GEOCRYOLOGICAL MAP OF THE USSR AT A SCALE OF 1:2,500,000

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Abstract

A new Geocryological Map of the USSR at a scale of 1:2,500,000 results from research work performed by the Department of Geocryology, Faculty of Geology, MSU, over a 25-year period. This map shows: (1) geological formations of Pre-Quaternary rocks and genetic associations of Neogene-Quaternary deposits; (2) seasonally and perennially frozen ground, their composition, cryogenic structure, and volumetric ice contents; (3) mean annual ground temperatures; (4) permafrost thickness; (5) structure of the geocryological section; (6) distribution and thickness of earth materials with cryopegs; (7) distribution and thickness of relict (Pleistocene) permafrost, overlain by thawed ground; (8) cryogenic geological phenomena; (9) localities of underground water discharge and taliks.

The Geocryological Map of the USSR is supplemented by four general maps at a scale of 1:25,000,000 showing: (1) present environmental conditions; (2) permafrost thickness; (3) the cryogenic age of sediments and types of cryogenesis; and (4) a hydrogeocryological map.

Introduction

A new Geocryological Map of the USSR at a scale of 1:2,500,000 (Geocryological Map... 1997) will be presented at the Seventh International Conference on Permafrost. This map is published in 16 sheets and covers a total wall area of 12 m². The map shows the geocryological conditions of the former USSR, where permafrost occupies 49% of the territory, including the Russian Federation where it occupies 65% of the area. The map presented for discussion is the original. It shows, in detail, a set of geocryological parameters. Additional information on the permafrost zone of the USSR is presented on general maps. These are compiled at a scale of 1:25,000,000 and are located on the bottom margin of the map.

Compilation procedure

We compiled the map, following well-developed and widely applied procedures for compiling medium- and small-scale maps as a result of field geocryological investigations of the permafrost zone at various scales (Procedure... 1970; Kudriavtsev, 1979). An intimate connection between seasonally and perennially frozen rocks and environmental factors is established and studied. This connection is studied within all of the topographic forms throughout the study territory. The data obtained and the relationships observed in nature allow geotectonic and landscape-climatic regionalization of the territory. As a result, “key” areas similar in their main permafrost-forming factors and geocryological parameters are recognized on this map. Concentration of comprehensive geocryological investigations within these key areas allows the use of a wide range of the investigation techniques (drilling, geophysical and seismic methods, etc.) for studying the permafrost zone. Then the data obtained are extended to larger territories with similar natural and geocryological conditions.

Regions and areas of the field geocryological investigations at various scales were used as the key ones during compilation of the present map. These were supplemented by meteorological observations for air and ground temperature, precipitation, snow cover, etc. Laboratory data (rock composition and properties) and calculated data (mean annual ground temperature and permafrost thickness) were extensively used. As a result, the Geocryological Map shows four groups of geocryological parameters. Each group is shown by a particular means of representation (colours, shadings, and symbols).

Contents of the map

CRYOGEOLICAL CONTENTS

The map shows geological formations of Pre-Quaternary rocks and genetic associations of Neogene-Quaternary deposits. The composition, structure, and ice contents of all of the rocks are presented. Bedrock
formations are shown within denuded areas, where they are overlain by thin surficial deposits (3-5 m). The predominant composition, joint systems, cryogenic structures, and volumetric ice contents of each of the formations (to depths of 25 to 30 m) are shown in the legend and on the map. Unconsolidated Neogene and Quaternary deposits received primary attention, as they occur at the surface and are of vital importance in the heat exchange between the rocks and the atmosphere, as well as in cryogenic geological processes and phenomena (Procedure..., 1970; Kudriavtsev, 1979; Romanovskii, 1993). The map shows, therefore, in detail, the distribution of genetic associations of sediments and their predominant composition. Features of their composition, freezing type, cryogenic structure, volumetric ice content, and types of ice macroinclusions (polygonal-wedge and massive ice bodies) are presented in the legend and shown on the map by brown symbols.

**Distribution and Mean Annual Temperatures of Permafrost and Thawed Ground**

These parameters are of great importance for a study of permafrost and thawed ground. They are shown on this map by a coloured background. Latitudinal and altitudinal permafrost distribution is shown by a change (an increase in strength) of colour from the southern limit of permafrost to north. The discontinuity of permafrost distribution is determined by the formation of open and closed taliks of various types (Romanovskii, 1983, 1993). These are: (1) insolation-heat taliks that form in response to the latitudinal and altitudinal variation in the solar radiation at the earth’s surface; (2) taliks that form beneath deep rivers and lakes; (3) glaciogenic taliks that result from positive temperatures at the base of glaciers; and (4) ground-water taliks that form as a result of subpermafrost water discharge. The discontinuity of the permafrost zone is mainly determined by insolation-heat taliks. The continuous permafrost zone (the Northern Geocryological Zone) and the discontinuous permafrost zone (the Southern Geocryological Zone), which includes the zone of scattered permafrost islands and the zone of large permafrost islands (Fotiev, 1978), are distinguished on this map by the absence or the presence of this type of talik.

Permafrost distribution is shown in the map in more detail using mean annual ground temperatures that vary from south (0°C) to north (-17°C). These are shown on this map at 2°C intervals and at 1°C intervals in the transition zone between thawed and frozen ground (Dostovalov and Kudriavtsev, 1967; Procedure..., 1970; Kudriavtsev, 1979).

In the southern part of the Southern Geocryological Zone, permafrost islands of various sizes occur among generally thawed ground. In the northern part of this zone, islands of unfrozen ground occur among prevailingly frozen materials. Their proportions change from south to north and from lower topographic elevations to higher ones. These depend also on the composition and moisture content of the ground. The prevailing mean annual ground temperatures vary from +2 to -0.5°C in the zone of scattered permafrost islands, from +1 to -1°C in the zone of large permafrost islands, and from +0.5 to -2°C in the discontinuous permafrost zone (Dostovalov and Kudriavtsev, 1967; Kudriavtsev, 1978).

Within the zone of unfrozen ground on the territory of the former USSR, the mean annual ground temperatures are shown in the range from 0 to +21°C at 2°C intervals.

The ranges in the ground temperatures shown on this map represent the background values. They are representative of 75% of the territory in each part of the map. The mean annual ground temperatures of the rest 25% of the territory may be higher or lower.

**Permafrost Thickness and Structure**

Permafrost thickness records the permafrost evolution during the Cenozoic, beginning in the Pliocene and continuing to today (Velichko, 1973; Baulin, et al., 1988; Romanovskii, 1993). The permafrost thickness ranges from several meters up to 1500 m, or more.

The permafrost zone of the territory of the former USSR has a great latitudinal and longitudinal extent and, hence, a very complex cryogenic structure in section and a highly variable thickness. The thickness of the permafrost is closely related to its cryogenic structure. It is common practice, therefore, to show geocryological units (horizons, strata, layers) of rocks, having a negative temperature and composing the permafrost section in the geocryological maps of north Eurasia.

The permafrost structure is shown by mapping the following geocryological rock units:

(a) frozen strata (subaerial and submarine) that contain ice and dry permafrost;

(b) subaerial and submarine strata that have negative temperatures and contain saline water and brines (cryopegs);

(c) relict permafrost layers that are separated from the Late Holocene Permafrost in section, occur at the surface, or are overlain by thawed materials 100 to 200 m, or more, in thickness.

Permafrost thickness is shown on this map separately for each of these geocryological units, using shadings of different colour. Thus, the thickness of the frozen materials of the upper geocryological unit (a) in the
Southern Geocryological Zone is shown in steps of 0-15, 0-25, 0-50, and 0-100 m. The first number (0) means that all of the permafrost islands are separated by unfrozen areas. In the Northern Geocryological Zone, permafrost thickness is shown in 100 m intervals for plains and in 200 m intervals for mountain regions. The permafrost thickness is shown on this map in 18 steps, ranging from 0 to 1500 m or more, using red shading.

The thickness of the strata with subaerial and subma-
rine basal and underwater cryopegs (b) is shown by green shading. The thickness ranges from 25 to 100 m near coasts and from 500 to 900 m or possibly more, within old geological structures.

Relict permafrost units occur in the Southern Geocryological Zone in north-east Europe and in West Siberia. The thickness of relict permafrost (c) overlain by thawed sediments is shown by black shading in 10 steps, ranging from 30 to 200 m.

A great quantity of deep boreholes on this territory allowed the measurement of particular depths of occurrence and thickness of layers composing multilayered permafrost. Therefore, the particular depths of occurrence of the relict permafrost table and base are also shown on this map.

The total thickness of multilayered permafrost can be calculated by summing up the thickness of all of the geocryological units with negative temperature in section. This thickness is also shown in the supplementary map at a scale of 1:25,000,000, which is considered below.

The Geocryological Map shows that the permafrost thickness in the Southern Geocryological Zone is correlated with the present mean annual ground temperatures. In the Northern Geocryological Zone, where the permafrost thickness varies from 200 to 1500 m this correlation is conventional.

The greatest permafrost thickness beneath plains (1000 to 1500 m) is observed within the Siberian Platform, one of the oldest geotectonic structures on the Earth. The same thickness is observed also beneath the highest mountain ranges of North-East Siberia, the Far East, and the Central Asia. These permafrost strata are the oldest in cryogenic age, as they approach more than 1 Ma from the onset of rock freezing. The cryogenic age of permafrost is shown on a supplementary map at a scale of 1:25,000,000.

CRYOGENIC GEOLOGICAL PHENOMENA AND TALKIS

Both local and widespread cryogenic geological phe-
nomena are shown on this map. Types, sizes, and frequency of occurrence of cryogenic features are deter-
mined by the character of heat exchange at the ground surface. In the Southern Geocryological Zone, relict forms (ice-wedge casts, thermokarst depressions and lakes, and relict polygonal topography, etc.) are mainly shown. In the Northern Geocryological Zone, ice wedge systems, seasonal and perennial frost mounds, polygonal peatlands, etc. are shown.

The vertical extent of ice wedges (up to 10, 20, 30 or rarely up to 40 m) is presented. Massive ice beds and widely occurring ice wedge systems are shown for particular genetic deposits in which they formed and exist.

In the Northern Geocryological Zone, open and closed taliks are shown by a special symbol (red outline of lakes and red line along rivers). This map shows that both open and closed taliks can exist under one river, depending upon its width and depth, and groundwater sources. The symbol of a closed talik (solid line) is changed to the symbol of an open talik (dotted line) in this case. Icings are shown by a blue symbol. Icings of great thickness (5 to 10m) and great extent are depicted along river beds at scale. Locations of discharge of thermal water, saline water, and brines are shown by rings.

As mentioned above, beyond the southern limit of permafrost, positive mean annual ground temperatures are shown. The types of seasonal freezing (Dostavalov and Kudriavtsev, 1967; Procedure..., 1970; Kudriavtsev, 1979) are also shown by the “continentality” (by the amplitude of temperature fluctuations at the soil surface), along with the mean perennial freezing depths (black numbers).

In the zone of thawed and unfrozen deposits, especially those with mean annual temperatures from 0 to +9°C, cryogenic bodies overlain by soil or rock beds are shown. These are represented by soil wedges (ice-wedge casts, primary sand wedges, and ground involution), suggesting the presence of permafrost on this territory in the Late Pleistocene (Baulin et al.,1988).

General Maps of the Permafrost Zone of the USSR at a scale of 1:25,000,000

MAP OF PRESENT ENVIRONMENTAL CONDITIONS

This map shows:
1- geotectonic structures of first and second orders;

2-types of climate within these structures, depending upon the solar radiation at the earth’s surface, regime of atmospheric circulation, and effects of land and sea on climate;

3- types of heat exchange, depending upon the latitudinal and altitudinal variation in the solar radiation at the earth’s surface;

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4- types of megatopography and macrotopography that determine the heat exchange between the solar radiation and the ground;

5- vegetation zones, affecting the heat exchange; and

6- present boundaries permafrost.

MAP OF PERMAFROST THICKNESS
This map shows the total thickness of all of the layers (geocryological units), composing permafrost:

1- thickness of the upper geocryological unit of frozen (bonded) and dry frozen (non-bonded) sediments;

2- thickness of the underlying geocryological unit of rocks with cryopegs, having a negative temperature;

3- thickness of relict (Pleistocene) geocryological unit, buried under thawed Holocene sediments.

To show the total permafrost thickness on this small-scale map, we introduced new intervals. Within plains, the thickness of single-layer permafrost is shown at the same intervals as on the Geocryological Map of the USSR. In mountainous regions, the permafrost thickness is shown at intervals two to three times larger than those used on the Geocryological Map. The total thickness of two-layered or three-layered permafrost is 300 m near the southern limit of permafrost and 1500 m in the central part of the Siberian Platform and beneath mountain summits.

MAP OF CRYOGENIC AGE OF ROCKS AND TYPES OF CRYOGENESIS
This map shows:
1- permafrost of different cryogenic age, varying from the predominant Pleistocene, or sometimes Neogene-Pleistocene, to the Late Holocene; and

2- syngenetic and epigenetic earth materials, their volumetric ice contents and ice macroinclusions, and their relationship to genetic associations of Quaternary deposits and geological formations of Pre-Cenozoic rocks.

HYDROGEOCRYOLOGICAL MAP
This map shows:
1- hydrogeological structures of first and second orders;

2- distribution and thickness of permafrost as a cryogenic aquiclade;

3- distribution of fresh underground waters, cryogenic aquicludes, and cryopegs; and

4- effects of underground waters on permafrost occurrence and thickness.

Conclusions

The Geocryological Map of the USSR shows separately all of the geocryological parameters and environmental factors. Their variation from one topographic form to another can be observed. This allows an understanding of the interconnection between geocryological parameters and environmental factors. We can determine limiting values of these parameters within each of the study areas. We can see also a regular change in each of the geocryological parameters: from south to north, (reflecting the latitudinal climatic variation in the heat exchange at the ground surface); from west to east, (reflecting the “continuity” of the climate); from lower topographic elevations to higher ones (reflecting the altitudinal variation in the heat exchange); from occurrences of coarse deposits to fine-grained deposits and peats; from fissured and karst-affected rock bodies to monolithic ones; and from ice-rich and moist deposits to ice-poor and dry ones. In addition, we can forecast the trend and the character of changes in the geocryological parameters as a result of economic development of the territory and of natural evolution.

This map, reflecting the present geocryological situation, allows detailed-scale studies of permafrost and estimates of geocryological features in all of the regions. It is of great importance for the compilation of geocryological maps at a scale of 1:1,000,000, 1:500,000, and 1:200,000. This map may be used at a survey stage for the preparation of feasibility reports for construction of important structures on permafrost. It also allows preliminary estimates of the geocryological parameters for competing options for the large-scale construction.

This map allows the compilation of a new map to forecast the change in geocryological parameters due to climatic changes or due to an increase in CO₂ content in the atmosphere. It may be used for the selection of optimal sites for industrial and radioactive waste disposal. Using this map, one can estimate the permafrost conditions for the development of mineral deposits, including deeply occurring ones. This map may be used for solving the problems of water supply and ground water protection from pollution. Geocryological features of the territory, shown on this map, allow the estimates of the geocological situation, taking into consideration permafrost as a cryogenic aquiclade and taliks permeable to water.

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References


