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PROSPECTS OF GEOMECHANICS DEVELOPMENT IN THE CONTEXT OF NEW TECHNOLOGICAL PARADIGM

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The article describes the role of geomechanics for forecasting the development of geosystems and ensuring the safety of mining operations during the transition to a new technological paradigm. The state and prospects of development of the mineral resource base, including the Arctic zone of the Russian Federation, are considered. The directions of technological breakthroughs and the possibility of transforming industrial production based on «cross-cutting» technology and the digital economy are presented. The analysis of geomechanical problems was carried out considering advanced technological changes and the rapid growth of requirements for the preservation of the Earth's interior and natural landscapes. The concept of the development of geomechanics and geodynamics to ensure rational subsoil use in terms of the use of «breakthrough» technology is proposed, and the need to integrate scientific and industry collaboration into the system of engineering and professional education is shown.

***Key words*:** mineral resource complex; geomechanics; concept; development priorities; new technological paradigm

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Introduction. Annually more than 200 billion tons of minerals are mined from the Earth's interior and more than 17 billion tons of industrial wastes are generated, which leads to an increase in the geodynamic activity of large rock mass and causes the emergence of previously unknown geomechanical processes [1, 19, 21]. The large-scale anthropogenic impact on the Earth's biosphere with the use of high-performance technology in the context of deteriorating mining and geological conditions and increasing depth of deposit development leads to its negative change and increases the risk of global catastrophic events.

Russia is one of the world leaders in the number of reserves and mining of many types of minerals (see table). For example, 32 % of world gas reserves, 33 % of nickel, 31 % of potassium salts and 25 % of iron are in Russia [4, 7].

The state of the mineral resource base of the Russian Federation (as of 01/01/2016)

Mineral resource	Reserves		Mining
	$A+B+C_1$	C_2	
Oil, million tons	18 435.4	11 221.8	501.6
Condensate, million tons	2 314.2	1 270.1	26.6
Gas, trillion m^3	50.7	19.3	0.637
Coal, billion tons	196.2	78.35	0.373
Iron ore, billion tons	58.4	51.6	0.334
Aluminum raw million tons			
Bauxite	1 124.8	282.4	5.661
Nepheline	4 189.4	779.6	31.4
Copper, million tons	69.6	28.2	0.87
Titanium, million tons TiO_2	261.4	339	0.663
Gold, tons	8 159.6	5 657.8	286.6
Silver, thousand tons	65	53.8	2.3
Platinum, tons	9 782.4	5 288.1	143.2
Diamonds, million carats	982.8	204.3	42.1

Several promising deposits are in the Arctic zone and require a special development technique and tools. The territory of the continental Arctic zone of Russia is 4.9 million km^2, and the shelf seas reach an area of 4 million km^2, which is comparable with the territory of Canada [9].

The total resource potential of the fuel and energy raw materials in the depths of the Arctic zone of Russia exceeds 1.3 trillion tons of reference fuel, including 61 % of coal [3].

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According to the US Geological Survey, in 2014, the undiscovered reserves of traditional hydrocarbons in the Arctic amount to about 13 billion tons of oil, 47 trillion m^3 of gas and 6.5 billion tons of gas condensate. This is about 13 % of the total amount of unexplored oil reserves in the world, 30 % of natural gas and 20 % of gas condensate [8, 20].

Research. Over the next 10-20 years, the «cross-cutting» technology for all types of production will be automation and robotization, as well as the intellectualization of production processes. This technology should ensure functional efficiency, environmental friendliness and resource efficiency of production [10, 11, 14].

Already at the turn of 2025-2035, several technological breakthroughs are expected, reflecting the deep technological changes that will lead to the transformation of traditional industrial production, including the following [6, 12, 18]:

• sensory revolution (biosensors, digital sensors, quantum computers, and communications, photo electronics);

• management based on mathematical models and digital data of all technological objects and processes;

• new solutions in the field of information and communication technology (new media, blockchain, artificial intelligence technologies, machine learning, the transition to new generations of mobile communication, etc.);

• distribution of robotic and automated systems, non-traditional methods of processing materials (additive production, atomically precise production, etc.);

• application for analytics and process control of augmented, virtual reality, and artificial intelligence;

• the wide use of nature-like technologies (bionics, bio-engineering, synthetic biology, biotechnological production, etc.).

Given the new technological structure and the rapid growth of requirements for the conservation of the Earth's interior and the safety of mining, there is an obvious need to maximize research activities and engineering services in the field of geomechanics to predict the development of geosystems and ensure the safe operation of mining enterprises. It is necessary to develop technology and geomechanical methods capable of ensuring the preservation of natural landscapes and the integrated subsequent use of underground space with minimal environmental consequences.

Today it is impossible to imagine the design and operation of an underground structure or a mining enterprise without geodynamic zoning of a deposit, a detailed analysis of the physical and mechanical properties of rocks, a geophysical analysis of the geological structure of the rock mass and the construction of geological and geomechanical models.

There are several complex geomechanical problems in the transition from the open to the underground mining methods. Mining enterprises in Russia have already encountered these problems: OJSC Apatit, OJSC Olkon, OJSC Alrosa, and others [5, 16].

A huge social responsibility falls on geomechanics in the operation of hydro-technical structures, subways, mines under the cities and water bodies [21, 22]. Thus, in the area of the Solikamsk depression, during the development of the Verkhnekamsk deposit of potassium and magnesium salts at a depth of 600 m, more than 30 oil and gas fields are being developed at depths of 2,000 to 3,000 meters [15]. As the depth increases, the tension of the rock mass and tendency to dynamic manifestations of rock pressure increase. All ore deposits at great depths are classified as rock bump hazardous. Therefore, one of the main problems of geomechanics is the forecast of the stress-strain state of the mass and the justification of safe methods and technology for mining in the context of active dynamic phenomena.

New integrated geomechanical and technological solutions are required for the construction of multi-level spatial structures of large cross sections in transport and hydraulic engineering. The role of geomechanics has increased significantly to improve the efficiency of oil and gas field development, especially with hard-to-recover reserves (shale oil and gas), the creation of large underground hydrocarbon and helium store facilities.

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For example, such problems are solved during the construction of the new gas pipeline «Sila Sibiri» and the development of the Bazhenovskaya suite [2, 13]. In the future, the growth of requirements for the preservation of the Earth's interiors and the complex use of mineral resources predetermines the development of geomechanical methods of targeted impact on the physical properties of minerals and the stress-strain state of rock masses.

The development of digital technologies for designing «intellectual deposits» and the use of unmanned mining using robotized complexes and remote control of technological processes require the development of a new concept of geomechanics and geodynamics and priorities for the development of the mineral resource complex in the following areas:

• Remote, including laser-space methods of prospecting and exploration of mineral deposits with the identification of new genetic types of deposits.

• Coal gasification technology to produce synthetic fuels, chemicals, and agrochemistry products.

• Systems of complex advanced processing of solid natural and man-made materials, including carbon-containing materials, to increase the coefficient of extraction of useful components and the production of fuels and products of a wide economic purpose.

• Technology for enhanced oil recovery in fields with hard-to-recover reserves, including «heavy oil», gas hydrates, shale gas, etc.

• Biotechnology of in-situ leaching.

• Ensuring the integrated safety of the development of deposits on the continental Arctic shelf.

• The digital technology of environmental monitoring and risk management at the facilities of the mineral complex.

• Digital systems for modeling and design of robotic field development complexes using artificial intelligence («Smart fields»).

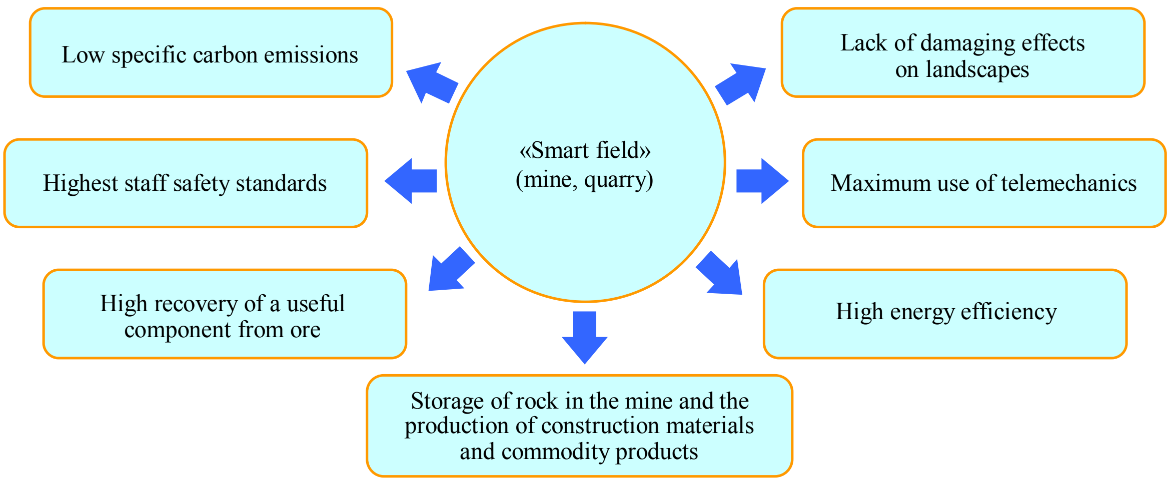
• Technology for generating electricity from unconventional sources: wind, sun, sea, heat of the Earth, biomass and municipal solid waste.

• Intellectual systems of energy saving and storage.

• Intellectual active-adaptive systems of guaranteed energy supply of technological processes.

• Systems and equipment for preliminary beneficiation of ores in a quarry or mine operating on various physical principles (gravitational, magnetic, electrical, flotation, pulsed, radiation, and radiation-thermal).

For example, the project «Smart field», funded by the European Union, aims to develop a set of technology and know-how to create automated underground mines with minimal human presence and zero environmental impact (see figure).



«Smart field» (mine, quarry)

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Complex geomechanical problems arising from the development of deposits and underground space cannot be solved without the cross-industry and interdisciplinary collaboration of researchers. Therefore, the challenge of time is the need to ensure continuous cooperation of specialists in different areas for solving complex tasks. Strengthening international scientific and educational cooperation for the development of sound policies in the field of higher education and scientific activities will help the world community successfully move to a new scientific and technological structure.

The most important problem is the training of specialists in the field of geomechanics and geodynamics. It opens possibilities to form a new system of geographic centers, including around the leading universities, bring together researchers and developers of breakthrough technology, as well as creators and consumers of advanced products and services; and shift to experimental-oriented education by creating and distributing educational factories and laboratories (FABLAB).

The International Center of Competence in mining engineering education under the auspices of UNESCO has been opened at The Saint-Petersburg Mining University, which brings together leading world scientists and specialists to effectively exchange experience and develop sound policies in the field of higher education and sectoral research.

The forecast of the scientific and technological development of the world mineral resource complex considers the need to create conditions for combining the efforts of the world community to solve the following problems of geomechanics and geodynamics:

• Development of high technology for remote sensing and geophysical research of the Earth's interior.

• Development of nonlinear geomechanics of saturated inhomogeneous porous fractured rock mass.

• Development of a theory of the formation of the natural field of the stress-strain state of the rock mass and identifying the mechanisms of tectonic processes and cyclic geodynamic movements of the upper part of the lithosphere.

• Identification of geomechanical patterns of development of geosystems for the safe development of the Earth's interior.

• Development of computer geospatial models of the rock mass, considering the temporary change in the stress-strain state of rocks during the development of deposits and underground space.

• Development of methods of geodynamic zoning of the rock mass.

• Development of geomechanics methods in the development of unconventional hydrocarbon fields (heavy oil, shale gas, etc.) and enhanced oil and gas recovery (hydraulic fracturing methods).

• Development of new tools and digital automated systems of hydro-mechanical monitoring of the state of the rock mass and forecasting of dynamic processes and phenomena.

• Forecasting of the stress-strain state and dynamic phenomena based on the properties of a real rock mass having a block, layered and complex structure, tectonic faults and discontinuity under the conditions of tectonic forces, shears and shifts.

• Research of geomechanical, geodynamic and hydrodynamic processes in man variable rock massifs during the development of mineral deposits and underground spaces of cities and industrial agglomerations.

• Enhancement of integrated geomechanical engineering during the development of mineral deposits and underground space.

• Development of express methods for determining the physical-mechanical properties and assessment of the stress state of the rock mass using the «memory» effects in rocks.

• Development of methods for ensuring sustainability and management of the stress-strain state of the rock mass.

• Development of new materials and technologies for supporting underground structures.

Conclusion. The demanding requirements for the preservation of the Earth's interior and the safe development of mineral deposits and underground space significantly increase the role of geomechanics for predicting the development of geosystems and ensuring rational subsoil use.

The integration of scientific and industry collaboration in the system of engineering and professional education, training of specialists in geomechanics will contribute to the formation of optimal control systems for the processes of prospecting, exploration, mining, transportation, and processing of minerals.

REFERENCES

1. Adushkin V.V., Turuntaev S.B. Technogenic processes in the Earth's crust (hazards and catastrophe).Moscow: INEK, 2005, p. 252 (in Russian).

2. Belozerov V.B. Open fracturing of the Bazhenovskaya suite and prospects for its development. *Izvestiya Tomskogo politekhnicheskogo universiteta. Inzhiniring georesursov*. 2018. Vol. 329. N 1, p. 150-158 (in Russian).

3. Bogoyavlenskii V.I. Oil and gas production in the oceans and the potential of the Russian shelf. Fuel and energy development strategy. *Morskoi sbornik*. 2012. N 6, p. 44-52 (in Russian).

4. State report «On the status and use of mineral resources of the Russian Federation in 2016-2017». Moscow: Minprirody Rossii. 2018, p. 370 (in Russian).

5. Demidov Yu.V., Zvonarev A.Yu., Leont'ev A.A. Combined open and underground mining of apatite-nepheline ore reserves. *Gornyi zhurnal*. 2009. N 9, p. 39-42 (in Russian).

6. Ivanov V.V., Malinetskii G.G. Digital economy: myths, reality, and prospects. Moscow: RAN, 2017, p. 63 (in Russian).

7. Kozlovskii E.A. Mineral resources in the economy of the world and Russia. *Gornyi zhurnal*. 2015. N 7, p. 47-54 (in Russian).

8. Larichkin F.D., Fadeev A.M., Cherepovitsyn A.E. Problems of study and development of mineral resources of the Arctic region. *Arktika: ekologiya i ekonomika*. 2012. N 1(5), p. 8-16 (in Russian).

9. Mel'nikov N.N. The role of the Arctic in the innovative development of the Russian economy. *Gornyi zhurnal*. 2015. N 7, p. 23-28 (in Russian).

10. National Program «Digital Economy of the Russian Federation»: Order of the Government of the Russian Federation of 07.28.2017. N 1632-p (in Russian).

11. New technological revolution: challenges and opportunities for Russia: Expert-analytical report. Moscow: Tsentr strategicheskikh razrabotok, 2017, p. 136 (in Russian).

12. On the strategy of scientific and technological development of the Russian Federation: Decree of the President of the Russian Federation of 12/01/2016. N 642 (in Russian).

13. Khan S.A., Igoshin A.I., Kazaryan V.A., Skryabina A.S., Sokhranskii V.B. Underground storage of helium. Moscow-Izhevsk: Institut komp'yuternykh issledovanii, 2015, p. 272 (in Russian).

14. Sadovaya E.A. The digital economy and the new paradigm of the labor market. *Mirovaya ekonomika i mezhdunarodnye otnosheniya*. 2018. Vol. 62. N 12, p. 35-46 (in Russian).

15. Sanfirov I.A., Nikiforova A.I., Kalashnikova M.V., Zhikin A.A. Seismographic substantiation of the possibility of joint development of deposits of mineral salts and hydrocarbon raw materials. *Vestnik Permskogo nauchnogo tsentra*. 2017. N 1, p. 76-79 (in Russian).

16. Kovalenko A.A., Tishkov M.V., Neverov S.A., Neverov A.A., Nikol'skii A.M. The technology of mining of pit reserves in complex mining and geological conditions. *Fundamental'nye i prikladnye voprosy gornykh nauk*. 2016. Vol.1. N 3, p. 305-311 (in Russian).

17. Trubetskoi K.N. Prospects for the innovative development of the mining industry. *Gornyi zhurnal*. 2015. N 7, p. 19-22 (in Russian).

18. Dobrynin A.P., Chernykh K.Yu., Kupriyanovskii V.P. et al. Digital economy – various ways to effectively apply technology. *International Journal of Open Information Technologies*. 2016. N 1 (4), p. 4-10 (in Russian).

19. Chanturiya V.A. Prospects for sustainable development of the mining and processing industry in Russia. *Gornyi zhurnal*. 2007. N 2, p. 30-33 (in Russian).

20. Shafranik Yu.K. Oil and gas complex of Russia: problems and development objectives. *Gornyi zhurnal*. 2015. N 7, p. 55-58 (in Russian).

21. Protosenya A.G., Karasev M.A., Belyakov N.A. The procedure of geomechanically safe development of megalopolis underground space. *International Journal of Applied Engineering Research*. 2016. Vol. 11. Iss. 22, p. 10857-10866.

22. Trushko V.L., Protosenya A.G. Geomechanical Models and Prognosis of Stress-strain Behavior of Rock Ore in Development of Unique Deposits of Rich Iron Ores Under Water-bearing Formations. *Biosciences Biotechnology Research Asia*. 2015. Vol. 12. Iss. 3, p. 2879-2888.

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