Fundamentals of converging mining technologies in integrated development of mineral resources of lithosphere

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Abstract. The paper sets forth a theoretical framework for the strategy of the radically new stage in development of geotechnologies under conditions of rapidly aggravating environmental crisis of the contemporary technocratic civilization that utilizes the substance extracted from the lithosphere as the source of energy and materials. The authors of the paper see the opportunity to overcome the conflict between the techno- and bio-spheres in the area of mineral raw materials by means of changing the technological paradigm of integrated mineral development by implementing nature-like technologies oriented to the ideas and methods of converging resources of natural biota as the object of the environmental protection and geotechnologies as the major source of ecological hazards induced in the course of development of mineral resources of lithosphere.

The modern civilization evolves perennially with the outpacing consumption of a variety of natural resources and with the rapid expansion of their range.

In this respect, a peculiar place belongs to the industries related to minerals and raw materials which feed and power manufacturing of 70% of of the world’s overall final product and which grow twice as fast as the population [1].

By analogy with the nature and man conflict, the equal opportunity principle should hold true for development of the techno- and biosphere. Academician of the Russian Academy of Sciences N.N. Moiseev defined that principle as “…a policy of co-evolution…” of intrinsically antagonistic systems [2]. Evidently, the scope of this policy is insufficient to completely overcome global contradictions; however it is absolutely indispensable to make these contradictions nondestructive relative to wildlife by means of fundamentally new technologies to be envirosafe and to allow perspective recovery of the man-violated balance between production and consumption of mineral resources with regard to restrictions imposed by ecological imperative.

The modern technocratic civilization is currently at the point of bifurcation. The plain truth is that extensive and unlimited use of natural resources inevitably and irreversibly changes natural environment and the further existence of the society is connected with the creation and application of new resources and technologies based on the modes of wildlife by converging natural sciences and engineering. The key phases of the convergence include: 1—transition to nanosizes; 2—modifying the paradigm from the analysis to the synthesis; 3—approach and interaction of technosphere and wildlife; 4—interdisciplinary approach instead of monotechnics [3].

Judged by the essence of convergence as occurrence of similarity in the structure and functioning of distantly related systems [4], there are two methodological approaches to converging technologies:
technologies reproducing processes in biological systems;
technologies having the same functional organization as natural systems.

The Earth’s biota as a system develops by the laws and principle that are unchangeable by a man at pleasure. All interrelations in the biota are based on trophic (food) chains of variable complexity; these chains usually have a few trophic scales subjected to the law of reduction in biomass on each net scale (Figure 1).

Existence of the natural equilibrium ecosystems is based on the large and small circles of biotic exchange as a nonstop process of regular cyclic thought nonuniform in time and space redistribution of substance and energy multiply re-entering continuously regenerating biosphere or elementary biological systems. For this reason, considering the nature of interaction and mission of basic categories of organisms in ecosystems, the first principle of ecosystem functioning may be formulated as: production and of resources and reprocessing of waste within the closed cycle of all elements [6].

The major portion of the solar energy on the earth surface induces physical circulation of mobile elements of biota, the rest energy is taken by photosynthetic living systems and engenders circulation of biogens in natural ecosystems. By arranging the constituent organisms in accordance with their nutritional interrelations with indication of ‘entrance’ and ‘exit’ of energy and biogens on each scale, it becomes evident that biomass is larger on each lower scale. This is the essence of the second principle of biosystem functioning: on each trophic scale a new biomass is produced in amount inversely proportional to the length of food chains [6].

As known, all biological system possess a threshold crossing of which leads to a sharp qualitative change in the processes running in a biosystem—the change in their organization. This feature of threshold (bifurcation) mechanisms has a perfectly peculiar part in development of biosystems. Upon crossing the bifurcation phase, a biological system as is forgets (or nearly forgets) the past. Evolution pathways fork at this point, and, by virtue of probabilistic nature of the threshold crossing, there is no way back (or, more properly, the probability of evolution repeat is close to zero). The irreversible nature of biological evolution (known as Dollos’ law) is the core of the third principle on function of all components in the Earth’s Biota [6].

The most important property of natural ecosystems is stability ensured by the dynamic equilibrium between the biological potential of populations and resistance of the environment. The change in the environment initiated succession ending with a climax ecosystem stage. At this stage, all species parturiate at the relatively constant population while an ecosystem is a species diversity [6]. In a terrestrial ecosystem, producers are plant communities—phytocoenosis. The producers have absolutely the same internal structure composed of three systems of plant species of different coenotic value: edificator, assectator and adventity; edificatory determines species composition and direction of cyclic succession for the whole phytocoenosis. Accordingly, the fourth principle of ecosystem

![Figure 1. Pyramid of biomass [5].](image-url)
functioning states that stability and endurance of an ecosystem depends on the state of phytocoenosis with its structure and species composition conditioned by its edificator synusia [7].

Flow energy in natural ecosystems totally agrees with the law of thermodynamics. Solar energy is converted to chemical energy under photosynthesis, and chemical energy turns into other energy forms along food chains. However, the major energy of the Sun is spent to heat the planet. Heat is the driving force of water and air circulation and, finally, diffuses in outer space. Whence, the fifth principle of ecosystem functioning says that they exist on the strength of pollution-free and nearly eternal solar energy the quantity of which is relatively constant and excessive [6].

Regarding a nature-like geotechnology, the ‘antagonists’ are the Earth’s Biota and technocratic anthropogenic system of extraction of wanted raw materials and energy sources from lithosphere by means of mineral mining.

Out of the general approaches described above, the first approach is inapplicable in mineral mining inasmuch as nature features none of such processes. On the other hand, the second approach offers a true pathway to a fundamentally new development paradigm in geotechnology.

Unlike the traditional bionics with its attempt to engineer equipment with the cloned functions and abilities of biota elements, development of converging geotechnologies is possible based on conversion and content transformation of general principles of interaction between elements of biota. For this reason, in view of the antagonistic nature of the conflict between bio- and technosphere, the methodology should be founded on the known provisions of homeostatics on the means of sustaining vital parameters of interacting system through contradictions management.

Regarding a general methodology, the homeostatic approach allows synthesis of antipodes. In relation to the man and nature interaction, this means that the two antagonists are not contraposed but united within a system of controllable harmony achieved owing to limitation of anthropogenic impact to a tolerance range of biota elements. This allows transferring biological information in technosphere by stage-by-stage formation of geotechnology homeostat based on the structure of biological homeostat by substituting the conceptual elements of the latter for their geotechnological analogs [8].

The final result of the transformation is a nature-and-technology system of mineral mining using technologies based on biotic principles and limited in terms of external effect on survival and recovery of biological systems free from the contradictions between the biota and technosphere.

Mineral mining process always results in displacement of immense quantities of rocks and in formation of an anthropogenically altered area in lithosphere. A general structure of this new lithosphere object and transformation of substance during this object initiation and growth is described in Figure 2.

As seen in Figure 2, all ecological consequences of mineral mining are connected with the transition of substance from lithosphere to technosphere and placement of waste in the biosphere later on. By analogy with the first biosystem function principle above, we state that a converging geotechnology is imposed with an obligatory requirement to ensure closed-loop circulation of substance in the course of mining.

It should be mentioned that this principle of organization and functioning of a mine has long been developed as separate problems of science and technology given the modern advance in mining technologies but is unsatisfactorily and inappropriately implemented.

The techno-transformation of the second biotic principle is possible through replacement of the ‘produced biomass’ notion by its geotechnical analog—‘mineral’ [1]. In this case, a geotechnology function principle is pure production of nothing but target mineral. Generally, the concept of this trend means that the level of selective mining, by targeted preference or development of engineering solutions, should conform with the nature and level of variability of natural distribution of minerals in lithosphere. The key point is in situ segregation of ore and barren rock by natural or artificial signs (Figure 3).

Based on the principle of conformance between selectivity of a technology and nonuniformity of mineralization, it is clear that any combination of nonuniform mineralization and ore–rock segregation method should have a proper engineering solution implemented at one of the mining stages. Given the
stringent ecological constraints, this technological trend can become the most efficient way of abating industrial load on the Earth’s Biota [9, 10].

![Diagram of production-altered subsoil structure and flow of lithosphere substance in the course of mineral mining.]

**Figure 2.** Production-altered subsoil structure and flow of lithosphere substance in the course of mineral mining.

![Diagram of ore and barren rock separation techniques.]

**Figure 3.** Classification of ore and barren rock separation techniques.

The known Dollo’s law in biological systems works out as the succession in the period of critical accumulation of aggravating extraneous factors goes in the direction eliminating influence of these factors. As a result, the species structure of biota upon crossing the bifurcation point transforms so that its new state is independent of the factors which have caused the transformation. In the converging nature-like geotechnologies, this singularity of living systems can be converted into thesis that the
basic methodological provision of the innovative technological development is the anticipatory stageby-stage elimination of the least effective processes and operation by means of modification of the
general structure of a geotechnology in space and time, which can be formulated as the preventive
action principle in the technology-related decision-making and implementation.

The preventive action principle in the decision-making on a geotechnology structure transform
into a geophysical concept of an eco-geotechnology when a production damage area is anticipatorily
outlined in the in the field of geophysical change of lithosphere by means of separating the processes
of mineral mining and the processes of overcoming of geomechanical disturbance consequences in
time.

Elaboration of these provisions will result in a theoretical framework of a brand-new trend in the
sphere of mining science as a since on mineral extraction in the course of integrated development of
natural resources of the Earth. Judging by biologically governed sequence of mining when the early
erected structure ensures geomechanical relaxation of the interior ore reserves and serves as a frame
inside which large-scale stoping is carried out, the newly proposed scientific trend may be the
development of the ‘framing’ geotechnology as the deterministic system of different-purpose process
clusters that interact in time in conformity with the biogenic principles [11].

Application of general biological principle in construction of the proposed ‘framing’
geotechnology opens up prospects of successful and final solution of ecological problem generated by
mineral mining:
—advanced construction of load-bearing ‘frame’ preserves integrity of overlying strata and
ground surface during actual mining;
—framing of the mining zone before the production start shields fluid-containing strata and
protects mining from their influence;
—formation of mined-out area as a system of artificially framed voids offers condition for any
kind waste storage.

The fourth principle of biological system functioning in the framework of the discussed issue
leaves the content of technological solutions aside and acts as a complimentary criterion to control
making and selection of technological decisions.

Regarding the problems connected with the development of mineral resources, this means that
concurrently with the new geotechnologies, it is necessary to create a system to control interaction
between techno- and biospheres by indexes and criteria reflective of the Earth’s Biota properties and
response to mining impacts. Such system to be created needs two fundamental problems to be solved:
—foundation of a general methodology for transformation of biological constraints of mining-
induced impact on the elements of natural ecosystems into technical standards and regulations for
production processes, as well as development of design procedures to calculate these standards;
—generation of cardinally new diagnosis system for the environmental threat of mining, including
variety of mining-induced impacts and diversity of purposes and biostructures of violated ecosystems.

The fifth principle of biological system functioning transforms in the technosphere into two
backbone provisions for converging geotechnologies:
—resources coming to a technical system from outward source respect the first principle of
functioning of biological system;
—energy supply of converging geotechnologies can be obtained from the substance extracted
from lithosphere.

It is advisable to generate and use a nonmonetary criterion of the production-caused ecological
consequences (including mineral mining). The value of this criterion named the environmental price
should be, alongside the monetary criterion, the second obligatory characteristic of any item produced
or manufactured, and the society should pronounce this price and do all its best to minimize its value.
This is the only impelling and not compulsory motivation to find the least ecologically hostile
technologies just like the global avowal of the minim cost stimulated persistent advance toward
reduction in consumption of material and labor resources in the technical progress. The structure and
the contents of the proposed notion are in detail described in the work [12].
The essence of the second provision above completely contradicts the actual structure of the extensive energy supply the present authors suggest for the mining industry, i.e. the energy required for subsoil development is taken from the subsoil resources.

Naturally, a single way of the energy supply modernization in the current technocratic civilization is efficient economic utilization of the natural renewable energy sources. And it is equally natural that any activity sector will modernize energy supply and utilize renewable energy sources in accordance with the specific character of technologies which are in service in this sector [13].

The implemented research shows that mineral mining industry can use renewable energy sources for (Figure 4):

— general power supply and
— power saving.

In the first case, it is preferable to construct power plants in package with mines. Positively, it is the most efficient to construct different small-size hydroelectric power plants, especially in Siberia and in the Far East of Russia holding nearly unlimited water-power resources. Energy-saving development also agrees with the current trend of construction of small mines to operate by the mode of rotation.

The natural renewable energy sources offer an option of energy saving in the course of mining. With a long history behind, gravity caving technology is barely used today. The implementation of the above-described ‘framing’ geotechnology opens up new prospects for wider application of gravity caving in underground mineral mining [11].

![Figure 4. Utilization of natural renewable energy sources in underground mineral mining.](image)

By the common definition, renewable energy sources are the sources of existing or cyclically arising energy in the world. As has been said earlier, subsoil development methods are the sequence of actions or processes that result in separation of a large material volume from lithosphere and displacement of this volume from the occurrence position to the ground surface. At the same time, any specific geotechnology has a functioning structure which combines the mineral flow in the mentioned direction with the practicality of downward (counter) flows of broken barren rocks, mine fluids and different backfill mixtures. In line with the above definition, there always are “cyclic energy flows” in the framework of a geotechnology, identified as the local renewable energy sources by this paper.
authors. Unlike the continuous renewable energy sources defined as global sources, the local energy sources are not to be used directly in mining processes due to some specific features but can partly make compensation for general energy consumed.

Actualization of the use of such natural renewable energy source needs specific case study and engineering, including special systems of power generators but the potential resource saving based on their application is estimated very high [13].

Not less amplitudinous than gravitation of the Earth, constant and global in terms of subsoil development is the energy source represented by solar irradiation. On the other hand, this immense energy is extremely nonuniformly spread over the earth surface. The solar energy flow density is maximum at the equator and diminishes towards high latitudes. As a consequence, inside vast territories of continents, especially in the Northern hemisphere, average annual temperatures are permanently negative. This difference in the heat balance in different periods of time is factually a renewable energy source when not the solar irradiation but its deficiency is considered the energy value. Based on that, it is possible to introduce definition of a cryo-georesource understood as a geographically and climatically conditioned negative temperature of ambient air and rock mass, usable in mineral mining processes.

This resource can be divided into climatic and geological components, and each of these components varies in time and space by its own laws and exerts different effect on decision-making on process solutions [14]. It is known that ecological cleanness of functioning in biological systems is achieved through the simultaneous effect of all above-listed general principles; thus, the most important methodological aspect of converging geotechnologies is assumed the obligatory synchronism of involvement of all described biogenic principles.

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