Extraction of minerals on celestial bodies as a new scientific direction

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Abstract: The paper presents the analysis of the problems encountered in the extraction of minerals. The areas that are affected by the activities of the mining industry are named. The prerequisites for the beginning of global development of the mineral resources in outer space are analyzed. It is concluded that there is a need to develop the resources of celestial bodies. The legal aspects of the development of space bodies' resources are touched upon. It is noted that the existing laws on space are not perfect or contradictory. The use of different interpretations of the laws on space for obtaining preferences in the assignment of resources of the mineral resource base of outer space is indicated. Various stages of the scientific development of outer space are touched upon. It is noted that the catalyst for space exploration was the military-political confrontation during the cold war. The significant role of the United States and Russia, as the legal successor of the USSR, in the field of scientific research and development of outer space, as well as their importance in the development of space programs of other countries, is emphasized. A new vector in space exploration has been identified, and with it the new goals have been formed. The prerequisites for the beginning of the commercial development of space resources are formulated. It is noted that the study of outer space, as well as the development of its mineral resource base, goes beyond the scope of monodisciplinarity. For the successful implementation of the program of the extraction of mineral raw materials from celestial bodies, it is necessary to develop a number of scientific directions, parallel and consistent with the other ones. At the same time, it is indicated that for a more successful implementation of these scientific programs, it is necessary to combine all scientific directions into one scientific discipline. It is recommended to allocate a new scientific discipline based on the experience and development of geotechnologies.

1. Introduction – the scope of the study
Industrial society cannot do without consuming natural resources. Currently, the volume of mineral resources extracted in the world is estimated at billions of tons, which leads to a rapid development of the mining industry, and in consequence, to the depletion of natural resources. Production activities of the mining complex have a significant impact on the environment: harmful substances are released into the atmosphere, polluted wastewater is discharged into reservoirs, and a huge amount of solid waste is stored on the surface of the earth. As a rule, the area of territories that have been disturbed as a result of mining enterprises is not comparable to the development area itself, and often exceeds the area of adjacent cities [1]. Emerging man-made disasters go beyond the previously known form and
impact on the environment [2]. When developing deposits, rock-tectonic shocks occur, causing
destruction on the surface, the formation of sinkholes, and man-made seismicity is noted [3, 4]. In
Russia, there were several mining areas in which technogenic seismicity became a social factor, led to
an increase in the risk of exploitation of other industrial productions, and began to have a direct impact
on the biological optimum for humans [5]. As a result of depletion of reserves, the activities of mining
enterprises stop and then there is a social question in the places where the mining enterprise is the
main employer in the city. The development of deposits goes to great depths, which brings about the
change in the vertical amplitude of the natural environment, considering the depth of development and
the height of dumps/landfills in the mining regions of Russia: 2 000 – 2 500 m (6,500 – 8,200 ft) [6].
Currently, the impact of human activity in general and the economic consequences of mining on the
environment has reached the size commensurate with the impact of natural processes on the Earth [7].

2. Prerequisites for the development of the mineral resource base of celestial bodies
Due to the huge impact of the mining industry on the Earth: depletion of natural resources; negative
impact on the earth's crust (increased fracturing; disappearance of groundwater streams; mining and
man-made impacts and earthquakes; destruction of the surface and formation of sinkholes; withdrawal
of large areas of land resources from circulation); negative impact on the environment (water
pollution; groundwater pollution; atmospheric pollution); impact on the biological optimum for
humans; solving social issues when reserves are depleted, there are prerequisites for stopping the
extraction of minerals on Earth and searching for new sources of natural resources. It is quite obvious
that the demand for mineral raw materials will only increase in the near future, and it is only possible
to avoid the negative impact of the mining industry on the Earth if this industry is moved off the
planet. Today, one of the most promising activities in outer space is the extraction of natural resources
on celestial bodies. Mining space resources will bring great benefits and improve the Earth’s ecology.
Before talking about the prospects for space development, it is necessary to understand which space
bodies can be used for mining minerals and what is to be extracted. The closest and most studied space
object is the Moon. However, it should be considered that there are many asteroids around our planet
and each of them may contain valuable materials [8]. The mineralogical composition of some of the
celestial bodies is well studied: asteroids containing platinum, iron ore, frozen water. The Moon has
reserves of helium-3, which is an excellent energy supplier. Mars has hematite on its surface, which
indicates large reserves of iron and boron, which, in turn, is a substance accompanying water. These
components make these bodies quite attractive in terms of the development of the planetary mining
industry [9].

From the economic point of view, the extraction of natural resources on celestial bodies and their
subsequent delivery to Earth is not financially rewarding today. However, with the development of
technological progress [10] and the decrease in the number of minerals on Earth, this activity can
become profitable for humanity. Interest in space exploration is shown not only by the United States in
their space programs, but also by private corporations. In addition to the economic, technical and
 technological issues that arise in the development of mineral mining on celestial bodies, there are also
legal aspects to resolve.

3. Legal aspects in the field of development of the mineral resource base of space bodies
Of the five outer space treaties, only two (the 1967 Outer Space Treaty and the 1979 Moon
Agreement) address the issue of the appropriation of space resources. Article 11 of the Moon
Agreement of 1979 is devoted to the legal regulation of natural resource extraction, where it is
specified that the Moon, its surface, and its natural resources are the common heritage of mankind.
The Moon and its interior are not subject to national appropriation. Various countries undertake to
establish an international regime to regulate the exploitation of the moon's natural resources when such
exploitation will become possible [11].

Even though the Moon Agreement contains special rules concerning the extraction of natural
resources on the Moon, there are many "pitfalls":
• First, only 18 states are parties to this treaty, and it does not create obligations for space powers [12].
• Secondly, it is worth noting that every year private corporations begin to play an increasing role in the development of the outer space, and general regulations for such companies are no longer sufficient [9, 11].
• Thirdly, we should note the conflicting opinions of scientists on the concept of res communis humanitatis: some argue that in order to use celestial bodies, it is actually necessary to acquire the parts of these celestial bodies, while others argue that all natural resources that were extracted in the outer space and brought to Earth can be used for commercial purposes if they are used for the benefit of the world community [13].

The controversy increased after some countries adopted national legislation allowing their national corporations to conduct mining activities on the celestial bodies. These countries include the United States and Luxembourg. As practice has shown, most countries did not react to the adoption of such national legislation, but some governments strongly stated the need for an international legal regime or, at least, a multilateral approach to resolving this issue, for example, on the basis of the intergovernmental agreement under article 11 of the 1979 Moon Agreement or other special decisions [14, 15].

Also, by its presidential decree of April 07, 2020 "Executive Order on Encouraging International Support for the Recovery and Use of Space Resources", the United States once again emphasized its position on this issue [16]. In it, the US once again emphasize that its policy does not contradict the 1967 Outer Space Treaty. However, it is worth noting that the adopted Artemis program (Artemis Accords) [17] involves the creation of "Safety Zones" for each State or Corporation operating in this place, and the discussion of this new term caused a strong reaction in the scientific community.

4. Confrontation in space: from military-political to commercial

It should be taken into account that many countries are interested in the development of outer space and the mineral resource base itself: Russia [18]; the United States [13, 14]; China with its Chang'e program; the European Union with JUICE program (JUpiter ICy moons Explorer); India, the Chandrayaan and Mars Orbiter Mission (Mangalayaan) programs, and others. Global interest in the mineral resource base of celestial bodies is justified due to the fact that the countries have entered a phase of a new round of competition and division of the spheres of interest. If there were previously known territorial disputes: land, seas, oceans, then the vector of development of global conflicts goes to cyberspace (the Internet) and outer space, which is still not sufficiently studied, although it is not a new space. Space exploration began in the early 50s of the last century and took place in the context of a tough military and political confrontation between the two countries of the USSR and the United States. The struggle for global supremacy on Earth and attempts to militarize space gave a huge impetus to the development of research activities in space and its peaceful development [19].

With the collapse of the Soviet Union and the end of the “arms race” of the country, competition in the scientific field, including space, was replaced by partnership, which allowed us to move away from duplicating certain achievements and spend more constructively on space research. In a relatively short period many countries, and often private companies (SpaceX, Orbital Sciences Corporation), using the achievements of Russia (the successor of USSR) and the United States, made rapid strides in the field of space technologies and currently have their own proprietary software for space exploration [20]. Such a rapid increase in activity in space exploration, and even more so the closeness, causes concern for the United States.

Competition in space did not start today, but at this stage it has acquired a new vector, and with it new goals: defining borders, zones of interest and security zones; commercial development of the mineral resource base of outer space; economic and military use of celestial bodies; and redistribution of resources of celestial bodies. Therefore, at this stage, prerequisites for the beginning of global development of the mineral resource base of outer space may be juxtaposed in Table 1.
Table 1. Prerequisites for the beginning of the mineral resource base of outer space.

| objective (direct): | subjective (indirect): |
|---------------------|------------------------|
| 1. depletion of the Earth's mineral resource base, | 1. replenishment of the mineral resource base, |
| 2. increasing the impact of the mining industry on the Earth's ecology, | 2. distribution of areas of interest in outer space, |
| 3. large reserves of minerals on celestial bodies, | 3. the struggle for military and political global superiority on Earth |
| 4. fairly good knowledge of the mineral resource base of some celestial bodies | |

5. Accumulation of new knowledge as a stage of formation of a new scientific direction

At the same time, it should be noted that the issue of extracting useful components on celestial bodies is not a single-disciplinary one. When developing space bodies and extracting minerals, it is necessary to: develop extraction technology (attract specialists in mining); develop logistics: design the delivery of cargo and materials to space objects and useful components to Earth (attract specialists in the field of cosmonautics); develop legal bases for the development, use and differentiation of celestial bodies (attract specialists in the field of space law).

For the above named reasons, research in various industries is quite scattered and does not have a clear link. When extracting minerals from the subsurface, there is a science, geotechnology, which combines the following subjects of study: mining-geological and mining-technical conditions and characteristics of deposits; methods of opening and methods of access to geo-resources; research and optimization of parameters of physical-technical, physical-chemical and construction technologies; quality management of mining enterprises; development and scientific justification of criteria and technological requirements for the creation of new mining machinery and equipment; development of scientific and methodological bases for studying the processes of changing the construction properties of soils; development and scientific justification of criteria for economic evaluation of technology and technological solutions for extracting minerals; development and scientific justification of criteria and norms governing relations in the field of mining and related activities, etc.

As follows from a rather incomplete list of sciences that are the subject of study: economics; mechanical engineering; geology; construction; land management, etc., geotechnology combines these sciences, which allows each to develop progressively, complementing each other. At the same time, geotechnology acts as a kind of connecting and controlling science, which, based on the scientific achievements of each individual science, develops independently, taking into account the needs, problems and experience of the mining industry. It develops the sectors of each of the sciences separately. At the same time, it should be noted that the technology of extracting resources from celestial bodies has a rather limited commonality with geotechnology. Geotechnology, as a science, was initially developed based on the experience gained in the mining sector.

It should be noted, that there is no experience in the development of the mineral resources of celestial bodies. In addition, there is no unified systematization of all scientific research, with a single interpretation and terminology. As a result, the development of society is the accumulation of knowledge. According to the law of dialectics, "negation of negation": some knowledge remains new until it is replaced by other, newer ones, and the previous ones become obsolete or become special cases of newer judgments [21]. So, in science, when one science becomes obsolete, another is born. At the same time, just like the evolution of society, the development and birth of science goes in a spiral, so one new scientific direction repeats the previous one at a new turn [22]. In this case, the extraction of minerals from celestial bodies is geotechnology, only at a new turn of the development spiral.

But as it was noted earlier, the extraction of minerals from celestial bodies has not yet been singled out as a separate scientific direction. The lack of a unified picture does not allow us to combine the acquired knowledge into a single whole and determine a consolidated path of development [23]. Therefore, only the reinterpretation of previously obtained knowledge, recognizing it as outdated when replaced by new realities and knowledge, will lead to qualitative changes in the scientific direction [24]. Therefore, without a clear uniform systematization of knowledge under a single scientific direction, it is impossible to develop the planetary mining industry (Figure 1).
Figure 1. The way to new scientific direction.

Systematization of research and the creation of a uniform practice for the development of the mineral resource base of celestial bodies is possible by combining the accumulated experience into a single science [25]. The first stage of the formation of a new science or a new scientific direction is the selection of a new object of scientific research.

6. Conclusion - New scientific direction
When developing the mineral resource base of celestial bodies, the science that studies the ways and processes of its development, creating theoretical foundations and engineering solutions for effective and economically viable extraction, is planetary (space) technology or astrotechnology.

Astrotechnology (from the ancient Greek words: ἄστρον - star; τέχνη – art, skill; λόγος - word, thought, meaning, concept) is a natural and understandable name of a new scientific direction that aims to study and develop technologies for extracting minerals from space bodies.

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