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MAGMATISM OF THE EARLY PRECAMBRIAN

Abstracts: In the geotectonic isoeopy of the continental Earth's crust in the Early Precambrian there can be distinguished three main stages: progeosynclinal, proto-geosynclinal and protoorogenic or the stage of stabilization of the early platforms. Character of magmatism is changed correspondingly with stages, the number is increasing and material variety of natural association of the magmatogenic rocks (formations), their ore-bearing productivity increases. Cycling-trend of evolution of the Early Precambrian magmatism is formed, what is conditioned by an accretion of the crustal thickness, by decrease of its geoenergetic potential, with missing magma forming processes to the great depth and with the complication of the crustal structure and increase of its consolidation.

Резюме: В геотектонической истории континентальной земой коры в раннем докембрии выделяются три главных этапа: прогресинклинальный, протогеосинклинальный и протоорогенный или этап стабилизации древних платформ. От этапа к этапу закономерно меняется характер магматизма, возрастает число и вещественное разнообразие естественных ассоциаций магматогенных пород (формаций), возрастает их рудообрахующая продуктивность. Устанавливается циклично-направленная эволюция раннедокембрийского магматизма, что обусловлено возрастанием мощности коры, снижением ее геоэнергетического потенциала, с уходом процессов магмообразования на все вольшую глубину и с усложнением структуры коры при нарастании степени ее консолидации.

1. The analysis of the conditions, place, time and character of magmatic processes of the early stages of the earth's crust formation in the Early Precambrian, fulfilled by the author and his colleagues (Magmatic Formations . . ., 1980) gave the opportunity to reveal the general trend of magmatism and its specific characteristics. The main problem of such an analysis was the distinction of certain natural associations of the orthomagmatic and ultrametagenic rocks (complexes and suits), which are closely connected in their structure, origin, time and conditions of their formation, structural localization and relationship with the kinematics of the earth's crust.

2. The history of the tectonic development of the earth's crust in the Early Precambrian can be divided into three main stages: progeosynclinal, protogeosynclinal and proto-orogenic, i.e. stage of the stabilization of the early platforms (Shurkin, Mitrofanov, 1969).

According to the modern chrono-stratigraphical scale of the Precambrian of the USSR the first stage corresponds to the Early Archean (more than 3 b.y.), the second — to the Late Archean (3.0 — 2.6 b.y.), and the third — to the Early Proterozoic (2.6 — 1.6 b.y.). By the end of the third stage the consolidation of Early Precambrian basements of anoient platforms had been completed, and beginning from the Riphean their sedimentary covers were formed (the platform stage of their geological existence).

3. According to modern geological and geochronological data the oldest rocks of the earth' crust are plagiogranitoids (tonalitic gneiss, trondhjemites,

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granodiorites, plagiogranites), which are preserved as relics in the domes of the sialic basement of „primary" (G l i k s o n, 1975) granite greenstone belts (Greenland, Labrador; Swaziland, Zimbabwe etc.). The age of these granitoids varies in the range of 3.9—3.5 b.y., and that of the volcanic rocks developed in the interdome structures falls into the range 3.5—2.5 b.y. These volcanics have mainly basaltoid composition, but in places (Onverwacht group, South Africa) they comprise high magnesian ultrabasites (komatiites) and also (Isua series in Grennland, Sebakwe Group in Zimbabwe etc.) the interlayers of sedimentary rocks (quartzites, jaspilites, schists etc.).

The age relationship between granitoids and volcanics is problematics due to the fact the volcanics on the one hand, occur on the erosional surface of the granitoids, and on the other hand, the latter xenoliths of metavolcanics and parametamorphites similar in composition to greenstone complexes.

4. Considering the full range of the geological, petrographical, geochemical and other data the author supposes it possible to regard the sialic basement of the greenstone belts as the earliest earth's crust, which was originally constituted by the volcano-plutonic rock association, including dacitic, andesito-dacitic, and subordinate basaltic volcanic partly their redeposited erosional products, as well as the intrusions of tonalites, diorites and plagiogranites. These rocks were subsequently subjected to regional metamorphism, possibly, repeated rheomorphism and recrystallization, which resulted in homogenization and relative consolidation of the crust. The formation of the greenstone volcanic cover due to the external eruption of abyssal magma melts was connected with the tectonic or meteoritic and breakage of a primary sialic crust, whose thickness according to the geochemical criteria (C o n d i e, 1973) varied from 20 to 30 km.

As to the origin of the substance of the rocks of sialic protocrust the author considers that at the stage of the accretion of the Earth a protoplanetic matter was already differentiated according to the density and matter composition (cf. R u d n i k, S o b o t o v i c h, 1973); and he also thinks that by the beginning of the Earth's geological history, the external part of the lithosphere was formed by the rocks of intermediate (dacite- andesite-labradorite) composition. The existence of such a layer in the lower part of the modern continental crust of the Russian and Siberian platforms is proved by the presence of the xenoliths of eclogite-like rocks with different ratios of albite-oligoclase, diopside, with 10 % jadeite molecule, garnet (39—44 % Pyr, 42—66 % Alm, 13—15 % Gros). The petrophysical characteristics of these xenoliths (density 2.95—3.23, longitudinal waves velocity 6.5 — 7.0 km/sec) practically correspond to the rocks of the geophysical „granulite-basite layer" of the modern continental crust. It is quite possible that these rocks at a time formed the earths protocrust, and now they are preserved in the depth — beneath the gneiss-granitic layer, which seems to be the product of their exogenic (erosion, sedimentary differentiation etc.) and endogenic (anatexis, metasomatosis, regional metamorphism, ultrametamorphism etc.) reworking.

As a result of the geochemical affinity of the radioactive elements and the sialic rocks, the protoplanetic lithosphere in its external part may have provided most favourable conditions for the generation of magmatic chambers under the influence of the radioactive heating. These resulted in the appearance of a subsurface complex of the primary-crustal plagiogranitoids and andesite--dacite volcanics.

5. Today the structural position and geotectonic conditions of the primary granite-greenstone belts, as well, as the formational classification of associated magmativ complexes remain uncertain. The author supposes that these relatively stable „islands" of the primary-crustal granitoids and volcanics can be applied to the structures of the progeosynclinal stage, which coexisted along side the surrounding areal-mobile (permobile — after L. I. Salop) areas.

The latter are characterized by the accumulation of the thick volcanic piles with the subordinate terrigenous sediments, which were dislocated and areally transformed into different schists and charnockite-migmatites about 3.0 b.y. ago. The most characteristic features of these progeosynclinal structures are the areal development of magmatism with the dispersed intrusive bodies amoung volcanics and regional development areas of the ultrametagenic granite-migmatitic complexes isofacial in the conditions of their formation to the regional metamorphism of supracrustal rocks.

6. The volcano-plutonic association of basaltoids and sub-volcanic intrusions of basalts and ultrabasites prefolded andesite-basaltoid formation. Later there appeared early folded anorthosite-ultrabasite--gabbroid and enderbite formations, which could be paragenetically related to their paternal magmas formed as a result of the selective melting of eclogite-like rocks forming the andesite-anorthosite crustal layer.

Petrogenetical calculations regarding the experimental data (Green, 1968; Green, Ringwood, 1968) theoretically allow to acquire from certain rocks melts, which can during crystallization differentiation, under high pressure, from the wide range of the rocks of the two mentioned above associations beginning with norites, gabbro, gabbrolabradorites — including, enderbites, charnocites and plagiogranites. In the Belomorian region, where both associations are most favourably represented, there is no structural localization of the numerous minor rootless intrusions of different composition, which were formed of different levels of succession of the volcanogenic — terrigenous Belomorian series. They were crystallized under hypabyssal conditions that is suggested by rare „capture" of enclosing volcanics by intruding magma (in massifs of gabbro—labradorites and hypersthene diorites).

The subsequent sinfolded association are charnockite-migmatite and granite-migmatite having ultrametagenic origin. They are characterized by the diffusivedispersed distribution of granitoid material formed in the process of the anatexis, metasomatosis and metamorphic differentiation, mineral composition of which being dependent upon the composition of the substratum and the PT-conditions of granitization. These associations are indicative of the ascend of granitoid front into the volcanogenous-sedimentary part of the crust. Morphologically they appear tu be vast migmatite areas of the autochthonous-stratiform structure, within whose there are numerous minor accumulations of the autochthonous granitoid material and small suballochthonous massifs (blocks) of charnockite-enderbites and granites. Based on structural criteria, V. M. Shemyakin considers it possible to distinguish two independent late-folded associations: a) metasomatic charnockitoides and b) magmatic (intrusive) charnockitoides, but K. A. Shurkin regards both of them to be only genetical varieties of the rocks of the mentioned above charnockite migmatite suite.

By the end of the magmatic activity of the progeosynclinal stage the two post-folded a l a s k i t e and a p l i t e suites are represented by the dike (dike-like) and veined fractured bodies, occurring among rocks of the granulite and amphibolite facies correspondingly. Their anchieutectic composition is the sign of the formation from the residual sources of the ultrametagenic granitoid magma, and their confinement to faults indicates the consolidation of the granite-gneiss layer by the end of the progeosynclinal stage.

7. The next, p r o t o g e o s y n c l i n a l stage of the development of the earth' crust is characterized by its structural differentiation and changes in the geotectonic regime. At this stage the first mobile belts of the linear type were formed: a) *the continental protogeosynclines,* which form the systems of the synclinefolded zones, separated by the median massifs — the blocks of dissected Archean granulite-gneiss-granite basement (East-European type) and b) *the marginal protogeosynclines,* framing the protoplatformic structures of Early Archean stabilization (Siberian type). The most intense tectono-magmatic activity and high gradient metamorphism are connected with these structures, the originally rigid median massifs being subjected to rheomorphism and structural reconstruction during tectonic culmination.

8. The group of the magmatic associations of the protogeosynclinal stage comprise both orthomagmatic rocks originated from the subcrustal magmas and ultrametagenic intercrustal rocks. The oldest are prefolded volcanogenous suites s p i l i t e - d i a b a s i c, d a c i t e - a n d e s i t e - b a s a l t i c, and l e p t i t i c (rhyolite-dacitic composition).

Spatially and progenetically these volcanics are connected to the intrusions of the early-folded associations especially h y p e r b a s i t e - g a b b r o i d and p l a g i o g r a n i t o i d suites, small blocks of which can be found in the faults of the basement adjacent to the troughs.

Simultaneously to the folding in the protogeosynclinal structures there was regional metamorphism in the range from the granulite or amphibolite to the green-schists facies of the andalusite or kyanite types in different structures. In these zones of the development of processes of the ultrametamorphism there were formed the following associations: p l a g i o g r a n i t e - m i g m a t i t i c and later p l a g i o m i c r o c l i n i c g r a n i t e s and m i g m a t i t e s (ademellite-migmatitic). The former was connected with the early-inversion tectogenetic phase, and the latter with the culmination of tectonic movements. The synfolded granitoids and migmatites are commonly spread in the lower parts of supracrustal rocks, but the anatectite granitic bodies can be found in the allochthonous position far from the ultrametagenetic focuses. The processes of the granite formation were most intensely evident at the protogeosynclinal stage being closely connected with the katazonal rheomorphism of Early Archean gneiss-granitic basement. This resulted in the accretion of the crust and degree of its consolidation by the end of the protogeosynclinal stage. The rigid behaviour of the crust is confirmed by the post-folded dike suite of the p e g m a t o i d g r a n i t e s and a p l i t e s and dike complexes of m e t a b a s i t e s (orthoamphibolites).

9. The metallogenic specialization of the sedimentary-volcanogenous, intrusive and ultrametagenetic association of the protogeosynclinal stages is rather

variable the former are associated with the commercial deposits of the iron and pyrite ores, the latter are connected with the deposits and ore manifestations of nickel, copper, titanium, iron and molybdenum, and the ultrametagenetic pegmatites are the source of the ceramic raw materials and sometimes carry the rare-earth mineralization.

10. The next protoorogenic stage of the crust, development in the Early Precambrian — in the time interval 2.6 — 1.6 b.y., is characterized by the increase in the extent of its structural differentiation against the background of the growing consolidation of its platform segments. At this stage there existed more or less simultaneously the structures of the different geotectonic regime — there were approximately stable areas of the „completed folding", where the primary orogenic regime in the process of the increasing consolidation of the crust turned into subplatform regime by the end of the stage, and on the other hand, there were structures of the subgeosynclinal type, i.e. the superimposed troughs with the specific features of the internal structure and development, which became the part of the stabilizing ancient platforms after the termination of vigorous tectono-magmatic activity avoiding the orogenic stage. At the Russian platform in the Early Proterozoic the inherited superimposed troughs appeared twice with the intermediate period or the relative stabilization of the protoplatform.

The first earlier troughs (Saxaganides) were initially formed directly at the place of the protogeosynclines having been transited into the range of structures of the „completed folding", and were formed at the time interval from 2.5 to 2.3 b.y., and the second later (Svekofennides) embraced the western, south-western and southern parts of the stabilizing platform, which had been subjected to the selective tectono-magmatic activization in the time range 2.3 — 1.65 b.y., ago. The latter date is accepted as the isotope-chronological limit between the Lower and Upper (Riphean-Vendian) Precambrian in the chrino-stratigraphical scale of the USSR.

11. According to the differencies of the tectonic regime in the mentioned above types of structures, the large group of the magmatogenetic formations of the stabilization stage of the ancient platforms is divided into two subgroups; the first being characteristic to the protorogenic-subplatform development, and the second subgroup constituent of the troughs of subgeosynclinal type.

All the associations of the first subgroup are orthomagmatic, i.e. they are connected with the abyssal magmatic sources confined to fault-bounded tectonic deppressions or to the zones of deepseated faults. In particular, this subgroup includes the volcanic suites of tholeiite-basaltic differentiated magmas: the andesite-basaltic, subalkaline-basaltic, picrite-basaltic and spatially and paragenetically connected with them gabbro-hyperbasic suite. At the Russian platform these formations are developed in the graben-synclinal structures of the Jatulian-Suissarian and are conjugated with the volcanic centres, and diabases can contain the natural copper ore manifestations, and differentiated intrusions of the hyperbasites can be commercially nickel-bearing.

At the Siberean platform the basic-ultrabasic complexes are localized outside its boundaries and are dated from the Late Proterozoic. Volcano-plutonic complexes synchronous to the Jatulian are spread in the marginal parts of the platform and are represented by trachy-andesitic and sienite-grano-dioritic, trachy-liparitic and grano-syenite-granitic, granite-granophyric and liparitic suites.

At the Baltic shield the massifes of the layered peridotite-gabbro-noritic intrusions, partly commercially nickel-bearing, in the other cases with the titanium-magnetitic mineralization are confined to the deep-seated faults.

Subsequently in the time interval 1900 — 1750 m.y. Polyphase intrusions connected with the systems of faults of different depths were formed: the alkaline-gabbroid series composed of ore hyperbasites, leucogabbro, different alkaline rocks with the rare metal mineralization; the alkaline-granitic series composed of the arfvedsonite- and aegirine-bearing granites and the sienic metasomatites; the alkaline-earth syenites the massifs of which comprise the olivine-pyroxene sienites connected by the transitions, quartz syenites, granosyenites; the porphyroid granitoids — represented by the intrusives, made up of quartz diorites and monzodiorites (1 stage), the porphyroid granites and granodiorites (2 stage), microcline-plagioclasic granites (3 stage), the leucogranites, aplites, quartz porphyries (4 stage), the grano-syenites and monzonites (5 stage); the gabbro-diorite-ademellitic of ring intrusions. Ore manifestations of the non-ferrous, rare and minor metals are connected with some of the granitoid associations.

12. The subgroup of the magmatogenic formations of the protorogenic stage in the structures of the subgeosynclinal regime includes the same types of associations, which were mentioned while characterizing the protogeosynclinal stage magmatism, therefore we shall speak only about new formations, appearing at this stage. For example the volcanics of Soumian-Sariolian age of the liparite-andesite-basaltic suite including as well subvolcanic intrusions of gabbro-diabases, diabasic porphyrites, quartz porphyries. The U-Pb zircon age of the quartz porphyries is 2450 m.y. These volcanics together with the boulder-pebbled and sandyquartzous deposits fill the inherited-superimposed troughs. The terrigenous material was brought from the adjacent protrusions of the Archean basement. In other troughs volcanogenous rocks were not much developed and the sandy-schistic high-aluminous (Keivy) or siliceous-ferrogenous sediments (iron formations of Krivoy Rog, KMA) became the most important rocks; the latter are connected with the richest iron ore deposits.

At the initial stages of the tectogenic activity there appeared fracture systems to which the associations of deep-seated faults are connected, especialy, a) gabbro-anorthositic and b) charnockitoid suites. The zonal regional metamorphism was of cover sequences connected with the main folding stages, and the Archean basement had suffered a rheomorphic granitization with the development of the ultrametagenic granitoid associations of the beforementioned types. Besides, the suite of essentially potassic microcline-ortoclasic granites, structurally connected with the faults of the basement appeared.

After the termination of the active magmatic activity these structures acquired the regime of the areas of the „completed folding" which were mentioned above.

13. Magmatism accompanying the formation of the late troughs and

associated zones of tectono-magmatic activization revealed itself in the development of the full formational range: andesito-basaltic volcanics and gabbro-diabasic sills — intrusions of gabbro-diorites and plagiogranites — plagiogranite-migmatitic synfolded and to some extent later microcline-plagiogranite-migmatitic complexes — essentially potassic granites and metasomatite-migmatites — postfolded pegmatoid and aplitic granites. All the mentioned complexes are in composition and in genesis similar to the corresponding formational types considered before. Specific for this age structural group of the magmatic associations are the following suites: the late-folded micro-cline-porphyric granites and the post-folded anorthosite-rapakivi-granites. The synfolded and late-folded granitoids are isotopically dated at 1900 $\pm$ 100 m.y. and rapakivi granites were formed at the age boundary of 1650 $\pm$ 50 m.y. and mark the end of the stabilization stage of the ancient platforms. Some of the beforementioned granites show rare metal mineralization (molybdenite, scheelite etc.), soma rapakivi-granite massifs are commercially ore-bearing (tin, zinc, lead etc.), others include chambered pegmatites with jewel stones (topas, morion, rock crystal etc.) and quartz feldspatic ceramic raw material.

The end of the protorogenic and the beginning of the platform or, as V. E. Khain calls it, „platform-aulacogenic" stage is marked by the last outbreak of the Early Precambrian magmatism — the generation of the dolerite-diabasic (trap) suite, structurally connected with some particular tectonic depressions, formed on the rigid consolidated crust.

14. The formational analysis of the Early Precambrian magmatism shows that the amount of the formational rocks grows from one stage to another, mainly due to the associations of orthomagmatic origin. The ultrametagenic granitoid associations which had played an important part in the generation of the granite-gneiss crustal layer during the protogeosynclinal stage, eventually appear more locally. This signifies the gradual change of the level of the intercrustal granite formation to the larger depth from one stage to another one. Some Early Precambrian magmatogenic formations are „throughout" ones — they appear at every stage (tholeiite-basaltic volcanics, gabbroids etc.), the others show mutual genetic resemblance (ultrametagenic granitoids and migmatites), but evolve in their composition and quantity from the high-temperature to the relatively low-temperature ones, and the third, at last are specific and derive only at a certain stage of the structural evolution of the crust (trondhjemite-plagiogranitic, anorthosite-hyperbasite-gabbroid, gabbro-anorthositic and charnockitoid, anorthosite-rapakivi-granitic), while the subalkaline and alkaline rocks (alkaline-gabbroid, alkaline-granitic, trachy-andesitic, syenite-granodioritic etc.) appear only at the protorogenic stage of the crust development.

Thus, the cyclic unidirected character of the evolution of the Early Precambrian magmatism in established. In the author's opinion it is connected with the growth of the crustal thickness, mainly owing to the thickening of the granite-gneiss layer, with the gradual decrease of the geoenergetic potential of the crust, with the deepening of the granite-formation processes to the lower levels of the lithosphere, and, at last, with the structural evolution of the crust, the complication of its structure with the increase of its consolidation.

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