General mechanisms of the formation and development of permafrost

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Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/20358670
Technical Translation (National Research Council of Canada), 1964

PREFACE

This translation is the second arranged by the Permafrost Subcommittee of the Associate Committee on Soil and Snow Mechanics of the National Research Council of the Russian permafrost publication "Principles of Geocryology". The first translation in this group was of Chapter VI entitled "Heat and Moisture Transfer in Freezing and Thawing Soils" by G.A. Martynov (TT-1065).

This translation of Chapter IV by P.F. Shvetsov reviews the various ideas of the origin and nature of permafrost which have been developed since the nineteenth century. Following this review, the current concept of permafrost as a condition arising from a negative heat balance in the ground is discussed. The extent of permafrost and its temperature regime are a reflection of heat exchange between it and the surrounding lithosphere and atmosphere. Because permafrost is very sensitive to thermal changes, even small fluctuations in the heat exchange between it and its environment can result in noticeable changes in its occurrence and character.

The Division of Building Research is grateful to Mr. G. Belkov of the National Research Council's Translations Section for translating this chapter in response to the request of the Permafrost Subcommittee.

Ottawa
February 1964

R.F. Legget
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NATIONAL RESEARCH COUNCIL OF CANADA

Technical Translation 1117

Title: General mechanisms of the formatior and development of permafrost

(Obshchie zakonomernosti vozniknoveniya i razvitiya mnogoletnei kriolitozony)

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Reference: Principles of geocryology (permafrost studies), Part I, General geocryology, Chapter IV. Academy of Sciences of the USSR. Moscow 1959. p.77-107

(Osnovy geokriologii (merzlotovedeniya), Chast' pervaya, Obshchaya geokriologiya, Glava IV. Akademiya Nauk SSSR. Moskva 1959. s.77-107)

Translator: G. Belkov, Translations Section, N.R.C. Library

GENERAL MECHANISMS OF THE FORMATION AND DEVELOPMENT OF PERMAFROST

The most important problem in the study of permafrost is the elucidation and comprehension of the mechanisms involved in the freezing and thawing of the earth's crust, and the formation of frozen layers and strata of the lithosphere. At the basis of particular laws applicable to the study of permafrost is the law of the conservation and transformation of matter and energy. Along with the general and particular laws governing the development of nature there are also empirical and theoretically established mechanisms of variations in depth of freezing, the composition, structure, temperature and thickness of the frozen strata of the earth's surface.

The interrelationship and transfer of heat and mechanical forms of motion become evident in the process of freezing, for example, an active layer of clay soil underlain by a frozen subsoil: the soil cover is deformed - it heaves and cracks. The same is observed in the formation of ice and peat mounds. The thawing of soil that has a high ice content is accompanied by settlement of the soil strata and depressions in the surface of the ground.

Before setting out present-day notions of the conditions and mechanisms of the growth and development of permafrost it would be well to make a brief résumé of the conclusions derived by our predecessors on this subject. A valid evaluation of the role played by these scientists in solving this question can only be made in a historical perspective.

"The concentration of frozen soil is obviously inside the Arctic Circle since the permafrost here is only an expression of constancy and force with which the cold of the atmosphere, regardless of the resistance of the internal heat of the earth, has penetrated the soil", - this is the way the origin and the conditions for the existence of permafrost was explained by A.F. Middendorf (1862, page 467). There is nothing surprising in this if one takes into account the fact that at this time the phlogiston theory was in vogue by which many thermal phenomena were explained incorrectly but simply and graphically. Molecular-thermal motion and the thermodynamic characteristics of the state of physical systems in general and the earth's crust in particular were not generally accepted, although M.V. Lomonosov more than 100 years previously in 1744 maintained that the heat of bodies consists in internal motion. In 1753 he wrote that "the earth's surface heated by the sun and the rays reflected from it act more on the lower strata of the atmosphere than on the middle or upper strata"; "the earth's surface having been heated by the hot summer sun warms up the air lying on it which then expands and displaces the cold middle strata of the atmosphere above the clouds" (1952, Vol. 3, pages 39 and 45).

The approach of G. Vil'd to determining the southern boundary of permafrost in Russia was also based on the concept of a relationship between constant (mean annual) temperature of the air alone. The extremely cold climate and the below-freezing mean annual air temperatures were advanced as the sole reasons for the origin and existence of permafrost in the earth's crust. Not only was the earth's crust below the layer of variable annual temperatures but even the upper layer of soil in its relationship to the atmosphere remained as if inert, passive heat and cold receivers during the development of permafrost and during the ages of its existence. This approach to the study and determination of the distribution of permafrost or frozen strata of the earth's crust, in the light of new data and a scientific approach, turned out to be inconsistent; however, parts of this approach can be found in the work of permafrost scientists even up to the present time.

Scientists came much later and gradually to the establishment of an interrelationship between the temperatures of the air, soil and subsoil and also to the important role of the soil in forming the thermal regime of the atmosphere adjacent to the soil and that of the lithosphere in explaining the origin of permafrost. The first steps in this direction were taken by A.I. Voeikov and L.A. Yachevskii.

The importance of the investigation of the great Russian geophysicist and geographer A.I. Voeikov, the founder of genetic climatology, in the study of permafrost zones is not limited only to the establishment of the role of snow cover and winter inversion in the distribution of air temperature or heat exchange between the earth's crust and the atmosphere and outer space. One can say without exaggeration that A.I. Voeikov worked out the first principles of the concept of heat exchange in the system lithosphere-soil-atmosphere which corresponded fully with the level of the development of physics at the end of the 19th century.

On finishing university A.I. Voeikov in 1865 defended a thesis of the title: "The direct insolation in various regions of the earth's surface". Soon after he posed a very important geophysical problem "Keeping an input-output log of solar heat received by the earth and its atmospheric and aqueous shells" (Voeikov, 1884); this was done at a time when scientific actinometry did not yet exist (Budyko, 1956).

In 1886 A.I. Voeikov, basing his work on what was still a small quantity of geothermal data, formulated the principle of equilibrium thermal state of the earth's crust; if the quantity of heat received by the soil from the sun remains constant over a prolonged period of time or changes very negligibly, the heat loss from the layer of earth with variable temperatures throughout the year reaches an equilibrium with the heat arriving from the sun and from deeper layers of the lithosphere. The index of equilibrium in the thermodynamic interraction of the soil with the lithosphere, atmosphere and outer space is the mean annual temperature of the earth's crust.

"Equilibrium", wrote A.I. Voeikov, "should have been established everywhere on the earth's surface but of course because of the difference in the amount of solar heat received, and because of other conditions when the mean temperature of the surface is high in the warmer countries of the earth, equilibrium set in at approximately +30°C whereas in the coldest countries it was approximately -20°C" (Voeikov, 1952, page 378).

Independent of M.V. Lomonosov who taught in 1753 that "The earth's surface covered by a deep layer of snow transfers less heat to the adjacent atmosphere", A.I. Voeikov established that:

"(1) Snow as a poor conductor of heat protects the soil from cooling all the while the temperature of the air and surface of the snow is below 0°C; (2) this effect is the greater the less the density of the snow; the effect is the least when the snow is saturated with water or is packed and has an icy structure; (3) when the temperature is above 0°C the effect of snow on the temperature of the soil is inverse; (4) snow decreases variation in the temperature of the soil absolutely and relatively; (5) the snow cover helps to retain the heat in the earth's surface protecting it from radiation. Without snow the temperature of the land would be much lower than it is now" (Voeikov, 1889, page 186).

Thus both A.I. Voeikov and M.V. Lomonosov considered the earth in the thermodynamic sense as being a self-developing system which actively participates in the heat exchange with the atmosphere. According to P.I. Koloskov, A.I. Voeikov not only discovered and showed the extensive effect of snow cover on the temperature of the earth but also indicates that the snow cover helps to retain heat in the soil and thus facilitates cooling of the atmosphere lying above the snow (Koloskov, 1952). In criticizing the opinion of Vil'd who considered that the southern boundary of permafrost coincided with the mean annual isotherm of the air at -2°C, A.I. Voeikov suggested that in some regions of Siberia where there is deep snow in the winter the subsoil would not be frozen even if the mean annual temperature of the air were -5°C.

L.A. Yachevskii, a contemporary of Voeikov, also elucidated the role of snow cover in the heat exchange between the soil and the atmosphere. Using the region of Turukhansk as an example he showed that it was impossible to have deep penetration of frost into the ground when there is deep loose snow on the ground even when the mean annual temperature of the air is -7° (Yachevskii, 1889).

In the opinion of Yachevskii the origin, duration and the particular features of permafrost zones - its temperature, depth and extent of discontinuity - are determined not only by climatic but also geological conditions. The geological, geomorphological and hydrological conditions of the heat exchange between the soil and the atmosphere and lithosphere were called local conditions by Yachevskii as contrast to climatic conditions.

A paper published by Voeikov in 1904 "The thermal cycle in the outer shell of the earth's crust" was and continues to be of great importance in explaining the mechanism of the formation and development of permafrost. It can be considered a classical scientific work on the question of heat exchange between the earth's crust and the atmosphere and outer space.

In this paper* A.I. Voeikov develops the principle, advanced by him in 1886, of the equilibrium of the thermal state of the earth's crust which was called the law of equilibrium in temperature distribution in the soil and lithosphere. In spite of the differences between temperature distribution in the earth's crust and in fresh water bodies, they both conform to the law of equilibrium of the thermal states of various strata corresponding to the minimum energy transfer between them as well as the atmosphere and outer space. Here the author refers to the radiation law of Stefan. For land areas the thermal equilibrium law for the soil and lithosphere is expressed, in the opinion of Voeikov, by the principle that the colder the surface of the earth's crust the less heat it radiates or transfers by convection to the atmosphere. The constancy of the temperature in the formations underneath the Paris Observatory throughout a period of 120 years demonstrates the uniformity in solar radiation and physical properties of the atmosphere throughout this period of time.

If subsequently the sun transmits more or less heat than at the present time, the temperature of the earth's crust will begin to increase or decrease until a new equilibrium is established at a higher or lower mean annual temperature of the soil and lithosphere.

* This paper was published in a book comprising a collection of papers on physics and it is possible that for this reason it is not well known to permafrost scientists. In both editions of the monograph by M.I. Sumgin "Permafrost within the boundaries of the USSR" (1927 and 1937), in "General permafrost studies" (1940) and in the monograph by N.V. Tolstikhin "Ground waters in permafrost zones" (1941), no mention is made of this paper by A.I. Voeikov.

In fresh water lakes of medium and high latitudes the equilibrium law is expressed by the principle that temperature changes of the entire water body proceeds more rapidly in the direction approaching 4°C. As a result of this the heat loss from fresh water lakes, particularly after an ice cover has formed, which is possible only after a temperature inversion (i.e. a reduction in temperature going from the bottom upwards), is very small throughout the fall and winter.

The upper stratum of the earth's crust, which receives heat from the sun and air and transmits it to the air by radiation into space or to clouds, was called "the outer active layer" by Voeikov. "The temperature of the outer surface of the earth has a great effect on the temperature of the lower stratum of air; the latter depends mainly on the temperature of the ground or water surface ... Because of this the determination of the temperature of the temperature of the outer active surface is of great importance" (Voeikov, 1952, page 187).

In his time A.I. Voeikov noted that the calculation of the temperature of various strata of the earth's surface with the use of Fourier's heat transfer equations can give precise results only for those places where the soil and underlying strata are uniform, monolithic and without macropores, for example a rock mass. Water plays an important role in heat transfer. It is an important component part of soil and is unevenly distributed throughout the earth's crust and at the same time has a high heat capacity. Evaporation of water and ice in the soil, condensation of water vapour in the soil, melting and freezing, and finally the movement of water in the soil where the water transfers heat directly, all have an important influence on the distribution of temperature in the earth's crust.

The initial point for calculating the temperature of the earth's crust should be taken not at the surface where variation in temperature is rapid and uneven but at some depth, for example 1 m, where there are no rapid changes in temperature.

It is also important to note that A.I. Voeikov, the founder of genetic climatology, did not once mention that the temperature regime of the earth's crust is a "product of climate".

From the pronouncements of A.I. Voeikov in 1886, 1889, 1904 and those of L.A. Yachevskii in 1889 and 1905 it follows that it is just as normal for the temperature at a depth of 25 m in Yakutsk to be -3 to -6°C as it is for the temperature under Moscow to be 5 to 6°C or that under Tbilisi to be 14.5°C at the same depth.

In 1910 B.B. Polynov established from his research data that in some regions of the Amur oblast under the same climatic conditions only peat-covered areas contained permafrost, whereas in other more northern regions peat, clay, clay loam and sand loam were perennially frozen. Thus the reason for the deep penetration of frost in the southern parts of the oblast was the presence of bogs with the growth in depth of the moss cover, whereas on neighbouring areas to the north the same conditions prevailed as well as an additional purely geological condition, that of a clay deposit on the surface of the earth. Subsequently in 1913 N.I. Prokhorov wrote of the rather extensive freezing of the earth's crust in swamp areas and the absence of permafrost in neighbouring comparatively dry areas. Up to the present time after the permafrost investigations in Bureya and in the middle cross-section of the Selemdzha River valley the opinion of B.B. Polynov that the "petrographic conditions" are of prime importance in the formation of "summer frost" on the southern boundary of the permafrost zones turned out to be indisputable.

The engineering, geological and hydrogeological survey along the track of the Amur railroad and investigations of the Tunka depression in the basin of the Irkut River (1907 - 1916) was distinguished by the production of the hypothesis concerning the formation of strata of permafrost during sedimentation in depressions owing to freezing from below rather than from above, i.e. frozen strata were subsequently covered by sediment which in turn froze. The authors of the new hypothesis of a stratum of permafrost growing of its own accord were A. Arsen'ev (1908) an engineer, V. Nekipelov (1908), A.V. L'vov and G. Kropachev (1909) and A.V. L'vov (1916), geologists.

Sometime later S.G. Parkhomenko (1937) isolated freezing from below as one of the characteristic factors in the subarctic type of growth of permafrost strata.

The subsoil along the track of the Amur railway according to the data of V. Nekipelov was perennially frozen only in river valleys and on the plains. From this he concluded that the frozen stratum in such places developed gradually upwards by a process of systematic accumulation of sediment. However, on regions subject to erosion as for example steep slopes "permafrost could not form" (L'vov, 1916). The Tunka depression in the opinion of A.V. L'vov and G. Kropachev is slowly but continuously settling and the layers that freeze through the winter do not have time to thaw during the summer and each year a thin unthawed layer remains which accumulates and forms the entire stratum of permafrost. At the foot of mountains, in shaded areas and in narrow valleys there is no permafrost (L'vov, Kropachev, 1909). If A.V. L'vov had been able to tie in the hypothesis of A. Arsen'ev and V. Nekipelov and his "Tunka hypothesis" with the freezing of the active layer from below (the freezing starting from below before it starts freezing from above during the winter) as established in 1910 by D.V. Domrachev, then the theory of the formation of syngenetic strata of permafrost in low-lying regions and depressions of north and east Russia and also Alaska would have been formulated 40 years ago.

In addition to the above-mentioned reason this hypothesis was underestimated for a long time because it pretended to be universal and because of the sharp criticism directed by M.I. Sumgin. The authors of the hypothesis suggested applying it to explaining the origin of permafrost not only in the Baikal region and in the Amur oblast, but also for all other parts of the world.

All the new concepts introduced into the study of permafrost by A.I. Voeikov, L.A. Yachevskii, B.B. Polynov, A.V. L'vov and others contradicted the conclusions derived by A.F. Middendorf and G. Vil'd on the origin of permafrost. These new concepts made it possible to formulate the hypothesis concerning the unavoidable generation and prolonged existence of permafrost on extensive areas and individual localities on the earth's surface because of changes in the physical-geographical and geological conditions of heat exchange between the soil and lithosphere on the one hand, and atmosphere and outer space on the other. However many of the achievements of these authors were not subsequently analyzed thoroughly and evaluated and some of them did not withstand strict criticism and were long forgotten by permafrost scientists.

In the first edition (1927) of the monograph by M.I. Sumgin the question of the origin of permafrost was reduced to the time of the origin of permafrost. In agreeing with E.V. Toll' and K.A. Vollosovich that the thickest and most extensive deposits of ground ice in Northern Siberia are the remains of the ice age, M.I. Sumgin considered permafrost as a survival from a distant cold epoch which brought about the ice age*.

The attempts by V.B. Shostakovich, A.V. L'vov and others to explain the presence of permafrost by present-day climatic conditions and geological processes were met with sharp criticism. Even the fact that the upper layer that thaws seasonally could freeze from below as established by D.V. Domrachev who pointed out the possibility of permafrost forming of its own accord in the present epoch, was largely disregarded by Sumgin although he discovered this effect himself as a result of his observations in Bomnak (Sumgin, 1927, page 173-175). The freezing of soil from below seemed to him only theoretically possible. M.I. Sumgin figured that permafrost was at the present time in a stage of degradation.

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* A similar point of view for the origin of permafrost was advance in 1881 by A. Denk and hotly defended by E. Toll'.

In the second edition of his monograph published in 1937 Sumgin admits that at the present time it is possible to have the formation of permafrost in those regions of northern Eurasia where it did not exist before. His attention was drawn to this by the new data of deep frost penetration of a recently formed island in the delta of the Pechora River and on the notation by Grigor'ev on the inadmissibility of mixing the question of the origin of permafrost with the question of the conditions under which it can be formed and exist to-day. It might be mentioned here that the polemic of Sumgin with Shostakovich who considered permafrost to be the product of present-day climatic conditions arose because they mixed these two questions.

In analyzing the hypothesis of Arsenev, Nekipelov, L'vov and Kropachev, Sumgin no longer criticizes them as severely as he did in 1927. He writes "First of all it should be remembered that the fundamental reason for the formation of frozen strata in the ground is a deficiency in the heat balance that keeps the temperature below freezing in the given strata of ground; this applies equally to seasonal frost as well as to permafrost, the difference is only in time. And for a given deficiency in the heat balance there will be a given deficiency in the heat balance there will be a given thickness in the stratum of frozen soil. In the heat balance of a given stratum of soil the internal heat of the earth participates as a positive component" (Sumgin, 1937, page 243).

The temperature regime of permafrost, the mechanism of the change in temperature along the vertical cross-section of the earth's crust and particularly degradation of permafrost, M.I. Sumgin as before considered to be in direct relationship with variations in climatic conditions, to the moderation of the climate during the latter epoch of the anthropogenic period. He considered that in regions where there is degradation of permafrost present-day climatic conditions "are in disharmony with the distribution of temperatures in the soil with depth" (Sumgin, 1937, page 251). The zone of frozen subsoil was considered as before the product of a cold climate in the distant ice age and the chief indication of changes in its regime is the degradation of permafrost under the effect of a warmer climate.

The thorough investigations of V.A. Kudryavtsev of the highly discontinuous permafrost zone in the middle reaches of the Selemdzha River in which geological, geomorphological, hydrogeological, hydrological and geobotanical conditions were taken into account in considering the existence and mechanism of the propagation of strata and masses of frozen subsoils, led to the conclusion of undoubted signs of "intensification of permafrost" along with its degradation in the same general locality. This locality is in the southern boundary of the permafrost zone where the climatic conditions are uniform;

even temperature inversions in the strata of air adjacent to the earth in shallow depressions with gentle slopes cannot be attributed to any particular significance in the formation of the difference in temperature regime of the subsoil of negative and positive forms of relief (Kudryavtsev, 1939).

Having repeated much of what was said earlier by Voeikov (1886, 1889, 1904), Yachevskii (1889), Obruchev (1891), Koz'min (1892), Polynov (1910) and others concerning the role of local physico-geographical and geological conditions in the formation of the temperature regime of the earth's crust and, in particular, in the development of permafrost, Kudryavtsev concluded that there was "dynamics in permafrost" in connection with changes in geobotanic, hydrological, geological and hydrogeological conditions. The consistent and simultaneous manifestation of..."two completely contradictory processes (formation and degradation of permafrost. - P. Shumskii) do not in any way contradict each other but are completely consistent and are explained by hydrogeological and hydromorphological conditions of the region resulting in sharp deviations from general degradation of permafrost" (Kudryavtsev, 1939, page 116).

Although the concepts of "contemporary process" and "contemporary dynamics" are inconsistent with the concept of "permafrost" as an inheritance from the ice age, many permafrost scientists did not seem to notice it at that time. In general such a phenomenon has been observed many times in the history of science. C. Lyle for many years did not notice the inconsistency of his theory with the assumption of constancy of organic species. According to his original hypothesis the earth did not develop gradually in a specific direction, it did not cool but simply changed in a random manner.

A year after Kudryavtsev published his paper, V.G. Tumel', in considering the relationship between permafrost and the cold climate of the ice age and present-day climatic conditions, formulated a very important hypothesis. It can be reduced to the statement that "the problem of permafrost cannot be solved only from considerations of palaeoclimatic investigations" (Sumgin and others, 1940, page 224). In considering the mechanisms of the change in temperature regime of the soil "one should study first of all the soil itself. One can for example maintain that deposits from post-glacial lakes or sea transgression, if they are frozen, froze after the ice age and even after water had departed from the given area..." (ibid.).

In subsequent sections of this chapter we will attempt to adhere to this hypothesis of V.F. Tumel' but we will begin with the consideration of the temperature regime of the soil, i.e. the outermost layer of the earth's crust which covers everything else, "for it is also part of the lower strata and by being adjacent to them receives from them and gives up to them reciprocally..." (Lomonosov, 1949, page 18).

The Origin of Permafrost in the Process of Heat Exchange Between the Soil, Atmosphere and Lithosphere*

In the opinion of Prof. L.A. Yachevskii the existence of "permafrost" is decisive proof of the predominance of radiation over insolation, the predominance of the loss of heat over the heat received. "Permafrost will continue to exist in the latitudes where it is now found at the present time as long as the conditions of rotation of the earth, its position with respect to the sun and as long as the sun continues to live the life it is living at the present time are retained", is the way Yachevskii (1905, page 226) defined the general objective mechanisms of the existence of permafrost.

Although in itself this idea of Yachevskii is not precise since there is no well-defined connection between the existence of frozen subsoil and the predominance of radiation, nevertheless the extensive astro-geophysical approach of this investigator to the elucidation of objective laws governing the origin and existence of permafrost deserves close attention. In fact it would be impossible to understand correctly the heat exchange in the system lithosphere-soil-atmosphere without looking upon the earth as a cosmic body. Looking upon the earth in this manner we see that the surface is irradiated by the sun and other stars. Because of the spherical shape of our planet, its continuous rotation and its motion about the sun as well as the inclination of its axis of rotation to the plane of the ecliptic (at the present time it is at the angle of 66°33'), the angle of incidence of solar rays on the earth's surface varies continuously in space and time. On land this angle depends also on the angle and orientation of the slope of the surface.

A given portion of the surface of the land or ocean is irradiated by the sun for only a specific period of time, divided by periods of various duration during which there is no advent of solar radiation. Radiation from the earth's crust into the atmosphere and to outer space takes place at all times but the density of the radiation flux from the earth, as well as the intensity of insolation of the soil, varies periodically. Outer space in relationship to the earth's crust is a heat receiver of infinite capacity.

The density of the radiation flux and the total amount of radiation energy from the sun to a unit of surface area in various parts of the land and ocean is a function of the geographic latitude, composition and physical properties of the atmosphere. This is what produces differences in climate by

* Heat exchange in the system lithosphere-soil-atmosphere is the name we give to the sum total of all physical processes of the conversion of one form of energy to another and energy exchange between the lithosphere, soil, atmosphere and outer space.

latitude*, soil, vegetation and also the conditions of heat exchange in the system lithosphere-soil-atmosphere.

The periodic nature of insolation and the natural radiation of the soil results in periodic - daily and yearly - variations or, as it is said, oscillations in the temperature of the soil**. These temperature variations of the surface strata of soil are transmitted to deeper soil strata and to the subsoil. For a quantitative mathematical description of this process Russian geophysicists even in the last quarter of the 19th century used the method of harmonic analysis of "the temperature wave" in the soil and subsoil.

The temperature of the surface of the soil during its periodic variation is a harmonic function of time, i.e.

$$t = A_0 \sin (\omega\tau + \varphi), \qquad (4.1)^{***}$$

where A_0 is the oscillation amplitude of temperature on the surface;

$\omega = \frac{2\pi}{\tau}$ is the angular frequency of oscillation;

τ is time for which the temperature is determined;

φ is the initial phase of the oscillation.

Assuming that the coefficient of thermal conductivity of the soil and subsoil a is constant with depth, the amplitude of temperature oscillation A at a given depth z is

$$A_z = A_0 e^{-z\sqrt{\frac{\pi}{aT}}}, \qquad (4.2)$$

where T is the period of the temperature wave.

This relationship is obtained from the previous formula (4.1) by solving the thermoconductivity equation

$$\frac{\partial t}{\partial \tau} = a \frac{\partial^2 t}{\partial z^2}.$$

From equation (4.2) it follows that:

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* Climate is defined as the weather regime taken over many years and characteristic of a given locality by virtue of its geographic location. By regime is meant the total and successive variation of weather conditions (S.P. Khromov and L.I. Mamontov. Meteorologicheskii slovar'. Gidrometeoizdat. Leningrad, 1955).

** Daily variaitions in the temperature of the soil are scarcely noticeable in the polar regions in winter and in summer when for a period of several months there is continuous night or continuous day.

*** In numbering the formulae the first cipher denotes the number of the chapter and the second the number of the formula.

(1) the time lag for the maximum or minimum temperature at the depth z by comparison with the time of their occurrence on the surface of the soil, $\tau = \frac{z}{2}\sqrt{\frac{T}{\pi a}}$, i.e. the lag increases with depth;
(2) the oscillation period of soil temperature $T = \frac{2\pi}{\omega}$ does not change with depth;
(3) the amplitude of temperature oscillation decreases with depth according to the exponential law: if the depth increases in arithmetic progression, the decrease in amplitude is in geometric progression;
(4) depth at which vibrations of various periodicity decrease by the same factor are related as square roots of the periods, i.e.

$$\frac{z_2}{z_1} = \frac{\sqrt{T_2}}{\sqrt{T_1}}.$$

If T_2 is equal to a year and T_1 is equal to a day then

$$\frac{z_2}{z_1} = \frac{\sqrt{365}}{\sqrt{1}} \cong \frac{19}{1} \text{ or } z_2 \cong 192\ z_1.$$

Field observations show that the daily variation in temperature of the soil is almost attenuated at a depth that rarely exceeds 1.5 m whereas the annual depth is 30 m.

The daily and annual temperature variations of the layer of atmosphere adjacent to the earth reflect temperature variations of the earth's surface for the corresponding period of time. The variations in air temperature throughout the year are fixed throughout the troposphere.

The first thorough observations of Sumgin on variations in temperature of the soil and subsoil in the southern boundary of the permafrost in Bomnak (1916 - 1919) showed that annual variations are almost completely attenuated at a depth of 6 - 8 m. The rather small thickness of this stratum of annual temperature variation was explained by the effect of a "zero curtain" - of the isothermal processes of thawing during the summer of the soils and subsoils containing ice and freezing of the supersaturated stratum (that thaws seasonally) during the fall and early winter. From this he showed how far removed from reality were the predictions of the temperature regime of the earth's crust made by G. Vil'd on the basis of calculating the dependence of the temperature regime on air temperature and by analogy with the geothermal data obtained from the shores of the Baltic Sea.

The method of analyzing the temperature wave although it has great theoretical and practical importance, does not nevertheless of itself elucidate the mechanism of changes in the temperature regime of the soil and lithosphere for a period of time greater than a day or year, respectively.

In order to elucidate such mechanisms one should recall an assumption made in deriving the relationship (4.1) and one practical result following from equation (4.2). The point is that the variations in temperature of the soil and the subsoil are rarely completely harmonic or purely sinusoidal as noted by Voeikov (1894) and as stated by A.F. Chudnovskii (1948). During prolonged sections of an annual period the positive and negative deviations of temperature from those fixed in the preceding day of its equilibrium value, i.e. "the physical amplitudes" of the temperature oscillations are not equal, or in other words they are not equal to half the meteorological amplitude ($\frac{A}{2}$). As the result of this there is a displacement, with some deviation but generally in one direction, of the "axis of daily oscillations in temperature" or a variation in the mean daily temperature of the soil throughout the annual half periods.

It is customary to say that the daily and annual variations in temperature of the earth's crust "are practically attenuated" at appropriate depths, for example 1.5 and 28.5 m. In fact the daily variations in temperature theoretically and practically are not attenuated at the depth of 1.5 m. One of the curves of extreme values of the temperature of the soil, depending on the time of the year and variation in weather conditions, on approaching asymptotically the oscillation axis for the previous day at the depth of 1.2 m usually does not coincide with it not only at the depth of 1.5 m but even at a much greater depth on the surface. However, the curve of opposite values does intersect its axis. Thus during the course of the year the axis of daily variations in temperature of the soil shifts, stopping only for periods of time, which results in a variation in temperature at a depth of 1.5 m throughout the year by 5 - 10°C and in places even more. Engineers know how important this phenomenon is.

The same can be said concerning the annual variation in temperature of the earth's crust deeper than 25 - 30 m for the temperature regime of the lithosphere over a long period of time. The absence of necessary devices for determining the year-to-year changes in temperature of the subsoil at depths of 25 - 30 m and in some localities at 10 - 15 m makes it difficult but does not exclude taking into account the continuous shift in the axis of the annual variation in temperature. This process is connected with variations in the external conditions of heat exchange between the lithosphere and the soil which fundamentally changes the geothermal conditions for a historic-geological portion of time. In analyzing the data of geothermal observations in drill holes L.A. Yachevskii in 1905 came to the correct conclusion that such a stratum of the earth's crust in which variations in surface temperature are not reflected has not yet been found.

In addition to the cosmic and general planetary geophysical processes in the atmosphere and hydrosphere and also physico-geographical conditions one must also consider the continuous supply of heat coming from the earth's interior and its effect on the heat exchange between the soil, atmosphere and the lithosphere.*

The continuity in heat exchange between the soil and atmosphere and the lithosphere indicates a continuous difference in temperature between the surface of the earth and the adjacent stratum of air on the one hand** and on the other hand at considerable distances along the vertical in the earth's crust. In the lithosphere below the upper stratum with its variable annual temperature there is a relatively constant geothermal gradient brought about by the flow of heat from the centre of the earth along the vertical axis to the surface. The temperature gradient (vector) directed downwards towards the centre of the earth and indicating an upward thermal flux we will call, by convention, negative, and the temperature gradient in the opposite direction indicating a downward flux we will call a positive temperature gradient.

At a depth of 6000 m as indicated by geothermal observations in a hole drilled 40 km from the town of Farson in the State of Wyoming (in the Rocky Mountains at a latitude of 42°06'N and a longitude of 109°25'W with an absolute altitude of about 2000 m), the temperature of the rock is 149°C.

However the temperature gradient is negative not only within the range of the lithosphere; it is also negative in the lower stratum of the atmosphere from 7 - 12 km in height in moderate latitudes. In the troposphere, as is known, the mean annual temperature of the air decreases with altitude.

Knowing the temperature of the air in the tropopause (Kondrat'ev, 1952), the surface of the earth (mean annual temperature) and that of rock at a depth of 6000 m, we can construct a curve determining the direction and magnitude of the vertical temperature gradient (see Fig. 2, where the temperature axis corresponds with the surface of the soil). As this curve shows, the temperature gradient in all strata of the earth's crust and in the troposphere is negative and the absolute value in the earth's crust is greater than in the troposphere.

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* Here and below only the land surface is considered which is connected with the ocean in heat exchange by advective transfer of heat and moisture.

** In the opinion of A.I. Voeikov (1904) the mean annual temperature of the soil is higher than the mean annual temperature of the air over the continents in the medium and high latitudes by 4°, in tropical mountain regions by 2° and along the coasts in medium and high latitudes by less than 1°. In general this order is confirmed.

Similar curves are obtained also for other regions of the land mass. Thus the upper strata of the earth's crust act as the heat donors in the process of heat exchange with the troposphere.

In addition to the vertical or geothermal temperature gradients there are in the earth's crust horizontal temperature gradients and not only along meridians. The existence of horizontal temperature gradients along the meridian are caused by the variation in the amount of solar radiation reaching the soil with latitude and also non-zonal differences in the physico-geographical conditions of heat exchange between the soil and the atmosphere. Particularly large horizontal temperature gradients occur in the subsoil between one type of relief and another which has a different orientation and a greater or lesser slope or moisture content. The same thing occurs when one goes from land to the sea or lakes and also towards large rivers.

The presence of large horizontal and inclined temperature gradients in the subsoil where there is a runoff of surface and ground water and the adjacent slopes of the ravines of the Selemdzha river basin was established by V.A. Kudryavtsev (1939). Here the horizontal and inclined flows of heat are directed from the slopes towards the runoff zone. Later D.V. Redozubov established the existence of even greater horizontal and inclined temperature gradients in the subsoil in the region of Vorkuta where the thermal flux is directed in a different manner, from the runoff zone to the elevated regions (Redozubov, 1946). In these small regions of the land mass the temperature curves in the subsoil measured in vertical excavations are very different; some of them are "in harmony with present-day climate", others have no gradient whereas still others represent degradation of "permafrost".

Particularly large horizontal and inclined temperature gradients and corresponding heat flux in the subsoil are observed near deep lakes and rivers of the north. This is shown by the diagram of the distribution of temperatures in the subsoil near Lake Glubokoe in the Ust'-Yana raion (Fig. 3) which was constructed by the authors of the report describing the Yano-Indigirka expedition of the V.A. Obruchev Permafrost Institute (N.F. Grigor'ev and others, 1956). The effect of this lake on the thermal state of the shores is felt at a distance of more than 100 m from the lake. Such is the effect of deep lakes or rivers on the temperature regime of the shores. This explains the considerable decrease in the thickness of the permafrost stratum as one approaches the bed of the Mackenzie River at Norman Wells: from 81 m at 106 m from the shore to 41 m at 60 m and 18 m at 30 m from it (Jenness, 1949).

In the small alluvial deposits between lakes in the northern plains, the horizontal and inclined heat flux from lakes and the unfrozen deposits under the lakes play an important role in forming the thermal field and heat exchange between the earth's crust and atmosphere. In these regions the lakes in the winter time act as heat donors to the atmosphere and all year round they give up heat to the surrounding permafrost.

The horizontal temperature gradient in the soil results mainly from various geological and physico-geographical, including geomorphological, and climatic conditions of heat exchange in the systems subsoil-soil-atmosphere and the earth's crust-liquid cover-atmosphere. The presence of horizontal temperature gradients in the soil and in the lithosphere shows that in the solid shell of the earth, as well as in the liquid and gaseous envelopes, there are horizontal thermal fluxes. Of course in the solid shell this process is immeasurably slower than in the liquid or gaseous envelopes, since the coefficient of convective heat transfer (mixing coefficient of water and air) reaches very high values even with relatively small differences in temperatures of these envelopes in various parts of the planet. Equilibration of temperature in the gaseous and liquid envelopes is reached rather quickly by means of air and sea currents. The role of sea currents is particularly important in equilibrating the temperatures between low and high latitudes.

If there were no atmospheric and oceanic advection the temperature gradients horizontal to the latitudes in the soil and lithosphere would be much greater than they are. They would, like the values of temperature in the soil and subsoil, correspond to "solar climate". Local horizontal temperature gradients are particularly large near the boundary between a river and a permafrost zone and between frozen and water-bearing strata. Large horizontal and vertical temperature gradients are found in the frozen and unfrozen substrata near geochemically active ore bodies, which by exothermic reactions evolve large quantities of heat. Present-day considerations concerning the basic mechanisms of the development and propagation of permafrost over large areas of the earth's surface follow from the work of M.V. Lomonosov and A.I. Voeikov and are expressed as follows.

1. Permafrost originates, develops and disappears as a result of heat exchange between the earth and the sun, the earth and interplanetary space, the earth's crust and the atmosphere, the layer of air adjacent to the earth's surface, the soil and deeper strata of the earth's crust. The heat exchange between the lithosphere and the atmosphere, the lithosphere, hydrosphere and atmosphere are processes that are properties of the physico-geographical envelope of the earth whose qualitative and quantitative aspects are determined by the law of conservation and conversion of energy.

The basic source of heat that the soil receives and then gives up to the atmosphere and outer space is radiation energy from the sun. The heat flow from the inner reaches of the earth is a thousand times less than the flow of radiation energy from the sun.

2. Permafrost is a regional phenomenon connected with the existence of particular latitudinal geographical zones and longitudinal belts such as for example climate, soil and vegetation of the tundra. Non-zonal permafrost in the subsoil exists only in a few localities and is caused by particular geographical conditions in the heat exchange of the system earth's crust-soil-atmosphere as well as geochemical effects.

Seasonal and perennial freezing of the earth's crust are determined not only by the reserves and flux of external heat sources and external heat losses observed above the "underlying surface" or on the "underlying surface" itself but also by reserves and flux of the interior heat of the earth*.

The question arises: What are the particular features of heat exchange in the system lithosphere-soil-atmosphere which produce extensive freezing of the earth's crust where the subsoil remains frozen for long periods of time in specific latitudes and longitudinal belts, and why these phenomena are absent (as zonal phenomena) for example in the medium latitudes of the European part of the USSR?

For the time being this question can only be answered in general terms: The particular features of heat exchange in the system lithosphere-soil-atmosphere, which result in deep freezing of the earth's crust and perennial existence of frozen subsoil, are that the heat cycle in the soil and subsoil begins to have a below-freezing mean annual temperature or below-freezing geothermal level which then continues for a prolonged period of time.

As far back as 1904 A.I. Voeikov wrote that permafrost should occur where the mean annual temperature of the soil is below 0° and at a depth where the amplitude of temperature variation is greater than the absolute value of the mean annual below-freezing temperature by the factor of two (Voeikov, 1952).

The geothermal level in heat exchange or of annual thermal cycles in the earth's crust is a characteristic of the mobile equilibrium in the thermodynamics of the interaction between the soil, the atmosphere and the subsoil, expressed by the temperature of the subsoil at the interface with the stratum having an annual variation in temperature. The geothermal level does not coincide as a rule with the mean annual temperature of the soil; the latter is usually lower than the temperature of the subsoil at a depth of 25 - 30 m. As shown by the data of geothermal measurements in Igarka, Yakutsk and in Zagorsk in the vicinity of Moscow the mean annual temperature of the soil and subsoil

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* The concept of "interior heat of the earth" is more extensive than the concept of "subterranean heat of the earth": here we are dealing with reserves of heat and heat flux in the strata underlying the frozen layer.

under ordinary conditions increases with depth starting from the very surface of the soil.

In any case a mean annual temperature of the soil at a depth of 0.1 - 1.5 m definitely determines whether or not there will be permafrost. Thus the location of the geothermal level of heat exchange between the soil and atmosphere at various depths are expressed approximately by the curve formed by the axis of temperature variations of the soil and the underlying subsoil during the period of a year. As mentioned above, the axis of temperature variations on the graph of annual changes in temperature of the earth's crust usually deviates from the vertical to the left although it is close to the vertical: the slope indicates the existence of a geothermal gradient and is proportional to it.

The basic different geothermal levels of heat exchange between the soil and atmosphere and resultant freezing of the soil is shown in Fig. 4.

The signs and numerical values of the zonal geothermic levels of heat exchange are determined basically by the quantity of heat entering the soil from above, from the sun and from the atmosphere, but depend to some extent also on the quantity of heat flux coming from the interior of the earth or from the geochemical effects in the soil and lithosphere.

As regards the non-zonal geothermal levels of heat exchange between the earth's crust and the atmosphere, their signs and numerical values depend on the particular features of local physical-geographical and geological conditions, including the percolation and circulation of ground water, geochemical processes in the lithosphere, for example oxidation of sulphides, and other exothermic and endothermic reactions. Particularly evident non-zonal features can be observed for example in the geothermal levels of the El'gi depression in the Kolyma river basin and the Markovo depression in the Anadyr' river basin.

Since the thermodynamic equilibrium in the system atmosphere-soil-lithosphere is mobile and short-lived, the geothermal levels of heat exchange between the soil and lithosphere vary in magnitude and direction. They cannot be constant if each year the amount of heat entering the soil and leaving it varies.

The direction and intensity in the change of the geothermal level of heat exchange over a number of years depends on the sign and absolute value of the total input and output components of the thermal balance of the soil or, more precisely, the bottom of the stratum in which the annual temperature varies. Twenty years ago M.I. Sumgin wrote of this in discussing the reasons for the formation of strata of frozen soil, in the second edition of his monograph (Sumgin, 1937, page 243).

One should take into account the reciprocal influence of geothermal levels resulting from particular geological, hydrogeological, hydrological and geochemical conditions, on the heat exchange between the soil and the atmosphere at a given latitudinal region and longitudinal belt. This can help to explain the particular features of the temperature regime of the air adjacent to the earth of some limited sections of land which is not connected with the general circulation of the atmosphere or the meso-relief.

The continuous changes in the temperature of the soil and subsoils have an effect on the daily, annual and more prolonged changes in the quantity of heat entering the soil and leaving it, the continuous shift in the latitudinal and longitudinal climatic zones, the development of landscapes, as well as the progress of complex biological, biochemical, geochemical and tectonic phenomena in the earth's crust.

The existence of permafrost at a given portion of land is the result of relatively stable below-freezing geothermal level of heat exchange in the system atmosphere-soil-upper stratum of the earth's crust over a period of many annual cycles.

The Process and Conditions of Heat Exchange Between the Soil and the Atmosphere and the Lithosphere and the Soil

Speaking of the geothermal levels of heat exchange between the soil and the atmosphere and between the soil and underlying strata of the earth's crust and of the origin of seasonal and perennially frozen zones, one should not confuse geophysical processes of heat exchange, heat cycle in the soil and lithosphere with geographical and geological factors or conditions. Physico-geographical and geological conditions define only the course and results of geophysical processes of heat exchange between the soil and atmosphere over some specific period of time. This was well understood by A.I. Voeikov and particularly convincingly demonstrated by S.P. Khromov (1951, 1952).

The fundamental natural geophysical processes and heat exchange in the system lithosphere-soil-atmosphere which determine the temperature regime of the soil and subsoils are the following:

(1) the incidence of direct and scattered short-wave radiation on the surface of the soil, the reflection and absorption of solar rays by the soil and the long-wave radiation by the soil itself, which constitute a single process of "radiation heat exchange" of the earth's crust with the atmosphere and outer space;

(2) convective (turbulent) heat exchange in the system soil-stratum of air adjacent to the soil, caused by the difference in temperature between the upper thin layer of soil and the stratum of air adjacent to the soil which are

in turn caused by solar radiation, radiation coming from the earth's crust and atmospheric advection and also by the circulation of air masses in cracks and other openings in the upper strata of the earth's crust;

(3) heat exchange between the soil and the atmosphere and lithosphere and between the component parts of the earth's crust (strata, massifs), connected with moisture exchange in these systems;

(4) heat exchange between the soil and lithosphere and between the component parts of the earth's crust (strata, massifs) connected with changes in the state of the water above the soil, in the soil and in the subsoil;

(5) rising and horizontal flow of heat in the earth's crust caused by geothermal and horizontal temperature gradients and connected with the flow of water in the lithosphere.

These geophysical processes of heat exchange in the system atmosphere-soil-lithosphere interact closely and develop reciprocally. Included is a very important cosmic process of irradiation of the earth's surface by solar radiation. This phenomenon provides a thermal connection between the sun and the earth because of which all the fundamental geophysical, biological, geochemical processes in the atmosphere, hydrosphere, soil and in the eroded crust of the lithosphere have taken place and continue to take place.

The intensity in development and the results of heat exchange in the system lithosphere-soil-atmosphere depend, understandably, on the heat and moisture exchange in the system ocean-atmosphere and also between lakes and rivers and the layer of air adjacent to the earth. The horizontal circulation of the atmosphere caused by the great difference in the heat cycle in the upper strata of the land and sea surfaces (by the factor of 3 - 4; see Krylov, 1952, pp.18 and 19) and for other reasons brings about a redistribution of heat and moisture between continents and oceans and between seas and individual land portions. All of this is taken into account in listing the physico-geographical conditions of heat exchange between the soil and the atmosphere.

Of the physico-geographical and geological conditions for the development of permafrost which determine its composition, structure, space distribution, temperature and thickness one can list:

(1) the geographical latitude;

(2) the heights above sea level (and relative heights);

(3) the origin, composition, structure, properties and process of circulation of air and water masses (the area occupied by land and the distribution of land portions with respect to the sea, the effect of sea breezes on the temperature and the moisture content of the air);

(4) the relief (and the position of the given portion of land with respect to basic elements such as macro- and meso-relief, slope and orientation of the slope of its surface, etc.);

(5) vegetation cover;

(6) snow cover (depth and density of the snow cover, the time of the year when snow cover appears and when it disappears);

(7) cloud cover;

(8) surface waters - rivers, lakes and swamps (the influence of lake and river water masses on the temperature of the air and that of floods on the temperature of the subsoil of temporarily flooded regions and belts along river valleys);

(9) the composition and structure, in particular the water penetrability and air penetrability of soil and subsoils;

(10) the moisture content of the surface and lower strata of soil and subsoils;

(11) ground waters (their hydraulic, temperature and chemical regimes).

The specific conditions of heat exchange between the earth's crust and the atmosphere occurring in regions of the land surface covered by large ice fields, valley glaciers and giant taryns (temporary ice fields). Under the ice cover temperature fields are formed in the earth's crust which are different from that of the lithosphere in neighbouring regions adjacent to the ice fields.

As we see the conditions for heat exchange between the earth's crust and the atmosphere and outer space is multifold and complex. The changes in these conditions of heat exchange between the earth's crust and the atmosphere with latitude, longitude and vertically are as a rule different in the direction and intensity of their influence on the temperature regime of the soil and lithosphere brought about by the mechanisms of unequal origin.

There are particularly sharp changes not connected with changes in geographical coordinates in the area of geological, orographical, hydrographical and hydrogeological conditions of the formation of permafrost. Of course the significance of local geomorphological mechanisms in changes in the depth and density of snow cover, radiation density reaching the earth's surface from the sun and other important conditions in the formation of the temperature field of the lithosphere are known. The above listed physico-geographical and geological conditions of heat exchange are changing at an increasing rate under the influence of industrial production. During industrial production people consciously or unconsciously change the direction of development and the geothermal level of heat exchange between the soil and atmosphere and as a result change the local climate.

It is known that such important indices of climatic conditions as temperature and moisture content of the stratum of air adjacent to the ground are determined primarily by the temperature and moisture content of the upper stratum of soil. In this connection one cannot consider correct the expression "permafrost is a product of climate". It is incorrect from the point of view of permafrost scientists as well as from the point of view of meteorologists and climatologists (Voeikov, 1886, 1889_2, 1904; Khromov, 1951, 1952). Climate is the weather regime over a period of years characteristic of a given place by virtue of its geographic position and brought about by solar radiation, by the nature of the underlying surface, variations in its physical properties and resulting circulation of the atmosphere (Alisov et al. 1952; Khromov and Mamontova, 1955).

Of course climate, in reflecting the progress and results of heat exchange and moisture exchange of the soil, rivers and stream, lakes, seas and oceans with the atmosphere and outer space, has a direct influence on the development and results of heat exchange between the above-mentioned systems. Cloud cover, wind velocity, the absolute values and differences in the temperature of the soil and the atmospheric layer adjacent to it and other climatic conditions, to a considerable extent, determine the sign and absolute value of the geothermal level of heat exchange between the earth's crust and the atmosphere. But nevertheless the climatic conditions as well as the time of the year the snow cover appears, its depth and density and duration do not reflect the mechanisms of such phenomenon, as for example the deep penetration of frost into the earth's crust and the existence of permafrost at the bottom of the Sredne-Burein or the Selemdzha depressions. The supersaturation of the clay subsoil and soil, the bog formation over these low, almost flat, portions of land because of the unfavourable conditions of runoff and filtration of the surface water predetermined the unavoidable formation of permafrost; in neighbouring regions under essentially the same climatic conditions but different geomorphological and geological conditions there is no permafrost.

By changing the surface and soil strata one can within a relatively limited scope change the temperature level of heat exchange between the earth's crust and the atmosphere and in this way change the local climate. Here one should take into account the opposite effect of snow cover on the temperature of the air and soil during the winter which follows from the above-mentioned arguments of M.V. Lomonosov and also that of A.I. Voeikov (1889_2). P.A. Shumskii and P.I. Koloskov, following A.I. Voeikov, noted that snow, in decreasing the intensity of heat exchange in the system soil-atmosphere adjacent to the earth and having the property of reflecting the sun's rays (a large albedo), results in cooling of the stratum of air adjacent to the snow (Koloskov, 1952; Shumskii, 1955).

The factors noted by the above-mentioned investigators indicate that the soil is simultaneously a cover over the earth's crust which is thermodynamically directly connected with the lithosphere and an intermediary in the heat exchange between the subsoil and the atmosphere and outer space.

Just as the atmosphere adjacent to the earth is not indifferent to the thermal state of the soil so the soil reacts to changes in the temperature of the air adjacent to it.

An understanding of the fundamental geophysical processes and conditions of heat exchange in the system lithosphere-soil-atmosphere can help in a correct understanding of a quantitative expression and estimation of the value of cooling-freezing and heating-thawing of the soil and subsoil. In this way geophysicists arrived at an equation for the heat balance of the "underlying surface" of the soil with vegetation cover which is a particular and somewhat conventional analytical expression of the law of conservation and transformation of energy.

Up to the present time actinometry has achieved great success. It has helped to solve very important climatological problems and has given rise to climatology of heat balance - a new branch of geographico-geophysics. The main credit for establishing the climatology of heat balance should go to the head of the A.I. Voeikov Geophysical Observatory.

Knowledge of the thermobalance of the "underlying surface" makes it possible for climatologists and physico-geographers in general to explain the mechanism of the temperature regime and circulation of the atmosphere as well as the development of the physico-geographical envelope (A.A. Grigor'ev, 1951, 1954 and 1956$_1$; Budyko, 1956). Permafrost scientists are interested mainly in the heat balance of the soil which reflects the progress and results of all processes of heat and matter transfer in the atmosphere.

In defining the concept of "radiation balance" and "heat balance of the underlying surface", as well as their analytical expressions, there is as yet no precise agreement among meteorologists, climatologists and specialists in the physics of heat exchange in the soil. Representatives of the Main Geophysical Observatory, the authors of the most exhaustive surveys of these problems (M.I. Budyko, T.G. Berlyand, L.I. Zubenok, K.Ya. Kondrat'ev, S.A. Sapozhnikova and others), define the radiation balance of the underlying surface R as the difference between the total absorption of solar radiation by the upper stratum of soil and vegetation and the net radiation of this "active layer":

$$R = (Q + q)(1 - \alpha) - I, \qquad (4.3)$$

where Q is the total flux of direct radiation; q is the total flux of scattered radiation; α is the albedo; I is the net radiation (the difference between the total flux of radiation from the "active layer" and the counter radiation from the atmosphere).

In other words, the value of R is the sum of the heat radiation flux at the level of the earth's surface (Budyko, 1956, page 9). It is equated to the sum of terms of the heat balance of the underlying surface

$$LE + P + A,$$

where LE is the total consumption of heat on the evaporation of water or the difference in the total consumption of heat on the evaporation from the surface of the soil and vegetation and the addition of heat from the condensation of vapour on the surface (L is the latent heat of evaporation or condensation and E is evaporation or the difference between evaporation and condensation);

P is the total convective (turbulent) flux of heat between the soil and the atmosphere;

A is the total flux of heat between the underlying surface and strata of soil and subsoils.

Assuming that A = 0 for the mean annual period averaged over many years, the equation for heat balance of the underlying surface

$$R = LE + P + A \tag{4.4}$$

can be reduced to the expression

$$R = LE + P. \tag{4.5}$$

Thus in the opinion of M.I. Budyko the radiation balance is equal to the heat balance

$$R = (Q + q)(1 - \alpha) - I = LE + P. \tag{4.6}$$

On the basis of the physical meaning of equation (4.6) one can conclude that the evaporation of moisture from the soil and from its surface and the convective heat transfer to the atmosphere exhausts all physical phenomenon of heat exchange between the earth's crust and the atmosphere.

This schematic representation of heat exchange between the soil and the atmosphere and outer space may be admissible in climatology but does not satisfy permafrost scientists. First of all it does not give a detailed description of thermodynamic processes in the earth's crust itself. The most important of these, in addition to the evaporation of water from the soil and from its surface, is the movement and freezing of water in the soil and subsoil, the melting of ice in the soil and subsoil, the movement and condensation of water vapour in the cavities of the soil and subsoil, etc. This was mentioned by A.I. Voeikov (1904). These isothermic processes, irreversible over a long extent of time, play an important role in the development of the temperature field of the earth's crust and lead to fundamental changes in conditions of heat exchange between the lithosphere, soil and atmosphere.

Although climatologists do consider that the heat exchange between the "underlying surface" and the various strata of the soil and subsoil expressed by the term A in the heat balance equation (4.4) is equal to zero for the mean annual period averaged over several years, it is however known that in fact the changes in this value of A express the cooling or heating, i.e. freezing or thawing of the earth's crust.

In order to establish the dependence of the temperature regime of the soil and subsoil on the heat balance of the underlying surface and take into account the qualitatively and quantitatively very evident annual loss or addition of heat by the soil and generally the entire heat exchange in the earth's crust connected with the transformations of various forms of energy, one must investigate the heat cycle of the layer with variable annual temperature. The first to become interested in this was A.I. Voeikov using the data of F. Khomen and others. He established a relationship between the daily and annual temperature variation of the atmosphere with the daily and annual heat cycle in the soil and in water bodies and indicated their role in the formation of climate (Voeikov, 1904).

The ideas of A.I. Voeikov concerning the heat cycle in the soil and in water bodies and the significance of the heat cycle in the formation of local climate were developed by M.M. Krylov. The annual heat cycle of the soil and the underlying subsoil or of the upper stratum of water bodies he called the half-sum of heat entering the soil and subsoil from above and transmitted by the soil upwards, in other words the annual heat cycle is the heat entering the soil and leaving the soil over a year considered separately (Krylov, 1952). The flux of heat from the interior of the earth and the effect of biochemical processes are not taken into account.

The notion of the heat cycle in the earth's crust and in water bodies as it is considered by M.M. Krylov can be expressed by the equation

$$\sum q = \int_0^h c\gamma(t_1 - t_2)dh + \int_0^h lSdh + \int_0^\omega Led\omega, \tag{4.7}$$

where $\sum q$ is the total heat cycle;

c is the specific heat capacity;

γ is the unit weight;

$t_1 - t_2$ is the difference between extreme temperatures for a year;

l is the heat of freezing or melting;

S is the content of water or ice in a unit of volume;

L is the heat of evaporation or condensation;
e is the evaporation from the surface of the soil or water surface (condensation);
h is the thickness of the stratum of soil, subsoil or water under consideration;
ω is the area of the cross-section of a column (prism) of the earth's crust or water.

The total annual heat cycle in a column of land with a cross-section of 1 m^2 is expressed as 350 - 400,000 kcal; a column of lake water of the same cross-section more than 10 m in height has a cycle of about 700 - 1,000 kcal. Such heat cycles are observed in the earth's crust and in fresh water in the moderate latitudes.

The heat cycles in the earth's crust and in water representing the consumption of heat can be called negative whereas the influxes of heat from the outside, i.e. from the sun and atmosphere, are positive. Being interconnected they are only in rare cases, more likely imaginary cases, equal to each other. Under natural conditions when a relative steady state has been achieved in the heat exchange regime over a number of years between the lithosphere-soil-atmosphere and between the water-atmosphere, the negative heat cycles of the soil and fresh water in moderate and high latitudes is greater than the positive. This is generally known and has been mentioned above in discussions of the continuous transfer of heat from the earth to outer space.

The annual negative heat cycle of soil and subsoil or water bodies of medium and high latitudes can theoretically be quite large. In fact they are limited as a rule by positive heat cycles, i.e. by the quantities of heat energy accumulated by the soil and subsoils or surface strata of water throughout the year; these quantities of heat energy are themselves determined by the influx of radiation energy, convection heat and the transfer of heat from the deeper recesses of the earth's crust to the surface, the albedo of this surface, the density, radiation penetrability, the heat capacity, heat conductivity and other physical properties of the soil, subsoil and water.

It is known that to increase the negative heat cycles of the soil in order to reduce its temperature and decrease the evaporation of moisture from the soil during the vegetation period, M.M. Krylov suggested increasing the effective heat capacity of the "active layer" of arid regions by winter irrigation.

Thus the mean thermal state of the soil and subsoil or water in the upper stratum of a lake or river, expressed by their mean annual temperature, is determined basically by positive heat cycles.

Natural or artificial variations in the ratio of negative and positive heat cycles result in changes in the heat state of the subsoil at the bottom of the layer with variable annual temperatures and below this point. They are expressed particularly by changes in enthalpy, a characteristic function of state known to physicists and physical chemists.

Taking into account the complexity of the concept of this function of state and the impossibility of determining its absolute value, N.S. Ivanov introduced a different index of a purely thermal state of the soil and subsoil - "heat level". The heat level was defined by N.S. Ivanov as the positive or negative accretion of internal energy of the prism or stratum of soil or subsoil subtracted from the conventional value of their enthalpy that corresponds to the temperature of 0°C. The half-sum of the extreme value of the subsoil heat level in the stratum having an annual variable temperature is called the mean heat level. Neglecting the heat effect of mechanical, chemical, biological and electrical processes and considering unchanged the generalized force and coordinate (in particular the pressure and volume), N.S. Ivanov admits the existence of a well-defined dependence between the increase or decrease of the heat level of the subsoil and its temperature (Ivanov, 1956).

On this basis he established a connection between the mean heat level U_m and the geothermal level of the heat exchange of a unit of volume of subsoil taken from the lower part of the stratum with variable annual temperatures (where there is no phase transition of H_2O):

$$U_m = \frac{U_{max} + U_{min}}{2} = c_\gamma \frac{t_{max} + t_{min}}{2} \tag{4.8}$$

where c_γ is the "volumetric differential effective heat capacity of the subsoil".

It is not difficult to see that $\frac{U_{max} + U_{min}}{2}$ is the heat cycle of a given elementary volume of subsoil in the concept of M.M. Krylov. Thus the greater the heat cycle in the layer with a variable annual temperature the higher the geothermal level of heat exchange. In the Arctic tundra and the trans-polar taiga of the Asian part of the USSR the highest geothermal level of heat exchange is observed in the bottom deposits of fresh water lakes deeper than 5 m.

In the equations of the heat balance of elementary volumes of soil and subsoil the heat level is expressed by the so-called "accumulative term" which denotes the positive or negative accretion of heat in separate elements of the earth's crust during a day, year or a longer period of time (Chudnovskii, 1948; Kolesnikov, 1952). Thus if the annual supply of heat transmitted to an element of a layer of soil from above is denoted by Q_{pv}, that from the sides adjacent to the lateral face of the soil mass by Q_{pb}, that from below from the underlying stratum or from above by Q_{pn}, the loss of heat upwards or downwards by Q_{rv} and the loss to the adjacent lateral faces of the soil by Q_{rb}, the equation for the heat balance of the selected volume of the earth's crust can be written as follows:

$$Q_{pv} + Q_{pb} + Q_{pn} + Q_{pv} + Q_{pb} + Q_{ak} = 0$$

$$Q_{ak} = Q_{pv} + Q_{pb} + Q_{pn} + Q_{rv} + Q_{rb}, \quad (4.9)$$

where Q_{ak} is the changes in the heat content in the given volume of soil.

With a similar equation one can express the heat balance of a prism taken from any uniform section of land consisting of soil and lithosphere; the height of it may vary depending on which strata of the lithosphere are being considered.

Of the great variety of specimen columns or prisms taken from the "outer active layer" of the earth's crust the lowest heat cycles and lowest temperatures are found in peat-moss and clay-peat-moss soils. Because peat and clay soils (including fine silt soils) are relatively impervious to water and because of the supersaturation of the upper parts of such prisms, since they usually occur in depressions of the relief, the annual positive heat cycle occurs in the uppermost stratum of the earth's crust. Most of the sun's heat is consumed on evaporation from the soil and vegetation and of the heat that is accumulated in the soil during the warm period of the year most of it radiates and is transferred by convection into the atmosphere during the first two or three months of the fall and winter.

This particular feature of heat exchange between peat-clayey soils and the atmosphere and its effect on the temperature regime of the soil and particularly the formation of permafrost was noted as early as 1910 by B.B. Polynov.

According to the value of the annual heat cycle one can construct the following series from the variety of lithological prisms (going from the lowest to the highest values of this geothermal index): peat-moss, clay-peat-moss, clay loam-peat-moss, clay, clay loam, sand loam, sand, sand-gravel, gravel, gravel-pebble, pebble, rubble stone, boulder, rubble stone-solid rock and rock. In the future a detailed classification will have to be worked out for the various cross-sections of the earth's crust.

The value and sign of the accumulative term of the heat balance in the earth's crust reflect the influence of all physical processes involving continuous heat exchange between the earth and the atmosphere, geological, biogeochemical and other phenomena. For us the most important of these physical processes is the deep freezing and thawing of the lithosphere. Freezing of the lithosphere to depths of 100, 200, 300 m and more occurs as the result of considerable losses of heat or the predominance of the negative value of Q in the heat balance equation (4.9) for a prolonged, undoubtedly historical-geological period of time, measured in thousands of years. These negative values of Q_{ak} are the result of varying annual negative heat cycles.

A negative heat cycle extending over many years results in very large irreversible losses of heat energy from the frozen strata and also large quantities of heat from great depths, particularly when there is progressive freezing of the earth's crust during the period when the heat exchange between the earth and the atmosphere had not reached a steady state. In the geological sense low areas that were recently covered by water and some high areas of extensive erosion are living through such a period. It is possible that for this reason the geothermal stages of the upper reaches of rivers flowing from mountain ridges in the northeast part of the USSR are but comparatively small.

Permafrost scientists would like to elucidate the mechanism of development and appearance and disappearance of seasonally frozen soil or permafrost as geophysical phenomena not isolating them from the external or internal heat effects. The extremes in estimating the value of heat from solar radiation and from the internal heat of the earth are the result of the narrow specialization of geophysicists. In spite of the very small quantity of heat coming from the inner reaches of the earth, it nevertheless results in the existence of a lower boundary to the frozen strata. This is a level of mobile equilibrium between the liquid and solid phases of ground water which shifts in one direction or the other because of changes in heat loss of the soil and earth's crust.

Permafrost scientists cannot ignore such an important index of the development of permafrost and heat exchange between the upper strata of the earth's crust and the atmosphere as the reciprocal transition of the physical state of ground water accompanying fundmental changes in the physico-chemical system. The simplification of complex phenomena of heat exchange for the sake of ease in mathematical formulation would necessitate the exclusion of all thermodynamic effects in the soil connected with transitions in the physical state of moisture in the soil as well as endothermic and exothermic reactions.

The mechanisms of the development of heat exchange in the system soil-subsoil, freezing and thawing of soil and subsoil, and conditions of origin and existence of permafrost can be understood better if one regards the soil and subsoil as highly complex physico-chemical systems and not anisotropic and homogeneous solid bodies.

The complexity of these physico-chemical systems comes from their being made up of many components and existing in three phases. The basic components of these systems are: solid mineral particles, true and colloidal aqueous solutions and gas inclusions. They are of themselves not homogeneous. Moreover, the aqueous solutions of various components and also the gases filling the pores and cavities in this soil (for example frost cracks, drying, physical erosion and leeching) are made up of many components and are continuously moving in connection with diffusion, convective and turbulent heat exchange in the systems.

A.F. Lebedev in considering the migration of water vapour in the pores of the soil and subsoil noted the effect of this phenomenon on heat exchange between the various strata of the earth's crust. "The movement of water vapour in the soil and subsoil is a function of the temperature of the upper strata of the earth's crust, and is undoubtedly one of the most powerful factors in the heat exchange of the soil. The continuous flow of water vapour from the lower reaches of the earth's crust to the surface and their condensation at the surface increases the temperature accelerating the energy of heat exchange between the deeper parts and the surface strata of the earth" (Lebedev, 1936, page 271).

The migration of liquid water along the pores and cracks of the soil and subsoil and not only that of water vapour, as noted by Lebedev, is of great importance in the heat exchange of the various strata of the earth's crust. In all non-steady state processes of freezing and cooling of the soil and subsoil from the surface, particularly when they are seasonal, film and capillary water are active transporters of heat. The movement of film and capillary water along pores in soil and subsoil when there is a temperature difference in them towards horizons of intensive cooling and ice formation results in a decrease in the gradient inside the water-transmitting and heat-transmitting strata.

In nature, film and capillary water moves along the pores through strata of soil and subsoil in two directions: (a) towards the bottom of the strata with annual temperature variation as well as also towards horizons of lower temperature in the earth's crust, and (b) towards the surface of the soil, since the direction of the temperature gradients above and below these horizons are in opposite directions. In this, as in other natural phenomenon, there is a contradiction: The movement of the film and capillary water caused by temperature difference tends to destroy this reason by decreasing the temperature difference and the geothermal gradient (the LeChatelier principle).

In water-saturated sand or broken stone deposits saturated with water there would seem to be some convective heat exchange although it is more evident in rock formations where cracks open up into stagnant water bodies.

Up to 1950 the study of heat transfer was enriched by the work of Prof. A.V. Lykov on heat-moisture transfer observed in moist porous materials, "heat-moisture conductivity introduces a correction into the heat conductivity law of Fourier since a specific portion of the heat is transferred by the flow of moisture" (Lykov, 1950).

The Fourier heat conductivity law (the density of heat flux is in direct proportion to the temperature gradient) expressed by the equation

$$q = -\lambda \nabla t,$$

is altered and takes on the form

$$q = -(\lambda + k\gamma_0 \delta Y)\nabla t - k\gamma_0 Y \nabla u,$$

where q is the density of heat flux in $kcal/m^2 \cdot hr$,

λ is the heat conductivity coefficient in $kcal/m \cdot hr \cdot degree$,

k is the moisture transfer coefficient in m^2/hr,

γ_0 is the moisture density,

δ is the heat-moisture transfer coefficient in $\frac{1}{degree}$,

Y is the heat content of the moisture transferred inside the material in kcal/kg,

∇t is the temperature gradient,

∇u is the moisture gradient.

The result of the movement of any form of water upwards or downwards in the subsoil either because of a temperature difference or the force of gravity is an equilibration of temperature in the frozen stratum or, in other words, a decrease in the temperature gradient.

This cannot be ignored either in calculating the thickness of a seasonal frozen stratum when one is determining the upward flux of external heat only by the temperature difference at the foot of this layer or in considering the so-called "normal geothermal gradient" (S.A. Kraskovskii, 1948), since the temperature field in the upper strata of the earth's crust cannot be considered to be in an unconditionally steady state. At the present time one cannot explain the difference in rates and depth of thawing in clay loam and sand soils only by the difference in the heat conductivity coefficient as was done by previous investigators (A.F. Middendorf and others).

Solid, liquid and gaseous bodies comprising the vertical cross-section of the lithosphere are subject to the thermal, gravitational and other physical fields of the earth.

Taking into account all the effects of these fields on the solid, liquid and gaseous components of the upper stratum of the earth's crust, i.e. the correlation of kinetic, potential and "surface-partial" energies under actual conditions and knowledge of the possible thermal motions makes it possible to get a good understanding of liquid and gas transfer and heat exchange in the soil and subsoil.

Heat exchange in the systems atmosphere-lithosphere, surface of the soil-upper strata of the earth's crust, stratum of water-bottom of a water body take place by means of the following:

(1) radiation;

(2) absorption of radiation energy;

(3) heat conductivity;

(4) convection;

(5) turbulent mixing of liquids and gases;

(6) diffusion of water vapours and motion of film and capillary water;

(7) the reciprocal transition of the three physical states of H_2O.

In the vertical cross-sections of the systems, stratum of air adjacent to the ground-surface of the soil-upper layer of lithosphere or atmosphere-bottom of a water body the above-mentioned types of heat exchange coincide and are superimposed one on the other or one is replaced by the other.

The various conjugations and substitutions in forms of heat exchange explain the difference in activity and results of heat exchange in these systems on neighbouring sections of land with equal heat supply at the surface of the soil but with varying composition and structure of the soil and subsoil.

For example, azonal permafrost massifs of limestone with large karst cavities (in the valley of the Ufa River in the region of the Kungur caves, in the Razvalka Mountain and other places) are due to the activity of turbulent and convective mixing of cold and therefore heavy air with warmer and therefore not so heavy air in the karst cavities during the winter and the absence of this type of active mixing during the summer.

The circulation of cold air in karst cavities during the winter due to the force of gravity is a fundamental condition for the generation and existence of permafrost masses or lenses in karst-containing limestone. In such places one does not find the usual ratio between the mean annual temperature of the air and the temperature of the rock at the bottom of the stratum with annual variation in temperature, the former is higher than the latter. This explains the fact that the temperature of fresh water of the Razvalkin spring is 4.4°C below the mean annual temperature of the air in Zheleznovodsk. The geological condition - the presence of large cavities (caves and fissures opening to the air) - is completely sufficient for deep penetration of frost into the subsoil converting it into a permafrost stratum even though the climatic conditions may be unfavourable for permafrost.

The effect of adiabatic expansion of underground gases, for example carbon dioxide jets arising from below along karst cavities and cracks of other origin, can also bring about local permafrost in the subsoil in relatively low latitudes. But this effect occurs rarely.

The origin and present-day existence of permafrost strata in the bottom sedimentary deposits of the shallow water shelf of the Arctic Ocean, as well as the freezing of the bottom of salt lakes (A.I. Dzens-Litovskii, 1938), is explained as follows. As the thickness of ice cover increases the concentration of sea water adjacent to the lower surface of the ice increases, and therefore the water at the interface with the ice becomes heavier and colder than the deeper water and descends to the bottom. The cold water is replaced at the boundary between the solution and ice by warm bottom water which being lighter rises to the undersurface of the ice. In this way there is transfer of matter and energy in a medium that is under the influence of gravitational and temperature fields.

As a result, the concentration of salt in the water adjacent to the bottom increases and the temperature decreases, whereas the concentration of salt in the water that has previously penetrated into the bottom muck at some depth from the surface of the bottom remains as before.

The temperature difference at the boundary between the layer of sea water descending from the ice surface above and the bottom muck results in heat loss and a decrease in the temperature of the muck, and in some cases freezing of the muck. Returning to the question of heat balance in the soil, it should be noted that all cooling and freezing of the earth's crust occurring over a space of time is connected with a decrease in enthalpy (heat content) of the lithosphere, whereas heating and thawing of permafrost results in an increase in the heat content of the lithosphere.

Regardless of how large is the annual influx of heat to the soil it is under ordinary natural conditions less than the external heat loss of the soil during an annual cycle. Artificial or natural changes in the conditions of heat exchange between the soil and the atmosphere can made the difference in influx and loss of heat for a specific period of time a positive value. Then the temperature of the earth's crust will increase and permafrost will thaw. Only the increase in the quantity of heat reaching the soil from above and below results in the increase in the geothermal level of heat exchange between the soil and the atmosphere. It is for this reason that one observes an increase in the mean annual temperature of the soil moving from the north to the south, and not because in the south the heat balance of the soil is positive whereas in the north it is negative. Generally speaking, the terms "positive" and "negative" placed in front of the terms "heat balance of the soil" contradicts the definition "heat balance is the equilibrium between influx and loss of heat".

Permafrost scientists, like other investigators of the thermal regime of the soil, must of course take into account the fact that they do not in all cases know the difference between the influx and loss of heat, since they have at their disposal the temperature as an index of changes in heat reserves in the soil.

Nevertheless one cannot fully agree with the idea that knowledge of the temperature of the soil and the direction in which it is changing gives all the necessary information for predicting the energy processes in the soil and controlling them.

From their experience in investigation and in solving many practical problems, permafrost scientists have been convinced of the necessity of constructing even very approximate algebraic sums of the influx of heat to the soil and the loss of heat energy by it, and an analysis of the components of the heat balance for working out rational methods of controlling freezing and thawing of soil and subsoil. The control of processes of freezing and thawing of soil and subsoil is, in fact, the main task of permafrost scientists. The success in solving this problem depends on the success in investigating the fundamental mechanism of heat exchange in the systems soil-atmosphere, soil-lithosphere in close connection with experience in the utilization of territories containing frozen subsoil. The investigations of P.I. Koloskov (1930, 1932_2) and V.P. Bakakin (1955_2) proved this convincingly.

One frequently deals with heat exchange in the system soil-upper stratum of the earth's crust and with the heat balance of the soil, but not with the heat exchange in the system atmosphere-upper stratum of the lithosphere, and not with the heat balance of the layer of atmosphere adjacent to the earth. In fact, the soil is heated directly by solar radiation and cooled by its own radiation resulting from the transformation of heat from various sources into radiation energy and is cooled or heated by a convective heat exchange with the air, evaporation from its surface and condensation of moisture in the soil. Knowing the heat balance and the temperature of the soil makes it possible to determine precisely the geothermal level of heat exchange between the soil and upper strata of the earth's crust, the mobile levels of thermodynamic equilibrium at which the annual heat cycle in the soil and lithosphere take place.

The equations for the heat balance of the uppermost stratum of soil, 10 cm in thickness for example, if one takes into account only the fundamental aspects of its heat cycle, can be represented by the following expression:

$$Q_{pr} + Q_{rr} + Q_m + Q_v + Q_o + Q_i + Q_{ik} + Q_k + Q_{ak} + Q_{vn} + Q_t = 0, \quad (4.10)$$

where Q_{pr} is the heat of direct solar radiation,

Q_{rr} is the heat from diffused radiation of the sky or scattered radiation,

Q_m is the heat brought or removed by atmospheric precipitation,

Q_v is the heat of incident radiation from the sky,

Q_o is the heat of radiation reflected by the soil,

Q_i is the heat radiated by the soil surface,

Q_{ik} is the heat of evaporation of moisture (condensation of vapour),

Q_k is heat transferred or heat received as a result of convective (turbulent) heat exchange between the soil and the atmosphere,

Q_{ak} is the heat accumulated or lost by a stratum of soil,

Q_{vn} is the heat rising to the surface of the soil from deeper strata of the earth's crust,

Q_t is the heat supplied by water moving towards the cooling plane connected with migration of ground water.

This analytical expression for the heat balance of the soil does not take into account heat received or given off by the surface of the soil by advection during heat exchange with air moving above it (during winds). But as established by M.I. Budyko (1956) this is not required.

In the above rather expanded equation for the heat balance of the uppermost stratum of soil the component Q_{ak} contains all the accumulated or lost heat of the soil, including the heat of freezing and melting of water.

As we can see, this equation is very complex. The numerical values of many of the terms expressing the annual total loss or advent of heat are unknown to permafrost scientists or geophysicists. To the present time investigators do not know the radiation constant of the atmosphere, they have not learned to determine precisely the radiation constant of the soil. Difficulties have been experienced in obtaining a precise determination of the index of evaporation from the surface of the soil and condensation on it and in the soil itself.

But the notion itself of an annual heat balance of the outer stratum of the soil as a particular expression of the law of conservation and transformation of energy is a powerful weapon in the hands of permafrost scientists when they are developing methods of using natural sources of heat and cold for controlling thawing and freezing of the upper strata of the earth's crust.

The most cursory analysis of the structure of the heat balance of the upper stratum of soil 10 cm in thickness shows which components can be changed by man by the means available to him. It is clear that it is not within the power of man to change the quantity of radiation energy from the sun (direct solar radiation Q_{pr} and scattered radiation Q_{rr}). However, it is within his power to change the quantity of solar radiation reflected from the soil Q_o by changing the albedo of the earth's surface; he can decrease the loss of heat of evaporation of surface water and soil water Q_{ik} by drying the soil, decrease the quantity of heat radiated and transferred by the soil to the air by increasing the depth and friability of the snow cover, and thus change the quantity of heat accumulated in the soil.

As the result of all of these changes, the geothermal level of heat exchange in the soil increases or decreases, and in local areas of particular interest to permafrost scientists the soil may be changed from the frozen to the non-frozen state or vice versa. In this connection it would be fitting to recall again the conviction of A.A. Grigor'ev that one should not confuse the question of the age of permafrost with the question of the conditions under which it can exist at the present time. In his opinion "if permafrost arose during a preceding geological epoch it is retained at the present time only in those regions where it could now develop, otherwise it would have disappeared long ago" (Grigor'ev, 1930_1, page 47).

The freezing and thawing of the soil and subsoil is very complex. The accompanying physico-chemical and physico-mechanical processes vary in content, form, significance in the transformation of the composition, structure and texture of the soil and underlying mineral matter depending on their peculiar features: extent of dispersion and the extent to which the cavities and pores are filled with water and air.

Soil and ground water as solutions or solvents have a continuous physical or chemical action on the soil and mineral matter.

Thus in considering the processes of cooling and freezing, the heating and thawing of the soil and upper strata of the soil, we should continuously keep in mind that they contain aqueous solutions of various concentrations and compositions which move at varying rates depending on the strength of gravitational, thermal and other physical fields, interact chemically and physically with the solid mineral aggregate under the influence of forces of surface tension.

Freezing and thawing of dispersed and finely dispersed soils and mineral matter is a particularly complex process.

In 1866 I.A. Lopatin turned his attention to the "self stratification" of clay subsoils in the valley of the Enisei to the north of Dudinka which had cracked and were composed of succeeding layers of frozen clay loam and ice. In writing of this in 1873 he came to the idea that this "false stratification" is the result of the freezing process of these deposits. At the present time permafrost scientists are intensively studying the cryogenic texture, the shrinkage and cracking of fine silted clays, clay loam and sand loam at temperatures of -2 to -3°C, the settlement on thawing of these "stratified" ice-containing soils for using them as a base for building construction.

In any dispersed frozen soil at any low temperature there is always some quantity, although it may be very small, of unfrozen water.

The region of intensive phase transition of water for clayey soils is in the temperature range of 0 to -2°C, for sandy soils it is from 0 to -0.5°C. Only when the temperature of sand, sand loam and clay loam soils is below -7 and -10°C can one for practical purposes neglect phase transition of the moisture contained therein.

The phase transitions of water in the soil and the quantitative relations between the different phases of water have a very important effect on the physical and mechanical properties of frozen soil.

Generally in processes of cooling and freezing, heating and thawing of moist soil and water-bearing subsoil one finds all the mechanisms of changes in a multiphase system proving the validity of the equations for the state of such systems. The level of mobile equilibrium of phases in the system ice-water in the subsoil shifts in one or the other direction immediately there is a change of any one of three variable magnitudes - temperature, pressure or concentration of the solution. However it is known that the temperature of the soil and subsoil, like the pressure components, changes continuously and therefore there is a continuous shift in the equilibrium level in the systems ice-water, frozen-unfrozen soil.

The external conditions and geophysical processes such as solar radiation and the radiation of the earth itself, heat exchange between the surface of the soil and the atmosphere, moisture cycle, cannot be constant and therefore any equilibrium between the liquid and solid phases of ground water will be sooner or later upset.

Physico-chemical interactions between unfrozen water and mineral particles occur even at below freezing temperatures, namely, exchange reactions, coagulation, dissolving and crystallization, etc.

One cannot therefore say that permafrost is a zone of chemical rest, although it is perfectly clear that at the freezing temperature of the bulk of ground water (gravitational and film) there is a step-like change in the reaction rate in the soil.

The migration of water and other physico-mechanical and physico-chemical effects occur at a rapid rate (at the temperature of phase transitions) in finely dispersed soils and subsoils making up the stratum with an annual change of temperature. This is explained by the very large temperature gradient caused by seasonal cooling and heating of the upper strata of the soil and subsoil.

The unsteady temperature field and the large temperature gradients in the stratum of soil with an annual temperature variation, which is particularly large in its upper horizons, are tied in with the majority of the so-called permafrost effects: heaving, thermal karsts, cracking of the soil, peat mounds, medallion spots, ice formations, etc. The increase in ice content of clayey and fine silted deposits are connected and coincide with these particular features of the temperature field of a given stratum of the lithosphere.

Below the bottom of the stratum with annual temperature variations, where there is a relatively steady state (throughout the course of a year) in the temperature field, there are no such large gradients.

The fundamental hypotheses in permafrost studies mentioned in this paper concerning the mechanisms of the freezing and thawing, composition, structure and properties of frozen soils have been obtained as the result of investigations of A.I. Voeikov, L.A. Yachevskii, V.A. Obruchev, M.I. Sumgin, A.V. L'vov, A.A. Grigor'ev, P.I. Koloskov, N.A. Tsytovich, N.I. Tolstikhin and many members of an increasing number of Soviet permafrost scientists.

Literature

Abel's, G. Daily temperature variation of snow and the relationship between heat conductance of snow and its density. St. Petersburg, 1893.

Abolin, R.I. Perennially frozen soil and fossil ice. Zap. Chitin. otd. Russk. geogr. ob-va, No. 9, Chita, 1913.

Abolin, R.I. Geobotanical and soil description of the Lena-Vilyui plains. Tr. Komiss. po izuch. Yakutskoi ASSR, Vol. 10, Izd-vo AN SSSR, Leningrad, 1929.

Abramov, I.N. Meteorological and agricultural observations at the Bomnak Station during the summer of 1910. Tr. Amursk. eksped., No. 14, St. Petersburg, 1913.

Abramova, M.I. The transfer of moisture in soil during evaporation. Tr. Pochv. in-ta AN SSSR, Vol. 41, Izd-vo AN SSSR, 1953.

Adams, M.F. Relation abrégée d'un voyage à la mer glaciale et découvérte des restes d'un mammouth. Journ. du Nord, XXXII. St.-Pétersb., 1807.

Aidinyan, R.Kh. The separation of soil colloids without chemical treatment. Kolloid. zhur., 1947, Vol. 9, No. 1.

Akimov, A.T. Investigation of permafrost by geothermal and geoelectric methods in the eastern part of the Bol'shezemel'skaya tundra. Rukopis', fondy In-ta merzlotoved., 1951.

Akimov, A.T. A preliminary account of permafrost investigations along the Adz'va River. Rukopis', fondy In-ta merzlotoved., 1952.

Alekin, O.A. Hydrochemistry of the rivers of the U.S.S.R. Tr. Gidrol. in-ta, No. 10 (64), Leningrad, 1948; No. 15 (69), Leningrad, 1949.

Alisov, B.P., Drozdov, O.A. and Rubinshtein, E.S. Course in climatology, Pts. 1 and 2. Gidrometeoizdat, Leningrad, 1952, 1954.

Aller, G.D. Post-pliocene deposit of the Chelyuskin Peninsula. Izv. Gos. geogr. ob-va, 1936, Vol. 68, No. 3.

Allix, André. Nivation et sols polygonaux dans les Alpes françaises. La géographie. (Paris), 1923, Vol. 39, No. 4.

Al'tberg, V.Ya. and Troshin, V.F. On new forms of crystalline ice. Izv. Gidrol. in-ta, 1931, No. 32.

Alyukhin, S.Z. Summer field work at the Tugan-Urkan Meteorological Station during the summer of 1910. Tr. Amursk. eksped., No. 14, St. Petersburg, 1913.

Ananyan, A.A. Investigation of the passage of an electric current through freezing and frozen soils. Rukopis', fondy In-ta merzlotoved., 1950.

Ananyan, A.A. The transfer of moisture in frozen soils under the influence of electro-osmotic forces. Kolloid. zhur., 1952, Vol. 14, No. 1.

Andersson, J.G. Solifluction, a component of subaerial denudation. Journ. of Geol. (Chicago), 1906, Vol. 14, No. 2.

Andreev, V.N. Hydrolaccoliths (bulgunnyakh) in the West Siberian tundra. Izv. Gos. geogr. ob-va, 1936, Vol. 68, No. 2.

Andreev, V.N. Investigation of tundra deer pastures from an aircraft. Tr. In-ta polyarn. zemled., seriya olenevodstva, No. 1. Izd. Glavsevmorputi, 1938.

Andreev, V.N. The advance of trees into the tundra in relationship to the protective properties of afforestation in the North. Botan. zhur., 1954, Vol. 39, No. 1.

Andrianov, P.I. I. Expansion coefficients of soils during freezing. II. Freezing temperatures of soils. Izd. SOPS i Komiss, po izuch. vechn. merzl. AN SSSR, Moscow-Leningrad, 1936.

Andrianov, P.I. Bonded water in soils. Tr. In-ta merzlotoved., Vol. III. Izd-vo AN SSSR, Moscow, 1946.

Andriyashev, M.M. Thermal calculations in designing water ducts under conditions of permafrost. Moscow-Leningrad., Gosizdat stroit. liter., 1941.

Anisimova, N.P. Hydrochemical characteristics of the Lena River in its middle reaches. Issledovanie vechnoi merzloty v Yakutskoi respublike, No. 3. Izd-vo AN SSSR, 1952.

Anuchin, D.N. Report on the restoration of a mammoth for the anthropological exhibit of 1879. Izv. Ob-va lyubit, estestv., antrop. i etnogr. pri Mosk. univ., Vol. 35, Antrop. vyst. 1879, Vol. III, Part I, Moscow, 1880.

Arkhangel'skii, A.D. Geological structure and geological history of the U.S.S.R. Izd. 4, Vol. 1, 1947; Vol. 2, 1948, Moscow-Leningrad, Gosgeolizdat.

Aronov, S.N. Designing of water ducts. Moscow-Leningrad. Gos. izd-vo liter. po stroit. i arkhit., 1953.

Arsen'ev, A. A brief orographic report from the Uryum to the Chaldonka stations. Rukopis', fondy Upravl. stroit. Amurskoi zh. d., 1908.

Atlas of the World. Moscow, 1954.

Baer, K.E. Materialien zur Kenntniss des unvergänglichen Boden Eises in Sibirien. From documents of the Archives of the Acad. of Sciences USSR. Trans. from German. Ms. in Lib. of Permafrost Inst., Acad. of Sciences USSR.

Baer, K.E. Beiträge zur Kenntniss des Russischen Reiches. IX. Bändch., 50-te Abteil., 1855.

Baer, K.E. Neue Auffindung eines vollständigen Mammuths, mit der Haut und den Weichteilen, im Eisboden Sibiriens, in der Nähe der Bucht des Tas. Bull. Acad. imp. Sci. de St.-Pétersb., 1866, t. X.

Bakakin, V.P. Methods of improving the efficiency of mining operations in the regions of permafrost and deep winter freezing. Rukopis', fondy In-ta merzlotoved., 1954.

Baranov, I.Ya. Southern boundary of perennially frozen soils. Materialy k osnovam ucheniya o merzlyukh zonakh zemnoi kory. Vol. II, Moscow, Izd-vo AN SSSR, 1955.

Baranov, K.A. Some cryospheric textures of tertiary deposits in the Arctic. Priroda, 1946, No. 6.

Barygin, V.M. Permafrost and ground waters in the Vorkuta region. Rukopis', fondy In-ta merzlotoved., 1952.

Barygin, V.M. (1) Experiments in using aerial photography in studying permafrost in the Vorkuta region. Izd-vo AN SSSR, Moscow, 1953.

Barygin, V.M. (2) Ground waters of the Vorkuta region. Moscow, Izd-vo AN SSSR, 1953.

Barygin, V.M., Tumel', V.F. et al. Report of the Noril'sk brigade of KOVM, Vol. 5 and 7. Rukopis', fondy In-ta merzlotoved., 1938.

Bastamov, S.L. et al. On the freezing of soils. Sb. 12 Nauchno-issled. In-ta puti NKPS, 1933.

Beechey, F.W. Narrative of a voyage to the Pacific and Bering's Strait, Vol. 1. London, 1831.

Belokrylov, I.D. et al. Permafrost and railroad transport. Sb. Vechnaya merzlota i zheleznodorozhnoe stroitel'stvo, 1931, No. 8.

Belyakin, D.S. On water in some minerals. Tr. Petr. in-ta AN SSSR, No. 4, Leningrad, 1933.

Benninghoff, W.S. Interaction of vegetation and soil frost phenomena. Arctic, 1952, Vol. 5, No. 1.

Ber, K.M. Data on recognizing non-transient soil ice in Siberia. Perevod s nemetskogo. 1842. Rukopis', biblioteka In-ta merzlotoved.

Berch, Fr., Sherer, Dzh. and Spaiser, G. Handbook for geologists on physical constants. (Russian translation). Izd.-vo inostr., liter., 1949.

Berezantsev, V.G. The resistance of soils to local load during constant below freezing temperature. Materialy po laboratornym issledovaniyam merzlykh gruntov. Sb. 1, Moscow, Izd-vo AN SSSR, 1953.

Berlyand, T.G. Radiation and thermal balance of the land surface north of the tropics. Tr. Gl. Geofiz. observ., No. 18/80, Leningrad, 1949.

Beskow, G. Tjälbildningen och Tjällyftningen med särskild Hänsyn till vägar och järnvägar. Sver. Underosökning. Stockholm, 1935, ser. C. No. 375. English translation: Soil freezing and frost heaving with special application to roads and railroads. Evanston, Illinois, 1947.

Birkengof, A.L. Observations of forest cover and permafrost (in the Indigirka River basin). Tr. Komiss. po izuch. vechn. merzl. AN SSSR, Vol. 3, Leningrad, 1934.

Birkengof, A.L. On the southern boundary of permafrost in the region of Komsomol'sk on the Amur River. Tr. Komit, po vechn. merzl., Vol. 9, Moscow-Leningrad, Izd-vo AN SSSR, 1940.

Bakakin, V.P. (1) Ice as a material for filling space left by the extraction of rock. Moscow, Izd-vo AN SSSR, 1955.

Bakakin, V.P. (2) Experience in controlling heat exchange of the active layer of frozen soils for the purpose of improving the efficiency of excavation. Moscow, Izd-vo AN SSSR, 1955.

Bakakin, V.P., Zhukov, V.F. and Meister, L.A. Perennially frozen soil and building conditions in the central part of the Bureya depression. Moscow, Izd-vo AN SSSR, 1954.

Bakulin, F.G. Ice content and settlement during thawing of tertiary deposits in the Vorkuta region. Moscow, Izd-vo AN SSSR, 1958.

Bakulin, F.G. and Zhukov, V.F. Deformation of frozen granular soils during thawing. Izv. AN SSSR, Otd. tekh. nauk, 1955, No. 7.

Bal'ts, V.A. Data and observations of the Pikan meteorological station for the summer of 1910. Tr. Amursk. eksped., no. 14, St. Petersburg, 1913.

Bal'ts, V.A. and Prokhorov, N.I. Data and observations of the Bomnask meteorological station for the year 1909. Tr. Amursk, eksped., No. 14, St. Petersburg, 1913.

Baranov, I.Ya. Report of the Bratsk permafrost-hydrogeological station for 1931. Rukopis', fondy Vost.-Sib. geol. upravl. Irkutsk.

Baranov, I.Ya. (1) Report of the Bratsk permafrost-hydrogeological station for the year 1932. Rukopis', fondy Vost.-Sib. geol. upravl. Irkutsk, 1933.

Baranov, I.Ya. (2) Preliminary remarks on the terminology in the science of permafrost. On the geological front of Eastern Siberia. Sb. 1, Moscow-Irkutsk, 1933.

Baranov, I.Ya. On the methodology of formulating permafrost maps (applicable to the Transbaikal region). Tr. Komit, po vechn. merzl., Vol. 6, Moscow-Leningrad, Izd-vo AN SSSR, 1938.

Baranov, I.Ya. Southern boundary of the permafrost region. Gidrogeologiya SSSR, No. 17. Vostochnaya Sibir', Book 2, Moscow-Leningrad, Gosgeolizdat, 1940.

Baranov, I.Ya. Some ice formations on the surface of the soil. Priroda, 1949, No. 10.

Baranov, I.Ya. Permafrost and the primary structure of soils. Tr. In-ta merzlotoved., Vol. 9, Moscow, Izd-vo AN SSSR, 1950.

Baranov, I.Ya. Geothermic features of the Kola Peninsula. Moscow, Izd-vo AN SSSR, 1951.

Baranov, I.Ya. The transition zone between seasonal freezing and permafrost within the U.S.S.R. and neighbouring countries (the southern boundary of permafrost). Rukopis', fondy In-ta merzlotoved., Moscow, 1952.

Baranov, I.Ya. Permafrost features of the Kola Peninsula. Tr. In-ta merzlotoved., Vol. 13, Izd-vo AN SSSR, 1953.

Black, R.F. Permafrost - a review. Bull. of the Geol. Soc. of Amer., 1954, Vol. 65, No. 9.

Black, R.F. and Barksdale, W.L. Oriented Lakes of Northern Alaska. Journ. of Geol., 1949, Vol. 57, No. 2.

Blagovidov, N.D. Quaternary deposits, climate and soils of the Tyung River basin (Yakut A.S.S.R.). Moscow-Leningrad, Izd-vo AN SSSR, 1935.

Blinskii, A.I. Underground mining of coal and ore deposits in the region of permafrost by packing the excavated space with ice. Merzlotovedenie, Vol. 1, No. 2. Moscow, Izd-vo AN SSSR, 1946.

Bliznin, G.Ya. Moisture content of soils according to observations of the former Elizavetgrad meteorological station, 1887-1889. St. Petersburg, 1890.

Boch, S.G. Snow flakes and snow erosion in the northern portions of the Urals. Izv. Vses. geogr. ob-va, 1946, Vol. 78, No. 2.

Boch, S.G. Observations of the micro- and meso-relief of quaternary deposits connected with frost processes. Metodich. rukov. po izuch. i geol. s'emke chetvert. otlozh. Gosgeolizdat, Moscow, 1955.

Boch, S.G. Solifluction and the formation of diluvial deposits. Mat. po chetvert. geol. i geomorfol. SSSR, Moscow, Gosgeoltekhizdat, 1956.

Boch, S.G. and Krasnov, I.I. Processes of bald mountain formation and the formation of mountain terraces. Priroda, 1951, No. 5.

Bodmann, W. Ergebnisse der Schwedischen Sudpolarexpedition, 1901-1903.

Bogdanov, N.S. Permafrost and erecting buildings on it. Izd. Osoboi vysshei komissii dlya vsestoronnego issledovaniya zh-d. dela v Rossii, No. 33, St. Petersburg, 1912.

Bogdasarov, N.V. A rational method of constructing water ducts and water mains in the southern regions of the permafrost zone. Rukopis', fondy In-ta merzlotoved., 1954.

Bogoslovskii, P.A. Calculation of long-term changes in the temperature of earth dams constructed on permafrost. Tr. Gor'k. inzh.-stroit. in-ta, No. 27. Gor'kii, 1957.

Boiko, I.V. Investigation of the dependence of the phase composition and mechanical properties of frozen soils on temperature and pressure. Kandidatskaya dissertatsiya. Rukopis', fondy In-ta merzlotoved., Vorkuta, 1956.

Boiko, I.V. On the heat capacity of frozen soils in the temperature region of phase transformations of water. Sb. statei Vses. zaochn. politekhn. in-ta, 1957, No. 16.

Bokserman, Yu.I. Basic results of investigations on the problem of decreasing the depth of laying gas mains. Neftyanoe proizvodstvo, 1950, No. 9.

Bondarev, P.D. Deformation of buildings in the Vorkuta region, their reason and methods of prevention. Moscow. Izd-vo AN SSSR, 1957.

Bonshtedt, E.M. Ice columns. Priroda, 1921, No. 10-12.

Bunge, A. Einige Worte zur Bodeneisfrage. Zap. imp. S. Peterb. Miner. ob-va, 11 ser., ch. 40, St. Petersburg, 1903.

Bunge, A.A. Preliminary report of the expedition to the New Siberian Islands. Izv. Russk. geogr. ob-va, 1888, Vol. 23.

Bunge, A.A. Description of an expedition to the mouth of the Lena River, 1881-1884. Tr. Russk. polyarn. stantsii na ust'e r. Leny, Part I. Izd. RGO, St. Petersburg, 1895.

Bykov, N.I. and Kapterov, P.N. Movement of moisture during the freezing of soil. Izv. AN SSSR, seriya geogr. i geofiz., 1938, No. 1.

Bykov, N.I. and Kapterov, P.N. Permafrost and construction on it. Transzheldorizdat, Moscow, 1940.

Cajander, A. Ein Beitrag zur Entwicklungsgeschichte der nordfinnischen Moore. "Fennia", 1902-1903, 20 No. 7. Helsinkfors.

Charnyi, I.A. Determining the boundary of change in the state of aggregation during the cooling or heating of bodies. Izv. AN SSSR. Otd. tekh. nauk, 1948, No. 2.

Chekotillo, A.M. Secondary ice formations and combatting them. Moscow, Dorozhn. izd-vo Gushosdora NKVD SSSR, 1940.

Chekotillo, A.M. Seasonal freezing of soil in the plane territory of the European part of the U.S.S.R. and problem connected with laying pipes. Izd-vo AN SSSR, 1955.

Chernov, V.A. Quantitative mechanisms in the diffusion of anions in soils. Tr. Pochv. in-ta AN SSSR, Vol. 20, 1939.

Chernyshev, M.Ya. Water pipes in frozen soils. Izd. Gos Dal'nevost. univ., 1925.

Chernyshev, M.Ya. Water supply in regions of permafrost. Tr. Vses. nauchno-issled. in-ta vodosnabzh. i santekhn. Moscow, 1933.

Chirikhin, Yu.D. Permafrost in the basin of the Indigirka River. Tr. Komiss. po izuch. vechn. merzl., Vol. 3, Leningrad, 1934.

Chirikov, V.F. and Malyugin, A. Moisture conditions in podsol soil during freezing and thawing. Nauchno-agron. zhur., 1926, No. 1.

Chirvinskii, N.N. Rod-fibrous ice. Izv. RGO, 1936, Vol. 68, No. 6.

Chudnovskii, A.F. The physics of heat exchange in soil. Moscow, Gostekhizdat, 1948.

Chudnovskii, A.F. Heat exchange in fine-grained media. Moscow, Gostekhizdat, 1954.

Chudnovskii, A.F. On the mechanics and the role of condensation inside the soil. ZhTF, 1955, 25, No. 1.

Collected instructions and programs for studying frozen soils and permafrost. Moscow-Leningrad, Izd-vo AN SSSR, 1938.

Correns, C.W. Über die Erklärung der sogenannten Kristallisationskraft. Sitzungsb. d. Preuss. Akad. k. Wiss., 1926, X-XI, Phys.-math. Kl. Berlin.

Dadykin, V.P. The growth of vegetation on cold soil. Moscow, Izd.-vo AN SSSR, 1952.

Dalmatov, B.I. The effect of frost heaving on foundations of structures. No. 27, Leningrad-Moscow, Gos. Izd-vo liter. po stroit, i arkhit., 1957.

Darwin, C. Circumnavigation of the earth on the ship "Beagle" (Russian translation), Vol. 1, 1871.

Datsev, A.B. Concerning Stefan's linear problem. Dokl. AN SSSR, 1947, 58, No. 4.

Datsev, A.B. Concerning Stefan's linear problem - two phases of finite thickness. Dokl. AN SSSR, 1950, 74, No. 3.

Datskii, N.G. Southern limit of permafrost in the Mezenskii region of the Arctic. Tr. Komiss. po izuch. vechn. merzl., Moscow-Leningrad, Izd-vo AN SSSR, 1937.

Dement'ev, A.I. Elimination of uneven thermal settlement of buildings by artificial heating of the permafrost base. Stroit. promyshl., 1944, No. 5-6.

Denisov, N.Ya. The deformation of clay soils. Izd. Minist. rechn. flota. Moscow, 1951.

Denisov, N.Ya. Structural properties of loess and loess-like clay loam. Moscow, Gos. izd-vo po stroit. i arkhit., 1953.

Dergunov, I.D. Study of forces of heaving. Tekhnika zheleznykh dorog, 1945, No. 1-2.

Deryagin, B.V. Elastic properties of thin layers of liquid. Zhur. fiz. khimii, 1932, Vol. 3.

Description of anything conceivable on a journey from Arkhangel'sk by sea to China and from there to eastern India. Lectures in the domain of history and antiquities of Russia at the Moscow University. No. 4, 1893, and No. 4, 1895.

Dobrowolski, A.B. Historia naturalna lodu. Kasa pomocy dla ocob pracujących na polu naukowem im Z. Mianowskiego, XXVI, Warszawa, 1923.

Dokuchaev, V.V. Works. Vol. 2, Izd-vo AN SSSR, 1950.

Dolgov, S.I. Investigation of the mobility of soil moistures and its accessibility to plants. Moscow-Leningrad, 1948.

Domrachev, D.V. Data on the climate, soil and vegetation of the upper reaches of the Tungir River of the Yakut Oblast. Tr. Amursk, eksped., No. 14, St. Petersburg, 1913.

Borovik-Romanova, T.F. Super-cooling of water in capillaries. Zhur. Russk. fiz.-khim. ob-va, ch. fiz., 1924, Vol. 56, No. 1.

Borovik-Romanova, T.F. Super-cooling of water drops. Tr. Leningr. in-ta eksper. meteorol., No. 1, 1937.

Bouyoucos, G.Y. Movement of soil moisture from small capillaries to the large capillaries of the soil upon freezing. Journ. of Agric. Res., 1923, Vol. 24, No. 5. Washington.

Bozhenova, A.P. Some developments in the experiments of Teber on the study of soils with vertical stratification. Tr. In-ta geol. nauk AN SSSR, No. 22, 1940.

Bozhenova, A.P. Migration of water in freezing soils. Rukopis', fondy In-ta merzlotoved., 1946.

Bozhenova, A.P. Super-cooling of water during the freezing of soils. Mat. po labor. issled. merzl. gruntov. Sb. 1. Izd-vo AN SSSR, 1953.

Bozhenova, A.P. The significance of osmotic forces in the migration of moisture in soils. Mat. po labor. issled. merzl. gruntov. Sb. 3. Izd-vo AN SSSR, 1957.

Bozhenova, A.P. and Bakulin, F.G. Experimental investigations of the mechanisms of moisture migration in freezing soils. Mat. po labor. issled. merzl. gruntov. Sb. 3. Izd-vo AN SSSR, 1957.

Bozhenova, A.P. and Shimanovskii, S.V. Instructions on the study of the freezing of soils. Mat. po labor. issled. merzl. gruntov. Sb. 2. Izd-vo AN SSSR, 1954.

Brattsev, L.A. Permafrost in other countries. Rukopis', fondy In-ta merzlotoved., 1940.

Buckingham, E. Studies on movement of soil moisture. U.S. Dep. Agric. Bur. of Soils. (Washington), 1907, Bull. 38.

Budnikov, A.N. Formulae for determining the depth of laying water pipes. Vodosnabzhenie i sanitarnaya tekhnika, 1938, No. 7.

Budyko, M.I. Heat balance of the northern hemisphere. Tr. Gl. geofiz. observ. No. 18/80, Leningrad, 1949.

Budyko, M.I. Heat balance of the earth's surface. Leningrad, Gidrometeoizdat, 1956.

Budyko, M.I., Berlyand, T.G. and Zubenok, L.I. Heat balance of the earth's surface. Izv. AN SSSR, seriya geogr., 1954, No. 3.

Bunge, A. Naturhistorische Beobachtungen und Fahrten im Lena Delta. Aus Briefen an den Akadem. L. v. Schrenk. Bull. Acad. imp. Sci. de St.-Pétersb., 1884, t. 29.

Bunge, A. Die von der Kaiserlichen Academie der Wissenschaften ausgerüstete Expedition nauch den Neusibirischen Inseln und dem Jana - Lande. Beiträge zur Kenntniss des Russischen Reiches und der angrenzenden Länder Asiens. 3-te Folge, Bd. III, St.-Pétersb., 1887.

Dorcey, N.E. Properties of ordinary water substance. N.Y., 1940.

Dostovalov, B.N. Physical conditions of the formation of frost fissures and the formation of fissure ice in soil. Sb. Issled. vechn. merzl. v Yakutsk. resp., No. 3, Izd-vo AN SSSR, 1952.

Dostovalov, B.N. (1) Mapping ground ice and the thickness of permafrost by the direct current method. Izd-vo AN SSSR, 1955.

Dostovalov, B.N. (2) The fundamentals of electric surveying of frozen soil by the resistance method. Rukopis', fondy In-ta merzlotoved., Moscow, 1955.

Dostovalov, B.N. Changes in the volume of soils on freezing and the formation of frost fissures. Mat. po labor. issled. merzl. gruntov, Sb. 3. Izd-vo AN SSSR, 1957.

Dranitsyn, D.A. On some zonal forms of relief in the Far North. Pochvovedenie, 1914, No. 4.

Dreving. The phase rule. Izd-vo MGU, 1954.

Dubinin, M.M. Surface oxides and the adsorption properties of active charcoal. Uspekhi khimii, 1955, No. 5.

Dücker, A. Frosteinwirkung auf bindige Böden. Strassenbau Jahrbuch. 1939/1940.

Dücker, A. Untersuchungen über die frostgefährlichen Eigenschaften nichtbindiger Böden. Forschungsarbeiten aus dem Strassenwesen, Bd. 17, Berlin, 1939.

Dumanskii, A.V. Heat of wetting and the hydrophilic properties of fine-grained systems. Kolloid. zhur., 1950, Vol. 12, No. 5.

Durdenevskaya, M.V. Permafrost and fossil ice in the shores of lakes in the valley of the Irkut River. Tr. Komiss. po izuch. vechn. merzl., Vol. 1, Leningrad, Izd-vo AN SSSR, 1932.

Dylik, J. Strukthury peryglacjalne w Tarzymiechach i ich znaczenie dla morfogeney i stratygrafii czwartorzedu. Biuletyn peryglacjalny, No. 3. Lodz, 1956.

Dzens-Litovskii, A.I. Mineral lakes under conditions of permafrost. Tr. Komit. po vechn. merzl., Vol. 6, Izd-vo AN SSSR, 1938.

Efimov, A.I. The Yakut artesian basin of sub-permafrost water. Izv. AN SSSR, seriya geol., 1945, No. 4.

Efimov, A.I. On the development of thermokarst lakes in central Yakutia. Investigation of permafrost in the Yakut Republic. No. 2, Izd-vo AN SSSR, 1950.

Efimov, A.I. Non-freezing fresh water springs of Ulakhan-Taryn in Central Yakutia. Issled. vechn. merzl. v Yakutsk. resp. No. 3. Izd-vo AN SSSR, 1952.

Efimov, A.I. and Grave, N.A. Cellar ice in the region of Lake Abalakh. Sots. stroit., No. 10-11. Yakutsk, 1940.

Efimov, A.I., Grave, N.A., Saltykov, N.I. and Solov'ev, P.A. Forms of relief, hydrogeological conditions and fossil ice in the region of Lake Abalakh. Rukopis', fondy In-ta merzlotoved., 1942.

Efimov, A.I., Kachurin, S.P. and Solov'ev, P.A. Permafrost-hydrogeological description of the region near the village of Churapcha (Lena-Amgin region of the Yakut ASSR). Rukopis', fondy In-ta merzlotoved., 1948.

Efimov, A.I., Mel'nikov, P.I. and Solov'ev, P.A. Sub-permafrost water of the city of Yakutsk. Rukopis', fondy In-ta merzlotoved., 1944.

Efimov, A.I. and Shumskii, P.A. Fossil ice in the region of Krest-Khal'dzhaya on the river Aldan. Rukopis', fondy Yakutsk. st. in-ta merzlotoved. i in-ta Merzlotoved., 1952.

Efimov, A.V. History of great Russian geographical discoveries in the Arctic and Pacific oceans in the 17th and 1st half of the 18th centuries. Moscow, 1950.

Egerev, K.E. Electric method of determining the tangential reactions distributed along the lateral surfaces of a pile with load applied and frozen in the soil. Tr. In-ta merzlotoved., Vol. 14, 1958.

Egorov, N.I. Frost maps and plans of the U.S.S.R. Tr. In-ta merzlotoved., Vol. 9, 1952.

Emel'yantsev, T.M. Geological investigations in the regions of the Kheta, Khatanga Rivers and the Taimyr Peninsula in 1935-1936. Geol. issled. Nordvik-Khatangskogo r-na. Izd-vo GUSMP, 1939.

Epshtein, P.S. Course in thermodynamics. Gostekhizdat, 1948.

Erikssen, S. Über die Einwirkung des Frostes auf die Struktur der Lehm- und Tonboden. Lantbrukshögskolans Annaler, Vol. 9, Upsala, 1941.

Ermolaev, M.M. (1) Geological and geomorphological notes on the Bol'shoi Lyakhovskii Island. Polar Geophysical Station on the Bol'shoi Lyakhovskii Island. Part I. Sb. statei. Tr. SOPS AN SSSR Leningrad, Izd-vo AN SSSR i Vses. arkhtich. in-ta, 1932.

Ermolaev, M.M. (2) Instructions on the field investigation of fossil ice as a geographic factor. Izd-vo Arkhtich. in-ta, Leningrad, 1932.

Ermolaev, M.M. Geology and minerals of the New Siberian Islands. Tr. SOPS AN SSSR, Yakutskaya ASSR, No. 2, Leningrad, 1933.

Ermolaev, M.M. History of the discovery of the New Siberian Islands, their investigation and development of industry on them. Sb. statei Polyarn. geofiz. st., na ostr. Bol'shom Lyakhovskom. Izd-vo AN SSSR i Vses. arkhtich. in-ta, Leningrad, 1952.

Erofeev, B.N. Brief geological survey of Chukchi. Mat. po geol. i polezn. iskop. Sev.-Vost. SSST, No. 1, Magadan, 1945.

Evdokimov, P.D. and Zauerbrei, I.I. The effect of freezing and thawing of moraine clay loam on its structural properties. Gidrotekhn. stroit., 1950, No. 2.

Evdokimov-Rokotovskii, M.I. The construction and utilization of engineering structures on permafrost. Tomsk, Izd-vo Sib. stroit. in-ta, 1931.

Fedosov, A.E. Physico-mechanical processes in soils during freezing and thawing. Moscow, Transzheldorizdat, 1935.

Fedosov, A.E. Mechanical processes in soils when liquid water freezes in them. Tr. In-ta geol. nauk, ser. inzhen.-geol., No. 35, No. 4, 1940.

Fedosov, A.E. (1) The prediction of the settlement of buildings on thawing permafrost (the moisture diagram method). Issled. vechn. merzl. v Yakutsk. resp., No. 1, Yakutsk, 1942.

Fedosov, A.E. (2) Phase composition of frozen soils. Sb. Issled. vechn. merzl. v Yakutsk. resp., No.1, Yakutsk. gos. izd-vo, 1942.

Fedosov, A.E. Predicting the settlement of buildings with thawing of the soil base. Tr. In-ta merzlotoved., Vol. 4, 1944.

Figurin, A.E. (1) Notes of the medical surgeon Figurin on various aspects of natural history and physics in the Ust'-Yana and surrounding regions in 1822. Sib. vestn. Gr. Spasskogo, Part 4, St. Petersburg, 1823.

Figurin, A.E. (2) Extract from the papers of Figurin on a description of the shores of northeastern Siberia. Zap. Gos. admiralt. depart., Part 5, St. Petersburg, 1823.

Filatov, M.M. Soil physics in the U.S.S.R. Editors N.A. Kachinskii and A.A. Yarilov. Moscow, Sel'khozgiz, 1936.

Fink, O.I. Stability of buildings under conditions of deep frost penetration. Sb. Vechn. merzl. i zhel.-dor. stroit., 1931.

Fiveiskii, D.A. The sinking and reinforcement of shafts in a permafrost stratum of the European North of the U.S.S.R. Tr. In-ta merzlotoved., Vol. 6, Moscow-Leningrad, Izd-vo AN SSSR, 1944.

Fotiev, S.M. Physico-geographical and geological bases for the effectiveness of various methods of thermal improvement of frozen soils. Rukopis', fondy In-ta merzlotoved., 1956.

Franchuk, A.U. Heat conductance of building materials in relationship to moisture. Stroiizdat, 1941.

Franchuk, A.U. Tables of heat engineering indices for building materials. Moscow-Leningrad, Stroiizdat, 1949.

Frank, F. and Mizes, R. Differential and integral equations in mathematical physics. Glavn. red. tekhn. liter., 1937.

Fries, Th.M. and Bergström, E. Några iakttagelser öfver palsar och deras förekomst i nordligaste Sverige. Geol. för. i Stockh. förh., 1911, Bd. 32, H. 1.

Fuks, N.O. The seeding of crystals. Uspekhi fiz. nauk, 1935, Vol. 15, No. 4.

Fundamentals of geocryology (permafrost studies). Chapter II. Engineering geology. Moscow, Izd-vo AN SSSR, 1959.

Fundamental concepts and terms in geocryology (permafrsot studies). Izd-vo AN SSSR, 1956.

Gallwitz, G. Eiskeile und glaziale Sedimentation. Geologica, 2. Berlin, 1949. Akademie-Verlag GmbH.

Gardner, W. The role of capillary potential in the dynamics of soil moisture. Journ. Agric. Res., 1936, 53, 57.

Gedroits, A.E. Geological investigations in the Transbaikal Oblast along the railway line between Sretenskoe and Pokrovskaya. Geol. issled. i razved. raboty po linii Sib. zh. d., No. 6, St. Petersburg, 1897.

Gedroits, N.A. Taimyr lowlands. Tr. Nauchno-issled. in-ta geol. Arktiki, Vol. 13, Leningrad-Moscow, GUSMP, 1951.

Gel'mersen, G. Notes concerning a well dug in Yakutia. Gorn. zhur., 1838, Part II, No. 4.

Gel'mgaker, Ya. The Siberian method of digging prospect pits in suspended soils. Vestn. zolotopromyshl, i gorn, dela voobshche, 1892-1893. No. 18, 19 and 20.

Gel'val'd, F.V. In region of permanent ice. History of expeditions to the North Pole from the earliest times to the present. Translated from German. St. Petersburg, 1881.

Georgi, J.G. Bemerkungen einer Reise im Russischen Reich in den Jahren 1772, 1772 und 1774. S.-Pb., 1775.

Gerasimov, I.P. Present-day survival of the late ice age phenomena in the region of the coldest part of the world. Izv. AN SSSR, ser. geogr., 1952, No. 5.

Gerasimov, I.P. and Markov, K.K. Ice age in the territory of the U.S.S.R. Tr. In-ta geogr. AN SSSR, No. 38, Moscow-Leningrad, 1939.

Gignoux, M. Les sols polygonaux dans les Alpes et la genèse des sols polaires. Ann. de géogr. (Paris), 1931, Vol. 40, No. 228.

Given, G. Kolloidale Eigenschaften des Tons und ihre Beeinflussung durch Kalksalze. Inaugural-Dissertation. Göttingen, 1915.

Gladtsin, I.N. Stone polygons. Izv. RTO, 1936, Vol. 68, No. 6.

Gmelin, G. Reise durch Sibirien. Göttingen, 1752.

Gokoev, A.G. Frost mounds and hydrolaccoliths in the Kazakh steppe. Izv. VGO, 1939, Vol. 71, No. 4.

Gol'dshtein, M.N. The migration of moisture in soil. Sb. nauch. issled. In-ta puti NKPS. Issledovanie raboty grunta v zheleznodorozhnykh sooruzheniyakh. Moscow, 1940.

Gol'dshtein, M.N. On calculating the forces of heaving. Stroitel'stvo zheleznykh dorog i putevoe khozyaistvo, 1941, No. 5-6.

Gol'dshtein, M.N. Deformation of the earth road-bed and foundations of structures during freezing and thawing. Tr. Vses. in-ta zhel.-dor. transp., No. 16. Transzheldorizdat, 1948.

Gol'dtman, V.G. The thawing of permafrost by re-cycle spraying. Tr. Vses. Magadansk. nauchno-issled. in-ta Minist. tsvetn. metall. SSSR, No. 3, Magadan, 1956.

Golovachev, F.A. Mineral springs in the southeast part of the Chukchi Peninsula. "Arctica", 1937, No. 5.

Golovkov, N.P. (1) Notes on the structure and morphological features of ice crystals. Zap. Vses. mineral. ob-va, Vol. 68, No. 2, 1939.

Golovkov, N.P. (2) Investigation of the ice in the Kungur cave. Uchen. zap. Leningr. univ., 21, seriya geol.-pochv. nauk, No. 5, 1939.

Gorbatskii, G.V. Some methods of physico-geographical study of the Arctic land mass in connection with its basic natural features. Uchen. zap. Leningr. gos. univ., No. 152, ser. geogr. nauk, No. 8, 1952.

Gorodkov, B.N. Large-mound peat formations and their geographic distribution. Priroda, 1928, No. 6.

Gorodkov, B.N. Permafrost and vegetation. Vechnaya merzlota. Sb. Materialy KEPS, No. 80, Leningrad, Izd-vo AN SSSR, 1930.

Gorodkov, B.N. Permafrost in the northern regions. Tr. SOPS AN SSSR, seriya sev., No. 1, Leningrad, Izd-vo AN SSSR, 1932.

Gorodkov, B.N. Problems of studying permafrost in connection with problems of northern development. Tr. Ural'sk. filiala AN SSSR, No. 2. Izd-vo AN SSSR, Leningrad, 1934.

Gorodkov, B.N. Pre-ice age landscape of the pleistocene in northern Asia. Dokl. AN SSSR, 1948, Vol. 61, No. 3.

Gorodkov, B.N. On soil-vegetation associations in the tundra and Arctic desert landscapes. Tr. 2-go Vses. geogr. s'ezda, Vol. 3, Moscow, 1949.

Gorodkov, B.N. Frost fissures of the soil in the North. Izv. Gos. geogr. ob-va 1950, Vol. 82, No. 5.

Govorukhin, D.S. Mound-studded swamps of northern Asia and warming of the Arctic. Uchen. zap. Mosk. obl. pedag. in-ta, Vol. 9, 1947.

Gräno, J.G. Die geographischen Gebiete Finnlands. Fennia, 1911, 52, No. 3.

Grauman, L. Drilling in permafrost. Vestn. zolotopromyshl. i gorn. dela voobshche, 1896, No. 12.

Grave, N.A. Fossil ice in the water divide of the Lena and Aldan Rivers. Tr. In-ta merzlotoved., Vol. 4, Moscow, 1944.

Grave, N.A. Geographic distribution of large masses of ground ice in the permafrost region and the extent to which they have been investigated. Mat. soveshch. po izuch. snega i l'da. Moscow. Izd-vo AN SSSR, 1951.

Grave, N.A. Permafrost in the valleys of rivers of the southwestern part of the central Siberian plateau. Tr. In-ta merzlotoved., Vol. 10, Moscow, Izd-vo AN SSSR, 1952.

Grave, N.A., Bobov, N.G., Sergeeva, V.I., Shvetsov, P.F. and Chkheidze, M.I. Permafrost in the valleys of rivers of the southwestern part of the central Siberian plateau. Otchet Nizhne-Tungusskoi eksped., 1950. Rukopis', fondy In-ta merzlotoved.

Grave, N.A. and Zaklinskaya, E.D. Cellar ice in the mouth of the Anadyr' River and some aspects of the quaternary history of this region. Mat. soveshchan. po izuch. snega i l'da. Moscow, Izd-vo AN SSSR, 1951.

Greze, V.N. The Taimyr Lake. Izv. VGO, 1947, No. 3.

Grigor'ev, A.A. Geology, relief and soils of the northwestern part of the Lena-Aldan plateau and the upper Yana ridge from the data of the 1925 expedition. Mat. Komiss. po izuch. Yakutsk, ASSR, No. 4, Leningrad, 1926.

Grigor'ev, A.A. Geomorphological notes on Yakutia. "Yakutiya". Izd-vo AN SSSR, Leningrad, 1927.

Grigor'ev, A.A. (1) Permafrost and ancient ice formation. Vechnaya merzlota. Sb. Materialy KEPS, No. 80, Izd.-vo AN SSSR, 1930.

Grigor'ev, A.A. (2) Morphology of the northeastern part of the Vilyui Okrug. Mat. Komiss. po izuch. Yakutsk, ASSR, No. 31, Leningrad, 1930.

Grigor'ev, A.A. Glaciation of Yakutia during the quaternary period. Tr. Komiss. po izuch. chetvert. perioda. Izd-vo AN SSSR, Vol. 1, 1932.

Grigor'ev, A.A. Some questions of physical geography. Voprosy filosofii, 1951, No. 1.

Grigor'ev, A.A. Geographical zones and some of their regularities. Izv. AN SSSR, ser. geogr., 1954. No. 4 and 5.

Grigor'ev, A.A. (1) The inter-relationship and inter-dependence of components of the geographic media and their role in the exchange of matter and energy. Izv. AN SSSR, ser. geogr., 1956, No. 4.

Grigor'ev, A.A. (2) The Subarctic. Izd. AN SSSR, 1946, i Gosgeografizdat, Moscow, 1956.

Grigor'ev, N.F. The role of permafrost and fossil ice in the formation of the landscape of the Lena River delta. Rukopis', fondy In-ta merzlotoved., 1950.

Grigor'ev, N.F. Frost and geological features of the northern part of the Yana River delta in the region of the mouth of the right-hand tributary. Issled. vechn. merzl. v Yakutsk. resp., No. 3, 1952.

Grigor'ev, N.F., Kuznetsova, T.P. et al. The characteristics of the upper strata of the frozen zones in the Ust'-Yana region of the Yakut A.S.S.R. Rukopis', fondy In-ta merzlotoved., 1955.

Grigor'eva, V.G. On the decrease in the freezing temperature of water in fine-grained soils. Sb. Mat. po labor. issled. merzl. gruntov, No. 3, Izd-vo AN SSSR, 1957.

Guany, B. Sorption of water and toluene vapors on bentonite. Journ. Indian Chem. Soc., 1954, Vol. 31, No. 1.

Gubkin, N.V. Notes on the hydrogeology of part of the Okhotsko-Kolyma Krai. "Kolyma", 1944, No. 6.

Gubkin, N.V. (1) Permafrost hydrogeology and the construction of mine shafts in the Okhotsko-Kolyma Krai. "Kolyma", 1946, No. 8.

Gubkin, N.V. (2) Ground water flow under river beds as a base for winter supply of water. "Kolyma", 1946, No. 11.

Gubkin, N.V. Ground water of the upper reaches of the Kolyma River. Moscow, Izd-vo AN SSSR, 1952.

Gukhman, A.A. Physical basis of heat transfer. ONTI, 1934.

Gusev, A.I. (1) Post-tertiary history of the northern part of the Kharaulakh ridge. Izv. GGO, 1938, Vol. 70, No. 2.

Gusev, A.I. (2) Tetragonal soil in the arctic tundra. Izv. Gos. geogr. ob-va, 1938, No. 3.

Gusev, A.I. Post-tertiary and present-day geological phenomenon in northern Kharaulakh and adjacent regions. Rukopis', fondy In-ta merzlotoved., 1940.

Gusev, A.N. Geology, coal and oil deposits in the lower reaches of the Olenek River. Leningrad-Moscow, Tr. Nauchno-issled. in-ta geol. Arktiki, 1950.

Hamberg, A. Zug Kenntnis d. Vorgänge im Erboden beim Gefrieren und Aufrauen sowie Bemerkungen über die erste Kristallisation des Efses in Wasser. Geol. Fören. i Stockh. Förh., 1915, Bd. 37, H. 5.

Handbook of Chemistry and Physics. Chemical Rubber Publishing Co. Clevelland, Ohio, 1951.

Hedin, Sven. Central Asia and Tibet. Vol. I, II, 1903.

Hedin, Sven. Über den Transhimalaya, 1919. Köln, H. Schlaffstein.

Henkel, L. Eis als geologische Schicht. Geogr. Ztschr. (Leipzig), 1911, Jg. 17.

Hesselman, H. Studier över skogskäxt a mossar. Skogsvärdsförentidskr., 1907.

Högbom, B. Einige Illustrationen zu den geologischen Wirkung des Frostes auf Spitzbergen. Bull. Geol. Inst. of the Univ. of Upsala, 1910, Vol. 9 (1903-1909).

Högbom, B. Über die geologische Bedeutung des Frostes. Bull. Geol. Inst. of the Univ. of Upsala, Vol. 12, 1913-1914.

Högbom, B. Beobachtungen aus Nordschweden über den Frost als geologischer Faktor. Bull. Geol. Inst. of the Univ. of Upsala, Vol. 20, 1925-1927.

Holmquist, P.J. Über mechanische Störungen und chemische Umsetzungen in dem Bänderton Schwedens. Bull. Geol. Inst. of the Univ. of Upsala, 1897, Vol. III, p. 2, No. 6. Upsala, 1898.

Holmsen, G. Spitzbergens jordbundsis. Det Norske Geogr. Selskabs Aarbok, XXIV. Kristiania, 1912-1913.

Homen, Th. Der Wärmeumsatz im Boden. Leipzig, 1897.

Ignatovich, N.K. On the distribution and formation of ground water. Dokl. AN SSSR, 1944, Vol. 45, No. 3.

Il'in, V.S. Ground water. Bol'sh. sov. entsikl., Vol. 19, 1943.

Instructions on studying frozen soils in Siberia. Pod ped. I.V. Mushketova. Prilozhenie k Izv. Russk. geogr. ob-va, Vol. 31, No. 1, 1895.

Instructions on protecting soils and soil foundations from freezing. Gos. izd-vo liter. po stroit. i arkhit., Moscow, 1953.

Investigations of frost heaving on automobile roads. Sb. pod ped. prof. N.V. Ornatskogo Tr. DORNII, No. 2, Moscow, Dorizdat Gushosdora NKVD SSSR, 1941.

Ivanov, B.A. Diagram of the geological regions of Eastern Siberia. Irkutsk, 1939.

Ivanov, N.S. (1) Dynamics of heat exchange in the soil stratum having an annual temperature variation and in the upper permafrost strata in the region of Yakutsk. Rukopis', fondy In-ta merzlotoved., 1956.

Ivanov, N.S. (2) Method of thermal calculations and dynamics of heat exchange in soils in the region of Yakutsk. Rukopis', fondy In-ta merzlotoved., 1956.

Ivanova, E.N. and Koposov, N.A. Soils of the tundra in the region of Khibiny. SOPS AN SSSR, No. 13, 1937.

Izmail'skii, A.A. Soil moisture and ground water. 1894.

Jenness, L.J. Permafrost in Canada. Arctic, 1949, Vol. 2, No. 1.

Johnston, W. Frozen ground in the glaciated parts of Northern Canada. Transact. Roy. Soc. Canada. Sect. 4, 3-rd ser., Vol. 24, Pt. I, 1940.

Jung, E. Weiterer Beitrag zur aggregirenden Einwirkung des Frostes auf den Erdboden. Ztschr. f. Pflanz. Düng. u. Bod., 1932, B. 24, H. 1/2.

Jura, G. and Harkins, W.D. Surfaces of solids. XI. Determination of the decrease (π) of free surface energy of a solid by an absorbed film. Journ. Amer. Chem. Soc. (Washington), 1944, Vol. 66, No. 8.

Kachinskii, N.A. Freezing and thawing and the moisture of soil during the winter in forests and fields. Moscow, Izd-vo Mosk. gos. univ., 1927.

Kachurin, S.P. (1) Permafrost and geomorphological observations in the mouth of the Anadyr' River in 1935. Tr. Komit. po vechn. merzl., Vol. 6, Moscow-Leningrad, Izd-vo AN SSSR, 1938.

Kachurin, S.P. (2) The receding of permafrost. Dokl. AN SSSR, 1938, Vol. 19, No. 8.

Kachurin, S.P. Solifluction terraces in regions of permafrost. Tr. Komit. po vechn. merzl. Vol. 7, Izd-vo AN SSSR, 1939.

Kachurin, S.P. On the genesis of the more common fossil ice of the North. Izd-vo AN SSSR, Moscow-Leningrad, 1946.

Kachurin, S.P. (1) Permafrost in the extreme northeast of the U.S.S.R. Tr. In-ta merzlotoved., Vol. 7, 1950.

Kachurin, S.P. (2) Types of permafrost in the central and eastern Transbaikal regions. Tr. In-ta merzlotoved., Vol. 8, 1950.

Kachurin, S.P. Some data on permafrost and forms of relief in the region between the Lena and Vilyui Rivers. Tr. In-ta merzlotoved., Vol. 12, 1953, Moscow, Izd-vo AN SSSR.

Kachurin, S.P. Thermokarsts on the territory of the U.S.S.R. Doktorskaya dissertatsiya, Rukopis', fondy In-ta merzlotoved., 1956.

Kachuro, Yu.I. Water discharge from the Lazo spring. "Kolyma", No. 7, 1946.

Kalabin, A.I. Water supplied to the Dal'stroi enterprise under conditions of permafrost. Izd-vo "Sovetskaya Kolyma", Magadan, 1945.

Kalabin, A.I. Permafrost and the hydrogeology of northeastern U.S.S.R. Rukopis', fondy Mosk. gos. univ., 1955.

Kalabin, A.I. Problems of permafrost as related to development of the north-east, Dal'stroi (25th anniversary). Sb. "Magadansk. knizhn. izd-vo, 1956.

Kalesnik, S.V. General glaciology. Uchpedgiz, Leningrad, 1939.

Kalesnik, S.V. Fundamentals of general soil science. Uchpedgiz, Moscow, 1955.

Kamenskii, G.N. Surveying for ground water. Gosgeolizdat, 1947.

Kapustinskii, A.F. and Samoilov, O.Ya. Thermal chemistry and the structure of the atom. Izv. AN SSSR, Otd. khim. nauk, 1950, No. 4.

Katasonov, E.M. Lithology of frozen quaternary deposits (cryolithology) of the Yana coastal lowlands. Rukopis' kand. issled., fondy In-ta merzlotoved., 1954.

Kersten, M.S. The thermal conductivity of soils. Proceedings. 2-nd Intern. confer. on soil mechanics and foundation engineering, Vol. 3. Rotterdam, 1948.

Kersten, M.S. Thermal properties of soils. Frost action in soils. A Symposium. Highway Research Board Special Report 2, Minneapolis, 1949.

Khakimov, Kh.R. Problems of theory and practice in the artificial freezing of soils for construction purposes. Izd-vo AN SSSR, Moscow, 1957.

Khmyznikov, P.K. Hydrology of the Yana River basin. Izd. Akad. nauk i Gidrograf. upr. GUSMP, Leningrad, 1934.

Khromov, S.P. On reasons and factors of climate. Izv. Vses. geogr. ob-va, 1951, Vol. 33, No. 6.

Khromov, S.P. Climate, macro-climate, local climate and micro-climate. Izv. Vses. geogr. ob-va, 1952, Vol. 35, No. 3.

Khromov, S.P. and Mamontova, L.I. Meteorological dictionary. Leningrad, Gidrometeoizdat, 1955.

Kihlman, A.O. Pflanzenbiologischen studien aus Russisch Lappland. Acta Soc. pro fauna et flora fennica, VI, 1890.

Kim, N.V. and Pavlov, B.S. Ground ice. Byull. tekhn. inform., Noril'sk, komb. MVD, 1943, No. 5-6.

Kim, N.V. and Pavlov, B.S. Methods of basing structures on frozen soil. Byull. tekhn. inform. Noril'sk, komb. MVD, 1945, No. 3-4(10-11).

Kin, B.A. Physical properties of soil. Leningrad-Moscow, GTTI, 1933.

Kintzl, H. Beobachtungen über Strukturboden in den Ostalpen. Peterm. geogr. Mitt. (Gotha), 1928, Jg. 74.

Kirpichev, M.V., Mikheev, M.A. and Eigenson, M.F. Heat transfer. Gosenergo-izdat, 1940.

Kitredzh, D. (Kittredge). The effect of forest on climate, soil and water regime. Moscow, Izd-vo inostr. liter., 1951.

Klute, F. Ergebnisse d. Forschungen am Kilimandscharo, 1912. Berlin, 1920.

Kokkonen, P. Beobachtungen über die Struktur des Bodenfrostes. Acta forestialia fennica, 1926, 30, No. 3.

Kolesnikov, A.G. On changing the mathematical formulation of the problem of soil freezing. Dokl. AN SSSR, 1952, Vol. 82, No. 6.

Kolesnikov, A.G. and Martynov, G.A. Calculation of the depth of freezing and thawing of soils. Mat. po labor. issled. merzl. gruntov. Sb. 1, Moscow, Izd-vo AN SSSR, 1953.

Koloskov, P.I. On the problem of thermal improvement of the soil. Izv. opytn. polei Amursk. obl., No. 2. Blagoveshchensk, 1918.

Koloskov, P.I. Climatic bases of agriculture in the Amur Oblast. Far eastern regional meteorological bureau. Vol. 8, Blagoveshchensk, 1925.

Koloskov, P.I. On the problem of thermal improvement in regions of permafrost and deep frost penetration of the soil. Vechnaya merzlota. Sb. Materialy KEPS, No. 80, Izd-vo AN SSSR, 1930.

Koloskov, P.I. (1) The relationship between the temperature of the soil and the temperature of the air in regions of permafrost as an indicator of agricultural and climatic potentials. Tr. Komiss. po izuch. vechn. merzl. Vol. 1, Izd-vo AN SSSR, Leningrad, 1932.

Koloskov, P.I. (2) Preliminary organizational plan of experimental permafrost studies for the gold mining industry and programme of operations for the summer of 1932. Rukopis', fondy In-ta merzlotoved., 1932.

Koloskov, P.I. On the origin of ground ice. Izv. AN SSSR, ser. geogr. i geofiz., 1946, Vol. 10, No. 6.

Koloskov, P.I. Drying and ground ice in Central Yakutia. Rukopis' fondy In-ta merzlotoved., 1947.

Koloskov, P.I. On taking into account climatical factors of soil freezing. Rukopis', fondy In-ta merzlotoved., 1952.

Kolosov, D.M. On secondary ice formation as a geomorphological process. Probl. fiz. geogr., Vol. 6, 1938.

Kolosov, D.M. Problems of ancient glaciation of the northeastern U.S.S.R. Tr. GGU GUSMP, No. 30, 1947.

Komarova, N.A. The movement of water in soils in connection with diffusion of fertilizers. Sb. nauch. rabot komsomol'tsev AN SSSR, posvyashch. X s'ezdu VLKSM, 1936.

Kondrat'ev, K.Ya. Thermal regime of the stratosphere. Priroda, 1952, No. 7.

Konstantinova, G.S. Permafrost in the Yenisei-Pyasina river valleys. Rukopis', fondy In-ta merzlotoved., 1954.

Korkina, R.I. Report on electrometric field work in Yakutia in 1950. Rukopis', fondy In-ta merzlotoved., 1952.

Koshlakov, K.V. Better utilization of radiant solar energy in open cast mining. "Kolyma", 1953, No. 7.

Kostetskaya, T.P. and Martynov, G.A. X-ray investigations of frozen soils and ice. Rukopis', fondy In-ta merzlotoved., 1951.

Kotsebu, O. and Shamisso, A. Journey in the "Yuzhnyi" Ocean and the Bering Strait in search for a northeast sea passage undertaken in 1815, 1816, 1817 and 1818 on the ship "Ryurik" under the leadership of Lt. Kotsebu. Part I-III, St. Petersburg, 1821-1823.

Kotzebu, O. Entdeckungsreise in der Südsee und nach der Beringstrasse. Weimar, 1821.

Kovner, S.S. On one problem in heat conductance. Zhur. geofiz., 1933, Vol. 3, No. 1.

Koz'min, N.M. On the influence of permafrost in some localities of Eastern Siberia. Izv. Vost.-Sib. otd. Russk. geogr. ob-va, 1892, Vol. 23, No. 4-5.

Kraskovskii, S.A. Geothermal measurements in the U.S.S.R. Moscow-Leningrad, Izd-vo AN SSSR, 1941.

Kraskovskii, S.A. The temperature gradient in the earth's crust. Izv. Vses. geogr. ob-va, 1948, No. 2.

Krasnov, I.I. Result of investigations of the quaternary deposits of the "Bol'shesemel'skaya" tundra and the Pechor'e lowlands. Byull. Komiss. po izuch. chetvert. perioda, 1947, No. 9.

Krebs, Norbart. Klimatisch bedingte Bedenformen in den Alpen. Geogr. Ztschr. (Leipzig), 1925, Jg. 31, H. 2.

Krylov, M.M. The accumulation of cold in the soil as a factor in reducing drought. Vestn. sel.-khoz. nauki. Melioratsiya i gidrotekhnika, No. 1, 1940.

Krylov, M.M. Frozen dams. Merzlotovedenie, 1946, Vol. 1, No. 1. Izd-vo AN SSSR, 1946.

Krylov, M.M. Isothermic ice deposits. Izd-vo AN SSSR, 1951.

Krylov, M.M. Transformation of nature by means of hydrothermal improvement. Voprosy geografii, Sb. 28, 1952.

Kudryavtsev, V.A. Permafrost dynamics in the northern basin of the Selemdzhi River and building conditions in this region. Tr. Komit. po vechn. merzl., Vol. 8, Moscow-Leningrad, Izd-vo AN SSSR, 1939.

Kudryavtsev, V.A. Methods of determining the dynamics of the freezing process during engineering-geological investigations. Rukopis', fondy In-ta merzlotoved., Moscow, 1944.

Kudryavtsev, V.A. Temperature regions in the permafrost zones of the U.S.S.R. Rukopis', fondy In-ta merzlotoved., 1950.

Kudryavtsev, V.A. (1) Processing the results of temperature measurements in the Sherginskii mine in Yakutsk for the period of 1845 to 1941. Tr. In-ta merzlotoved., Vol. 12, 1953.

Kudryavtsev, V.A. (2) On the dynamics of permafrost. Tr. In-ta merzlotoved., Vol. 12, 1953.

Kudryavtsev, V.A. (3) Seasonal freezing and thawing of soils in the permafrost regions of the U.S.S.R. Rukopis', fondy In-ta merzlotoved., 1953.

Kudryavtsev, V.A. Temperature of the upper strata of permafrost within the U.S.S.R. Leningrad, Izd-vo AN SSSR, 1954.

Kursanov, A.L. The importance of isotopes and other recent methods of investigation in biology for solving problems in agriculture. Izv. AN SSSR, ser. biol., 1954, No. 1.

Kushev, S.L. (1) Permafrost in the lower reaches of the Nizhnei Tunguski River. Komiss. po izuch. vechn. merzl., Vol. 3, Izd-vo AN SSSR, 1934.

Kushev, S.L. (2) Geomorphology of the valley of the lower reaches of the Nizhnei Tunguski River. Tr. Geomorfol. in-ta AN SSSR, No. 2, 1934.

Kushev, S.L. Morphology and genesis of hillocky forest covered marshlands and their geographical distribution. Tr. Komit. po vechn. merzl., Vol. 8, Izd-vo AN SSSR, Leningrad-Moscow, 1939.

Kuzeneva, O.I. Evolution of swamps in the Amur Oblast and experiments in classifying them. Pochvovedenie, 1911, No. 2.

Kuznetsov, V.D. Surface energy of crystals. Priroda, 1952, No. 9.

Kuznetsov, V.D. Surface energy of solids. Moscow, 1954.

Kvashnin-Samarin, N.V. On the question of frost as a factor in soil formation in the western part of the Amur Oblast and on the Olekma water divide. Mat. po izuch. russk. pochv. No. 20, St. Petersburg, 1910.

Kvashnin-Samarin, N.V. On some observations of the micro-relief of frozen soils and its significance. Mat. po izuch. russk. pochv. No. 23, St. Petersburg, 1913.

Laboratory investigations of mechanical properties of frozen soils. Tr. Dal'nevost. kompl. eksped. AN SSSR, Sb. 1. Moscow-Leningrad, Izd-vo AN SSSR, 1936.

Laboratory investigations of the mechanical properties of soils. Tr. Dal'nevost. kompl. eksped. AN SSSR, Sb. II, Moscow-Leningrad, Izd-vo AN SSSR, 1936.

Laletin, N.V. Problems of calculating non-linear deformation of natural bases. Vestn. Voenno-inzh. Krasnoznam. akad. im. V.V. Kuibysheva, No. 78, Sb. po osnovaniyam i fundamentam. Moscow, Izd-vo Voenno-inzh. akad., 1954.

Lamansky, W.W. Das Absterben der Gletscher und die Eiszeit. Zs. f. Gletscherk, 1914, Bd. 8, H. 3.

Lamé and Clapeyron. Mémoire sur la solidification par refroidissement d'un globe liquide. Ann. Chim. et Phys. (Paris), 1831, Vol. 47.

Lange, O.K. Data on the classification of ground water. Tr. 1 go gidrogeol. s'ezda. No. 8, Leningrad, 1934.

Lange, O.K. Ground water regions. Notes on the hydrogeological regions of the U.S.S.R. Mat. k pozn. geol. stroen. SSSR, nov. seriya, No. 3/12, MOIP, 1947.

Lapkin, G.I. Calculating the settlement of structures on thawing permafrost based on experiments with natural specimens carried out under laboratory conditions. Byull. Soyuztransproekta, 1939. No. 12.

Lapkin, G.I. Calculation of the settlement of structures on thawing soils by the method of contact pressures. Moscow, Stroiizdat, 1947.

Laptev, Kh.P. Notes on observations of the fleet under the command of Lt. Khariton Laptev during the Kamchatka expedition between the Lena and Yenisei rivers on the condition of the rivers and of the people living on them. Zap. Gidrograf. depart. Morsk. minist., Part 9, 1851.

Lebedev, A.F. The role of water vapour in the regime of ground water. Tr. po sel.-khoz. meteor., No. 12, 1913.

Lebedev, A.F. On the movement of salts in soil having moisture of different category. Tr. Pochv. in-ta AN SSSR, No. 3-4, 1930.

Lebedev, A.F. Ground water. 1-e izd. Sel'khozgiz, Moscow-Leningrad, 1930; 4-e izd., Moscow-Leningrad, 1936.

Leffingwell, K. Ground ice wedges, the dominant form of ground ice on the north coast of Alaska. Journ. Geol., 1915, Vol. 23, No. 7.

Leffingwell, K. The Canning River region, Northern Alaska. Unit. Stat. Geol. Surv. Prof. Pap., No. 109. Washington, 1919.

Leibenzon, L.S. Handbook on mechanics in the petroleum industry. Moscow, ONTI, 1931.

Leibenzon, L.S. On the question of hardening of the earth's crust from an initial molten state. Izv. AN SSSR, ser. geogr. i geofiz., 1939, No. 6.

Leibenzon, L.S. The movement of liquids and gases in a porous medium. Gostekhizdat, 1947.

Leonov, P.A. Ice fill. "Za ugol' Vostoka", 1931, No. 15.

Leont'ev, A.V. The effect of rivers, lakes and snow cover on the temperature regime of the soil in one region of the Taimyr. Rukopis', fondy In-ta merzlotoved., 1947.

Levitskii, A.P. On the problem of the evolution of swamps in the Amur Oblast. Pochvovedenie, 1910, Vol. 12, No. 1.

Lichkov, B.L. Fundamental characteristics of the classification of ground water. Tr. Gos. gidrol. in-ta, No. 2, 1933.

Liverovskii, A.V. and Morozov, K.D. Construction under conditions of permafrost. Moscow-Leningrad, Stroiizdat, 1941.

Lomonosov, M.V. "On earth strata" and other papers on geology. Gosgeolizdat, 1949.

Lomonosov, M.V. Notes on atmospheric phenomena of electric origin. Sobr. soch., 3, 1952.

Loparev, M.G. and Tolstikhin, N.I. Hydrolaccoliths of Khada-Bylaka. Izv. VGO, 1939, Vol. 71, No. 9.

Lopatin, I.A. On the solving the problem of the origin of false stratification of soil. Zap. Mineral. ob-va, ser. 2, Part 8, St. Petersburg, 1873.

Lopatin, I.A. Some information on ice strata in Eastern Siberia. Prilozhenie No. 1 and 29. Zap. Akad. nauk. St. Petersburg, 1876.

Lopatin, I.A. Diary of the Turukhan expedition in 1866. Zap. Russk. geogr. ob-va, Vol. 28, No. 2, 1897.

Lukashev, K.I. Mound formation as a manifestation of ground pressure in connection with permafrost. Uch. zap. Leningr. gos. univ., No. 10. Zemnaya kora, Vol. 2, 1936.

Lukashev, K.I. The premafrost region as a particular physico-geographical and construction region. Leningrad, Izv. Leningr. gos. univ., 1938.

Luk'yanov, V.S. Method of calculating the depth of freezing of the soil. Soobshch. No. 10. TsNIIS MPS, Moscow, 1951.

Luk'yanov, V.S. and Golovko, M.D. Instructions on the thermal calculation of water pipes laid in regions of seasonal freezing of the soil (project). 1954.

Luk'yanov, V.S. and Golovko, M.D. Calculation of the freezing depth of soil. Transzheldorizdat, 1957.

Luk'yanov, V.S., Gol'dshtein, M.N. et al. Construction of earthen road beds during the winter. Moscow, Transzheldorizdat, 1946.

L'vov, A.V. Search and testing of water supply in the western part of the Amur railroad under conditions of permafrost. Irkutsk, 1916.

L'vov, A.V. and Kropachev, G. A short account of the results of investigating Arshan. Izv. Vost.-Sib. otd. Russk. geogr. ob-va, 1909, Vol. 40.

Lykov, A.V. On the theory of moisture migration in bodies containing capillaries and pores. Kolloid. zhur., 1947, Vol. 9, No. 2.

Lykov, A.V. The theory of drying. Moscow-Leningrad, 1950.

Lykov, A.V. (1) Differential equations of heat and mass exchange and the system of criteria in hydrothermal similarity. Izv. VTI, 1952, No. 10.

Lykov, A.V. (2) Theory of heat conductance. Gostekhizdat, 1952.

Lykov, A.V. Transfer in bodies containing capillaries and pores. Moscow, Gostekhizdat, 1954.

Lykov, A.V. Heat and mass exchange during the drying process. Gosenergoizdat, 1956.

Lyuboslavskii, G.A. On the effect of soil cover on its temperature. Izv. St.-Petersburg lecn. in-ta., St. Petersburg, 1900.

Lyuboslavskii, G.A. The effect of the surface cover of soil on temperature and exchange of heat in the upper strata. St. Petersburg, 1909.

Lyundegord, G. The effect of climate and soil on vegetation. Moscow, 1937.

MacCarthy, E.E. Stripping frozen gravel in Theraskow. Min. Mag., 1914, No. 10.

Maddren, A.G. Smithsonian Exploration in Alaska in 1904, in search of Mammoth and other fossil remains. Smith. Misc. Coll., 1905, Vol. 49, No. 1884.

Maidel', G. A journey along the northeast part of the Yakutsk Oblast in 1868-1870. Vol. 1, 1884; Vol. 2 with atlas, 1896.

Makarenko, F.A. On the mechanism of underground water supply for rivers. Dokl. AN SSSR, 1947, Vol. 57, No. 5.

Makerov, Ya. Mountain terraces in Siberia. Izv. Geol. kom., 1913, Vol. 32, No. 8.

Maksimov, V.M. and Tolstikhin, N.I. Hydrogeological sketch of the Yakut artesian basin adjacent to the Lena River. Rukopis', fondy In-ta merzlotoved., 1944.

Maksimovich, G.A. Cave ice. Izv. VGO, 1947, Vol. 59, No. 5.

Marinesko, N. Polarisation diélectrique et structure des colloides. Journ. Chem. et Phys., 1931, No. 1.

Markov, F.G. Geological investigations along the meridian intersect from the middle reaches of the Kotyya River across Taimyr Peninsula to the mouth of the lower Taimyr River. Tr. Nauchno-issled. in-ta geol. Arktiki, GUSMP, Vol. 16, 1951.

Markov, K.K. Polygonal (cellular) formations in northern Pamir. Izv. Gos. geogr. ob-va, 1934, Vol. 16, No. 3.

Markov, K.K. On the metachronism of glaciation. Izv. AN SSSR, ser. geogr. i geofiz., 1938, No. 2-3.

Markov, K.K. Present-day problems in glaciology and paleoglaciology. Vopr. geogr. Sb. 1. Geografgiz, Moscow, 1946.

Martynov, G.A. Thermal properties of permafrost. V sb. Mat. po labor. issled. merzl. gruntov, razd. I, Ch. 5 §2. Izd-vo AN SSSR, 1957.

Martynov, G.A. and Shimanovskii, S.V. Thermocouples for investigating the temperature regime of soils under natural conditions. Sb. Sezonnoe promerzanie i protaivanie gruntov, Moscow, Izd-vo AN SSSR, 1957.

Matthes, F. Glacial sculpture of the Bighorn Mountains, Wyoming. "Twenty-first annual report" of the Unit. St. Geol. Surv., p. II. Washington, 1900.

Matyushkin, F.F. Journey to the large and small Anyui in 1821 and letters. Ch. 3, Part 2. Journey along the northern shores of Siberia and the Arctic Ocean by F.P. Vrangel'.

Medvedev, P.M. Concerning the northern tree line and reasons for the lack of forests in the tundra region of Asia. Izv. Vses. geogr. ob-va, 1952, Vol. 84, No. 3.

Meglitskii. General account of the Verkhoyana search party during the summer of 1850. Gorn. zhur., 1851, Part II, No. 5.

Meister, L.A. Permafrost in the region of Igarka and methods of mapping it. Rukopis', fondy In-ta merzlotoved., Moscow, 1948.

Meister, L.A. Defects in the classification of ground water in regions of permafrost. Sb. Mat. k osnov. uchen. o merzl. zonakh zemn. kory. No. 2, Moscow, Izd-vo AN SSSR, 1955.

Meister, L.A. and Shvetsov, P.F. On some terms in the study of permafrost zones and its place among other sciences. Izv. AN SSSR, ser. geogr., 1955, No. 1.

Meister, L.A. and Shvetsov, P.F. On basic concepts, their definition and terms in the study of permafrost zones. Dokl. Mezhduved. soveshch. po merzlotoved. v marte 1956.

Melamed, V.G. On solving the Stefan problem by reducing it to a system of ordinary differential equations. Dokl. AN SSSR, 1957, Vol. 116, No. 4.

Mel'nikov, P.I. Permafrost in the region of Yakutsk. Sb. Issled. vechn. merzl. v. Yakutsk. resp., No. 2. Izd-vo AN SSSR, 1950.

Mel'nikov, P.I. Permafrost-geological conditions for the construction of civilian and industrial buildings in the territories of Central Yakutia and experience in construction. Moscow, Izd-vo AN SSSR, 1951.

Mel'nikov, P.I. Dynamics of permafrost under buildings and the calculation of foundations for conditions of low temperature permafrost in the city of Yakutsk. Sb. Issled. vechn. merzl. v Yakutsk. resp., No. 3. Izd-vp AN SSSR, 1952.

Mel'nikov, P.I. and Efimov, A.I. Experience in the utilization of ground water in regions of permafrost in Central Yakutia. Izd-vo AN SSSR, 1953.

Mel'nikov, P.I. and Meister, L.A. Determining the adhesive force between frozen ground and wood and concrete and sheer resistance of frozen soil under field conditions. Tr. Komit. po vechn. merzl., Vol. 10, Moscow-Leningrad, Izd-vo AN SSSR, 1940.

Middendorf, A.F. Journey to the north and east of Siberia. Part I, St. Petersburg, 1860.

Middendorff, A.Th. Reise in den äussersten Norden und Osten Sibiriens. Bd. I, Th. 1, 1848.

Middendorff, A.Th. Reise in den äussersten Norden und Osten Sibiriens. Bd. IV, Th. 1, 1861.

Mikhailov, N.I. Geomorphological observations in the western part of the Putorana mountains. Vopr. geogr., sb. 3, 1947.

Mikheev, M.A. Fundamentals of heat transfer. Gosenergoizdat, 1949.

Mishin, M.D. Data and observations of the Ulangin meteorological station for the summer of 1910. Tr. Amursk. eksped., No. 14, St. Petersburg, 1913.

Mizerov, A.V. Data on snow cover on the northwestern shore of Kamchatka Peninsula. Izv. Gos. geogr. ob-va, 1937, No. 2.

Mordvinov, A.I. Relief and permafrost of the left-hand bank in the middle course of the Byssy River and the adjacent foothills of the western slope of the Turana mountain ridge. Tr. Komit. po vechn. merzl., Vol. 9, 1940.

Morland, M. Adsorption of ammonia by clays and muck. Soil Sci., 1955, Vol. 80, No. 1.

Moroshkin, V.I. On the question of the formation of ice crystals in frozen soil. Sb. 28, NIIP NKPS, 1933.

Mortensen, H. Einige Oberflächenformen in Chili und auf Spitzberge. Peterm. geogr. Mitt., 1930, Erg. H. 209.

Moskvitin, A.I. On fossil remnants of "permafrost". Byull. Komiss. po izuch. chetvert. perioda, No. 12, Izd-vo AN SSSR, Moscow, 1948.

Mukhin, N.I., Grigor'eva, E.G., Tolstov, A.N. et al. Permafrost-geological conditions in the eastern part of the Yano-Indigirka coastal lowlands and the Sredne-Indigirka lowlands. Rukopis', fondy In-ta merzlotoved., 1955.

Mullokandov, R.N. Contact heat conductance of a layer of spherical particles. ZhTF, Moscow-Leningrad, 1947, Vol. 17, No. 10.

Mushketov, I.V. Physical geology. Vol. 2, 1905.

Myshkovskaya, E.E. Meteorological, soil and botanical-geographic observations at the Bomnak Station during the summer of 1910. Tr. Amursk. eksped., No. 14, St. Petersburg, 1913.

Naginskii, N.A. Mechanism of the increase in quaternary ice cover of the west Siberian lowlands. Dokl. AN SSSR, 1953, Vol. 91, No. 3.

Nansen, F.V. Into the land of the future. The great northern route from Europe to Siberia through the Kara Sea. Petrograd, 1915.

Nasedkin, N.A. and Pokrovskii, G.I. On heat diffusion in clay and peat. ZhTF, 1939, Vol. 9, No. 16.

Nekipelov, V. Geological description of a place in the region of the railroad from the Kerak to the Chaldonka stations. Rukopis', fondy stroit. Amursk. zhel. dor., 1908.

Nersesova, Z.A. Changes in the ice content of soil depending on temperature. Dokl. AN SSSR, 1950, Vol. 75, No. 6.

Nersesova, Z.A. On the thawing of ice in soils at below freezing temperatures. Dokl. AN SSSR, 1951, Vol. 79, No. 3.

Nersesova, Z.A. (1) The calorimetric method of determining ice content. Mat. po labor. issled. merzl. gruntov. Sb. 1, Izd.-vo AN SSSR, 1953.

Nersesova, Z.A. (2) Phase composition of water in soil during freezing and thawing. Mat. po labor. issled. merzl. gruntov. Sb. 1, Izd.-vo AN SSSR, 1953.

Nersesova, Z.A. Categories of moisture in frozen soils. Mat. po labor. issled. merzl. gruntov. Sb. 3, Izd-vo AN SSSR, 1957.

Nikiforov, K. On some dynamic processes in soils in regions where permafrost is propagating. Pochvovedenie, 1912, No. 2.

Nikiforov, K. Soil and geographical observations in the summer of 1910 in the region of the Unakhi meteorological station. Tr. Amursk. eksped., No. 14, St. Petersburg, 1913.

Nikiforov, K. The perpetually frozen subsoil of Siberia. Soil Sci., 1928, Vol. 26, No. 1.

Nikol'skii, A.P. Hot springs in the region of the Lavrentii Bay and Mechigmen Inlet. "Arktika", 1937, No. 5.

Notes on observations carried out in the Kerchinskii industrial district on freezing and thawing of soil in 1836 in regions that have been ploughed for cereal crops. Gorn. zhurn., 1838, Part II, No. 4.

Novakovskii, S.F. Investigation of the thermal regime of a railway station water system constructed under conditions of permafrost. Fondy Gos. bibliot. im V.I. Lenina, 1943.

Obidin, N.I. Frozen zones of the lithosphere and ground water in the Soviet Arctic. Tr. Arktich. in-ta, Vol. 16. Izd-vo Glavsevmorputi, Moscow-Leningrad, 1948.

Obolenskii, V.N. The influence of trees on the temperature of the soil and on the temperature and humidity of the air. Zhur. geofiz. i meteorol., 1923, Vol. 3, No. 3, 4.

Obolenskii, V.N. A course in meteorology for institutions of higher learning. Gidrometeoizdat, 1944.

Obruchev, S.V. Solifluction (mountain) terraces and their genesis based on investigations in the Chukchi Krai. Probl. Arktiki, No. 3 i 4. Izd-vo Arktich. in-ta Glavsevmorputi, 1937.

Obruchev, S.V. The region of Chaunskaya guba (geological and orohydrographic sketch). Tr. Vses. arktich. in-ta, Vol. 112, No. 4, 1938.

Obruchev, S.V. General sketch of the tectonic and phase volcanization of eastern Yakutia. Geologiya SSSR, Vol. 18, 1947.

Obruchev, V.A. Geological investigations of the Olekmin-Vitim mountain region and its gold-bearing deposits in 1890. Izv. Vost.-Sib. otd. Russk. geogr. ob-va, 1891, Vol. 22, No. 2-3.

Obruchev, V.A. Remarks on the paper by S.V. Obruchev "Work of the Kolyma geomorphological section of the Yakut expedition". Izv. AN SSSR, 1929, VII ser., No. 8.

Obruchev, V.A. Glaciation of northern Asia. Priroda, 1930, No. 5.

Obruchev, V.A. Signs of the ice age in northern and central Asia. Byull. Komiss. po izuch. chetvert. perioda, 1931, No. 3.

Obruchev, V.A. History of the geological investigations of Siberia. Seriya vypuskov Akad. nauk SSSR, 1931-1949.

Obruchev, V.A. Geology of Siberia. Vol. 1, 2, 3, 1938.

Obruchev, V.A. 100th anniversary of the first expedition of the Academy devoted to the investigation of permafrost. Izv. Vses. geogr. ob-va, 1946, Vol. 28, No. 5-6.

Obruchev, V.A. Advances in permafrost stüdies in the U.S.S.R. Yubil. ob. posvyashch. 30-letiyu Velik. Oktyabr'sk. sotsial. revol., Vol. 1; Izd-vo AN SSSR, 1947.

Observation of frozen soil in the Nerchinsk region in 1836 in uninhabited areas during prospecting for placer gold. Gorn. zhur., 1838, Vol. 2.

Okladnikov, A.P. Yakutia before it was attached to the Russian State. Istoriya Yakutskok ASSR, Vol. 1, Izd-vo AN SSSR, Moscow-Leningrad, 1955.

Orlov, V.O. The adhesive force of freezing between foundation and soil during the process of heaving (under conditions of deep permafrost and through taliks). Rukopis', fondy In-ta merzlotoved., 1956.

Ostroumov, G.A. Free convection under conditions of the internal problem. Gostekhizdat, 1952.

Ovcharenko, F.D. and Bykov, S.F. The hydrophilic properties of bentonites in connection with their physico-chemical nature. Kolloidn. zhur., 1954, Vol. 16, No. 2.

Owston, F.G., Kathleen, L. The crystalline structure of ice. Jour. of Glaciology, 1948, Vol. 1, No. 3.

Pallas, P.S. Journeys over various provinces of the Russian Empire. 3 parts in 5 volumes. St. Petersburg, 1773-1778.

Parkhomenko, S.G. Some data on the nature of the Nizhne-Lenskii Krai. Tr. Komiss. po izuch. Yakutsk. ASSR, Vol. 3, Leningrad, 1929.

Parkhomenko, S.G. A schematic map of regions of permafrost and deep frost penetration of the soil in the U.S.S.R. Tr. TsNII geodezii aeros'emki i kartografii, No. 18, Moscow, Izd-vo GUGSK NKVD SSSR, 1937.

Parkhomenko, S.G. Permafrost studies as a study of cryophilic soils. Tr. Komit. po izuch. vechn. merzl., Vol. 6, Izd-vo AN SSSR, Moscow-Leningrad, 1938.

Parkhomenko, S.G. Freezing of top soil and sub-soil. Mat. k osnov. uchen. o merzl. zonakh zemn. korv, No. 3, Izd-vo AN SSSR, Moscow, 1956.

Parry, W.R. Journal of voyage for the discovery of a northwestern passage in 1819-1820. London, 1821.

Pchelintsev, A.M. (1) Frost texture and its role and significance in the physico-mechanical properties of frozen soils. Rukopis', fondy In-ta merzlotoved., 1948.

Pchelintsev, A.M. (2) On the structure and texture of frozen soils. Rukopis', fondy In-ta merzlotoved., 1948.

Pchelintsev, A.M. The texture of frozen soils and its role and significance in their physico-mechanical properties. Scientific reports for 1952 and 1953. Rukopis', fondy In-ta merzlotoved., 1953.

Pchelintsev, A.M. The prediction of settlements during the thawing of permafrost. Tr. Igarsk. nauchno-issled. merzl. stants., No. 1, Izd-vo AN SSSR, 1954.

Perkarskaya, N.K. Content of soils of the Vorkuta region. Rukopis', fondy In-ta merzlotovod., 1951.

Penck, A. Versuch einer Klimaklassification auf physiogeographischer Grundlage, Sitzungsb. d. königl. preuss. Acad. d. Wiss., II. Berlin, 1910.

Perekrestov, P.P. Ice formation in the Imachinskii cut of the Amur railroad and combatting it. Merzlotovedenie, 1946, Vol. 1, No. 2, Moscow, Izd-vo AN SSSR.

Pervukhina, A.E. Salt sources of the northern regions. Tr. Severnoi bazy AN SSSR, No. 5, Izd-vo AN SSSR, 1939.

Petropavlovskii, V.N. Olenek and Khatanga. Rukopis', fondy In-ta merzlotoved., 1948.

Petrov, V.G. Icing on the Amur-Yakutsk main rail line. Leningrad, Izd-vo AN SSSR, 1930.

Petrov, V.G. Permafrost expedition along the line of the Taishet-Padun (Angara) in 1933. Tr. Komiss. po izuch. vechn. merzl., Vol. 5, Moscow-Leningrad, 1937.

Pisarev, G.F. Permafrost in the Tunka depression. Tr. Komiss. po izuch. vechn. merzl., Vol. 4, Moscow-Leningrad, Izd-vo AN SSSR, 1935.

Pistov, P.M. Problems of agricultural development in regions of permafrost of the far eastern krai. Tr. Vses. sel.-khoz. akad. im V.I. Lenina, No. 13, 1937.

Plotnikov, V.P. Permafrost in the Chernov brown coal region of the Transbaikal area. Merzlotovedenie, 1946, Vol. 1, No. 2, Moscow, Izd-vo AN SSSR.

Pod'yakonov, S.A. Along the Aldan and Olekma. Izv. Vost.-Sib. otd. Russk. geogr. ob-va, 1900, Vol. 31, No. 1-2.

Pod'yakonov, S.A. Secondary icing in eastern Siberia and its genesis. Izv. Russk. geogr. ob-va, 1903, Vol. 39, No. 4.

Pokshishevskii, V.V. The contribution of Russian travellers to the knowledge of permafrost. Priroda, 1954, No. 5. Handbook on the establishment of order in scientific and technical terminology. Pod Red. akad. A.M. Terpigoreva, Izd-vo AN SSSR, Moscow, 1952.

Polubarinova-Kochina, P.Ya. Theory of the movement of ground water. Gostekhizdat, 1952.

Polynov, B.B. Soil and geographic sketch of the Tyrma mountain taiga of the Amur Oblast. Tr. Pochv.-botan. eksped. po issled. koloniz. raionov Aziatskoi Rossii. Part I, 1909.

Polynov, B.B. (1) On perennial frost and forms of ice and snow that last throughout the summer in the Amur Oblast. Zemlevedenie, 1910, No. 3.

Polynov, B.B. (2) Particular conditions of erosion and soil formation in the Amur Oblast. Ezheg. po geol. i mineral. Rossii, Vol. 12, No. 5-6, 1910.

Polynov, B.B. The surface of the earth's crust. Part I. 1934.

Ponomarev, V.M. Hydrogeological sketch of the Amderma region. Tr. Gornogeol. upr., No. 1, 1937.

Ponomarev, V.M. Engineering-hydrogeological conditions in the region of Kozhevnikova harbour. Rukopis', fondy In-ta merzlotoved., 1938.

Ponomarev, V.M. (1) On the history of the Kozhevnikova harbour region during the quaternary period. Sov. geol., 1940, No. 11.

Ponomarev, V.M. (2) Further information on the hydrogeological conditions of the Razdel'nii Peninsula (Vaigach Island) and Amderma. Probl. Arktiki, 1940, No. 4.

Ponomarev, V.M. The formation of ground water along the coast of the northern seas in the region of permafrost. Izd-vo AN SSSR, 1950.

Ponomarev, V.M. The time and conditions of formation of fossil ice in Chukchi. Mat. Soveshch. po izuch. snega i l'da. Fondy In-ta merzlotoved., 1951.

Ponomarev, V.M. Permafrost and ground water in the region of Ust'-Yenisei port (investigations of 1941). Tr. In-ta merzlotoved., Vol. 10, Moscow, Izd-vo AN SSSR, 1952.

Ponomarev, V.M. (1) The geothermal stage in the arctic region of permafrost. Tr. In-ta merzlotoved., Vol. 12, 1953.

Ponomarev, V.M. (2) Perennial frost as one of the basic reasons for increasing the size of the fresh water zone. Rukopis', fondy In-ta merzlotoved., 1953.

Ponomarev, V.M. (3) Ground water in the region of thick permafrost strata and their practical importance. Rukopis', fondy In-ta merzlotoved., 1953.

Ponomarev, V.M. (4) Quaternary deposits and permafrost of Chukchi. Izd-vo AN SSSR, 1953.

Ponomarev, V.M. Frozen strata of soils and ground water in the region of the Aldan iron ore deposit and the Chul'man coal deposit. Report for 1955. Fondy In-ta merzlotoved.

Ponomarev, V.P. Heaving along railway lines and methods of combatting it. Tr. Vses. nauchno-issled. in-ta zhel.-dor. transp., 1952, No. 50.

Popov, A.I. Frost fissures and problems of fossil ice. Tr. In-ta merzlotoved., Vol. 9, 1952.

Popov, A.I. (1) Permafrost in western Siberia. Izd-vo AN SSSR, 1953.

Popov, A.I. (2) Permafrost-geological regions of the permafrost zone of the U.S.S.R. Rukopis', fondy In-ta merzlotoved., 1953.

Popov, A.I. (3) Particular features of the genesis of alluvial plains under conditions of a severe climate. Izv. AN SSSR, ser. geogr., Moscow, 1953, No. 2.

Popov, A.I. Origin and development of thick fossil ice. Mat. k osnov. uchen. o merzl. zonakh zemn. kory, No. 2, 1955.

Popov, I.V. Fundamentals of engineering-geological soil science. Tr. Spetsgeo, No. 9, 1941.

Porkhaev, A.P. The kinetics of imbibition of liquids by elementary capillaries and porous materials. Kolloidn. zhur., 1949, No. 5.

Porkhaev, G.V. Design of ventilated crawl space of buildings. Tr. In-ta merzlotoved., Vol. 11, Moscow, Izd-vo AN SSSR, 1952.

Porsild, A.E. Earth mounds in unglaciated northwestern America. Geogr. Rev., Vol. XXVIII, 19[illegible], No. 1.

Poser, H. Einige Untersuchungen zur Morphologie Ostgrönlands. Meddel om Gr., 1932, Bd. 94, No. 5.

Pozdnyakov, L.N. The effect of vegetation on the depth of summer thawing of the soil in the Verkhoyansk region. Tr. In-ta merzlotoved., Vol. 9, 1952.

Prasolov, L.I. Permafrost in the steppe zone of the Transbaikal region. Pochvovedenie, 1914, No. 4.

Priklonskii, V.A. Engineering soil science. Chapter I, Moscow. Gosgeolizdat, 1949.

Proskuryakov, B.V. On modelling temperature fields in a thawed-frozen medium. Izv. Vses. nauchno-issled., in-ta gidrotekhn. im. Vedeneeva, 1939, Vol. 25.

Pryanishnikov, A.V. Meadow formations in the tundra. Botan. zhur., 1954, Vol. 39, No. 1.

Puri, A. Soil Chemistry, 1949.

Pustovalov, E.V. and Chukhrova, A.N. The effect of freezing and thawing on the density of soils. Tr. Vses. nauchno-issled. in-ta zhel.-dor. stroit. i proektir., No. 7, Vopr. proektir. i sooruzh. zemlyan. polotna, 1952.

Puzakov, N.A. Design and construction of the earthen road base of railways and automotive roads. Theoretical basis for the accumulation of moisture in road beds and practical utilization. Izd-vo AN SSSR, 1950.

P'yavchenko, K.I. Peat mounds. Izd-vo AN SSSR, 1955.

Rabkin, M.I. The Neshkenskii hot springs. "Arktika", No. 5, 1937.

Rabkin, M.I. Geological structure of the southwest part of the Anabar range. Tr. Nauchno-issled. in-ta geol. Arktiki, GUSMP, Vol. 20, 1951.

Radde, G. Dauro-Mongolian boundary in the Transbaikal region. Vestn. RGO, 1858, Part 22, Section 2.

Rakovskii, A.V., Tarasenkov, D.N. and Komandin, A.S. The effect of adjacent solid phase on the freezing temperature of water and weak water solutions. Zhur. obshch. khimii, 1955, Vol. 5, No. 10.

Rathjens, K. and Weissmann, H. Oberflächenformen und Eisboden in Lappland Peterm. Geogr. Mitt., (Gotha), 1929, Jg. 75.

Razumova, L.A. Migration of moisture in soil from data of laboratory investigations. Information Bulletin No. 1. Dynamic and agricultural meteorology. Leningrad, Gidrometizdat, 1951.

Razumova, L.A. Seasonal freezing and moisture of the soil in the European territories of the U.S.S.R. Tr. Tsentr. in-ta prognozov, No. 051, Sel'khoz. meteorol., Moscow-Leningrad, Gidrometizdat, 1953.

Rebinder, N.A. Physico-chemical investigations of the deformation of solids. Yubil. sb. posvyashch. 30-letiyu Velik. Oktyabr'sk. sotsial. revol., Vol. 1, Izd-vo AN SSSR, 1947.

Redozubov, D.V. Mechanisms of the temperature field of permafrost in Vorkuta. Tr. In-ta merzlotoved., Vol. 1, Moscow-Leningrad, Izd-vo AN SSSR, 1946.

Resolution No. VII of the Interscience Conference on Permafrost. Moscow, Izd-vo AN SSSR, 1956.

Richards, L.A. Capillary conduction of liquids through porous mediums. Jour. Appl. phys., 1931, I.

Rikhter, G.D. Snow cover, its formation and properties. Moscow-Leningrad, Izd-vo AN SSSR, 1945.

Rikhter, G.D. Scientific basis for controlling present-day natural processes of the tundra zone. Izv. AN SSSR, ser. geogr., No. 1, 1954.

Rode, A.A. Soil moisture. Izd-vo AN SSSR, 1952.

Rozen, M.F. Observations of the propagation of permafrost in the delta of the Pechora River. Tr. Komiss. po izuch. vechn. merzl., Vol. 4, Moscow-Leningrad, Izd-vo AN SSSR, 1935.

Rubinshtein, E.S. Ed. Climatic Atlas of the U.S.S.R. GGO, GMK SSSR, 1933.

Rubinshtein, E.S. On problems of change in climate. Leningrad-Moscow, Gidrometeoizdat, 1946.

Rubinshtein, L.I. (1) On determining the position of the interface in the unidimensional problem of Stefan. Dokl. AN SSSR, 1947, Vol. 58, No. 2.

Rubinshtein, L.I. (2) On solving the Stefan problem. Ser. geogr. i geofiz., 1947, 11, No. 1, Izd-vo AN SSSR.

Rubinshtein, L.I. (1) On the problem of the existence of a solution for the Stefan problem. Dokl. AN SSSR, 1948, 62, No. 2.

Rubinshtein, L.I. (2) On the stability of the interface boundary in a two-phase heat conducting meadium. Izd. AN SSSR, ser. geogr. i geofiz., 1948, 12, No. 6.

Rubinshtein, L.I. On a question of a unique solution to the single-dimension problem of Stefan in the case of a single-phase initial state. Dokl. AN SSSR, 1951, 79, No. 1.

Ruckli, R. Gélivite des sols et fondations des routes. Bull. Techn. de la Suisse Romande. Lauzanne, 1943.

Ruckli, R. Der Frost im Baugrund. Wien, Springer-Verlag, 1950.

Ruckly. Two and three-dimensional groundwater flow towards the ice-lenses formed in the freezing ground. Proc. of the Sec. Intern. Conf. on Soil Mech. a. Found. Eng., Vol. II. Rotterdam, June 21 to 30, 1948.

Ruoff, Z.F. On the question of age and origin of peat mounds in the northern pre-ural region. Probl. fiz. geogr., Vol. 16, Moscow-Leningrad, Izd-vo, AN SSSR, 1951.

Safronov, G.P. Quaternary deposits of the Vorkuta region. Tr. In-ta merzlotoved., Vol. 6, 1944.

Sakharov, M.I. The freezing and thawing of soils in forest-covered regions. Meteorologiya i gidrologiya, 1938, No. 11-12.

Saks, V.N. On the quaternary glaciation of northern Siberia. "Arctica", 1936, No. 4.

Saks, V.N. Some data on permafrost in the lower reaches of the Yenisei. Problemy Arktiki, 1940, No. 1.

Saks, V.N. (1) Some data on permafrost in the basin of the Pyasina River. Tr. Gorno-geol. upr. GUSMP, No. 21, 1945.

Saks, V.N. (2) New data on the geological structure of the basin of the Pyasina River. Tr. Gorno-geol. upr. GUSMP, No. 16, 1945.

Saks, V.N. (1) Quaternary history of the Chukchi region. Problemy Arktiki, 1946, No. 3.

Saks, V.N. (2) Quaternary deposits of the New Siberian Islands and the Primor'e lowlands. Problemy Arktiki, 1947, No. 4.

Saks, V.N. Quaternary period in the Soviet Arctic. Tr. Arktich. in-ta, Vol. 201, 1948.

Saks, V.N. (1) Quaternary deposits in Eastern Yakutia. Geologiya SSSR, Vol. 18, Moscow-Leningrad, 1951.

Saks, V.N. (2) Quaternary deposits in the northern part of the West Siberian lowlands and the Taimyr depression. Tr. Nauchno-issled. in-ta geol. Arktiki, Vol. 14, 1951.

Saks, V.N. Quaternary period in the Soviet Arctic. Tr. Nauchno-issled. in-ta geol. Arktiki GUSMP, Vol. 77, Moscow-Leningrad, 1953.

Saks, V.N. and Moor, G.G. Geology and petrography of the Alazei Plateau. Tr. Gornogeol. upr., Vol. 5, 1941.

Saltykov, N.I. (1) Buildings of the Bol'shezemel'skaya tundra. Tr. In-ta merzlotoved., Vol. 4, 1944.

Saltykov, N.I. (2) The installation of sewer pipes under conditions of permafrost. Izd-vo AN SSSR, 1944.

Saltykov, N.I. On the formations of buildings in the city of Yakutsk. Tr. In-ta merzlotoved., Vol. 1, Moscow-Leningrad, Izd-vo AN SSSR, 1946.

Saltykov, N.I. Theoretical basis for designing the foundations on thawing bases. Moscow, Izd-vo AN SSSR, 1952.

Saltykov, N.I. Brief instructions on designing foundations on thawing bases with respect to calculating settlement and reaction of the base with the footing of the foundation. Moscow, Izd-vo AN SSSR, 1953.

Saltykov, N.I. On the history of the development of engineering permafrost studies. Rukopis', fondy In-ta merzlotoved., 1954.

Sambikin, M.M. The influence of the accumulation of moisture in the soil depending on temperature gradiants of the soil. Nauchno-agron. zhur., 1926, No. 5-6.

Samoilov, O.Ya. Coordination numbers and dehydration of ions of Li, Na, K, Cl, Br and I in aqueous solutions. Izv. AN SSSR, Otd. khim. nauk, 1952, No. 3.

Satow, G. Das Bodeneis in der Arktis, Aus dem Archiv der Deutsche Seewarte, Bd. 49, No. 5, Hamburg, 1930.

Sauer, M. An account of a geographical and astronomical expedition to the northern parts of Russia, performed by commodore Joseph Billings in the years 1785 to 1794. London, Cadell and Davies, 1802.

Saukov, A.A. Geochemistry. 2nd edition. Moscow, Gosgeolizdat, 1951.

Savarenskii, F.P. Hydrogeology. ONTI, 1935.

Schimper. Pflanzengeographie auf der physiologischen Grundlage. Jena. Fischer, 1947.

Semikhatov, A.N. Ground water in the U.S.S.R. Gorno-geologoneftyanoe izd. Moscow-Leningrad, Novosibirsk, 1934.

Serebryakov, I.G., Tolstov, A.N., Pchelintsev, A.M. and Konstantinova, G.S. Permafrost in Pyasina River Basin (Report of the Taimyr expedition). Rukopis', fondy In-ta merzlotoved., 1950.

Sergeev, L. Structural settlement of perennially frozen soils during thawing. Byull. Tekh. inform. Noril'sk. kombin., 1946, No. 7-8 (14-15).

Sergeev, E.M. General permafrost studies. Izd-vo MGU, 1952.

Sergeev, M.E. Investigations along the line of the Transbaikal region of the Siberian railway to elucidate conditions of water supply for future stations. Geol. issled. i razved., rab. po linii Sibirsk. zhel. dor., No. 4, St. Petersburg, 1897.

Shackleton, E.H. The heart of the Antarctic. Being the story of the British Antarctic expedition 1907-1909. With an introduction by Hugh Robert Mill, an account of the first journey to the South magnetic pole by prof. T.W.E. David. London, 1909.

Shadrin, G.S. Determining the depth of thawing under a water duct laid in frozen soil. Izv. Vses. nauchno-issled. in-ta gidrotekhn. im. Vedeneeva, 1947, Vol. 33.

Shadrin, G.S. Modelling of thermal processes accompanying changes in the state of aggregation in laminar media. Sb. Ledotermich. vopr. v gidrotekhn. Moscow, Gosenergoizdat, 1954.

Sharp, R.P. Ground-ice mounds in the tundra. Geogr. Rev., 1942, Vol. XXXII, No. 3.

Shatskii, N.S. On the tectonics of the Arctic. Tr. 1-i geol. razved. po Severy SSSR, Vol. 1, GUSMP, 1935.

Shchegolev, D.I. and Tolstikhin, N.I. Ground ice in fissured soil. Tr. Leningr. otd. Spetsgeo, No. 1, Moscow, 1939.

Shcherban', A. Fundamental theory and methodology of thermal calculations of air in mines. Moscow-Khar'kov, Ugletekhizdat, 1953.

Sheveleva, N.S. Spotty formations in the tundra of the lower reaches of Ob' basin. Tr. In-ta merzlotoved., Vol. 9, Moscow, 1952.

Shilo, N.A. Particular features in the formation of loose rocky ground in the zones of permafrost development. Sov. geol. sb. 53, 1956.

Shimanovskii, S.V. Instructions on determining the heat conductance of soil for above and below freezing temperatures. Mat. po labor. issled. merzl. grunt. Sb. 2, Moscow, Izd-vo AN SSSR, 1954.

Shimanovskii, S.V. and Shimanovskaya, T.S. The thermal characteristics of frozen and thawed soils. Report for 1952 (written by G.A. Martynov). Fondy In-ta merzlotoved.

Shostakovich, V.B. Climatic conditions for the existence of permafrost. Tr. Irkutsk. magnitn. i meteorol. observ., No. 2-3. Irkutsk, 1928.

Shtukenberg, V.I. Notes on frost heaving on railroads and methods of eliminating them. "Inzhener", 1885, No. 10.

Shtukenberg, V.I. On combatting frost heaving on railroads. Zhur. Min. put. soobshch., 1894, No. 2.

Shumskii, P.A. Present-day glaciation in the Soviet Arctic. Tr. Arktich. nauchno-issled. in-ta, Vol. 11, 1949.

Shumskii, P.A. Preliminary report on the problem "structure and origin of fossil ice in Central Yakutia". Rukopis', fondy In-ta merzlotoved., 1950.

Shumskii, P.A. Investigation of fossil ice in Central Yakutia. Issled. vechn. merzl. v Yakutsk. resp., No. 3, 1952.

Shumskii, P.A. (1) On the question of passive orientation effect of a solid base on a growing crystal. Dokl. AN SSSR, 1953, Vol. 93, No. 1.

Shumskii, P.A. (2) Ground ice. BES, 1953.

Shumskii, P.A. (3) Notes on the history of the investigation of ground ice. Rukopis', fondy In-ta merzlotoved., 1953.

Shumskii, P.A. (1) On the method of microscopic investigation of the structure of frozen soil. Mat. po labor. issled. merzl. grunt. Sb. 2, Izd-vo AN SSSR, 1954.

Shumskii, P.A. (2) The structure of natural ice. Izv. Vses. geogr. ob-va, 1954, Vol. 86, No. 1.

Shumskii, P.A. (1) On the accretion of ice crystals onto a solid base. Sb. posvyashch. 90-letiyu akad. V.A. Obrucheva, Izd-vo AN SSSR, 1955.

Shumskii, P.A. (2) Fundamentals of the study of ice structure (petrography of fresh water ice as a method of glaciological investigation). Moscow, Izd-vo AN SSSR, 1955.

Shumskii, P.A. The structure of frozen soil. Part I. On physical phenomena and processes in freezing, frozen and thawing soil. Mat. po labor. issled. merzl. grunt. Sb. 3, Moscow, Izd-vo AN SSSR, 1957.

Shumskii, P.A., Vtyurin, B.I. and Katasonov, E.M. Glaciological and permafrost-lithological investigations in the Primor'e lowlands of northeastern Yakutia. (Preliminary report No. 3, expedition No. 1 of the Institute of Permafrost Studies, 1953). Rukopis', fondy In-ta merzlotoved., 1953.

Shumskii, P.A., Shvetsov, P.F. and Dostovalov, B.N. Engineering-geological survey in regions of vein ground ice. Moscow, Izd-vo AN SSSR, 1955.

Shusherina, E.P. Methods of determining the coefficients of thawing and compacting of frozen soils. Mat. po labor. issled. merzl. grunt. Sb. 1, Moscow, Izd-vo AN SSSR, 1953.

Shusherina, E.P. Investigations of changes in the physico-mechanical properties of soils resulting from freezing and subsequent thawing. Dissertatsiya. Rukopis', fondy In-ta merzlotoved., 1955.

Shusherina, E.P. and Tsytovich, N.A. Some experiments on the study of the effect of freezing and subsequent thawing on the strength of clay soils. Mat. po labor. issled. merzl. grunt. Sb. 3, Izd-vo AN SSSR, 1957.

Shvetsov, P.F. Some data on the characteristics of hot mineral springs in Chukchi. Voprosy kurortologii, No. 5, Moscow, 1937.

Shvetsov, P.F. Permafrost and engineering-geological conditions in the Anadyr region. Leningrad, Izd-vo Glavsevmorputi, 1938.

Shvetsov, P.F. On problems of the relationship between temperature and the thickness of permafrost to the geological and hydrogeological factors. Izv. AN SSSR, ser. geol., 1941, No. 1.

Shvetsov, P.F. (1) The upper Yano-Kolyma mountain region as a specific permafrost-hydrogeological region. Izd. Vses. geogr. ob-va, 1947.

Shvetsov, P.F. (2) Fossil ice and ground water in the region of Anadyr and Bukhta Ugol'naya. Sb. "Nedra Arktiki", No. 3, 1947.

Shvetsov, P.F. On the importance of the thermal form of motion in the circulation and supply of ground water in mountain regions with respect to systems of tectonic fissures. Dokl. AN SSSR, 1950, Vol. 23, No. 3.

Shvetsov, P.F. (1) On designing some concepts in permafrost studies. Moscow, Izd-vo AN SSSR, 1951.

Shvetsov, P.F. (2) Ground water in the upper Yano-Kolyma folded mountain regions and the particular features associated with low temperature permafrost. Izd-vo AN SSSR, 1951.

Shvetsov, P.F. (1) On the construction of a system of stratigraphy of the quaternary deposits and history of the development of the Yano-Indigirka coastal lowlands (working hypothesis derived from factual data). Rukopis', fondy In-ta merzlotoved., 1952.

Shvetsov, P.F. (2) Anomalies in the thermal regime of the Indigirka River at two characteristic gauge points and their origin. Yakutsk. sb. No. 3. Izd-vo AN SSSR, 1952.

Shvetsov, P.F. (3) On the conditions and time of formation of the fundamental system of frost fissures and ground ice associated with them. Sb. Issled. vechn. merzl. v Yakutsk. resp., No. 3, Moscow, Izd-vo AN SSSR, 1952.

Shvetsov, P.F. On explaining some physico-geological phenomena from the results of the Yano-Indigirka expedition. Rukopis', fondy In-ta merzlotoved., 1953.

Shvetsov, P.F. Introductory chapters to fundamentals of geocryology. Mat. k osnov. uchen. o merzl. zonakh zemn. kory, No. 1, Moscow, Izd-vo AN SSSR, 1955.

Shvetsov, P.F. (1) On the principles of establishing permafrost regions. Mat. k osnov. uchen. o merzl. zonakh zemn. kory, No. 3, Moscow, Izd-vo AN SSSR, 1956.

Shvetsov, P.F. (2) Origin and mechanism in the distribution of ground ice. Vestn. AN SSSR, 1956, No. 3.

Shvetsov, P.F. and Meister, L.A. Infiltration of sprayed water as a method of artificially thawing loose rocky ground. Izd. AN SSSR, ser. geogr., 1956, No. 6.

Shvetsov, P.F. and Sedov, V.P. Gigantic ice formations and ground water of the Taskhayakhtakh ridge. Moscow-Leningrad, Izd-vo AN SSSR, 1941.

Sidenko, P.D. Permafrost and ground water on the Yurung-Tumus Peninsula. Tr. Nauchno-issled. in-ta geol. Arktiki GUSMP, 1951.

Skuratov, S.M. On the question of heat capacity of bonded water. Kolloidn. zhur., 1951, Vol. 13, No. 5.

Skvortsov, E.F. Coastal tundra of Yakutia. Tr. Komiss. po izuch. Yakutsk. ASSR, 1930.

Slin'ko, V.L. Data on searching for a sea port in the Ob' Inlet near the Kamennii Cape in 1847-1848. Rukopis', fondy In-ta merzlotoved., 1949.

Smith, P.S. Geology and mineral resources of the Salomon and Casadepaga quadrangle, Alaska. Bull. Unit. St. Geol. Surv., 1910, No. 433.

Smith, P.S. Mineral resoureces of Alaska. Washington, 1930.

Sochava, V.B. Reason for forest-free areas in Eastern Siberia and Primor'e. Priroda, 1944, No. 2.

Soergel, W. Diluviale Eiskeile. Ztschr. Deutsch. Geol. Ges., 1936, Bd. 88, H. 3.

Soergel, W. Die eiszietliche Temperatuverminderung in Mitteleuropa. Jb. Mitt. Oberrhein. Geol. Verein, 1942, Vol. 31.

Sokolov, N.D. The hydrogen bond. Uspekhi fiz. nauk, 1955, Vol. 57, No. 2.

Sokolova, E.M. Thermal regime of rivers of the U.S.S.R. Tr. Gos. gidrol. in-ta, No. 30/84, 1950.

Solntsev, N.A. Small glaciers as a geomorphological factor. Nauchno-issled. in-ta geogr. MGU, 1949.

Solov'ev, P.A. Permafrost-hydrogeological investigations in the region of the villages of Mai and Lamuto. Rukopis', fondy In-ta merzlotoved., 1946.

Solov'ev, P.A. (1) Extension of the fossil firn ice in the region between the Lena and the Amgin rivers. Merzlotovedenie, 1947, Vol. 2, No. 2.

Solov'ev, P.A. (2) Ice in the permafrost in the regions of the village Anadyr'. Nedra Arktiki, 1947, No. 2.

Solov'ev, P.A. Temperature regions of the region between the Lena and Amgin rivers. Rukopis', fondy In-ta merzlotoved., 1948.

Solov'ev, P.A. Permafrost, relief and quaternary deposits in the region between the Lena and Amgin rivers. Rukopis', fondy In-ta merzlovoted., 1951.

Solov'ev, P.A. Frost mounds in Central Yakutia. Issled. vechn. merzl. v Yakutsk. resp., No. 3, 1952.

Spethmann, H. Über Bodenbewegungen auf Island. Ztschr. Ges. Erdk., 1912, v. 4.

Spizharskii, T.N. Quaternary glaciation of the Lena-Indigirka Oblast. Problemy Arktiki, 1941, No. 11.

Spizharskii, T.N. New Siberian islands. Geologiya SSSR, Vol. 26, Moscow-Leningrad, 1947.

Standards and technical requirements for designing natural bases for buildings and industrial structures (N i TU 127-55). Gos. izd-vo liter. po stroit. i arkhit., Moscow, 1955.

Statsenko, V.P. Parts of a building. Izd. 4, 1912, and izd. 5, 1916.

Steche, H. Beiträge zur Frage der Strukturböden. Bericht Verh. Sächs. Akad. Wiss. Leipz., Math.-Phys. VI, Bd. 85, IV. Lpz., 1933.

Stefan, J. Über einige Probleme der Theorie der Wärmeleitung. Sitzungsb. d. Akad. d. Wiss., Bd. 98, Abt. II. Wien, 1889.

Stefan, J. Über die Theorie der Eisbildung, insbesondere über die Eisbildung im Polarmeere. Sitzungsb. d. Akad. d. Wiss., Wien, 1890, Bd. 98, Abt. II.

Stotsenko, A.V. Seasonal freezing of soil in the northern Caucasus. Izd-vo AN SSSR, 1953.

Stotsenko, A.V. Formulae for determining the depth of freezing of soil. 1950.

Stotsenko, A.V. Seasonal freezing of soil in the Far East outside the permafrost zone. Izd-vo AN SSSR, 1952.

Structure of the earth's crust. Vol. 1, 2, 3. Moscow, Gosgeolizdat, 1948.

Stulov, N.N. Ice crystals. Zap. Vses. mineral. obshch., Part 78, No. 3, 1949.

Stupishin, A.V. Lomonosov and permafrost studies. Priroda, 1951, No. 9.

Sukachev, V.N. On the influence of frost on soil. Izv. Akad. nauk, 1911, 6 ser., Vol. 5, No. 1.

Sukhodol'skii, E.I. On the construction of a road bed out of frozen earth under conditions of the northern regions of the permafrost zone. Tr. In-ta merzlotoved., Vol. 2, Moscow, Izd-vo AN SSSR, 1945.

Sulin, V.A. Water in the petroleum deposits of the U.S.S.R. ONTI, 1935.

Sumgin, M.I. Geographic distribution of permafrost in the Amur Oblast. Izv. Meteorol. byuro Amursk. r-na, 1914, No. 2. Blagoveshensk. (Rukopis').

Sumgin, M.I. Physico-mechanical processes in moist and frozen soils in connection with frost heaving on roads. Izd-vo "Transpechat'", 1929.

Sumgin, M.I. Present-day state of the investigation of permafrost in the U.S.S.R. and the desirable approach to these problems in the near future. Vechnaya merzlota. Sb. Tr. KEPS, No. 80, Leningrad, Izd-vo AN SSSR, 1930.

Sumgin, M.I. A short course in geophysics as applied to roads. Moscow, Gostransizdat, 1931.

Sumgin, M.I. (1) Methods of freezing water in the film state. Sb. Tsentr. nauchno-issled. in-ta avtomob. dorozhn. transp. Moscow, Gostransizdat, 1932.

Sumgin, M.I. (2) Degradation of permafrost in some region of the U.S.S.R. Tr. Komiss. po izuch. vechn. merzl., Vol. 1, Leningrad, Izd-vo AN SSSR, 1932.

Sumgin, M.I. Southern boundary of permafrost within the limits of the U.S.S.R. Tr. Komiss. po izuch. vechn. merzl., Vol. 2, Leningrad, Izd-vo AN SSSR, 1933.

Sumgin, M.I. Permafrost in northern U.S.S.R. Geology and mineral wealth of northern U.S.S.R. Sb. Tr. Pervoi geol.-razved. konfer. Glavsevmorputi 24-27 aprelya 1935, Vechnaya merzlota. Vol. 3, Leningrad, Izd-vo Glavsevmorputi, 1936.

Sumgin, M.I. Perennially frozen soil within the U.S.S.R. 1st edition. Vladivostok, 1927; 2nd edition, Moscow, 1937.

Sumgin, M.I. (1) On the prospects of investigating permafrost in the Yakut Republic. Tr. Komiss. po izuch. vechn. merzl., Vol. 9, 1940.

Sumgin, M.I. (2) On the theory of the formation of permafrost ice mounds. Dokl. AN SSSR, 1940, Vol. 28, No. 2.

Sumgin, M.I. (3) Ice in perennially frozen soils (in a book by Veinberg, B.P. et al. Ice). Moscow, Gostekhizdat, 1940.

Sumgin, M.I. Permafrost studies. Sb. Uspekhi geol.-geogr. nauk v SSSR za 25 let. Moscow-Leningrad, Izd-vo AN SSSR, 1943.

Sumgin, M.I. Permafrost in the Yakut ASSR. Geology of the U.S.S.R. Vol. 18, Moscow-Leningrad, 1947.

Sumgin, M.I., Kachurin, S.P., Tolstikhin, N.I. and Tumel', V.F. General permafrost studies. Leningrad-Moscow, Izd-vo AN SSSR, 1940.

Supplements to "Acta Historica" collected and published by the Archaeological Commission, Vol. 11, 1869.

Surin, A.A. The construction of water ducts in frozen soil. St. Petersburg, 1912.

Surin, A.A. On the question of constructing water ducts in frozen soil. 1914.

Suslov, S.P. The study of permafrost as a geographic factor. Sprav. putesh., Part II, 1950.

Sven Gedin. In the heart of Asia. Pamir-Tibet (Journey in 1893-1897). St. Petersburg, 1899.

Svetozarov, I.M. Hydrology of permafrost from the data of investigations in the region of Yakutsk. Problemy sovetskoi geol., 1934, No. 10.

Taber, S. The growth of crystals under external pressure. Amer. Jour. Sci. (New Haven Coun.), 1916, 4th Ser., Vol. 41, No. 246.

Taber, S. Pressure phenomena accompanying the growth of crystals. Proc. of Nat. Acad. Sci., 1917, Vol. 3.

Taber, S. (1) Ice forming in clay soils will lift surface weights. Engineering News-Record, 1918, Vol. 80, No. 6.

Taber, S. (2) Surface heaving caused by segregation of water forming ice crystals. Engineer. News-Record, 1918, Vol. 81, No. 15.

Taber, S. Frost heaving. Jour. of Geol., 1929, Vol. 37, No. 5.

Taber, S. (1) Freezing and thawing of soils as a factor in the destruction of road pavements. Public Roads, 1930, Vol. 11, No. 6.

Taber, S. (2) The mechanics of frost heaving. Jour. Geol., 1930, Vol. 38, No. 4.

Taber, S. Perennially frozen ground in Alaska: its origin and history. Bull. Geol. Soc. Amer., 1943, Vol. 54, No. 10.

Tamman, G. Aggregatzustande. Leipzig, 1922.

Tanfil'ev, G.I. The tree line in northern Russia. Odessa, 1911.

Tarnuzzen, Ch. Die Schuttfacetten d. Alpen. Peterm. geogr. Mitt., 1911, No. 2.

Tatishchev, V.N. General geographic description of Siberia. Izbr. tr. po geogr. Rossii. Moscow, Geografgiz, 1950.

Thorroddsen, Th. Polygonboden und «Thufur» auf Island. Peterm. geogr. Mitt., 1913, No. 2.

Tikhomirov, B.A. On the geographic distribution of frost mounds in northern Eurasia. Priroda, 1948, No. 1.

Tikhomirov, B.A. Forest-free tundra and its development. Botan. zhur., 1953, Vol. 38, No. 4.

Titov, I.A. On the interaction of vegetation and conditions of the medium. Moscow, 1952.

Toll, E. Die von der Kaiserliche Akademie der Wissenschaften ausgerüstete Expedition nach den Neusibirischen Inseln und dem Jana-Lande. Beitr. z. Kennt. des Russ. Reich. und der angrenz. Länd. Asiens, 3-te Folge, Bd. III. St. Petersburg, 1887.

Toll', E.V. Soil ice and the conditions under which the bodies of post-tertiary animals were preserved in northern Siberia. Izv. Vost.-Sib. otd. Russk. geogr. ob-va, 1892, Vol. 23, No. 2.

Toll', E.V. Expedition of the Imperial Academy of Sciences in 1893 to the New Siberian Islands and the coast of the Arctic Ocean. Izv. RGO, 1894, Vol. 30, No. 4.

Toll', E.V. On the expedition to the New Siberian Islands and the coast of the Arctic Ocean from Svyatogo Nosa to Khatangskii Inlet. Zap. Akad. nauk, 1895, Vol. 75.

Toll', E.V. Fossil glaciers on the New Siberian Islands, their relationship to the bodies of mammoth and the glacial period. Zap. RGO po obshch. geogr., 1897, Vol. 32, No. 1.

Tolmachev, I.P. On the origin of cirques. Tr. S.-Peterb. ob-va estestv., Vol. 30, No. 1, 1899.

Tolmachev, I.P. Soil ice in regions of the Berezovka River (in northeastern Siberia). Nauchnye rezul'taty ekspeditsii Akad. nauk dlya raskopki mamonta v 1901, Vol. 1, St. Petersburg, 1903.

Tolmachev, I.P. Information on the Khatanga expedition under the direction of I.P. Tolmachev (from the letters of I.P. Tolmachev to F.I. Chernyshev). Izv. RGO, 1906, Vol. 42, St. Petersburg, 1907.

Tolmachoff, I.P. The carasses of the mammoth and rhinoceros found in the frozen ground of Siberia. Trans. Amer. Phil. Soc., 1929, Vol. XXIII, Pt. I, Art. 1, Philadelphia.

Tolstikhin, N.I. Ground water in the Transbaikal region and their hydro-laccoliths. Tr. Komiss. po izuch. vechn. merzl. AN SSSR, Vol. 1, 1932.

Tolstikhin, N.I. (1) Ground water in the quaternary deposits in regions of permafrost. Tr. Assots. po izuch. chetvert. per. Evropy, Vol. 2, Moscow-Leningrad, 1933.

Tolstikhin, N.I. (2) Regions of mineral waters in the U.S.S.R. Problemy sov. geol., 1933, No. 3.

Tolstikhin, N.I. (1) Hydrogeological conditions of water supply in regions of permafrost. Geology and mineral resources of northern U.S.S.R. Tr. Pervoi geol.-razved. konfer. Glavsevmorputi 24-27 aprelya 1935, Vol. 3, Vechnaya merzlota. Leningrad, Izd-vo Glavsevmorputi, 1936.

Tolstikhin, N.I. (2) On the question of classifying ice and ice containing soil. Probl. sov. geol., 1936, Vol. 6, No. 7.

Tolstikhin, N.I. Mineral waters in the permafrost regions of the earth's crust. Tr. Komit. po vechn. merzl., Vol. 6, Moscow-Leningrad, Izd. vo AN SSSR, 1938.

Tolstikhin, N.I. Ground waters in regions of permafrost. Moscow-Leningrad, Gosgeolizdat, 1941.

Tolstikhin, N.I. (1) Artesian wells in the permafrost regions of the U.S.S.R. Merzlotovedenie, 1947, Vol. 2, No. 1, Izd-vo AN SSSR.

Tolstikhin, N.I. (2) Relief and the distribution of ground water. Izd-vo VGO, 1947.

Tolstikhin, N.I. Mineral waters of the Yakut A.S.S.R. Yakutsk. sb. AN SSSR, No. 2, 1950.

Tolstikhin, N.I. Hydrogeology of the U.S.S.R. Vol. 28. Leningr. gornyi in-t. Leningrad, 1953.

Tolstikhin, N.I. and Obidin, N.I. Secondary icing in the eastern part of the Transbaikal region. Izv. Gos.-geogr. ob-va, 1936, No. 6.

Tolstov, A.N. Some observations on fissure and cellar ice in the tundra of the Dudinka region. Tr. In-ta merzlotoved., Vol. 2, 1941.

Transactions of the Commission on the Study of Permafrost. Vol. 3, Leningrad, Izd-vo AN SSSR, 1934.

Trupak, N.G. The freezing of soil during sinking of shafts. Moscow, Ugletekhizdat, 1954.

Tsyplenkin, E.I. Permafrost and its importance in agriculture. Tr. Vses. sel.-khoz. akad. im. V.I. Lenina, No. 13, 1937.

Tsytovich, N.A. On the question of designing foundations of structures erected on permafrost. Gipromez, 1928.

Tsytovich, N.A. Lectures on designing foundations under conditons of permafrost. Izd. Lengr. in-ta sooruzh., 1933.

Tsytovich, N.A. Investigations of the deformation of frozen soils. Rukopis', fondy In-ta merzlotoved., Leningrad, 1940.

Tsytovich, N.A. (1) Calculations of the settlement of foundations. Gosstroiizdat, 1941.

Tsytovich, N.A. (2) Construction under conditions of permafrost. Tez. dokl. na konfer. po razv. proizvod. sil Yakutsk. ASSR 17-22 marta 1941, Moscow-Leningrad, Izd-vo AN SSSR, 1941.

Tsytovich, N.A. On the theory of equilibrium state of water in frozen soils. Izv. AN SSSR, ser. geogr., 1945, 9 No. 5-6.

Tsytovich, N.A. On unfrozen water in soils. Izv. AN SSSR, ser. geol., 1947, No. 3.

Tsytovich, N.A. Soil mechanics. 3rd ed. Moscow-Leningrad, Gosstroiizdat, 1951.

Tsytovich, N.A. Principles of the mechanics of frozen soils. Izd-vo AN SSSR, 1952.

Tsytovich, N.A. On the laboratory investigations of frozen soils. Mat. po labor. issled. merzl. grunt. Sb. 1. Moscow, Izd-vo AN SSSR, 1953.

Tsytovich, N.A. Ed. Data on the laboratory investigation of frozen soils. Sb. 1, pod ped. N.A. Tsytovicha, Moscow, Izd-vo AN SSSR, 1953.

Tsytovich, N.A. Ed. Data on the laboratory investigation of frozen soils. Sb. 2, pod ped. N.A. Tsytovicha, Moscow, Izd-vo AN SSSR, 1954.

Tsytovich, N.A. Some general questions in the methodology of investigating physico-mechanical properties of frozen soils. Mat. po labor. issled. merzl. grunt. Sb. 2, Moscow, Izd-vo AN SSSR, 1954.

Tsytovich, N.A. Investigations of the effect of the conditions of freezing and thawing on the strength of water-saturated sand. Sb. posvyashch. 90-letiyu akad. V.A. Obrucheva. Izd-vo AN SSSR, 1955.

Tsytovich, N.A. Ed. Data on the laboratory investigation of frozen soils. Sb. 3, pod ped. N.A. Tsytovicha, Moscow, Izd-vo AN SSSR, 1957.

Tsytovich, N.A. Fundamental mechanisms in the mechanics of frozen soils (recent investigations). Mat. k IV mezhdunar. kongr. po mekhan. grunt. i fundamentostr. Moscow, Izd-vo AN SSSR, 1957.

Tsytovich, N.A., Saltykov, N.I., Zhukov, V.F. and Mel'nikov, P.I. Foundations of generating stations on permafrost. Moscow, Izd-vo AN SSSR, 1947.

Tsytovich, N.A. and Sumgin, M.I. Fundamentals of the mechanics of frozen soils. Izd-vo AN SSSR, 1937.

Tugarinov, A.Ya. The finding of fossil ostrich eggs in the Transbaikal region. Priroda, 1930, No. 5.

Tulaev, A.Ya. A review of the literature devoted to the study of frost heaving and measures in combatting it published up to 1938. In the book: "Investigation of frost heaving on automotive roads". Moscow, 1941.

Tumel', V.F. (1) On permafrost in the basin of the Vikhorevaya River. Tr. Komiss. po izuch. vechn. merzl., Vol. 4, Moscow-Leningrad, Izd-vo AN SSSR, 1935.

Tumel', V.F. (2) On seasonal thawing at the Irkuto-Baikal' water divide between the villages of Bystriya and Kulguk. Tr. Komiss. po izuch. vechn. merzl., Vol. 4, Izd-vo AN SSSR, 1935.

Tumel', V.F. Fifth All-Union Conference of Permafrost Studies. Vestn. AN SSSR, 1936, No. 4-5.

Tumel', V.F. On some changes in the permafrost regime of soils in connection with the burning of the vegetation cover. Tr. Komit. po vechn. merzl., Vol. 8, Moscow-Leningrad, Izd-vo AN SSSR, 1939.

Tumel', V.F. On permafrost photography. Izv. AN SSSR, ser. geogr. i geofiz., 1945, Vol. 9, No. 2.

Tumel', V.F. Map of the distribution of permafrost in the U.S.S.R. Merzlotovedenie, 1946, Vol. 1, No. 1, Moscow, Izd-vo AN SSSR.

Tushinskii, G.K. Snow slides. Tr. 2-go vses. geogr. s'ezda, Vol. 1, Moscow, 1948.

Tverskii, P.N. Ed. Course in meteorology (physics of the atmosphere). Gidrometeoizdat, Leningrad, 1951.

Tyrtikov, A.P. (1) On the thermotropism of roots in nature. Dokl. AN SSSR, 1951, Vol. 78, No. 6.

Tyrtikov, A.P. (2) The distribution of the root system of trees at the northern tree line. Vestn. MGU, Otd. biol., 1951, No. 10.

Tyrtikov, A.P. The thawing of soil in the region of Igarka. Tr. In-ta merzlotoved., AN SSSR, Vol. 12, 1952.

Tyrtikov, A.P. The length of tree roots at the northern tree line. Byull. Mosk. ob-va ispyt. prirody, Otd. biol., 1954, Vol. 59, No. 1.

Tyrtikov, A.P. (1) Vegetation in the Aldan mining region. Rukopis', fondy In-ta merzlotoved., AN SSSR, 1955.

Tyrtikov, A.P. (2) The growth of trees at the northern tree line. Byull. Mosk. ob-va ispyt. prirody, Otd. biol., 1955, Vol. 1.

Tyrtikov, A.P. (1) The effect of vegetation on permanently frozen soil. Mat. k osnov. uchen. o merzl. zonakh zemn. kory, No. 3, Moscow, Izd-vo AN SSSR, 1956.

Tyrtikov, A.P. (2) Vegetation in the lower reaches of the Yana River. Byull. Mosk. ob-va ispyt. prirody, 1956, No. 1.

Tyuremnov, S.I. Annual moisture conditions and the conditions affecting it in the eastern pre-Caucasus leached black earth. Tr. Kubansk. sel.-khoz. in-ta, Vol. 1, No. 2, Krasnodar, 1924.

Tyutyunov, I.A. Migration of water in peat-gley soil during the freezing and frozen states where the permafrost stratum is near the surface. Izd-vo AN SSSR, 1951.

Tyutyunov, I.A. (1) Permafrost in the European north, its development and significance in the national economy. Rukopis', fondy In-ta merzlotoved., 1953.

Tyutyunov, I.A. (2) The origin and development of small-mound micro-relief. Tr. In-ta merzlotoved., Vol. 12, Izd-vo AN SSSR, 1953.

Tyutyunov, I.A. Processes of cryogenesis and their effect on the temperature of top-soil and sub-soil. Rukopis', fondy In-ta merzlotoved., 1955.

Tyutyunov, I.A. Changes and transformation in top-soil and sub-soil at below-freezing temperatures (cryogenesis). Rukopis', fondy In-ta merzlotoved., Moscow, 1957.

Ul', E.F. A review of literature on the temperature and seasonal freezing of soils in the territory of the U.S.S.R. outside the permafrost zone. Rukopis', fondy In-ta merzlotoved., 1955.

Ule, W. Polygonaler Strukturboden auf dem Hochland von Norwegen. Peterm. geogr. Mill. (Gotha), 1922, Jg. 68.

Urantsev, N.N. Ancient glaciation in the north of the U.S.S.R. Tr. 1-i geol.-razved. konfer. Glavsevmorputi. Geol. i polezn. iskop. severa SSSR, Vol. 1, Leningrad, 1935.

Uspenskii, V.A. Carbon balance in the biosphere as related to the distribution of carbon in the earth's crust. Leningrad, Gostoptekhizdat, 1956.

Vadilo, P.S. The formation of ice and salt strata in soil. Uchen. zap. Kishinev. gos. univ., Vol. 3, No. 4, Kishinev, 1951.

Val'ter, O.A. and Begacheva, V.A. The activity characteristics of the root system of plants in the polar region. Eksperimental'naya botanika, No. 6, Moscow, 1940.

Vasil'evskii, M.M. Schematic of the fundamental hydrogeological regions of the European part of the U.S.S.R. Sovetskaya geologiya, 1930, No. 8-9.

Veinberg, B.P. Properties, origin and disappearance of ice. Moscow-Leningrad. Gos. Izd-vo tekh.-teor. liter., 1940.

Vel'mina, N.A. Catchment of ground water under conditions of permafrost (eastern Transbaikal and Amur regions). Moscow, Izd-vo AN SSSR, 1952.

Vel'mina, N.A. and Uzemblo, V.V. Geology of the central part of southern Yakutia. Izd-vo AN SSSR, Moscow, 1957.

Venyukov, M.I. Advances in the natural-historical study of Asiatic Russia. Tr. S'ezda russk. estestv. Izd-vo AN, St. Petersburg, 1868.

Vernadskii, V.I. (1) History of the minerals of the earth's crust. Vol. II. History of natural waters, Part 1, No. 1 and 2, 1933.

Vernadskii, V.I. (2) Regions of cooling in the earth's crust. Zap. Gos. gidrol. in-ta, Vol. 10, 1933.

Vernadskii, V.I. (3) History of the minerals of the earth's crust. Part II, No. 3, 1933.

Vernadskii, V.I. Notes on geochemistry. 4-e izd. Gorgeoneftetzdat, 1934.

Vil'd, G. Temperature of the air in the Russian Empire. St. Petersburg, 1882.

Vil'yams, V.R. Soil science. Moscow, 1946.

Vize, V.Yu. Seas of the Soviet Arctic. Moscow-Leningrad, Izd-vo Glavsevmorputi, 1948.

Voeikov, A.A. Climates of the earth, particularly of Russia. St. Petersburg, 1884.

Voeikov, A.I. Cooling of the earth's sphere in connection with the distribution of temperature in the earth's crust and oceans. Godichnyi akt. S.-Peterb. univ. 8 fevralya 1886, St. Petersburg, 1886.

Voeikov, A.I. (1) Permafrost in Siberia along the intended railroad route. Zhur. Min. putei soobshch., No. 4, 1889.

Voeikov, A.I. (2) Snow cover, its effect on soil, climate and weather and methods of investigating it. St. Petersburg, 1889.

Voeikov, A.I. Variations and changes in climate. Izv. Russk. geogr. ob-va, 1894, Vol. 30, No. 5, St. Petersburg.

Voeikov, A.I. Heat cycle in the earth's crust. Sb. statei po fizike, pamyati prof. F.F. Petrushevskogo. St. Petersburg, 1904.

Voeikov, A.I. Selected papers. T.Z. Izd-vo AN SSSR, Moscow, 1952.

Voitkovskii, K.F. Design of buildings of ice and snow. Moscow, Izd-vo AN SSSR, 1954.

Vollosovich, K.A. (1) Excavation of the Sanga-Yuryakh mammoth in 1908. Izv. AN, VI ser., Vol. 3, 1909.

Vollosovich, K.A. (2) Report on an expedition between the Lena and Tastakh Lake in the summer of 1908. Izv. AN, V. ser., Vol. 3, 1909.

Vollosovich, K.A. Mammoth of the Bol'shoi Lyakhovskii Island. Zap. Mineral. ob-va, Part 50, 1915.

Voznesenskii, A.V. and Shostakovich, V.B. Fundamental data on the study of the climate of Eastern Siberia. Irkutsk, 1913.

Vrangel', F.P. Expedition along the northern shores of Siberia and the Arctic Ocean carried out in 1820, 1821, 1822, 1823 and 1824. Izd-vo Glavsevmorputi, 1948.

Vtyurin, B.I. (1) Fossil ice on the shore of the Chukchi Sea in the region of the Schmidt Point. Rukopis', fondy In-ta okeanol. i In-ta merzlotoved., 1951.

Vtyurin, B.I. (2) On the origin and structure of fossil ice in the region of Anadyr'. Rukopis', fondy In-ta merzlotoved., 1951.

Vysotskii, G.N. Biological, soil and phenological observations in the Great Anadol. Tr. Opytn. lesnich. St. Petersburg, 1901.

Vyalov, S.S. Long-term strength of permanently frozen soils and permissible loads. Tr. Igarskoi nauchno-issled. merzl. st., No. 1, Izd-vo AN SSSR, 1954.

Vyalov, S.S. Geological properties and load-bearing capacity of frozen soils. Rukopis', fondy In-ta merzlotoved., 1956.

Water supply for railroads in regions of permafrost. Sb. pod ped. M.I. Sumgina. Moscow, Transzheldorizdat, 1941.

World Agroclimatological Handbook. Gidrometeorolog. izd-vo, 1937.

Washburn, A.L. Classification of patterned ground and review of suggested origins. Bull. geol. Soc. Amer., 1956, Vol. 67, No. 7.

Weiser, S. Permanent ice in a mine in Rocky Mountains. Philos. Magaz., 1875, 4 ser., Vol. 49, No. 322.

Winterkorn, H. and Fehrman, K. The effect of freezing-thawing and wetting-drying cycles on the density and bearing power of five soils. Proc. Soil Sci. Amer., 1945, Vol. IX.

Wollosowitsch, K.A. Übersicht der Wissenschaftliche Arbeiten Baron Tolls und allgemeine geologische Resultate seiner letzten Expedition. B kh: Toll, E. Die Russische Polarfahrt der «Sarja» (1900-1902), Berlin, 1909.

Yachevskii, L.A. On permafrost in Siberia and ice strata. Izv. Russk. geogr. ob-va, 1889, Vol. 25, No. 5.

Yachevskii, L.A. A case of gypsum deposition with the participation of ice. Geol. issled. i razved. raboty po linii Sibirsk, zhel.-dor., No. 11, St. Petersburg, 1899.

Yachevskii, L.A. The thermal regime of the land surface in winter in connection with geological processes. Gorn. kurn., aprel', mai, iyun', 1905, Vol. 2.

Yanchkovskii, A.V. The effect of permafrost on operations at the placer mine on the river Bodaibo. Vestn. zolotopromyshl. i gorn. dela voobshche, 1893, No. 11.

Yanovskii, V.K. Expedition to the Pechora River to determine the southern boundary of permafrost. Tr. Komiss. po izuch. vechn. merzl. Vol. 2, Leningrad, Izd-vo AN SSSR, 1933.

Yanovskii, V.K. On the methodology of investigating permafrost for the purpose of designing engineering structures. Geology and mineral resources of northern U.S.S.R. Tr. Pervoi geol.-razved. konfer. Glavsevmorputi 24-27 aprelya 1935, Vol. 3. Permafrost. Leningrad, Izd-vo Glavsevmorputi, 1936.

Yanovskii, V.K. Permafrost in the region of the Vorkuta coal mine. Rukopis', fondy In-ta merzlotoved., 1944.

Yanovskii, V.K. Methods of investigating permafrost for engineering-construction purposes. Izd-vo AN SSSR, 1951.

Zaikov, B.D. The mean run-off and its annual distribution over the territories of the U.S.S.R. Tr. Gos. gidrol. in-ta, No. 24, 1946.

Zaitsev, I.K., Gurevich, M.S. and Belenova, E.S. Hydrochemical map of Siberia and the Far East. Gosgeoltekhizdat, 1955.

Zaitsev, I.K. Ed. Explanatory notes for the hydrochemical map of the U.S.S.R. at the scale of 1 : 5,000,000. Gosgeotekhizdat, 1958 (sostavlena kollekt. VSEGEO v sostave B.N. Arkhangel'skogo, E.S. Belenovoi i dr.).

Zakharov, N.K. Investigation of sheer resistance during thawing. Avtoreferat, 1951.

Zalesskii, S.P. Geothermal observations at the Ilim open cast mine in the Transbaikal Oblast in 1894. Vestn. zolotoprom. i gorn. dela voobshche, 1895, No. 1.

Zamorskii, A.D. Needle-shaped ice in soil. Priroda, 1949, No. 10.

Zenkov, N.A. Report on hydrogeological investigations in Soviet territories on the islands of West Spitzbergen carried out in 1935-36. GUSMP, 1937 (manuscript).

Zhidkov, B.M. The Yamal Peninsula. Zap. Geogr. ob-va, Vol. 49, 1913.

Zhukov, V.F. (1) Frost fissures in permafrost regions. Tr. In-ta merzlotoved., Vol. 4, Izd-vo AN SSSR, 1944.

Zhukov, V.F. (2) A method of determining pressure on pit props in regions of permafrost. Tr. In-ta merzlotoved., Vol. 6, Moscow-Leningrad, Izd-vo AN SSSR, 1944.

Zhukov, V.F. Thawing of permafrost soils at the base of structures. "Kolyma", 1946, No. 11.

Zhukov, V.F. (1) Calculating the settlement of thawing soil, taking into account load applied. Rukopis', fondy In-ta merzlotoved., 1956.

Zhukov, V.F. (2) The force of frost heaving on a foundation. Rukopis', fondy In-ta merzlotoved., 1956.

Zhukov, V.F. Pre-construction thawing of permafrost foundation bases (fundamental method of construction). Izd-vo AN SSSR, 1958.

Zhukov, V.F. and Bakulin, F.G. Deformation of frozen fine-grained soils on thawing. Izv. AN SSSR, Otd. tekhn. nauk, 1955, No. 7.

Zhukov, V.F. and Saltykov, N.I. Permafrost in the region of Cape Kamenskii. Rukopis', fondy In-ta merzlotoved., 1948.

Zol'nikov, V.G. Geomorphological characteristics of the aluvial plain in Central Yakutia. Rukopis', fondy Yakutsk, fil. AN SSSR, 1949.

Zol'nikov, V.G. The origin of fossil ice in Central Yakutia, their function in the formation of relief and the geomorphological regions of Central Yakutia. Rukopis', fondy Yakutsk, fil. i SOPS AN SSSR, 1950.

Zonov, E.N. Secondary ice formation and ice-free spots on rivers of the Yansko-Kolyma mountain region. Tr. In-ta merzlotoved., Vol. 4, 1944.

Zubakov, V.A. Fossil ice and passive icing. Izv. Vses. geogr. ob-va, 1951, Vol. 83, No. 6.

Zubov, N.N. Ice of the Arctic. Izd-vo GUSMP, 1945.

Zvorykin, A.A. Pioneers in the study of the Arctic (expedition of Roman Neplyuev to Novaya Zemlya in 1651-1653). Priroda, 1946, No. 12.

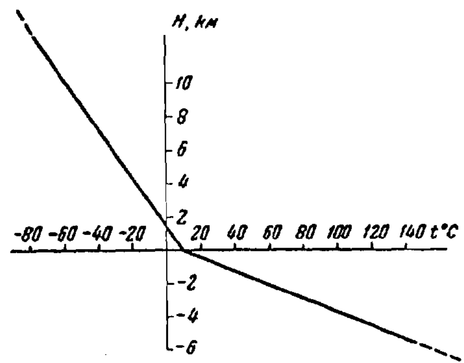

Fig. 2

Curve for air temperature in the troposphere (positive H) and lithosphere (negative H)

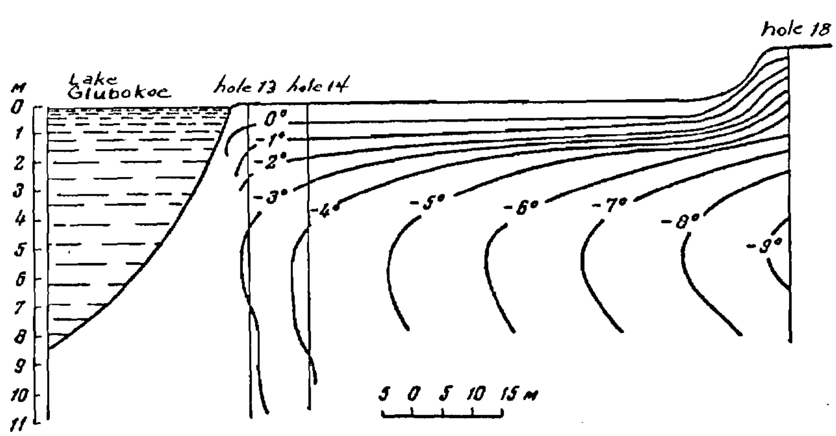

Fig. 3

Variations in temperature moving away from Lake Glubokoe

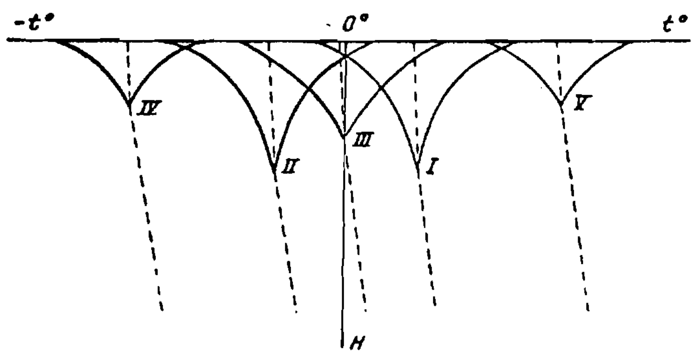

Fig. 4

Variations in the geothermal level of heat exchange between the soil and atmosphere

I - medium latitudes where the subsoil under the seasonally frozen soil is unfrozen; II - zones of continuously frozen subsoil and seasonally thawed soil; III - southern or lower boundary of the zone of continuously frozen subsoil where the thickness of the seasonally frozen stratum is equal to the thickness of the seasonally thawed stratum of the earth's crust; IV - high latitude polar zones; V - tropic zones