Adaptation of geotechnologies to mineral mining conditions in permafrost: Challenges

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Abstract. The author addresses problems of efficient mineral mining in the zone of permafrost. It is illustrated that geotechnologies for the development of solid minerals in permafrost rocks should make use both of positive and negative factors of internal and external environment. The article reports about the research findings of the Chersky Institute of Mining of the North towards improvement and development of efficient and eco-friendly innovative technologies, methods and equipment for mineral mining and processing to be highly adaptable to the conditions of the permafrost zone.

1. Introduction
Mineral mining is the major industry promoting sustainable social and economic development of a country and the well-being of the nation. The mining industry in Russia faces problems governed by negative trends of the recent decades. One of the key problems is the outrun of increase in the cost of mineral mining as against the increase in the output [1]. A root cause of this situation is depletion of easily accessible and rich mineral deposits. For this reason, the average content of useful components in mineral deposits planned for or currently under development steadily declines, mining goes to deeper levels, processing circuits are fed with rebellious materials and, eventually, the cost of mining rise while productivity drops as scientific and technological advance falls behind the appreciation of mining operations.

Currently, in view of increasing depletion of mineral and hydrocarbon reserves in the middle of the country, the new mining projects steadily drift to poorly developed regions in the east and north-east. These regions feature vast territories, weak infrastructure and low density of population, remoteness from processing and consumption facilities, expensiveness of goods and services, deficiency of highly skilled personnel, etc. The natural environments (physiographic and geological) have dominant influence on economic efficiency in all sectors of industry, including mining. The problem is particularly acute in the zone of permafrost (which is 64% of the territory of Russia). The permafrost zone is distinguished for the subarctic climate (long and cold winters, short and hot summers), difficult ground conditions in rock mass of very poor quality and high moisture content (ice content), multiple cycles of freezing and thawing in the course of mining, poor knowledge on local geology and outdated economic-and-geological evaluation of mining efficiency. Located in these areas, proven reserves registered in the state balance sheet in the late 1900s (large deposits of solid minerals, unique in terms of quality and quantity) lack proper and responsible investors in the context of market economy, which impedes the industrial development in these territories of Russia.
2. Mineral mining in permafrost conditions

An illustration of the internal and external bars for the efficient development of mineral wealth in the country is the Republic of Sakha (Yakutia) the third of the immense territory of which lies in the Arctic zone. Yakutia is the largest region both in the Russian Far East and in entire Russia, covering the area over 3 million cubic kilometers. At the same time, the population of the region is 950 thousand people (1100 thousand people before 1990). By the end of the previous century, Yakutia possessed mineral reserves of unique variety, quality and quantity [2].

Started in the mid-1990s and continuing currently, the dynamic commercial development of mineral reserves in the north-east of Russia, including Yakutia, called for the proper scientific support of mining operations in the conditions of extremely severe nature and climate. Naturally, in 1970 Academician N.V. Chersky initiated an idea to found a department of mining within the existing Institute of Physicotechnical Problems of the North in the Yakutsk Division of the Siberian Branch of the Russian Academy of Sciences. Later on in 1980, on the Institute base, the first academic institution in the region—Institute of Mining of the North named after Chersky—was founded.

In the main research areas (integrated development of mineral reserves in conditions of permafrost; thermal physics and geomechanics of permafrost rocks and rock mass with regard to anthropogenic factors), the Institute’s scientists have obtained a series of fundamental and applied results in geomechanics and mine thermophysics, open and underground mining technologies in permafrost zone, processing and deeper conversion of raw materials, geophysical studies of soil and rock mass, geostatistics and geoconomy of subsoil management in the North, etc. These achievements made a framework for the development of new mining machines and technologies, concepts and practical guidelines, and many of them were successively trialed or implemented at different times in mines in the North [3].

Upon transition to market economy in the 1990s, considerable portion of proven reserves was abandoned. Thus, it is of the current concern to refine the methods of investigation, appraisal and economic-geological re-evaluation of such mineral deposits to identify cost-effectively mineable objects. In the sphere of industrial geology and geostatistics, the Institute’s scientists developed theory of grain size analysis for geo-materials, mathematical modeling of statistic and special distribution of minerals and basic texture types of ore, assaying of rocks and ore, as well as appraisal of places and ore bodies [4]. The models of quality management in mineral mining, processing and delivery are worked out. The concept of transition to graduated quality standards, with regard to geological conditions per block and natural laws of cluster and discrete structure of ore substance is proposed. A descriptive (verbal) and analytical model is constructed for a complex and dynamic georesource–geotechnological transformation–product and effect system functioning. A new method is put forward and justified for assessing effect of ore dilution on mine performance by assuming dilution as a sump of the conventional geotechnical element and new structural and economic-geological constituents governed by standards of delineation and appraisal of mineral reserves. Application of this method to advance the earlier developed model show that the economic geopotential of solid mineral deposits, given the modern geotechnologies as well as loss and dilution standards, is under-used. This fact emphasized the demand for new and efficient regulations and technologies for the transformation of georeserves into products and new resources [1, 5].

The permafrost ground facilitates wide application of the ground-penetrating radar methods. The Institute has designed a dedicated geo-radar set with the appropriate software support for the geophysical research. This instrumentation enables sufficiently reliable appraisal of mineral deposits, as well as information on detail structure and cryogenic condition of permafrost rock mass. The method is trialed in the appraisal of Mayat deposit diamonds, as a result of which a paleochannel and geological dislocations have been revealed in the zones of high concentration of minerals as per the data of geological assayng (Almazy Anabar company) [6, 7].

The basic knowledge framework for solving mining problems in the conditions of the North is the developed and persistently modified computation methods for geomechanics and mine thermophysics backed by continuous monitoring of thermomechanical behavior of permafrost [8–11]. In particular,
science-based technologies have been offered for low-energy control of thermal conditions in underground mines in the North. For example, implementation of heat-shield shotcreting of underground excavations in the permafrost zone has appreciably increased stability of openings in mines as well as improved safety and operational comfort of personnel in mines of Aldanslyuda of NorNickel and ALROSA. The other projects include 2D and 3D mathematical models and software system for solving problems of heat exchange between rocks and backfills during slice mining of ore bodies, considering heat development due to binder hydration and phase transition of moisture in permafrost rocks; bundled software for monitoring and adjustment of thermomechanical behavior of rocks at the bottom of headframe foundation at vertical shafts in Internatsionalny, Mir, Udachny and Aikhal mines, ensuring long-term failure-free operation; procedure and software system for joint computation of ventilation and heating modes in the nonstationary mine network in the permafrost zone. The investigation results in the form of efficient methods of mine support, ventilation and heat regulation, etc. are included in project documentation for underground and placer mining of diamonds at ALROSA (pipes Internatsionalnaya, Nyurbinskaya and Botuobinskaya; placer Solur-Vostochnaya).

In the field of improvement of geotechnologies and adapting them to low-temperature conditions based on the outcome of long-term research into properties of frozen backfill, mechanisms of its placement and interaction with permafrost formations, instructional guidelines are made for evaluation of structural constraints and technology of frozen backfilling in different conditions of geomechanical and thermal behavior of permafrost rock mass. The technology has been successfully introduced at the Badran deposit of Zapadnaya Mining Company in the Republic of Sakha (Yakutia) [12, 13]. For open pit coal mining in the permafrost zone, based on the investigations of heat and moisture conditions in rock mass and in broken-rock disintegration, grain size analysis of broken rocks, dragline cycle time in the periods of different temperatures, the recommendations are made for evaluation and selection of efficient parameters for coal mining with direct internal dumping of broken overburden rocks prone to re-adfreezing [14]. A continuous flow process technology has been industrially introduced in mining deep-buried placer near the Kuranakh River (South Yakutia). Commercial use of a conveying&rotating system has been implemented in such climatic conditions for the first time [15].

In the field of geomechanics, jointly with Usolmash (Usolye-Sibirskoe), a brand-new technology and equipment of modular mobile ore processing plant has been full-scale trialed in gold ore assaying. The plant is composed of new-designed and patented machines (combined impact crusher DKD-300, impact centrifugal mill TsMVU-800, pneumatic separator POS-200). The dry method of disintegration and milling as well as pneumatic method of ore pretreatment allows three-times reduction in process water consumption and makes it possible to use the plant in cold seasons for ore processing and pretreatment, which thereby prolongs the period of production in the conditions of long winter and short summer [16, 17].

This article presents a short list of R&D projects accomplished by the fellows of the Chersky Institute of Mining of the North, SB RAS.

3. Conclusions
In the context of emphasis Russia lays on advance socio-economic advancement in the underdeveloped areas of East and North-East of the country, chiefly by means of the immense mineral wealth management, it is necessary to aim maximum efforts of theory and practice in the field of mining toward solution of wide range of problems connected with modernization and innovative development of efficient and eco-friendly geotechnologies, methods and equipment to the utmost adaptable to the unique geographic and climatic conditions of actual operation.

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