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CRYOGEOLOGICAL PHENOMENA IN THE NORTH PAMIR (CENTRAL TRANS-ALAI)

In this paper the results of the cryogeological investigation carried out at the close of the summer season (August—September 1961) in the North Pamir as a part of my complex geomorphological study are presented. The investigation was made within the framework of an international expedition of seven members whose aim was to attain Point 7134 (the Lenin Peak — the former Kaufmann Peak). My main task was — in addition to reaching the highest Point of the Trans-Alai — to gain geological and geomorphological material from the altitudes above the snow line.

In addition to the orientation investigations at the northern piedmont of the Tien-Shan, in the Fergana basin and in the Pamiro-Alai the central parts of the high mountain Alai depression and the Trans-Alai (Achik-Tash area) were investigated in greater detail. The geomorphological position of the area studied, the geological and geomorphological conditions and the scanty literature on the problems of this area are dealt with in the paper „Results of the Geological and Geomorphological Investigation in the Pamir — Central Trans-Alai" (J. Sekyra 1964). From this paper I take for the orientation of the reader only the most important results of the field work in the high mountain area of the North Pamir.

Various forms of eolian sedimentation were established; they show most varied transitions of facies, for instance, typical eolian pelites (loess), rhythmically bedded deluvio-eolian sediments, psammitic eolian sediments blown out from fluvial, glaciofluvial or glacigenic accumulations etc. Genetically different sediments were subjected to lithological and granulometric analyses. Eolian sedimentation was found at the maximum altitude of 3800 m above sea level.

The terrace system of the river Kysyl-Su (source river of the river Amu-Darya) in the Alai high mountain depression was determined and the connection with the glacigenic and proluvial sedimentation was examined. The maximum glacigenic and proluvial accumulations adjoin

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terrace Q_{R-2}[1]; terraces Q_{sR} up to $Q_{R-3\,(?)}$ can be parallelized with the terrace system of the eastern part of the Fergana basin in the north-western part of the piedmont of the Pamir.

The main phases of the mountain or piedmont glaciation (Q_R — $Q_{R-3\,(?)}$) were determined according to the modellation of cirques and troughs, the degree of weathering of glacigenic sediments and the parallelization of glaciofluvial sediments with terrace accumulations were determined. By the form of the oscillation walls we may judge the regression of glaciers at the present time and thus a moderation of the harsh climate of high mountains.

The altitude of the snow line (= 4520 m above sea level) was determined and the relative values for the depressions of the fossil snow-line were computed.

On the basis of the orientation field measurement and according to the compilation of the photographic material (without the possibility of using topographical maps) a glaciogeological map, showing in addition to the glaciogeological position also the geological structure, was elaborated.

Basic data on tongues of glaciers AT I and II were established. Of special importance are the data pertaining to the movement speed of the glacier AT I: The glacier tongue Q_{sR} with the upper moraine stagnates, while the recent ice tongue „flowing down" on the glacier Q_{sR} moves in its central part at 0.15 up to 0.35 average rate per day. From the glaciological point of view so-called thermokarstic phenomena were established (for instance „nieve penitente", cryoconite pits, glacier tables, glacier gates, supra-glacier streams with sink-holes and springs).

Previous knowledge on the geological structure of the anticline of the North Pamir in the area of the Central Trans-Alai (according to V. P. Rengarten 1934, B. A. Borneman and S. K. Ovchinikov 1936[2]) was partly confirmed and extended. Mesozoic and Paleozoic groups of rocks, which in the uppermost part of the Trans-Alai in the main crest area are epizonally altered, were established and important tectonic lines were defined.

K. K. Markov's[3] opinion (1948) on the geomorphological development of the Alai basin was roughly confirmed. A paleogeomorphological sketch of the central part of the Trans-Alai in the Achik-Tash valley was

[1] In order to designate as objectively as possible the stratigraphic position of quaternary sediments or geomorphological forms I use the symbol Q; the youngest (recent) complexes are designated as Q_R, the subrecent Q_{sR}, the sediments of the latest glaciation (stadial) established have the index$_{R-1}$, of the penultimate glaciation $_{R-2}$.

[2] J. Sekyra 1964, l. c.

[3] J. Sekyra 1964, l. c.

elaborated. The establishment of thick fossil weathered rocks in the central part of the Achik-Tash valley probably corresponding to the interglacial (interpluvial) time-spans $Q_{R-1/R-2}$, i.e. intervals after the regression of the maximum glaciation, is of great importance in paleogeography.

According to the divergence of the Early or Middle Quaternary terrace levels in the Achik-Tash valley or according to the interruptions of their course in the longitudinal sections we may assume that up to the beginning of the Middle Quaternary intensive tectonic movements occurred here. This opinion is supported by the fact that in the sedimentation basin of the Alai depression terrace levels earlier than Q_{R-2} are lacking. The uplift took place not only in the area of the North Pamir anticline (the difference between the Lower- and Middle Quaternary levels can be assessed to 400 up to 500 m) but also in the Pamiro-Alai (compare the striking vertical differences of the terrace levels in the upper part of the course of the river Gulcha).

Cryogeological observations from the Pamir area are not numerous. Various photographs are frequently seen or cryogenic phenomena are mentioned (usually stone-nets, for instance, R. D. Zabirov 1955), but with the exception of K. K. Markov (1934) nobody has tried to evaluate them. The results of the investigation carried out by the above-mentioned author have been analysed by C. Troll (1944) in his comprehensive work on structural soils and solifluction.

The absence of tall plants and the extensive areas without any vegetation at all, and especially the climatic conditions [4] (high aridity, considerable differences in diurnal and nocturnal temperatures) are responsible for intensive cryogenic processes (gelivation, frost segregation, presence of gelisol, solifluction etc.) and in basins for deflation and eolian accumulation. A high degree of mechanic disintegration gives rise to huge glacigenic, proluvial, fluvial, deluvial and other accumulations on which cryogenic forms develop under ideal conditions.

Cryogeological observations are given in the text in the direction from the lower to the upper positions (i.e. from the bottom of the high mountain

[4] The climate of the northern piedmont of the Pamir — with some slight differences — can be compared with that of the station Murgab in the central Pamir at 3600 metres above sea level. The mean annual temperature is —1.0 °C, maximum temperature + 28 °C, minimum —46.7 °C; humidity of air in summer 30—40%, annual average precipitations 73 mm, rainfall 3 days, snow 23 days per year. The maximum range of diurnal and nocturnal temperatures attains in summer season up to 50 °C.

The desert high mountain area of the Trans-Alai, similar to those of the rest of the Pamir, belong to the arid subtropical climatic zone (subnival to nival).

The climatic and geographic conditions in general are roughly evaluated in the publication „Geology of U.S.S.R.," v. 24, 1959.

Alai depression between the Pamir and the Pamiro-Alai at 2800 to 3300 metres to upper altitudes — more than 7000 metres above sea level) which corresponds to the direction of the advance of the expedition towards Point 7134 (= the Lenin Peak, the former Kaufmann Peak); the areas in which the investigation was carried out are numbered and designated in the scheme showing the geological section (fig. 1):

(1) In the vicinity of the village of Sary-Tash (the eastern part of the Alai basin) gentle slopes inclining westwards are covered with loess sediments resting conformably with the surface, sporadically forming flat dunes. The unequal sedimentation is due to the varying distribution of vegetation and irregular humidity conditions influenced by the geological and hydrogeological character of the area. On the subrecent stabilized loesses or mixed deluvio-eolian deposits so-called „kastanosem steppe soils" are developed which are interrupted by numerous wedge-shaped formations. Such forms of soils — up to 0.6 m deep — have been described as Young Pleistocene loesses in Central Europe and the wedges developed in them have been described as cryogenic forms although they really are desertic arid forms which are not bound to gelisol, but are due to exsiccation or seasonal cryogenic processes.

(2) On the lowest (3—5 m high) terrace of the river Kysyl-Su (20 km WSW of Sary-Tash) with a continuous turf cover at 3100 m above sea level where turf layers occasionally are developed typical thufur fields occur (pl. 2). They account for a subnival periglacial climate (C. Troll 1944; M. Prosová & J. Sekyra 1960).

(3) In the depressions (in Kirghizian „chukury") between the moraines Q_{R-1} up to Q_{R-2} above the 3500 m isohypsis the so-called „Kochkarskaya bolota" (Kochkar marshes) occur (P. D. Zabirov 1955). They are a function of pergelisol bound to subnival inclement climatic conditions of the Pamir area. Such forms have been reported, for instance, by K. K. Markov (1934) from the Kara-Kul area. The heterogeneous up to homogeneous ice in psammitic psephitic glacigenic sediments is conserved under a turf layer which forms a heat insulator.

(4) The ablation area of glaciers AT I and AT II (Achik-Tash) at 3700 to 4200 m above sea level. In the area of the upper and lateral moraines deposited on a cracked glacier in many places at up to 4000 m above sea level so-called glaciosolifluction was established (i.e. gliding of debris on plates of glacier dipping 5° to 30° and exposed southwards; the movement takes place especially at high day temperatures). At the lower parts of glacier plates the mash-like more or less loamy material is usually more than 5 m thick and the area of glaciosolifluction occasionally attains more than 10 ares. The water-bearing mass of unhomogeneous material glides

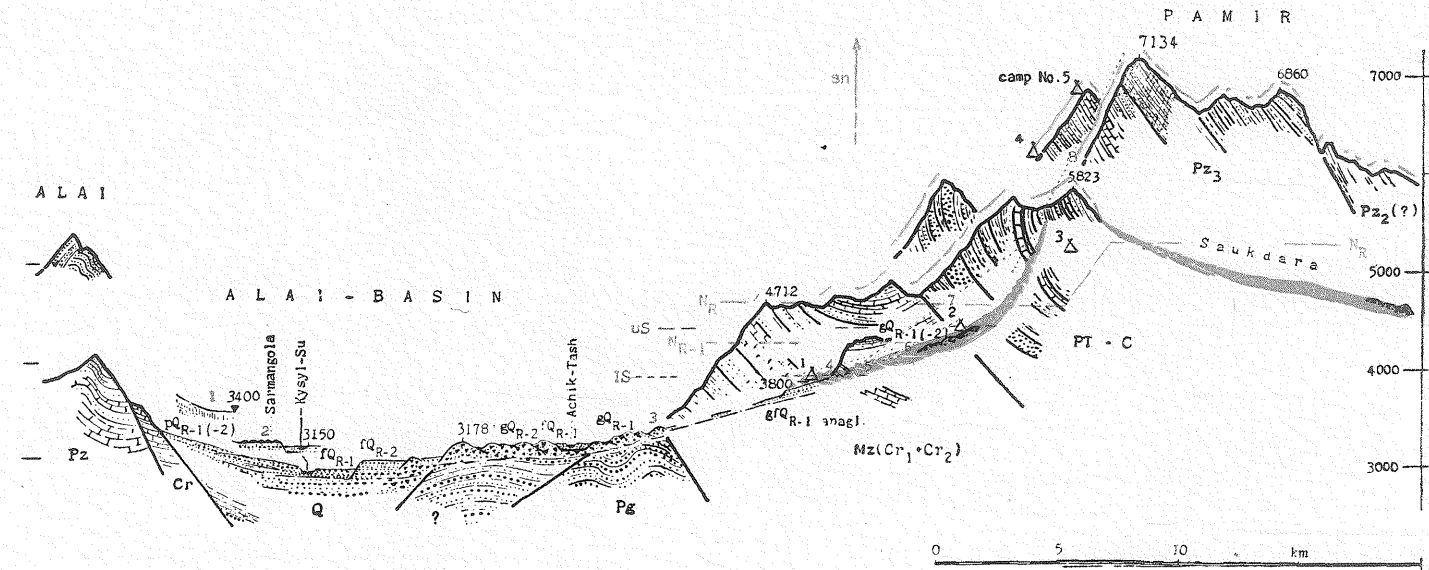

Fig. 1. Section across the Alai depression and the Trans-Alai drawn roughly along the axis of ascension from Sarmangola to P 7134

Pz — Paleozoic of the North Pamir anticline (Silurian and Devonian) including the epizone; PT-C — Permo-Triassic up to Carboniferous groups of rocks thrust northwards over the Mesozoic; Mz — Mesozoic, especially Cretaceous (Cr_1—Cr_2) carbonate formations; Pg — Paleogene up to Neogene terrestrial groups; gQ_{R-2}— glacigenic sediments of the maximum Middle Quaternary glaciation; fQ_{R-2}— fluvial sediments of the main (Middle Quaternary) terrace; gQ_{R-1}— glacigenic sediments of the last expressive Quaternary glaciation; fQ_{R-1}— fluvial sediments of a low (Young Quaternary) terrace; gfQ_{R-1}anagl.— glacifluvial sediments of the last expressive Quaternary glaciation (of the anaglacial phase); $pQ_{R-1(-2)}$— proluvial accumulations, predominantly of polygenic character; 1—8 — numbers of localities given in the text; uS — upper limit of segregation cryogenic forms; lS — lower limit of segregation cryogenic forms; N_R — recent snow-line; N_{R-1}— snow-line from the last „Pleistocene" glaciation; sn — snow („ice") of sublimation chacacter on ice surface, overlaps in various ways and when the dip exceeds 12° it actually visibly flows. The glaciosolifluction matter disappears in the cracks of the glacier or is carried away by the ice river. In the proximity of the glacier's snout huge glaciosolifluction cones were observed resembling the so-called „bad lands". The origin of the oscillation walls is also connected with the glaciosolifluction accumulation in the vicinity of the detached portions of the glaciers. Oscillation walls corresponding to three subrecent to recent climatic oscillations were established.

On the upper moraine of glacier AT I at about 4100 metres above sea level subaquatic polygons in small lakes were established. The segregation of material of these structural forms developed just before the origin of the lake at the time of an intensive wetting (impermeable bottom of transitory water reservoirs is formed by the glacier's body proper). Polygonal structures with segregation centres of 0.3 to 1.2 m in diameter are transitory cryogenic forms.

(5) The periphery of the ablation area of the glaciers AT I and AT II. On a ground without vegetation, predominantly in periodically wetted depressions between the morainic walls (Q_{R-1} to Q_{R-2}) micropolygonal ground up to micro-stone stripes occur. The segregation of unhomogeneous material under optimum microclimatic and soil conditions (especially wetting, differences in temperature, dip of the area up to 15°, etc.) was observed at 3850 to 4150 metres above sea level. Especially expressive microstructures appear on eluvia, deluvia and glacigenic sediments formed by rocks showing clayey up to sandy loamy weathering. On an eluvium of red shales up to sandstones at about 4000 metres above sea level micro--stone polygons and micro-stone stripes originate; their diametre is up to 30 cm (pl. 3). The segregation can be observed up to the depth of 15 cm. The forms here are throughout transitory microforms predisposed by exsiccation forms typical of high mountain areas of tropical and subtropical high mountains (compare the evaluation of such forms in the paper by C. Troll 1944). K. K. Markov (1934) calls attention to such forms in the Pamir area.

In addition to the transitory segregation forms many other forms occur here; they are reminiscent of vegetation soil forms conditioned by arctic frost. They are most varied disturbances and deformations of the turf cover, be it needle-ice, solifluction or in junction with wind erosion etc. (in world literature similar forms are usually designated as *Feinerdeflecken*, *Rautenboden*, *Rasenwalzen*, etc. — compare C. Troll 1944).

(6) In the area between the glacier tongues AT I and AT II (pl. 7) in the vicinity of camp No. 2 (4200 m) about 200 m below the snow line the following forms and structures were established:

On glaciofluvial microsander sediments of glacier tongue of the hanging glacier in the depressions below the morainic walls close to camp No. 2 in addition to segregation microstructures — see under (5). The author establishes typical stone-polygons with centres of 0.7—1.2 m in diameter and with angular segregated blocks (pl. 4). Within the centres on the surface of loamy-sandy material exsiccation cracks appear; they arise in summer months under the influence of night frost. On glacigenic sediments, especially on the tops and slopes of moraines (Q_{R-2}) in areas with a dip not exceeding 15°, at 4350 m above sea level typically developed micro-polygons with centres of up to 5 m in diameter were established.

Under morainic accumulations (Q_{R-2}) at 4160 m above sea level outcrops of strongly weathered whitish Upper Paleozoic up to Lower Mesozoic rocks (in situ or re-deposited) were found. Close to the surface of these weathered rocks typical fossil solifluction structures appear; they are up to 1.3 m thick. The solifluction structures very expressive in colour appear on the walls of coulisses and earth pyramids in the main accumulation of the central moraine AT I and AT II.

(7) The rough and arid climate of the high mountain area of the Pamir is responsible for the origin of segregation structures and for the intensive frost weathering — the gelivation. The influence of the climate is especially remarkable at altitudes above or on the snow line which in the Achik-Tash area lies at 4520 metres. In all outcrops which have not recently been denuded intensive gelivation can be observed. Some typical congelifraction in various types of rocks are as follows:

Upper Cretaceous platy limestones (altitude 3900 m above sea level above camp No. 1 — culmination of the central moraine Q_{R-1}) — disintegration in angular blocks up to fine debris-like material without signs of corrosion; segregation occurs especially in the places where between coarse fragments loamy up to loamy-sandy interstitial matter is to be found;

red shales (Werfen ?) — saddle 2 km SW of camp No. 1 at 4000 metres above sea level, splintery disintegration of rock weathered into the depth; on platform-like ground there are thick loamy eluvia;

red sandstones (Werfen ?) — platform above the walls of trough, 2.5 km W of camp No. 2, at 4150 metres above sea level — thick sandy weathered rocks with huge mass of debris below the outcrops; the debris is loosened by gelivation, especially along bedding planes and joints;

grey bituminous shales (Upper Paleozoic) — in the top portion of the morainic wall (Q_{R-2}) in the southern vicinity of camp No. 2 at 4250 metres above sea level — slate-pencil disintegration (pl. 5);

dolomite (northern border of the Upper Paleozoic epizone) — trough wall below P 5200, vicinity of camp No. 3a — powdery disintegration with debris:

black calcareous shales (Upper Paleozoic) — a slope above the trough wall at 5100 metres above sea level in the vicinity of camp No. 3a — strongly weathered outcrops crumbling when strong wind is blowing; the compressibility of splintery eluvium is considerable;

Permo-Carboniferous conglomerates forming a great part of the morainic block material (Q_{R-1}) — 4200 to 4300 m above sea level, southern vicinity of camp No. 2 — are most resistant against the congelifraction and do not show recent gelivation.

The congelifraction effects on limestones, dolomitic limestones, quartzites and other massive rocks manifest themselves in the form of stony up to block eluvium, below the walls huge block fields form.

(8) The ascension proper towards Point 7134 — area above the snow line. During the ascension on steep slopes of snow and ice from the north towards the main ridge of the Trans-Alai between the camps Nos. 3a and 5 the author could observed in addition to the changes of facies in the snow- and ice cover the disintegration on outcrops exposed at high altitudes (mostly crags projecting on slopes). At altitudes roughly above the limit of 6200 m snow of the firn type or firn ice no longer exists. The snow cover decreases by sublimation; a sublimation form of milky white imperceptibly layered snow originates; the hardness of such snow approaches that of ice. The old snow cover consolidated by deflation consists of the above-mentioned milky white fine-grained substance. On its surface honeycomb (dish-shaped) forms developed which are due to sublimation; they are reminiscent of those known from firn fields of various high mountain areas of temperate to torrid zones. The existence of the honeycomb microrelief — see pl. 9 (compare „Schmelzschalen" — H. Poser 1935) has nothing in common with melting — as this phenomenon sometimes is interpreted — but represents the result of varying sublimation intensity due to a very slight humidity of air, low temperatures and relatively great differences between nocturnal and diurnal temperatures (about 30°C during the period of diurnal insolation) and to high psychrometric range and partly also to the unhomogeneity of snow.

On the spur projecting from the main ridge towards WNW at about 6650 metres above sea level and consisting of intensively gelivated bituminous shales, quartzites, marbles, crystalline limestones and on the still higher situated outcrops of diabase tuffs and agglomerates (6000 to 7134 m above sea level) fissures and bedding joints are filled with white „ice" of sublimation character which at these altitudes plays a similar role as the ground ice in lower areas. The primary disintegration effects, however, can be seen in strongly varying volume of rocks due to a great range of diurnal and nocturnal temperatures (differences up to 40°C).

The congelifraction effects in outcrops and their vicinity are accounted for not only by accumulations of angular blocks (up to 1 m in diameter) and outcrops with frost cliffs but also by sings of „cryoplanation platforms" (at Point 6900 and near Point 7134 — see pl. 8).

Most intensive eolization effects can be seen among Upper Paleozoic rocks on marbles. The eolian wear is reminiscent of karstic rocks especially on the fronts of layers in exposed outcrops. Signs of eolization are, however, also to be found on outcrops of diabase conglomerates up to diabase tuffs disturbed by congelifraction which occur on the north-eastern spur below Point 7134.

CONCLUSION

In addition to some cryogenic forms described by K. K. Markov (1934) — especially micro-stone-polygons — and by R. D. Zabirov (1955) — high mountain pergelisol — forms new for the Pamir area were established: microwedge forms, thufurs, fossil macropolygons and solifluction structures, glaciosolifluction in the ablation part of glacier, various forms of gelivation close to and above the snow line where a normal disintegration by hyaline ground ice no longer takes place etc. The fossil character of macropolygons and solifluction structures was determined on the basis of geological and geomorphological criteria of comparison. On the basis of distribution of recent and fossil forms it was also possible to ascertain various ages of morainic accumulations ranging from Q_{sR} to Q_{R-2}.

According to analogous establishments of cryogenic phenomena in other high mountain areas of the world (the Andes — A. E. Corte 1953, L. Lliboutry 1957; the Caucasus — M. Prosová & J. Sekyra 1960; the High Atlas — J. Sekyra 1962; the Himalayas — N. E. Odell 1925; the Karakorum — K. Wiche 1962; etc.) the major part of the recent phenomena can be designated as a sensitive indicator of a subnival high mountain arid climate. The establishment of the presence of these forms and processes can particularly be used in the special determination of the altitude of the snow line as most of them (stone-nets and stone stripes, solifluction and glaciosolifluction) usually occur at 100 up to 300 m below the present-day snow line. The problem of the limite of the snow line and structural cryogenic forms was fequently discussed in literature and is not therefore dealt with in this paper. The recent results of the W. Klaer's (1962) investigation can on the whole be accepted. Klaer summarized the most important literature on this subject and he himself made many valuable observations in the high mountain area of Asia Minor.

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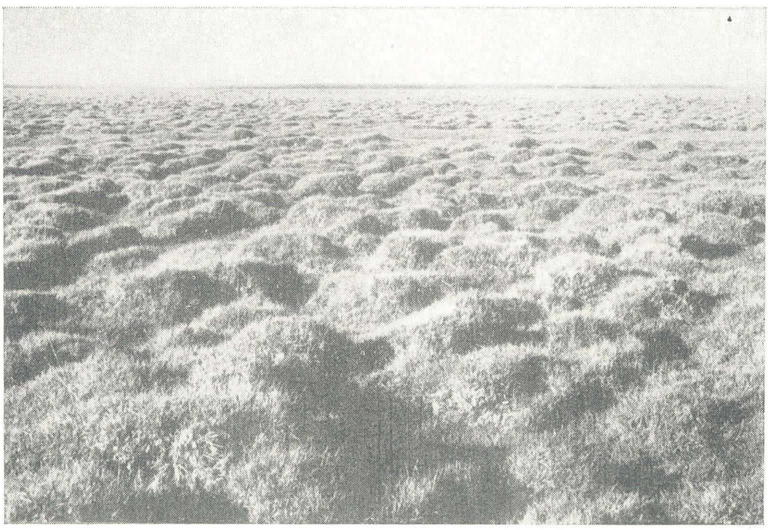
Pl. 1. Northern precipices under P 7134

summit portions of the shield consist of Upper Paleozoic diabase tuffs; in the foreground part of the trough wall under P5547 composed of Carboniferous (?) conglomerates and the lateral moraine (Q_{R-1}) of the glacier tongue AT I (about 4300 m above sea level)

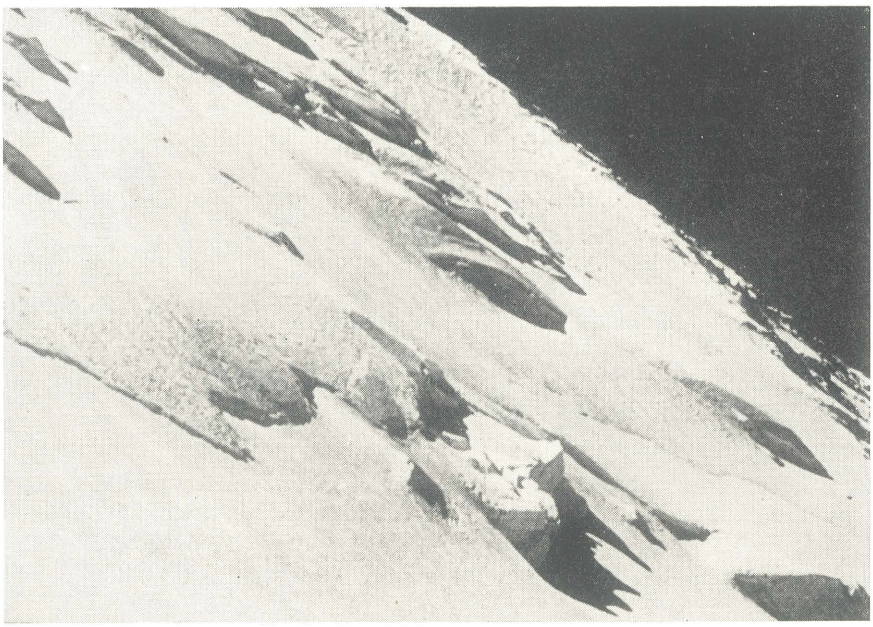


Pl. 2. Thufurs up to 0.9 m high at the first low non-flooded terrace (Q_{sR-1}) of the river Kysyl-Su at 3150 m above sea level (the Alai basin)

Pl. 3. Cryogenic microstructures with centres of 0.3 m in diameter, 4100 m above sea level

Pl. 4. Typical cryogenic segregation structures, diameter 0.7—1.2 m on unhomogenous morainic material at an altitude of about 4200 m above sea level (in the vicinity of camp No. 2)

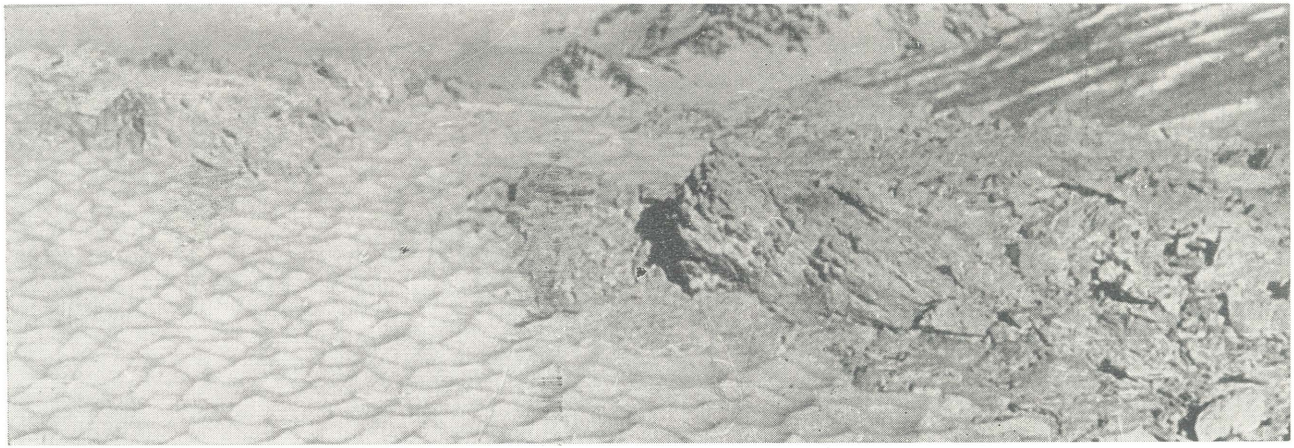
Pl. 5. Upper Paleozoic bituminous carbonate rocks disturbed by gelivation (about 4300 m above sea level)



Pl. 6. Snow fields and blocks disintegration of Upper Peleozoic diabase tuffs at 7050 m above sea level (the northern slope of the Lenin Peak)

Pl. 7. Lower part of the slope glacier above camp No. 2 (4200 m above sea level); in the background the main crest of the Trans-Alai in the western vicinity of P 7134

Pl. 8. Summit plateau (of cryoplanation origin) on the Lenin Peak (7134 m); view from the main isolated outcrop of diabase tuffs south-westwards toward the central Pamir



Pl. 9. Eolized outcrops of Upper Paleozoic marbles in the vicinity of camp No. 5 at about 6700 m above sea level; at these altitudes the sublimation honeycomb relief is typical for the snow surface