic granites; 16 — post-Jurassic granites; 17 — Pamirs—Karakoram strike-slip; 18 — Latites.
Deep rifts and overthrusts: 20 — Vakhsh thrust; 20 b — Momuk rift zone; 21 — North Pamir thrust; 21 b — Tokhtakoram rift zone; 22 — Uysuy rift; 23 — Akbaital overthrust and rift zone; 24 — Rushan Pshart—Uprang—Loqzung rift zone; 25 — Upper Shyok (?)—Shaksgam rift zone; 26 — Pangkong lower Shyok rift zone; 27 — the upper Indus tectonic boundary zone.

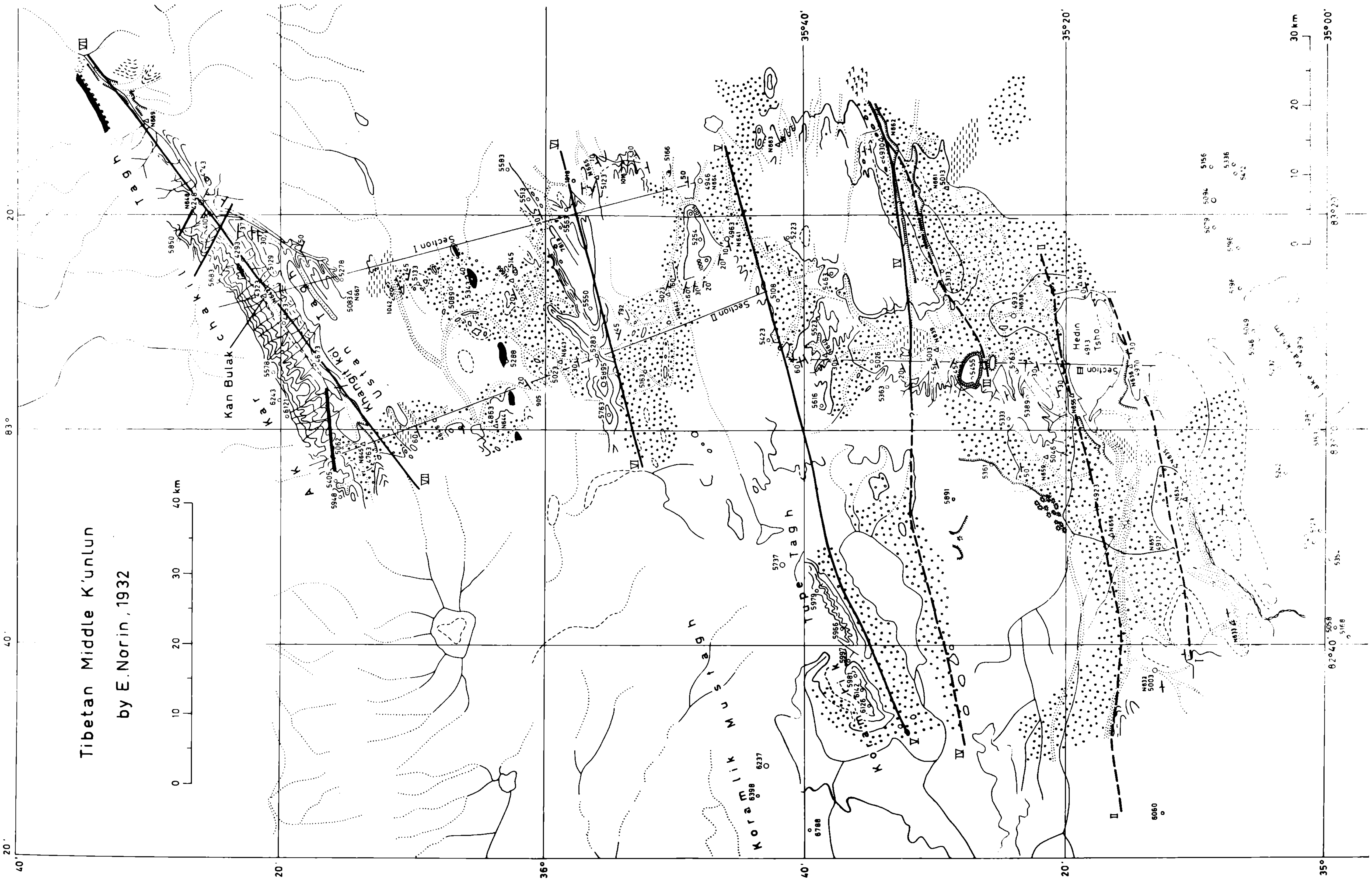

Fig. 4. The Middle K'unlun (Sections I—III, see Fig. 7). Gravelly plain Silty plain Salt crust Volcanic greenstones.

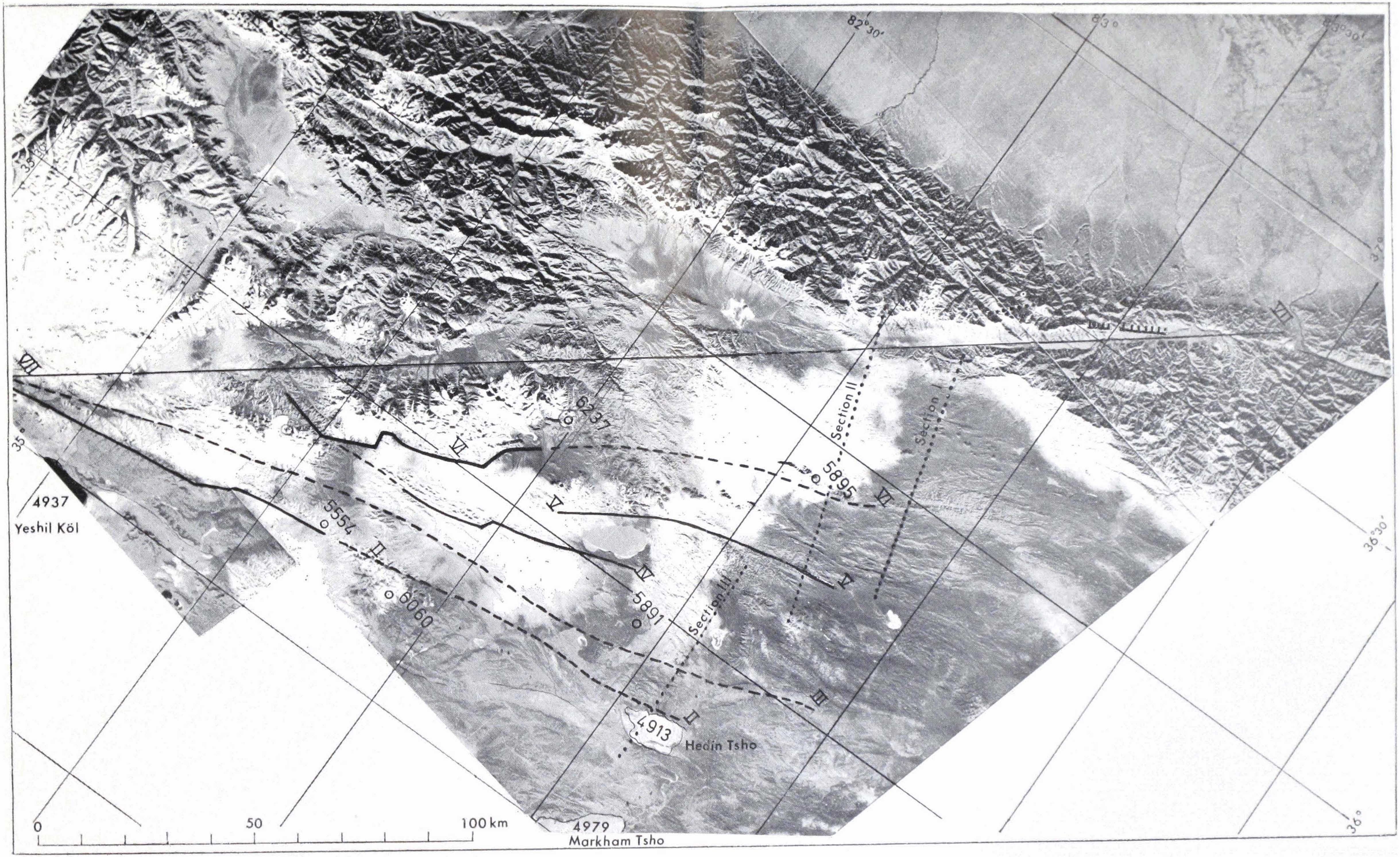

Fig. 5. ERTS photogram of the Middle K'unlun (Sections I—III, see Fig. 7).