Geology

Correlation of the Role of Sialic and Basaltic Crusts and Mantle with Phanerozoic Volcanism and Metallogeny in the Caucasus and Adjacent Regions

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ABSTRACT. The volcanism and mineralization are correlated with scale of participation of sialic and basaltic crusts and mantle. In the western segment of Eurasian active margin the scale was regulated by subduction at the pre-collision stage and by post-subduction transformation of the subducted slab at the post-collision stage. The calc-alkaline volcanism and gold-copper base metal (Au, Pb, Zn,Cu) mineralization are related to steady state subduction. The above process was controlled by participation of sialic and basaltic crusts and mantle. Intensification of transformation of the subducted slab, the mantle diapir invasion, rifting, intensive spreading conditioned transformation of backarc-interarc setting that is associated with shoshonite–alkalibasalt–tholeiitic volcanic activity and copper-zinc mineralization with minimal participation of lead (mainly at trace level). The process was going on with participation of basaltic crust and mantle material with subordinate sialic crust. The intensification of the process, steepening of the subducting slab and the invasion of mantle diapir at shallow level caused intensive spreading and transition of back-arc into minor ocean setting characterized by ophiolite volcanic activity, ultramafic dunite-peridotite magmatism and copper-pyrite mineralization. The source of magmatism and mineralization at this stage is the mantle. Participation of the sialic crust here is not recorded and basaltic crust was involved only at the beginning of oceanic spreading. Therefore the source of copper is mantle, the source of zinc is basaltic crust and the source of gold and lead is a sialic crust. At the first stage of post-collision activity synorogenic granitoid magmatism and gold-copper base metal and low sulfide gold mineralization occur accompanied by trace metals (Sb, W, Mo and Hg). The source of mineralization is a thick orogenic sialic crust. The second stage is manifested in the form of calc-alkaline volcanism and the shoshonite-alkali basaltic volcanic activity. The latter was stipulated by the invasion of mantle material in deep volcanic chambers. Due to thick orogenic lithosphere mantle diapir invasion did not cause rifting here. *© 2017 Bull. Georg. Natl. Acad. Sci.*

Key words: mantle, lithosphere, subduction, pre-collision and post-collision settings

Phanerozoic geodynamic development in the western segment of Eurasian active margin is related to the Tethys ocean subduction and collision during convergence of the Eurasian and Gondwana continents. Here are completely revealed the pre-collision and post-collision stages of development. The pre-collision stage is recorded in the island arc, backarc-interarc and minor ocean settings with the related volcanism and gold-copper-base metal mineralization. The post-collision stage is shown in two settings. The first is controlled by synorogenic granodiorite magmatism and fold-thrust tectonics accompanied with gold-copper-base metal porphyry and epigenetic low sulfide gold mineralization attended by trace metals (Sb, W, Mo and Hg) association. The second is represented by calc-alkaline and subalkaline shoshonitic and alkalibasalt volcanic activity [1-8].

The pre-collision stage is related to stable subduction and to steepening (transformation) of the subducting slab, whereas post-collision stage is manifested by the termination of subduction, but due to post-collision stress of continents the subducted slab continues its transformation.

The island arc development at the pre-collision stage is related to stable subduction, without subducting slab steepening and accompanied by calc-alkaline volcanism and gold-copper-base metal porphyry, epigenetic and Kuroko type VMS mineralization against the background of zeolite and chlorite–albite propylitization. The mineralization consists of Au, Ag, Pb, Zn and Cu. Under such setting volcanism and mineralization are conditioned by participation of the sialic and basaltic crusts and mantle sources. The deepening of oceanic slab in the mantle under the Eurasian active margin caused smelting of andesite magma from the subducted slab and from the lithosphere.

Steepening of slab (roll back, break off, detachment and delamination) during the process of subduction caused incursion of mantle diapir and provoked the rifting. The increased amount of mantle component in the volcanic chambers gave rise to shoshonitic and alkalibasalt-tholeiitic volcanic activity, with the background high temperature propylitization and Cu-Zn bearing chalcopyrite-sphalerite-pyrite mineralization, without participation of gold and lead. At this stage of rifting formation of magma and mineralization proceeded without sialic crust participation. Basaltic crust and the mantle are sources of volcanic activity and mineralization. Further intensification of transformation of the subducted slab stipulated higher level invasion of mantle diapir, intensive spreading and passing of backarc setting into the minor oceanic situation. At this stage the only source of magma and mineralization is the mantle. The volcanic activity is presented by oceanic ophiolites and ultramafic dunite-peridotite intrusions. The background hydrothermal alteration is presented by epidote-actinolite propylitization and serpenitization. The mineralization is represented by Cyprus type copper–pyrite ores without participation of gold, lead and zinc is established only at trace level. Therefore at this stage the source of volcanic, magmatic activity and mineralization is only a mantle.

Thus, sources of island-arc andesite volcanic activity and gold-copper–base metal metallogeny are sialic and basaltic crusts along with the mantle and source of precious metals gold and silver, as well as lead, is a sialic crust. The sources of shoshonite–alkalibasalt-tholeiitic volcanism for zinc and copper are the basaltic crust and mantle, whereas the source of ophiolite volcanic activity and ultramafic dunite-peridotite magmatism and copper-pyrite mineralization is the mantle.

The described situation occurs in the western segment of the Eurasian active margin within the limits Iran, Caucasus, Turkey and the Carpathian-Balkanian regions.

The island arc setting with calc-alkaline volcanism and gold-copper-base metal mineralization, is established in the Lesser Caucasus within the limits of the Bolnisi ore district in the Madneuli ore cluster. The ore deposits here are distributed in the Turonian-Santonian volcanic series (Mashavera suite) consisting of dacite–rhyolite volcanics [1]. According to geochemical and petrochemical criteria they belong to calc-alkaline volcanic series and are characterized by $^{87}Sr/^{86}Sr$ 0.706 – 0.710, $^{206}Pb/^{204}Pb = 18.6$, $^{208}Pb/^{204}Pb = 38.7$ ratios [1, 4, 9]. Sr and Pb isotopic analysis is fulfilled in the laboratory of Lausanne University.

The host rocks of the Madneuli cluster are characterized by Cs, Ba, Th, U and Pb high content against the background of low grade Nb and Ta. The similar characteristics were established for the Upper Cretaceous calc-alkaline volcanic series, host rocks of gold-copperporphyry, epithermal and Kuroko type VMS deposits in the Eastern Pontides of Turkey, Bulgarian Srednegorie, Serbian Timok, connected to island arc setting [10, 11, 12]. At the same time in the shoshonite-trachyandesite and tholeiite-alkalibasalt series of interarc and backarc rifts with zinc-copper-pyrite VMS type stratimorphic mineralization host rocks are characterized by different geochemical and petrochemical criteria. So, in the Forerange zone of the Caucasus, host rocks of VMS deposits of Hudes group (Urup, Hudes, Daud) [13] are genetically related to Paleozoic tholeiite-rhyolite bimodal type of volcanic activity during interarc rifting. The tholeiites here according to iron fractionation belong to abyssal tholeiites, but by Ti content and K/Rb ratio they correspond to island arc tholeiites [14]. Similar geochemical dualism is characteristic of modern interarc rifts of New Georgia and the Hebrides [14]. The mineralization of Hudes group of deposits is represented by zinc-coper mineralization without lead. The source of zinc is the subducted slab and basaltic crust. The source of copper is a mantle diaper that caused the rifting.

Another example of such situation in the Caucasus is the Lower Jurassic backarc setting that passed into the marginal sea [15]. The tholeiitic volcanism here is simultaneous with turbidite sedimentation. Here tholeiites are characterized by low content of REE and by normal chondrite content of Ni, Zr, Hf and Y. According to $^{87}Sr/^{86}Sr$ =0.7034 ratio they belong to backarc-interarc type tholeiites [16].

The mineralization in the Filizchai group of deposits (Filizchai, Catsdag, Kizildere, Adange) is controlled by tholeiitic volcanism and consists mainly of pyrite-chalcopyrite-sphalerite-pyrrhotite mineralization. They are represented by VMS type stratiform ores related to tholeiite-basaltic lava flows alternating with turbidites of the Lower Jurassic flysch. The source of zinc here is the spreading basaltic crust and the source of copper is a mantle diapir [1].

The minor ocean setting in the western segment of the Eurasian active margin is the Kure Complex in the Central Pontides. In the Late Paleozoic intensification of steepening of the subducting slab and the spreading was revealed in transformation of backarc settings into oceanic setting. The Kure Complex consists of ophiolite extrusions, MORB type basalts, tholeiites, serpentinized peridotites, cumulative gabbro that in ascending section passes into microgabbro and is cut by diabase dikes. They are overlain by tholeiitic pillow lavas and lavabreccias and semipellagic slate series. The Cyprus type copper-pyrite mineralization occurs between the lava flows and slates and is represented by VMS type stratiform ores [17]. In this area the Ashikoy and Bakibaba copper-pyrite deposits occur. Zinc and lead in ores mainly at a trace level is fixed.

The Cyprus type mineralization is known, also in the ophiolitic belt separating Anatolides and Taurides. The ophiolites here represent eastern continuation of the Trodose belt ophiolites. The ophiolites comprise hartzburgites and dunites; they are overlain by gabbro-dunites, pyroxenites, verlites, pillow lavas and cut by diabase dikes [18]. Here occur Maden (Elazig) and Madekoy (Siirt) copper-pyrite deposits. In the ores zinc and lead are not observed. Thus, in the oceanic setting the copper source is the mantle.

In the Bolnisi and Panaguirishte ore districts in ascending succession is fixed the transformation of island arc setting to a back arc one [1,10,19]. The Madneuli and Beqtacari ore clusters in Bolnisi ore district are divided by fault onto two blocks [3]. The Madneuli block consists of the Turonian-Santonian volcanic series. Its K-Ar and U-Pb age dating shows 88-90Ma. The K-Ar age of Beqtacari block volcanics is the Campanian (79-81Ma). The Madneuli block consists of dacite-rhyolite volcanic series (the Mashavera suite) and contains gold-copperporphyry and epithermal low sulfide mineralization. The

Beqtacari block consists of trachyrhyolite and trachydacite volcanics (the Gasandami suite) upward passing into trachybasalt-olivine basalt-trachyandesite series (the Shorsholeti suite). The Mashavera suite volcanics according to Sr and Pb isotope ratios $^{87}Sr/^{86}Sr$= 0.706-0.709, $^{206}Pb/^{204}Pb$ =18.0, $^{208}Pb/^{204}Pb$ =38.7 belong to island arc volcanic series. Whereas the olivine basalts of the Shorsholeti suite are characterized by REE and HFSE high content and subordinate quantities of HREE $(La/Sm)_n$ =2.89, $(La/Yb)_n$ =2.83, Yb_n =8.17, $(Sm/Yb)_n$=2.83, Yb_n =7.35. Such data are characterized by depleted basalts of oceanic ridges [20], so they would belong to volcanic series of the backarc setting. G.Nadareishvili [21] according to petrochemistry and TiO_2/P_2O_2 ratios attribute them to volcanic series of continental rifts. Thus, the formation of Bolnisi ore district is related to island arc setting and steady state subduction in the Cenoman-Santonian, in Campanian passing into backarc setting due to incursion of mantle diapir. At the incipient stage of backarc development temporary transition of island arc calc-alkaline volcanic activity into the trachyrhyolite-trachydacite volcanism took place and later on the last one passed into trachybasalt-olivine basaltic volcanic activity. The similar process occurs in the Panaguirishte ore district of Bulgarian Srednegorie. There calc-alkaline magmatism and gold-copper-base metal mineralization is associated with steady state subduction, later on when steepening of the subducting slab took place diapir incursion enriched the volcanic chambers with mantle material and stipulated bakarc volcanic activity [10].

In the Caucasus region in the areas bordered with the Black and Caspian Seas in the western Adjara–Trialeti and Eastern Talysh zones due to steepening of the subducting slab in space and time the changes in geodynamic development as well as in the volcanic activity and tectonics took place [1]. The western segment of the Adjara –Trialeti zone in the Middle Eocene was presented as an interarc rift, where tholeiite–alkali basalt volcanism took place. Westwards in the Black Sea basin the backarc rift passed into a minor ocean setting with ophiolite volcanic activity. The Black Sea minor ocean to the west in the Burgas zone transformed again into backarc rift represented by alkalibasalt volcanic series [22].

In the Adjara–Trialeti zone the tholeiite–alkali basalt volcanic series laterally to the east, in upward succession in time passed into shoshonite-trachyandesite volcanites indicating slackening of rifting [1]. It is confirmed by petrochemical and geochemical criterion of the volcanic rocks. The $^{87}Sr/^{86}Sr$ ratio in alkali basalts equals 0.7034 [16].

Similar situation occurs in the Talysh backarc zone. Here, alkalibasalts in ascending succession are overlain by Upper Eocene sedimentary series and are cut by ultramafic dunite-peridotite extrusions pointing to distinctly increasing mantle influence. The Middle Eocene backarc of Talysh to east passed into the minor ocean of the Caspian Sea [16]. Therefore the Adjara-Trialeti zone from the Middle to the Upper Eocene is represented by shoshonitic series. In the Talysh backarc the mantle influence was strengthened revealed in evasion of ultramafic dunite-peridotite stocks specific for oceanic settings. The relation of magmatism, volcanism and hydrothermal activity with the compressional and extensional tectonics is described in East Pontides of Turkey [11]. The above events were confirmed by interaction of crustal and mantle sources. Here in the Emecsen and Guzeliala district magmatism and hydrothermal activity is dated as 82-77 Ma indicating the transition from the compression to the extension tectonic evolution, whereas Late Cretaceous magmatic and hydrothermal processes (77-70 Ma) in Elbeili is controlled by the extension stipulated by increasing mantle influence. The extensional tendency must be related to mantle diapir invasion. The Cu-Mo porphyry mineralization here, also, is controlled by calc-alkaline volcanic activity.

The post-collision setting development was related to the convergence of Afro-Arabian and Eurasian continents closing of the Tethys Ocean and termination of the subduction**.** However, transformation of the subducted slab stipulated by pressing the continents to each-other showing the scale of interrelation of crustal and mantle material. The steepening of the slab provoked of high temperature fluid streams as well as incursion of mantle material into a thick orogenic lithosphere. The first Oligo-Miocene stage of post-collision activity revealed in the formation of fold and thrust structures, smelting of sialic crust, invasion of granodiorite intrusion stocks and the activity of high temperature fluid streams in orogenic thick lithosphere. The fluids were leaching gold and trace metals (Sb, W, Mo and Hg) from the sialic crust with gold–copper-porphyry and epithermal low sulfide gold mineralization. The porphyry ores are characterized by low grade of base metals and high grade of gold. The low sulfidation gold mineralization related to quartz-antimonite and quartz-scheelite stockworks with high grades of gold. They both are accompanied with the above mentioned trace metals spread as in ore wall altered rocks, so widespread in host rocks. Thus it is geochemical indicator of post-collision setting. The association of trace metals is exploration criterion of gold mineralization.

The first stage of post-collision activity in Iran and the Caucasus was substituted with pre-collision rock series and is characterized by high geochemical background of the trace metals which are geochemical indicators of post-collision setting. It is noteworthy, that relation of this association of trace metals is widespread in the post-collision gold deposits of various regions of the world [1, 23].

The second stage of post-collision activity in the studied region is the Pliocene–Quartenary presented by calc-alkaline and shoshonite-thachybasalt-tholeiitic volcanism, characterized by geochemical indicators of the pre-collision setting. Volcanic activity of pre-collision alkalibasalts and tholeiites is connected with copper-zinc-pyrite VMS mineralization, however in the post-collision settings rifting and VMS type ores are not known. Volcanic activity here might be related to fissure explosion from deep chambers. At post-collision stage thick lithosphere of orogens impeded diapir invasion at shallow level and rifting.

Conclusion. The researches conducted in the Caucasus, Iran, Turkey and the Balkan-Carpathian regions confirmed that volcanism, hydrothermal activity and mineralization was related to Tethys Ocean subduction and collision. Various stages of pre-collision and post-collision development were controlled by different scale of participation of the sialic, basaltic crusts and the mantle. At the island arc stage of pre-collision setting by volcanic activity and mineralization were confirmed sources of the sialic, basaltic crusts and mantle. The volcanism here is represented by calc-alkaline basalt-andesite-basalt, andesite-dacite and rhyolite volcanic series and gold-lead-zinc-copper mineralization. The source of gold and lead is the sialic crust, source of zinc is basaltic crust and the source of copper is the mantle. During subduction, subducting slab is steepening accompanied by mantle diapir invasion causing the rifting in interarc-backarc settings. During the rifting and extension participation of the sialic crust is diminished in volcanism and mineralization processes. In interarc-backarc rifts shoshonite-alkalibasalt-tholeiitic volcanic activity and zinc-copper mineralization are stipulated by participation of basaltic crust and mantle. The source of zinc is basaltic crust and the source of copper is mantle diapir. The further amplification of steepening of the subducting slab and diapir incursion at shallow levels caused intensive spreading and transformation of backarc setting to the minor ocean setting characterized by ophiolite volcanism, dunite-peridotite invasions and copper-pyrite mineralization. In the copper-pyrite ores lead and zinc are measured only at trace level. The source of magmatism and mineralization here is the mantle only. The sialic and basaltic crusts did not participate here. It is established that the mantle is the source of copper. The level of mantle diapir invasion determined the temperature regime of the background hydrothermal activity. Background low temperature zeolite propylitization changed via chlorite-albite up to high temperature epidote-zoisite and actinolite propylitization.

At the post-collision stage of development magmatic, volcanic activity and metallogeny are also, controlled by participation of the sialic, basaltic crusts and mantle sources. The processes are stipulated by steepening of the subducted slab at the syn- and post-orogenic stages.

Syn-orogenic granitoid magmatism, gold-copper-base metal porphyry and low sulfide gold-mineralization is accompanied by trace metals association (Sb, W, Mo and Hg) and gold leaching by fluids from thick orogenic sialic crust. The mentioned association subtitutes the pre-collision rocks and is geochemical indicator of the first stage of post-collision activity. In the Caucasus and Iran the age of this stage is Oligocene-Miocene.

The second, Pliocene-Quartenary post-collision stage was revealed in the calc-alkaline and shoshonite-alkalibasalt volcanic activity characterized by geochemical criteria the same as for volcanites of pre-collision setting. However, at this stage of post-collision activity rifting and mineralization is not revealed. The thick lithosphere of orogens prevents rifting and volcanic eruptions happen from deep chambers.

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გეოლოგია

სიალური, ბაზალტური ქერქისა და მანტიის როლის კორელაცია ფანეროზოულ ვულკანიზმსა და მეტალოგენიასთან კავკასიასა და მოსაზღვრე რეგიონებში

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ვულკანიზმი და მადანწარმოშობა კორელაციაშია სიალური, ბაზალტური ქერქისა და მანტიის მონაწილეობის მასშტაბთან. ევრაზიის კიდის დასავლურ სეგმენტში ეს მასშტაბი რეგულირდება ტეთისის ოკეანის სუბდუქციით პრეკოლიზიურ ეტაპსა და სუბდუცირებული ფილის შემდგომი ტრანსფორმაციით პოსტკოლიზიურ სტადიაზე. კავკასიისა და მომიჯნავე რეგიონების მაგალითზე

დადგინდა, რომ სტაბილური სუბდუქციის პროცესს უკავშირდება კირ-ტუტე ვულკანიზმი და ოქრო-სპილენძ-პოლიმეტალური (Au, Pb, Cu, Zn) მადანწარმოშობა, რომელიც სიალური, ბაზალტური ქერქისა და მანტიის თანამონაწილეობას ასახავს ვულკანური აქტივობის და მადანწარმოშობის პროცესში. სუბდუცირებული ფილის ტრანსფორმაციამ და მანტიური დიაპირის შემოჭრამ განაპირობა რიფტინგი და ზეკარკ-ინტერარკული ვითარება, მასთან დაკავშირებული შოშონიტ-ტუტებაზალტ-ტოლეიტური ვულკანური აქტივობა და სპილენძ-თუთიის მინერალიზაცია Au და Pb მინიმალური მონაწილეობით. ეს პროცესი განპირობებულია ბაზალტური ქერქისა და მანტიის მონაწილეობით. სიალური ქერქის მონაწილეობის როლი რიფტინგის პროცესში მკვეთრად ეცემა. სუბდუცირებული ფილის ტრანსფორმაციის გაძლიერებამ, მანტიური დიაპირის მაღალ დონეზე შემოჭრამ და ინტენსიურმა სპრედინგმა ზეკარკის მცირე ოკეანურ ვითარებაში გადასვლა განაპირობა, რაც ასოცირდება ოფიოლიტურ ვულკანურ აქტივობასთან, ულტრაფუძე დუნიტ-პერიდოტიტულ მაგმატიზმსა და სპილენძ-კოლჩედანურ მინერალიზაციასთან. სიალური ქერქის მონაწილეობა პროცესში აქ არ დგინდება, ხოლო ბაზალტური ქერქის მონაწილეობა მხოლოდ სპრედინგის საწყის ეტაპზე ფიქსირდება, აქედან გამომდინარე სპილენძის წყაროს მანტია წარმოადგენს, თუთიის წყარო ბაზალტური ქერქია, ხოლო ოქროსა და ტყვიის — სიალური ქერქი. პოსტკოლიზიური სტადიის პირველ ეტაპზე სინოროგენული გრანიტოიდული მაგმატიზმი, ოქრო-სპილენძ პოლიმეტალური და მცირე სულფიდური ოქროს მინერალიზაციაა დადგენილი თანმხლებ იშვიათ მეტალთა (Sb, W, Mo, Hg) კომპლექსთან ერთად, რომლის ძირითადი წყარო ოროგენების მძლავრი სიალური ქერქია. მეორე ეტაპი კირ-ტუტე ვულკანიზმითა და შოშონიტ-ტუტებაზალტური აქტივობით ხასიათდება, რომელიც მანტიური მასალის გავლენითაა განპირობებული, რომლის შემოჭრა ღრმა ვულკანურ კერებში ხდებოდა. მძლავრი ოროგენული ლითოსფერო ხელს უშლიდა მანტიური დიაპირის უფრო მაღალ დონეზე შემოჭრას და რიფთინგს.

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