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CRYOLITHOGENESIS, THE COMPOSITION AND STRUCTURE OF FROZEN ROCKS, AND GROUND ICE (THE CURRENT STATE OF THE PROBLEM)

In the article, we intend to briefly discuss the problems of cryolithogenesis, of the composition and structure of frozen rocks, and those of ground ice — as these appear to stand in the U.S.S.R. at the present time.

CRYOLITHOGENESIS AS A LEADING LITHOGENIC PROCESS IN THE ZONES OF STABLE COOLING OF THE EARTH

The recent years bring an increasingly great attention on the problem of cryolithogenesis, i.e. geological processes associated with the origin and dynamics, in the Earth's crust, of ice — as a rock and as a mineral within polymineral perennially frozen and seasonally freezing rocks. Cryolithogenesis should be understood as a complex of processes in the cryolithosphere, i.e. in the zones of stable cooling of the Earth, that determine the development of cryogenic rocks and cryogenic relief. Hence cryolithogenesis is a natural consequence of the specific physical-geographical zonal conditions and is a controlling landscape-forming factor in a number of the geographical zones of the Earth.

Cryolithogenesis predetermines the characteristics of the polar zone of the northern hemisphere and that of whole Antarctica in the southern hemisphere. The exogenic processes are essentially altered under the effect of cryolithogenesis almost throughout the humit zone, as well as in the high mountains.

The science of cryolithogenesis as a science of lithogenesis in the zones of stable cooling of the Earth (Popov, 1967), which was termed cryolithology, is understood in different ways by various specialists.

The term of *cryolithology* was introduced by E. M. Katasonov (1954) as a synonym of the notion of "lithology of the frozen Quaternary deposits". He defined the purposes of the new scientific discipline, *viz.* studying the structure and genesis of deposits formed under permafrost conditions. Such deposits, later termed *cryolithogenic deposits* (Katasonov, 1972), are

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a result of interaction, at all the stages of rock-formation, between the processes of cryogenesis (water crystallization, etc.) and lithogenesis in the traditional sense of the term, with the character of processes of cryogenesis and lithogenesis being determined by the sedimentation environment, i.e. cryogenic-geological conditions of accumulation and freezing, which results in the formation of deposit facies differing in composition and cryogenic structure.

Cryolithology that came into being in connection with KATASONOV's method of permafrost-facies analysis had little, if any concern with the mineralogical-petrographic and geochemical aspects of this scientific discipline. The well-known monograph by N. M. STRAKHOV (1960) has changed the situation in this respect.

V. A. ZUBAKOV (1966) suggested that, besides the humid, arid and glacial climatic types of lithogenesis distinguisched by STRAKHOV, a fourth i.e. cryogenic type be singled out. He divides the latter into cryohumid (glacial) and cryoarid (permafrost) sub-types.

A. I. POPOV (1967, 1970) regards cryolithology as a discipline dealing with cryogenic phenomena in the Earth's crust in terms of geology. Cryolithogenesis is a cryogenic geological process which includes (1) cryogenic diagenesis whose geological essence lies in ice formation and the related transformation of the very mineral substratum of sediments and the formerly lithified loose rocks (compaction, desiccation, etc.), and (2) cryogenic weathering, i.e. disintegration and stage transformation of any rock into the final silty product (fine earth, or cryopelite) due to seasonal freezing and thawing. As a result of the effect of these cryogenic geological processes, i.e. cryodiagenesis and cryogenic weathering, cryogenic rocks are formed, such as cryolith (a monomineral ice rock), cryolithite (polymineral ice rock) as a result of cryodiagenesis, and cryogenic eluvium as a product of cryogenic weathering. The epigenetic and syngenetic freezing of rocks are regarded as independent types of cryolithogenesis.

N. A. ŠILO (1971), amplifying STRAKHOV's work, distinguishes a type of periglacial lithogenesis characterized by negative mean annual temperatures, by certain dificiency in atmospheric precipitation and by water in solid and liquid phases. He makes an attempt to discuss questions of geochemistry and mineralogy. Also, he emphasizes the role of periglacial (cryogenic) processes in the chemical and physical-chemical transformation of eluvium constituting the seasonally thawing layer within watershed areas. The transformation of aluminosilicates proceeds as followings: (1) hydromica — beidellite — montmorillonite, what is generally due to the acid or neutral medium; (2) muscovite — hydromica — kaolinite (rarely); and (3) ferro-magnesian silicate — hydromica. Attention is given to the development of ice veins and lacustrine thermokarst in the Subarctic plains.

Š. Š. GASANOV (1973), like ŠILO, suggests that a fourth type of lithogenesis should be singled out, namely cryolithogenesis; he touches upon the questions of physical-chemical weathering and of the basic factors of "slope denudation in the cryosphere", i.e. frost sorting and solifluction, gives characteristics of the terminal basins of runoff in the cryosphere, such as domination of therrigene sediments, hydromica-montmorillonite compositon of clay minerals, and others.

N. N. LAPINA *et al.* (1968) use the term of "polar lithogenesis" to characterize mainly the deposits of arctic basins in terms of their granulometric and mineralogical-petrographic composition, organic matter and salt content, formation of concretions, etc.

V. A. USOV (1966, 1967) describes cryolithogenesis of marine rock series. He studied the conditions of accumulation and freezing, as well as the cryogenic structure of deposits forming within the pre-estuary offshore zone (avandelt), shallow lagoons, and tidal-marsh coastal plains.

G. P. MAZUROV (1970) understands cryolithogenesis to be a combination of the physical, physical-chemical and chemical processes of alteration and transformation of any rocks and minerals during freeze-and-thaw, as well as in the frozen state. This author restricts cryolithogenesis within the horizon of seasonal freezing and thawing.

Thus, we see that the concepts of "cryolithology" and "cryolithogenesis" are defined in different ways, because the scientists who represent different trends in the science of frozen rocks deal with various aspects of this science. However, all the authors point out that cryolithogenesis is lithogenesis (periglacial, or polar) in the zones of stable cooling of the Earth with negative temperatures, i.e. within the area of permafrost and deep seasonal freezing.

KATASONOV believes it necessary to enlarge the definition of cryolithogenesis as a combination of geological and cryogenic processes taking place at all the stages of rock formation and resulting in the formation of perenially frozen deposits. Cryolithology is a science of rock formation in the zone with negative temperatures, a science of cryolithogenesis. It studies the perennially frozen, i.e. cryolithogenic deposits of this zone.

In POPOV's opinion, the restriction of cryolithogenesis to just freezing participating in the process of sediment accumulation and syngenetic frozen rock-series formation, as is done by KATASONOV, narrows this phenomenon unwarrantably. Cryolithogenesis, according to POPOV, is any effect of cryogenic factors upon the forming sediment, upon loose rock, and upon compact (crystalline, etc.) rock, when this sediment or rock undergoes alterations, viz. is either lithified primarily or secondarily, or is subjected to cryogenic weathering, i.e. when freezing itself is understood as a geological process.

It should be noted that it appears unfounded to single out the so-called periglacial type of lithogenesis alleged to occupy an intermediate position between the glacial and the humid types of lithogenesis (the two latter — according to STRAKHOV, 1960). The local character in glacier distribution, presence of liquid-phase water during the warm season of the year on/and near glaciers at any rate, atmospheric precipitation which exceeds evaporation in glacier areas like in the humid zone, all these do not allow considering as strictly grounded the distinguishing of a glacial type of lithogenesis as an independent type of rock formation.

The geological work of glaciers (and of snow fields — nivation), especially in terms of its resultant, is in such close dependence on cryogenic factors that certainly the so-called glacial type of lithogenesis should be viewed together with cryolithogenesis, without singling it out independently. And since there is no point in distinguishing a glacial type of lithogenesis, then no periglacial type should be singled out either. Worth being singled out as independent is only the cryogenic type of lithogenesis, or of cryolithogenesis, whose zone lies northward of the humid zone, and in the Alpine areas.

Problems of the geographical zonality of cryolithogenesis are discussed by Popov with particular reference to North Eurasia, for whose vastness this zonality is manifested most completely. Within this rather spacious continental area, the present zonal and regional character of cryolithogenesis and the distribution of its morphogenetic types are determined by the following geological-geographical and historical factors.

1. Factor of latitudinal zonality, i.e. of geographical zonality of the highest rank, determined the spatial structure of cryolithogenesis in its most important aspects, but it is not the one and only acting factor.

2. Subordinate factor, essential but of a lower rank, and oriented at certain angle to the latitudinal zonality. As applied to Eurasia, it is a factor of correlation between land and see, i.e. a factor fo the degree of continentality of its different parts.

3. Neotectonic factor that determines the basic trend in the development of exogenic processes, either under the conditions of predominant denudation or accumulation, or under those of attenuation of both the processes and establishment of relative stabilization in sedimentation and drift. Factor of vertical zonality should be also referred here.

4. Factor of substratum, or lithological factor.

5. Historical factor, i.e. shifting of the natural environmental zones, different in varius places of the vast continent of Eurasia, during the Pleistocene and Holocene. This factor acts in other respects as well.

While the factor of latitudinal geographical zonality determines the main features of the spatial structure of cryolithogenesis, all the rest (except the historical factor), acting jointly and by combination and superposition, predetermine the most important provincial differences in the cryolithogenesis types. The regionalization of areas of cryolithogenesis is based on the intrinsic relationshops between these factors taken due account of.

Cryolithogenesis as a geological phenomenon is understood as an eluvial process in some cases, and as a diagenetic process in the others. Each of these is met by a certain set of cryogenic formations such as rocks and relief forms (Popov, 1967).

The special features of the structure of cryogenic rocks that form regularly built frozen rock series allow to distinguish two basic, already mentioned, cryogenic complexes (or types), namely epicryogenic and syncryogenic types.

The specific features of the structure are accounted for both by freezing (epicryogenic type — after the formation of rocks, and syncryogenic type — during the process of sedimentation), and by the temperature conditions of freezing and the related different degrees of activity of the freezing process.

The temperature conditions of freezing and the related different degrees of activity of the congelation process, that are responsible for the origin of specific textures or characteristics features of the structure, render possible to identify, on the basis of the latter, genetic horizons in the epi- and syncryogenic rock series.

Features of the geographical zonality of cryolithogenesis of the second and higher orders are accounted for mainly by the correlation between the genetic horizons characteristic of epicryogenic and syncryogenic rock series in different subzones.

Epicryogenic rock series show the most expressive zonal character, and therefore the distinguishing of subzones can be demonstrated most clearly in this type of cryogenic formations. However, the syncryogenic type does not escape the investigator's attention who tries to perform zonal distribution of cryolithogenesis processes and the related formations.

As was already mentioned, the division into genetic horizons can be done in relation to the temperature regime of the rock series that predetermines different courses of the freezing process at different depths and causes different geological effects. Most significant in terms of zonation is the subtype of epicryogenic rock series, that corresponds to the series of frozen loose sediments and rocks.

The following horizons are distinguisched within such rock series from above downwards:

(1) horizon of active cryosupergenesis (with changes of phases),

(2) horizon of active cryodiagenesis, and

(3) horizon of passive cryodiagenesis.

If the narrow shelf belt of the polar seas where cryolithogenesis develops specifically and azonally enough is disregarded, then the entire land area of North Eurasia that is subject to the effect of cryolithogenesis exemplifies its manifestation sufficiently zonally, with the zonality being displayed first of all in changes in the proportions, from north to south, between the genetic horizons of epicryogenic rock series.

The general trend in the zonal change in the character of cryolithogenesis from north to south is associated with the change both in the mean annual temperature and, to a considerable degree, in the temperature gradients during autumn—winter time. And here are meant both the recent stage and the stage when the permafrost formation took place.

On the basis of appropriate cryostructural features, four subzones of sublatitudinal extension are distinguished schematically within North Eurasia: polar, subpolar, boreal and subboreal subzones. Each of them is characterized by thicknesses of the genetic horizons, by winter temperature gradients with a certain depth of the snow cover, by distinctive morphological features, i.e. products of cryogenic weathering, cryogenic textures, large ice bodies — cryolithies, etc.

Frost fissuring within the polar and partly subpolar subzones acts mainly as the diagenetic factor; it leads to the formation of polygonal-wedge ice and the related characteristic polygonal relief. Within the boreal and particularly subboreal subzones it acts as the cryoeluvial factor favouring the formation of polygonal ground-veined systems that accompany loessial rocks, and formation of polygonal hummocky-sinky relief. This regularity, alongside the others, illustrates most perfectly the zonal nature of cryolithogenesis processes.

The general trend in zonal alteration of cryolithogenesis from north to south in North Eurasia, that is due both to the mean annual temperature and to the temperature gradients in the winter season, is displayed in a change of the geographical subzones, with products of cryodiagenesis domination in the north and products of cryogenic weathering — in the south.

The regularities outlining the zonal structure of cryolithogenesis as exemplified in North Eurasia are being revealed but schematically so far, and, as was already noted, the numerous aforenaimed factors appreciably complicate the full picture of the spatial character of this complex natural phenomenon which is of particular significance to our country.

COMPOSITION AND STRUCTURE OF CRYOGENIC ROCKS

In the recent years there has been an essential progress in the study of the composition and structure of cryogenic rocks. Especially, it is due to the more thorough studies of clay minerals and their alteration under the effect of freezing, and also of the organic matter during freezing, which is of great importance for understanding the essence of cryogenic weathering.

Also of importance is the detailed study of the microstructure of frozen rocks and ice which allows essential conclusions to be drawn for interpretation of their genesis.

Achievements in the development of the mentioned progressive trends do not dismiss the task of studying the specific features of microstructure of frozen and thawed cryogenic rock series, as the formation of these features proceeds also in its own way, which is not always and not entirely related to the origin and development of fine structure. Simultaneously, the knowledge of coarse features of structure is of great importance for the solution of many problems of cryolithology and geocryology, both in scientific studies and practical respects.

Thus, for example, it is known that the structure of frozen and of fossil already unfrozen, Quaternary deposits is widely used in various paleogeographical and, in particular, paleoclimatical reconstructions. And, due to inadequate morphogenetic criteria for cryogenic formations of different origins, essential miscalculations and errors are being commited. Suffice it to point out isomorphism of some cryogenic and non-cryogenic formations (e.g. wedge-shaped pseudomorphoses after polygonal-veined ice and again wedge-shaped bodies due to convective instability of liquid precipitation) as a cause of numerous delusions of geologists and erroneous inferences lying behind this.

But to return to the new achievements mentioned above.

One cannot but admit that the most important task of cryolithology is that of studying the regularities of transformation of the mineral component of rocks under conditions of the cryosphere. The solution of this problem is associated first of all with the study of composition and properties of sedimentary formations that originated under the conditions of stable and continuous freezing of the Earth's crust.

During the past decade, V. N. Koniščev obtained many data on the specific features of the composition of deposits formed in the zone of cryogenesis, such as loess-like formations, moraines, glacial-marine deposits, and syngenetic frozen rock series in the Yana—Indigirka lowland. These data show that the most important features of the composition of sediments peculiar to the cryosphere originate at the stage of mobilization of material in the weathering horizon, i.e. in the course of formation of cryogenic eluvium. At the same time, its basic qualitative features are related above all to the effect of the repeatedly alternating freeze—thaw processes upon different types of parent rocks.

An analysis of the modern notions of the interaction between water and various groups of minerals depending on temperature and ice formation in grounds, and the experimental data allow Koniščev come to the conclusion that the cryogenic failure of rocks is due to two groups of processes, viz. wedging of ice that leads to coarse disintegration of primary minerals, and hydration (basically physical-chemical) degradation which results in essential transformation of the structures of inherited clay minerals. Alongside the difficulties in synthesizing clay minerals from products of weathering of massive crystalline rocks (V. O. Targulyan), this leads to enrichment of the cryogenic eluvium and the products of its nearest redeposition with colloids, hydrated organic-mineral compounds represented by deteriorated forms of clay minerals, by amorphous groups of SiO_2, Al_2O_3 and Fe_2O_3, and by organic matter.

Supervised by KONIŠČEV, a research was carried out into the resistance of basic rock-forming primary minerals in respect to the factors of cryogenic weathering, which presents possibilities for a more objective identification of products of cryogenic transformation in the loose mantle of the Pleistocene deposits over the territory of permafrost occurrence and ancient periglacial areas.

V. V. ROGOV, as a result of a detailed study of the microstructure of natural frozen rocks and experimental studies of artificial mixtures subjected to freeze—thaw cycles, has obtained data allowing a more accurate estimation of the fine structure of these rocks with freezing, and of some new structural features of cement-ice and segregation ice. He developed original methods to study microsections of frozen rocks under ordinary indoor conditions. The significance of these microstructural investigations for understanding the genesis of frozen and formerly freezing rocks can scarcely be exaggerated.

There also have been accomplished other important studies of the structure and composition of frozen recent and relic cryogenic formations. A. M. PČELINCEV (1964) deals, in an uncommon way, with the problem of formation of cryogenic textures in connection with the specific features of water migration within finely divided rocks and in connection with the associated phenomenon of heaving. A number of problems of segregation-ice formation, also in association with the conditions of texture formation, are touched upon in "Ice formation in rocks", a monograph by E. A. and B. I. VTYURIN (1970).

Several works by KATASONOV are devoted to the formation of cryogenic textures. In particular, he, proceeding from the specific features of ice inclusions, their disposition and combination, distinguishes three non-classification groups of textures which constitute the basis for elaborating several classifications of textures separately by physical and geological principles.

T. N. ŽESTKOVA (1966) has shown that frozen deposit series that froze from above have "an ice lattice thinning out with depth" in some cases, and alternation of layers with high and low ice content in the others. The author explains this by the fact that the strata froze after the type of "open" and "close" systems, by the effect of rock composition, any by the sharp changes in temperature conditions on the surface.

B. I. VTYURIN (1963), and G. I. DUBIKOV and M. M. KOREIŠA (1964) have broadened the concept of the processes in epigenetically freezing rock series, and have argued the possibility of formation of large sheet deposits of injection ice at significant depths. N. G. BOBOV (1966) and V. V. BAULIN (1972) suggested a hypothesis on the formation of the same sheet ice in a segregational way.

G. F. Gravis (1970) emphasizes great importance of pressure-water migration in the formation of small inclusions and large deposits of ground ice. In his opinion, segregation and injection often take place simultaneously, closely interlarding with each other.

In characterizing the general regularities of the cryogenic structure of perennially frozen rocks in Mongolia, Gravis (1974; also in: "General Geocryology", 1974, Acad. Sci. publ.) singles out the following three horizons of ice formation in epigenetically frozen deposits (from above downwards): (1) horizon of ice formation under the conditions of non--pressure water migration towards the front of freezing, with cryogenic textures of the segregation type; (2) horizon of ice formation under the conditions of pressure-water migration towards the freezing front, with cryogenic textures of the injection type; and (3) horizon of passive ice formation, with lithogenic cryotextures or so-called ice cementation. Particularly distinguished for novelty is the second horizon that is characterized, as noted by the author, by a rhythmic-cyclic cryogenic structure. The author gives a hypothetical explanation of the causes of the rhythmic--cyclic structure.

Gasanov (1969) classified cryogenic textures in relation to the granulometric composition of rocks.

G. E. Rozenbaum (1973) has considered the processes of formation of cryogenic textures and polygonal-wedge ice in close dependence on the specific features of development of alluvium facies and delta deposits in the basins of the Yana and Omoloi rivers.

Mechanism of syngenetic sedimentation and of segregation ice formation is discussed in literature for the first time (Popov, 1967). It has been established that the increment of the cryogenic perennially frozen rock series (due to the base of the active layer failing to thaw with sedimentation) occurs as a transition of whole "assises" of layers into the perennially frozen state (in which the reticulate and stratified cryogenic textures are clearly manifested), rather than by annual increases of the frozen layer, equal to the thickness of the sediment accumulated during the year. Such a mode of syncryogenesis is predetermined by correlation between the rate of sedimentation and the cyclic change in the depth of thawing of the active layer for a number of years, i.e. by cyclic recurrence of the climate. Later this matter is touched upon by L. N. Maksimova (1970) on the basis of the same principle.

Certain attention was given to problems of the cryogenic structure of the active layer. E. A. Vtyurina distinguisches, as a result of detailed investigations, classes, subclasses and types of the cryogenic constitution of rocks in the seasonally thawing layer, which makes it possible to map it according to special features of the cryogenic structure.

To the same kind of research can be also ascribed ascertaining the regularities of formation of the horizon of cryosupergenesis (i.e. active layer) from cryostructural indications (N. V. TUMEL and YU. V. MUDROV, 1973), and a presentation by E. M. NAUMOV (1973) of the problem of influence of cryogenic factors on soils.

Of exceptionally great importance for understanding the genesis of the structure of frozen dispersed rocks are the experimental studies carried out by E. P. ŠUŠERINA (1974) of the mechanical properties of such rocks and ice, and their tensile strength at low temperatures.

During the recent years there appeared a number of publications by G. M. FELDMAN (1974) and V. G. MELAMED (1974), devoted to the problems of research on the thermophysical basis of formation of the cryogenic textures, in which methods are suggested to calculate thicknesses of ice schlieren throughout the entire depth of the active layer.

Problems of the composition of frozen and formerly frozen rocks are dealt with in passing in many publications issued in the past years. Singularly, these questions are considered, apart from the aforecited, by F. N. LOŠČIKOV and T. G. RYAŠČENKO (1973), and also by M. N. USKOV (1973), as applied to clay grounds and minerals which, as it is known, are of the greatest interest in studying the cryogenic phenomena.

Least of data we have at our disposal on ice in compact (crystalline, metamorphic, and other) rocks. There is only a report by S. YA. ŽUKOVSKY *et al.* (1973) concerning new data on the ice content of solid rocks.

It was already noted that indications of former freezing and of cryogenic rock formation expressed in large wedge-shaped structures or in involutions and cryoturbations are widely used for the purposes of paleogeographic and climatic-stratigraphic reconstructions. However, modes of such use have been not quite perfect or reliable up to now, and they need improvement.

Yet, both recent "live" permafrost and "fossil" permafrost which has left traces in deposits and weathering mantle can be used in paleogeographical reconstructions.

Fossil permafrost is particularly popular with Quaternary geology scientists. Indeed, traces of cryogenic processes in the active layer and in the horizon underlying permafrost are recorded most distinctly. These are mainly polygonal soil wedges, which, under the conditions of deep seasonal freezing—thawing, are important indicators of the degree of rigour and continentality of the climate in the past.

Degradation of thin polygonal wedge-ice can lead to origin of soil pseudomorphoses after ice wedges. Unfortunately, the above noted fact of isomorphism with wedge-shaped bodies due to convective instability (see works by A. G. KOSTYAEV) makes identification of pseudomorphes extremely difficult. Attempts to overcome these difficulties in studying pseudomorphoses after ice veins are found in the works of the recent years by F. A. KAPLYANSKAYA in West Siberia and A. A. ARKHANGELOV in the Kolyma basin. A most important and demonstrative analysis of pseudomorphoses indicating the presence of permafrost in the Low Pleistocene deposits of the Northeast of the U.S.S.R. is contained in the publication by ARKHANGELOV and A. V. ŠER (1973).

Also, questions of the structure and composition of frozen and formerly freezing rocks are discussed directly or otherwise in publications devoted to broader topics. Thus, for example, of interest in terms of genesis is the article by N. N. ROMANOVSKY (1973) concerning the influence of the recent tectonic movements on the formation of frozen rocks.

UNDERGROUND ICE AS AN INDEPENDENT PROBLEM

The problems of general classification of underground ice can be considered as solved earlier and, therefore, the recent decade has not produced any theoretically new propositions in this respect. Only some specifications have been introduced into the existing classifications of which P. A. ŠUMSKY's (1955) is the most comprehensive classification.

By their occurrences and share of participation in frozen rock series, worthy of greatest attention are such types of ground ice as polygonal-wedge, veined, injection, and segregation ice, and ice-cement.

The latest generalizing work on ground ice is the publication by B. I. VTYURIN (1975) concerning the regularities in the distribution and the quantitative evaluation of ground ice over the territory of the U.S.S.R. Worth notice in it is the indication of the fact that deposit-forming ice comprises 10% of the total reserves of visible underground ice (without account of ice-cement) and that out of it only polygonal-wedge ice and sheet deposits of segregation and injection ice are most widespread and are of great practical interest. According to this author's calculations, the reserves of visible ground ice in the territory of the U.S.S.R. make up about 19,000 km^2, and about 35,000 km^2 in the Earth as a whole. Out of the deposit-forming ground ice, reserves of the polygonal-wedge ice have been estimated to make up about 1000 km^2.

Particular attention of geocryologists and cryolithologists studying ground ice is attracted by problems of the genesis of polygonal-wedge ice and of thick sheet-ice deposits.

Polygonal-wedge ice, being an important component of thick syncryogenic rock series, is the most independent genetic type of the underground ice formation, constituting the massive lattice-work as a monomineral ice rock over the vast areas of North Eurasia, Alaska and Canada.

The discussion is still going on concerning the genesis of polygonal-wedge ice. No doubt, the complicated mechanism of development and syngenetic growth, in the course of sediment accumulation, of this type of ice has not been ascertained completely up to now, although attempts to explain it have been made by a number of workers during the past years.

In this connection it should be noted that the so-called repeatedly--weined mechanism of development of this type of ice, as being the only right one (according to B. N. DOSTOVALOV and ŠUMSKY), is not fully acceptable. If due account is taken of the specific features of structure of contacts at ice veins (frequent absence of deformations in the enclosing rocks), the presence of features of horizontal stratification of ice, and the peculiarities of its structure, then the inference of only partial (though considerable and determining in many respects) significance of the said classic mechanism in the development of polygonal-wedge ice becomes evident. Nevertheless, some investigators, as if noticing no existing difficulties in the explanation of the genesis of vein ice, continue to profess its repeatedly--veined mode of development as the only true one. Certainly, the role of this mechanism is original, important and determining in many respects, but it is not the one and only mechanism; it is undoubtedly complicated by other mechanisms, by the so-called frontal growth, in particular, which fact is acknowledged by many scientists. But these mechanisms are not adequately ascertained.

A hypothesis of KONIŠČEV and A. D. MASLOV (1968) is one of the serious attempts to overcome the deadlock in explaining the mode of syngenetic growth of vein ice. According to it, the frontal growth of ice veins proceeds by squeezing out the ice due to the lateral pressure on the part of the enclosing frozen rock with a change in the temperature regime. However, this hypothesis is not quite acceptable either, because it fails to explain some specific features of the structure of the ice-mineral complex as a whole.

KOSTYAEV (1967) discusses the growth of ice veins also due to ice being squeezed out upwards. Occasionally wedge-shaped and dome-like upwarpings of layer above ice veins are caused, in his opinion, by pressure of the veins themselves or of their protruding top portions. KOSTYAEV believes that such a phenomenon can be explained satisfactorily only by the development of the mechanical migrations within the ice—frozen-rock system. Ice, being a more fluid material (with lasting stresses) than the enclosing rock, is slowly squeezed out upwards by the rigid polygonal framework.

An article by E. V. ARTYUŠKOV (1969) presents an attempt of physical substantiation of the squeezing-out of vein ice by the enclosing rock. Unfortunately, the two latter hypotheses are characterized by the same weak points as the previous hypothesis.

V. I. SOLOMATIN (1970, 1974) has come to the conclusion as to the great role of segregation-ice formation in vein ice development. He was the first to suggest a classification of textures of polygonal-wedge ice. The textural features are determined by addition of inclusions from the enclosing deposits (due to segregation-ice formation at lateral contacts) and from the overburden (as a result of frost-crack processes and simple-veinlet formation), and by redistribution of inclusions, mainly gaseous ones, under the effect of oriented lateral stresses.

GASANOV (1973) describes the mechanism of self-regulation of ice vein growth in width, due to the gradual alteration of the dimensions of a frost-caused fissure as ice veins grow, as a result of decreasing summary coefficient of temperature deformation of the ice and frozen ground; as veins grow in width, the fissure becomes narrower and decreases in depth. A gradual build-up takes place of such quantitative features as reach critical values at a certain stage, which bars the further growth of the veins in width.

On the whole, it should be just said once again that knowledge of the mechanism of vein ice development, and especially of its syngenetic type, is a matter of the future.

The research into sheet ice characteristic of epicryogenic rock series resulted in identifying several types in which either segregational or injectional processes, or else their combinations, participated (BAULIN, DUBIKOV, BOBOV and GASANOV).

However, the study of the cryogenic structure of the Quaternary deposits in the Yamal Peninsula, including sheet ice-bodies, has led KOREJŠA to the conclusion that many problems of the theory of cryogenic structure, in particular the problem of segregation and injection genesis of the basic mass of sheet-ice deposits in the marine Quaternary deposits, are deprived of any sound basis because of the inadequately developed physical theory of ice crystallization in dispersed rocks. He points out quite righfully that one of the ways of investigating the cryogenic structure and genesis of the Quaternary frozen deposits can be that of experimental modelling of the process of freezing under laboratory and field conditions.

It appears necessary to reckon with the fact that in some cases sheet ice of different origins is found buried under sediments, such as marine, fluvial and naledies (icings), and also glacier ice in some mountain and piedmont areas. But there are exceptionally few reliable data on buried ice.

The texture-forming ground ice, such as segregation and injection ice and ice-cement, was partly considered above, and so there is no need to dwell upon it in this chapter.

In conclusion it should be noted that method of visual observations and direct description dominates in studies of the structure of frozen rocks; this method will be of great importance in the future as well, it cannot be substituted for by any other and only needs improvement. But it is necessary to point out that the current introduction of microscopic methods to study the cryogenic textures and structures renders possible to find even now new regularities in the structure of frozen rocks and to draw important conclusions concerning their genesis. Hence, in prospect prompt attention should be given to precise petrographic methods introduced into the studies of structure of frozen and formerly frozen rocks.

Research into the relations between the cryogenic structure and the conditions of freezing requires joint thermophysical, physical-chemical and petrographic studies of frozen rock-series development.

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