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Abstract

Ophiolitic formation of Albanides, named as Mirdita zone, represents a compact segment of oceanic lithosphere of Middle-Upper Jurassic. Based on petrographic, geochemical and metalogenical features two types of belts are distinguished: western MORB and eastern SSZ types. In fact, structural and geological units as well as many other elements have shed light on lack of a sharp separation between the two belts.

Recent investigations have evidenced that different ultramafic massifs of western ophiolitic formation, represent an evident variation of their composition from harzburgite to lherzolitic -types. This composition reflects a different grade of partial melting of upper mantle. Peridotites show a high variability, from 0.3 - 3.8 wt.% Al_2O_3, varying from small to highly extreme depleted peridotite.

On the contrary, Albanian eastern belt, it seems to be formed by a more homogeneous hartzburgitic mantle.

Detailed petrologic and metallogenic investigations have evidenced that this belt changes also from one massif to another, naturally at a smaller level, therefore it is easier to be named relatively homogeneous. It is distinguished by a higher melting degree, chiefly of hartzburgitic-type, characterized by whole and thick ultramafic section, as well as by metalogenic variety, mostly of metallurgic-type of chromite mineralization. It is supposed that rock-forming and mineraluzation processes have been developed not uniformly along the ophiolitic belt.

Keywords: *Chromite, ophiolite section, SSZ-type.*

1. Introduction

Albanides, the geological structure of Albania situated in south of Shkodra-Peja transversal fault, as a segment of Dinarides-Hellenides arc, are characterized by the presence of the ophiolitic formation.

The most important of geological event of Albania during Jurassic has been ocean spreading in Mirdita zone. Western belt is thought to have been composed by an ocean ridge, the eastern one by development of an immature island arc (Beccaluva *et al.*, 1994; Shallo *et al.*, 1995; Kodra *et al.*, 1995). During Middle Jurassic, intraoceanic subduction was associated with formation of metamorphic sole. In the Early Tithonian, due to the compression regime, overlapping (obduction) of ophiolite occur.

The Albanian ophiolite formation has classically divided into western and eastern belts. The western ophiolitic belt, similar to western Mediterranean type as MORB-type ophiolite, is characterized by presence of lherzolite ± hartzburgite type, plagioclase - rich basal cumulates, TiO_2 - rich basaltic lavas (1.5 - 2% TiO_2), and by scarce chromite mineralization, chiefly of Al - rich refractory type. A particular Fe - Ti mineralization, related to Fe-gabbro, is also present. For this belt is characteristic

the crystallization order: olivine+chromite+plagioclase+clinopyroxene and geochemical features of association high-Ti basalts, that an oceanic spreading system without any influence of subdacted related processes (Beccaluva *et al.*, 1994; Shallo *et al.*, 1995; Hoeck *et al.*, 2002). The western ophiolite belt is originated from magmatic source that was less depleted, 5-10% (Koller *et al.*, 2009; Çina, 2010).

The eastern belt is si milar to eastern Mediterranean-type, as IAT-boninitic, SSZ setting of ophiolite-type, is characterized by presence of hartzburgitic-type mantle, pyroxene-rich basal cumulates and by TiO_2 poor lavas of boninitic affinity with range down of 0.3%.

This ophiolitic belt is particularly distinguished by high potential chromite-bearing mineralization of Cr-rich metallurgic type. Other types of mineralizations are occur also such as PGM and Ni-sulfide, associated with PGE. As is suggested by Nicolas *et al.* (1999), the slow spreading, oxygen fugacity and the cool action of overlayered crust have played their role in high chromite concentration.

The eastern belt is most depleted, about 25%. This belt, the petrologic characteristics of the cumulate sequence, and the strongly underlying depleted mantle tectonics, along with geochemical features of lavas, indicate a suprasubduction generation of parental magmas (Beccaluva *et al.*, 1994; Shallo *et al.*, 1995). Their crystallization order is olivine + chromite, followed by clinopyroxene and/or orthopyroxene and then plagioclase. Generation of such magmatic system implies intra-oceanic subduction of a pristine lithosphere.

2. Geological setting

The Albanian ophiolitic formation is situated in eastern part of Albania, about 250 km long. Its northern part is bounded by Shkoder - Peja transform fault. The Labinot - Diber transversal fault zone separates the northern and southern ophiolitic formation.

The Albanian ophiolite formation is situated in the western flank of Korabi - Pelagonian microplate. The contact zone of this formation is usually marked by a narrow belt of metamorphic rocks of amphibolites, green schist facies and pre-ophiolitic volcano-sedimentary series.

The primary sedimentary cover of Albanian ophiolite consists of Late Jurassic radiolarian charts and flyschoidal sediments of Tithonian to Early Cretaceous age (Shallo *et.al*., 1995; Kodra *et al.*, 1995). According to recent micro-paleontological investigations (Chiari *et al.*, 2004) radiolarian chart formation located on top and within volcanics, in upper part is older than Upper Bajocian and younger than Lower Oxfordian, therefore it is thought to be of Middle Jurassic. The age of Albanian ophiolite calculated by K - Ar method, is 160 ± 7.5 ml years, and by Rb - Sr method is 158 ± 4.1 ml years (Tashko *et al.*, 1990, CRPG, Nancy, France).

3. Petrological and metalogenic features

Eastern ophiolitic belt consists of some ultramafic massifs, from Tropoja - Has of northeastern area, to the south and southeast, where are situated Kukes, Lura, Bulqiza, Shebenik-Pogradec massifs and some other occurrances in Bitincka, Devolli area (Figure 1).

Based on geophysical measurements, ophiolitic formation of eastern belt is very thick, 5 - 7 to 10 - 12 km toward northeast.
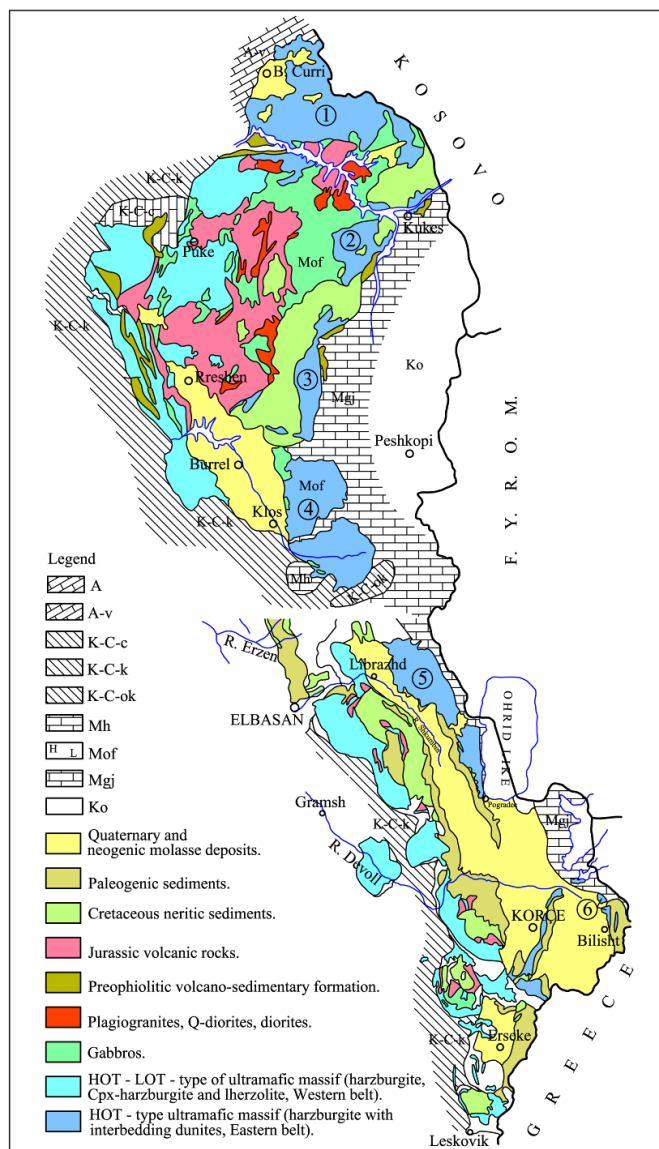
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Figure 1 - Albanian ophiolitic formation. A-Albanian Alps; K-C- Krasta-Cukali zone; M-Mirdita zone: M-of- Mirdita ophiolites; Ko-Korabi zone. Ultramafic massifs, eastern ophiolitic belt: 1-Tropoja-Has, 2-Kukesi, 3-Lura, 4-Bulqiza, 5-Shebenik-Pogradeci, 6-Bitincka.

Dominated rocks of this area are mantle ultramafics, chiefly mantle harzbugites, less dunites and transition zone dunites. Ultramafic cumulates, dunites, pyroxenites and wehrlites are thin, about 50 – 200 m. Other part of crust sequence, the mafic, is very thick, about 1500 - 1800 m. It should be noticed that in northeastern zone, occurs a large gabbro massif, named Kaptena, which covers a

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territory of 350 km². This sequence is composed by different gabbro rocks, even amphibole gabbro and quartz gabbro. Small quartz diorite and plagiogranite massifs have intruded in gabbro sequence and in lower part of volcanic unit (Figure 2).
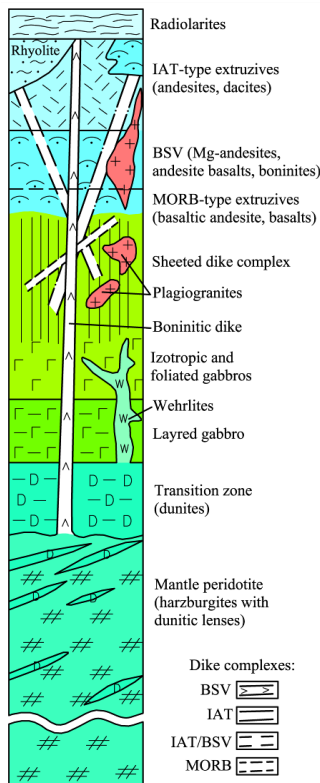

Figure 2 - Generalized column of eastern Albanian ophilitic belt.
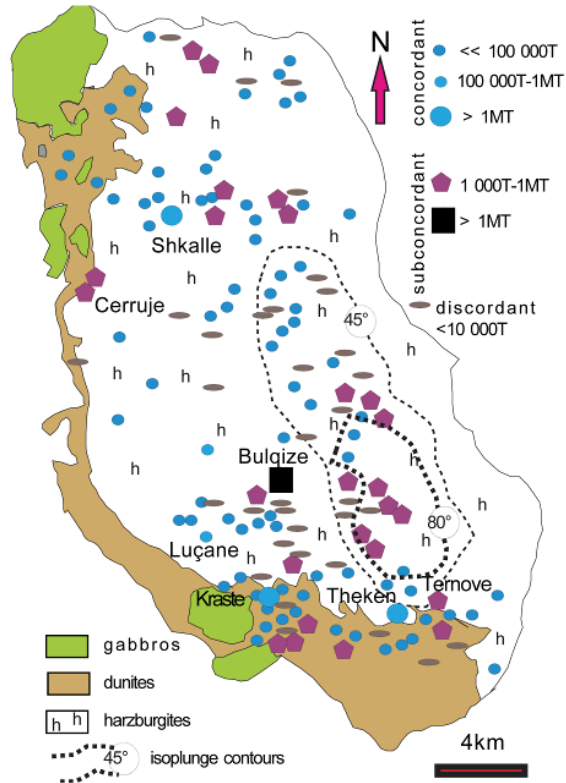

Figure 3 - Distribution of chromite ore bodies and their structural types of Bulqiza massif.

Extrusive volcanic rocks of IAT- type, with a considerable thickness of 1500 - 2200 m, are represented by basalts, basalt andesites, boninites, dacites and rhyolites.

Presence of sheeted dyke complex is another distinctive feature of eastern belt. It is situated in northeastern axial part wth 1000 - 1200 m thickness. They perform an IAT boninitic affinity, but are also of MORB type (Manika, 1994; Shallo *et al.*, 1995). Presence of boninites in eastern belt represents a significant petrologic interest.

Some ultramafic massifs show a relative variation regarding to rock-types, thickness of their sequences, metallogenic features, mineralization types, their potential and shapes of ore bodies. General characteristics of eastern belt are hartzburgite composition of mantle, highly magnesium composition of rock-forming minerals, of enstatite En_{90-92}, as well as forsterite Fo_{90-93}, a few Al_2O_3 and CaO (tenths of %) and very stable composition of chromite ores.

3.1. Tropoja-Hasi massif

Tropoja - Hasi ultramafic massif has a special position, since it appears as a common node for two belts. This massif is large and is composed by mantle hartzburgites, as well as by transition zone

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dunites. In the central part of the massif occur pyroxenites and gabbro dykes. Main mineral is chromite, related to mantle hartzburgites and dunites of super-MOHO zone. Many occurrences with some average size and some deposits from 0.5 to 1 milion ton reserves occur. Ore bodies have lenticular - platy shapes and composed by ores with varied textures, whereas chromite itself belongs to Cr-rich type with high grade metallurgic ores. Average chemical indicators are as following (Table 1): Cr/ (Cr + Al) = 0.79-0.82, while Mg/ (Mg + Fe^{2+}) = 0.60 - 0.65. Some occurrences of chromite, related to relatively deeper mantle hartzburgites, belong to Al-rich-type with (Cr/ (Cr +Al) about 0.65. A special chromite type is that of schlieren chromite, associated by pyroxenite veins, distinguished for euhedral crystals of chromite, at size of some mm, and with highly Fe content Mg/ (Mg + Fe^{2+}) = 0.40 – 0.45 and FeO^{tot} = 27.4 – 31.5wt.%. Another metalogenic distinction of Tropoja - Hasi massif is presence of unique mineralization in Albanian ophiolites, such as PGE, which occurs within schlieren chromite related to pyroxenite veins and magmatic brecciated dunites (Bregu i Bibes, Zherge, Shpati i Dajcit deposits).

Albanian eastern ophiolite belt; 1, 4, 6, 7, 9 and 10- chromite related to mantle hartzburgites and transition zone dunites from ultramafic massifs; 2- Fe-rich chromite PGE-bearing ores; 3- Al-rich chromite related to deeper Cpx-hartzburgites; 5 and 8- Al-rich chromite related to cumulate ultramafics; 11- Al-rich chromite related to lherzolite western belt massifs (Çina *et al.*, 1986; Çina 2010); Vourinos (Greece) massif: 12-Xerolivado (Economou *et al.*, 1986).

Table 1 - Representative electron microprobe analyses of chromite.

	1	2	3	4	5	6	7	8	9	10	11	12
SiO_2	0.05	0.06	0.09	0.08	0.06	0.07	0.05	0.06	0.05	0.06	0.05	0.25
Al_2O_3	10.12	9.38	21.49	9.91	13.68	10.26	10.06	22.97	10.72	9.92	23.43	9.85
Cr_2O_3	59.06	50.74	46.7	59.22	52.52	60.45	60.45	42.92	58.76	60.66	44.53	59.58
Fe_2O_3	3.96		5.2	4.3	4.18	2.03	1.85	4.18	5.62	2.57	2.88	4.78
TiO_2	0.05	0.15					0.2	0.26	0.06	0.15	0.19	0.18
MgO	15.32	7.54	17.35	14.88	13.57	14.84	14.62	15.81	16.58	12.79	15.71	10.87
FeO	11.02	31.3*	8.32	11.69	15.74	12.58	12.92	12.86	7.9	13.20	12.40	13.05
MnO	0.16	0.4	0.31				0.2	0.17	0.37	0.33	0.16	0.66
NiO	0.05	0.18	0.05			0.1	0.16	0.17	0.06	0.13	0.22	0.13
Total	99.99	99.75	99.51	100.1	99.75	99.8	99.95	99.54	100.1	99.81	99.57	99.35
Al	3.083	2.887	6.113	3.037	4.2	3.151	3.066	6.595	3.095	3.033	6.769	2.968
Cr	12.07	11.05	8.908	12.135	10.928	12.451	12.363	8.261	11.78	12.42	8.630	12.043
Fe^{3+}	0.77	2.018	0.949	0.838	0.828	0.398	0.36	0.766	1.068	0.501	0.531	0.920
Ti	0.039	0.028					0.039	0.048	0.011	0.03	0.070	0.069
Mg	5.59	3.114	6.213	5.459	4.799	5.432	5.406	5.675	6.228	4.957	5.452	4.667
Fe^{2+}	2.358	4.815	1.674	2.466	3.201	2.536	2.698	2.6	1.667	2.941	2.474	3.142
Mn	0.011	0.097	0.064				0.044	0.035	0.08	0.074	0.032	0.161
Ni	0.020	0.035	0.01			0.032	0.033	0.034	0.012	0.028	0.042	0.030
Cr#	0.8	0.8	0.6	0.8	0.72	0.8	0.8	0.53	0.79	0.8	0.55	0.80
Mg#	0.7	0.39	0.78	0.67	0.60	0.68	0.66	0.68	0.78	0.63	0.56	0.60

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The PGE amount is about 2000 ppb up to over 10.000 ppb (Ohnenstetter *et al.*, 1991; Neziraj, 1992). PGM are dominated by Pt + Fe alloys, commonly isoferroplatinum and tetraferroplatinum, while other minerals as alloys of PGE + BME are less contained. The other characteristic of this mineralization is elevated content of Rh (4-5%). The composition of olivine: from mantle hartzburgites Fo=91.53-91.83; from mantle dunites Fo=91.32-92.93; Opx of mantle hartzburgites En=89.33-90.77; Cpx Wo=47.2-49.6, En=49.65-49.96.

Some quartz-sulfide veined mineralizations of Cu and several lens-like ore bodies of Cu - Ni sulfide-type are related with gabbro - norite massifs.

3.2. Kukesi massif

The following ultramafc massif, Kukesi massif further south, is smaller, about 80 km^2. In northern and western side it contacts with gabbro rocks, while to the east occur Triassic and Cretaceous limestones.

The distinguishing feature of this eastern ophiolitic massif is specific formational composition. It is composed partly by mantle harzburgites, but is dominated by dunite of transition zone, up to 800 m thick. Between dunite and gabbro massifs is observed a thin belt of 100m thickness, composed mostly of wehrlites.

Kukesi ultramafic massif is also chromite-bearing. Several occurrences and any small chromatic deposit are situated within mantle hartzburgites. On the contrary, higher chromite-bearing potential belongs to thick dunitic sequence. There are also evidenced some horizons of layered bodies, composed of disseminated, schlieren and banded ores, with micro to fine-grained texture. Chromite belongs to Cr-rich metallurgic type, while its ore is low grade, containing 15 - 25% Cr$_2$O$_3$. Disseminated and banded chromitic ores of like-layered shape ore bodies are observed also in thick dunite lenses, situated in upper parts of hartzburgite - dunite sequence. The size of some chromitite ore bodies reach to 1000 m in strike, and perform a gentle dip. In dunite, close to the contact with gabbro massifs is observed Ni - As maucherite mineralization.

3.3. Lura massif

Lura massif, situated in the south, is also small. It covers an area less than 100 km^2. It is bounded to the east by Triassic limestone, whereas to the west is covered by Cretaceous limestones. This massif, consist mainly of mantle hartzburgites while dunites of the transition zone are very limited. Its chromite-bearing potential is limited, since there are only some occurrences and any small chromite deposit. The chromite belongs to Cr-rich metallurgic type (Table 1).

3.4. Bulqiza massif

Bulqiza ultramafic massif is situated at the west of Korabi microplate. The contact zone is usually marked by narrow belt of ultrametamorphic rocks of amphibolites and green-schist facies. The western flank is covered by molasse sediments of Burreli depression, whereas in southwestern flank, are located Triassic limestones. Further south, the Labinot - Diber transverse zone divides the Mirdita ophiolite belt in two sectors.

This massif covers a large territory, about 350 km^2 while the ultramafic section is very thick about 3-5 km.This massif is dominated by mantle hartzburgites with any dunitic lens. The upper part of hartzburgite sequence switches to a hartzburgite - dunite composition, and above continue dunites of transition zone, situated on southern and western part of the massif. This sequence has a considerable thickness, about 300 - 500 m. Further on are observed cumulate ultramafics, plagioclas dunites, pyroxenites and wehrlites, not very thick (50 - 150 m). Some small massifs of gabbro rocks occur in the western edge of the massif. In addition to these, for Bulqiza massif is characteristics presence of intrusive ultramafic wehrlitic bodies (Bebien *et al.*, 1995).

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There is a high level of magnesium in Bulqiza massif composition since rock-forming minerals are orthopyroxene and olivine. In addition, they are enstatite En_{90-92} and forsterite Fo_{90-93} mineral-types respectively, whereas olivine of chromitite is extremely forsteritic Fo_{93-96}.

The grade of partial melting of mantle, results to be very high about 25% (Beqiraj *et al.*, 2001). Another distinguishing feature of Bulqiza ultramafc massif is its metallogeny, which can be proved by presence of highly intensive chromite mineralization, as well as some other mineralizations, such as PGE and Ni-S (Karaj, 1992; Çina, 2010). Chromite mineralization is related with some sequences of ultramafic section, concretely in mantle hartzburgite, hartzburgite - dunite/or mantle dunite - hartzburgite, dunite of transisition zone and in ultramafic cumulate sequence. Thin Cr-picotite bands are observed also in troctolites.

In Bulqiza massif occur many occurrences and some middle sized, large and very large chromite deposits. Among them can be mentioned Bulqiza deposit, which in resources and extraction reaches about 25 milion ton. The highest chromite mineralization is related mainly to mantle hartzburgites and partly with dunites of transition zone. Ore bodies are lens-like - platy shaped, whereas some other ore bodies are platy folded (Bulqiza deposit) and pencil-like (Shkalla deposit). They are very large: ore bodies of Bulqiza - Batra deposit are 5 km in strike and 500 - 1200 m dip. Ore bodies are exploited from an altitude of 1570 m, down to 200 m, though resources are located down to 300 m below sea level. The principal ore body of Shkalla deposit is oval - shaped of horizontal section, about 25 m, whereas in dip 1500m. In dunite sequence of transition zone are observed some horizons of layered bodies, composed by low grade, disseminated, schlieren and banded ores (Krasta deposit). According to structural classification are evidenced concordant, subconcordant and discordant chromite ore bodies (Meshi *et al.*, 2005; Çina and Meshi, 2013) (Figure 3).
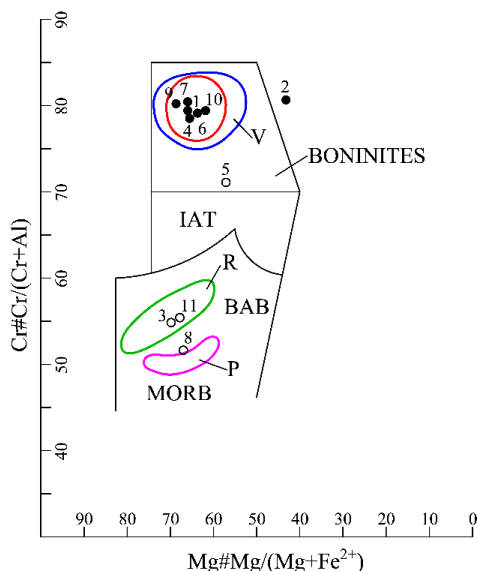

Figure 4 - Cr# versus Mg# of chromite from Albanian chromitite, eastern ophiolitic belt (1- 11) and average composition of Vourinos massif (V), Rodiani (R) area and Pindos massif (P) (Economou *et al.*, 1986) with reference to boninitic lavas from western Pacific, IAT, BAB and MORB environments (after Dick and Bullen, 1984).

Almost on the whole chromite of this massif belongs to Cr-rich metallurgic type, with Cr/(Cr + Al) averagely 0.78-0.82 and Mg/ (Mg + Fe^{2+}) averagely 0.61-0.68 (Figure 4). Difference is at The

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chromite of deposits occur in cumulate ultramafics is composed by A-rich type, Cr/(Cr + Al), about 0.52 (Çina *et al.*, 1986; Çina 2010). Olivine of mantle hartzurgites Fo=90.80-91.60 and from mantle dunites Fo=91.73-92.74; Opx of mantle hartzburgites En=89.5-91.0 and Cpx Wo=47.08-47.75 En=49.09-49.7; olivine of chromitites Fo=93.98-96.59.

Another characteristics of Bulqiza massif, is presence of Ni-S, pentlandite mineralization, occurs as disseminations in dunite + chromite sequence of transition zone. With this mineralization are associated PGE in high quantity, reaching to 2200 ppb (Krasta deposit). Similarly another mineralization is that of chromite, associated with Ni - sulfide and PGE, reaching to 9000 ppb. This mineralization is related with cumulate ultramafites of western side of the massif were occur Cerruja, Rrasa Martin, Kunji i Gjate deposits (Ohnenstetter *et al.*, 1991; Karaj, 1992).

3.5. Shebenik-Pogradeci massif

At southeastern end of ophiolitic belt, is situated Shebenik - Pogradec ultramafic massif, dominated by mantle hartzburgites. Other rock components, dunite of transition zone, are limited. This massif contains some chromite occurrences and deposits with reserves vary from 0.5 to 1 mln ton, composed by average to high grade ores (Katjel and Pojska deposits). This mineralization is related with mantle hartzburgites and only some chromite occurrences occur in dunites of transition zone. Chromite, for both groups of mineralizations, belongs to Cr-rich type, Cr/ (Cr + Al) = 0.80 – 0.81, whereas Mg/ (Mg + Fe^{2+}), 0.63 – 0.68. This area of Librazhd-Pogradeci is distinguished also for presence of a large Fe – Ni mineralization and particularly of Ni-silicate lateritic type.

4.6. Vourinos massif

In Greek territory as the continuation of Albanian eastern ophiolitic belt is situated the largest Vourinos ultramafic massif covering an area of 450 km^2.

Based chiefly on geochemical investigations (Beccaluva *et al.*, 1984; Konstantopoullo and Economou-Eliopoulos, 1990), the Jurassic ophiolites have been proposed as supra-subduction and island arc composition.

The Vourinos ophiolite contains the largest producing chromite mines in Greece. Chromite ores are related with tectonite and cumulate parts of ophiolite section. Here ores occur as minor layers in dunite bases.The grade of Cr$_2$O$_3$ in chromitite ores vary from 12-18-25%. As for disseminated and schlieren ores, is 35 - 50%. All economic concentrations are found in 2-3 km thick stratigraphic zones at the below the cumulate-tectonite contact. Chromite deposits are related with dunite host rocks of two types, as following: cumulate rocks, associated with ophiolitic magmatic suite and deformed bodies within mantle level sequence of ultramafic tectonites (Economou *et al.*, 1986; Rassios *et al.*, 1990).

In Vourinos massif, most of chromite mineralization belongs to C-rich type with Cr/ (Cr + Al) 0.79 - 0.82, whereas Mg/ (Mg + Fe^{2+}), averagely 0.62 - 0.68 whereas some other types related with cumulates, are composed of chromite of Al-rich type with ratio Cr/ (Cr + Al) 0.58, Mg/(Mg + Fe^{2+}) 0.63. Chemical composition of chromite ores leads to the idea, that Vourinos is formed from an environment, characterized by a higher grade of partial melting, that's why this eastern ophiolite zone contains Cr-rich type chromite ore (Economou *et al.*, 1986). The PGE content, related to chromitite, is very low, about 100 - 200 ppb, whereas the Chondrite normalized patterns show similarity for chromitite of Bulqiza, Vourinos, Turkey and Oman (Economou, 1983, 1986; Ohnenstetter *et al.*, 1991; Alliu *et al.*, 1994).

The Pindios massif as southern continuation of Albanian western ophiolitic belt contains a few of Al-rich chromite occurrences (Economou-Eliopolis and Vacandios, 1995) any of them are metamorphoused (Kapsiotis *et al.*, 2007).

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5. Conclusions

The Albanian eastern ophiolitic belt is formed by relatively homogenous hartzburgite mantle, nevertheless its evident the lithofacial and metallogenic variation along north-south direction.

This relatively variation of Albanian eastern ophiolitic belt was conditioned to a certain grade of different degree of partial melting of upper mantle, from the various intensity of mantle-peridotite residue action, by degree of development of magmatic cameras and from diverse activity of magmatic and post magmatic mineralizing processes.

The high chromite-bearing potential and the Cr-rich-type is conditioned by chiefly high magnesium and hartzburgitic composition of upper mantle as well as by high grade of its melting. The slow spreading, oxygen fugasity and the cool action of over layered crust have played also their role for this high chromite concentration.

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