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MAGMATISM AND METALLOGENY OF THE MAJOR STRUCTURES OF THE EARTH'S CRUST

(Fig. 1, Tab. 1)

Abstract: Metallogenic evolution of the Earth, differently from previous experiments in this field, has been studied according to major structures of the Earth's Crust. Accordingly, two contrasting types have been distinguished. The first one- geosynclinal-folded type- demonstrates the accretion of the continental crust, whereas the second type- tectonic-magmatic activization- suggests different stages of destruction of the sialic layer. Metallogeny of these two trends of the Earth's Crust development is diverse, more productive ore mineralization being related to the juvenile magmatism accompaning riftogenic processes.

Резюме: Металлогеническая эволюция Земли, в отличие от предыдущих опытов в этом направлении, рассмотрена по главным структурам земной коры. В качестве таковых выделены два контрастных типа. Первый из них, геосинклинально-складчатый, знаменует аккрецию континентальной коры, тогда как второй — тектоно-магматической активизации — фиксирует разные стадии деструкции сиалической оболочки. Металлогения, сопровождающая два противоположных направления развития земной коры различна, причем более продуктивная рудная минерализация связана с ювенильным магматизмом, сопровождающим рифтогенные процессы.

Evolution of ore formation in geological history of the Earth is analysed in limited number of works by S. D. Turovskii, D. V. Rundkvist, V. S. Domarev, V. S. Sinitsin, V. I. Smirnov, D. I. Gorjevskii, V. N. Kozarenko, A. I. Tugarinov, F. S. Turner, R. E. Folinsbi, R. V. Hutchison. The metallogenic analysis is carried out following the major stages of evolution of the Earth's Crust. Some authors (D. I. Gorjevskii, V. N. Kozarenko) accept as main metallogenic landmarks the stages by Shtille (1964)- Deuterogene, Protogene, Neogene, others consider as such the main boundaries of the regional reconstructions of the structural pattern of the Earth's Crust (Tvalchrelidze, Folinsbi). In his recent work dedicated to the problem Smirnov (1982) distinguishes 6 metallogenic periods (lunar, nuclear, protogeosynclinal, intrageosynclinal, geosynclinal, riftogenic) and 11 stages named after tectonic cycles from the Greenlandian up to Alpine. The age limits of the successive stages progressively shorten from 1200 m.a. for the oldest ones up to 100 m.a. for the youngest.

Metallogenic analysis carried out by the mentioned authors on global scale leads to the unanimous couclusion that composition of magmatic rocks and of related ore deposits becomes more and more complicated and number of ore formations encreases with time. Tvalchrelidze (1970) distinguished „time--trough“ ore formations traced from the most encient epochs till the Alpine time without any essential changes, and “typomorphic” ore formations characterizing metallogeny of certain periods of the Earth development.

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The present short review deals with the results of a new experiment in the field of global metallogeny, which is based on different principles. The metallogenic analysis is carried out for major structures, formed due to contrasting processes, that caused heterogenous structure of the Crust and diversity of geodynamic environments during individual stages of its transformation. The author (T v a l c h r e l i d z e, 1982) distinguishes two major types of processes working in opposite directions. One of them is responsible for growth of the continental crust and the other produces the oceanic one. The former is a constructive process leading to development of the thick continental block of the Earth characterized by complex composition and structure. The latter, in contrast, has a destructive nature and leads to disruption of the sialic shell and formation of oceanic crust, that is primitive in composition and structure. Growth of the "granite-metamorphic" layer is a result of long polycyclic and at the same time irreversible development.

These two contrasting trends of the Earth's Crust formation occur simultaneously complicating and prolonging successive, irreversible development of the rigid frame of the Earth's surface. At the same time, certain periods are characterized by predominance of either processes stimulated by global compression or extention of the planet. Such pulsing of the Earth is indicated by several authors (M i l a n o v s k i i, 1980; K h a i n, 1979; K a z a r i n o v, 1979). Occuring periodically on different scales, it conditions cyclic character of Earth's development- alternation of stages of folding, metamorphism and granitization (compresion) with the stages of break up and dismembering of continents and formation of oceanic basins.

Diverse geological structures are material manifestation of these two opposed processes in the Earth Crust. The trend leading to development of continental crust is expressed by geosynclinal process. The latter is studied in great detail in its tectonic, lithologic, petrologic and metallogenic aspects. The time span exceeding 100 years separates us famous works by D. H a l l and D. D a n a, founders of the theory of geosynclines. During this long period, the theory was strictly formulated, complemented precised and generally acknowledged, but finally grew somewhat outdated, as indicated by recent heavy critisism.

Without going into details of the problem, that requires a special consideration, the following assumptions of geosynclinal theory seem to be acceptable and quite applicable to metallogenic analysis: 1. formation of continental crust by geosynclinal process, 2. existense of geosynclinal zones of different types, 3. polycyclic and multistage geosynclinal development, 4. division of the tectonic cycle into two main geosynclinal and orogenic stages, the latter leading to development of the sialic layer from primitive oceanic crust, 5. an intense activity of juvenile basaltoid magma during geosynclinal stage and of palingenetic granitoid magma-during the orogenic one, 6. a successive increase of consolidation grade of the Earth Crust with development of polycyclic geosynclinal process.

Ore content of the geosynclinal and orogenic stages of tectonic cycles is different. During the formen the deposits of copper, lead and zinc of pyrite group, skarn-copper and magnetite deposits, veined quartz-polymetallic and auriferous copper-porphyric ores and some others belonging to the basaltoid line are formed.

The orogenic stage is characterized by deposits of granitoid line related to orogenic magmatism and metamorphism. Such are formations of rare-metal pegmatites, greisen and apogranitic deposits of molibdenum, beryllium and uranium; quartz-sulphide veined mineralization with copper, lead, zinc, sometimes stanniferous is manifested on comperatively smaller scale.

Ore content of separate sectors of geosynclinal systems has been studied rather completely by many authors, hence the scheme of evolution of the metallogeny can be considered as proved by numerous examples (Ore content. . ., 1981). The systematics of ore-bearing structures, which has a great prognostic importance, in some cases still remains controversial. In fact, basing on manifestation of diverse pyrite deposits on early stage of development of eugeosynclinal zones, the author limited the subdivision of these zones to five varieties- ophiolitic, primary eugeosyncline of Urals type, secondary ones- of Lesser Caucasian and Ore-bearing Altai types, slate-geosynclines of Rammelsberg type (T v a l c h r e l i d z e, 1978). The first of these types of ore provinces, with magmatic deposits of chromite and chalcopyrite of Cyprus type later on was excluded from geosynclinal (island arc) structures and assigned to oceanic rifts. As it turns out, the secondary oceanic nature is also characteristic of the earlier stages of development of slate-geosynclines (mictogeosynclines), where mineralization associates with undifferentiated tholeiitic basalts, as it is in ophiolitic zones (T v a l c h r e l i d z e, 1982).

Tectonic-magmatic activization is opposite to the geosynclinal development by direction of its processes resulting in destruction of continental crust and formation of new oceanic crust. This multistage process lasts for a long time span and is manifested by formation of various geological structures such as arch-block uplifts and troughs, rift structures of different nature, trappe fields, some parts of platform cover and oceanic rifts. The above structures can not be considered as belonging to a successive line, representing separate stages of a single process; they correspond to directed succession of definite geodynamic environments. At the same time distinct varieties of these structures characterize the definite periods of the Earth's Crust development. The typomorphic ore formation are related to such structures.

The author has carried out the global analysis of metallogenic evolution basing on the above defined structures of the Earth's Crust. In present short review this analysis can be presented only in form of the summarizing schematic table, offered here for discussion (Tab. 1). Eartly Precambrian, Early and Middle Proterozoic, Riphean and Phanerozoic are taken for the main periods of development of the Earth's Crust as far as they turned out to be most convinient for metallogenic analysis. A more detailed subdivision of the periods of ore formation seems still somewhat conventional since it is difficult to prove the global scale of manifestation of distinct tectonic cycles as well as to date precisely their age limits.

Data given in the table are specified by diagram (Fig. 1). Both the table and the diagram contain wide information on ore content of the Earth's Crust with several conclusions that may follow. Among these, the conclusions casting new light on the metallogenic evolution of the Earth from the most ancient periods of its development, as well as on the character of ore content of the major types of crustal structures are considered below.

First of all, as it follow from the diagram, quantity of ore formations constantly encreases in time, being the direct function of irreversible compli-

Table 1
Ore Content of the Main Structures of the Earth Crust

Main periods of ore formation (megacycles)	Main types of ore-bearing structures	Magmatic ore formations	Ore formations	Examples of ore regions and deposits
1	2	3	4	5
Early Precambrian (Catarchean and Archean)	Greenstone belts	basalt-rhyolitic	copper-zinc-pyrite	Noranda, Flin-Flon and oth., Canada; Yellowknife, Porcupine, Canada;
		basaltoidic	stratiform and veined gold mineralization	Kalgoorlie, Western Australia; Kolar, India;
		comatiitic	copper-nickel	Kimbaeda, Western Australia; Abitibi, Canada;
		of soda granitoids	rare-metal pegmatitic	Coolgardie, Western Australia; Preisak-Lakorn, Canada; Southern Rhodesia, Transvaal, South Africa;
Early-Middle Proterozoic	Protogeosyncline belts	basalt-rhyolite	sulphur-copper-pyrite	Copper belt of Karelia-Finland-Sweden;
		potassic granites	pegmatite, greisen rare-metal	Western Australia; Southern Africa; Brazil; Canada; Baltic shield;
	Protoaulacogens	basite-ultrabasite	chromite-platinoid, copper-nickel	Southern Africa (Great dike, Bushveld), Canada (Sadbery), Monchegorsk, USSR;
		alkaline-basalt in the lower part of section	ferruginous-siliceous group of formations	Krivoi Rog, Kursk magnetic anomaly, USSR; Lake Superior, USA; Hamersley, Australia; Minas-Gerais, Brazil;
	Protoplatform mantle		gold-uranium-bearing conglomerate	Vitvatersrand, Republic of South Africa; Blind-River, Canada; Serra de Jacobina, Brazil;
Riphean	Geosynclinal belts	basalt-rhyolitic	copper-zinc-pyrite	Jarom, Duktown, Ore-Nop, USA; Saudi Arabia;
	Aulacogenes	gabbro-noritic	copper-nickel	Linn, Manitoba, Canada; Stanovoi Ridge, USSR;
		tholeiite-basaltic	native copper	Lake Superior, USA;
		gabbro-dunite-pyroxenitic	titanium-magnetitic	Kiruna, Sweden; Aldan shield, USSR;
		carbonatitic	phlogopite-magnetitic	Alnë, Sweden; Fën, Norway; Kovdor, USSR;
		tholeiite-basaltic	pyrite-polymetallic	Mount-Isa, Mac Arthur, Australia; Sullivan; Canada; Kholodinskoe, USSR;

1	2	3	4	5
	Platform mantle		cuprous sandstones and slates	Udokan, USSR; Copper belt of Rhodesia;
			stratiform lead-zinc in carbonate rocks	Congo, Africa;
Phanerozoic	Primary eugeosynclines	basalt-rhyolite	copper-zinc-pyrite	Urals, Northern Caucasus, USSR; Norway; Rio-Tinto, Spain;
	Secondary eugeosynclines of Lesser Caucasian and Ore Altai types	basalt-andesite-dacite-rhyolite	copper-zinc-pyrite	Sredna Gora, Bulgaria; Pont, Turkey, Chingis-Tarbagatai, Lesser Caucasus; Ore-bearing Altai, Gissar, USSR; New-Brownswik Canada; Kuroko, Japan;
	Microgeosynclines	tholeiite-basalt	pyrite-polymetallic	Alvin, Canada; Rammelsberg, RG; Filizchai, Jairem, Ozernoe, USSR;
	Orogenic belts	potassic granits	greisen rare-metal	The Cordilleras, USA; The Andes, Southern America; Primorje, USSR; Saksonian-Turingian zone of Europe;
Phanerozoic	Arch block structures	granitoidic	greisen and quartz veined tin-tungsten, copper-molybdenum, lead-zinc-fluorite, barite, antimony-mercury, gold-silver, radioactive metals	Transbaikal; Northern Mongolia; The Andes, South America; Rocky Mountains, North America; Eastern China;
	Trap fields	ferro-gabbro-doleritic	titanium-magnetitic	Pudojgoran, Siberia;
		dolerite	magmatic-magnetite	Of Angara-Ishim group, Siberia;
		gabbro-diabase	copper-nickel,	Kurei region, Siberia
		gabbro-diabase	Iceland spar	Noginskoe, Siberia;
	Continental rifts	basite-ultrabasite	copper-nickel chromite, titanium-magnetite	Norile region, USSR; South-Western Alaska, USA; Northern Greece;
		alkaline-ultramafite	phlogopite, apatite iron-ore, rare metal	Khibin, Kovdor, Kurei zone, Siberia;
		kimberlite	diamonds	Viluisk, Anabar-Aldansk provinces, Siberia; Kimberli, Republic of South Africa;

Continuation of Tab. 1

1	2	3	4	5
	Oceanic rifts	tholeiite-basalt	copper-pyrite	Cyprus; Ergany-Modern; Newfoundland;
	Platform mantles		cuprous sandstones and schists straiform lead-zinc in carbonate rocks	Jezkazgan, USSR; Mansfeld, RG; Lower Silezia, Poland; Tree-State, USA; Pine-Point, Canada; Upper Silezia, Poland; Kara-Tau, Sardana, USSR;

cation of composition of the Earth's Crust and of a successive increase of its thickness.

Some ore formations are formed only in certain periods of Earth's Crust development. These are predominantly gold-uranium-bearing conglomerates and ferruginous quartzites. The first one is restricted to Early Proterozoic protoplatform cover of South Africa, Brasil and Canada. Deposition of these detrital rocks starts in protoaulacogene structures (Dominion, Reef and Transvaal sethe grabens covering relatively vast territory (Vitvaterries) and later on they are spread beyond the limits of the grabens covering relatively vast territory (Vitvater – srand and overlying younger series).

All the large deposits of ferruginous quartzites are of Early Proterozoic age. They are restricted to terrigenous deposits infilling trenches of protoaulocogenic structures. Sedimentation is preceded by eruption of alkaline basalts. Ferruginous quartzites occur in Archean volcanic-sedimentary deposits of Kursk magnetic anomaly, Krivoi Rog, Western Greenland and other countries; however, they never form large and rich ore accumulations of Krivoi Rog or Suerior type.

To typomorphic formations are attributed several ore formations characteristic of Phanerozoic, such as copper-pyrite deposits of Cyprus type, first appearing in Cambrian ophiolites of Newfoundland; copper-porphyric deposits– the oldest belonging to Cambrian of Kazakhstan (Boschekul); copper-molybdenum formation unknown from rocks older than Paleozoic; mercury deposits known in Hercynian period but characteristic predominantly of Alpine metallogenic epoch. Stratiform, lead-zinc deposits in carbonate rocks (Gorevskoe, Kongo) are first manifested in Late Riphean; cupreous sandstones and schists (Udokan), as well as pyrite-polymetallic mictogeosynclinal formations (Broken-Hill, Mount-Iza)- in Middle Proterozoic. Pyrite-polymetallic deposits of Kuroko type (Ore-bearing Altai) are not known in deposits older than Ordovician (New-Braunswik), they are widest developed in Devonian (Ore-bearing Altai Lisar).

Typical "persistent" ore formations, passing without visible changes through geological time from the oldest metallogenic epochs, are copper-zinc-pyrite ore formation of primary eugeosynclines (the oldest deposits of Canada- 3 milliard years old) and chromite formation of ultrabasic rocks (the oldest deposits of South Africa and Western Greenland are more than 3 milliard years old). Titanomagnetitic formation traced from Early Proterozoic also can be attributed to "persistent" ore formations. Carbonatitic formation of peralkaline and basic magmatic

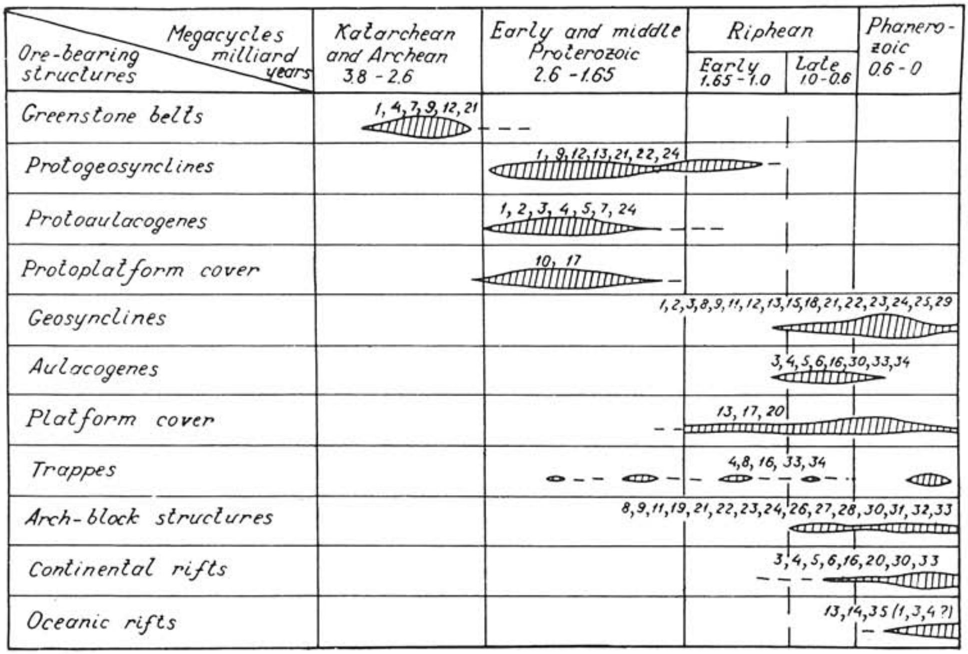

Fig. 1. Scheme of metallogenic evolution of different type geological structures of the Earth's Crust.

Explanations: Main endogenic ore formations (figures on the diagram). 1-chromitic, 2-platinium, 3-titanomagnetitic, 4-copper-nickel, 5-carbonatitic (apatite-nepheline, titanium-niobium, phlogopite), 6-kimberlitic, diamond-bearing, 7-ferruginous quartzite, 8-skarn-magnetite, 9-stratiform and veined gold-sulphide, 10-gold-uranium bearing conglomerates, 11-volcanogenic silver-selenium-tellurium, 12-copper-zinc--pyrite, 13-pyrite-polymetallic, 14-copper-pyrite, 15-pyrite-gold-barite-polymetallic, 16--native copper, 17-cuprous sandstones and schists, 18-copper-porphyric, 19-copper--molybdenum, 20-stratiform lead-zinc in carbonate rocks, 21-rare-metal pegmatites, 22-silicate cassiterite-tungsten, 23-sulphide-cassiterite-tungsten, 24-five-element, 25--skarn-copper, 26-skarn-scheelite-molybdenum, 27-skarn polymetallic, 28-veined and stockwork quartz-molybdenitic, 29-stratiform scheelitic, 30-mercury, 31-realgar-orpiment, 32-ferberite-antimonite, 33-barite-fluorite, 34-Iceland spar, 35-ferruginous--manganic (Parapedi formation).

provinces is first manifested in Middle Proterozoic (Palbara), and is randomly distributed ever after occuring as central type massives.

Geological history of the Earth is marked by irregularity of manifestation of ore formations. Several most productive periods can be distinguished, when important deposits of various metals have been formed almost simultaneously in different parts of the globe. To such productive periods belongs the Archean. Its metallogeny turns out to be quite expressive contrary to the traditional point of view (Kazanskii, 1981). In particular, deposits of North American protoplatform, Western Greenland, Western Australia and some in South Africa count 3 milliard years and more.

Gold, copper, nickel, chromium, platinium and titanium deposits, unique in scale, were formed in Early Proterozoic (Great Dike, Bushveld, Badberg). They are the largest in the World. Proterozoic is marked by formation of very large deposits of copper, lead and zinc of copper schist and pyrite types. A considerable decrease of intensity of ore formation is observed in Riphean. Smirnov (1982) defines the period within the limits of 1300—1000 m.a. and relates it to Algoman consolidation by Shtille (1964) and formation of stable continental block of Megogea characterized by subdued endogenic activity.

In Phanerozoic the Hercynian metallogenic epoch seems to be espacially productive, when geosynclinal development and corresponding deposits of basaltoid (predominantly pyrite and skarn) as well as granitoid (greisen- rare--metal) profile flourished. In Mesozoic-Cenozoic period the structures resulting from tectonic-magmatic activization (arch-block and rift structures) become most important. They contain tin, tungsten molybdenum, copper, nickel, lead, zinc, platinum and diamond deposits.

An analysis of bank of data on global metallogeny leads to one more important conclusion- on the much higher productivity of structures, resulting from process of tectonic-magmatic activization, in comparison with the geosynclinal ones. In fact, though deposits of chromium, titanium, copper, nickel, lead, zinc, platinium and gold, related to basaltoid magmatism of various riftogenic structures, are comparatively rare, still they contain largest ore reserves of worldwide significance, whereas geosynclinal deposits though rather numerous are of limited resources. It is to be mentioned that ore formations synchronous to the initial stages of subsidence, marked by destruction of continental crust, are attributed here to rift type, whereas their further history seems to follow geosynclinal trend.

The widely accepted concept relating endogenic ore mineralization to the most acid members of successively differentiated melts of magma chambers requires revision. In fact, we can indicate numerous examples of ore deposits related to undifferentiated tholeiite basalts (pyrite deposits of Filizchai types) as well as examples of a higher productivity of ultrabasic magmatic melts, in comparison to that of subsequent acid members (e.g. Buschveld complex).

The author wholly realizes the necessity of further study of several essential aspects of ore content of geological structures. The rather limited knowledge on rift structures belongs to their number. Milanovskii's well-known works (1980) in this field are not always sufficient for working out rift systematics for metallogenic purposes. Some additional data on character of magmatism and mineralization of aulacogenes and rifts are required.

Petrochemical aspects of ore content of magmatic rocks also need closer examination. Works by Marakushev (1979), as well as recent works by Bogatikov with co-authors (1983) deal with effects of liquation and differentiation on the process of ore formation. In future these should be correlated with details of geodynamic environments. There exist some other unsolved problems of modern theoretical metallogeny, but it is impossible to review them in the present short paper.

In conclusion, it should be mentioned, that recent paleotectonic reconstructions, should be reinforced by magmatic and metallogenic characteristics of diverse geological structures. These additional data often happen to be keys to solution of problems of vertical extension, regional distribution, duration of developments, time of formation of geological structures, to say nothing of economic effect of such an approach.

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