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Relation of Tethys Ocean Subduction, Collision and Closure with Regional Metamorphism, Volcanism and Mineralization Exemplified on the Eurasian Active Margin

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Abstract: The geodynamic development of Eurasian active margin is related to subduction, collision and closure of Tethys Ocean. It is divided on pre-collision and post-collision stages. The pre-collision development controlled by subduction, whereas post-collision related by orogenesis, granodiorite magmatism gold base and trace metals (Sb,W, Mo and Hg) metallogeny. The mentioned trace metals association is the geochemical indicator of first stage of post-collision development. The second stage revealed in andesite basalt, shoshonite, olivine basalt and tholeiite volcanic activity. Pre-collision stage is controlled by steady state subduction related with metamorphism and calc-alkaline volcanic activity in subaqual and island conditions of island arc setting. It is lately with steepening of subducting slab and incursion of mantle diapir transferred in interarc-backarc and minor ocean setting with shoshonite-trachyandesite and alkali olivine basalt and tholeiite volcanism and later with ophiolite volcanism, dunite-peridotite magmatism and Cu-pyrite mineralization of minor ocean setting. The pre-collision stage is developed temporally and spacially along dipping of subducted slab in the island arc setting transferring in the backarc-interarc and minor ocean settings. The similar transferring occurs laterally to dipping of slab and ascending succession. The alternation of settings shown the cycling along dipping spatial and temporal alternation of island arc, backarc and minor ocean settings. Laterally to dipping alternation is only spatial, whereas in ascending succession cycling is only temporal, localized spacially. The pre-collision development occurs in subaqual condition, whereas related to orogenesis post-collision development is mainly subaerial.

Key words: Phanerozoic geodynamics, Tethys Ocean, Eurasian active margin, metallogeny.

1. Introduction

The dividing lithosphere on sialic, basaltic crusts and hard upper mantle and redistribution within them Au, Pb, Zn and Cu occurred in Precambrian [1]. Au and Pb are concentrated in sialic crust, Zn—in basaltic, whereas Cu is rested in the mantle. In Phanerozoic, when geodynamic development is controlled by modern plate tectonic, metamorphism, character of volcanism and mineralization are depended on the scale of the crustal-mantle influence and hot flows at various settings of geodynamic development. The regional metamorphism and forming of granite-metamorphic complexes are related to earlier stage of subduction, when the temperature of fluids is not prevailed 750-800 °C. Later, when the temperature increased up to 1,000 -1,100 °C the andesite is smelted from subducting slab and lithosphere, provoked calc-alcaline volcanism and Au-Pb-Zn-Cu mineralization of island arc setting. At this stage, source of volcanism and mineralization are sialic, basaltic crusts and mantle with prevalence of crustal influence. At the next stage is steepening of subduction coincide with incursion of mantle diapir occurs in backarc-interarc setting, revealed in

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shoshonite-tholeiite-olivine basalt volcanic activity coincided with intensive rifting resulted to spreading out sialic crust from zone of volcanism and ore formation. Mineralization here consists of Zn and Cu, without Au and Pb. Thus, in interarc-backarc settings the source of volcanism and mineralization is basaltic crust and mantle. The increasing steepening of subduction slab and invasion of mantle diapir on highest level is resulted in forming ocean setting occurred in ophiolite volcanism, dunite-peridotite magmatism and Cyprus type Cu-pyrite mineralization. The most intensive spreading here caused in spread out the sialic and basaltic crusts and processes here are controlled only by mantle, without any crustal influence. The post-collision stage related to closure of ocean occurs in orogenesis and termination of subduction, but steepening of the subducted slab is continuing. Penetration of high temperature fluids exsolved from deep magma chambers into the thickened crust caused smelting granitoid magma and leaching of Au, base and trace metals Sb, W, Mo, Hg and forming of gold—base metal porphyry and epithermal gold and trace metals mineralization is the geochemical indicator of the first stage of postcollisional activity.

The second stage occurs in volcanism from dip volcanic chambers manifested in andesite-basaltic, shoshonitic and tholeiite explosions, which are geochemically resumebled that the pre-collision stage criteria and are not associated with trace-metals-geochemical indicator of the first stage of post-collision development.

The above mentioned data are distinctly confirmed on the Eurasian active margin development during northvergent subduction, collision and closure of Tethys Ocean.

2. Materials

The materials represent pre-and post-collision development of Eurasian active margin along subduction of Tethys Ocean slab.

2.1 Pre-collision Development Controlled by Subduction Revealed in Metamorphism, Volcanism and Mineralization

The studied region is spread across Iran, Caucasus, Turkey and Balkan-Carpathians defined as Tethys-Eurasian Metallogenic Belt located in the western segment of Eurasian active margin (Fig. 1)

It was developed during Phanerozoic convergence of the Afro-Arabian Eurasian continents at the evolution and closure of the Tethys Ocean, include terranes rifted from the Afro-Arabian passive margin [2, 3]. The geodynamic development comprises pre-collision and post-collision stages with associated metamorphism, volcanism, magmatism and mineralization. The geodynamic development of pre-collision stage related to subduction the slab of Tethys Ocean. The incipient stage of subduction occurs in regional metamorphism predates the smelting of andesite melt and calc-alkaline volcanic activity. The metamorphites are expressed in high temperature amphibolites and granulites facies assemblages, which along decreases in fluid temperature, exhibits retrograde greenschist, zeolite and phylite facies. The temperature of regional metamorphism is 350-750 °C. At 700-750 °C, granitic magma is smelted from the lithosphere and accordingly granite-metamorphic complexes form. The subsequent rising temperature up to 1,000-1,100 °C leads to smelting of andesite melt and calc-alkaline volcanic activity of island arc setting. In the studied region, as well as other regions of the world this is defined by co-existing metamorphic complexes and calc-alkaline volcanic series rocks. In the Caucasus it is examplified by Transcaucasian Intermountain Block of Paleozoic granite-metamorphic complexes of Dzirula and Khrami massives merged to Upper Carboniferrous and Triassic calc-alkaline, island arc volcanic series-Narula, Chiatura suites and Khrami suites at Dzirula and Khrami massives [4]. So as at North Caucasus Paleozoic metamorphic complex merged to Upper Paleozoic calc-alkaline volcanic series of Bechasin zone.

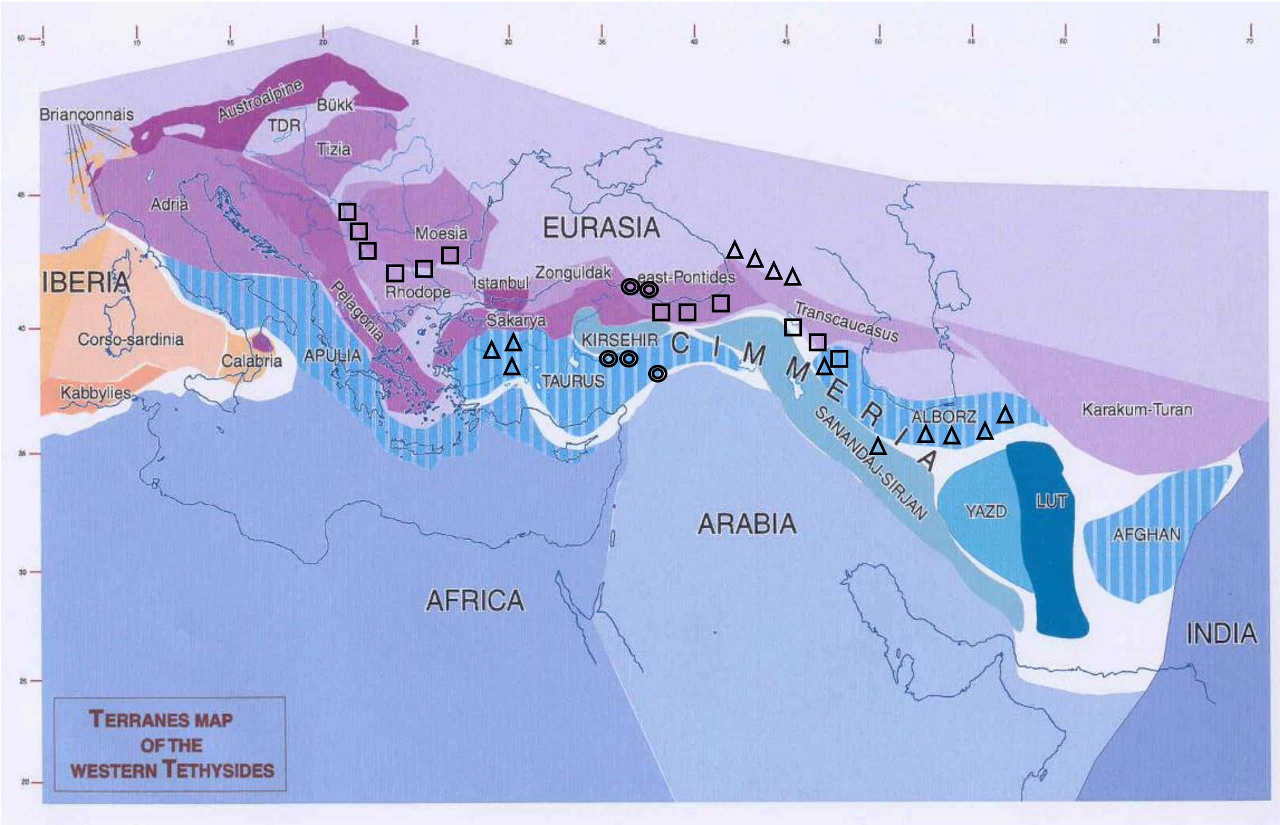

Fig. 1 Map of the Western Tethysides and generalized scheme of metallogeny [3].
◎ minor ocean, backarc, marginal sea vms mineralization;
□ subduction related porphyry, epithermal and kuroko type mineralization;
△ postcollisionorogenic and intrusive related lode and porphyry mineralization.

Numerous studies confirm that smelting andesitic magma is preceded by regional metamorphism [5]. Such relationships are well known in the Lake region of Wales, where amphibolite dated of 475-420 Ma precedes calc-akaline volcanic activity [6]. Another example is that of the Hertsinian Belt of West Europe (Moldanub structural zone), where 340-320 Ma migmatites are intercalated with Carboniferrous molasses comprising thick trachyandesite volcanic series units [7]. Saton [7] also presents examples from Scotland, where Lower Devonian calc-alkaline volcanic series rocks overlying the amphibolites metamorphic facies units related to Caledonian stage events at 420-400 Ma. In the western Pacific Ocean arc region, this andesite volcanic series is underlain by a belt of regional metamorphic rocks [8]. Therefore, the regional metamorphism develops progressively and typically is terminated by smelting of of andesitic magma. Hence, the regional metamorphism of the mobile zones predates the andesite volcanic activity. During subduction of slabs temporally and spatially tend to steepening and diapirs of various intensity caused alternation of island arc, interarc-backarc and small ocean settings, reflected as along, so laterally to dipping slab, as well as temporally and ascending succession [5].

The distinct example of island arc setting with calc-alkaline volcanism and mineralization is the Bolnisi ore district represented transition of island arc setting (Madneuli ore cluster) in the backarc setting (Beqtakari ore cluster) [5]. That’s are divided by regional fault on two giant blocks (Fig. 2). The regional fault is related to detachment produced incursion of mantle diapir and alternate the island arc setting to back arc through transitional stage of development [5].

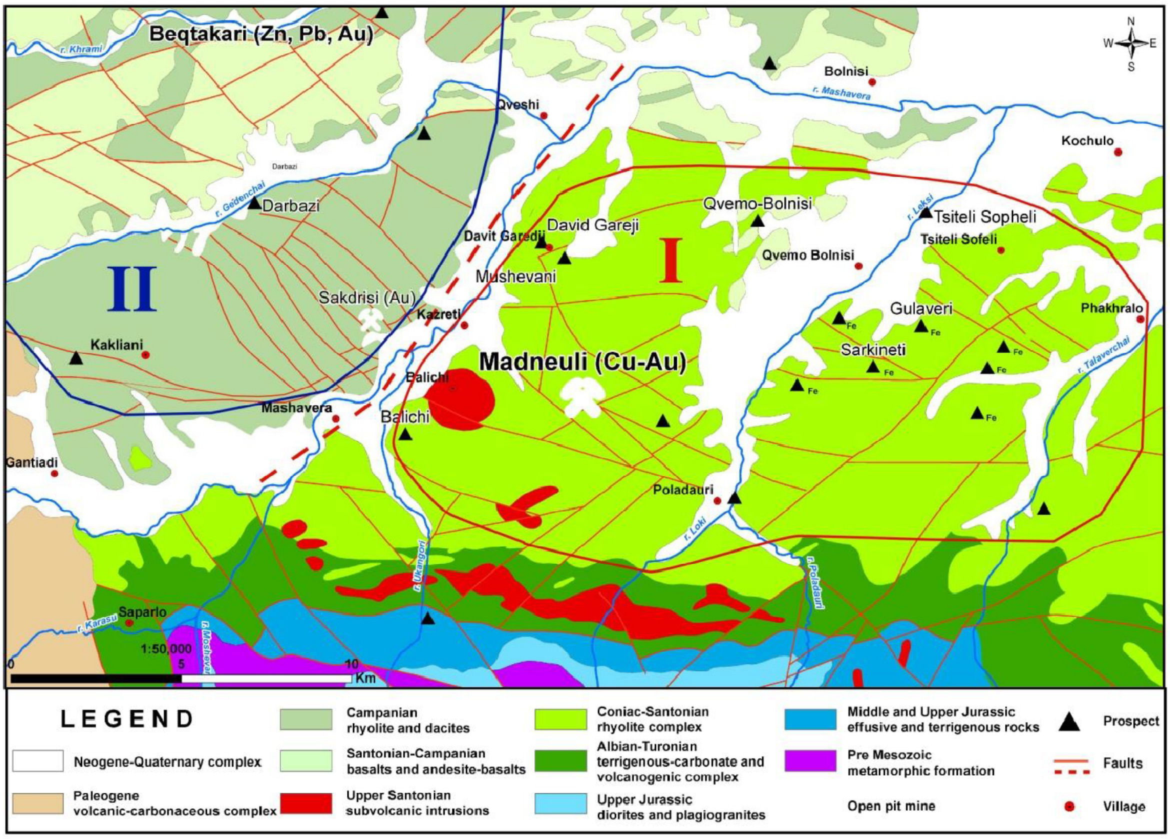

Fig. 2 Geological map of Bolnisi ore district (1:50,000) [5]. I Madneuli cluster, II Bectaqari cluster.

Madneuli cluster exemplified the island arc setting with calc-alkaline volcanism, Au, Pb, Zn, Cu mineralization and geochemical criterion (1) The mineralization (90-88 Ma) is distributed in Turonian-Coniacian calc-alkaline rhyodacite volcanic series rock (Mashavera suite). Ore formation is preceded by silicification, that was overprinted by Au-Pb-Zn-Cu porphyry subsequently by sulfide poor, gold rich epithermal quartz-chalcedony veins and stockworks and coexisting VMS type mineralization. The ore formation is controlled by granodioritic intrusive stocks. Their intrusion caused tumescence of sea bottom and emerging of islands. The stocks were transferred into acid volcanic chambers explosed ignimbrites.

The ignimbrite explosion was terminated by caldera subsidence, determined by incursion of rhyolite domes around ring structures [5]. The emerging of island and caldera subsidence caused the synvolcanic block structuring, characterized for island arcs [9]. The mineralization of Madneuli deposit and in the Bolnisi ore district generally preceded the ignimbrite explosion and caldera subsidence. The porphyry and epithermal mineralization occurred on the islands, whereas the coexisting Kuroko type VMS mineralization is subaqueous.

The mineralization of Beqtakari cluster is located in Campanian Gasamdami suite in adularized trachyrhyodacite volcanic. The adularization here is goldbearing. So of subalkaly volcanic activity. Subalkaly volcanic activity and K-feldspar alteration would be determined by diapir influence. The strengthen of diapirism at Upper Campanian revealed in alkaline olivine basaltic volcanic activity of Shorsholety suite revealed to intensive detachment and incursion of mantle diapir on higher level.

The mineralization in the Beqtakari cluster is located in Gasandami suite, where occurred nonsulphide disseminated goldbearing mineralization, so gold related to quartz-K-feldspar veins and stockworks. Here occur the gold-base metal porphyry ores are controlled by gabbrodiabase intrusive stocks. The latter's would be apophyses of volcanic chambers of basaltic Shorsholeti suite. The mineralization coincide with high temperature epidote-zoisite propylitization. The high temperature hydrosulfide fluids of propylitization leached Au from goldbearing K-feldspar altered rocks and it was the reason the high content of gold in the ores, which is not characteristic to backarc setting. Shorsholeti olivine basalts are not consists of VMS deposits.

The better example of interarc setting occurs in the Forrange of North Caucasus, represented by Late Paleozoic-lower Jurassic tholeiite-olivine basaltic series consists of VMS Zn-Cu pyrite mineralization of Hudes group deposits (Hudes, Urup, Daud) [9]. The source of Zn here is basaltic crust, source of Cu-the mantle. The sialic crust was spread out by rifting from zone of volcanic activity. Hence, lack Au and Pb here may be explained by this reason. The Sr isotope ratio of interarc tholeiites is $^{87}Sr/^{86}Sr = 0.7036$.

The volcanism and mineralization of interarc rift, predate here by Paleozoic calc-alkaline volcanism and Au, Pb, Zn, Cu-mineralization of island arc setting of Bechasin zone southern bordered the interarc setting. Alternation of island arc and backarc setting here is developed along dipping of subducting slab.

The similar subsequence occur on the other objects of western segment of Eurasin margin (Fig. 3). The Panaguirishte ore field (Bulgaria) in the Cretaceous , as in the Bolnisi ore district, along dipping of slab the steady state subduction transferred into incipient stage of backarc setting and later coincide with steepening of subducting slab and strengthening of mantle diapirs' transformed into full-fledged backarc setting. The process is coincide with increase the mantle influence from steady state subduction to steepening of subducting slab. Mineralization of Chelopech, Elatsite Medet and Asarel deposits related to steady state subduction and crustal influence of volcanism and ore formation, whereas Vlaikov Urukh, Elshitsa and Capitan Dimitrievo are controlled by slab steepening and mantle diapirism and increasing of mantle influence [10].

The Serbian Timok, also, is characterized by relation of steady state subduction with calc-alkaline volcanism coincided with Au, Pb, Zn, Cu mineralization in Bor and Maidanpek deposits [11]. In the Romanian-Carpathians, the steady state subduction with calc-alkaline volcanism are related porphyry and epithermal low sulfidation deposits Baie-Mare and Almaz Stanija [12]. In Turkish Pontides in the island arc setting are distributed porphyry and epithermal Au, Pb, Zn, Cu deposits in calc-alkaline volcanic series rocks, as well as Kuroko type VMS deposits. Guzelaila, Derekoi, Gumushane, Balikoi, Tak, Mastra, Akbaba, Kozaki are porphyry and epithermal whereas Chaeli, Cheratepe, Lahanos and Corpubas belong to VMS Kuruko type. The epithermal and Kuruko mineralization consist high content Au [13].

The most intensive steepening of subducting slab and invasion of mantle diapir on highest level resulted to form of small ocean basin. It is exemplified by the Paleozoic-Lower Jurassic Küre complex of Central Pontides (Turkey). It consists of ophiolites, MORB type tholeiites, serpentinized peridotites and Cu-pyrite mineralization of deposits Ashikoi and Bakibaba [14]. The ratio $^{87}Sr/^{86}Sr = 0.7024$.

The formation of ocean basin Küre complex preceded Paleozoic back arc volcanic activity. The formation of small oceanic basins took place in the Eocene and Cretaceous in the Caucasus. The Cretaceous ocean basin of the West Black Sea to the west in merged to Burgas East interarc rift (Bulgaria) consisted of tholeiites and olivine basalt volcanic series [15]. Whereas the East Black Sea Eocene oceanic basin to east transferred in interarc rift of Achara Trialety (Georgia). As well as Azerbaijan Eocene the Talysh backarc rift laterally eastern merged to Caspian ocean basin (Fig. 4). It is northworthy, that Black Sea ocean

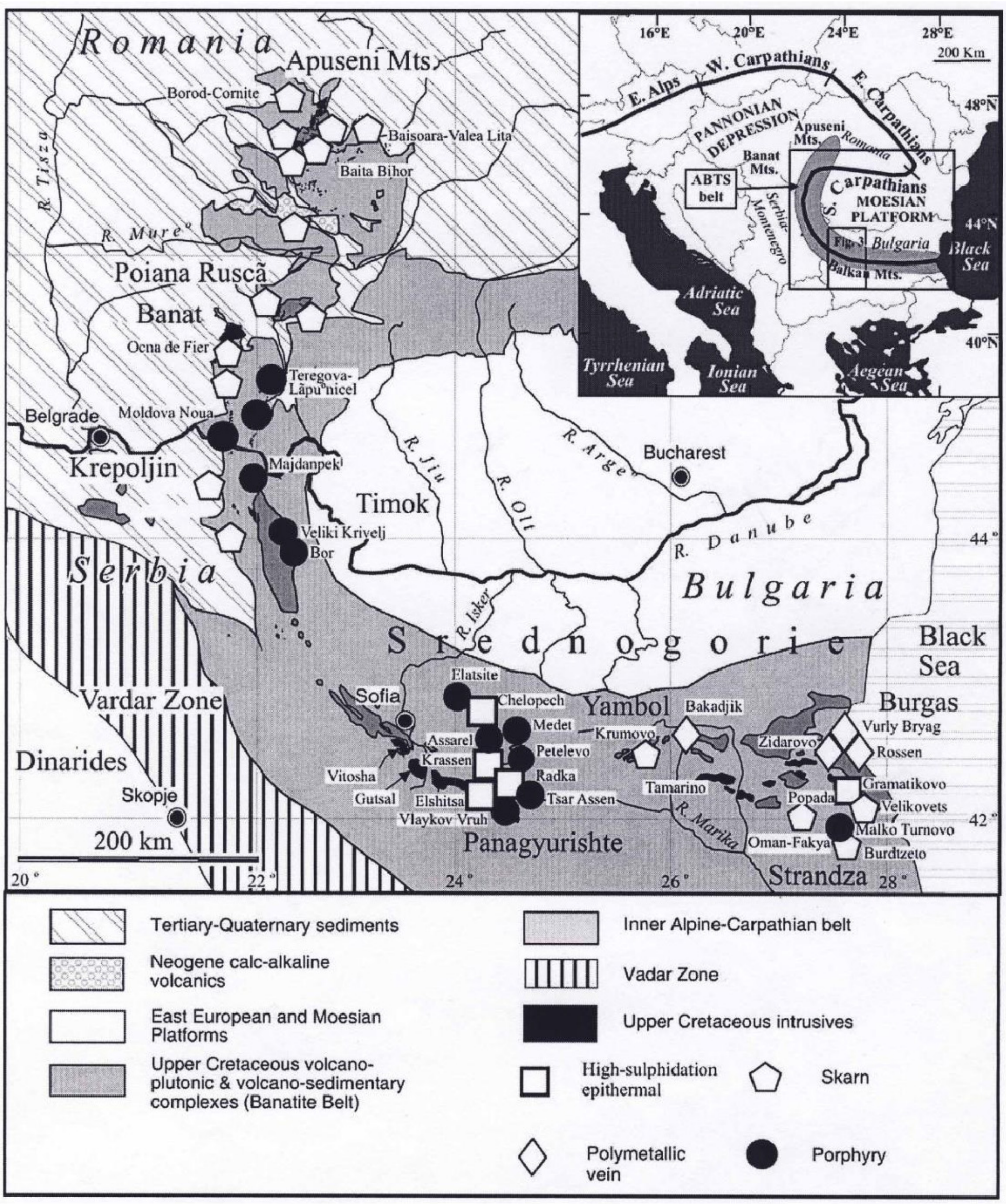

Fig. 3 Schematic geological map of the Srednegorie, Timok, Banat and Apuseni region with porphyry and epithermal mineralization [10].

basin southern is bordered to shoshonite-olivinian basaltic backarc of East Pontides. At the South of Caspean Ocean basin is disposed backarc setting consists of shoshonite-tholeiite basalt series of the Alborts-Azerbaijan zone. Hence, intensification steepening of subducting slab and mantle diapirism along its dipping resulted in forming of ocean basin. As in Achara Trialety, so in Talysh ascending succession the development of rifting occurred differently. In Achara Trialety rifting upstears was slackening and tholeiites are overlain by shoshonite trachyandesite rocks and later in the Upper Eocene rifting is wanning manifested in calc-alkaline andesite volcanism and Au, Pb, Zn, Cu mineralization controlled by granodiorite intrusive stocks [5].

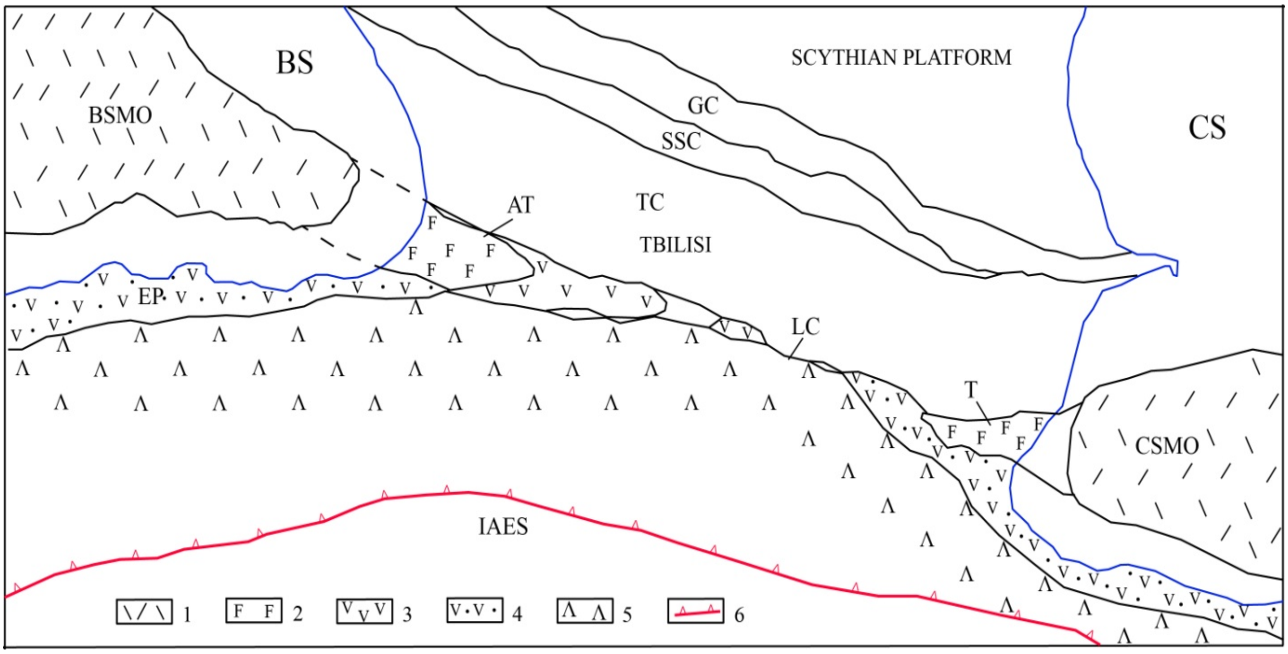

Fig. 4 Schematic map reflects the E-W lateral geodynamic transformation of subducted slab above IAES suture, showing the character of the Eocene volcanic series in the East Pontides and Lesser Caucasus.

1—Ophyolites, 2—Alkaline olivine basalts and tholeiites of backarc settings, 3—Eocene calcalkaline volcanic series of island arc, 4—Shoshonite series, 5—Cretaceous calc-alkaline series of island arc. BS—Black Sea, CS—Caspian Sea, GC—Great Caucasus, SSC—Southern Slope of Caucasus, TC—Transcaucasus, AT—Achara-Thrialety, LS—Lesser Caucasus, EP—East Pontides, BSMO—Black Sea Minor Ocean, T—Talysh.

Temporally alternation geodynamic setting ascending succession may be explained by temporal alternates steepening slab and various levels of invasion of mantle diapir ascending succession.

Whereas in Talysh inter-arc olivine basalts upstears transferred in the dunite-peridotite intrusive stocks of oceanic setting, cutting Upper Eocene rocks of sedimentary series [16]. In Achara Trialety zone tholeiite volcanic of interarc rift laterally to east syncronally transferred in shoshonite-dellenite volcanic, shown slackening rifting and farther to calc-alkaline volcanic of island arc setting [5]. The alternation of geodynamic development along dipping of oceanic slab under Eurasian active margin of the studied region shown on the idealized scheme (Fig. 5) [8] and characterized of cycling and succession volcanism and mineralization. It is distinctly seen in the Caucasus region. The cycling are represented by temporally alternation of island arc calc-alkaline volcanism and mineralization as first stage, in interarc-backarc setting volcanism and mineralization the second stage and in minor ocean setting as third stage along the dipping of subducting slab in the temporal units: Paleozoic-Triassic Lower Jurassic, Middle-Upper Jurassic, Upper Cretaceous-Eocene [8]. Phanerozoic evolution represents temporally alternating cycles from Paleozoic to Upper Cretaceous-Eocene [3].

Examplified on the Eurasian margin of studied region. The Paleozoic—Triassic-Lower Jurassic cycle on the Southern Slope of Caucasus began with regional metamorphism transferred in calc-alkaline dacite-andesite volcanism (Dizi series)—the first stage of cycling continuing in Paleozoic-Lower Jurassic tholeiite interarc volcanic activity in the For Range of North Caucasus. The other Paleozoic—Lower Jurassic cycle occurs in the Intermontane Block of Trans Caucasus as island arcal Paleozoic-Triassic calc-alkaline volcanic series (Narula, Chiatura and Khrami suites) transferred in the tholeiitic backarc Lower Jurassic

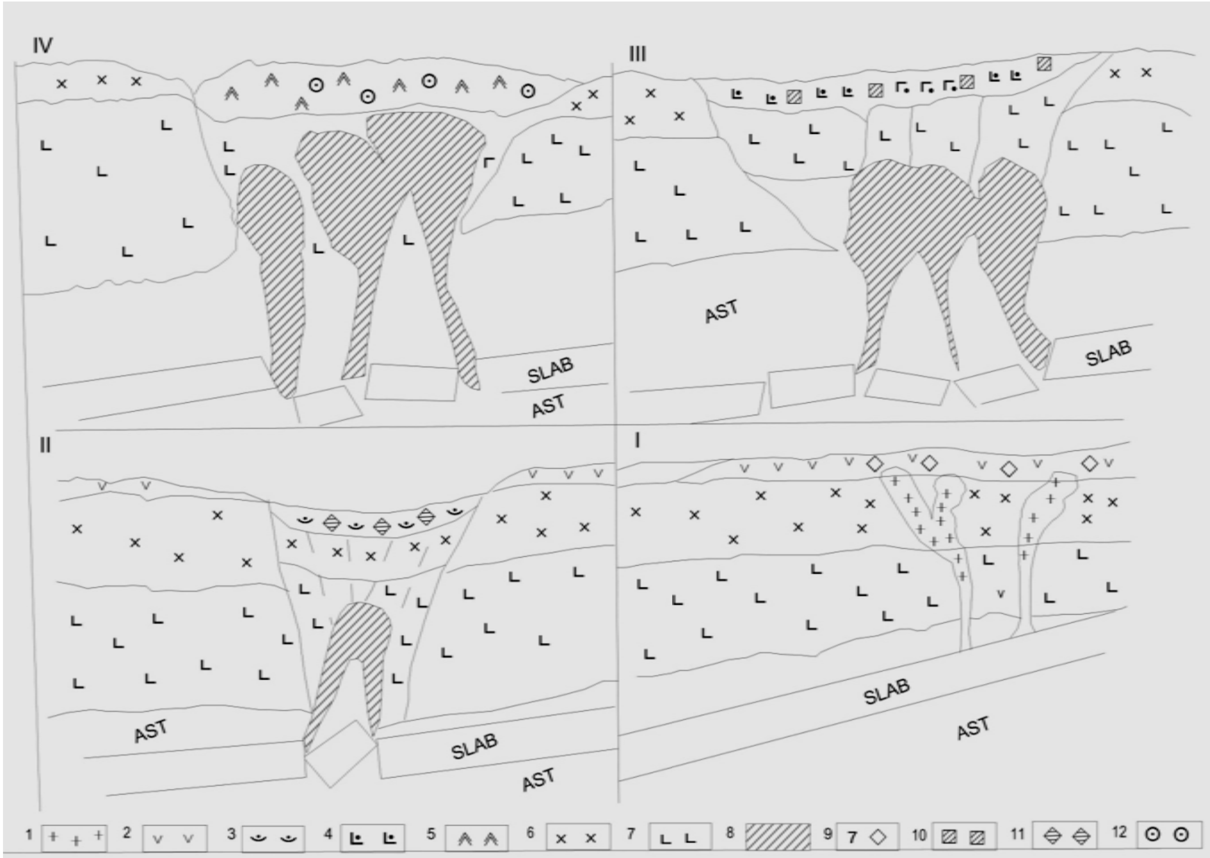

Fig. 5 Idealized scheme of interrelation of volcanism and mineralization at various stages of subduction of the Tethys ocean slab.

I—Steady state subduction and island arc setting, II—Incipient stage of steepening of subducting slab, III—Reinforcement steepening and backarc-interarc setting, IV—Intensive spreading and minor ocean setting.

1: granodiorite stocks, 2: calc-alkaline rhyodacite volcanics, 3: trachy-rhyodacite and alkali olivine basalt and trachybasalt volcanics, 4: olivine basalt and tholeiite volcanics, 5: ophiolite volcanics and dunite-peridotite intrusive bodies, 6: sialic crust, 7: basaltic crust, 8: mantle diapir, 9: Au-Pb-Zn-Cu mineralization, 10: Au-Pb-Zn-Cu mineralization with high grade of gold, 11: Zn-Cu VHMS ores, 12: Cu-pyrite Cyprus type ores.

volcanic series in the Southern Slope of Caucasus. Middle-Upper Jurassic cycle began in the Intermontane Block of Trans Caucasus as Bajocian island arcal calc-alkaline andesite-basaltic volcanism and terminated by Upper Jurassic interarc Kimmeridgian-Titonian alkali olivinian basalt-tholeiitic volcanism in river Rioni depression. The Cretaceous—Eocene cycle controlled by Turonian-Coniacian island arc calc-alkaline volcanism Mashavera suite (88-90 Ma) alternates with Upper Campanian alkali olivinian basalt series Shorsholety suite (80 Ma) and terminated by Eocenian Chidila suite of tholeiite-alkali olivine basalts of interarc setting. The another Cretaceous cycle is determined in the Panaguirishte ore district (Balkans). Here the first stage is represented by calc-alkaline volcanism and Au, Pb, Zn, Cu mineralization (92 Ma)—Chelopech, Medet, Asarel deposits, related to steady state subduction, after steepening of subducted slab the mantle influence increased occurred in alkali olivine basalt volcanism with Zn-Cu mineralization (Vlaikov Vrukh, Capitan Dimitrievo deposits) of the terminating of Cretaceous cycle. In the studied region occurs three staged cycles along dipping of subducting slab merged Black and Caspian Seas Eocene oceanic basins. In the East Pontides and Alborz-Azerbaijan bordered zones, where the first stage of cycling began by calc-alkaline island arc volcanism, the second stage in the East

Pontides represented by shoshonite-olivinian basalt backarc merged in Black Sea minor ocean, whereas the Eocene minor ocean of Caspian Sea southern bordered with shoshonite-tholeiite backarc, transferred to south in island arc setting consists of calc-alkaline volcanic series.

Hence, in studied region along dipping of subducting slab temporally and spatially cycling characterized by alternation of regional metamorphism, calc-alkaline volcanism via interarc-backarc stages terminated by oceanic setting. Subsequence of cycles began in Paleozoic and terminated by Cretaceous-Eocene.

The subsequence of alternation occurs laterally to dipping, as well, however, in difference to subducting along dipping the cycling here it is synchronal and controlled spatially. It is exemplified by interrelation of Achara-Trialety and Talysh interarcs and Burgas backarc with Black Sea Cretaceous and Eocene minor ocean settings and Caspian Sea Minor Ocean. The Achara-Trialety Eocene interarc laterally western merged Black Sea Eocene minor ocean, whereas Cretaceous alkali olivine basaltic backarc laterally transferred in the Cretaceous minor ocean basin. The Eocene interarc of Talysh merged with Caspian Sea Eocene Minor Ocean. Achara-Trialety interarc laterally to East alternates from Eocene tholeiites in trachybasalt-dellenite series and farther to calc-alkaline volcanic of island arc setting revealed the slackening of rifting and increasing of crustal influence. The western segment of Achara-Trialety interarc evidenced ascending succession temporal alternation in local space. Here the Cretaceous calc-alkaline volcanic series upstear transferres in Lower Eocene shoshonite-trachyandesite series of incipient interarc setting (Nagvarevi suite) and farther in Eocene tholeiitic Chidila suite. The latter upstears is overlaid by calc-aslkaline volcanics of island arc setting. The such alternation evidenced spacially localized steepening of subducting slab and mantle diapir incursion. At the same time, olivine basaltic series of Talysh interarc is overlaid by Upper Eocene sedimental series cutting dunite-peridotite ultramafic stocks evidenced that here assending succession interarc is transferred in minor ocean setting.

2.2 Post-collision Development Related with Orogenesis Revealed in Magmatism, Gold, Base and Trace Metal Metallogeny and Volcanic Activity

The convergence of the Eurasian and Afro-Arabian continents caused closure of the Tethys Ocean. Deformation of the Eurasian margin accompanied the pre-collision to post-collision evolution revealed in orogenesis and fold-and-thust structuring. The steepening o subducting slab below thickened orogenic crust caused upwelling of astenospheric material and focusing of high temperature mantle source fluids. The hot fluids smelted granitoid magma and leached gold and trace metals (Sb, W, Mo and Hg) from crustal rocks, which controlled the post-collision magmatism and metallogeny. The post-collisional mineralization and intrusive activity was related to fold-and-thust evolution through the studied region from Iran, Caucasus and Turkey up to Balkan-Carpathians [3]. All of them consist Oligocene-Miocene dacite-granodiorite stocks emplaced into Paleozoic and Mesozoic rocks. These stocks provided pathways from fluids focused from deep-seated magma chambers, which moved along these stocks and system of faults and shear zones into the rocks of various ages. The age of intrusive stocks in the studied region everywhere is Oligocene-Miocene and it is the age of first stage of post-collision activity in the region.

The post-collision mineralization in Iran includes the Cenozoic Sungun and Mazra base metal porphyry deposits, the epithermal gold deposits of Harvanas group (Mivehrud, Anderian, Astaragan, Halfian), Muteh orogenic gold deposits of the Sanandaj-Sirjan zone and deposits of the East Iran magmatic belt (Zarshuran, Akdareh, Kom, Dashkesan). All this deposits are goldbearing, some of them with important base metal mineralization and occurring as veins and stockworks. They are all related to Oligocene-Miocene dacite-granodiorite stocks emplace into Paleozoic and Mesozoic rocks. This stocks were pathways for fluids focused from deep-seated magma chambers. The fluids moved along these stocks and system of faults and shear zones into the rocks of various age. All deposits are coincide with trace metals (Sb, W, Mo, Hg), which widely spread in country rocks.

The post-collision activity, magmatism and mineralization took place in the Caucasus, its Southern Slope and in Lesser Caucasus. The significant gold deposit in the Great Caucasus is Zopkhito. It consists of Au mineralization included trace metal enrichment (Sb, W, Mo, Hg). The mineralization occurred as quartz-stibnite stockworks and Au-Cu-base metal lodes. The trace metal association occurs as in wall altered rocks, so widespread in the country rocks. The other significant occurrence in the Great Caucasus is Lukhumi with gold-arsenopyrite-stibnite mineralization. It is controlled by shear zones developed in Upper Liassic schists and limestones, where quartz-stibnite-realgar-orpiment and qurtz-sheelite stokworks are also present. In the Great Caucasus range, The Hokrila Achapara prospect is controlled by a regional fault [17], where gold is associated with enrichments in Sb and W. Gold mineralization is present in quartz-scheelite, quartz-base metals and quartz-veins. Gold grade correlates with Sb and W concentrations.

Many other post-collision prospects are known in the Greater Caucasus such as Carobi Mo deposit, Sheelite occurrence Notsara, cinnabar deposits Akhey and Akhahcha. All of them are controlled by faults and shear zones.

The post-collision setting in the Lesser Caucasus is represented in the Megri-Ordubad Cenozoic magmatic province, where significant Au-Mo mineralization is associated with Sb, W and Hg, related to Oligocene-Miocene granitoid stocks (deposits Kajaran and Agarac). As well as the large Zod and Merhadzor Au-bearing stibnite deposits, located along Sevano-Akera suture and controlled by Cenozoic granodiorite—porphyry stocks [18].

The post-collisional Au mineralization in Turkey, associated with Hg, Sb and W concentrations is best known n the Paleozoic rocks of Mendres Massif (West Anatolides), represented as Cungurlu, Emerli and Halicoy deposits. They are controlled by Cenozoic faults and shear zone in the metamorphic core complex [13].

Fault controlled post-collisional Cenozoic Au mineralization is also known in the Rhodopean Ada-Tepe deposit in Bulgaria [19], as well as in Slovakian Carpathians, where occurrences Au-Cu-base metal mineralization coincides with Sb-Hg-As [20].

A similar situation is characteristic to post-collisional setting worldwide. The Au and associated trace metals detected in the Tethys—Eurasian metallogenic belt are also exemplified by Muruntau and other deposits in the late Paleozoic part of the Central Asian Orogenic Belt. Late Paleozoic terrane collisions generated of giant deposits (Muruntau, Kumtor, Zarmitan) during final ocean closure and terrane amalgamation in the Tianshan Province [21]. The gold mineralization throughout the Belt is associated with Sb, Mo and W.

A similar association of gold associated with these trace metls occurs in the Tombstone gold belt of Yukon in western Canada. The post-collisional mineralization is related to Jurassic, and Cretaceous orogensis and is controlled by synorogenic intrusions [22]. Post-collisional continental margin development was linked to Triassic-Cretaceous convergence between the North American and Farallon plates, which led to collision of the oceanic terranes with the continental margin. Gold mineralzation in quartz veins occurs in association with W, Au, Ag, Pb, Zn and Sb. Similarly, in the western part of the Lachlan orogeny in southearn Australia, syncollisional orogenic gold mineralization is marked by a relationship with a Bi, Te, As, W, Mo, Sn and Sb association [23].

3. Results and Discussion

Convergation of Eurasian and Afro-Arabian continents related to Tethys ocean subduction, collision, and closure revealed in orogenesis. The process of evolution occurred in pre-collision and post-collision stages of geodynamic development. The pre-collision development at continental margin related to sea bottom subsidence. The steady state subduction of island arc setting revealed in subaqual and island conditions. The steepening of subducting slab and invasion of mantle diapir at high level bring up to extension sea bottom, rifting and backarc-interarc setting. The farther strength of steepening and incursion of mantle diapir at highest level revealed in intensive spreading and minor ocean setting. The interarc-backarc and minor ocean settings are characterized of subaqual volcanism, whereas the post collision development is related to orogenesis, elevation and provoke subaeral volcanic activity. The pre-collision stage coincides with subduction of oceanic slab manifested in regional metamorphism, volcanic activity, mineralization and tectonic development. The processes are controlled by heat flows, volcanogenic, petrogenic and tectonic indicators, geochemical criteria and by the scale of crustal-mantle influence in various geodynamic settings. The island arc setting is controlled by steady state subduction coincide with metamorphism calc-alkaline volcanism, Au, Pb, Zn, Cu mineralization.

The steepening of subduction crust and mantle diapir inclusion, caused intensive rifting wih spread out the sialic crust from zone of volcanism, in interarc-backarc settings. It is characterized by tholeiite-alkali-olivine basaltic volcanism, Zn-Cu mineralization, extensional tectonics (rifting) and influence of basaltic crust and mantle on the processes. Between the island arc and interact settings occurred the transitional stage, which is characterized by weak steepening of subducting slab, and mantle incursion on the deepest level. At this stage, the sialic crust is not spread out from zone of volcanic activity. It is characterized by synvolcanic blocking and mantle influence here revealed in subalkaly trachyrhyodacite volcanism and intensive K-feldspar alteration coincides with gold mineralization. Incursion the mantle diapir on highest level provokes intensive spreading and forming of small ocean basin, characterized by ophyolite volcanism, dunite-peridotite magmatism, serpentinisation and Cu-pyrite mineralization. The processes here are influenced only by mantle. The sialic, so as basaltic crusts here are spreaded out from zone of volcanism and mineralization. The Sr-isotope ratio of oceanic setting is 0.7024.

Hence, along the dipping of subducting slab temporally and spatially cycling revealed in alternation of island arc, calc-alkaline volcanism, preceded tholeiite-shoshonite volcanic activity of interarc-backarc rifting, the cycle is terminated by ophiolite volcanism and dunite peridotite magmatism of small ocean setting. The cycling controlled by steady state subduction and steepening of subducting slab according strength and level of mantle diapir invasion. Whereas laterally to dipping of subducting slab the alternation of geodynamic settings occur synchronously and spatially. At ascending succession, the alternation and cycling occurs only temporally and depended on stratigrapfically upstears alternation of steepening of subductig slab and scale of diapirism.

The steady state subduction and steepening of the subducted slab at Eurasian active margin, along dipping of subducting slab, so as laterally to dipping and ascending succession alternates temporally and spatially. The metamorphism was transferring into calc-alkaline volcanism caused by increasing of heat flows. Transferring of island arc into interarc-backarc setting depended on mantle diapirism and rifting.

Reinforcement of steepening and incursion diapir on the highest level. Dipping of slab occurred as spatially, so temporally controlled by alternation of geodynamic settings, whereas laterally alternation to dipping going synchronously exemplified by transferring laterally to west Cretaceous Black Sea small oceanic basin in Cretaceous Burgas backarc rift. The Eocene Black Sea small oceanic basin to east merges into Achara-Trialety Eocene interarc settings. The Talysh interarc Eocene settings is merging into small oceanic basin of Caspian Sea.

Ascending succession alternation of geodynamic settings goes temporally. It is exemplified in the western segment of Achara-Trialety, where Cretaceous calc-alkaline volcanics upstear transfeffed in lower Eocene incipient stage of interarc setting, later in Middle Eocene interarc rift, farther with slackening rifting again into incipient stageof interarc overlaid by calc-alkaline volcanic of island arc setting. At the same time, Middle Eocene olivinian basalts of interarc rift of Talysh in Upper Eocene transferred in ultramafic dunite-peridotite activity characterized for oceanic setting.

Hence, the geodynamic development at pre-collision stage along dipping of subducted slab, so laterally to dipping and ascending succession revealed in cycling temporally and socially. Along dipping it occurs as temporally, so spatially alternation laterally to dipping development is synchronal alternation occurs spatially, whereas ascending succession localized spatially temporal cycling.

The converging of the continents and closure of the Ocean revealed in termination of subduction, orogenesis and transferring the pre-collision stage in post-collision. However, steepening of subducting slab is continuing and provokes the faults and shear structures in lithosphere caused the crustal-mantle interrelation. At the first stage of post-collision development the hot fluids, ascending from mantle , smelt the granitoid magma from thickend sialic crust and forming granodiorite intrusive stocks. The hot fluids, at the same time, are leaching gold, base metals and trace metals (Sb, W, Mo, Hg) from the crust and caused the forming of goldbearing epithermal, porphyry and trace metals—stibnite, sheelite, molibden and cinnabar deposits. The mentioned trace metals association coincide with mineralization and widespread in country rocks of pre-collision stage. Hence, the association of trace metals is the geochemical indicator of the first stage of post-collision activity, whereas the calc-alkaline granodiorite magmatism is the petrogenic indicator.

The next stage of post-collision development is volcanic activity similar to volcanism of pre-collision stage represented of andesite-basalts, shoshonites, tholeiite and olivine basalts with geochemical criteria of pre-collision stage. They are not consist of mentioned trace metal association and controlled by crustal-mantle dependence of volcanic activity.

Hence, the pre-collision and post-collision stages of geodynamic development are depended on the scale of crustal-mantle influence controlled by steady state subduction, steepening of subducting and subducted slab and on the strength and level of incursion of mantle diapir. The calc-alkaline volcanism of island arc setting and Au, Pb, Zn, Cu mineralization are depended mainly on crustal influence. The tholeiite-olivine basaltic volcanic activity of interarc setting and Zn-Cu mineralization caused by basaltic crust and mantle influence, whereas oceanic setting ophiolites and dunite-peridotites with Cu-mineralization are depended only on mantle influence. At the first stage of the post-collision setting the magmatism and mineralization are depended mainly on crustal influence, but processes of smelting granitoid magma and leaching base and trace metals caused by hot fluids coming from mantle. As to volcanic activity of the second stage it is controlled by crustal-mantle influence. The mantle material is penetrated along faults and shear zones in lithosphere and subducted slab into deep volcanic chambers, mixing with crustal melt.

4. Conclusions

Precollision development, volcanism and mineralization are controlled by steepening of subducting slab and scale of mantle diapir incursion along dipping slab, so laterally to dipping and ascending succession depended on scale of stress during subduction at various direction.

Hence, various settings of pre-collision stage of development are controlled by steady state subduction and steepening of subducting slab are characterized by following indicators:

* Transferring metamorphism in calc-alkaline volcanism is controlled by increasing temperature of heat flows during steady state subduction.

* It is noteworthy, that in studied region regional metamorphism occurs only in Paleozoic cycle evidenced that it is related to beginning subduction of Tethys ocean slab under Eurasian margin. In subsequent cycles from Lower Jurassic to Eocene the regional metamorphism was not occurred and that begin of calc-alkaline volcanism, controlled by higher heat flow and temperature reveled in melting andesite from subducting slab and Lithosphere.

* The calc-alkaline volcanism and related Au-Pb-Zn-Cu mineralization caused by prevalently crustal influence with sialic crust participation. Ascending succession transferred in alkali olivine basaltic volcanism of backarc setting.

* The interarc-backarc setting evidenced by tholeiite olivine basaltic volcanism, intensive rifting spreading out the sialic crust from zone of volcanism and Zn-Cu mineralization controlled by basaltic crust and mantle and lack of Au and Pb sourced in sialic crust. The intensive rifting is caused by mantle diapirism. Tectonic indicator basaltic crust and mantle influence on volcanism and mineralization is evident.

* The forming oceanic setting caused by most intensive steepening and mantle diapirism on highest level of lithosphere, ophiolite volcanism, dunite-peridfotite magmatism, serpentinization and Cyprus type Cu-mineralization. The spreading is tectonic indicator. The only source of volcanism and mineralization here is the mantle.

The post-collision development is devided in two stages, the first revealed in granodioritic magmatism, gold-base metal porphyry and gold trace metal lowsulfidation mineralization and second stage oregenous volcanic activity.

The first stage of post-collisional development is characterized by following indication:

* The tectonic indicator of the first stage of post-collision development are orogenesis and fold-thrust structures.

* The petrogenic indicator the dacite-granodiorite intrusive stocks controlled mineralization occurs in studied region everywhere from Iran up to Balkan-Carpathian.

* The metallogenic indicators are epithermal gold-trace metals and base metal porphyry deposits and occurrences associate with Sb, W, Mo, Hg mineralization and in wall altered rocks.

* The trace metals widespread in the country rocks as well, so they are geochemical indicators of the first stage of post-collision development overlaid on the pre-collision rock of various age from Paleozoic up to Cenozoic. The pre-collision rocks are not consist of the trace metal association.

* The mantle source of the first stage is only hot fluids coming from deep magmatic chambers. Thus, the first stage of magmatism and mineralization are mainly controlled by crustal sources.

The last, second stage of post-collision development is expressed by Late Miocene—Quarternary volcanic activity. The relation between post-collision volcanism and geodynamic development was studied in detail by Dilek, et al. [24]. Their study area encompasses Arabia, Iran, the Lesser Caucasus and eastern Turkey. They investigated post-collisional volcanism and determined the spatial and temporal impact of astenospheric evolution on the character of volcanism.

The first stage of volcanic activity is Late Miocene-Early Pliocene as revealed in calc-alkaline andesite-basalt and shoshonite—trachuandesite units. The Later Pliocene—Quarternary volcanism was tholeiitic-alkalic olivine basaltic and characterized by an increasing of mantle influence. Petrochemical and geodynamical feature are similar to those formed in pre-collision interarc-backarc volcanism. from deep-seated magmatic chambers. Mineralization is not related to post-collision magmatic activity. The similar data is presented by N. Sadradze [25], exemplified on the post-collision volcanism of the Lesser Caucasus and Southern Slope of Greater Caucasus.

Hence, post-collision volcanism is influenced by crustal-mantle sources, whereas magmatism and hydrothermal activity of the first stage mainly caused by crustal sources.

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