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DOWOO — A NEW TYPE OF EARTH MOUNDS IN CONTINENTAL PERMAFROST DOMAIN (CENTRAL MONGOLIA)**

Abstract

In the outlet of dells to the zone of alluvial fans of different age occurring in the vicinity of Chojor Nuur (Central Mongolia), the rampart forms and mounds reminding pingo with its appearance, have been discovered in spring seasons of the years 1976—1978. They were formed on the turn of April and May as a result of accumulation and compression under the permafrost or within its subterranean waters. The pressure up to the surface of waters, which were under the high hydrostatic pressure gave rise to the development of positive landforms. The decay of the mounds and the rampart followed fast. It was caused by the outflow of the water on to the surface, resulting from the upbreak of permafrost mantle which is already thin in June or at the beginning of July. The forms not yet revealed, by that time have been named dowoo which means a mound in Mongolian.

INTRODUCTION

Mongolia is situated within the influence of the southern part of cold Siberian anticyclone and in accordance with it the severe continental climate prevails in its area. The climate is characterized by the long, frosty winter and by the short summer with a not too long period of high temperature. In such a thermic situation a great part of this country area lies within the annual isotherm of —1 °C, which indicates, in A. JAHN's (1970, 1975) and A. L. WASHBURN's (1973) opinion, the extent of discontinuous permafrost. Morphological and structural aspects of the existence of permafrost in Mongolia are, among other things the hummocks of pingo type, thermokarst hollows, thufurs, solifluction tongues, the phenomena of thermokarst erosion and ice-wedge polygons (V. L. SUKHODROVSKI, 1974; Z. BABIŃSKI, M. GRZEŚ, 1975; Z. BABIŃSKI, K. PĘKALA, 1975/76, K. KLIMEK 1975; W. FROEHLICH, J. SŁUPIK 1977; W. FROEHLICH, J. SŁUPIK, T. BOASAN, 1977; K. ROTNICKI, Z. BABIŃSKI, 1977, B. NOWACZYK, 1984, K. PĘKALA, T. ZIĘTARA, 1980, and others).

In the years 1975—1980, the Mongolian—Polish Physical Geographical Research Station carried out observations in the area of Middle-undulated uplands in Gurwan Turuu (somon Bajan) (φ 47°03'N, λ 107°38'E). A detailed analysis of frost forms and structures was one of its research purposes. They have constituted

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the base on which the estimation of permafrost extent has been done in this region of Mongolia. Fulfilling the research tasks the author has investigated the commonly accepted indicators of permafrost existence (B. N. Dostovalov, 1960; J. Dylik, 1963, 1966; R. E. Black, 1969; A. Pissart, H. M. French, 1977; and others), namely: ice-wedge polygons, the hummocks of pingo type, and thufurs. Some regard the last of them as the evidence of deep seasonal freezing (V. L. Sukhodrovski, 1974), others take them as a part of seasonally frozen ground or permafrost existence (B. Nowaczyk, 1984).

During the investigations carried out in the vicinity of Chojor Nuur lakes which lie 12 km to the south-east of Gurwan Turuu, the attention has been paid to the forms reminding pingo with its appearance. More detailed observations of the hummocks mentioned above however, have pointed out that it was the water accumulating either under or within permafrost which played the main role in their development and not the injection or segregation ice which causes the formation of pingo (W. A. Kudryavcev, 1978; J. R. Mackay, 1978b). The forms of this type have not been recognized yet and therefore there is lack of information in the literature concerning cryogenic problems. For this reason, the author proposes to name them *dowoo*.

MORPHOLOGY, GEOLOGICAL FRAMEWORK, AND THE EXTENT OF PERMAFROST IN THE VICINITY OF CHOJOR NUUR

The Chojor Nuur lakes of tectonic or thermocarst origin lie in quite a wide tectonic-denudation depression separating two units different in lithology and morphology (Fig. 1). The depression runs parallelly to the main tectonic lines of the investigated area of NNW-SSE direction.

The north-eastern edge of the depression is built up of granitoids cut with numerous aplite and porphyry dykes. Within the granitoids there is a bedding joint the plains of which dip to the south (S. Dżułyński, 1977, 1978). Morphologically this area constitutes the planation surface lying at the altitude of 1440—1500 m above sea level, diversified by not too high longitudinal hummocks, which agree with the outcrops of dykes built of aplites and porphyries more resistant to denudation (B. Nowaczyk, 1978). The inselberg of gorgeous Bajan Owoo massif (1617 m above sea level, Pl. 2) making the rhyolitic-granitic intrusion, is elevated above the planation surface. The planation surface is cut with quite a dense network of the rejuvenated dells with considerable gradient, the bottoms of which are occasionally used by surface waters and only at short distances. The portion of them has their heads in Bajan Owoo massif (Fig. 1). In the outlet of the dells to a tectonic-denudation depression the zone of different-aged alluvial fans is spread. The waters responsible for the formation of alluvial fans flew to the west through the tectonic valley to the valley lying in a central depression.

In alluvial fans built up of sandy-gravely sediments highly saturated with water the insular occurrence of permafrost has been recorded (Fig. 1). It has

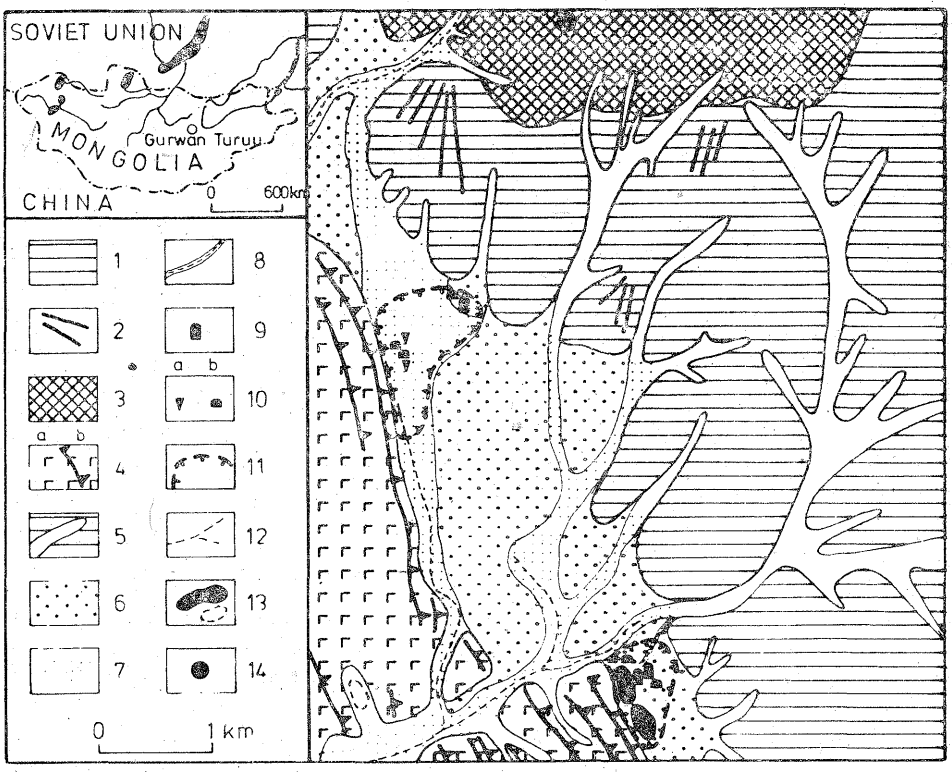


Fig. 1. Geomorphological map of the vicinities of Bajan Owoo and Chojor Nuur. (The geological map of the vicinities of Gurwan Turuu, by S. DŻUŁYŃSKI 1977, 1978 has been used in elaboration)

1. planation surface developed on granitoids; 2. ramparts developed on aplite and porphyric dykes; 3. Bajan Owoo inselberg, rhyolite-granitic intrusion; 4. fault scarps developed within basalt plateaus; a) gentle slopes; b) steep slopes (fault plane); 5. dell bottoms; 6. older alluvial fans; 7. younger alluvial fans, abandoned bed on the surface of the older fan; 9. cryogenic dowoo forms 10a. ice-wedge polygons; 10b thufurs; 11. permafrost extent; 12. intermittent streams; 13. permanent and intermittent lakes; 14. Bajan Owoo summit — 1617,5 m above sea level

also been noticed in the hollows infilled with clayey or silty sediments which contain considerable moisture. The undoubtful evidence of permafrost in this area are the ice-wedge polygons and thufurs (B. NOWACZYK, 1984). The lingering of permafrost in tectonic-denudation depression is generated both by low annual air temperatures and by cooling influence of the icing produced round the northern Chojor Nuur lake. Such a phenomenon is known from the V. A. KUDRYAVCEV'S observations (1978) and from the investigations made in Spitsbergen where the influence of the icing on the substratum has been undoubtfully proved by J. CEGŁA and S. KOZARSKI (1977, Fig. 2).

G. F. GRAVIS (1974) maintains that the discussed region of Mongolia is situated in the zone of occasional occurrence of permafrost where the low thickness of permafrost is characteristic of it. The permafrost, according to him, reaches in this zone from several decimetres to 5 metres in thickness, and only

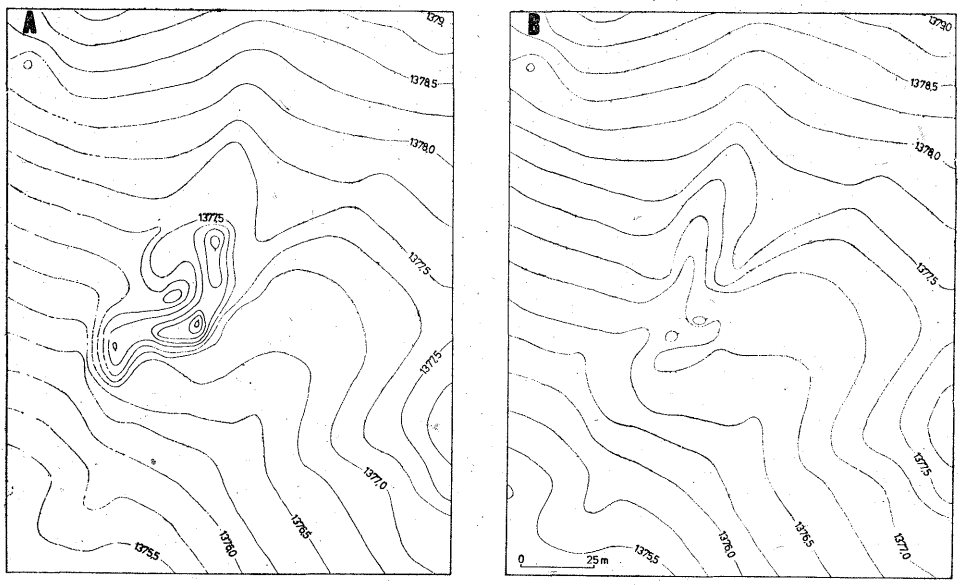


Fig. 2. Hypsometric map of the fragment of alluvial fan and of dowoo rampart, situated to the east of Chojor Nuur

A — the state recorded on June 11, 1977; B — the state recorded on July 2 and August 18, 1977 and on April 5, 1978

occasionally 10 metres. It results from the field observations carried out in the vicinities of Gurwan Turuu that the permafrost thickness amounts to over 3.5 m.

On the fans lying near Chojor Nuur and to the south-west of Bajan Owoo (Fig. 1) i. e. next to the outlet of dells to the fans zone, the occurrence of dowoo forms has been recorded. Each time they were connected with the presence of permafrost.

MORPHOLOGY OF EARTH MOUNDS — DOWOO

In south-western part of alluvial fan, situated in the foreland of widespread valley system which starts with south-eastern foothills of Bajan Owoo, relatively short river bed runs which is presently inactive, and almost completely covered with turf. In this bed and in the neighbourhood of the mentioned lake the dowoo forms have been observed in the spring of 1977 and 1978.

One of the forms was just 6 m away from the eastern edge of the lake. It was the mound of circle shape, the diameter of which amounted to about 17 m. The form was 2 m in height and its slopes were symmetrical and steep (Pl. 1A). The mound was cut with radially arranged tension fissures similar to those disrupting the mounds of pingo type. Some of them were opened to 20 cm in width and their depth amounted to 1 m.

The second more gorgeous form of different shape (Fig. 2A, Pl. 2A) lay 170 m to the east of the lake skore. It was the rampart with the curved

course, and with the length of 75 m, the width of 12—20 m and the maximum relative altitude amounting to 1.6 m. The top of the form was dissected by the tension fissures parallel to the morphological axis. The fissures reached the depth of about 1.5 m and were opened, in their top part, to the width of 25 cm (Pl. 3A,B). On the surface of the western part of the rampart the thufurs, the height of which amounted to 30 cm, (Fig. 3) occurred.

The form of similar appearance to the first ones mentioned above, but of somewhat smaller size (diameter of about 10 m and width of 1 m) has been noticed

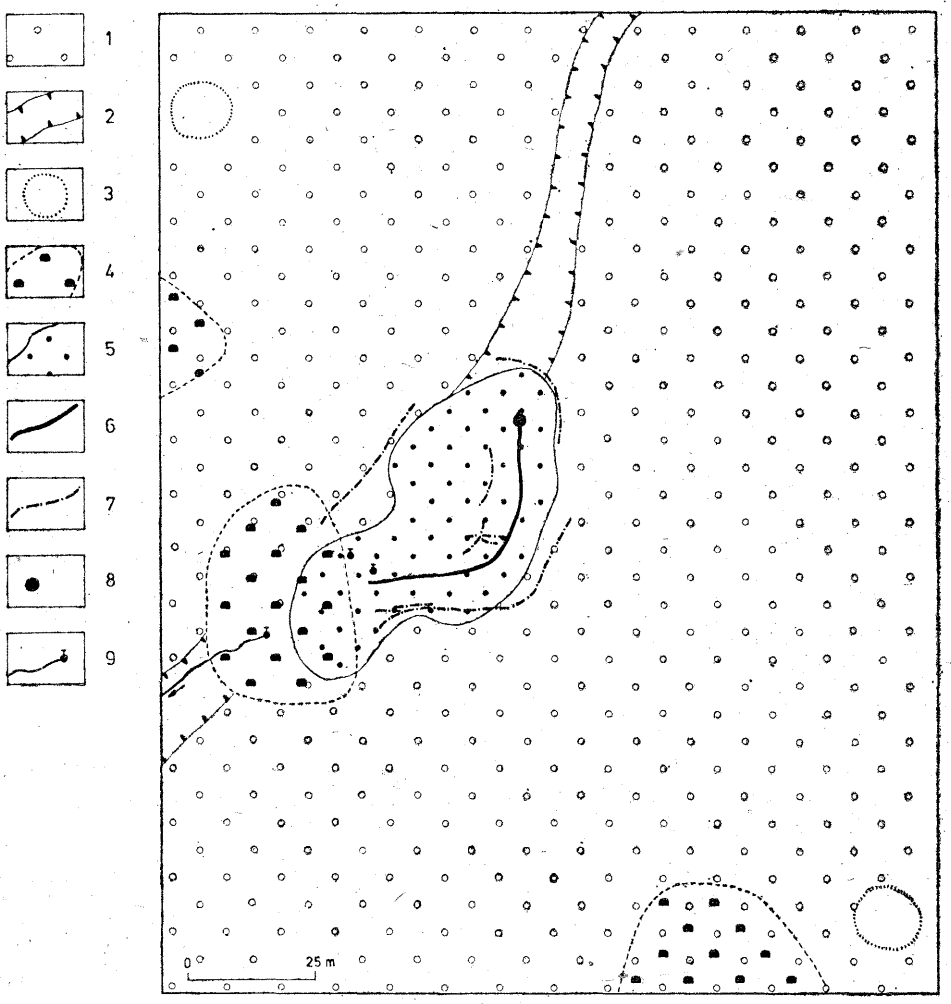


Fig. 3. Geomorphological map of the fragment of alluvial fan and of dowoo rampart, situated to the east of Chojor Nuur

1. older alluvial fan; 2. abandoned river bed; 3. closed depressions, the remnant after old dowoo forms; 4. thufurs; 5. the outline of dowoo form (the state recorded in the period from 9 to 30 of June, 1977); 6. tension fissures produced during the formation of the dowoo; 7. the fissures produced during the decay of the dowoo (indicating the extent of under- or interpermafrost water lense); 8. the sink produced during the water eruption in 1977; 9. distribution of the migrating source and the stream, active since the dowoo decay to the moment of source freezing

in 1976 in the outlet of another short dell which has its head at the south-western foothills of Bajan Owoo (Fig. 1). The earth mounds — dowoo observed in the years 1976—1978, always occurred in the stoss-side of allluvial fans. The forms discussed were formed on the turn of April and May, and already disappeared in June or on the first days of July.

ORIGIN AND DEVELOPMENT OF THE EARTH MOUND — DOWOO

The facts presented above prove that earth mounds dowoo are the ephemeral forms occurring within the reach of seasonally or permanently frozen ground. They appear in the middle of spring and already disappear in the end of it or at the beginning of summer. The reasons for the mounds development are not to be searched in the increase in injection or segregation ice lenses which occur in the period of the autumn decrease in temperature and results in the formation of pingo. Thus, during the analysis of the manner of the dowoo decay, the reason for their production may be only searched in the accumulation of water in the lense form under the mantle of permafrost, which causes the same results in the relief as the ice does in the case of pingo development.

The position of dowoos on alluvial fans near the outlet of dells makes the author relate their origin to the phenomena occurring in this system. The alimentation of subterranean waters within the alluvial fans lying on the depression situated to the west of the planation surface, seasonally appears due to the subterranean flow in the system of dells draining the area of the planation surface and of the Bajan Owoo massif. In spite of considerable shattering of the investigated region with the faults, the supply of subterranean fan water with the fault water is difficult to be accepted. It results from the fact that, according to W. Chełmicki (1978), the crevice origin of the water would have to lead to permanent outflows even during the exceptionally severe winter of 1976/77, meanwhile the phenomenon does not occur.

The dells possess, in greater part meridian orientation (Fig. 1). Thus both their bottoms and big fragments of the slopes are subjected for a long time to the sun ray action intensified by usually small cloudiness. As a result of the sun ray influence on little snow patches and first of all on weathered material and fluvial sediments, the thawing of them follows starting with April (B. Nowaczyk 1981b). This process generates the subterranean runoff of the water. It migrates both in the deposits of the dell bottoms and in the system of fissures of bed joint, the planes of which, as it was said earlier, dip in southern direction. From the valley sediments and from the bed joint planes the water moves into the deposits making up the alluvial fans. The thermal effect of water is small, because it is all the time in contact with permafrost or seasonally frozen ground. In the end, on the turn of April and May the ground waters reach the neighbourhood of the Chojor Nuur lakes or the alluvial fan lying to SW from Bajan Owoo, using, most probably, taliks. Here, they are deprived of the possibility

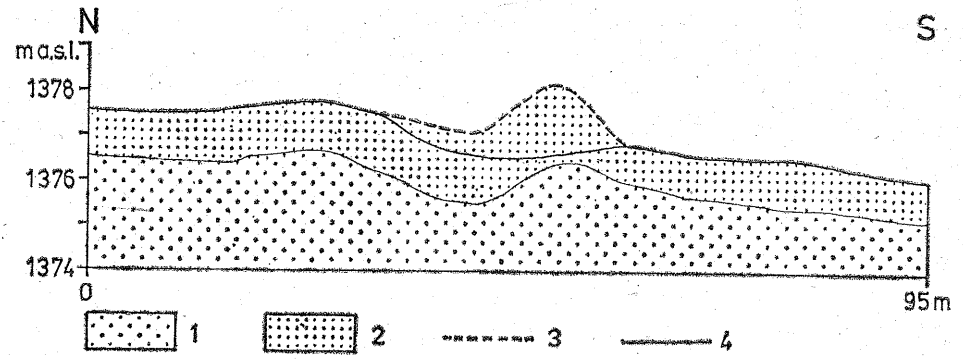


Fig. 4. Geological cross-section through alluvial fan, dowoo and abandoned river bed
1. permafrost; 2. active layer (the state recorded on June 11, 1977); 3. the profile of dowoo, the state recorded on June 9, 1977; 4. hypsometric profile of alluvial fan and of abandoned river bed

of the movement up to the surface, for, as it has already been proved, the permafrost is additionally preserved from the degradation by a turf cover. The pressure of the water trapped under or within the permafrost is extremely high because the source parts of the valley which has its end in the vicinity of Chojor Nuur, are situated about 100 m (above 1500 m above sea level) above the level at which the investigated forms occur (about 1400 m above sea level, Fig. 5). There is a great similarity in the manner of ground water migration in the vicinity of Chojor Nuur to that resulting in the development of pingo (of open system) (A. JAHN, 1970, 1975; A. L. WASHBURN, 1973, 1980).

The lack of permeable fissures in the sediments underlying taliks or the lack of the outflow tracks to another places leads, in the end, together with the permanent supply of water being under high hydrostatic pressure, to the elevation of a rampart or a mound and to the formation of the water-lense under it. Similar water lenses, but underlying ice-cored pingos have been observed on the Tuktayaktuk Peninsula (the delta of the Mackenzie River) by J. R. MACKAY (1977, 1978a). The accumulation of water under the ice caused the elevation of the mounds while its outflow through the fissures situated in the edges of the forms causes

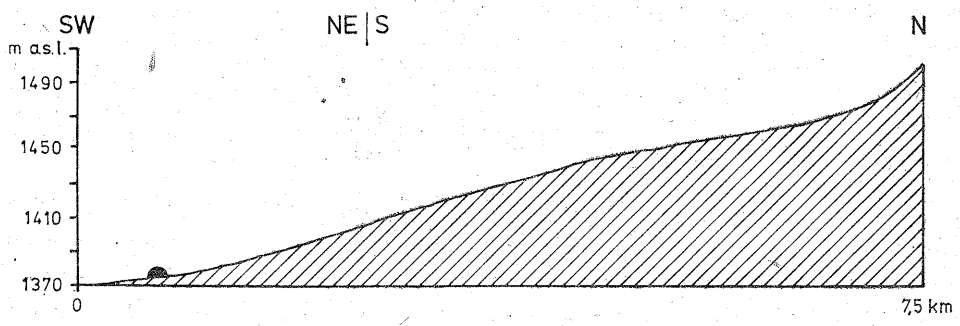


Fig. 5. Longitudinal profile of the dell running from the south-eastern foreland of Bajan Owoo and the stoss-side of the alluvial fan. The dowoo is marked with the black semicircle

the decrease in their height. The drilling which pierced through the ice core generated the outflow of the water under the artesian pressure. The height of the water column ejecting from the drill-hole with the diameter of 75 mm amounted to about 2.6 m. After this experiment the form decreased apparently in height. J. R. MACKAY (1977, 1978a) calls these forms "pulsating pingos".

The elevation of the permafrost mantle by pressing ground water releases the development of stresses leading to disruption of its coherence. As a result of this process the tension fissures are produced with different width, length and spatial pattern (Fig. 3). They do not, however, reach the water lense (Fig. 6A). The fissures are parallel to the morphological axis of the rampart forms, while in the case of mounds they are usually radially arranged.

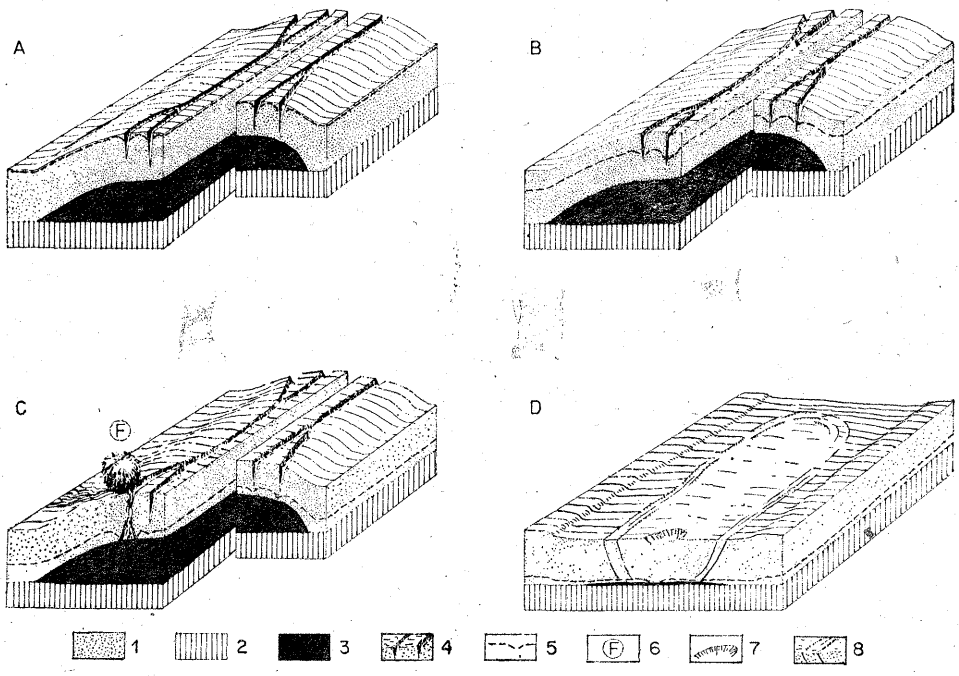


Fig. 6. Blockdiagrams presenting the stages of the dowoo development in the vicinity of Chojor Nuur
A — the formation of the dowoo and of the tension fissures; B — development of the active layer; C — the formation of the sink and the beginning of the dowoo decay; D — development of the fissures during the subsidence of the form; 1. the sediments making up the alluvial fan and the dowoo; 2. the fan substratum of the permafrost within the sediments making up the fan; 3. water lense; 4. tension fissures; 5. the thickness of the active layer; 6. water eruption; 7. the sink; 8. the fissures and the collapse structures produced during the dowoo decay

The meteorological conditions of May and April of the years 1976—1978 favoured the development of active layer over the permafrost. The wide tension fissures cutting, in many places, the rampart or the mound made the migration of atmospheric heat deep into the forms easier. Slow degradation of permafrost followed in this way, which was considerably faster under the dowoo forms than in the adjacent areas (Fig. 5 and 6B). The successive thawing of the ground

gave rise to the decrease in the thickness of the rigid permafrost mantle (Fig. 6C) which still bore the water pressure. In the case of the two forms considered, quite heavy precipitations (6 mm in only 2—3 hours) of storm type have been observed. In connection with it the tension fissures collected a considerable amount of water which gave its heat to the surrounding permafrost. As a result the fast degradation of permafrost followed, particularly in the surroundings of fissures where its top was more deeply situated (Fig. 6C). Decreasing permafrost thickness, beneath critical value, generated its break and violent outflow of water.

In the case of the rampart lying to the south of Chojor Nuur it was a very violent eruption. In the end of June, 1977, such an outflow, using the tension fissure produced a sink with diameter of 1 m and depth of 90 cm. First, for a spell just after the eruption, a great amount of water containing little admixture of mineral particles escaped from the sink as a spurt (Fig. 6C). The water also flew out from some sections of the tension fissures. Providing that the dimension of water lense trapped within the rampart approximated $1.5 \times 15.0 \times 70.0$ m the capacity of over 1500 m^3 is achieved. In the first stage of the dowoo decay such an amount of water flew into the lake, spreading out to 10—20 m in width, which was the reason for decrease, of about 30 cm through a day, in the level of lake water. The violent and abundant outflow of water is finished when its resources contained in under- or interpermafrost lense are used up. Further, the water flew out permanently, with the temperature of 0.1—0.2°C and with the efficiency of 5 l per sec, which is the very high value in this region of Mongolia. It lasted by the moment of repeated freezing of the ground, i. e. the source of water, which occurs in the third decade of October (W. Chełmicki, O. Cerev, 1977).

It is possible to draw a conclusion about the violent course of the phenomenon of the dowoo decay on the basis of turf pieces and the clods of the sediments making up the alluvial fan scattered within a radius of 4—5 m from the sink. They reached 20—30 cm in diameter (Pl. 4). Near the sink, the sediment clods have been found, the appearance of which indicated that they were thrown up as frozen bodies onto the surface where they underwent thawing (Pl. 4).

Following the decrease in the size of under or interpermafrost water lense, the succesive decay of the rampart occurred (Pl. 2B). The tension fissures decreased in width, and in the sections in which the outflow of water followed, they were infilled with the mineral material transported by water. At the same time new fissures of another type were produced in the edges of the dowoo (Fig. 3 and 6D, Pl. 5A, B). In some places, they took the form of step faults, with the throw of to 10 m, making the collapse structures (Pl. 6). The fissures usually merely open (to a few cm) were the structures to mark out the extent of the water lense formerly trapped.

Degradation process of the dowoo was varied. The form lying near the lake was decaying slowly. At the beginning of June, 1977, a small hole was produced at the foothill of the mound, on its southern side, through which the water flew

out under low hydrostatic pressure. The water with the temperature of 0.2°C flew into the lake. The loss of water away from the under- or interpermafrost lense generated the slow decrease in the mound height and the simultaneous tightening of the fissures. The fissures connected with the subsidence of the mound were also formed in the edges of it. The mound decayed within 12 hours, and the outflow of the water lasted two days only. When compared with that of rampart form, the earlier decay of the dowoo situated near the lake, should be referred to the thermic effect of the water (of the stable reservoir) on the permafrost. The migration of water from under the dowoo, through the subterranean fissures directly to the reservoir should not be excluded.

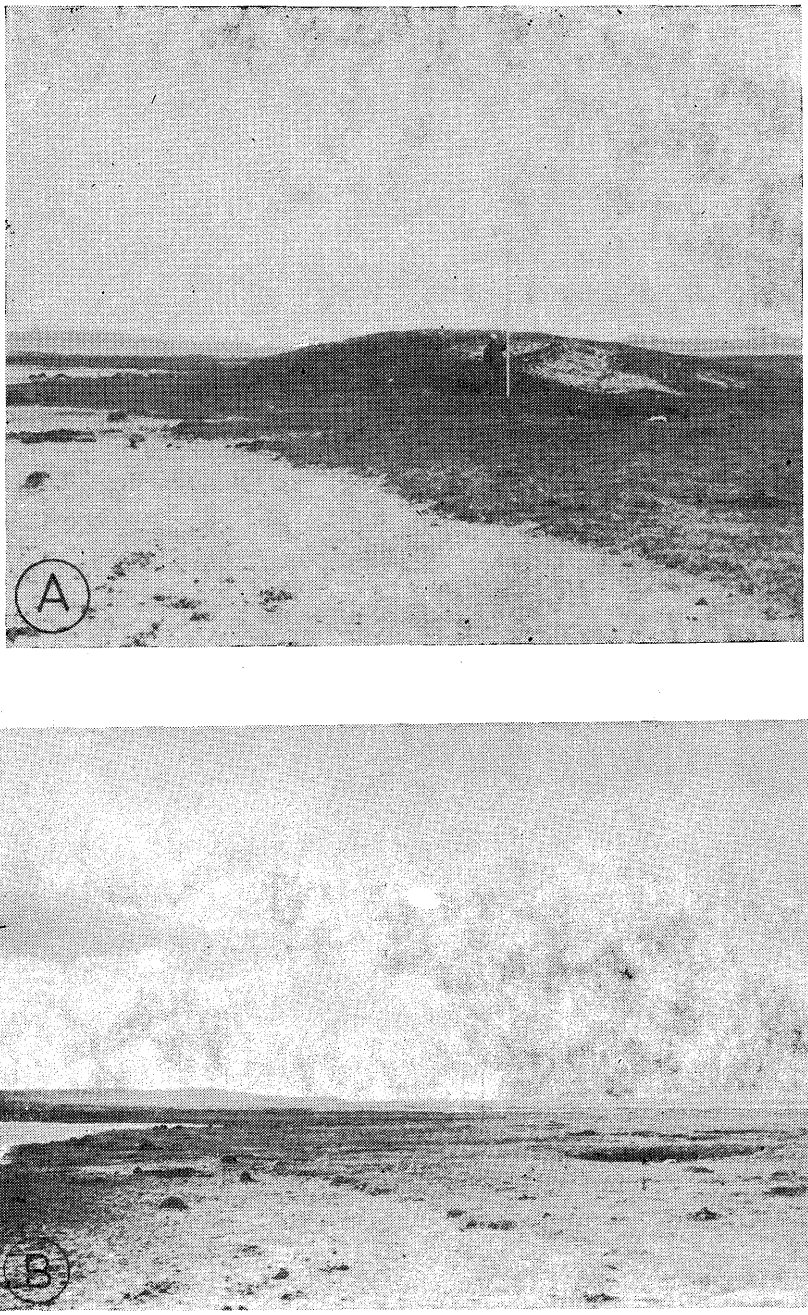
On the basis of the observations carried out in the nearest neighbourhood of Chojor Nuur the conclusion may be drawn that the dowoos are quite common forms in this region. They are formed in the inactie river bed mentioned above and the only apparent traces that were left are the sinks which are produced during the eruption and the fissures. Near the sink formed in 1977 the old sink has been noticed which has the diamenter of 1.6 m and the depth of 0.5 m and is completely covered with turf now. Not always, however, the dowoo decay results in the formation of sharply shaped sinks. In the extent of the alluvial fan the two large hollows occur (Fig. 3 pos. 3) which are, most probably, the traces left by the dowoos of bigger sizes.

CONCLUSIONS

The morphological features of the earth mounds — dowoo presented above and first of all the course of processes responsible for their origin are peculiar. On the one hand, they have certain features in common with pingos, and on the other hand they differ fundamentally from them. The similar features are: the shape of the form, its position in the areas of the occurrence of seasonally frozen ground and permafrost and the identical water supply as is known from the open system pingos (A. JAHN, 1970, 1975; A. L. WASHBURN, 1973); whereas most significant differences concern the initial stage of the dowoo development which occurs in the half of spring season, the morphogenetic process and their conspicuous ephemeral nature. In connection with it the dowoos cannot be included either in pingos or in bulgunyakhs.

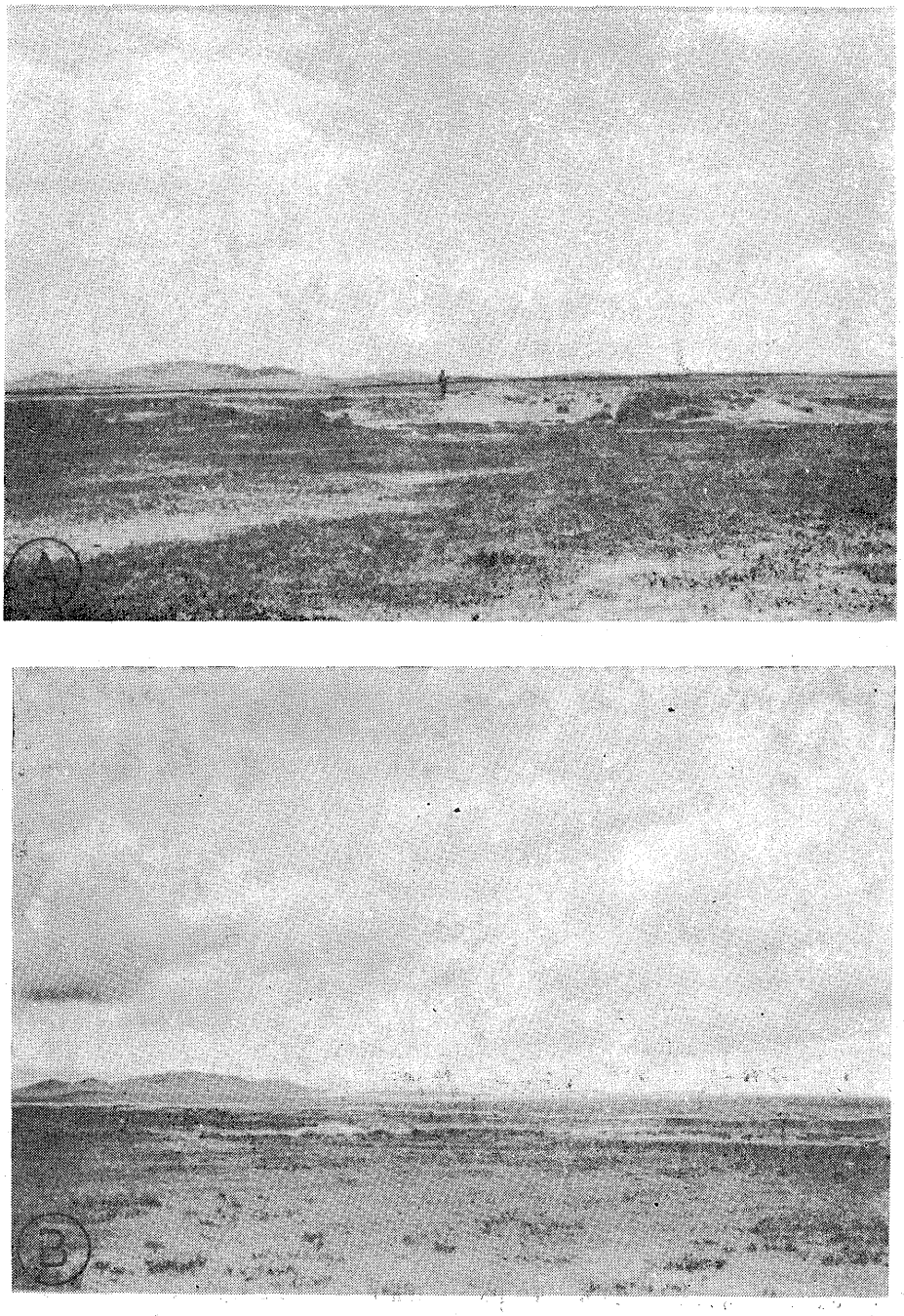
The essence of mounds and ramparts of the dowoo type, investigated in the vicinity of Chojor Nuur, would be best revealed by the term "hydrolaccolith" used, anyway, by W. CHEŁMICKI (1980). The term, however, is already preserved for the ice-cored forms (V. A. LVOV, 1916; N. I. TOLSTIKHIN, 1932). In that case, to avoid terminological chaos the author proposes to use the regional term and name the investigated mounds and ramparts "dowoo". This name means "a mound" in Mongolian language.

Thus, the dowoo may be defined as the ephemeral earth mounds or ramparts,



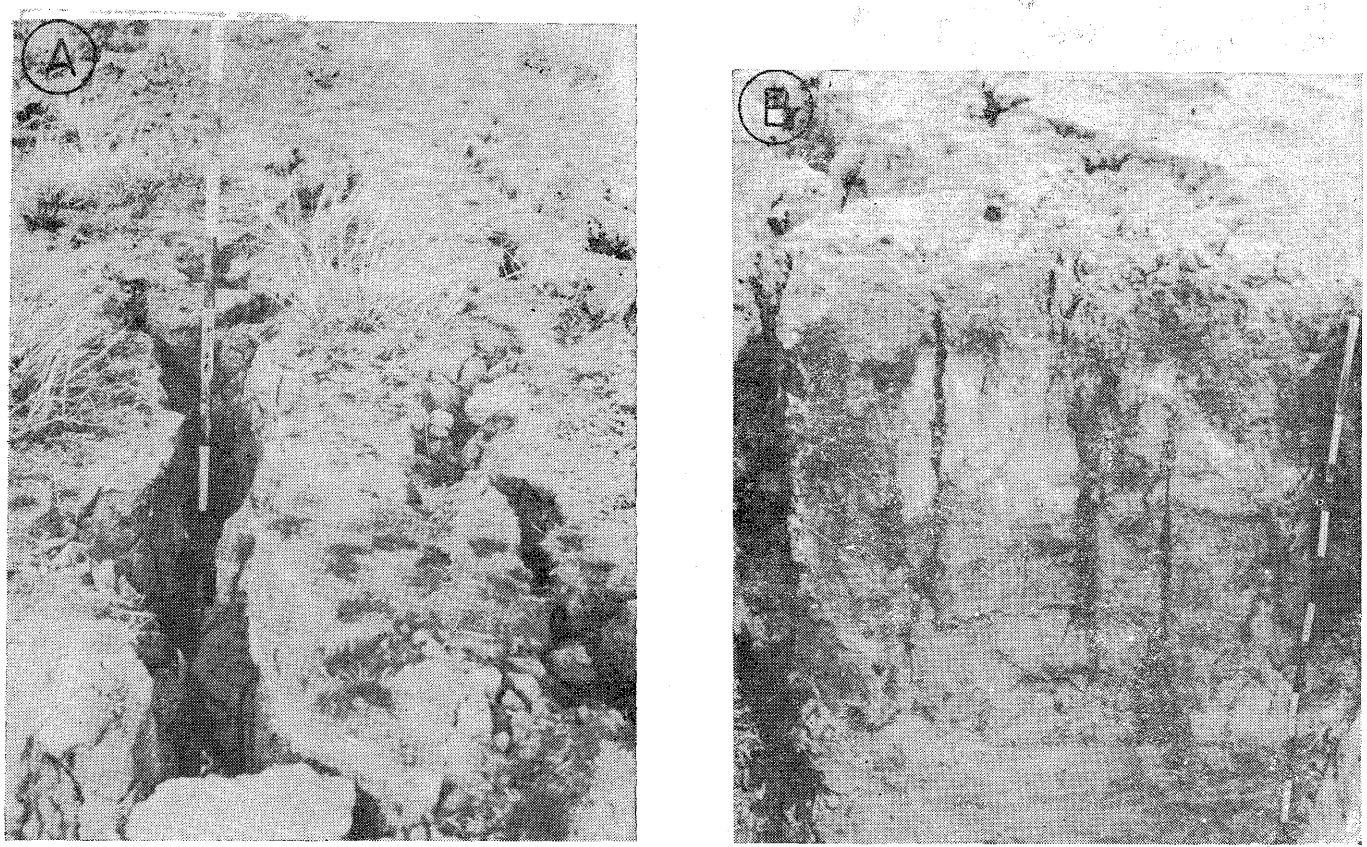
Pl. 1. Chojor Nuur. The dowoo with the outline of circle being directly adjacent to the lake

A — the state recorded on June 9, 1977; B — the state recorded on June 12, 1977

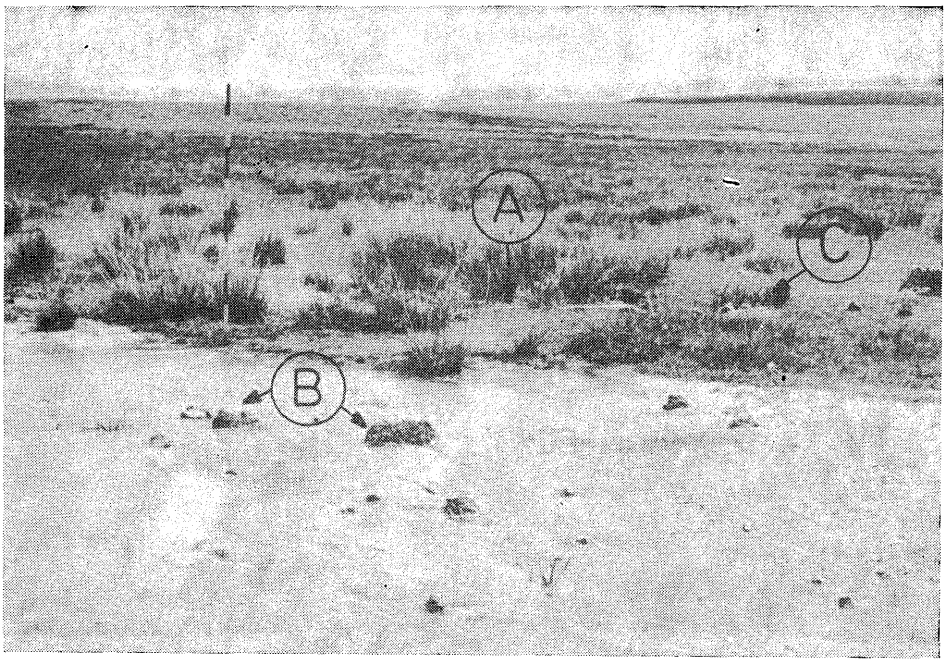


Pl. 2. Chojor Nuur. Dowoo — the rampart form in the foreground and the massif of rhyolite-granitic intrusion of Bajan Owoo

A — the state recorded on June 9 1977; B — the state recorded on July 1, 1977

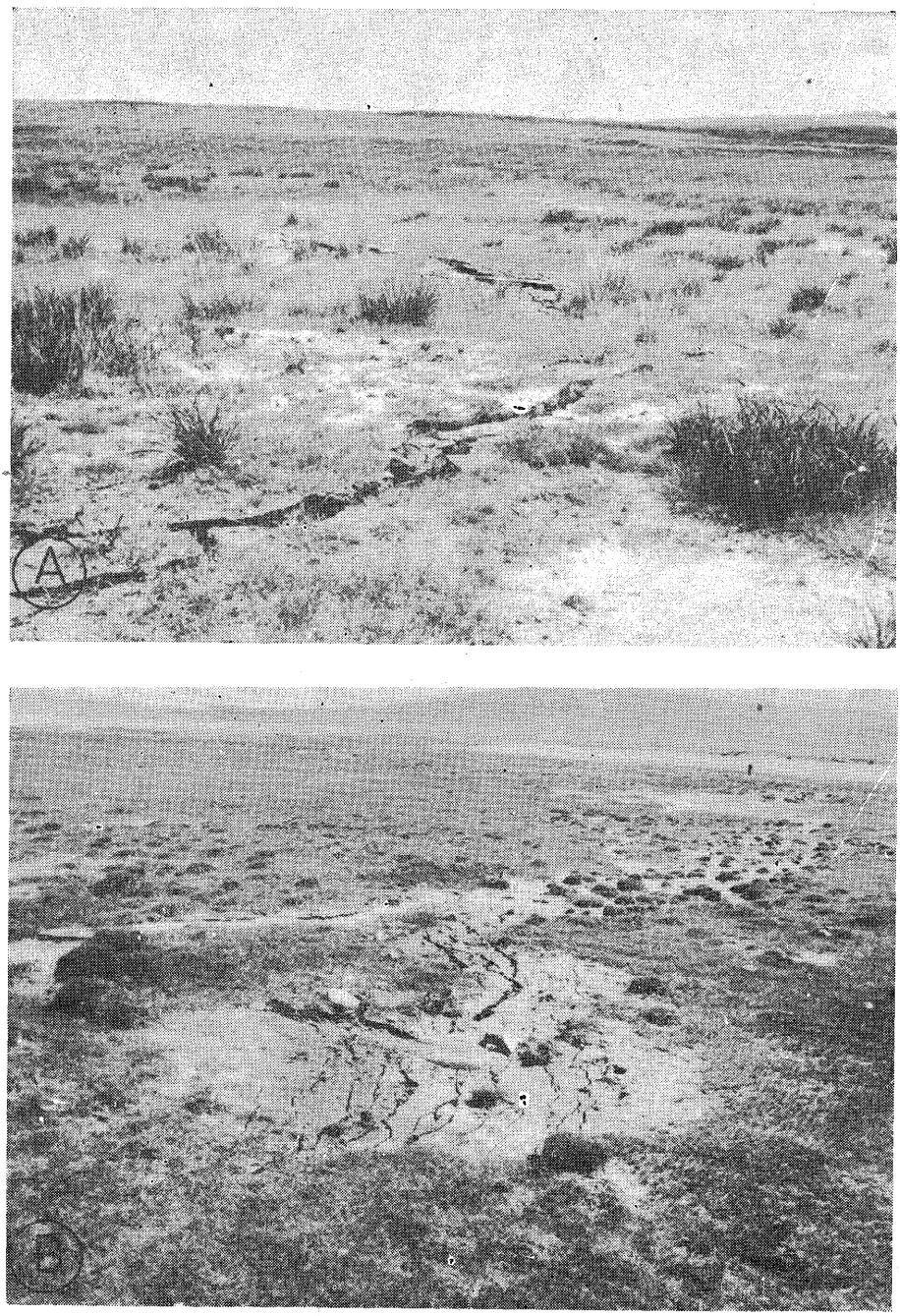


Pl. 3. Chojor Nuur. Dwoo — the rampart form
A) the tension fissures visible in horizontal plane; B) a view in vertical plane



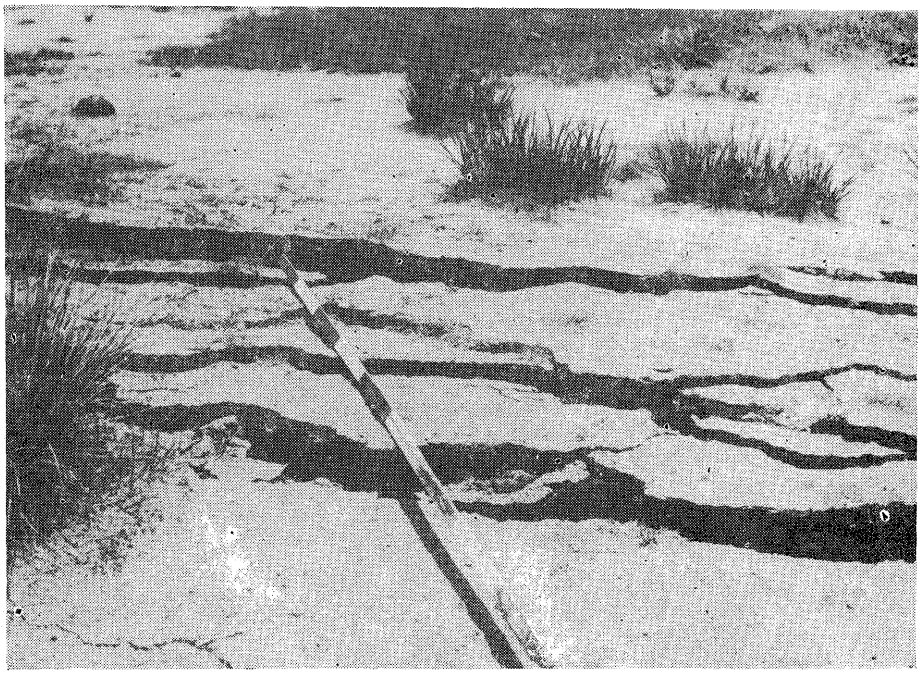
Pl. 4. Chojor Nuur. Dowoo — the rampart form

A — sink; B — turf clods; C — clods of thawed permafrost. The photo was taken few hours after the decay of the form on July 1, 1977. Near the sink the water runoff over the surface still occurred



Pl. 5. Chojor Nuur. The rampart form of dowoo. The fissures formed during the decay of the form on July 1, 1977

A — north-eastern part of the form; B — south-western part of the form — the river bed draining the water off the source, thufurs and the northern lake are visible



Pl. 6. Chojor Nuur. The rampart form of dowoo. The fissures arranged in steps — they are formed during the decay of the form

occurring in the zones of permafrost or seasonally frozen ground. They lie on the stoss-sides of alluvial fans near the dell outlets. The forms are formed on the turn of April and May as a result of vertical elevation of permafrost mantle by the pressing subterranean water flowing down from the areas of higher altitude. The decay of the form falls in June or at the beginning of July and occurs due to break of thin, and at that time, frozen layer by the water being under high hydrostatic pressure. The water outflow has frequently the nature of violent eruption. The dowoo ramparts and mounds are cut with numerous tension fissures as it occurs in pingos.

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