THE ROLE OF NEOTECTONICS IN THE EVOLUTION OF CRYOLITHIC ZONE

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ABSTRACT

Computer modelling was accomplished to determine dynamics of permafrost (PF) thickness in the conditions of neotectonic movements. The subsidence of separate blocks was assumed to be compensated by sedimentation that is typical for some depressions of the Russian North East. The working hypothesis used in this paper was the statement of V.A. Kudryavtzev that a subsidence with simultaneous sedimentation results in thicker PF.

Calculations were performed based on the numerical solution for one-dimensional Stefan problem. When temperature on the surface was from -1°C to -3°C, the average rate of PF formation (without movements of the Earth's crust) ranged within the interval from 4.5 to 9.7 m/thousand years. During the neotectonic motions, downwards with the rate of order 0.3 to 2.0 cm/year, the average rate of PF thickness increase was 4.5 to 23.2 m/thousand years. The modelling data confirm the possibility that PF with anomalous thickness can be formed in intermountain areas (for example, in the Ola depression it is 350 m thick) and its thickness can change abruptly along relatively small distances.

Neotectonics of block character with the compensational sedimentation in cryolithic zone environments is a more important mechanism of perennially frozen ground formation then the climate. Separate blocks with frozen ground of different thickness are the indicators of tectonic activity in the Late Quaternary stage.

The role of neotectonic movements in formation of cryolithic zone is considered to be, first of all, the factor of formation of heterogenous structure and changes of sedimentary cover thickness. Increased values of the heat flow and decreased thickness of perennially frozen ground occur under the arches of the anticline structure, and vice versa - under the syncline ones.

Recently new data on Late Pleistocene and Holocene tectonic activity and frozen ground-geologic composition of the intermontane areas of the Magadan region were obtained. In this paper on the basis of these data comparison with the results of computer modelling, we come to conclusions of the possible influence of neotectonics of block character and sedimentation processes on the dynamics of perennially frozen ground series formation (PFGSF).

In the Magadan region intermontane neotectonic cavities are isolated. In the central regions (Srednekan and Verkhne-Kolyma low-mountain reliefs), separate depressions are distinguished; in the costal zone occurrences are united into the Yana-Taui group (Baulin, 1985).

Cavities are the flat, swamped lowlands surrounded by the mountain ridges (Seimchan-Buyundin, Orotukan, Khasyn and others.) or they are open the side the Sea of Okhotsk (Taui, Ola, Arman and others.).

The characteristic feature of these cavities is the presence of one or several "transit rivers" in each of them. These "transit rivers" flow through the whole depression, receiving smaller streams. "Transit rivers" often serve as a regional drain, local basis of erosion, and the main line of sediments evacuation.

The central parts of the region belong to the area of continuous distribution of perennially frozen ground (PFG), and the coastal parts are characterized by the island or discontinuous development of PFD (Ershov, 1989).

From the tectonic point of view, the region belongs to the eastern flank of the Yana-Kolyma folded system, and the given depressions are characterized as conjugate, semi-isolated, and sometimes independent grabens and troughs superimposed on the Mesozoic structures.

The geological composition of cavities is rather complex. They have a folded mountain basement combining the rocks of different ages - from Precambrian to Cretaceous, inclusively. Sedimentary cover is represented by loose or poorly consolidated rocks of Paleogene and Neogene on which Quaternary sediments occur.

Lithological composition of the Tertiary sediments are various: conglomerates and coarse gravels; sands and sandstones; siltstones; argillites, clays, brown coals etc. Rocks of Neogene age prevail considerably.

Sediments of lower and medium stages of Quaternary system occur mainly at the depression flanges where they are exposed on the surface or cropped out by the comparatively shallow workings. In central parts of cavities, they are absent or not studied because of poor exposure of the territories.

Upper Quaternary and modern sediments are represented by the wide spectrum of stratigraphic-genetic complexes. Most of all there are sediments of alluvial, fluvial-glacial, proluvial, deluvial, and limnetic origin, and also their mixed types. Biogene accumulation are widely present.

Among the lithological differences, coarse gravels are widely spread while thin dispersions (sands, sandy loams, loams) are less spread. The process of formation of loose detritus in the cavities is extremely complex. It is supposed that there is a compensational sedimentation resulted from the vertical movements of the Earth's crust.

Cavity basement has a block composition. The position of separate blocks relative to surface is various. Some of them plunge for depths of 1500 - 2500 m determining the thickness of loose cover of the cavities (Ivanov, 1985; Koshkarev, Kuznetsov, 1986). At other places we can observe the outcrops of mountain rocks at the surface. These rocks sometimes form the relicts looking like the small hills.

The loose cove has the same peculiarities. On the cavities surface (particularly in piedmont parts) dome-like hills and ridges of Tertiary age are mapped. At other places, Neogene rocks plunge under the series of Anthropogene for depths of several tens or several hundreds meters.

By the results of interpretation of drilling geophysical works data, deciphering of cosmic- and aerophotomaterials, it was established that tectonic activity in the Quaternary period resulted in formation of numerous fault breaks crossing the loose cover of cavities and into the large number of blocks. The minimum sizes of several blocks are 0,5 - 0,8 km. At the surface some faults are expressed by the chain lakes distribution. They are expressed by the sharp bends and anomalous branching of channels. In the Upper Pleistocene and Holocene the rates of separate blocks settling were various. The plunges were compensated mainly by the accumulation of loose material removed from the outer frame or due to the wash out of neighboring sections that move slower. During the last years some new data on thicknesses of Quaternary sediments were obtained. The geological age of these sediments is determined on the basis of palynological method. Sediments of Zyryan, Kargin, Satran, and modern intervals were studied.

Within the Ola-Serdyakh Interfluve (the Ola depression) sand and coarse gravel series of 104 m thick is characterized by the spore-pollen complex of the first half of Syran glaciation or Sartan cooling of temperature.

On the north bort of the same cavity, in the Ola River valley by the drill hole sediments series formed during the Karagin interglacial was stripped. Down-stream of the Palatka River (eastern part of the Khasyn depression), the thickness of rocks of the same age is 141 m. Coarse-debris component prevail in the lithologic composition.

In the Seimchan-Buyundin cavity maximum thicknesses of sediments of Kargin interglacial stripped by the drill holes are about 40 m.

In the middle course of the Atargan River (the Ola depression) sediment thickness of the second half of Sartan cooling of temperature is 12,6 m. Layers characterized by spore-pollen complexes of the first half of Zyryan glaciation and Kargin interglacial are stripped by separate drill holes with the depth 20 m in the Ola depression. Lakes (for example, Chistoye Lake) formed in the sections of blocks separated from the lines of loose material removal. Sometimes these lakes formed with the partial compensation of sediments of the earth surface depression.

In the Ola-Tanon interfluve coarse gravel series of Holocene age occurs on the Neogene rocks. Its thickness is 30 m. At some places of the middle course of the Taui River (the Taui depression) the thickness of modern course gravels reaches 36 m. In the Ola River mouth (the Okhotsk Sea shelf) the foot of Holocene sands occurs at the depth of 20 m.

Tectonic activity of the block character in Late Pleistocene and Holocene resulted in the supply and redistribution of loose detritus in the intermontane cavities of the eastern flank of the Yana-Kolyma folded system. In several blocks the velocities of compensational sedimentation were 0,1 - 1,2 sm per year. The surfaces of other blocks were eroded. Earth surface depressions in isolation from the line of removal resulted in formation of lakes of tectonic origin.

On the base of repeated leveling on the triangulation net of high class, it was established that the velocities of settling of separate points in cavities were 0,3 - 1,0 sm per year.

The geological activity of channels (including water-glacial one) plays an important role in the compensational sedimentation. Rivers are characterized by high velocities of sedimentation and its changeable character (Koshkarev, Kuznetsov, 1986). By the data of comparative deciphering of aerophotomaterials in 1942, 1985, and by the data analyses of geological prospecting works of 1986-1988, it was established that the average velocity of formation of flood plain detritus by the Kolyma River in some points of the Seimchan-Buyundid cavity reaches 2,0 sm or more per year. An increment of proluvial (alluvial-proluvial) sediments that may increase due to the segregation ice separation during the syngenetic freezing of sediments is, probably, similar.

The depth of bedding of the PFG foot is various in the cavities area. It sharply decreases within the large faults. For example, the Ulakhan fault (within the boundary of the Seimchan-Buyundin cavity,central parts of the Magadan region) differs by its old location. The PFG thickness in this fault is 70,0 m. In some blocks of the same cavity the PFG thickness reaches 550 m. In other ones located near the thickness may decrease up to 180 m.

In some blocks of the Ola depression by the drill hole there is stripped the cryolithic zone with the thickness of 350 m. This fact is considered to be the anomalous one for the region of island or fragmental PFG distribution. Its average value here doesn't exceed 180 m.

Sharp change of the PFG thickness at relatively small distances (outside the faults) is due to that fact that in some cases the velocity of melting from below (because of the flow from the interior part of the earth) is less then the velocity of the PFG formation from above. This results in formation of PFG series with anomalous thickness (Kudryavtsev, 1967). The same may occur in the intermontane neotectonic cavities with a big velocities (up to 3 sm per year) of the newest settling of separate blocks with the full or partial compensational sedimentation (Basisty, 1993).

For the calculation of dynamics of the temperature field in PFG with the sedimentation at the day surface the following mathematical model was used:

$$C_i \frac{\partial T}{\partial t} = \frac{\partial}{\partial x} \lambda_i \frac{\partial T}{\partial x}, \; i = 1, 2 \tag{1}$$

$$T(0,t) = T_0 , \quad \frac{\partial T(x,t)}{\partial x} = g \tag{2}$$

$$T(x,0) = T_0 + gx \tag{3}$$

$$-\lambda_1 \frac{\partial T}{\partial x} + \lambda_2 \frac{\partial T}{\partial x} = L \frac{\partial \xi}{\partial t} \tag{4}$$

$$\eta = \{ at, \;\; 0 < t < t_s ; \quad \Theta, \;\; t > t_s \tag{5}$$

where (1) - an unvaried non-stationary equation of heat conduction in melted and frozen ground; (2) - marginal conditions at the day surface ($x = 0$) and depth $x = X$; (3) - initial distribution of temperature; (4) - Stefan's condition at the boundary of separation of melted-frozen ground phases; (5) - sedimentation environment.

In the equations the following designations are used:
λ_i - thermal conductivity; C_i - volumetric heat capacity; T - rock temperature; T_0 - average annual temperature at the day surface; Θ - maximum thickness of sedimentary rocks; L - volumetric latent heat of ice; ζ - position of the phase change; g - geothermal gradient; a - rate of sedimentation; X - depth; t - time; t_s - time of sedimentation; H - $_{\Delta}H$ - A - Indexes 1, 2 at the bottom correspond to the frozen and thawed state of the rock.

For the solution of the given marginal problem the method of finite differences was used.

On Fig. 1 the dynamics of PFG thickness for the calculated versions 3 and 10 is shown. In the first version sedimentation lasted during 8 x 10^3 years, in the second one - 2,1 x 10^4 years. At these time intervals the PFG thickness growth took place. Slow PFG melting began after that.

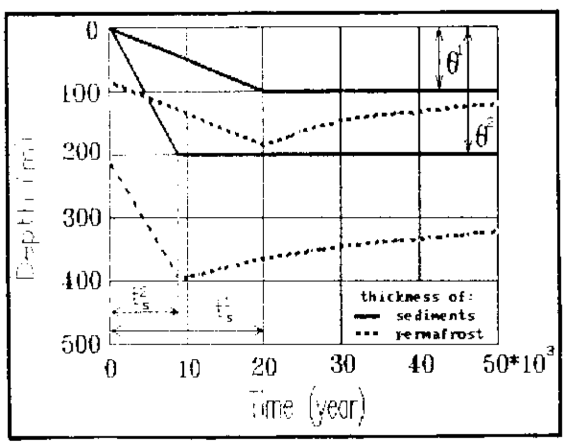
On Fig. 2 diagrams of the rock temperature change with the depth for the 10 version are given. Diagrams 1, 2, 3 show the temperature distribution at the time points 2 x 10^3. 10^4, 4,2 x 10^4 years, respectively.

In the Table there are given the data for several calculated versions differing by the average annual temperatures of the surface T_0 (^0C), velocities of sedimentation, a sm per year, time of sedimentation t_s, thousand years (in versions, where $a = 0$, t_s - time if growth of PFG thickness is due to the conductive thermal conductivity). In the last version of temperature $T_0 = -3^0$ C was preserved during 4 x 10^4 years, than suddenly changed up to $T_0 = -1^0$ C. In calculations the following parameters were used: $\lambda_1 = \lambda_2 = \ldots$ of numerical experiments. The size of calculated area (X values) was selected from the stationary conditions of the temperature field at the low boundary, $X = 1000$ m was given. As a result of calculations, the dynamics of PFG thickness was obtained. The maximum values for this thickness ($_{\Delta}H$, m) for the various versions are given in the Table, and the velocity values of growth of PFG thickness (A, m/th. y.) are also given in this Table.

Table. Calculations of PFG thickness and the velocity of its growth.

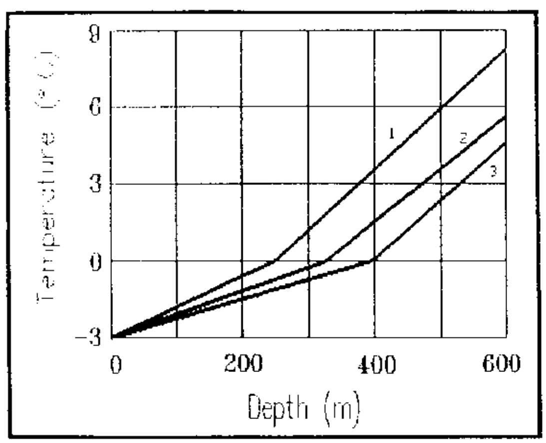
To at the surface	Version	a, sm / y	t, th.y.	H, m	$_{\Delta}H$, m	A m / th.y.
-1^0 C	1	0,0	21,2	82	-	4,5
	2	0,3	13,0	130	58	4,5
	3	0,5	20,0	190	100	5,0
	4	1,0	30,0	400*	310	10,0
	5	2,0	16,0	400*	310	19,0
-3^0 C	6	0,0	22,0	214	-	9,7
	7	0,3	23,0	298	84	3,65
	8	0,5	25,0	351	136	5,44
	9	1,0	17,0	400*	186	10,1
	10	2,0	8,0	400*	186	23,25
Change T_0: -3^0, then -1^0	11		39,0	214	124	3,1

* Stationary state is not obtained.



←Fig.1. Dynamics of thickness of sediments and perennially frozen ground.
1 - a = 0,3, Θ = 100, T_0 = -1; 2 - a = 2,0, Θ = 200, T_0 = -3.

Fig. 2. Temperature change with the depth. →
1 - t = 2000, 2 - t = 10000, 3 - t = 42000



At the temperature -1^0 C at the surface and without the movements the PFG thickness reached 82 m; at the temperature -3^0 C it was 214 m. With the neotectonic shoves with the velocities of 0,3 and 0,5 sm per year the PFG thickness had increased up to 130 and 190 m at the temperature -1^0 C; and up to 298 and 351 m - at the temperature -3^0 C, respectively (Table).

Velocities of PFG formation without movements and at the surface temperature -1⁰ C and -3⁰ C are 4,5 and 9,7 m / th.y., respectively.

With the tectonic shoves with compensational sedimentation the velocities of PFG growth at the same temperatures at the surface changed from 3,65 m / th.y. up to 23,25 m / th.y. (Table).

In calculated versions with the velocity of compensational sedimentation 1; 2 sm per year the stationary state in the position of phase ζ change was not reached even at the depth 400 m (Table).

In all versions, the velocity of melting from below was less then velocities of formation of frozen block from above. For example, a temperature change at the surface from -3^0 to 1^0 C the velocity was 3,1 m / th.y. (Table).

The results of mathematical modeling show that in nature there is a mechanism of PFG formation that is superior the climate role. This fact should be taken into account in the predictions of cryolithic zones dynamics in palereconstruction of climate, and also in connection with the further global rise in temperature of climate etc.

The sharp change of PFG thickness in the intermontane cavities of the Magadan region at small distances can serve as the good indicator of tectonic activity in Late Quaternary stage (Upper Pleistocene, Holocene).

An indication of separate blocks with the different PFG thickness is the good reason for distinguishing of faults, tectonically active at the same time intervals of Quaternary period.

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