T. P. Kuznecova

Moscow

SPECIAL FEATURES OF CRYOLITHOGENESIS IN THE ALLUVIAL PLAINS, CENTRAL YAKUTIA

The area under study is situated in the Lena–Viluj watershed divide, occupying a portion of the left-bank valley of the Lena river; administratively, this territory is part of the Namtsy region of the Yakutyan Autonomous Republic.

In the geomorphological respect, the territory in question can be divided into two macro-complexes:

(1) ancient alluvial plain (the interfluves of the Lena, the Khančaly and the Kenkeme rivers); and

(2) valleys of the Lena (a complex of the low left-bank terraces), the Khančaly and the Kenkeme rivers.

The surface of the ancient alluvial plain is heavily dissected by a dense erosional network (the valleys of the Khančaly, the Kenkeme and of their tributaries), and is also pitted by thermokarst, with alases (depressions with lakes or bogs) found in the surface of the plain. The Khančaly and the Kenkeme valleys are ca. 1 to 2 kilometres wide, and the first floodplain terraces are well developed there, which terraces constitute the valley bottoms. The surface of the floodplain terraces is full of oxbow and thermokarst lakes and swampy oxbow elongated cavities. The youth of the floodplain relief in the surface of these terraces indicates that the terraces have quite recently been in a stage of development. The left-bank portion of the Lena valley reaching a width of 10 kilometres in some places is represented by a complex of young terraces: first and second bottoms and first floodplain terrace.

In this area permafrost is of continuous occurrence, has a great thickness (200 to 400 m) and a rigorous temperature regime with mean annual temperatures of $-2.5°$ to $-3°$ at a depth of 15 to 20 m; even under the channel of the Khančaly river with its width of 5 to 7 m and a depth of ca. 1.6 m to 1.8 m, perennially frozen rock lies at a depth of 2.5 m from the channel bottom, and has a temperature of about $-2.3°$ at a depth of 9 m.

The ancient alluvial plain is built up of a thick series of Neogene–Low

Quaternary age[1], represented largely by grey and yellow feldspar-quartz sand with gravel. As a rule, the stratification of sand is expressed most legibly. In some cases these are horizontal thin (0.2 cm to 0.5 cm) alternating interlayers of dark and light sand, but slanting stratification is more frequent, being preconditioned by gravel accumulating into seams and lenses 0.5–1.0 cm to 2.0 cm thick. Here and there pebbles can be found in sand usually as an admixture, but occasionally forming lenses and seams. Thin horizontal or slightly undulating lamination is frequently observed, preconditioned by the washed up finest plant remnants being segregated over the stratum planes. In these interlayers some bigger tree remnants (bark, branches) are occassionally found. Vegetal material is present mainly in the form of small-sized detritus, but tree trunks, too, occur rather often in this series. It should be noted that the old alluvial sand includes a high content of silt which is particularly clearly noticeable in outcropping seams where sand in the talus is literally lost amidst silt.

Lenses (1.5 to 5 m thick) of dark grey, with brownish tinge, compact clay and dark-grey sandy loam that represent facies of minor stagnant reservoirs, i.e. floodplain lakes, are frequently found in the sand series. The horizons of compact clay in the weathered scarps of the old alluvial plain are heavily eroded: they consist entirely of separate sharp angled fragments of extremely compact clay, the fragments being 0.5 cm to 3 cm in size. Plant remnant aggregations (tree trunks up to 40 cm in diameter, branches or washed up flat plant remnants) are commonly observed near the bases of the clay horizons. It should be particularly emphasized that these remnants are well-preserved.

Unfortunately, insufficient knowledge of this series does not make it possible to express any well-founded opinion as to the regularities of its structure, its distinctive facies, or the interdependences between the facies. The general aspect of these deposits suggests an alluvial genesis.

The entire old alluvial series is in a frozen state, which fact determines a whole number of its features. The prevailing sand composition of these deposits predetermined the development of a massive cryogenic structure which makes this series "silent" with finding out the conditions of its freezing. At the same time, the clay and sandy-loam lenses embedded amidst the sand are characterized by an outstanding originality of the cryogenic structure, which allows to form an opinion about the features of permafrost lithogenesis as a whole.

The cryogenic structure of the clay deposits will be analysed in more detail. The data derived from several boring holes drilled in different sites of the ancient alluvial plain (Fig. 1) are dealt with for that purpose.

[1] The author identifies this series with the 80-metre level of the Mamontova Mountain, which Rusanov (1968) attributes to the Pliocene–Low Quaternary period.

In analysing the sections of the borings, the following characteristic features of the cryogenic structure of the clay and the loam sandy-loam horizons can be noted: high ice content in the clay horizons is traced immediately under the channel facies of the present rivers; deeper downward in the same horizons, and also in the clay horizons not overlain by recent alluvial deposits, visible ice inclusions are almost absent as a rule and the clay is distinguished by an extremely high compactness.

Massive-basal cryostructure is generally characteristic of the clay horizons shown by the borings in the Khančaly and the Kenkeme valleys, lying close under the channel deposits of these rivers (and occasionally likewise, under the river bed, Boring 5): the transparent ice mass is impregnated with small (0.5 cm to 1.5 cm in diameter) sharp-angled pieces of dark-grey clay. With thawing of the core sample, these pieces are easily taken out of their sockets, and traces in the form of "pock marks" are left in the ice. The small clumps of clay are so compact that they do not get soaked in water after complete thawing of the core. Even after removal of the core from the water in which it was placed to soak for a few days, these clay clumps maintain their shape and are as compact as before.

It appears that part of the frozen old alluvial series, finding itself within the sphere of the thermal effect produced by a talik under the Khančaly and the Kenkeme beds, thawed to an insignificant depth (the depth of the recent underchannel talik of the Khančaly river is 2.5 to 3 m). In the process of migration of the river channel and the accumulation of a new series of young alluvial sediments, the tailk freezes up mainly from below. Portions of some clay horizons oversaturated with ice (Fig. 1: Borings 1, 5) are best illustrating the talik freezing from below. Such massive-basal structure originated under conditions of slow freezing from below, when ice-schlieren were formed in the network of joints of diagenesis in the already weathered rock heavily saturated with water as a result of the infiltration of channel water. This was accompanied by expansion of the fragments of the weathered clay horizon, by their compaction, by increase of space between the fragments filled with ice, and the origination of a massive-basal cryostructure. The upper part of these clay horizons is less icy, usually showing reticulate and lens-like cryogenic structure, the latter having often the appearance of thin „scales".

The clay horizons opened in the Khančaly and the Kenkeme valleys and lying not very deep below the surface are characterized by high diagenetic jointing (weathering), which is undoubtedly a result of the partial thawing of this series, increased by recurrent freezing.

The depeer clay horizons that did not experience thawing are distinguished by very high compactness, absence of traces of diagenetic jointing and are

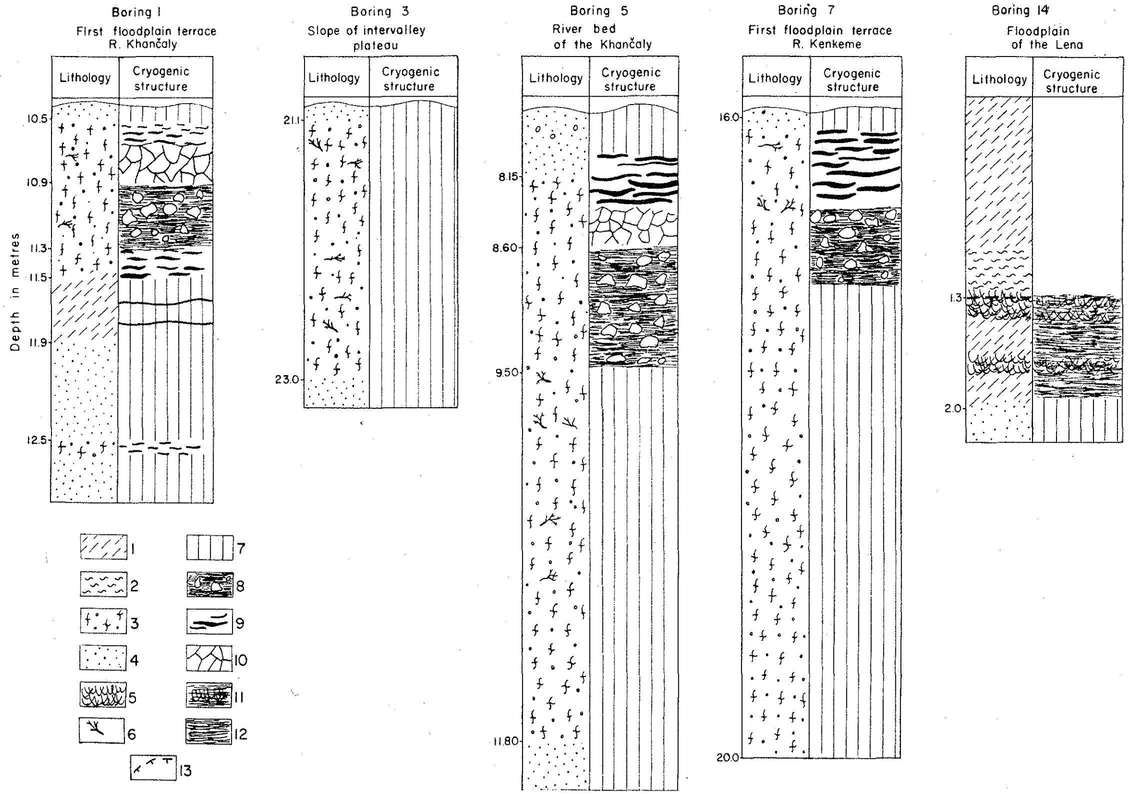

Fig. 1. Cryolithological sections of boring holes drilled in various localities

1. sandy loam; 2. loam; 3. clay; 4. sand; 5. slightly decomposed plant remnants (sedge); 6. small-sized plant remnants; 7. massive cryogenic structure; 8. massive-basal cryogenic structure; 9. lense-like cryogenic structure; 10. plant remnants cemented by ice; 11. and 12. ice; 13. boundary of seasonally thawing layer

devoid of visible ice inclusions (Fig. 1, Borings 3, 7). Since this series was fairly compacted and desiccated by the time of freezing, the processes of cryolithogenesis were passive here and thus are not clearly displayed now in the morphological aspect of the series (in its clay horizons in particular). These features permit of the assumption that in the main the old alluvial series froze up epigenetically with the exception of its uppermost part that froze up simultaneously with the completion of the stage of the old plain formation after the syngenetic type, and where such features of cryolithogenesis have been most vividly expressed as the development of polygonal-veined ice and earth veins in frost-caused fissures.

Now follows a discussion of these permafrost phenomena. The studies of the expedition show that polygonal-veined ice is widespread in the upper horizons of the ancient alluvial sand series[2]. At present this ice is in a state of preservation and partial destruction (on slopes). Because of poor outcropping, ice is not observed throughout almost the whole area. The feebly expressed polygonal relief in the inter-alasses, as well as the relatively widerspread alasses provide indication of the presence of polygonal-veined ice in the surface horizons of the ancient alluvial plain. The holes drilled in the interpolygonal trenches revealed the presence of polygonal-veined ice in the sand. The occurrence of dense vertical bands of sand is an interesting feature of these veins. The upper ends of all the ice veins have thawed out and lie very deep now (1.6 to 3 m), i.e., lower than the depth of the present seasonal thawing. The lower ends of the veins appear at a depth of 5 to 6 m. This is confirmed by the depths of the alass kettle-depressions, which do not exceed 5 to 8 m within the territory under study.

Along with polygonal-veined ice (often in the same system of polygonal relief), earth veins occur commonly in the inter-alass portions of the ancient alluvial plain, and also in the sand (Fig. 2). Earth veins are found in localities covered by pine or light (dry) larch forest. Polygonal-veined ice prevails in plane moist areas occupied by larch forest mixed with wild rosemary and bog bilberry. Thus the character of the superficial conditions reflects the lithological (facies) composition of the top horizons of deposits and should be therefore regarded as essentially important at all the stages of development of the earth and ice veins, for it determines the differentiation of their type.

On account of the widerspread occurrence and the relatively significant thickness of the polygonal-veined ice in the upper horizons of the ancient alluvial plain these formations may be referred to the syngenetic type, which developed simultaneously with the accumulation of sediments.

---

[2] Danilov (1964) and Katasonov (1963) confirm the widespread development of polygonal-veined ice in the Neogene – Low Quaternary deposits of the Viluj river basin.

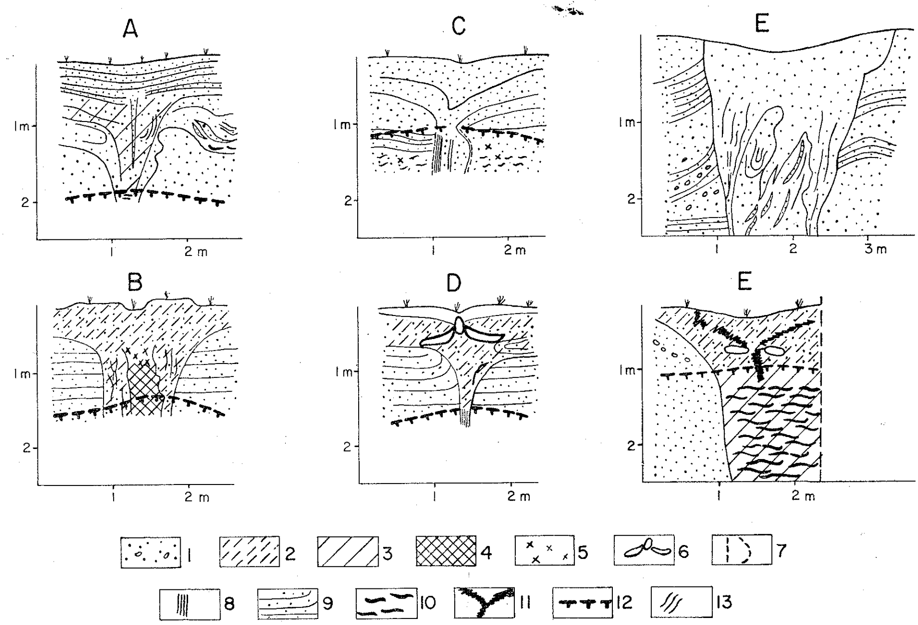

Fig. 2. Ground veins opened in various localities

1. sand; 2. clayey sand; 3. loam; 4. peat; 5. plant remnants; 6. hollows; 7. vertical bands of iron accumulation; 8. vertical ice streaks; 9. stratification in sand; 10. ice lenses; 11. humic sand; 12. boundary of seasonally thawing layer; 13. vertical lamination in wedges

The origination of permafrost in the area under consideration is dated by numerous investigators (Alekseyev, 1954; Solovev, 1959; and others) as Middle Pleistocene. Evidently, the concluding stage of formation of the old alluvial plain and the simultaneous upfreezing of its surface deposits should be also attributed to the Middle Pleistocene (probably the end of the Lower and the beginning of the Middle Pleistocene). Hence, the development of polygonal-veined ice in the surface deposits of the old alluvial plain and in the deposits of the Middle Pleistocene terraces of the Lena river took place almost simultaneously. The more favourable conditions of ice development in the Middle Pleistocene terraces of the Lena (sandy-loam and loam composition of the enclosing deposits, and a longer period of formation of the ice complex as a whole) provided possibilities of a more extensive and more expressive ice-formation in the deposits of these terraces.

The complex of young Upper Quaternary terraces of the Khančaly, the Kenkeme and the Lena rivers is discussed below. In the Khančaly and the Kenkeme valleys, alluvial deposits of the first floodplain terrace dating from the Upper Quaternary occur most commonly (nearly throughout the whole area). They are represented largely by sand with closely set lenses of bog-

-lacustrine (oxbow) peat-loam deposits that are rather widespread in minor river valleys abundant in overgrown and overgrowing oxbow lakes. High iciness is their distinctive feature. Cryogenic structure in this type of deposits is represented by dense fractured ice lenses 0.5 cm to 1–1.5 cm thick. Moreover the iciness of these deposits increases due to polygonal-veined ice occurring here extensively. Ice inclusions frequently occupy nearly 80 per cent of the entire rock volume. The polygonal-veined ice has a thickness of ca. 1.5 m in cross-section and 2 to 3 m in vertical extension.

Thus the lacustrine deposits, that accumulated in the places of the overgrown oxbow lakes, are characterized owing to specific lithologic conditions by a high content of structure forming ice (for it were heavily moistened, peaty and humus sediments that froze up), which in turn preconditioned the development of polygonal-veined ice throughout these deposits.

A major part of the polygonal-veined ice in the lake-side localities is in the stage of preservation, i.e., this ice does not grow at the present time. The depth of bedding of the top surface of the ice veins in the Khančaly valley was (for 26 September, 1960) 1.0 to 1.1 m, whereas the depth of seasonal thawing in this area was 78 cm to 90 cm. Besides, the flower-bed aspect of the polygonal relief also indicates that the veined ice in this locality is in a stage of preservation or partial destruction. Usually these areas are situated at some distance from the lake and are slightly elevated and dry (covered by dry mixed-grass meadow). Localities immediately adjoining the akes are usually damp, with dense tall sedge, without any clearly expressed polygonal relief, separate frost-caused joints being here and there well defined. In such localities, growing ice veins develop, providing evidences of syngenesis (step-shaped contacts and the top ends of the veins lying directly under the seasonally thawing layer). Conditions for ice vein growth are most favourable here: the enclosing deposits are usually peaty, silty and heavily saturated with segregation ice. The surface conditions in these localities are also most suitable, since they are yearly flooded by water from the lakes, and intensive sedimentation takes place here due not only to the growth of peat, but also to material introduced by water of rivers which in spring are connected with many floodplain lakes. The conditions described, favouring the growth of polygonal-veined ice, are found rather often in the valleys of such rivers as the Khančaly and the Kenkeme. In its turn, the high ice content of these deposits ensures, under certain conditions, the intensive transformation of oxbow lakes into thermokarst lakes that expand as a result of the thawing-out of polygonal-veined ice in the lake-side localities.

Deposits of the young Upper Quaternary terraces of the Lena are represented largely by fine-grained sand; the widespread oxbow-lake facies also consist mainly of fine-grained sand, often silty and peaty, occasionally interbedded with sandy-loam and loam. On the whole, neither high and inexpressive iciness (predominantly cement-ice), nor extensive occurrence of polygonal-veined ice is characteristic of these deposits. An exception in that respect is provided by the upper silty and peaty horizons of the oxbow facies where high iciness is occasionally observed, e.g., closely set lenses and ice seams 1 to 1.5 cm thick. Moreover, ice interlayers are found of 50 to 70 cm in thickness (Fig. 1: Boring 14). As shown in Fig. 1, the ice interlayers are confined to lenses of slightly decomposed plant remnants; such a considerable thickness of ice interlayers might be expected with the freezing of such lenses, as are saturated with water like a sponge.

Polygonal-veined ice occurs rarely in the deposits of the young terraces of the Lena. Only earth veins were disclosed by the shafts and holes set by the expedition in localities of polygonal relief development, in a village of the Namtsy region. According to the data of some authors (Katasonov and Solovev, 1969), ice veins occur in cavities (intercrest depressions) of floodplain and terrace relief, usually in areas of peaty ground development. The upper ends of the polygonal-veined ice lie directly under the seasonally thawing layer at a depth of 0.9 to 1.5 m, the ice veins being 0.2 to 0.9 m wide and 1 to 3 m in vertical extension. Such veins develop only under the most favourable conditions, that are rather rare on the left-bank part of the Lena valley. Specific surface conditions prevail here, that further desiccation of the active layer and its deep thawing. These specific conditions have been brought about by man's activities: large villages, farms and fields are situated on the left-bank terraces of the Lena, which are almost entirely deforested. In the author's opinion, this is one of the principle reasons of the poor development of recent polygonal-veined ice in the young left-bank terraces of the Lena.

Earth veins (originally ground veins), as another manifestation of cryolithogenesis, are of common occurrence within the territory under consideration. These are found in all components of the relief, but their occurrence is particularly extensive in the young terraces of the Lena river, and also in the Khančaly and the Kenkeme river valleys. The variety of the facies-landscape conditions of the area in question determines the diversified character of the earth veins.

Descriptions of some earth veins laid bare by cuts in various localities (Fig. 2) are given below. Some earth veins opened down to the base were traced to a depth of 1.5– 2 m to 3.5 m (veins A, C, E). The majority of earth veins, however, were not opened to the base, but their dimensions in vertical extension may be assumed to range within the same limits. As shown in Fig. 2, these earth veins are most diversified in configuration. In all probability, the earth veins opened by the shafts developed initially as ground veins and did not pass through the stage of ice veins. Especially the two-story shape of some earth veins confirms this inference (Popov, 1959). The formation of such veins took place largely in the seasonally thawing layer – which preconditioned the development of the broad upper portion of the vein – and in the perennially frozen series, where the narrow lower tip of the vein was formed, and where vertical bands of ice, i.e. elementary veinlets, are usually found (Fig. 2, veins B, E). Vein A opened in the second bottom of the Lena floodplain can serve as an illustration of the fact that such veins develop fairly intensively under present-day conditions in the layer of seasonal thawing. Attention should be given first of all to the narrow sand wedge in the vein. The vertical extension of the wedge is about 1 m, thickness in width is 3 to 4 cm, it is filled with light sand, which also constitutes the faulted horizontal seam above the wedge. The concluding phase at the given stage of earth vein formation is fixed in the compact horizontal sand interlayers overlapping the vein; as for the faulted sand seam and the narrow sand wedge, these are a graphic illustration of the essentiality of the process of development of the given earth vein in the seasonal thawing layer: deep frost-caused cracking, formation of vertical hollows, and their filling with talus material.

Clearly distinguishable features of syngenesis afford evidence of the original ground genesis of some veins. Vein D opened by the cut in the first floodplain terrace of the Lena can serve as an example of a syngenetic vein developed in the seasonally thawing layer and growing upwards with accumulation of sediments. A vertical "column" of peat mass inside the vein is an interesting peculiarity and a proof of its syngenetic growth, since there is neither peat nor any peaty deposits above the vein or anywhere nearly; it would be therefore unfounded to regard this vein as a pseudomorphosis. The development of such veins appears to have proceeded in the following way. Peat mass (slightly decomposed plant remnants mixed with humic loam) accumulates in the narrow interpolygon cavities where conditions are more humid than in the polygons and where swardflag tussocky surfaces often develop. As the floodplain sediments accumulate and expand, the peat "column" grows upwards too. The accumulation of peat mass, and frequently also the development of the entire vein, ceases with the completion of the floodplain stage, or with a change in the superficial conditions. In individual cases, the local facies conditions, peculiar to the interpolygonal cavities, promote the formation of quite a peculiar composition of the "body" of a vein (with peaty, humic or silty ground prevailing) as compared with the enclosing and the overlying deposits, because transformation (reworking) of the rock of the vein "body" is displayed more actively in the interpolygonal cavities as a result of higher humidity. Vein F opened in the watershed divide surface of the ancient alluvial plain seems to have developed under such conditions. In any case, such veins cannot by interpreted as pseudomorphoses, since the enclosing and the overlapping deposits sharply differ in lithologic composition from the body of the vein.

It should be noted that the earth veins of the watershed divide plateau have greater thicknesses (larger dimensions) than those of the veins developed in the deposits of the recent valley complex. This fact might be a result of a longer period of development of veins in the watershed divide plateau.

Hence, such morphological manifestations of cryolithogenesis as polygonal-veined ice and earth veins, which are characteristic of the deposits discussed, may be regarded as fairly significant and multiform despite the unfavourable lithological conditions (sand composition prevailing). The extensive development within the area under consideration of such permafrost processes as frost-caused joint-formation and the related ice and earth veins is preconditioned primarily by the continuous occurrence of permafrost and of its rigorous temperature regime.

Translated by E. Ščapova (Moscow)

References

Alekseyev, M. N., 1961 – Stratigrafiya kontinentalnykh neogenovykh i četvertičnykh otloženij Vilujskoj vpadiny i doliny nižnego tečeniya reki Leny (Stratigraphy of the continental Neogene and Quaternary deposits in the Viluj basin and in the Lower Lena valley). *Trudy Geol. Inst. Akad. Nauk SSSR*, vyp. 51; Moscow.

Danilova, N. S., 1963 – Pervično-gruntovye žily v četvertičnykh otloženiyakh reki Viluj (Primary-ground veins in the Quaternary deposits of the Viluj river). *In:* Usloviya i osobennosti razvitiya merzlykh tolšč v Sibiri i na Severo-Vostoke. Ed. Akad. Nauk SSSR, Moscow.

Danilova, N. S., 1964 – Podzemnye ldy doliny nižnego tečeniya reki Viluj, usloviya ikh obrazovaniya i paleogeografičeskoe značenie (Undergronud ice in the Lower Viluj valley, conditions of its development and its paleogeographic significance). *In*: Sovremennye voprosy regionalnoj i inženernoj geokriologii. Ed. Nauka, Moscow.

Kačurin, S. P., 1950 – Večnaya merzlota i relef na Leno-Vilujskom vodorazdele (Permafrost and relief in the Lena-Viluj watershed divide). *In*: Issledovanie večnoj merzloty v Yakutskoj respublike, vyp. 2; Ed. Akad. Nauk SSSR, Moscow.

Katasonov, E. M., Solovev, P. A., 1969 – Putevoditel k ekskursii po Centralnoj Yakutii – paleogeografiya i periglacyalnye yavleniya (Guide to the excursion to Central Yakutia – Paleogeography and periglacial phenomena). Yakutsk.

Katasonova, E. G., 1963 – Sovremennye mnogoletnemerzlye otloženiya i ikh boleye drevnie analogii v severe-vostočnoj časti Leno-Vilujskogo meždurečya (Recent perennially frozen deposits and their more ancient analogues in the northeastern part of the Lena-Viluj interfluve). *In*: Usloviya i osobennosti razvitiya merzlykh tolšč v Sibiri i na Severo-Vostoke. Ed. Akad. Nauk SSSR, Moscow.

Popov, A. I., 1959 – Gruntovye žily na severe Zapadnoj Sibiri (Ground veins in the north of Western Siberia). *Voprosy fizičeskoj geografii polarnykh stran,* vyp. 2; Moscow.
Rusanov, B. S., 1968 – Biostratigrafiya kainozoiskikh otloženij Yužnoj Yakutii (Biostratigraphy of the Cenozoic deposits of Southern Yakutia). Ed. Nauka, Moscow.
Solovev, P. A., 1959 – Kriolitozona severnoj časti Leno-Amginskogo meždurečya (The cryolithozone of the northern part of the Lena-Amga interfluve). Ed. Akad. Nauk SSSR, Moscow.