A. I. Popov *
Moscow

PERIGLACIAL PHENOMENA AND THE LAWS OF THEIR DISTRIBUTION IN THE U.S.S.R.

Abstract

The elucidation of the most important active factors of frost lithogenesis constitutes the base of the system proposed for genetic types of frost-caused geologico-morphological or so-called periglacial formations.

Three cryo-morphological genetic groups are here distinguished — a macrostructural one, comprising forms predetermined by frost-cracks; a microstructural group comprising forms predetermined by fissures of desiccation with subsequent alternate congelation and melting along the fissures and between them; an astructural group, uniting forms not predetermined by the formation of fissures.

Leading factors of frost-caused morphogeny under conditions of arctic countries and of periglacial environments are frost cracks; in a lesser degree — desiccation fissures in grounds. Other factors are less significant and occur only locally.

Differences in processes of frost-caused morphogeny in three regions, unequal in exogenetic development, determine also the most characteristic differences in the general aspect of the periglacial landscape.

Less important are climatically controlled provincial differences of the frost-caused morphogeny, and also the differences, provoked by an unequal historical development of diverse regions.

Throughout the USSR territory the following regions can be distinguished: (a) regions of accumulation, syngenetic with the development of periglacial forms. Characteristic is the formation of polygonal ice veins that grow upward together with the sediments. On the surface are clear polygons as a result of the ever--recurring growth of ice veins due to accumulation of sediments and formation of fissures; (b) regions of relative stabilization in accumulation and discharge with epigenetic development of periglacial forms. Characteristic is the formation of polygonal ground-veins, the transformation of upper rock horizons within fissure zones into a secondary product i. e. covering loam. On the surface, there are reduction of polygonal blocks. The formation of a stable sheet of covering loam is possible only in the absence of sedimental accumulation and denudation; (c) regions of prevalent denudation with epigenetic development of periglacial forms. Characteristic is the „eating up" of big polygonal blocks (altiplanation terraces) during the process of nivation and solifluxion, along the network of epigenetically formed fissures. Nivation-solifluction products upon the slopes, are very dynamic.

The enumerated regions are distinguished for both the present-day stage and for that of the Pleistocene.

Periglacial phenomena are geological and geomorphological features developed under the peculiar climatic conditions of a periglacial zone, ice-free but adjacent to the edge of an ice sheet. Periglacial phenomena are mainly of the permafrost kind. The complex of permafrost forms of relief and geological phenomena, called periglacial, is, however, characteristic to vast areas unconnected with glaciation. It is conceived here precisely in such a wider sense.

It is advisable to distinguish three morphogenetic groups of periglacial forms:

* Moscow State University, Geographical Faculty, Moscow.

(1) macrostructural, predetermined by frost fissures;

(2) microstructural, caused by desiccation crevices with subsequent differentiation due to freezing and thawing along the crevices and between them;

(3) astructural, not caused by the formation of crevices.

The first include large polygons (tens and hundreds of metres in diameter) with ice- and ground veins, as well as denuded polygons of the altiplanation terrace type; the second comprise tundra-ostioles microreliefs which also include stone polygons and similar forms of microrelief (from 10—20 cm to 1—2 m in diameter) corresponding in cross section to so-called cryoturbations; the third include mounds of frost heaving, solifluction and other forms not controlled by crevices.

Macro- and microstructural forms are generally fixed in the relief and deposits. Astructural forms are less pronounced and are hardly encountered among mineral forms.

Macrostructural forms are due to frost cracking of frozen ground, coalesced seasonal freezing and permafrost or only to a layer which has deeply frozen during the winter. Microstructural forms are due to processes consecutively following one another of the cracking of thawed ground during desiccation in the course of initial autumn freezing and subsequent alternate seasonal freeze—thaw.

Frost fissures forming large polygons are the chief factor productive of permafrost relief. An important role is also that by the processes operating within the layer of seasonal freeze and thaw forming the structural microrelief.

The development of periglacial forms greatly depends on the basic direction of the exogenous development of a polar, mountainous or periglacial region, i. e. whether it is subjected to either accumulation of sediments or denudation or whether it has been characterized by a long absence of the leading processes and appears to be relatively stable.

I. Periglacial formations on relatively stable surfaces (slightly disjointed plateaus, plains and above-river valley terraces) develop epigenetically. Permafrost is not bound to occur, but the morphological results vary, depending on its presence and on its depth. When permafrost is present, the surface remains constant. Most typical is the epigenetic occurrence of a network of frost-fissures whose development results in the formation on the Earth's surface of bulging polygonal blocks separated by depressed inter-blocks; polygonal ground-veins correspond to the inter-blocks.

Polygonal veins formed in an active layer as mere ground veins sometimes develop within the permafrost into ice wedges. When ice thaw, the ensuing void is filled with adjacent and overlying ground: ground pseudomorphoses appear along the ice wedges. But not infrequently ground seams also taper into the permafrost as primordial ground formations caused by the penetration of the ground into crevices cutting across permafrost. Like ice-veins, ground-veins are strictly wedgelike; but in an active layer, they are greatly deformed and extended under the impact of stresses arising during the multiple seasonal alternate freeze—thaw, i. e. they form two tiers in the vertical cross section. The signs of two tiers in the mineral structure of fossil ground seams affords reliable evidence of the presence of permafrost in the past and permits to determine the depth of the active layer during its formation.

Let us consider now the most characteristic types of upbuilding, chiefly of the macrostructural forms, with due consideration of the various climatic conditions. These forms mainly differ, depending on the nature of the alteration of rocks in an active layer due to frost fissures.

1. When the ground contains sufficient moisture, the initail material becomes transformed into secondary material or blanket loam. At a certain stage, owing to the penetration of ground into the frost fissures, the process of formation of ground seams is being complicated by physical and chemical erosion of gangue both parallel to the walls of the fissures and in interblock depressions.

Development of gangue ground into a secondary product, accompanied by shrinkage, is the most important cause of the appearance of depressed inter-block bands along the fissures. This process is supplemented in inter-blocks by biochemical weathering resulting from the vital activity of vegetation which is more abundant in depressed moistened inter-blocks than on blocks. Biochemical erosion in the Arctic and Subarctic zones shows a causal relationship with nivation which accounts for the existence near snow drifts of a specific vegetation, stimulating this process. Permafrost contributes to weathering by increasing humidity of the active layer. Thus spreading not so much downward as sidewise, the process leads to a gradual extension of the zones of fissures and to their invading the inner blocks. In the course of time, there arises a stable mantle of blanket loam with ground seams at the base, while on the surface there is a smoothing and a partial — less frequently also a complete — elimination of blocks; they are transformed into reduced indistinct forms.

The blanket deposit system, the ground seams, the covering loam and the reduced blocks, should be regarded as a peculiar weathering crust typical of a rigorous but relatively humid and not strictly continental climate. Such a type of weathering crust highly characteristic of the plain areas of the polar Eurasian western sector is also typical of the periglacial zone of ancient European glaciations, particularly of the Valdaï glaciation.

Local accumulation of sediments on stable surfaces accompanied by freezing up and the development of frost forms in lakes and swamps with a permafrost substrate should be attributed to syngenetic conditions and considered independantly. Such are the flat bulging polygonal peat bogs with small ice wedges occurring in the western sector of the Eurasian Subarctic zone (Gydan peninsula, Jamal, Bolshaya Zemlya tundra).

Epigenetic freezing of initially thawed sediments of shoaled lakes and peat bogs leads to heaving and the formation of protruding bulging peat bogs (north taïga zone in West Siberia and in the European part of the USSR).

2. A particular case is that of the development of macrostructural forms in the absence of permafrost, but under conditions of deep seasonal freezing and complete summer thawing. This case is similar to that of the formation of polygonal ground seams with deep-set horizon of permafrost. This provides only for the development of ground polygonal seams.

As a result of the relatively free infiltration of atmospheric water along the crevices, polygonal forms acquire the features of a suffusion relief. There appears a sag, chiefly on broken crevices, which creates a relief of closed hollow type. This type of mesorelief is of wide occurrence in areas with a sharply continental, relatively dry climate, with little snow, deep seasonal freezing, formation of frost fissures and deep summer thawing (Transbaïkal region and East Siberia).

Deep washing of the ground along the crevices, with insignificant chemical weathering in a dry climate with little snow, does not promote the formation of a weathering crust in zones of frost fissures. In such cases the contours of ground-veins are not distinct, and the seams often represent humus inflows.

The peculiar conditions afforded by a deeply freezing and thawing active layer (several metres deep) often enclosing water-bearing horizons contribute to the local appearance of bulging hydrolaccolithes (East Siberia, the Transbaïkal region, the Far East).

3. Relatively stable surfaces built up of ancient peat and slimy deposits with syngenetic crevice polygonal ice and a thin active layer (the plateaus of the Anabaro-Olenek and Yano-Indigirka lowlands, and the Novosibirsk islands) are not subjected to considerable impacts due to the freezing process, since the ice and mineral complex is so compressed as a result of an utmost growth of crevice ice that there is no longer any formation of crevices and consequently no development of new macrostructural forms. A small thickness of active layer is likewise unfavourable

for the development of frost-caused forms. Such surfaces are therefore inactive in the sense of being transformed by present-day freezing processes. Only thermal karst manifests itself in this case.

Microstructural forms attain their utmost development in stable surfaces of the Arctic and Subarctic zones. The sorting of large clastic material attains a high degree of development expressed by stone rings, etc.

II. Under conditions of predominant accumulation of sediments periglacial forms develop syngenetically with them. In polar and subpolar areas such development occurs in river valleys, deltas, shallow lakes and swamps, as well as under conditions of sandr and fluvioglacial fields in a strictly periglacial zone.

1. In the presence of permafrost, its upper surface rises following the accumulation of sediments. Polygonal ice-veins develop in the course of such a syngenesis and grow upwards together with the sediments. Distinct wedge polygons correspond on the surface, to underground ice--veins, the polygons being a result of the ever-recurring process of ice--vein growth in proportion to the stratification of sediments and the formation of frost-fissures. Deposits with ice-veins in polar areas, both recent and ancient, are chiefly represented by dusty-clayey and peaty-slimy material. Syngenetic freezing of such sediments occurs under conditions of great humidity and low temperatures of a slightly thawing active layer. After a short time, the deposited sediment passes into a permafrost state without undergoing any substantial changes, save the formation of ice.

2. Polygonal vein-forms in fluvioglacial deposits of Pleistocene glaciation are formations of another kind. These are mainly sand and gravel. Polygonal formations are represented in them by mineral ground seams which all the investigators classify as pseudomorphoses of the ice seams, but which initially were partly ground seams. Worth mentioning in this connection are cases of syngenetic accumulation of sediments together with seasonal freezing.

In the absence of permafrost, only the zone of seasonal freezing and thawing with the attending frost-caused forms becomes displaced upwards together with the accumulation of sediments.

With a sufficiently deep location of permafrost, such formations are observed only in the active layer and do not penetrate into permafrost. The effect in this case is similar to the previous one: all the processes occur wholly in the layer of seasonal freezing and are displaced upwards in the course of sedimental accumulation. Permafrost which likewise becomes gradually displaced upwards now encloses already all the formations which are no longer built up. Sediments which have been repeatedly subjected to seasonal freezing in the course of their accumulation, together with all the frost-caused forms, leave at last the zone of seasonal freezing, being gradually buried under new layers subjected to the wave of winter cooling.

Summer thawing eliminated the effect of winter freezing and therefore the formation of ice seams in frost fissures did not take place. In their stead only traces of thawing remained as ground seams.

Microstructural forms develop only when accumulation is retarded or ceases altogether. Therefore syngenetic alluvial or fluvioglacial deposits show no sings of microstructural forms whatsoever or contain them on a level corresponding to the retardation or cessation of sedimental accumulation.

Syngenetic forms that arose in such a way are encountered in alluvial, fluvioglacial and similar deposits of the periglacial zone of the Pleistocene glaciation.

III. Periglacial formations developed on mountains under conditions of prevailing denudation.

The origin of the so-called altiplanation terraces peculiar either to the mountains of polar countries or to the bald peak zone of high mountains has for a long time been a subject of study. The new hypotheses attributing such formations to nivation and solifluxion provide no explanation of their regular outlines, of the approximate similarity of their dimensions and of their storied occurrence at the same altitude. But there are features common to both altiplanation terraces and large polygons.

We shall confine ourselves to the major precepts regarding the dependence of altiplanation terraces on frost fissures.

A slope which has been subjected to cracking into large polygons does not erode uniformly: it is more intensively weathered in the crevices that inside the polygons. Solifluxion displacement of weathering material occurs on the slopes, most intensively along the crevice bands extending downslope. It is intensive in transverse bands, but it is here that erosion is most vigorous.

As a result of erosion, there is corrosion of the upper part of the inclined surface of every block within every transverse band, and this is accompanied by gradual leveling downward in the direction of its lower front part, where from the weathering material is displaced to both sides into the depressed bands, extending downslope. Platforms are thus formed, their dimensions being limited by crevices. There is a gradual destruction of blocks of the altiplanation terraces, in the course of lateral erosion, accompanied by a displacement of the secondary product.

The slope loses its terraced profile and is leveled by solifluxion.

We have thus recognized the most typical macrostructural formations in conditions of stabilization, accumulation and denudation. At the same time, within each of the three fields, morphological differences have been recorded, caused by the specific regional climatic conditions of their formation.

The following provinces have been considered in conformity with the Holocene and recent periglacial formations of Eurasia (except the islands):

1. Western Arctic and Subarctic zones. Reduced polygons with a weathering crust on stable surfaces. Mound polygons with ice veins, flat bulging peat bogs in the area of accumulation. A cold but not severely continental climate and a relatively thick snow cover account for the development of large polygons only, as well as for the relatively weak growth of ice veins. The comparatively short period of accumulation (only Holocene) accounts for the small depth of ice veins.

2. South-Western Subarctic zone. Heaving of peat swamps in the Upper Holocene period (following the stage of the climatic optimum) and the formation of protruding mounds of frozen peat bogs on stable surfaces. Because of the thick snow, there is no periglacial morphogenesis in the area of accumulation.

3. Eastern Arctic and Subarctic zones. There is only thermal karst on stable surfaces with deep ice lenses (Middle and Upper Pleistocene). On other substrata, there are polygons with a waste crust, but less so than in the west. In areas of contemporary accumulation there are mound polygons with syngenetic ice seams. The cold and severely continental climate, as well as the thin and compact snow blanket account for the development of polygons of several generations, ranging from large to small ones (60—10 m) and of an intensive growth of ice-veins sidewise.

4. North-East of Siberia. Thermal karst only is encountered on stable surfaces (the Lena-Viluy lowlands) with deep ice-veins (Pleistocene epoch). Locally there are polygons with weathering crust, but less so than in the west owing to the thin snow cover and the dryness of the severely continental climate. In areas of contemporary accumulation, there is a local development of mound polygons with vein-ice, owing to the considerable depth of freezing. There are local mounds of heaving resulting from deep freezing.

5. Eastern Siberia and the Far East. There is a polygonal hollow suffusion relief on stable surfaces (inter-mountain depressions), with slightly developed ground veins under conditions of a severely continental dry climate with hot summers and almost snowless winters. At sections of accumulation, there are only ground veins in layer of deep freezing —thawing, syngenetic to sediments. There is a wide though local occurrence of mounds of heaving, hydrolacccolithes, chiefly of a seasonal nature.