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PLASTIC AND RUPTURAL DEFORMATIONS IN BASIN SEDIMENTS

Deformations of the primary, sedimentation structure can be found in the Pleistocene marine and lacustrine deposits, the development of which took place in the course of sedimentation and of the subsequent transformation of sediment into rock. In their outward aspect, such deformations resemble frost-caused and glacial disturbances of sedimentary rock stratifications, and are frequently mistaken for them. The question of the genetic nature of deformations is of great importance in cases of paleogeographic reconstructions, since deformations are usually regarded as an indicator of the periglacial conditions prevailing in the period of the enclosing rock accumulation.

Studies of the marine and lacustrine Pleistocene deposits in the north of the West Siberian and Pečora lowlands show that the disturbances of the primary sedimentational rock structure, unrelated to the permafrost processes and to the past effect of the glacier, are of common occurrence and of several types.

PLASTIC DEFORMATIONS

Plastic deformations in basin sediments originate both at the stage of sedimentation (syngenetic deformations) and in the process of the subsequent transformation of sediment into rock (diagenetic deformations).

Syngenetic deformations are related to moisture-saturated downflowing and slumping grounds under bottom conditions. Shapes, character and dimensions of the deformations are diverse.

Deformations in the form of isolated large folds either inclined or horizontal (Pl. 1) are present in the stratified aleurite that constitutes the interlayers of the coastal marine sand. Since the folds lie within a single aleurite

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stratum and are overlain by the horizontally bedded sediments of the same stratum, their origin cannot be explained by the dynamic effect of the glacier. Besides, the deformed aleurite strata form a unified series of coastal marine deposits inside which no traces of interruptions in sedimentation can be found. The water-saturated ground creeping downslope of the basin bottom in the course of sedimentation is the only possible explanation of the origin of the deformations. It is known that silt sediments of an aleurite composition are most liable to this process, for their angle of repose changes abruptly with each change in the ground moisture.

Folded deformations occasionally embrace portions of aleurite and fine-sand silt rocks of considerable thickness (up to 3 m or 5 m). In such cases the folding becomes of a corrugated character (Pl. 2). Its origin is frequently explained by the dynamic effect of the former glacier. At some distance from the contorted rock, the stratification is rhythmic, horizontal, The deformed layers are conformly overlain by obliquely bedded medium-grained sand of aqueous origin. At the sites where deformations are absent, the horizontally bedded sand aleurite rock and the overlying obliquely stratified sand appear to constitute a genetically unified series of basin deposits. Hence, there is no reason to associate the origin of deformations with the dynamic effect of the glacier, whose sediments are absent.

Large slump deformations are found in the Pleistocene marine ice clay and loamy series. A characteristic example is supplied by a slump structure

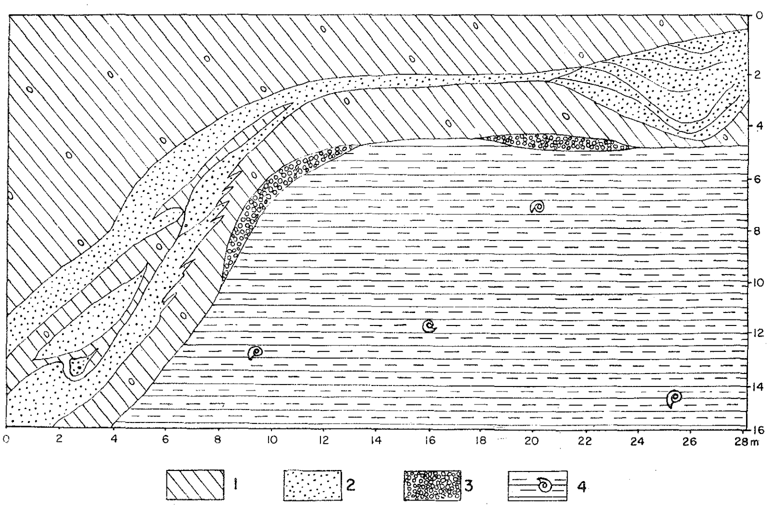


Fig. 1. Slump deformation in the marine-ice loam with sand interlayers above the eroded top of Jurassic schist

1. loam with pebbles, boulders and Foraminifera microfauna; 2. sand; 3. pebbles; 4. schist rock with Jurassic fauna

above the eroded top part of the Jurassic schist (Fig. 1). Marine-ice loam with sand interlayers is invloved into the deformation. Upward, the loam attains regular bedding conditions, the sand layers being arranged horizontally. The gradual upward transition of the deformed aqueous deposits to regular bedding conditions substantiates the inference that the deformations are of sedimental nature.

A large slump fold in the sub-surface part of the marine-ice clay and loam with sandy interlayers is shown in Fig 2. The vertical extent of the deformed strata is 6 m, and the horizontal one more than 15 m. The deformation is built of compact-grained and fine sand, forming a recumbent fold. Interlayers of sand in the clay and the clay rock itself participate in it, which indicates that the deformation appeared in slightly consolidated, water--saturated ground.

Diagenetic plastic deformations originate at the stage of the transformation of sediment into rock under bottom conditions. They are related to the transition of the saturated ground into a fluid, running state under the effect of the increasing load of the overlying, continuously accumulating strata.

Plastic diagenetic deformations are peculiar to rocks of silt composition, namely, to aleurite and fine-grained silt sand, and are preconditioned by their thixotropic properties, and also by an ability for fixing changes in the po-

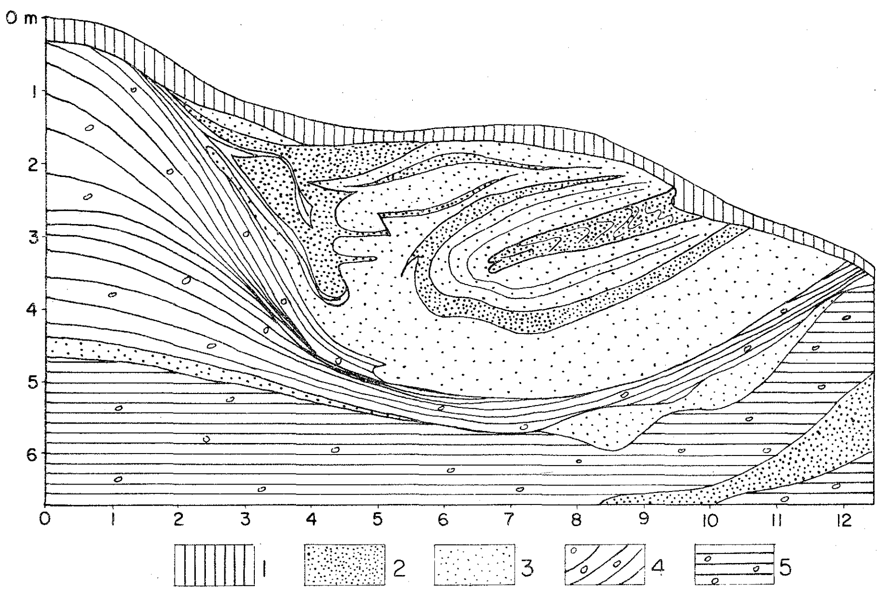


Fig. 2. Large slump deformation in the marine-ice deposits

1. covering loam; 2. fine-grained sand; 3. compact-grained sand; 4. deformed clay; 5. non-deformed clay

sition of the layers due to the abrupt loss of moisture with deformation. Moisture-saturated ground seems to be able to pass into a thixotropic, running condition not only under the effect of a dynamic load, but also as a result of its gradual increase over a long time period (Popov, 1962).

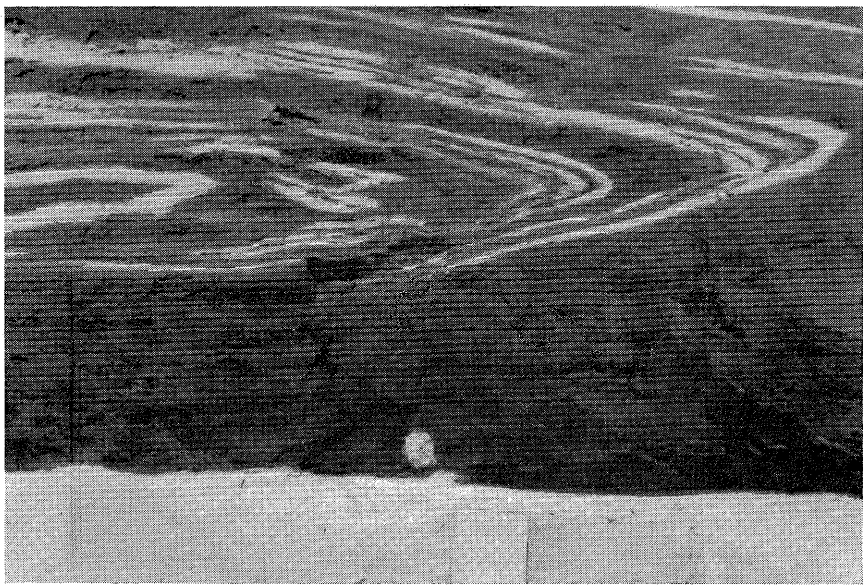
Scalloped intrusions of compact material of loam and clay interbeddings into the overlying less consolidated, looser sand (Pl. 3) constitute a widespread type of diagenetic deformations. The intrusions are of a microlaccolithic and batholithic nature. The structures presented in the photograph (Pl. 3) lie at the base of the series of lacustrine alluvial deposits. The formation of the series took place without any interruptions in sedimentation under bottom conditions; therefore, the origin of the deformations cannot be attributed to permafrost processes. Most probably their formation proceeded as follows.

Under the pressure of the accumulating sand, the water-saturated plastic material of the underlying clayey-loamy interbeddings tended to squeeze out. Since the rock underlying these interbeddings had by the time been sufficiently condensed and drained, the clayey-loamy material intruded upwards into the feebly consolidated, moisture-saturated sand, forming small scalloped structures. Mechanical deformation was accompanied by a loss of moisture in the sediments, owing to which the structures became fixed.

Structures similar in morphology were described by K. O. Emery (1950) from the Pleistocene sediments of an open bench in California. The accumulation of these sediments occurred in their thawed state, and therefore the origin of the structures cannot be related to permafrost processes. However, by their outward appearance they resemble involutions, cryoturbations, and are frequently regarded as an illustration of typical permafrost deformations associated with the active layer.

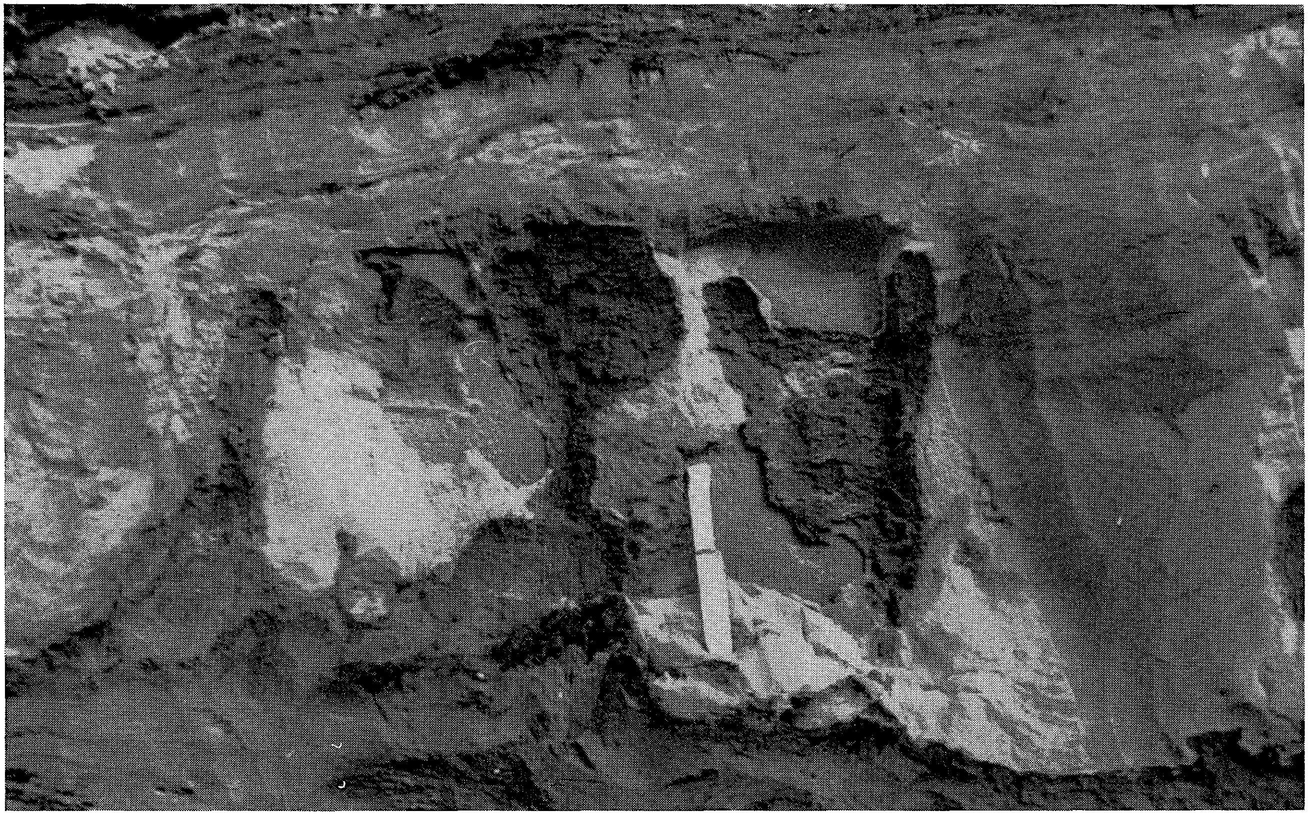
For comparison, an example can be cited of characteristic deformations of the active layer, buried in horizontally stratified floodplain sand (Pl. 4). The distinctive features of the deformations are in this case the presence of the buried podzolic and humus soil horizons, a general downward bearing of the tongue-like deformations, a one-sided inclination and the maintenance of the deformed layer in a horizontal direction.

Diagenetic disturbances of stratification, due to the transition of rock into a thixotropic running state, sometimes involve rather thick layers of basin sediments. A graphic example is provided by the deformations in the section of the second floodplain terrace of the Middle Usa river (a right-bank tributary of the Pečora). In the lower part of the section the terrace is built of obliquely stratified medium-grained sand at the base of which lies a fine--grained sand layer with aggraded peat lenses. Diatom flora of a lacustrine

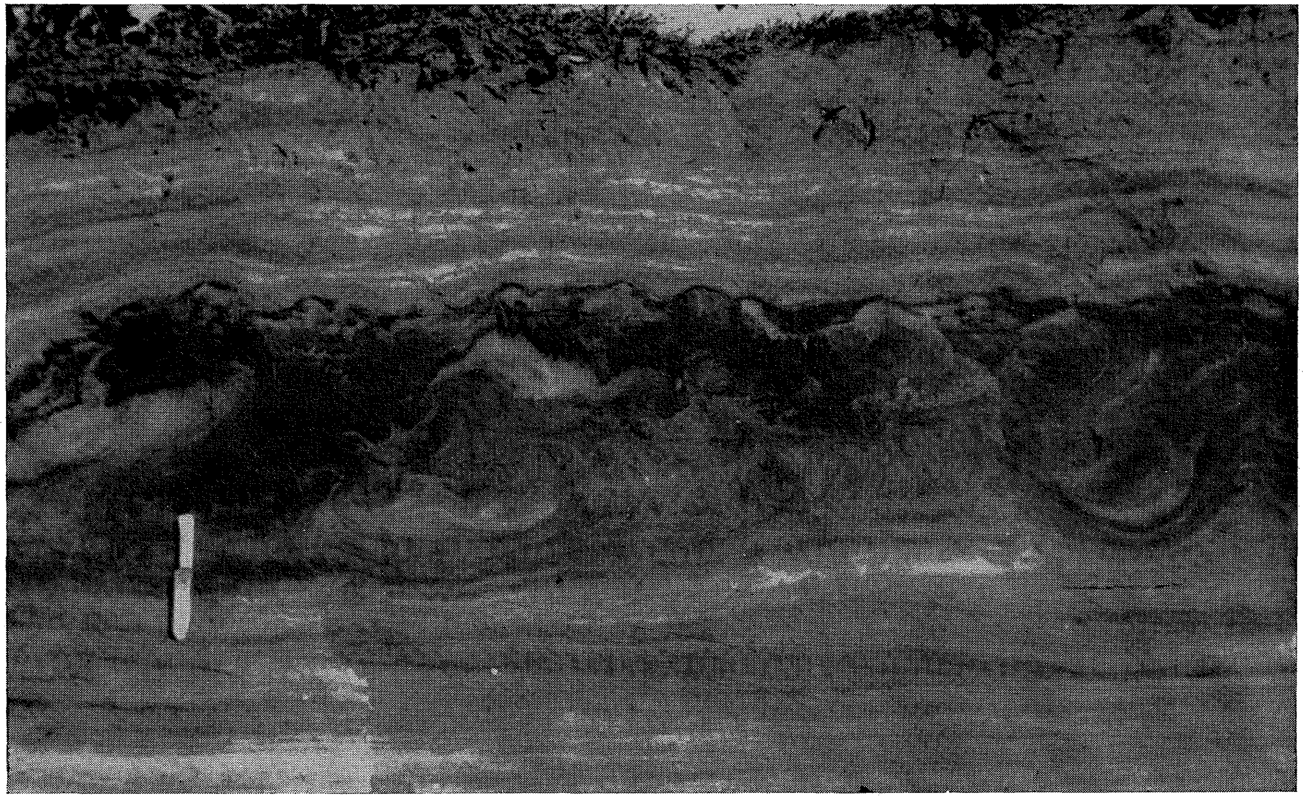


Pl. 1. Fold in the coastal marine horizontally stratified aleurite

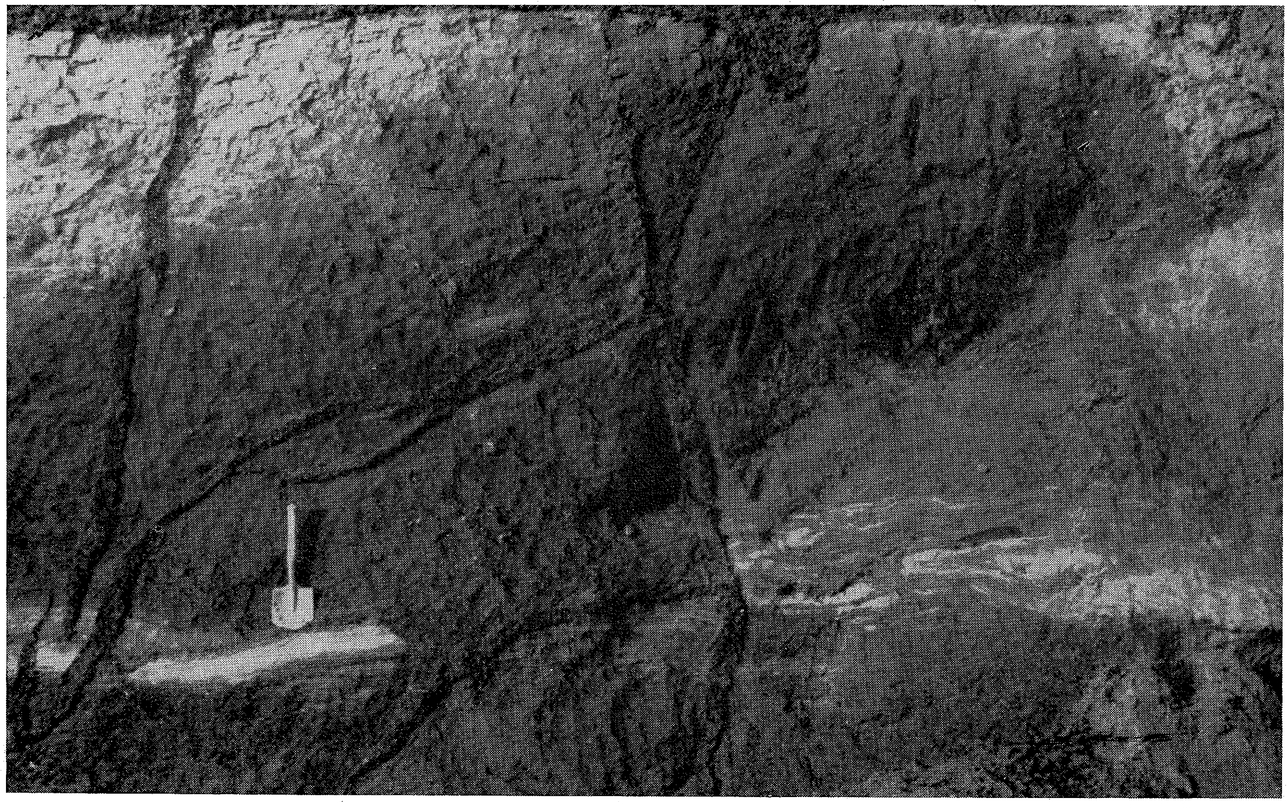
Pl. 2. Contorted stratification of fine-grained sand and aleurite of coastal marine genesis



Pl. 3. Scalloped intrusions of loam into the overlying whitish sand



Pl. 4. Buried deformations of the active layer in the floodplain alluvium



Pl. 5. Fissures and wedge-shaped saggings in the marine loam

alluvial aspect is present in the sand with peat. Upward the obliquely bedded medium-grained sand passes into fine-grained silt sand, undulated at first, and then horizontally stratified sand with sandy loam and aleurite interlayers. The sand is overlain by horizontally bedded clay which, upwards, gradually changes into banded clay. Along with fresh-water diatoms, brackish-water species are found in the clay.

The character of the changes in grain-size composition, in the stratification of the terrace deposits and in the diatom flora contained in them shows a gradual temporal shift of the channel water streamflow into a stagnant or feebly circulating basin of sedimentation whose depth constantly increased. The ponding-up of the basin with sea water infiltrating a'ong the Pečora and the Usa valleys affected the stage of accumulation of the horizontally stratified and banded clay, which resulted in brackish-water species appearing in the diatom flora. The banded-stratified sediments near the surface pass into lacustrine loamy clay with plant remains, overlain by peat.

Thus the deposits of the terrace accumulated in regular succession, in a single continuous cycle of sedimentation: the channel water streamflow; the ponded-up, at first shallow, and later on deep basin; the dead lake.

The deformations involve a stratum of fine-grained rhythmically bedded sand with sandy loam and aleurite interlayers, 2.2 m thick (Fig. 3). They are arranged in separate stages (0.2 m to 0.6 m thick) between which the rock beds are less intensively deformed. The upward flattenning-out of the deformed layers of each series can be traced. The morphology of the deformations shows that they were formed as a result of an intrusion of the underlying interlayers into the overlying ones, breaking up the stratification of the latter. Deformations appeared repeatedly in the process of sedimentation, owing to which they are arranged in several stages.

The contortion of the layers took place in their heavily water-saturated, nearly fluid state, therefore the coarser material slid down from the benches of the positive structures and accumulated in the small synclinal folds, which is clearly seen in Fig. 3. Deformations originated at the early stages of diagenesis, at insignificant depths from the surface of the bottom, which follows from the insignificant thickness (0.2 m to 0.3 m) of the sediments dividing the intensively rumpled layers.

The major stage of sedimental deformation, including the entire horizon of the contorted strata, occurred after the accumulation of a certain part of the overlying compact clay rock. Under the effect of the heavy clay load, the moisture-saturated silt-sand was transformed to a fluid state and deformed. The deformation of the layers under the action of the pressure constantly applied from above was followed by loss of moisture, which brought about the compaction of sand and reduction of its volume. As a result, poly-

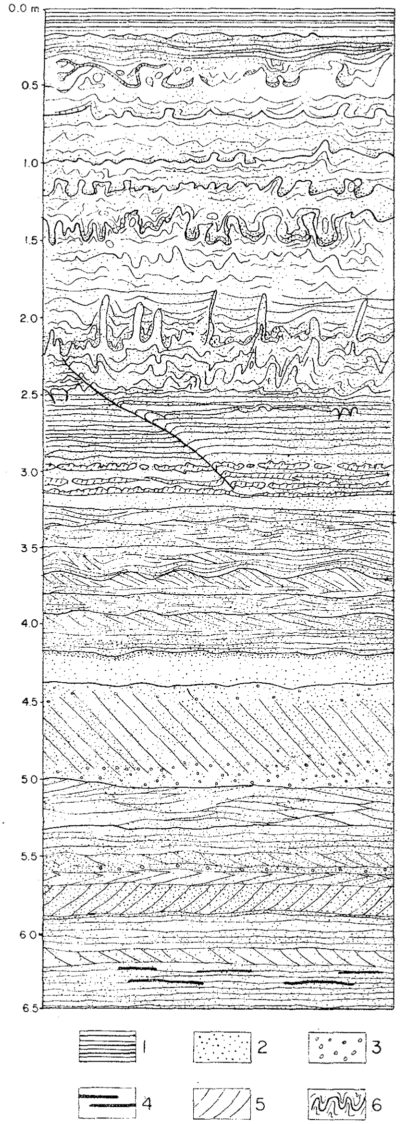


Fig. 3. Deformations of lacustrine-alluvial rhythmically stratified fine-grained sand with sandy loam and aleurite interlayers

1. banded-clay; 2. sand; 3. pebbles; 4. peat lenses; 5. sand stratification; 6. contorted strata

gonal fissures, or reduced vertical zones, appeared in the sand, down which occurred an intrusion of the overlying plastic, but heavier, clay rock (Fig. 4).

The clayey intrusions into sand have an irregular, elongated, tongue-like or wedge-like shape. Their vertical extent is 1.4 m to 1.7 m, the cross section in the upper, widened, part is 0.6 m to 1.0 m. The lower tip of the intrusions is usually blunt. The contacts with the enclosing rock are uneven, abrupt; chippings and faults appear at the contacts. Numerous lumps of clayey rock

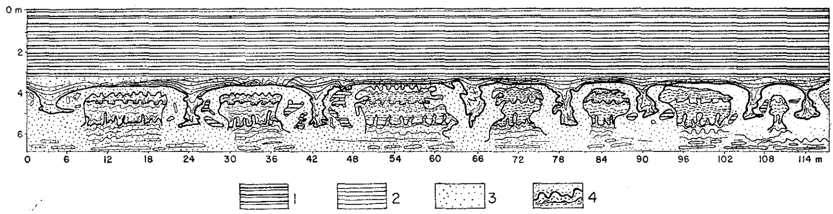


Fig. 4. Wedge-shaped intrusions of horizontally bedded clay into the underlying deformed sand strata

1. banded clay; 2. horizontally stratified sandy clay; 3. non-stratified sand; 4. contorted sand layers

separated from the basic bodies of the veins are deposited near the contacts in the sand. The clay rock saggings are sunk into sheathes of non-stratified sand. The horizontally deformed stratification peculiar to sand appears in it at some distance from the intruding structures. This fact indicates that the sand, at the time of the clay intrusion, was poorly compacted and rather sufficiently saturated. When intruding, the clay brought the adjacent sands into a fluid state, they intermixed and lost all the features of their primary sedimental structure.

An enveloping stratification can be traced inside the clay structures, which gradually flattens out upwards. The clay constituting the structure is similar to the horizontally stratified clay overlying the structures, and is gradually transformed into the latter. The horizontally stratified clay subsides above the intrusion structures, forming trough-like folds that flatten out up-section. Still higher upward, the horizontal stratification of the clay passes into banded stratification. The banded clay does not participate in the deformations, and has regular bedding conditions. On the plan, the clay saggings intersect each other, forming a polygonal network. The distance between the neighbouring structures varies from 8.5 m to 25 m, averaging 17 m to 23 m.

By their outward aspect and constitution, the structures under consideration resemble the "structures of enveloping" whose formation is associated with the melting-out of polygonal-veined ice (Romanovsky, 1958). On the other hand, similar formations are regarded by some authors (Artyuškov, 1964; Kostyaev, 1964) as a result of the development of convection instability processes in the moisture-saturated bottom sediments.

RUPTURAL DEFORMATIONS

In the process of transformation of sediment into rock, intensive desiccation and compaction takes place. In the sediments of clayey and loamy composition, this causes formation of diagenetic ruptural fissures filled with the overlying fluid bottom sediments. It is known, for example, that under the layer of the recent bottom sediments in the Black Sea, 0.2 m to 2.0 m thick, the Novoevksinsk clay deposits are broken by fissures into which the overlying sediment material flows (Strakhov, 1960).

Fissures in the Pleistocene marine deposits were observed by the present author in relatively deep (shelf) clayey-loamy rock in the north of Western Siberia and of the Pečora lowland. The rock enclosing the fissures contains sea mollusk fauna and rich complexes of Foraminifera, thus indicating deposit accumulation on the bottom of an open polar shelf, under conditions of normal salinity and considerable depths. Therefore there is no reason to presume a simultaneity in sediment accumulation and freezing.

Fissures are traced, for example, up from the base of the marine clay in the underlying loam stratum (Pl. 5). The contact between the clay and the loam is even, horizontal and clear, and was preconditioned by the alternation in time of the accumulating terrigenous material. Though arranged in the loam, the fissures are occupied by the overlying darker and plastic clay. The width of the fissures varies from 0.1 m to 0.2 m, and they are traced down to a depth of 4 m to 6 m from the top of the loam.

Within the marine loam stratum itself, lie the wedge-shaped saggings of up to 1.2 m in vertical extent and 0.5 m to 0.6 m in cross section in the upper broadened part. The wedges cut the horizontal vaguely expressed lens-shaped interlayers of whitish aleurite, owing to which they are clearly visible in the section. The occurrence of a wedge-shaped structure within a single layer of marine loam rules out any conjectures as to its relation to the former presence of permafrost and to the thawing-out of vein ice. The wedge-shaped sagging is not accompanied by plastic deformations, and there are no similar wedges in the section, that might afford evidence of the melting-out of the polygonal-veined ice system.

All the data indicate that the formation of the narrow deep fissures and wedge-shaped saggings took place along with the diagenesis of the bottom marine sediments, and was associated with the compaction and desiccation of the latter, rather than with the processes of frost-caused cracking of the ground or of the melting-out of vein ice.

CONCLUSIONS

1. In the course of accumulation of the bottom basin sediments and of their subsequent transition into rock, deformations of a plastic or a ruptured nature originate, that morphologically aproximate glacial dislocations and permafrost deformations.

2. At the stage of sedimentation occur rock shifts of a slump nature, resembling glacial dislocations.

3. In the process of sedimental diagenesis, plastic and ruptured deformations develop, similar to permafrost cryoturbations, involutions and pseudomorphoses along polygonal-veined ice.

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