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SOURCES OF BASE, PRECIOUS AND RARE METALS DURING THE TETHYAN PHANEROZOIC EVOLUTION OF THE CAUCASUS AND PONTIDES

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Abstract: Base, rare and precious metal deposits are widespread in the Caucasus and Pontides regions. They are the result of the Phanerozoic evolution of the Tethys Ocean, of various geodynamic settings, including oceanic, intra-arc, back-arc and island arcs. The various types of mineralization are discussed in terms of the participation scale of sialic, basaltic crusts and mantle sources. In oceanic settings, cupriferous Cyprus-type deposits occur, where the source of Cu is the mantle. In intra-arc settings, Beshi type Cu-Zn deposits were formed; the source of Zn is interpreted to be basaltic crust. As for the island arc and back-arc settings, Cu-Pb-Zn porphyry, stockwork, VMS and vein deposits are common. The source of Pb is interpreted to be the sialic crust. The rare metals (Hg, W, Sb) are related to post-collisional settings, where sialic crust is important. Mo is also related mainly to post-collisional settings, and it subordinately participates in the island arc settings. Precious metal mineralization (Au and Ag) predominantly developed in island arc and post-collisional settings. Therefore, in the process of mantle depletion and crust formation precious metals (Au and Ag) mainly accumulated in the sialic crust.

Keywords: Tethys, Phanerozoic, metallogeny, Caucasus, Pontides.

1. Introduction

The Caucasus and Pontides are the result of the Phanerozoic evolution of the Tethys ocean. The process was terminated by post-collisional activity. The geodynamic development is clearly reflected in volcanic activity and base, precious and rare metals metallogeny. During the Paleozoic, the Tethys Ocean was located between the Afro-Arabian and Eurasian plates. During the Late Paleozoic, the oceanic slab started its north-verging subduction, the ocean closed during the Early Paleogene and is expressed by the Izmir-Ankara-Erzindjan-Sevan ophiolite suture zone.

The Phanerozoic evolution of the Caucasus and the Pontides is divided in pre-collisional and post-collision stages with a variety of geodynamic settings. During the pre-collisional stages, oceanic, intra-arc, back-arc and island arc settings were formed with associated metallogeny. After the closure of the ocean, the Caucasus and the Pontides evolved into collisional and post-collisional stages, and was consequently accompanied by a change of the character of metallogeny.

Base and precious metals in the various settings of the pre-collisional development are differently distributed: the oceanic setting is characterized by cupriferous ores, with subordinate Zn mineralization, and devoid of Pb. At the same time, seafloor occurrences of the oceanic setting generally contain only little gold and silver mineralization according to Rona and Scott (1993). In intra-arc settings, Cu-Zn mineralization contains subordinate gold, and in marginal sea-back-arc settings, Cu and Zn can be accompanied by galena and gold mineralization. Finally in island arcs, Cu, Pb, Zn, Au and Ag ores can be accompanied by significant and widespread galena mineralization. It is noteworthy, that rare metals such as Hg, W and Sb are absent in pre-collisional settings. The diversity of distribution of rare, non-ferrous and precious metals in the various geodynamic settings depends on the scale of participation of sialic, basaltic and mantle sources in the process of mineralization.

According to Hutchinson (1973), during the Archean, when the crust only existed as a protocrust and the mantle was only weakly differentiated, only copper-zinc deposits were formed. Later, during the Proterozoic, when the sialic crust was developed, lead took part in the mineralization process and gained economic significance in volcanogenic massive sulfide (VMS) deposits.

Our aim is to examine mantle, basaltic and sialic crust influence on the character of mineralization in the Caucasus and Pontides region. Here during the process of Phanerozoic evolution, all types of geodynamic settings were present, including precollisional and post-collisional ones, with appropriate mineralization related to settings with predominant mantle, basaltic or sialic crust participation. The diversity of geodynamic situations, volcanic activity and ore formation of the region gives us an opportunity to consider and evaluate the rich variety of data.

2. Phanerozoic evolution and base, precious and rare metal metallogeny

The diversity of base, precious and rare metal deposits, which were formed during the Phanerozoic evolution of the Tethys described above are presented in Tables 1 and 2 and and Figures 1 and 2.

During the Late Paleozoic and Early Mesozoic in the Pontides, above a N-NW subducting slab, a minor ocean existed, with an ophiolite extrusion and MORB and island arc (IAT) tholeiites, confirmed by immobile element geochemistry. Here, the Kure complex consists of serpentinized perido-

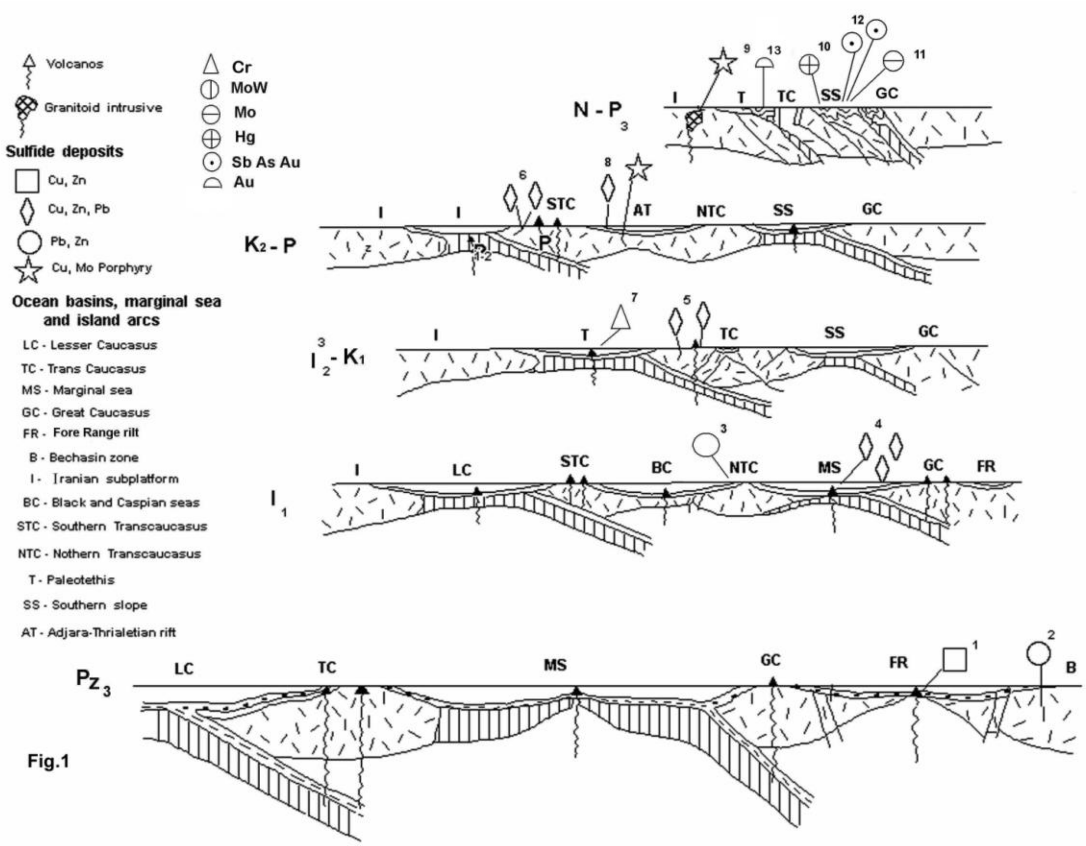

Fig.1 Palinspastic cross-section of the Caucasus according to Adamia et al. (1997) with nonferrous, rare and precious deposits related to different gaodynamic settings.

Precollision settings: 1. Cu-Zn Besshi type deposits of Urup group (intra-arc setting), 2. Pb-Zn vein deposits of Bechasin zone (island arc setting), 3. Pb-Zn vein deposits of Sadon, Kvaisa, Dzirsha groups (island arc setting), 4. Cu-Pb-Zn Filiz-Chai type deposits (backarc setting), 5. Cu-Pb-Zn VMS, porphyry, stockwork and vein type deposits od Somkhith-Carabakh zone (island arc setting), 6. Cu-Pb-Zn-Au porphyry, stockwork, epithermal and vein type deposits of Artvine-Bolnisi zone (island arc setting), 7. Cr vein and lens type deposits of Sevan-Akera suture zone (ocean setting), 8. Cu-Pb-Zn-Au porphyry, stockwork and vein type deposits of Ajara-Trialeti zone (island arc setting), 9. Cu-Mo porphyry deposits (Kajaran, Agarac), 10. Hg vein type deposits (Akhey, Avadhara), 11. Mo-W, Mo vein type deposits (Tirniauz, Karobi), 12. As-Sb-Au vein type deposits (Zopkhito,Lukhumi), 13. Au lode deposits (Zod, Meghrathzor).

tite at the base and is overlain by layered cumulate gabbros, passing upward into isotropic microgabbro and into a diabase sheeted dyke complex. The later is stratigraphically overlain by alternations of pillow lava, massive lava and lava breccias. Lava breccias are overlain by shales, which are interpreted as semi-pelagic sedimentary rocks according to Ustaomer and Robertson (1997). "Cyprus type" cupriferous pyrite deposits are found along the lava-sedimentary rock contact, and are expressed as disseminated and massive ores according to Guner (1980). The most significant deposits are: Asikoy and Bakibaba (Tab.3), massive sulfides consisting essentially of pyrite and chalcopyrite. Zn and Pb are only present as trace elements. Thus, the MORB mineralization of the Kure complex, which is a typical Cyprus type deposit, is characteristic for an oceanic setting.

The Beshi-type deposits of the intra-arc setting, related to the Urup group, are located in the fore-range of the Great Caucasus (Figs 1 and 2, Tab. 2). The intra-arc rift developed above a Paleozoic subduction, during the closure of the Great Caucasus minor ocean. The Paleotethyan branch is only represented by the allochtonous relic of its suture according to Adamia et al. (1981). The intra-arc rift is characterized by Paleozoic bimodal tholeiite-basalt-rhyolite volcanic activity and Au-bearing Cu-Zn Beshi type mineralization. The recent intra-arc rifts are similar to Fore Range basalts in K/Rb ratios and TiO_2 contents and enriched in the most lithophile and siderophile elements, as tholeiites of the Red Sea axial trough (Shavishvili 1983). The ores consist of copper-pyrite, copper-zinc, pyrite mineralization, with pyrite being prevalent (90-100%), and chalcopyrite and sphalerite being subsidiary (9%) according to Skripchenko (1972). Sialic crust material did not participate in the mineralization process, therefore the ores only contain Cu and Zn.

During the Lower Jurassic (Liassic), above the north-verging subduction zone, a back-arc rift appeared along the Southern Slope of the Great Caucasus and evolved into a marginal sea. It is characterized by the Filiz-chai group Cu, Zn, and Pb deposits, with subordinate gold mineralization (Figs. 1, 2; Tab. 1). The back-arc rifting here is associated with slow spreading without ophiolite extru-

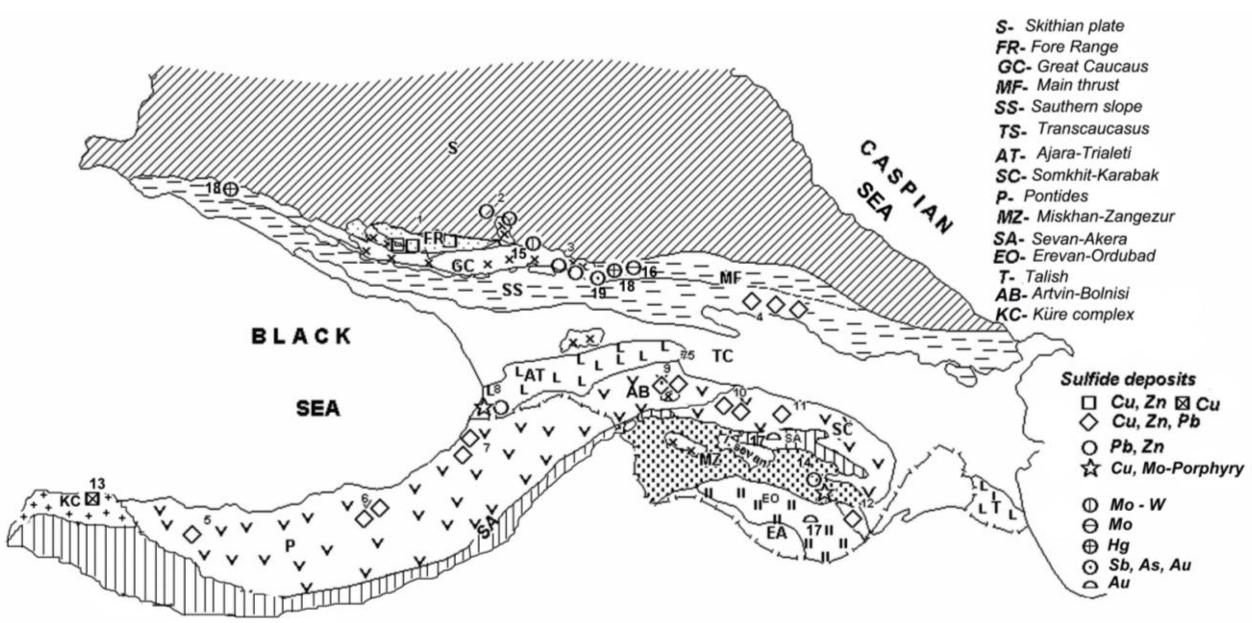

Fig.2 Geotectonic scheme of the Caucasus and Eastern Pontides with metallogeny of nonferrous, rare and precious metals deposits.

Precollision stage: 1. Urip group of Besshi type (Cu,Zn) deposits, 2. Pb, Zn – vein deposits of the Bechasin zone, 3. Pb, Zn vein deposits of Sadon group, 4. Filizchai type deposits, 5,6,7- (Lahanos, Madenkoy, Murgul VMS Kuroko type and polimetallic vein stockwork deposit of the East Pontides metalotect, 8- Cu-Mo porphyry and polymetallic vein deposits of Merisi group, 9- Au-Cu porphyry, Au –low sulfidation and vein and stockwork polymetallic deposits of Madneuli and Sakdrisi group. 10, 11, Cu-Pb-Zn VMS, vein and stockwork polymetallic and Cu porphyry deposit of Somkhit-Carabakh zone (Alaverdi group, Tekhut), 12- Kafan Cu porphyry deposit, 13- Cyprus type Cu deposits of Kure complex (Asikoy, Bakibaba), 14- Kajaran Cu-Mo porphyry and vein and stockwork polimetallic and stockwork deposit, 15- Tirniaus W-Mo vein and stockwork deposits, 16- Mo-Karobi, 17- Au lode and stockwork Zod and Maghradzor deposits, 18- Hg Akhei, Avadhara vein deposits, 19- Sb, As, Au Zopkhito, Lukhum vein deposits.

Table 1. Pre-collision metallogeny of the Caucasus and the Pontides

Metallogenic		Pre-collisional metallogenic unites							
Oceanic		Island arc		Intra arc		**Deposits**		**Deposits**	
		Deposits	Type of mineralization	**Variscan**	**Type of mineralization**	Deposits	Type of mineralization	Deposits	Type of mineralization
Variscan	VMS (Cu)	Okrila (Au)	disseminated veins (Au)	**Urup, Khudes, Beskes**	Beshi type VMS (Cu, Zn)			Asikoi,	VMS (Cu)
								Bakibaba	VMS (Cu)
A l p i n e	**Early (Lias)**	Sadon, Zgid, Holst	vein, stockwork (Pb, Zn)			Filiz-chai Katkh,	Filiz-chai type VMS (Cu, Pb,Zn)		
						Artana	vein (Cu, Pb, Zn)		
		Dzirsha	vein (Pb, Zn)						
	Middle (Dogger, Malm)	Brdzirsha	stratabound (Pb, Zn)						
		Kvaisa	vein (Pb, Zn)						
		Alaverdi,	VMS (Cu, Pb, Zn)						
		Tekhut,	porphyry (Cu)						
		Kafan,	" – " (Cu, Pb, Zn)						
	(Bajocian)	Kedabeck,	" – " (Cu, Pb, Zn)						
		Karadag,	" – " (Au, Cu, Pb, Zn)						
		Kizilbulag,	" – " (Au, Cu, Ag)						
		Gosha	Stockwork and vein (Au, Cu, Ag)						
	Late (Senonian)	Madneuli	porphyry, epithermal (Au,Cu, Pb, Zn)						
		Sakdrisi						Shorja	vein, lens (Cr)
		Poladauri	vien (Fe)						
		Murgul	stockwork and vien (Cu, Pb, Zn)						
		Madenkoy Lahanos	Kuroko type VMS (Cu, Pb, Zn)						
		Guzelaila	porphyry (Cu, Mo)						
		Balikasir Balia							
		Demirbaku	stokwork and vein (Pb, Zn, Ag, Au)						
		Altinoluk							
		Canakkale							
	(Eocene)	Merisi	porphyry (Cu, Ag, Pb, Zn)						
		Gujareti	vein, stockwork (Cu, Pb, Zn)						
		Dzama	skarn and porphyry (Fe, Au, Cu)						
		Algeti	vein (Mn)						

sions, and the seafloor was underlain by thin sialic crust according to Lomize and Panov (2002), which is thought to be source of lead in this setting, whereas the source of Zn are the subducted basaltic slab and slowly spreading basaltic crust. The tholeiites of the marginal sea are characterized by a low content of REE and a normal chondric distribution of Nb, Zr, Hf, and Y, but with slight distinct anomalies of Nb and Ti characteristic for island arc tholeiites. The ratio $^{87}Sr/^{86}Sr$ of 0.7034 is consistent with MORB compositions and is typical of back-arc and intra-arc basins according to Tarney et al. (1977) and Lordkipanidze (1980). Typical calc-alkaline volcanic activity preceded the riftogenic tholeiitic volcanism and was postdated by calc-alkaline dacite and gabbro-diorite intrusive bodies according to Lordkipanidze (1980). The Filiz-chai Cu-Zn-Pb deposit consists of stratiform ore bodies. The mineralization consists of pyrite with subordinate sphalerite, galena, chalcopyrite and pyrrhotite, with minor quantities of marcasite, arsenopyrite, cobaltite, magnetite and goethite.

Mezo-Cenozoic island-arc settings were formed above the north-verging subducting slab of the Tethys Ocean in the Caucasus and the Pontides. The settings are characterized by calc-alkaline volcanism and basic metals Cu, Zn-Pb, precious metals Au-Ag and subordinate Mo mineralizations (Figs 1, 2; Tab.1). Jurassic – Bajocian VMS, porphyry, stockwork and vein type deposits occur in the Somkhit-Karabakh zone of the Transcaucasus. They include the Alaverdi group (Alaverdi, Shamlug, Akhtala), Tekhut, Kedabek, Karadag, Kizilbulag, and Gosha deposits (Figs 1, 2; Tab.1). The Somkhet-Karabakh zone is continuing to the northwest into the Artvin-Bolnisi and the Eastern Pontides zone (Fig.1), which represent a Cretaceous island-arc setting, with calc-alkaline volcanic rocks and Cu, Pb, Zn, Au and Ag mineralizations. The Artvin-Bolnisi zone includes the Madneuli, Tsiteli-Sopeli and Sakdrisi deposits interpreted as porphyry, epithermal low sulfidation, stockwork and vein deposits with economic reserves of Cu, Pb, Zn and Au (Fig. 2; Tab. 1).

The same volcanic activity with Cu, Pb, Zn and Au mineralization took place in the Eastern Pontides

Table 2: Post-collision metallogeny of the Caucasus

Metallogenic Epoch		Post-collisional Metallogenic Unites			
		Fold-Thrust Belt		Fore-lands	
		Deposits	Type of mineralization	Deposits	Type of mineralization
		Zod	Vein, stockwork		
			Au, Mo, Pb, Cu	Chiatura,	exhalative-sedimentary (Mn)
	Early			Chkhari,	
	(Oligocene)			Ajameti	
					exhalative-sedimentary (Cu, Au)
		Meghradzor	Au, Mo, Pb	Nakhchevan	
		Kajaran, Agarak	porphyry		
			(Mo, Cu, Pb, Zn, Au)		
		Avadhara,	vein (Hg)		
		Akhei	vein (Hg)		
		Tsana	vein, disseminated (As)		
Alpine	Middle				
	(Neogene)	Zopkhito	vein, disseminated		
			(Au, Sb, As, Pb)		
		Karobi	vein, (Mo)		
		Notsarula	vein, (Mo, W)		
		Tirniauz	vein, stockwork (Mo, W)		
		Lukhumi	vein, carline type (Sb, As, Au)		
	Late	Enguri	placer, (Au)	Araks	placer, (Au)
	(Quartenary)				
		Khrami	placer, (Au)	Ureki	placer, (Fe, Ti, V)

island-arc volcanic series, which include the Murgul group of subvolcanic base metal deposits, the Madenkoy and Lahanos Kuroko-type VMS and porphyry Mo-Cu deposits, Guzelaiala, as well as the Cheratepe gold-bearing polymetallic ores (Fig. 2; Tab.1). All of them contain essential, economic reserves of Pb derived from sialic crust and calc-alkaline volcanic rocks, as well as Cu and Zn derived from mantle and basaltic crust. At the same time in the island-arc setting of the southern slope of the Great Caucasus, Dogger-Malm Pb-Zn vein type and stratabound deposits were formed, whereas the Liassic Pb-Zn Sadon, Zgid and Holst vein type deposits were formed in the main range of the Caucasus. It is noteworthy that in all deposits there is a prevalence of galena.

In the Western Pontides, the Upper Cretaceous polymetallic stockwork and vein-type deposits Balikasir Balia, Demirbaku, Altinoluk, and Canakkale-Handeress were formed. The mineralization is related to calc-alkaline volcanic rocks and intrusives of an island-arc settings and are characterized by a high abundance of galena and precious metals (Tab.3).

In the Adjara-Trialeti folded zone (Fig.1, 2; Tab.1), characterized by a Late Eocene island-arc setting with calc-alkaline intrusive and volcanic series, Cu, Pb, Zn, Au and subordinate Mo porphyry and vein-type deposits of the Merisi group were formed. The sources of the non-ferrous metals are inferred to be the same as for the above-mentioned island-arc settings.

The volcanic host rocks of the island-arc deposits of the Caucasus and the Pontides are characterized by: low contents of LILE, REE and typical island-arc flat trends for heavy REE, negative anomalies of Nb, and Ti, normal chondritic contents of Zr, Hf and Y, and comparatively high $Sr/^{86}Sr$ ratios of 0.7041 to 0.7045 according to Lordkipanidze et al. (1988). Thus, the Caucasus and Pontides Phanerozoic pre-collisional stage mineralizations are related to oceanic (MORB), intra-arc, and back-arc and island-arc settings. In ocean and intra-arc settings, the mineralization is characterized by basaltic crust and mantle material sources for Cu and Zn. Whereas in island-arc settings and along the southern slope-marginal sea, Cu, Zn, Au and Pb mineralizations were sourced by mantle and sialic and basaltic crusts.

The post-collisional Oligocene and Neogene stages are characterized by fold thrust belts of the fore-range and the southern slope of the Great Caucasus and the Lesser Caucasus, where rare metals deposits with W, Hg, Mo, As, Sb, Pb vein-type, stockwork and porphyry deposits occur, including the W, Mo Tirniauz, Notsarula, Hg-Avadhara and Akhey Mo-Karobi, Sb, As, Au – Zopkhito and Lukhumi, and Mo, Cu, Pb, Zn Kajaran deposits (Figs 1, 2; Tab 2).

Occurrences of precious metals are known in the oceanic settings and in intra-arc and back-arc rifts; however the most significant mineralization and deposits are related to island-arcs and post-collisional settings. Hence, during the process of differentiation and depletion of the mantle, precious metals were distributed between the mantle, and the basaltic and sialic crusts, but mainly accumulated in the sialic crust. This is the reason why the most significant precious metals deposits are related to island-arc and post-collisional settings, where sources of sialic crust prevailed during the process of mineralization. For instance, the richest gold deposits of the Kuskokuim group of Alaska are related to the post-collisional stage and are located in post-accretion terranes according to Gray et al. (1997). The orogenic giant gold deposits of Muruntau, Cumtor, and Chulboi are associated with rare metal (W, Sb, Hg, Mo) mineralization, are also related to the post-collisional stage of the Tethyan ocean evolution. Hence, it is concluded that the sources of gold and rare metals are in the sialic crust.

Oceanic intra-arc and back-arc mineralization lack any Mo and rare metals, as well as Hg, W, and Sb. The highest grades and reserves of Mo are contained in the post-collisional porphyry deposits of Kajaran and Agarak (Tab.2). The post-collisional deposits contain high reserves and high grades of W, Sb, and Hg as well. The latter are totally absent in oceanic, intra-arc, back-arc and island-arc deposits.

By contrast to the belt-thrust structures, where hydrothermal Mo and rare metals deposits occur, the foreland of the Transcaucasus is characterized by Early Oligocene exhalative, sedimentary Mn deposits at Chiatura, Chkhari and Ajameti, and the Nakhchevan Cu-Au sedimentary deposits Finally, Quaternary Au-placers were formed in the valleys of Enguri and Khrami (Tab.2).

3. Discussion

The geodynamic setting of the Caucasus and the Pontides and the related metallogeny of the non-ferrous, rare and precious metals enable us to dis-

Table 3. Nonferrous, rare and precious metals deposits of the Caucasus and Pontides.

Source of mineralization	Reserves	Deposit age	Content of mineralization	Host rocks	Geodynamic setting	Source of mineralization	Reserves
1	2	3	4	5	6	7	8
Mantle		Late Paleozoic – Early Mezozoic	Cu	Tholeiite			Ashikoy: 10.9mln.t
Ashikoy	Ashikoy: 10.9mln.t		Trace elements:	basalt and	Ashikoy	Mantle	ore; grade:2.17%Cu
Bakibaba			Zn, Pb, V, Ni,	black shales			Bakibaba: 1.9mln.t
			Ti, Cd, Co, As				Middle – Upper
Mantle and	Urup: 770 th.t Cu,	Middle – Upper	Cu, Zn,	Basalt-rhyolite;	Urup	Great Caucasus	Devonian
basaltic crust	300 th.t Zn, 2t. Au, 10 th.t Ag, Khudes: 500 th.t Cu, 260 th.t Zn, 40t Co, 4t Au	Devonian	subordinate:	spilite-	Khudes	basaltic crust	300 th.t Zn, 2t. Au, 10 th.t Ag, Khudes: 500 th.t Cu, 260 th.t Zn, 40t Co, 4t Au
Khudes			Au, Ag, Co	andesite-dacite			
Filiz Chai type VMS		Lowe		Tholeiite	Back-arc rift	Mantle	
Filiz Chai		Jurassic		basalts	Marginal sea,	basaltic and sialic crust	Filizchai: 504 th.t Cu, 3.01 mln.t Zn, 1.2 mln.t Pb; 20t. Katsdag: 17.3 th.t Cu, 99.3 th.t Zn, 36.0 th.t Pb; Kizildere: 1.07 mln.t Cu, 3.2th.t Zn
Katsdag	Southern slope of Great Caucasus		Cu, Zn, Pb		with sialic bottom		
Kizil Dere							
Adange							
Kuroko type VMS		Upper		Dacite-rhyolite-andesite	Island	Sialic, basaltic crust.	Madenkoy: 23.06mln.t
Madenkoy		Cretaceous		tuffs	arc	calc-alkaline	ore; grade: 2.88%Cu, 0.32%Pb, 4.34%Zn
Lahanos	East Pontides		Cu, Pb, Zn			volcanics. mantle influence	Lahanos: 2.3 mln.t ore
							grade: 3.59%Cu
							2.38%Zn
							Pb is not calculated
Subvolcanic polimetallic		Upper			Island	Sialic, basaltic crust.calc-	Murgul: 32 mln.t ore
stockwork	East Pontides	Cretaceous	Cu, Pb, Zn	Dacite-rhyolite	arc	alkaline volcanics. mantle	grade: 1.32%Cu,
Murgul						influence	0.1%Zn, 0.05%Pb
Tumiscent stockwork			Cu, Pb, Zn,	Rhyolite dacite		Sialic, basaltic crust.	
polimetallic, gold-copperporphyry, gold (low sulfidation)	Lesser Caucasus	Upper Cretaceous	Au	tuffs	Island arc	calc-alkaline	Madneuli: 800 th.t Cu, 120 th.t Zn, 40 th.t Pb, 28 t Au, Tsiteli Sopeli: 316 th.t Cu, 24.4 t Au, 91.7 t Ag, 179 t Mo
Madneuli						volcanics. mantle influence	
Tsiteli Sopeli							
Polymetallic stockwork and vein deposits				limestone		Sialic, basaltic crust.	Balikesir Balia: 13.5 mln.t. ore
Balikasir Balia,				metaarcos,		calc-alkaline	grade: 4.40%Pb, 4.26%Zn;
Demirbaku				siltstones,		volcanics. and intrusive bodies.	Demirboku: 3.7 mln.t
Altinoluk	West Pontides	Upper Cretaceous	Pb, Zn, Ag, Au	diabases, gabbros, schists, marbles of Permian Lower Triasian ages	Island arc		grade: 3.91%Cu, 3.81%Zn, 0.25%Pb;
Canakkale-Handeresi							Altinoluk: 271 th.t ore
							grade: 8.21%Pb, 6.72%Zn, 25g/t Ag, 5g/t Au;
							Canakkale-Handeresi:
							3.7 mln.t. ore;
							grade: 5.24%pb, 2.05%Zn
Polymetallic stockwork VMS and vein deposits						Sialic, basaltic crust. calc-alkaline	Shamlug: 123 th.t Cu, 5 th.t Pb, 14 th.t Zn; Alaverdy: 125 th.t Cu, Pb and Zn are not calculated
Shamlug, Alaverdy, Akhtala, Kafan	Lesser Caucasus	Middle Jurassic	Cu, Pb, Zn	calc-alkaline volcanic series; andesites dacites, rhyolites	Island arc	volcanics. mantle influence	Akhtala: 6.5 th.t Cu, 19 th.t Pb, 5 th.t Zn
							Kafan: 145 th.t Cu Pb and Zn are not calculated
Molibdenum-copper porphyry deposits							
Guzelyayla	East Pontides	Upper Cretaceous	Cu, Mo	Calc-alkaline	Island arc	Sialic and basaltic crust and calc-alkaline volcanics and intrusive bodies, Mantle influence	186 mln.t. ore
				Volcanics: Basalt, andesite dacite			grade: 0.3% Cu
							0.012 % Mo
							Pb and Zn are not calculated
				Granodiorite and sienite diorite intrusives and Calc-alkaline		Calc-alkaline volcanics and intrusives	
				Volcanics: andesite, thachyandesite trachytes		mantle influence	
Merisi		Upper Eocene					
	Lesser Caucasus		Cu, Zn, Pb, Mo				74.8 th.t Cu, 11 th.t Zn, 9 th.t Pb, 859 kg Au, 15 t Ag
					Island arc		
Vein type	Southern Slope of the Great Caucasus	Dogger Malm	Pb, Zn	Black slates	Island arc	Basaltic and sialic crust	2,8 mln. t. ore;
Kvaisa							Pb 56.2 th. t.
Stratabound							250 th.t. ore;
Brdzirsha	"	"	Pb, Zn	Limestones and marls	Postcollision	Sialic crust	15,5 th.t. Pb;
							23,2 th.t. Zn
Vein type	"	Neogene	Hg	"	"	"	480 th.t.ore;
Avadhara							1353 t. Hg
Akhei	"	"	Hg	"	"	"	824 th.t. ore;
							2546 t. Hg
Karobi	"	"	Mo	Black shales	"	"	55 th.t. ore;
							50 t. Mo
Notsarula	"	"	Mo, W	"	"	"	10,8 th. t. ore;
							50 t. W; 2t Au
Lukhumi	"	"	Sb, As, Au	Calcareous sandstones siltsontes	"	"	150 th.t. ore;
							11,1 th.t. As; 1,8 th.t.Sb; 1,4 th.t.Au
Vein disseminated	"	"	Au, Sb, As, Ag	Black shales	"	"	231,4 th. T. ore; 27,4 th.t. Sb; 8,8 t. Au, 39t. Ag
Zophito							
Tsana	"	"	As	"	"	"	355 th.t.ore;
							55th.t. As
Vein, stockwork							5 mln.t Cu;
Tirniauz	Forerange of the Great Caucasus	"	Mo, W	Granodiorite porphyry, rhyolite	"	"	1 mln.t.Mo;
							Pb and Zn are not calculated
Porphyry							1.8 bil.t. ore;
Kajaran	The Lesser Caucasus	"	Cu, Mo, Zn, Pb	Granodiorite porphyry, montsonites	"	"	4,48 mln.t. Mo
							Mo 0,25%
Vein, stockwork							16 mln.t ore,
Zod							125,5t.Au,
	"	Oligocene	Au, Mo, Pb, Cu	Granodiorite porphyry	"	"	160t. Ag
							Au 6,2 g/t,
							Ag 10 g/t
Vein, stockwork				Diorite			1,6 mln.t ore,
Mehradzor				porphyry			59,8t.Au,
	"	"	Au, Mo, Pb,		"	"	29,7t. Ag
							Au 8 g/t,
							Ag 10 g/t

cuss the sources of mineralization in the various settings. The mantle source of copper is evident for cupriferous Cyprus type deposits of oceanic settings. The Kure complex mainly consists of copper ores, and only traces of Zn and Pb. Mineralized fields of the modern ocean, investigated by Rona and Scott (1993) and Mozgova et al. (1999), predominantly contain copper, whereas zinc is subordinate and lead is absent or only present in traces. Gold and silver can also be present, but there are not any rare metals, such as Hg, W, Sb, or Mo. According to Hutchinson (1973), the formation of Zn-rich cupreous pyrite bodies in oceanic settings occurs during the early stage of rifting, when rifting between continental plates is small. In this setting, zinc may be derived from adjacent basaltic crust. Zinc contents decrease in younger (higher stratigraphic) bodies formed during subsequent stages, with more advanced rifting. Therefore, the source of zinc is in the basaltic crust and it is confirmed by the fore-range Beshi type Cu-Zn deposits of the Urup group related to intra-arc rifting. Zinc in the intra-arc setting may be extracted from the subducted basaltic slab causing stirring up mantle diapir and intra-arc rifting. However, zinc is also derived from rifted basaltic crust during spreading.

Lead mineralization is related to settings with active participation of sialic crust, such as island arcs and post-collisional settings. Economic lead mineralization is also known in the back-arc, marginal sea of the southern slope of the Great Caucasus, where participation of sialic crust is obvious. The marginal sea bottom is underlain by a thin sialic crust and calc-alkaline acid volcanic rocks according to Lordkipanidze (1980), and Lomize and Panov (2002), which is inferred to be source of lead in the Filiz-chai Pb-Cu-Zn deposit. Rare metals such as Hg, W, Sb, and Mo are related to island arc and post-collisional settings, where sialic crust is more predominant. Rare metal mineralization is typically absent in oceanic and intra-arc settings and is unknown in back-arc situations, where the role of sialic crust is subordinate.

The sources of precious metals (Au, Ag) mineralization are also interpreted to be ultimately of mantle and basaltic crustal source, because their subordinate mineralizations are present in oceanic mineralized fields according to Rona and Scott (1993) and in intra-arc and back-arc rifts of the Caucasus. However, the most significant gold mineralization occurs in island-arc and post-collisional settings, where sialic crust is predominant. Indeed, the richest gold deposits of the Caucasus are related to island arc post-collisional settings, including Madneuli, Sakdrisi, Cheratepe, Zod and Meghrazor (Fig.1; Tab.1). The giant gold deposits of Muruntau, Kumtor, Chulboi, Daugiztau, Amantaitau, etc. are related to the Altaid orogenic collage according to Yakubchuk et al. (2002), which corresponds to a post-collisional setting. The gold deposits are associated with rare metals, including W, Sb, Hg, and Mo. The mineralization is related to granitoid intrusions emplaced in the back-arc basin, carbon-rich sedimentary sequence. Magmatic events upgraded and added further precious and rare metals mineralization into structurally favorable traps.

4. Conclusions

The data about base, precious and rare metal mineralization in the various geodynamic settings during the Phanerozoic evolution of the Caucasus and the Pontides allows us to make the following conclusions:

1. The ultimate source of Cu must be mantle and ophiolites. This is confirmed by the Cyprus type oceanic rift deposits. They exclude any participation and influence of sialic crust during mineralization. The influence of basaltic crust source for Zn is subordinate, and occurs mainly during the first stages of spreading. Zn derived from the basaltic crust, is significant in intra arc mineralization. Au and Ag, participation is subordinate. Therefore in MORB and intra-arc settings Cu and Zn mineralizations are predominant.
2. The source of lead is in sialic crust and in calc-alkaline volcanic enriched with radiogenic lead. The content of lead in the basaltic crust and mantle is thought to be insufficient for producing essential galena mineralization.
3. In the island arc and marginal sea (back-arc rift) settings where sialic crust is widespread essential (economic) reserves of galena and precious metals occur, as well as Cu and Zn, because basaltic crust and mantle sources always participate in island arc ore formation.
4. The rare metal (Hg, W, Sb, and Mo) mineralizations are related to post-collisional settings as well as precious metals – Au and Ag where sialic crust is a major component.
5. Gold mineralization is common in all pre-collisional and post-collisional settings. However the most significant gold deposits developed in island arc and post-collisional settings with abundant sialic crust participation during mine-

ralization is prevalent. Therefore gold is accumulated in sialic crust and it is the main source of precious metals.

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References

Adamia Sh. A., Chkotua T., Kekelia M, Lordkipanidze M and Shavishvili I., 1981.Tectonic of the Caucasus and adjoining regions: implication for the evolution of the Tethys ocean. Journal of Structural Geology, 3, 437-447.

Adamia Sh. A, Ylmaz A, Lordkipanidze M, Shavishvili I, Chkotua T and Chabukiani A., 1997. Geodynamic evolution of the Black sea region. International Colloquium, Ankara, Turkey, 19-20 November, 8-9.

Gray I.E., Gent C. A. and Snee L.W. 1997. Epithermal mercury-antimony and gold-bearing vein bodies of Southwestern Alaska, Economic Geology. Monograph 9, 287-305.

Guner M. 1980. Massive Sulfide Ores and geology of Kure area, Pontides (N. Turkey), MTA Bulletin, 93/94, 65-109.

Hutchinson R. W. 1973. Volcanogenic sulfide deposits and their metallogenic significance. Economic Geology 68, 1223-1246.

Lomidze m. G.. and Panov d. I. 2002. Amagmatic initial stage of subduction at the Crimea-Caucasus margin of the Tethys. ”Geotectonica” N4 (in Russian with English abstract), 78-92.

Lordkipanidze M.B. 1980. Alpine volcanism and geodynamic of the Central Segment of the Mediterranean Folder Belt. (in Russsian with English abstract) Tbilisi. “ Metsniereba”, 160p.

Lordkipanidze M.B., Meliksetian B. and Djrbashian R. 1988. Mesozoic-Cenozoic Magmatic Evolution of the Pontian-Crimean-Caucasian Region. France, Nouvelle série, Paris 154, 103-24.

Mozgova N.N., Efimov A.V., Borodaev Y.S., Krasnov, Cherkasov G,A., Stepanova T.V. and Ashadze A. M. 1999. Mineralogy and chemistry of massive sulfides from Logachev Hydrothermal field (140 45’N Mid-Atlantic Ridge). Exploration and Mining geology. I. M. Franklin, I.P. Richard ed., 8, N3, 4, 375-395.

Rona P.A. and Scott S.D.. 1993. Preface of the Special Issue on Sea from hydrothermal Mineralization: New Perspectives. Economic Geology. 88, 1933-1976.

Shavishvili I.D.. 1983. Variscan volcanism in the Caucasus. IGCP Project N 5, Newsletter, 169-179.

Skripchenko N.S. 1972. Hydrothermal-sedimentary sulfide ores of the Basaltoid Formations. (in Russian with English abstract), Moscow, 211p.

Tarney J., Saunders A.D.,Weaver S.D. 1977, Geochemistry of volcanic rocks from the island arcs and marginal basins of the Scotia arc region. In: Island arcs, deep sea trenches and back-arc basins. M. Talvani, W.C. Pitman III (Eds). Washington, p. 367 - 395

Ustaomer T. and Robertson A. (1997), Tectonic Sedimentary Evolution of the North-Tethyan Margin in Central Pontides of Northern Turkey. In: Regional and Pertoleum Geology of the Black Sea and surrounding region. Published by the American Association of Petroleum Geologist. Tulsa, Oklahoma, USA 74101, 255-290.

Yakubchuk A., Cole A., Seltman R.. and Shatov. 2002. Tectonic setting, characteristics, and regional exploration. Criteria for gold mineralization in the Altaid orogenic Collage: The Tian Shan Province as a key Example. Society of Economic Geologists, Special Publication 9,177-201.