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PERIGLACIAL PHENOMENA AND SOME PALEOGEOGRAPHICAL PROBLEMS OF CENTRAL TIAN-SHAN

Central Tian-Shan is characterized by almost latitudinal mountain ridges and parallel valleys showing distinct traces of glacier activity down to about 2800–3200 m. More or less conspicuous intermontane depressions are places of local accumulation. One of such depressions, the Taragai Basin has been studied in detail. It is situated at an altitude of 3200–3500 m, 60 km south of Lake Issyk-Kul. The basin is surrounded by the ridge Dzhetymbel (mean

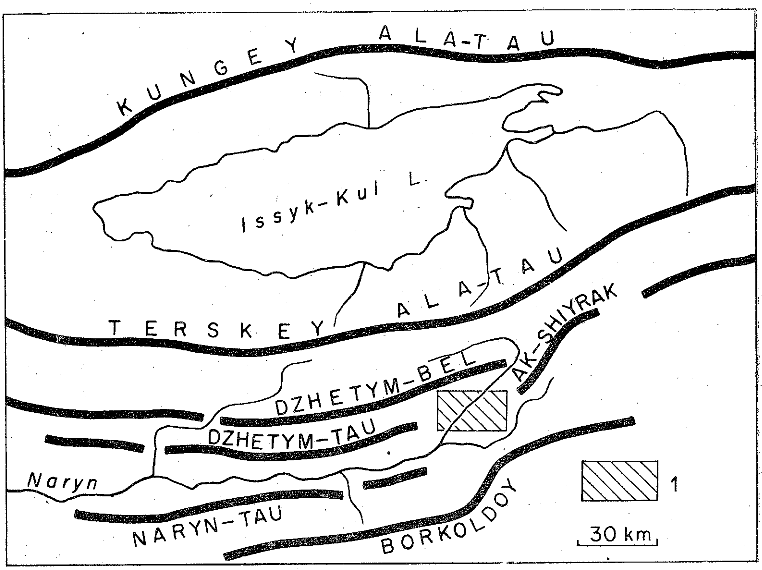

Fig. 1. Situation of the Taragai Basin

1. area investigated

height of the watershed is about 4300 m) from the north, by the ridge-branches of the Ak-Shiyrak massif from the east, and the Kulchuk-Kyrkoo ridge from the south (fig. 1).

The climate depends on high altitudes and on the intra-mountainous situation of the area in the central part of the Asiatic continent[1]. Due to the anticyclonic system in winter, the temperature falls to –43° C. The summer maximum is 21°C but the minimum daily temperature may be below 0° C during the summer months. Mean annual temperature is –7° C (1881–1950).

The total rate of precipitation is small: in 1936 it was only 214 mm, the greatest amount of 376 mm was recorded in 1953. The Taragai region has even scarcer precipitation than the Tian-Shan meteorological station. Precipitation occurs mainly between May and September (75% of total annual amount), the snow cover is therefore thin and does not exceed 32 cm. In the Taragai Basin the snow cover is very uneven, the southern and windward western mountain-sides are often deprived of snow during the whole winter.

Due to the very severe climate, permafrost is common in Tian-Shan above 3000 m. It is obvious that under such conditions cryogenic phenomena and related land-forms are widespread.

During the climax-phase of the last glaciation, the Taragai Basin was filled with glacier-ice, whose tongues flew down the Taragai valley from the north--east parts and down the valleys dissecting the southern slopes of the Dzhetymbel-Dzhananichke, Ekurgen, Sarytor, Suyek etc. The glaciers descended to 3250 m, and their thickness was 300–350 m and more in the valley (Bondarev, 1965).

The series of detrital material filling the Taragai Basin is regarded as corresponding with the old glaciation. Data collected by the Naryn-Chantery Expedition during the Second International Polar Year, 1932–1933, evidenced the glaciofluvial origin of these sediments (Kalesnik, Epstein, 1935). However, according to the authors' observations this formation is more complex. In many places the valley sides of periodical streams are built of non--sorted moraine-like material overlaid with a thin cover of silts. Towards the exit of the Egiztor the moraine-like series passes into deposits composed of stones and pebbles accumulated by streams flowing from the moraines. The sections in the Kyzyleshme valley show the morainal material passing into lacustrine deposits, which confirms its proluvial-colluvial nature. Postglacial alluvia are also widespread.

The following morphologic zones may be distinguished in the area investigated (fig. 2):

(1) Zone of conspicuous moraines occurring on the borders of the basin. The moraine belt is particularly distinct on the southern slopes

[1] Climatic data are provided by the meteorological station of Tian-Shan situated 3614 m above sea level, some 30 km northeast of the Taragai Basin, at the foot of the north--west mountain side of the Ak-Shiyrak massif. Climatic records have been kept since 1929 (Ryazanceva, 1965).

of the Dzhetymbel range, where a terrace of collapse origin stretches from the outlet of the Taragai glacial valley and then passes into the lateral moraine ridge, whose top line is 200–260 m above the present-day inundational terrace of the Taragai. The outlets of small valleys gathering waters from the area of 1 km^2 are blocked by the ridge. Westwards, the moraine joins the moraines in the upper segments of the Egiztor and the Dzhamanichke which look like stone glaciers.

On the southern margin of the basin, the moraine looks like a subsidence terrace. Moreover, the successive positions of the glacier front are well marked by two parallel valleys situated on two different levels.

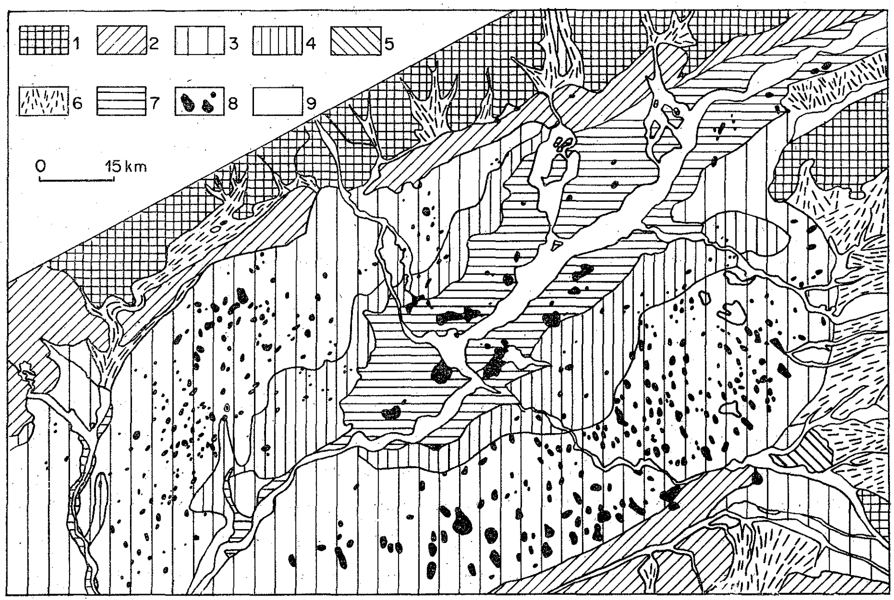

Fig. 2. Sketch geomorphological map of the Taragai Basin (after A. L. Bondarev)

1. mountain sides of solid rocks; 2. moraines of the last (late-Pleistocene) glaciation marked in the relief in form of ridges or subsidence terraces; 3. and 4. zone of funnel-like (3) and elongated (4) thermokarst forms associated with the moraine of the last glaciation; they are not marked in relief; 5. area built of lacustrine late-Pleistocene deposits; 6. alluvial cones built of prolluvial deposits; 7. post-glacial river terraces; 8. thermokarst depression; 9. present-day inundational terrace

(2) Zone of moraines slightly outlined in the land-relief occupying the larger part of the basin. Further on, it will be proved that the morainal sediments were repeatedly replaced due to processes causing the inversion of land-relief. The moraine surface was gradually transformed into the lake bottom or proluvial accumulational surface. The transition-lines between them are invisible in the relief.

The relation of the moraine series infilling the Taragai Basin to the last glaciation is proved by the small erosion of the moraines caused by the damming of small valleys with periodical streams on the southern slope of the Dzhetymbel. The same evidential significance is possessed by the sediments passing into the terraces of collapsing origin in the Taragai glacial valley sides and farther into the moraines Kum-Tora and Arabel-Su, which were undoubtedly accumulated during the last glaciation.

(3) Postglacial river terraces. Below the glacial segment of the Taragai valley there are 3 alluvial terraces, whose heights are 1–3 m, 5–7, and 15–20 m respectively. They are built of re-washed morainic deposits. Within the upper terrace there are blocks of 1 m in diameter, whereas the two lower terraces are built of finer material. Below the Kyzyleshme outlet the alluvial terraces wedge out because of the rising of transverse structure, i.e. the Kulchuk-Kyrkoo crest. All the terraces of the Dzhaaktasha (the name of the part of the Taragai which transsects the Kulchuk-Kyrkoo) are of the shelf--like character.

The area described, especially the zone of the indistinct moraines, displays remarkably well developed thermokarst relief occurring at altitutes of 3300––3500 m. Over an area of some 130–140 km^2 there are scattered more than 600 sink-holes, most of which have no outflow. The largest one is 200–300 m in diameter, its maximum depth being 30–35 m.

Many sink-holes are occupied by lakes (Pl. 1). The aerial photographs taken at the end of August and at the beginning of September 1959, revealed about 160 lakes. At that time of the year the water in lakes is lower. Many dry depressions bear traces of former water basins; fine-grained deposits form a takyr-like bottom. Sometimes two or more neighbouring sink-holes join together into one depression, but their bottoms remain on different levels.

The orientation of thermokarst depressions is notable: On the left side of the Taragai the longer axes of the holes are oriented north-west, while on the right side, between the Suekom and Egiztor the south-west direction prevails.

The present authors hold that the orientation depends on the original sloping of the surface. Kachurin (1961) pointed out that the elongated forms of the sunk relief develop at an inclination as small as 0.001^{0}.

On the left side of the Taragai the surface deprived of moraines slopes north-west at 2^{0}, whereas on the right side the vast area which stretches up to the upper part of the Egiztor is inclined south-west. The same orientation have also the longer axes of thermokarst depressions occurring in both areas. The thermokarst holes display a very characteristic asymmetry; the lowermost parts of the hole bottoms are generally directed down the sloping surface of the thermokarst area.

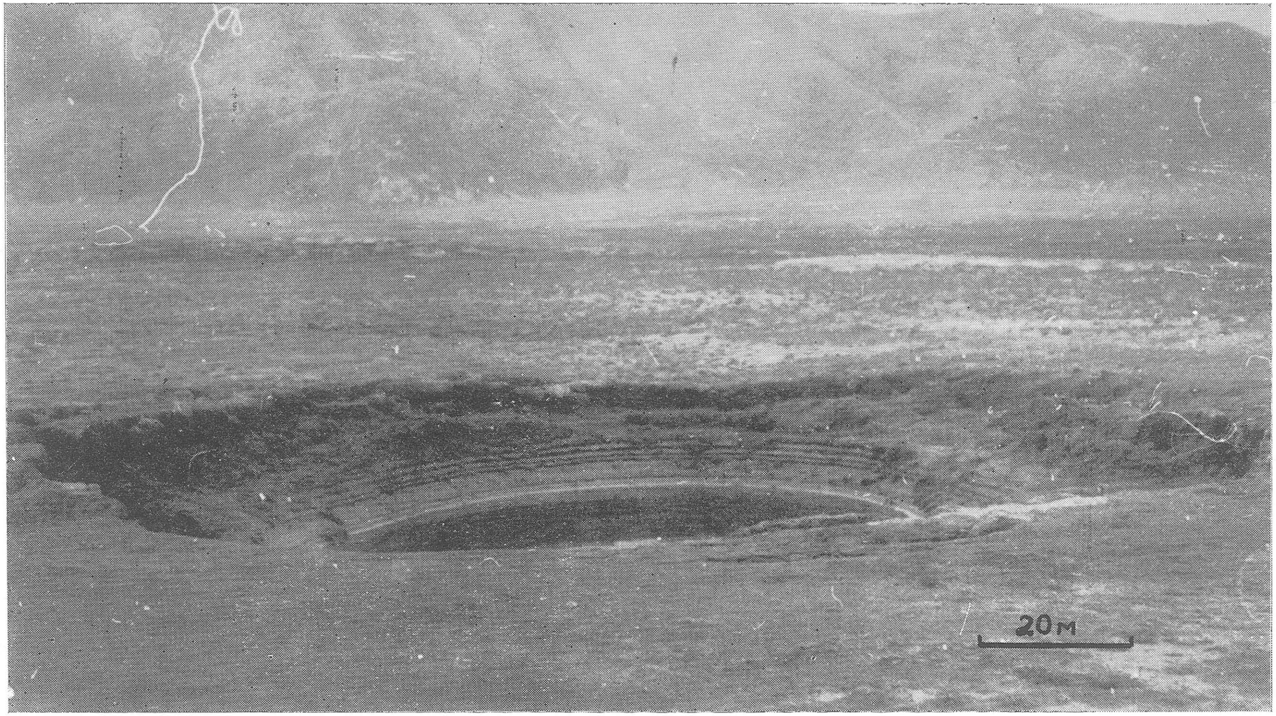

Photo by Z. V. Aleshinskaya

Pl. 1. Thermokarst funnel infilled with water

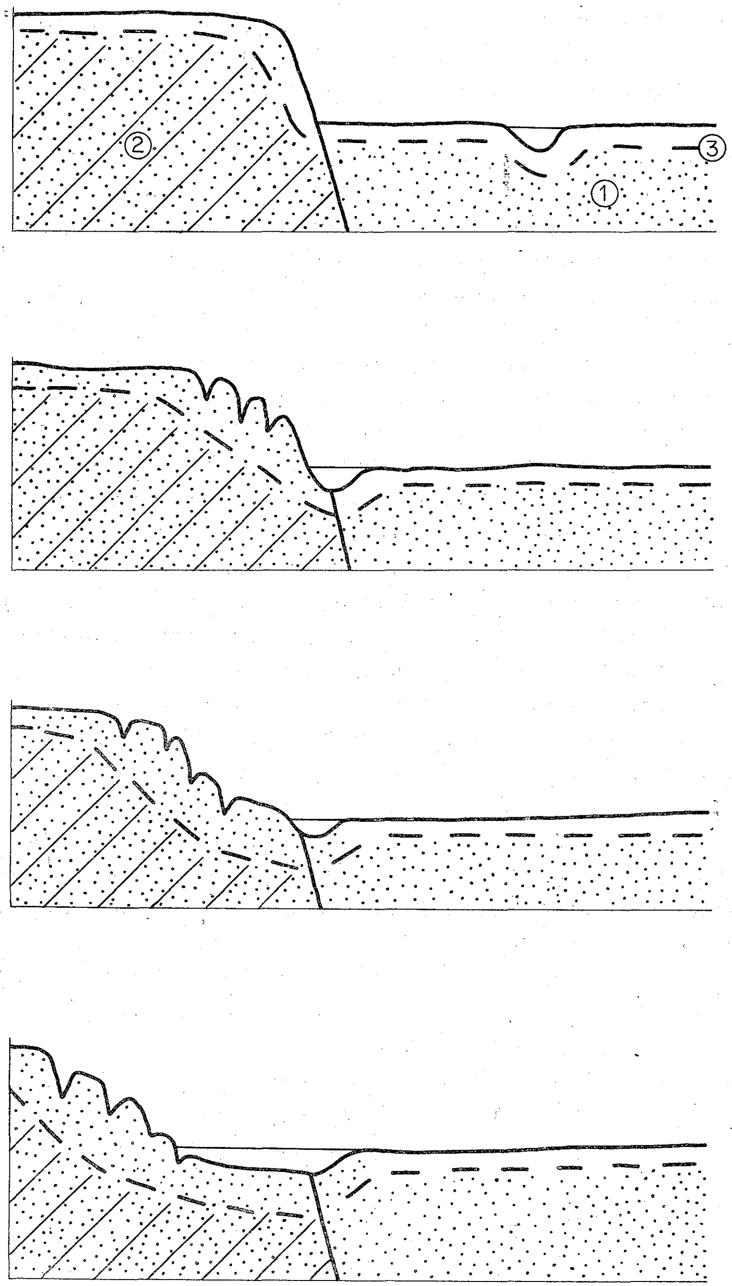

Fig. 3. Successive stadia of the development of a thermokarst funnel on the contact line between the terrace and valley bottom

1. alluvial deposits; 2. terrace alluvial deposits with much ice; 3. top of permafrost

Thermokarst sink holes occur also, though in a smaller number, on the flat surface of postglacial river terrace. Unlike those formerly described, they do not display any orientation and their outlines are often irregular.

Besides the basin-like depressions, numerous elongated forms of thermokarst origin may be found here. They are winding trenches, 300–400 m long, 4–5 m deep and 30–40 m wide. The long profile of their bottoms shows the segments inclined in opposite directions. The trenches often intersect a row of small closed hollows. In cross profiles they are asymmetrical: a gentle slope has 15–20°, while the opposite is as steep as 25–30°.

The elongated thermokarst forms appear at the foot of valley slopes forming a belt inclined towards the postglacial river terraces (fig. 2), but the thermokarst depressions are oriented in a general course parallel to the margin-line of a slope. It is obvious that the origin of these thermokarst depressions is associated with the breaking of the slope surface. They came into being from the large subsiding fissures formed during the thawing of the frozen ground in the marginal part of the slope foot.

The first information on the closed depressions in the Taragai Basin appeared in the reports of the Naryn-Chentegry Expedition; their origin being considered as thermokarst (Kalesnik, 1935). The studies made in 1963 by the present authors confirmed this opinion.

In the Taragai Basin permafrost is of common occurrence; in the old morainic sediments and in glacifluvial pebbles the permafrost table is at a depth of 2–3.5 m, in the lacustrine deposits at 1–2 m, and on wet and turfed meadows or on the bottom of erosional incisions it rises up to 1–1.5 m. The thickness of permafrost may be measured in tens of metres. Most characteristic of the permafrost in this area are "taliks" which reach down to the permafrost bottom. They were water passage ways from under the permafrost throughout the year. In the basin described there are about 7–8 taliks, most of them are connected with the fissure running parallel to the edge of the Dzhetymbel ridge.

The cryogenic structure of permafrost depends on its lithology, age and conditions of freezing. Thus, the morainic series displays a thick-layered cryogenic structure. The thickness of individual layers of segregation ice is 40–50 cm (Gorbunov, 1965). The basic structure of the glacifluvial sediments is cryogenic and the series of pebbles occurring in them is connected with ice. The frozen lacustrine sediments show the middle- and thin-layered structure, and sometimes check structure. The thickness of individual layers is 5–10 cm.

The relief of the area discussed underwent the postglacial development as follows: the Taragai Basin when left by the glacier was an uneven hilly morainic surface with the buried dead-ice blocks and numerous lakes. Large lakes were dammed by the lateral moraines. In one of such water basins in the upper part of the river Kyzyleshme (left side of the Taragai), the section reveals lacustrine sediments 10 m thick. The upper 4 metres are interbedded silts and fine sands – the layers being 3–15 cm thick; in the lower part the varved clays are composed of 5–7 mm varve-layers. Detailed examination of the varved clays dates them as being 1000 years.

Pollen analysis of the lacustrine sediments showed that the varved clays were formed under the conditions similar to the present ones but more arid, and only during the accumulation of the upper part of this series the climate was a little more humid than it is today. Because of the limited size of this paper, the paleobotanic data cannot be discussed in detail; this problem will be presented in a separate paper.

In the morainal hilly area the melting of dead-ice blocks caused transformation of land-forms and inversion of the surface-relief. Under such conditions and because of streams which being braided do not erode their beds, an accumulation of debris took place and was promoted by tectonic upheaving of the Kulchuk-Kyrkoo ridge lying across the track of meltwater outflow. Debris accumulation was associated with a slow freezing which facilitated the formation of segregation ice. In the Taragai Basin the accumulation was followed by a short period of planation due to which a thin, 0.5–1 m, cover of silts was deposited.

The authors state that the beginning of development of thermokarst phenomena in this area belongs to the next stage of the evolution of relief-forms, i.e. the erosional dissection of the basin bottom. Progressive incision of the Taragai river-bed and of the tributaries gave rise to the thermokarst phenomena. Initial cavities were places of water concentration in summer, and snow accumulation in winter. Such conditions favoured more intensive thawing in summer, whereas the winter freezing was impaired. The concentration of water, often pure mineral one, and of snow in the subsidence holes and trenches increased as their size grew larger, promoted melting of ground-ice without any supplementary agents. This phenomenon is called by Kachurin (1961) "thermokarst self-development".

On the surface of river terraces the largest depressions were formed due to the activity of river-water emitting heat. In such a case the lateral thermoerosion operates. If the terrace sediments contained a large concentration of ground-ice, the side shifting of the river-bed could have given rise to intensive thawing and subsidence of the ground. The bottom part of the terrace sediments often occurs below the surface of the present-day alluvium (fig. 3). Such are the lakes near the exit of the Kyzyleshme stream (left side of the Taragai) located on the border line between the terrace and valley bottom.

When speaking about the influence exerted by climatic changes upon the development of thermokarst in the Taragai Basin, the following facts should be borne in mind. The presence of permafrost in the inundational alluvium of the river Arabel-Su (Gorbunov, 1958) and the yearly complete up-freezing of the active zone prove that permafrost is also active nowadays. Under the unchanging climatic conditions the common development of thermokarst phenomena could be in progress only due to erosional dissections of the bottom of the Taragai Basin and by so-called thermokarst self-development. It should be emphasized that the thermokarst forms also at present undergo further development which is evidenced by the open fissures surrounding the edges of numerous funnel-like depressions.

Pollen analysis proves that the climate in the Taragai Basin during the postglacial period was for at least 1000 years more arid than it is today. The origin of many large thermokarst land-forms dates back to that time.

Kachurin (1951), who classified the thermokarst forms, has stated that funnel-shaped depressions originated as the result of melting of segregation ice are usually 4 m, but sometimes even more than 20 m deep. In the Taragai Basin, however, some of them are as deep as 30–35 m and resemble the forms which Kachurin determined as deep basin-like holes originated in places with buried glacial ice, on frozen lakes and so on. Thus, it may be assumed that in the Taragai Basin there exists not only segregation ice but also glacial dead--ice and buried naledis (icing) frozen to the lake bottom, buried snow drifts, etc.

Beside the thermokarst land-forms, there are also other cryogenic forms of smaller size in the Taragai Basin. They occur within the three morphologic zones formerly described.

The most remarkable is the complex of forms associated with erosional incisions overgrown with grass, because greater moisture of ground promotes the cryogenic processes. Up-heaving of water-saturated ground produces deformations and disrupts the turf giving rise to small hillocks (*bugors*) and spotted tundra (*pyatna medalions*) of various shapes. The small swellings are often the result of up-freezing of stones.

Frost-fissure polygons, 2–3 m in diameter, and individual fissures some metres long are the result of frost cracks of the ground surface deprived of a thick and continuous snow cover and where the soil is moist enough. Frost fissures usually do not penetrate to the permafrost table but are developed within the active zone. Their length is usually no more than 1 m.

On the stream- and lake-sides deprived of turf cover there are sorted polygons with silty convex centres containing ice lenses some tens of centimetres thick, and mounds, 1–1.5 m high. Usually they originate in autumn and may persist for several years if the ice lenses cannot melt completely during the short mountain summer.

On the bottoms of thermokarst depressions filled up with lacustrine silts the small hydrolaccoliths sometimes occur. They resemble in size the seasonal frost-heaving mounds. Unlike the latter, the hydrolaccoliths have ice cores, sometimes over 2 m thick, in the permafrost. The hydrolaccoliths develop during the long-lasting freezing of taliks below the lake bottom.

In some segments of the river valleys, their N, NE, and NW slopes appear to be indistinctly developed solifluction terraces whose fronts are interbedded with fossil soils.

In winter, the Taragai Basin is the area of river- and spring-icings. The former originate during the deep freezing of the Taragai, which in cold periods is supplied only with sub-permafrost waters. The latter develop in the direct vicinity of springs situated along the tectonic cracks. Such icings are the icy fields which have been coated by surficial mineral material. The largest of them cover some thousands of square metres. The thickness of ice is 1–1.5 m and more. In the Taragai Basin these icings increase from October–November to March–April, while they decay in April and May.

The formation of thermokarst gullies is also worthy of mention. They originate at the springs supplied with sub-permafrost water, in the loose, ice--saturated ground. Permafrost processes together with stream erosion lead to the removal of this material and promote the development of gullies. Such land-forms occur on the right side of the valley between the rivers Suek and Dzhetymbel, mainly in places where the spring icings are formed in winter.

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