This translation of a classic Russian work on geocryology makes available for the first time in English a wide ranging and up-to-date review of permafrost science, unique in presenting the Russian viewpoint. This revealing account demonstrates how the field developed in the former USSR (largely in isolation from related studies elsewhere), and provides a fascinating insight into the extent of Russian scientific involvement and input. The fundamental physics of frozen ground, geotechnical procedures for construction problems, distribution of permafrost in terms of geological history, and planetary geocryology are all considered. This English edition brings the work to a larger readership, allowing the value of the knowledge and concepts developed to be realized more widely.
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E. D. YERSHOV
Moscow State University

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Editor’s note

It is fitting that the holder of the only Professorial Chair of Geocryology (or permafrost studies as it used to be called), that at Moscow State University, is the compiler of a standard work on the subject. The book is the first of its type to be translated into English. Professor Eduard D. Yershov, who assumed the Chair in 1982, demonstrates the scope of Russian science and geotechnology for cold regions. The fundamental physics of frozen ground, geotechnical procedures for construction problems, distribution of permafrost in terms of geological history and even extraterrestrial (planetary) geocryology are all considered.

It is timely that such a book be made available in English because of the extent of interest and activity in the Russian permafrost regions on the part of companies and institutions internationally. This interest, which relates to the oil and gas industry especially but extends to other sectors, has come with the momentous changes since the end of the Soviet era. Although earlier textbooks could be obtained outside the Soviet Union, there was little of the exchanges otherwise characteristic of science and research. The Siberian permafrost areas and oil and gas fields were of course, particularly difficult of access by foreigners.

With the lack of personal, international contacts, the standards of translation of the papers available were not high. This further limited the chances that Russian progress, scientifically and technologically, could be appraised correctly by those outside the country. The Russian scientists and engineers working on the problems of foundation construction in areas prone to permafrost, have far outnumbered those elsewhere. Moscow State University’s Department of Geocryology produces tens of graduates in the subject each year. The extent of the Russian studies and their potential for geotechnical procedures and environmental remediation has not been fully understood.
Editor's note

In preparing the English version of Professor Yershov's book it was decided to invest much effort in ensuring a readable text, accurate in translation especially of technical and scientific terms, with an overall presentation of a standard equal to that accorded by Cambridge University Press to any comparable work by an English language author. Working with a translation provided from Moscow, the text was first substantially reworked into correct and readable English while attempting to preserve as far as possible the author's surely typically Russian style. In the interests of scientific accuracy a number of the chapters were further reviewed by specialists in the topics who generously gave of their time. The responsibility for shortcomings is not, of course, theirs, whose- ever it may be. Suffice it to say that the flaws that remain are in spite of the best efforts of many people.

We would welcome readers' comments on the translation of specific items. Important, too, was the help of the bibliographer of Russian materials at the Scott Polar Research Institute, Cambridge. Her work and that of several Russian colleagues is reflected in the Notes on translations and definitions. All these individuals are recorded in the acknowledgements below but it is appropriate to note here the willingness of Cambridge University Press to make the necessary budgetary provision for this diverse team effort. Dr Maria Murphy of the Press has dealt very imaginatively with the complexities of the project from its conception.

It is hoped that the translation of Professor Yershov's work will not merely provide details of interest to scientists in geocryology. It is important, too, that the extent of the Russian scientific involvement, as demonstrated by this book, be recognized by those working for international projects for oil and gas and other industrial or environmental projects within Russia. Quite generally in cold regions engineering (in Russia these regions are not limited to the Arctic or the North) there has been a failure to involve scientific research in the most cost-effective manner. The economic implications of the permafrost for the Siberian oil and gas industry are profound as indeed they are for the development of Canadian and Alaskan oil and gas. By opening Professor Yershov's book to a wider readership the value of the knowledge and concepts developed in Russia should be more fully realized worldwide.
Acknowledgements

The editor and publishers are indebted to those who have assisted in various ways in preparing the English version.

Isabella M.T. Warren, Russian Bibliographer, Scott Polar Research Institute, Cambridge, has been a constant source of help in refining the translation. The following gave expert advice in interpreting the finer points of particular technical terms in the original Russian: Evgeny Chuvilin, Evgeny Aksenov and Olga Toutoubalina, Moscow State University; and Vlad Roujansky, EBA Engineering, Edmonton.

Scientists and engineers, all in some degree geocryologists, have given advice on English terminology in their own areas of scientific and engineering expertise: R. van Everdingen, Arctic Institute of North America, Calgary; P.D. Groenevelt, Guelph University; D.W. Hayley, EBA Engineering, Edmonton; A. Judge, Geological Survey of Canada; J.A. Heginbottom, International Permafrost Association; B. Ladanyi, Ecole Polytechnique, Montreal; W.G. Rees, Scott Polar Research Institute, Cambridge; E. Jetchik, D.W. Riseborough, J. K. Torrance and T.L. White, Geotechnical Science Laboratories, Carleton University.

The initial translation was carried out in Moscow by N.B. Guseva (Introduction, Chapters 1 and 12-19); A.D. Ankin (Chapter 2); and L.V. Kholodobaeva and A.K. Stroganov (Chapters 3-11).

The editor adds his indebtedness to Kari Williams, for word processing, including the setting-up of the many equations and tables, and to Inger E. Williams, for preparing the English version of all the figures.
Notes on translations and definitions

In transliterations, the system used by the Scott Polar Research Institute’s bibliographic services has been followed. The following dictionaries, glossaries and similar items have been used:


xvi \hspace{1cm} \textbf{Notes on translations and definitions}

\textbf{Russian words accepted in literal translation, the meanings of which may be unfamiliar or unusual}

(Unless otherwise noted, the references are to items listed above.)

\begin{itemize}
\item Aleurite: unconsolidated deposits, grain size 0.05 to 0.005 mm. Aleurolite is similar, but consolidated (in the geological, not geotechnical, sense, – van Everdingen, pers. comm.)
\item Ataxite, -itic: disorder, -disordered, irregular
\item BAM: Baikal–Amur Mainline
\item ChPI: Chita State Politekhnicheskij Institut
\item Cryolitohzone, Cryolithic zone: usually synonymous with permafrost (regions) – including extensive areas where permafrost may be discontinuous or even rare.
\item Indeed phenomena of seasonally freezing soils found far distant from permafrost are referred to as typical of the cryolithohzone
\item Cryolite: ice considered as a mineral in the ground (not to be confused with the mineral cryolite, Na$_3$ AlF$_6$)
\item Cryopeg: ground which is unfrozen because of dissolved salts (usually below permafrost)
\item Crystallisation heat: latent heat of fusion
\item Dell: this transliteration, according to Romanovsky \textit{et al.} (1992), means indeed, a small wooded valley (Oxford English Dictionary)
\item Deserptium: surficial creep deposit resulting from volume change (Poppe and Brown, 1976)
\item Dispersion, dispersed: 1. fineness of particles 2. dispersed (loose) nature of material
\item Dust, dusty: a grain size fraction (0.05–0.01). Corresponds to coarse silt in English.
\item Eluvium: residual deposit following washing-out of fine material
\item Glets ice: ‘cold mountain ice’ (Romanovsky \textit{et al.}, 1992), ‘ice accumulated under a coarse surface layer from meltwater in spring’ (p. 267 this book)
\item Gosstroj: Gosudarstvenny Komitet po Delam Stroitel’stva (State Committee for Construction Affairs)
\item Illuvial: material moved into stratum by percolating water
\item Intercalated: inserted after deposition of bed (used, e.g. of ice layers or lenses)
\item Khasyre: thermokarst depression in epigenetic permafrost (contr. alas formed in syngenetic permafrost, with melting of syngenetic wedges). According to Romanovsky \textit{et al.}, 1992, a local, West Siberian term
\item Laida: coastal plain covered by tidal water (Evgeny Chuvilin, pers. comm.)
\item LGI: Leningradskiy Gornyi Institut (Leningrad Mining Institute)
\item Massive: (1) having ice in pores only; thus no segregation ice, and the ice masses are essentially no larger than pore size. (2) large (of a body of ground)
\item MISI Moskovskiy Inzhenerno-Stroitelnnyy Institut (Moscow Engineering and Construction Institute)
\item MSU: Moscow State University (this is an English abbreviation, the transliterated Russian being MGU)
\end{itemize}
Notes on translations and definitions

NIIOISP: Nauchno-Issel'ovatel'skiy Institut Osnovaniy i Podzemnykh Sooruzheniy (Scientific Research Institute for Foundations and Underground Structures)

Oligo-mitic consisting of one to two dominant minerals (Oxford English Dictionary-‘word of Russian origin’)

Paludification: swampiness, conversion to swamp or marsh

Paludal: pertaining to marshes

PNIIIS: Proizvodstvennyi i Nauchno-Issel'ovatel'skiy Institut po Inzhenernyy Izyskaniyam v Stroitel'stve (Industrial and Scientific Research Institute for Constructing Engineering)

Polynya: an area of open water in an otherwise extensive ice cover (on river, sea etc.)

RSFSR: Rossiyskaya Sovetskaya Federativnaya Sotsialisticheskaya Respublika (Russian Soviet Federated Socialist Republic)

Riphean: Russian term for a period of Mid-proterozoic, from 1650 Ma to 680 Ma.


Schlieren: repeated small ice lenses (German origin, here apparently often synonymous with 'streaks')

Sulfosion: a spreading out into a sub-stratum (e.g. filling of a solution cavity or a cavity from melting ice)


Tuffolava: extrusive rocks intermediate between tuffs and lavas (Challinor's Dictionary of Geology).

USSR: Union of Soviet Socialist Republics

VSEGINGEO: Vsesoyuznyi Nauchno-Issel'ovatel'skiy Institut Gidrogeologii i Inzhenernyy Geologii (All-Union Scientific Research Institute for Hydrology and Engineering Geology)


Frequently misinterpreted words

Readers acquainted with the Russian language may be interested in the following words which often cause confusion in translations. A direct transliteration or a literal translation gives an incorrect or, at least, misleading meaning. Some erroneous translations have recurred in so many publications as to have gained a certain currency. As a consequence they have often caused difficulties for the proper understanding and assessment of the Russian literature of geocryology. The correct translations, so far as could be established for the present work, are given below (bold). They are arranged alphabetically, according to the transliterated Russian word.
xviii Notes on translations and definitions

dispersnost = disperse: this word is widely used in the Russian, where English would require ‘fine-grained’ (‘greater dispersion’ = ‘more fine-grained’); also used, however, in the sense of ‘widely dispersed’ (i.e. widely spaced or loosely packed).

kriolitozona = cryolithic zone = cryolithozone: usually synonymous with permafrost regions – including extensive areas where permafrost may be discontinuous or even rare. Indeed phenomena of seasonally freezing soils found far distant from permafrost, are referred to as typical of the cryolithozone (for example, in Chapter 3). A term covering all ground affected by freezing (regardless of permafrost) would be useful. Cryolithosphere is occasionally used in this sense.

plotnost’ = density, in the normal sense, but is also used in the sense of ‘strength’ or ‘intensity’ for example of a flow of water (and would then usually be omitted in English).

suglinok: silty soil with more sand than clay (See quantitative limits in: Sanger, F. J. in Second Intern. Conf. Permafrost, USSR Contribution, National Acad. Sci., Washington. 1973 pp. xi, xii). Russian translators often use ‘silty loam’ for these soils but ‘loam’ in English is normally restricted to an agricultural or soil science context. Generally shown in the present work as sandy-silt or similar.

SNIIP: – although ‘snip’ is an appealing acronym, sometimes used directly by English-speaking engineers, the translation Building Norms and Regulations seems preferable.

supes: silty soil with more clay than sand generally translated in the present work as ‘clay-rich sandy silt’ or similar. See also comments under suglinok.

poroda: ground, rock or soil, according to context. Skal’naya poroda and gornaya poroda: bedrock

taly: literally, ‘thawed’ but often used for unfrozen part of ground, of soil sample etc. without reference to any previously frozen state. Thus, ‘unfrozen soil’, ‘unfrozen ground’. Where this meaning is intended rather than using the symbols t, th, or tha (used as subscripts) in equations and figures have been replaced by unf in the English.

migrationszno-segregationsionny led: literally, migrational-segregation ice: ice accumulating by cryosuction, normally in the form of ice lenses or layers (also called —schlieren), and characteristic of frost heaving soils.

ob’emino-gradientnokoye napryazheniye: literally, volume-gradient stress: an ‘all-round’ stress, esp. stress inducing shrinkage (volumetric strain). The term
Notes on translations and definitions

embodies the concept of gradients of such stress, which leads to cracking and shearing as a result of the differential volume changes.

zhila: 'wedge' or 'vein'. Ice wedge in the English sense, is povtorn' zhi'l'nyy led = 'recurring ice wedge' although the 'recurring' (povторнo) may often be omitted. Thus confusion may exist between ice wedge, and ice vein -usually the initial (first year) ice infilling of the tensile fracture crack. See also van Everdingen, R. O. (1994).

usadka: shrinkage (as in English, a distinction may be made between 'shrinkage' and 'consolidation' (soil mechanics sense) – although the process is similar)

Place names and personal names

Geographic names are given in anglicized form where such exists and is generally recognized (e.g. St. Petersburg). Otherwise a transliterated form (e.g. River Irtysch) is given following the guidelines of the British Permanent Commission on Geographic Names. The transliterated Russian term is used for geographical features ('strait', 'bay', 'island', 'mountain range' etc.) except for 'sea' and 'lake'. The guidelines normally correspond to those advocated by the United States Board of Geographical Names and are those used in The Times Atlas of the World and in current maps of the National Geographic Society, Washington.

Personal names are transliterated in the normal fashion except where the person is known by a different form in English.

Peter J. Williams
Geotechnical Science Laboratories
Carleton University. Ottawa
May 1997

Scott Polar Research Institute
University of Cambridge
Cambridge
Abstract

Theoretical concepts of the science dealing with frozen ground and cryogenic-geological processes are given. The principles of formation and development of frozen ground and seasonal freezing-thawing are elucidated. The particular features of the composition, structure and properties of frozen ground are described together with the conditions of their formation. The principles and methods of geocryological investigations and the classification of perennially frozen ground are considered. Also presented are the principles of engineering geology for design, construction and operation of engineering structures in the permafrost zone.

This work is particularly relevant for students studying in the specialization 'hydrogeology and engineering geology'.
Preface

*Geocryology* (the study of frozen soils) is a natural and historical science and a branch of geology, concerned with the laws of the formation and the evolution in time and space of frozen ground, its composition, cryogenic structure and properties, and with cryogeological processes and phenomena. The frozen ground may be hundreds of meters thick (up to 1500 m) in the region comprising the freezing zone of the lithosphere characterized by freezing temperatures (to \(-15^\circ\text{C}\)) and inclusions of ice or ice crystals.

As any other branch of knowledge, geocryology has resulted from practical needs, and its coming into being has reflected the economic development of huge permafrost tracts, which include currently 25% of all land on our planet and some 50% of the territory of the former USSR.

The subject of geocryology is now well-defined, as are a range of its basic problems, its practical and scientific significance; techniques and procedures for special geocryological researches have evolved; with its major fields and trends established, the prospects of geocryology gaining both in science and in application have proved very promising. Vladimir I. Vernadskii has noted earlier that it is the limits of cooling below the ground surface which define a task relating to the solution of problems which are all of great scientific and practical importance.

The topic of geocryology is frozen ground, including underground ice and snow accumulations. According to the views of A.B. Dobrovolskiy, V.I. Vernadskii and P.I. Koloskov, frozen ground occurs in the cryosphere, which is a thermodynamic envelope of the Earth where ice, water and vapour can exist simultaneously under negative temperatures. Permafrost is a natural geological formation noted for its distinctive laws of genesis, existence, evolution and distribution on the planet. Looking to outer space, most planets of the Solar system and other celestial bodies appear to be cryogenic, i.e. to be noted for permafrost developed on them. In other words,
xxii  Preface

our perspective extends from the cryology of the Earth to that of the planets or Universe, cosmic cryology.

Several works of generalization have been written on the fundamentals of geocryology. *General Frozen Ground Studies* by M.I. Sumgin, S.P. Kachurin, N.I. Tolstikhin and V.P. Tumel, came in 1940, and in 1959 *Fundamentals of Geocryology*, the magnum opus, put out by the Institute of Frozen Ground Studies. The first edition of the textbook *General Frozen Ground Studies* was printed in 1967, its second edition in 1978, and in 1981 came *Frozen Ground Studies (Concise Course)* prepared and edited by V.A. Kudryavtsev. *General Frozen Ground Studies* edited by P.I. Mel'nikov and N.I. Tolstikhin appeared in 1974. All these books have proved very important in laying the foundations of geocryology; now they are rarities, and what is more, many of their chapters are in need of considerable reworking due to substantial advances made recently in formulating the theoretical and applied (engineering) fundamentals of geocryology.

The present textbook, based on the latest advances in science and practice, expounds in condensed form the fundamentals of dynamic, lithogenic, regional, historical and engineering geocryology. It is designed for students and lecturers in geocryology at universities (the ‘Engineering geology and groundwater hydrogeology’ specialization), and in geological exploration, mining, oil and gas, building and transport, at institutions of higher education. There is no doubt it will be useful for a wide range of geologists in research and commercial bodies, and for many technicians in design and survey, building and mining establishments engaged in exploration and economic development of the permafrost regions.

Colleagues from the Department of Geocryology in the Geology Faculty at Moscow State University participated in compiling the textbook. Some chapters and subsections were written in collaboration with V.Ye. Afanasenko (Ch. 13), L.S. Garagulina (Introduction, #5; Ch. 16, #1–3; Ch. 19, #2), I.D. Danilov (Ch.9), K.A. Kondrat’yeva (Ch. 14, #3; Ch. 15, #1, 2, Ch. 16, #1 and 4), S.Yu. Parmuzin (Ch. 17–19). Participating in writing individual subsections were Ye.N. Dunayeva (Ch. 15, #3), V.Ye. Romanovskiy (Ch. 1 #4 and 5; Ch. 10, #1), S.F. Khroustiky (Ch. 10, #3; Ch. 12, #3); Ye.M. Chuvinin (Ch. 8, #4; Ch. 9, #3).

Ye. M. Chuvinin was responsible for preparing the manuscript for publication. Assisting him at all stages of its preparation were T.N. Kosatkova, L.A. Nikulicheva, O.N. Patrik.

The author would like to thank all these contributors, especially K.A. Kondrat’yeva who has read the final manuscript, for their invaluable help.
Preface

Chapter 2 was translated by A.D. Anikin. The Preface and Chapters 3–11 were translated by L.A. Kholdobayeva and A.K. Stroganov. The Introduction, Chapter I and Chapters 12–19 were translated by N.B. Guseva.