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Article

The Dynamic Structural—Material Complexes of the Earth's Crust

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Abstract: In the process of the Earth's development, under the conditions of self-organization, from the composition of the Solar System over a period of about 4.5 billion years, self-similar dynamic structural-material complexes (SMC) of the earth's crust are periodically formed. Each complex includes synchronous or close in time series of genetically or paragenetically related igneous, ore-mineral, metasomatic, sedimentary formations, their structures and other processes accompanying them. Each complex in its formation is limited in time and space, according to the manifestation of the features of a spontaneous dynamic process; spreads in the volume of the Earth in a certain historical period; forms the composition and structure of the earth's crust at this stage, determining its polycyclic development. The number of cycles is about 14, with decreasing duration of their manifestation.

Keywords: lithosphere; earth's crust; geological formations; structural and material complexes; composition; structure; self-organization; polycyclic development

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Introduction

In the structure of the Earth, with a high degree of heterogeneity, one can outline a number of asymmetric elements of a different order: from the mass volumes of the water basin of the world ocean and the solid Earth; large segments in the lithosphere - oceanic and continental; their internal structure: uplifts and troughs, mid-ocean ridges and mountain folded belts, rifts, platforms; structures of different geodynamic settings to a variety of forms of geological bodies of the lithosphere and features of their placement, and, finally, in the structure of geological bodies, their composition and age. Such an asymmetry of the heterogeneity of the lithosphere has a hierarchical character and, taking into account the elementary structure of matter, the chaotic nature of its internal content of the Earth determines.

Research Methods

Questions of the structure and development of the Earth's crust are being discussed [112,167]. At the same time, in the structure of the Earth and, especially, the lithosphere, a high degree of order is established both in material and structural terms. This is due to the dynamic features of the development of the Earth [59–61]. While analyzing the composition of the substance of geological formations, the conditions of their self-organization determined the generally accepted consideration of the levels of the hierarchy of organization in the series: elementary particles - nuclei - atoms - elements - ions - molecules - minerals - formations. All and each of them correspond to the structures formed in the process of self-organization of their interaction [61–63], which contribute to the manifestation of the development cyclicity [51–57], etc. An elementary, in the system of levels of the organization, the unit of geological and structural analysis is a geological formation and a characteristic of the features of the structure and development of the Earth at a certain period of time and is a unifying set of various synchronous geological formations, the formation process of which at this stage led to the formation of the Earth's crust and Lithosphere.

We previously [51–54] proposed to consider as the main geological structural unit a dynamic structural-material (formational) complex (SMC) of synchronous genetically or paragenetically

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related geological formations - igneous, sedimentary, metasomatic and ore-mineral. Its formation fixes the highest taxon in a number of levels of organization of matter, the process of formation of the Earth's crust (continental and oceanic) at a certain stage. In terms of volume, content, and formation time, SMC is identified with the metallogenic cycle of V.I. Smirnov [128] with some changes and details. The internal content of SMC is determined by geological formations that make up mainly lateral rows of synchronous (close in time of formation within the cycle) geological formations and characterize their variability and zoning depending on composition and genesis. The structure of the conditions of dissipation and fractalization of the primary morphology of the volume SMC is determined by occupied by geological formations. A complete description of the SMC can only be obtained with a global review, and in each specific region, the SMC is presented with a different degree of locality, fragmentarily. The time range for the formation of SMC in space within the cycle is established according to the actual data based on the study of the history of the geological development of the cycle. According to the genesis of geological formations, SMC combines elements of all known geodynamic settings and structures of the Earth [4,140,163], which simultaneously manifest themselves laterally , forming the Earth's crust. From these positions, the SMC is a planetary structural and material formation, which manifests itself in different ways in certain parts of the planet in a given period of time.

The SMC is based on homodromic associations of endogenous formations of igneous rocks, which determine the age volume of the cycle, associated ore-mineral, metasomatic and synchronous sedimentary geological formations, structural elements, various geophysical fields and phenomena [51–57,61–63]. Features of the proposed unified structural-material subdivision of the Lithosphere and the Earth's crust determine: a) material associations, their paragenetic and genetic relationships, sources of formation and features of formation; b) the dynamics of the formation of material associations and their placement in time and space; c) the time of formation of material associations and the frequency of their manifestation; d) the structure and morphology of material associations and the relationship of structure formation with their composition.

Research Results

Geological formations are distinguished according to the conditions of their formation: **igneous, ore-mineral, metasomatic, and sedimentary** [22,53]. Each of them creates their own complexes, united genetically or paragenetically formations. Here we should also add such substances as water and gas, for which formation affiliation is not used because of their special properties and state, but which play a crucial role in the processes of their development. Water occupies a leading position in the hierarchy of the planet's matter; it is an integral element of living and part of non-living matter [46]. In the free state, it fills the volume of the seas, oceans, river network, and part of the atmosphere and lithosphere [21,33].

In rocks, water binds as part of mineral associations [6] or is released during their physicochemical transformations [64], creating mineral waters, brines, and forming in the depths of magma chambers [90]. Water participates in the circulation in the Earth's crust and lithosphere [39], is a part of the general dynamic process and creates hydrogeological conditions for its occurrence [150]. The second substance - gas also occupies an important place in the material structure of the Earth and its immediate and distant surroundings. Hydrogen, helium [23], carbon monoxide and dioxide, methane, nitrogen, radon, argon, and other gases, all of which, to one degree or another and in different quantities, are found in minerals, rocks, circulate freely through cracks and faults in the earth’s crust and expire from the surface [5,23,135,137,138]. All the diverse matter of the earth's crust in the form of geological formations is concentrated in the following synchronous structure-material complexes that compose it at a certain stage.

Formational complex of igneous rocks of the Earth's crust. It combines synchronous and genetically (or paragenetically) related igneous rocks of different composition over a certain period of time (cycle). Despite the large number and compositional diversity of specific igneous formations [47,86,106], the number of formational petrochemical types is limited [2,3,12,32,36,37,55,161]. The formation of all igneous formations can be based on four classes of natural chemical compounds:

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ultrabasic (peridatite, ophiolite), basic (gabbro - basalt), intermediate (diorite-andesite) and acidic (granite - rhyolite) with sodium, potassium or potassium-sodium bias [52–55,160]. The rocks belonging to these classes are established practically among geological products of all ages [72,73,116]. The most ancient (lower Archean, possibly cat Archean) formations of the Earth's crust by ¾ are volcanogenic rocks metamorphosed to a high degree of facies, among which basic and ultrabasic ophiolites , metalavas , metatuffs , metatuffites are distinguished by composition [93,94], as well as igneous rocks of intermediate and felsic composition [1,12,41,42,54]. From a comparison of rocks and igneous formations of different petrochemical classes of the Earth's crust, it can be concluded that the physicochemical evolution of the Earth is accompanied by a change in the ratios of the content of various chemical elements and rock-forming oxides of abundant elements and all others - small, scattered, rare, radioactive [8, 152 , 160, 164, 165, 168, etc.]. Detailed studies have shown that these processes were not equilibrium and took place in a complex dynamic environment, due to both the dynamics of physicochemical reactions and the influence of the surrounding dynamic fluctuating environs and chambers [14,41,58–62,131]. This is manifested in the complex crystallization of igneous masses, their deformation, the presence of various impurities of accessory minerals, nanoparticles, and a large range of trace, rare and radioactive elements. Geological observations and textural and structural features of igneous rocks show a significant role in their formation of the dynamics of the process as a whole, similarity with segregation of silicate igneous melts of different composition. This whole process is superimposed by the general vibration-wave, fluctuating state of the Earth's matter [162]. The generation of magmatic melts, including those of granitoid composition, occurs mainly in the deep, subcrustal zones of the Earth - in the lower lithosphere, asthenosphere and mantle with the participation of segregation processes. Their self-organization is possible at different deep levels of the Lithosphere and the Earth's crust, depending on P –T conditions, melt viscosity, migration routes, and, all in all, dynamic conditions [88,168]. A source for magmatic melts can be an inhomogeneous mantle substrate periodically activated in the depths of the Earth. Their crystallization in the Earth's crust occurs with the formation of synchronous or close in time homodromous rocks associations in the series ultramafic – mafic – medium diorites and felsic granites [53,54,61–63,158]. The formations that make up a series are, as a rule, unequal in their quantitative ratios and separated in space, although conjugated associations are also found in many cases [44,65,79]. Liparite-basalt continuous, discontinuous, and contrasting volcanic formations have been described, while large slabs, terranes , and ancient blocks are also characterized by alkaline ultrabasic and alkaline – gabbroid –syenite series [10]. The volumes of igneous rocks arising in the Earth's crust synchronously or close in time from the series ultrabasic - basic - diorites - granites are one-stage paragenetically and genetically related associations (formations) and can be combined into a single igneous complex formed at a certain stage of the Earth's development from a common, solar in composition, substrate. The volume and boundaries of the igneous complex are determined by the volume of the substance that makes up its formations, and the time of formations is determined by the total age of the rocks included in it. Magmatic complexes were periodically formed in the history of the Earth, forming the basis of the polycyclic structure of the Earth's crust and Lithosphere.

Formational complex of ore-mineral formations of the Earth's crust. Various mineral deposits of endogenous and exogenous origin are known in the Earth's crust. Due to their material content and the peculiarities of the formation conditions, the entire group of minerals is also subdivided into mineragenic (ore) formations. As a rule, ore formations are complex in composition and are composed of associations (paragenesis) of ore and non-ore minerals. A source of material associations with different composition and depth can be served for the formation. Most of the magmatic plutonogenic , volcanogenic and hydrothermal ore-mintral formation apparently have a mantle source of ore matter [13,19,27,48,50,100,115,130,153]. The bulk of stratiform type ore deposits occurring in sedimentary and metamorphic rocks are syngenetic and mixed origin, and the source of ore matter from deep-mantle and due to mobilization crustal rocks and ore-bearing formations [66,123]. A significant group of diverse deposits of sedimentary and metamorphic origin has a syngenetic source of ore formation [29,44,101,119,129,130] . Many years of experience in geological observations have established empirical patterns, and experimental and theoretical studies have

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shown the possibility of a genetic relationship between endogenous ore deposits and igneous formations of different composition and facies [7,26,27,48,50,52,53,66,84,119]. These relationships are most reliable for basic and ultrabasic igneous rocks, volcanogenic and volcano-plutonic formations, and rare-metal deposits associated with acid rocks granitoids . The study of the physicochemical problems of magmatic and ore processes revealed the common features of their course, the relationship between the redox conditions for the formation of igneous rocks and their ore content. The possibility of a genetic connection between certain groups of ore deposits and certain series of igneous formations has been experimentally shown. The number of elements, for example, the tin, possibility of a genetic relationship in fluid-magmatic systems with both granitoid and basaltoid melts has been proved [75,78,80,82]. This indicates possible partial miscibility in fluid systems of silicate melts of different compositions [132]. More and more geological evidence, experimental data, and theoretical developments confirm the concept of the great importance of deep fluids in the selective smelting of melts and the formation of gas-liquid superheated solutions that can coexist at different levels and generate the corresponding mineral parageneses [78,80,130]. All available data on the geological manifestation of endogenous ore deposits indicate that their genesis is based on complex processes in the mantle and the heterogeneity of its composition, which led to the development of views on ore-magmatic (magmatic-ore) fluid systems [79,82,97]. Identified paragenetic and genetic relationships of a heterogeneous mineralization with heterogeneous, but synchronous igneous formations, allows us to talk about paragenetic relationships of the same age (or close in age) mineralization , represented by deposits of different formational affiliation. Among these deposits are almost all known types of mineral raw materials: iron, copper, nickel, platinum, molybdenum, tungsten, tin, lead, zinc, silver, gold, mercury, rare metals and earths, etc. They are formed simultaneously or close to time, but dispersed in space in accordance with the development and distribution of related igneous rocks, and in some cases complex multi-type multi-metal deposits are formed. This led researchers to understand the possibility of not only the spatial combination of heterogeneous endogenous formations [52,53,56,119–122,128], but also the synchronous, parallel manifestation of ore processes in the earth's crust. The main contribution to the concentration of ore matter in the course of magmatism is made by liquation, which is associated with the separation of fluid melt from parent magmas, which selectively concentrates ore-forming metals [88].

The most significant are selective segregation processes that manifest themselves against the background of the development of the process of mantle activation, when, due to the inhomogeneous field of P –T conditions, igneous magmas are synchronously formed – melts of the homodromous series ultramafic – mafic – granitoids and the corresponding ore-forming fluids-solutions. Their further paths in the earth's crust can diverge, obeying the natural course of development of physico-chemical conditions of vibration-wave non-equilibrium irreversible thermodynamics and structure formation under conditions of self-organization [61].

In connection with the above, the whole variety of endogenous ore manifestations of various formations formed during the development of a particular paragenetic and genetic homodromous magmatism , is a single complex of natural ore-mineral associations of the earth's crust during this period. Due to the great complexity and uncertainty of many issues, the systematization of ore formations has not been completed and has a long history.

V. M. Zeisler approached this issue most successfully and logically [146]. The names of ore-bearing formations are determined by mineral specialization. There are single-component and multi-component ore-bearing formations[53,56]. Mineral deposits of various formations that arise in the Earth's crust, genetically or paragenetically associated with the igneous complex ultramafic - basic - medium and acid granitoids , as well as coeval syngenetic ore-bearing formations, can be considered as a single ore-mineral complex of the Earth's crust. Ore-mineral complexes were formed periodically throughout the history of the Earth [56,119,129], emphasizing its polycyclic development.

Formational complex of sedimentary rocks of the Earth's crust. Sedimentary cover of the planet according to A. B. Ronov [117] is 80% on land and 76% on the ocean floor. Among sedimentary rocks, depending on the formed conditions, various geological formations are distinguished and stand out

[9,57,87,113,136,145,149,155,1456]. They include three main groups: a) biogenic, chemogenic and halogenic; b) products of chemical degradation and destruction of earlier formations; c) precipitation of volcanic, water, atmospheric and space activities. The characteristics of sedimentary formations are primarily determined by the geodynamic setting, geographic and climatic features, the regime of erosion, removal and accumulation of material, and the composition of the sources of destruction and physical and chemical transformations. The three main types of rocks are sandstones (95%), shales (80-85%) and limestones (18%) from the rest. The largest volume of sedimentary rocks and the diversity of formations are characteristic of oceanic structures: shelf and continental slope; less for plates and oceanic basins and much less for accretionary regions, intermontane and other types of troughs. The destruction of matter is a natural part in the general process of self-organization, which occurs immediately after its formation, and the accumulation of sediments is the most continuous process, which is closely related to the processes of erosion, exhumation and the development of surface morphostructures and relief formation within the continents, the bottom of the rivers, seas and oceans. At the same time, it is paragenetically associated with deep geodynamic processes, since the latter predetermine the features of the relief morphology and the composition of the emerging geological formations. Since the processes of relief formation and oceans, geographical and climatic conditions on the globe are interconnected, it can be considered that there is a paragenetic dynamic relationship between the whole variety of synchronous sedimentary formations [57,83,95,98,114,126,133,134,154,156]. In fact, this is a continuation, rather a reverse parallel spontaneous dynamic process of self-organization in the general history of the development of the Earth to create its structure. This relationship is more closely outlined for conjugated drift and accumulation forms, where transitional mixed formations and their series are formed [31]. The separation of formations occurs more often according to the material composition. Sedimentary formations contain various mineral paragenesis [83,101] and complex relationships with each other [139]. Many sedimentary formations are ore-bearing and contain syngenetic ore deposits [19,20,24,66,115,123], contain significant reserves of minerals: hard and brown coal, oil and gas, bauxites, placers of various minerals and metals, gold, phosphorite, fresh and mineral waters. In the formation of sediments, rhythmicity, cyclicity and periodicity are noted [30,43,96,133] in accordance with the general regime of the gravity, magmatic activity, the dynamics of the Earth and sedimentation. Accretion, accumulation of sedimentary formations occurs synchronously with the manifestation of magmatism and the formation of igneous rocks from the range of ultramafic - basic - diorites - granites and partly due to them and the destruction of more ancient exhumed rocks. Suppliers also include, mainly, products of magmatism , manifested on the surface of continents or the bottom of the oceans. The processes of deep intrusive magmatism and the general dynamics indirectly contribute to sedimentation, determining exhumation to varying degrees, the formation of morphostructures and structural topography of the bottom of the seas, oceans and the Earth's surface, creating features of its dynamic development. The set of sedimentary formations and mineral deposits syngenetic with them, formed during a period synchronous with the period of formation, corresponding to the igneous and ore-mineral complexes, is considered by us as a sedimentary complex of the Earth's crust in this period. The generation of periodic complexes of the sedimentary formations has throughout the continuous history of the Earth has occurred.

Formational complex of metasomatic rocks of the Earth's crust. Metasomatic rocks are developed in the Earth's crust in connection with thermodynamic processes in a wide temperature and pressure range from deep magmatism, surface volcanism, gas-fluid and hydrological activity, as well as the physicochemical regime of the geological environment and climatic conditions. We also include metamorphic rocks that are widely developed in the Earth's crust, although the conditions and, especially, the scale of their manifestation are somewhat different. At the same time, both of them are products of changes in the primary composition under the influence of physicochemical processes. The formational division of these formations is usually carried out for each specific case with detailed studies of processes and phenomena and with areal mapping. The experience of classifying metasomatic formations is presented in many works [35,57,87]. Metamorphic rocks are characteristic mainly of pre-Middle Proterozoic geological formations. They occupy about 85% of the time interval of the planet's age and make up most of the Earth's crust, possibly the Lithosphere, and are exhumed into the upper horizons and onto the modern surface. These rocks are believed to be formed by the transformation of primary rocks of different origin and composition, the nature of which is not always decipherable. The mechanism of this process is not entirely clear. Studies show that rocks are formed in places that are not similar either in mineral and often chemical composition or in structural and textural features to their possible primary representatives, about which we know almost nothing, except perhaps the elementary composition of the Earth. Of all the diversity of metamorphic rocks [35], the carbonate facies can most reliably be diagnosed by the presence of marbles [136] and, in part, greenstone formations similar in composition to ultrabasic and basic igneous rocks [1,3,12,28,40,91]. They have been studied and described from different standpoints of composition, age, structure, and ore content [45,68–70,93,94,157]. Among the metamorphic rocks, various formational groups are distinguished [87,106,146]. In general, these groups of formations, depending on the degree of study, are described as part of the identified structural and material complexes of metamorphic rocks [93,94,104,105]. They are very complex in composition and are distinguished by structural, geodynamic, physicochemical, and age features [11,153,157,164]. Three types are best known: greenstone, granulite and granite-gneiss belts. The greenstone belts, aged 1.6 to 3.9 Ga, are similar in composition to younger volcanic and sedimentary complexes. Granulite and granulite-gneiss belts also formed periodically over a period of time from 1.8 to 3.7 billion years. On Earth, in different regions, about 7 cycles of their manifestation are noted. Presumably, This triad: greenstone - granulite - granite -gneiss belts, can correspond to one structural-material cycle of the Earth's crust. They include magmatic formations, mainly of basic and ultrabasic composition, gabbro-anorthosites, granulites , quartzites, conglomerates, calciphyres , metasedimentary formations. Granite-gneiss belts are represented by granites, granite-gneiss, quartzite-gneiss and other metamorphic, mostly salic formations. Metamorphic formations cannot be combined into one common complex due to the long period of development and complexity. Various minerals of ore and mineral raw materials are associated with them.

Conclusions and Discussion

Dynamic structural - material complex - SMC of the Earth's crust. SMC - is a combination of the above-described synchronous formational of igneous, ore-mineral, metasomatic and sedimentary complexes, together with other phenomena and processes accompanying them in a certain period and forms a shell of the earth's crust of this period. The whole variety of geological processes is due to the dynamics of the material world in time and space [15–17]. The winged, figurative expression of V.I. Vernadsky : "... each grain of sand contains the entire periodic table ..." indicates that all chemical elements are involved in all processes occurring on Earth, in quantities corresponding to their concentration and thermodynamic conditions. This manifests itself in various forms of geological movement, which are based on the vibration - wave mechanism of the dynamics of matter-substance and the theory of their self-organization in time and space, developed by the author [51–63,162] based on the provisions in the works of I. Prigogine's schools [107–111] and G. Haken [142–144]. Geological observations, experimental data, and their analysis [34] indicate that the duration of the formation of individual phases granitoid plutons, according to various estimates, is 10^4–10^8 years. The time of formation of bodies of a particular igneous formation is estimated differently from 2-3 million years to 5-10 million years, and gabbro-granite series - 100-200 million years. A.G. Rublev [118] came to the conclusion that the period including emplacement of magma, its crystallization and deposition does not exceed 10–20 Ma. Time of formation of multiphase arrays - 20-30 million years; volcano-plutonic associations - 10-15 million years. The maximum duration of the act, the stage of magmatic activity is estimated at 40-50 million years. Similar figures are also given for formational analysis [87]. The time required for the formation of a deposit of a particular ore formation is also different. According to estimates (depending on the parameters and genesis), for plutonogenic, hydrothermal, and stratiform deposits, it is no more than 10^5–10^6 years [122,148]; in the case of polygenicity and polychrony, it is much longer [127,128]. The duration of the formation of sedimentary formations is also different. If we take into account the boundaries of the most intense rearrangements in the history of the Earth, then it corresponds to geological periods and, on average, is about 55 million years [22]. The possibility of manifestation of planetary geotectonic phases is discussed [43,52,53,69,73,81,103,133,134,139–141]. At the same time, based on the frequency of similar geological formations and their complexes, their age and duration of formation, taking into account the main geotectonic boundaries, many researchers recognize the periodicity and cyclicity of the development and formation of the Earth's crust. At the same time, depending on the principle of determining the boundary geodynamic, structural boundaries, from 5–7 to 17 and 22 subdivisions are distinguished [25,52–54,73,74]. The speed of geological processes is different [75], and the nature of the movement is oscillatory, [167, 93, 90, 141, 100; V. V. Belousov, V. A. Obruchev, M. A. Usov, V. A. Peive] . However, many authors invest in this understanding a different meaning and mechanism of origin. It seems to us that the Earth, from the moment of its inception to the present, is in a dynamic vibrational state of all its discrete elements and physical and chemical properties, which is the mechanism of its development as a self-organizing opening of system [58–63]. These features determine the discreteness, scale invariance, and hierarchy of structural and material associations in the Earth's crust [125,126], and the formation of a multi-scale system of faults and cracks throughout space [38,151]. All known chemical elements are found in the Earth's crust. Some of them (about 50%) are found in the native state, and some form molecular compounds (fullerenes, liquid crystals and supracrystalline compounds, brines, solutions, water and gases). More than 6,000 mineral species are known, forming many rocks and rock groups. Analytical, chemical and physical studies of various substances of the Earth's crust, as the accuracy of determining the characteristic quantities increases, show their close convergence depending on the total concentrations and thermodynamic conditions. The complex heterogeneous structure of the Lithosphere and the simultaneous occurrence of the whole variety of geological processes involved in its formation are more obvious, which indicates their interrelation and mutual conditionality. At the same time, a unified theory has not yet been created that would reveal the cause-and-effect relationships of geological processes, their periodicity, synchronism, asynchrony, symmetry, asymmetry, globality and locality. The revealed empirical regularities have not reached that high generality of theoretical synthesis, which could be taken as the basis for constructing a general theory. In this regard, consideration of the problem of structural and material transformations in the Earth's crust and the search for the closest paragenesis in the environment of geological objects is of great importance, giving. For the knowledge of both private and general patterns of the structure and development of the earth's crust, the conditions for the formation and distribution of minerals, the concepts of geological and ore formations have been developed, the methods and methodology of an integrated systematic approach to their study have been substantiated: facies, formational, structural, morphostructural, metallogenic analysis [18]. A number of regularities of the geological development of the Earth have been established, such as the complexity of the structure of geological bodies, the diversity of geological processes, their periodicity, frequency and dynamic nature of manifestation in different geodynamic settings. At the same time, their interpretation is based, in most cases, on empirical patterns. At the end of the last century, on the basis of new studies of the near space, the solar system, but mainly the development in the fields of physics, chemistry and mathematics of theories of non-equilibrium, irreversible nonlinear thermodynamics, synergetics and fractality of dynamic systems, a deeper understanding of the state and development of the Earth as an open nonstationary dynamic physicochemical system [59–64]. This determined three fundamental properties of the planet since its inception: 1) the exchange of energy and matter with the environment and the complex dynamic state of the planet and its matter; 2) self-organization, spontaneous irreversible development of all elements of its structure in time and space, under conditions of non-equilibrium non-linear irreversible thermodynamics; 3) vibration-wave mechanism of synergetics of all geological processes and phenomena. Taking into account these provisions, under the conditions of vibration-wave spontaneous self-organization, the development of matter in nature can be represented as hierarchical levels of its formation according to the scheme: elementary particles - nuclei - atoms - elements - compounds: ions, molecules, mineral, formation. Each of these levels can be characterized by certain physical properties in time and structural space. For the purposes of geological research, the most possible level of knowledge of matter and objects begins with chemical elements combined into various compounds that make up the whole variety of rocks of the earth's crust. At the same time, in the geological and structural analysis, it is advisable to use the formational consideration of material associations, according to the genetic basis of which the history of the Earth's development is studied.

Taking into account the above and, based on the features of the theory of self-organization of nature, it is proposed in the history of the development of the Earth to single out, as the highest taxon of the hierarchy of the level of organization of matter, a structural-material complex (SMC) of synchronous, or close in time formation, genetically (or paragenetically) related geological formations - igneous (formation complex), ore-mineral (formation complex), metasomatic (formation complex) and sedimentary (formation complex)[53,58–63].

The first three components of the complex are of the same nature and are formed in the general thermodynamic process (cycle) in connection with the activation of the deep zones of the Earth in a certain period. Sedimentary formations accumulate synchronously with the latter, but represent the next phase of self-organization, formed due to their destruction, and more ancient and exhumed geological formations and other factors, but it also has a complex meaning. Metasomatic and metamorphic formations are formed by the transformation of existing and earlier associations. Thus, the Earth's crust has been formed over 4.5 billion years due to the periodic formation of the self-similar dynamic structural-material complexes described above, which determine its structure and polycyclic development. The number of such cycles - complexes for the Earth's crust has not been established. But a preliminary analysis of the data on the study of the geological structure of the Planet shows that during the Middle Proterozoic period of history there were at least 7 of them (cycles of the formation of the triad: greenschist, granulite and granite-gneiss belts) and the same number in the Phanerozoic and up to modern times - 7 [52,63]. Presumably, there are 14 cycles of the development of the earth's crust and Lithosphere. The material composition of each and every discrete element of the SMC structure is close to the average composition of the Solar System, the Earth, and the Earth’s crust [167]. The formation of structural-material complexes of the Earth's crust is a consequence of the vibrational-wave state of matter and spontaneous development in the field of its resonances of geological processes of self-organization in time and space under conditions of irreversible, nonlinear, non-equilibrium thermodynamics of open systems. Structural elements are hierarchical, dissipative in nature and fractal structure.

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