PECULIARITIES OF THE ULTRABASIC ROCK MAGNETISM AND PALEOMAGNETISM DATA OF ALBANIDES OPHIOLITE

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Abstract

In Albania was gained a good experience for the geophysical exploration of chrome, copper and other solid mineral deposits, which are concentrated in the ophiolitic formation. For their exploration have been performed integrated geological-geophysical and geochemical ground and underground surveys. The geophysical complex for exploration was included gravity, magnetic and IP surface mapping at different scales, and the electrical and underground surveying. Underground surveying was carried out for the search around mine works and bore holes. In order to get the geophysical documentation of the boreholes, are observed the magnetic field, the gravitational field, the IP, the electromagnetic waves, the scattered gamma radiation and the neutron activation. In the complex of geophysical exploration are included gravitational and magnetic regional mapping at different scales and petrophysical studies, including density, magnetisation, electrical resistivity, induced chargeability, and radioactivity of ores and rock formations.
In this paper are generally presented the peculiarities of the ophiolite magnetization in condition of Alpine Folded Belt, especially pale magnetic studies results in Albania.

1. Introduction

In the paper are presented the peculiarities of the ophiolite formation magnetization in condition of Alpine Folded Belt, including paleomagnetic studies results in Albania. In Albania was gained a good experience for the geophysical exploration of chrome, copper and other solid mineral deposits, which are concentrated in the ophiolitic belt. For their exploration carried out integrated geological-geophysical and geochemical ground and underground surveys. The geophysical complex for exploration includes gravity, magnetic and IP surface mapping at different scales, and the electro-magnetic underground survey. Underground survey was carried out for the search around mine works and bore holes. In order to get the geophysical documentation of the boreholes has been used their well logging: electric, electro-magnetic, gamma, gamma-gamma, and radioactive logging, and magnetic surveys. Important part of the complex of geophysical direct explorations are included gravitational and magnetic regional mapping at different scales and petrophysical studies, including density, magnetism, electrical resistivity, induced chargeability, and radioactivity of ores and rock formations.

2. Study methodic

Study of magnetism of the rock is conducted by measurements of the magnetic susceptibility in outcrops in the field and induced and remnant magnetization determination in the samples collected in rocks of different formations from all Albanides ophiolite massifs. Sampling for the paleomagnetic studies have been carried out in fresh ultrabasic rocks, in gabbro, and in volcanic rocks of the Mirdita tectonic zone during 1995 year (Frashëri A, and Bushati S. 1995). Have been determined space orientation of the vector of magnetic magnetization, and for representative samples carried out thermal cleaning and demagnetization in the magnetic field of the alternative electric current. Sampling sites were located in six characteristic profiles on ophiolitic missives from south to the northern Albania. Magnetic properties of the rocks have been determined in Geophysical Chair, Faculty of Geology and Mining, Polytechnic University of Tirana, and Geophysical-Geochemical Center of Tirana. Paleomagnetic samplings were carried out by their joint team. Paleomagnetic determinations were performed in Paleomagnetic Laboratories of Leoben University, Austria, Aristotle University of Thessaloniki, Greece, and Institute of Geophysics, Academy of Sciences, Prague.

3. Results analyse

The ophiolite formation, with two ultramaphic massifs belt extends in the territory of Mirdita tectonic zone of the Albanides. The eastern ultramaphic belt has two different geological-petrological-geochemical and metallogenic sequences: tectonic sequence in lower part of geological cross-section in about 1000 - 2000m thickness and that of cumulate sequence, over tectonic one, is about 500 - 1000m thickness (Fig. 1, 2) . The lower part of tectonic sequence represents the hartzburgite facies with dunitic alternation, composed of fresh rocks in the lower levels up to medium serpentinized rocks in upper levels. The dunites represent lenses of thickness of some meters, stretching over hundreds of meters. These alternations represent 10-15 % of the rock mass. A narrow alternated hartzburgite-dunitic facie, with metallurgic chromite, is situated over the hartzburgite. The cumulate sequence is situated with angular unconformity over tectonite (petrological MOHO).

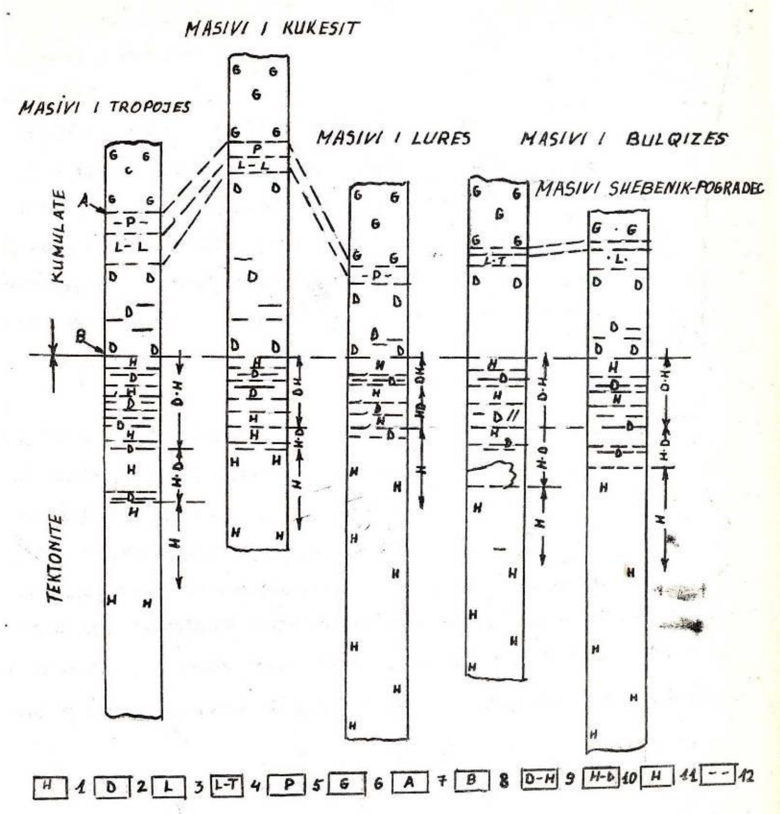

Fig. 1. The correlation scheme of the schematic geological sections of the eastern belt of ultramaphic rocks (Hallaçi H. et al, 1989).

1.Hartzburbite; 2.Dunite; 3.Lherzolite; 4.Lherzolite-troctolite; 5. Pyroxenite; 6. Gabbro; 7. MOHO velocity discontinuity; 8. MOHO petrological discontinuity; 9. Dunitic-hartzburgite facies of tectonites; 10. Harzburgite-dunitic facies of tectonites; 11. Hartzburgite facies of tectonites; 12. Mineralization levels.

The ultrabasic rocks have a magnetism, which changes in a broad band, conditioned by the presence of the ferromagnetic mineral accessories, mainly by secondary magnetite and less by the magnetized accessory chrome spinel (Tab. 1, fig. 3,4, 5). The variation of their remnant and chemical magnetism strongly depends also by the chemical transformations, recrystallization and redistribution of the mechanical stresses. Therefore, ultrabasic rocks can be classified as nonmagnetic, weakly magnetic and strongly magnetic ones. Being ferromagnetic, the ultrabasic rocks have a magnetic susceptibility, which varies also in broad limits. Apart from this, being ferromagnetic these rocks might have a large natural remnant magnetization (I_r). In this way the ultrabasic rocks can be considered from partially unmagnetic to strong magnetic.

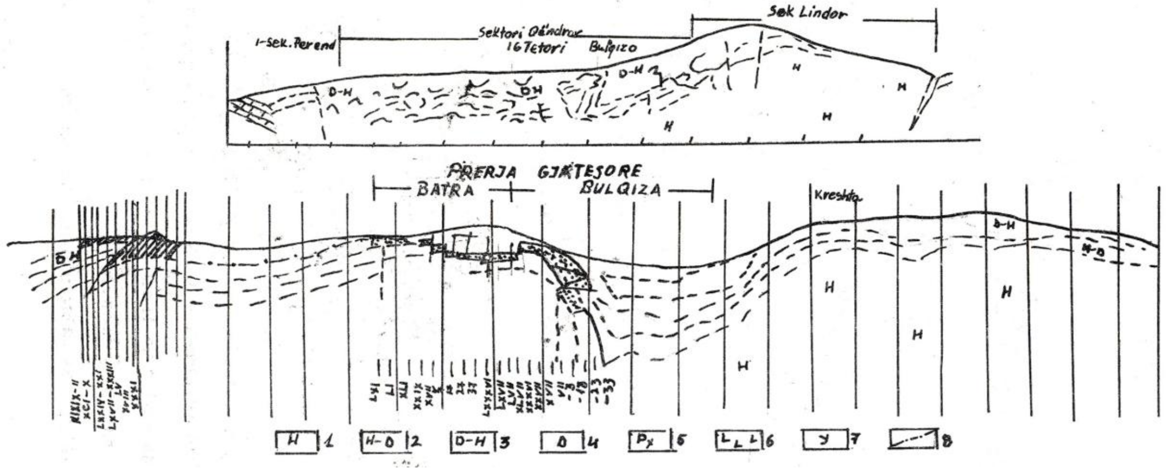

Fig. 2. Geological transversal (EW) and longitudinal (NS) sections in the Bulqiza ultramaphic massif (Hallaçi H. et al.1989).

1.Hartzburgite; 2. Hartzburgite-dunite; 3. Dunite-hartzburgite; 4. Dunite; 5. Mineralization levels.

The magnetic properties of the chrome spinel ore and the ultrabasic rocks.
(Frashëri A, 2008)

Table 1

Kind of ore or rock	Quantity of samples	Induced magnetization I_i, $*10^{-5}$ units (SI)			Remnant magnetization I_r, $*10^{-5}$ units (SI)			$Q_n=I_r/I_i$		
		Min.	Max.	Mode	Min.	Max.	Mode	Min/Max	Aver.	% of samp with $Q_n>1$
Dunite	85* 32**	0	700	10±10 50±30 200±80	10	1800	300±70	1.2/5	2.3	0.5
Serpentinized dunite	20	38	1000	350						
Harzburgite	109* 56*	0	700	15±15 300±100	20	1000	300±100	1.2/13.8	1.9	0.3
Serpentinized harzburgites	87* 14**	40	1000	300	20	1300	350±150	1.0/ 2.4	1.77	0.6
Serpentinites from dunites	82	0	3700	150±70	5	70000	300±90	1.0/ 31.0	1.8	0.6
Serpentinite from harzburgites	68	0	1100	250±50	5	9500	150±60	1.0/ 23.0	2.1	0.5
Pyroxenites	102	10	720	350±60	10	71000	150±90	1.0/ 114	4.0	0.7
Gabbro pegmatites	21	0	270	50	170	250		1.2/ 4.5	1.3	

Note: * samples quantity of I_i measurement
** Samples quantity of I_r measurement

The fresh dunites and hartzburgites of tectonic sequence are not magnetic and cannot be distinguished by their magnetization if their degree of serpentinization is equal (table 1). The magnetic properties of these two kinds of rocks vary within almost the same limits. Remnant and induced magnetization have respective values 10 x 10^{-5} units SI and 40 x 10^{-5} unit SI, so $Q_n<1$, in the fresh rocks practically unserpentinized and uncataclased. The ration $Q_n=I_r/I_i>1$ is approximately in 48% of the cases, with average value 2,3 for dunites and 1,9 for hartzburgites. That reveals the influence of the thermal nature of the remnant magnetization. With the increasing of the activity of cataclasis, magnetism is strengthened, especially the natural remnant magnetization. The fresh rocks have unequal magnetic properties in different regions.

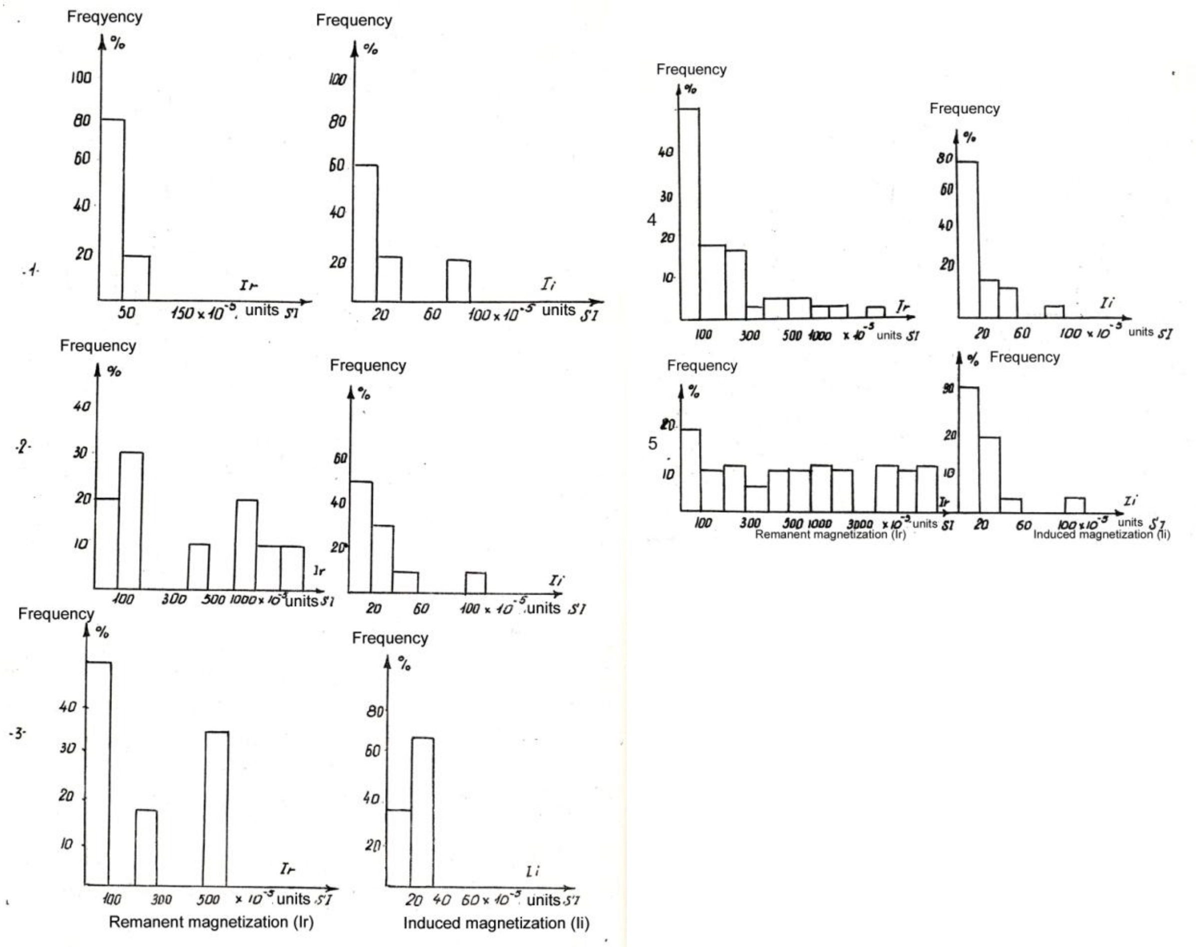

Fig.3. The histograms of the variation of remnant (I_r) and induced (I_i) magnetization of the rocks in Fushe Kalt (Bulqiza) deposit (Plotted by data Sharra Xh. Et al. 1987, accorded to the measurements of Kosho P., Dema Sh., Rrenja A.).

1. Average serpentinized dunites; 2. Strongly serpentinized dunites; 3. Little serpentinized hartzburgites; 4. Average serpentinized hartzburgites; 5. Strongly serpentinized hartzburgites.

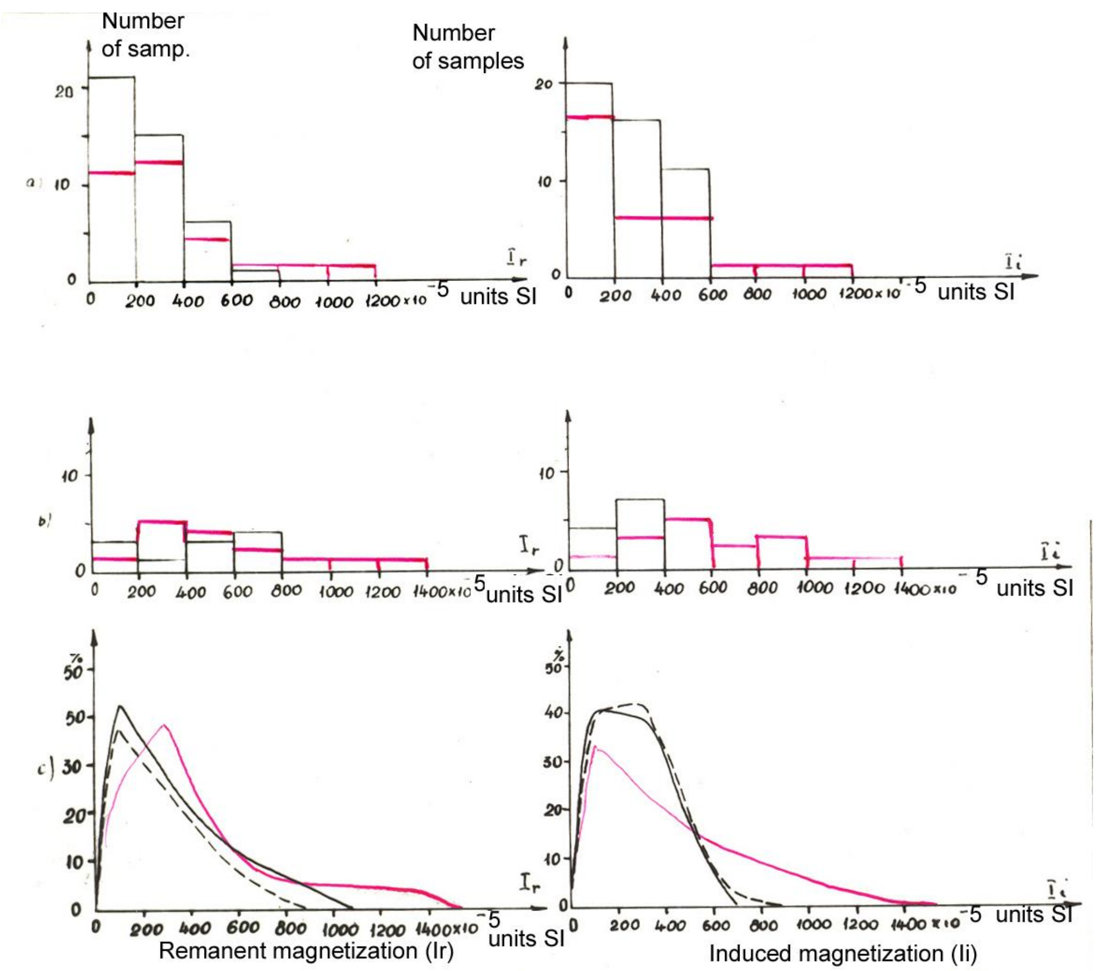

Fig. 4. The histograms of the variation of remnant (I_r) and induced (I_i) magnetization of the rocks in Kami (a), Vlahna (b) and variation curves (c) (Frashëri A., 2008).

1. Serpentinites from dunites (55 samples); 2. Serpentinites from hartzburgites (59 samples); 3. Piroxenites (102 samples).

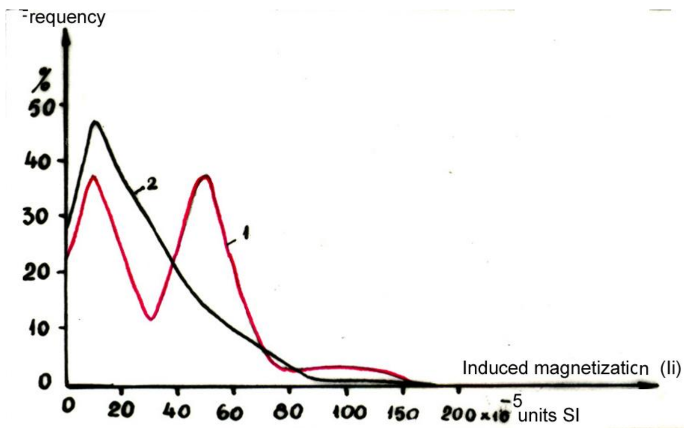

Fig. 5. The variation curves of induced (I_i) magnetization of the dunites (1) and hartzburgites (2), Ragami deposit, Tropoja Massif (Frashëri A. et al., 2008).

The rocks that contain ferromagnetic minerals, for example secondary magnetite are more magnetic. An induced magnetization (80-130) x10^{-5} units SI can be conditioned by presence of 0,1% of magnetite. In general, dunites are a bit more magnetic than hartzburgites that means that they are more serpentinized and contain more secondary magnetite. With the increase of the serpentinization process, the magnetization (in particular the remnant magnetization) of dunites and hartzburgites gets stronger. This can be explained by the increase of the secondary magnetite and the thermoremnant magnetization. The magnetism of the serpentinites has a particularly characteristic: Its values vary in a wide range, from practically unmagnetic to strong magnetic, with values of I_r = 70,000·10^{-05} SI units and I_i = 3100·10^{-05} SI units. This phenomenon can be explained by the degree of serpentinization because the quantity of serpentines in the rocks does not always determine the quality of secondary magnetite (Photo 1, 2, 3, 4). With the increase of the serpentinization process, the magnetization (in particular the remnant magnetization) of dunites and hartzburgites gets stronger. This can be explained by the increase of the secondary magnetite and the thermoremnant magnetization. The magnetism of the serpentinites has a particularly characteristic: Its values vary in a wide range, from practically unmagnetic to strong magnetic, with values of I_r = 70,000·10^{-05} SI units and I_i = 3100·10^{-05} SI units. This phenomenon can be explained by the degree of serpentinization because the quantity of serpentines in the rocks doest not always determines the quality of secondary magnetite. For example there is met serpentinites from hartzburgites totally serpentinized and transformed into serpentine and less in carbonate, which does not contain secondary magnetite and has I_i=80x10^{-5} units SI, I_r=200x10^{-5} units SI.

Photo 1. Serpentinit from dunite, with fissures of different ages, chrysotile-asbestos and magnetite, Kam deposits. Magnetic susceptibility χ>3000x10^{-5} units SI. Thin section, enlargement 35x, Nicoles parallel. (Frashëri A.et al. 2008).

Photo 2. Serpentinized hartzburgite, with dispersed as cloud of Magnetite, Kam deposit. Magnetic susceptibility χ>3000x10^{-5} units SI. Thin section, enlargement 25x, Nicoles +. (Frashëri A. 2008).

Photo 3. Serpentinite from hartzburgite, with magnetite in the chain, cloud and grain forms, Kam deposit. Magnetic susceptibility χ>3000x10^{-5} units SI. Thin section, enlargement 25x, Nicoles +. (Frashëri A. 208).

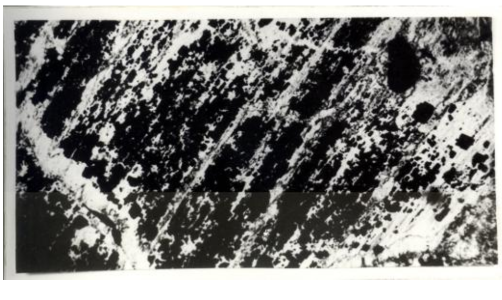

Photo 4. Serpentinite from dunite, with magnetite dense belts, Kam deposit. Magnetic susceptibility χ>3000x10^{-5} units SI. Thin section, enlargement 25x, Nicoles +. (Frashëri A. 208).

These great changes of the remnant magnetization, induced magnetization and of the Q_n ratio for chrome spinel ores, ultrabasic rocks, in general, and for the serpentinites in particular, is conditioned, not only by the contain of the secondary magnetite. These phenomena are conditioned by the chemical and mineralogical transformations of the rocks during the serpentinization and by the redistribution of mechanical stresses, as well. The effect of dislocations is observed under the action of mechanical stresses during the process of the serpentinization, of the dynamometamorphism and of the tectonic activity. For example, in Cerruja deposit, the dunites and hartzburgites of the tectonic sequence are serpentinized. The serpentine contain, in some cases, reaches from 50% up to 85-90% of the rock's volume.

Different amounts of secondary grains magnetite can be found along the skeleton network directions. Contain of the secondary magnetite in this kind of rocks is 4-5%, while contain of secondary magnetite grains inside the mass of the serpentine of the hartzburgites is 0.1-0.4%. For this reason, the susceptibility of this sequence varies in a wide range. The variation curve of the dunites has two maximums, one at the value of $120 \cdot 10^{-05}$ SI units and the other one at the value of $719 \cdot 10^{-05}$ SI units. This means that there are two kinds of dunites: weak magnetic and magnetic. The magnetism of the cumulate sequence rocks changes in the plane and in the cross-section. There are alternations of nonmagnetic and strongly magnetic rocks.

Vein rocks, like pyroxenites in the majority of the cases are made up to medium granular to coarse-grained enstatite more or less bastitized. The rock is cataclasised and in the jumping and fissures zone there is often observed contain of fine-grained secondary magnetite. The magnetism of pyroxenite varies within wide limits. However, the majority of pyroxenite are weak magnetic. The values of their induced magnetism are ($I_i = 350 \cdot 10^{-05}$ SI units, $I_r = 150 \cdot 10^{-05}$ SI units) (Table 1). With the increase of the quantity of the secondary magnetite, the magnetism increases. The ratio Q_n has an average value 4,0, but in particular samples up to 114. In these cases, the remnant magnetization has a thermal nature, under the influence of the magnetic field of the earth and surrounding rocks.

Volanic basalts and keratophyres in northern massifs in Mirdita tectonic zone have a remnant magnetization that vary o,061-3,716 A/m, although their magnetic susceptibility is higher, up to $102.500.10^{-6}$ SI units. Their magnetization is conditioned by content of ferromagnetic mineral accessories. In South-East of Albania have been observed a basalt individualization with the remnant magnetization I_r=117,803 A/m.

Gabbros magnetizations vary in different massifs. In Kurbneshi, at North-East of Albania, the gabbros have lower level of magnetization, averagely I_r=0,007 A/m and magnetic susceptibility 535.10^{-6} SI units. In Qafzezi village, South-Easter of Albania, gabbros have stronger magnetization; I_r=52,825 A/m.

Analyse of the stereographic projections of the remnant magnetization vector shows that parallel with common orientations are observed nearby samples with different orientation, positive and inverse negative. Such phenomenon argues the superposition of the isothermal and chemical and thermal magnetization on remnant thermal magnetization.

Petromagnetic studies have shown the presence of inverse magnetization phenomenon for chrome spinel ores in some deposits (fig. 6). From this picture, it can be seen that the ores in Kepenek deposit (Tropoja ultrabasic massif), are characterised by vectors of remnant magnetization oriented in the average azimuth $\Phi=356°$ and with dipping angle $\theta=-70°$, i.e. opposite to the direction of the vector of remnant magnetization for surrounding rocks. The surrounding dunites the dipping angles of the I_r vector is averagely $\theta=60^0$, where as the azimuth $\Phi=42^0$. The sample from the dunitic envelope with I_r vector, preserving the azimuth of direction $\Phi=46^0$ (as in the rocks that are far from the ore body), has a negative inclination angle, as in ore $\theta=-11^0$. The petrographic study of the orientated thin sections show that along the direction with azimuth of about 45^0, is noticed an event more accentuated development of the action of cataclasm of the rocks, which is expressed by a great number of cracks and microfissures. The majority of the microfissures, especially the most developed, are filled with serpentine of the chrysotile and microantigorite types and with some chrysotile-asbestos vein. There is found secondary magnetite concentrated in microfissures, especially in their periphery. Along the direction 45^0, some prolonged crystals of olivine are noticed in a lying position so the direction of the vector I_r agrees with the direction of the elements with primary structure (Photo 4.11).

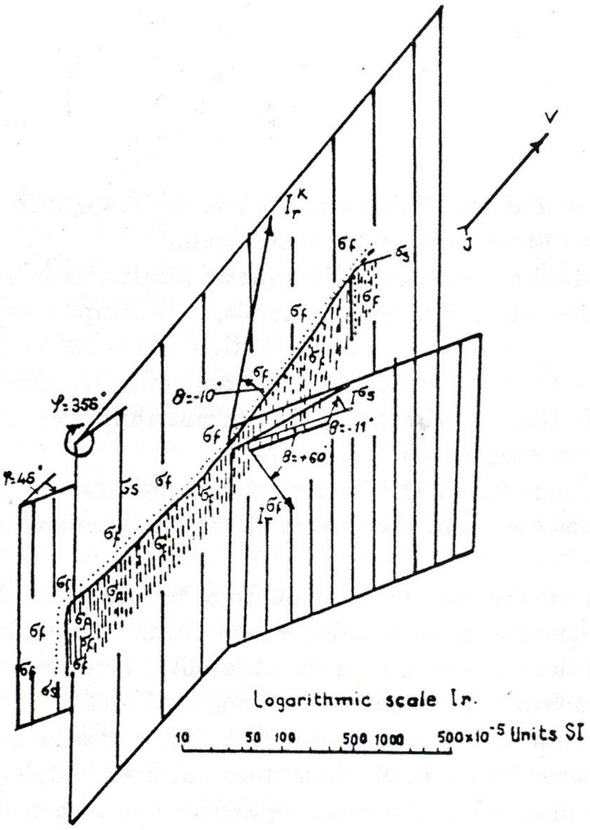

Fig. 6. The inverse remnant magnetization (I_r) for a chrome ore in Kepenek deposit, Tropoja ultrabasic massif.
(Frashëri A. 1989, 2008).

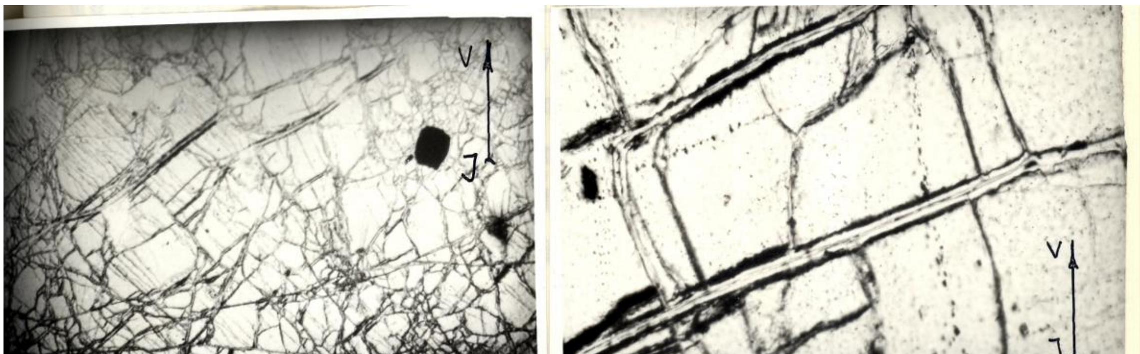

Photo 5. Direction of the cataclasis action (a), serpentine veins and secondary magnetite conentration (b) in the dunites, Kepeneku deposit. Oriented thin section. a) Enlargement 23x, Nicoles parallel; b) Enlargement 470x, Nicoles parallel. (Frashëri A., 1974).

The direction of I_r vector of the chrome-spinel coincides with the strike of the ore body. The negative direction of the inclination of the ore's remnant magnetization vector may be explained by the self inversion inside the spinel; or as a consequence of the demagnetization action of the magnetic field of the surrounding rocks (when the ore body was created after the process of the crystallization of surrounding rocks). These rocks were already magnetized and the ore was magnetized under the action of the demagnetising field of the surrounding rocks (Fig. 7). Under the thermical influence of the ore matter, in the dunitic envelope of the ore body the direction of the I_r inclination has changed.

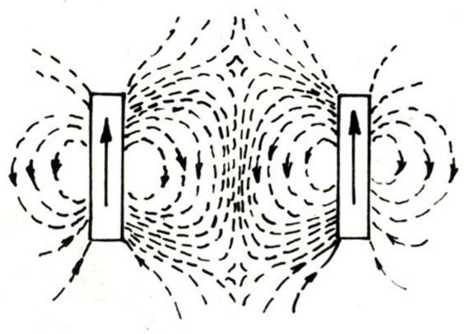

Fig. 7. Distribution of magnetic lines in the space between two bodies near each other, with the magnetization vectors in the same direction and sense.

There are some geological facts that are in the favour of this idea: Among the ultrabasic rocks there is also met chrome spinel ore, with a surface surrounded by 2-3 mm dunite salbande, yellow colour unlike the for dunites, which are more or less green (Photo 4-12). The microscopic study of the polished section has shown that chromite intercalates in the olivine and the part near of the contact is more serpentinized than the other part. This phenomenon shows the thermal influence of chrome spinel on the surrounding olivine. Apart this phenomenon there is also met ore that has cemented regular pieces of olivine (Photo 4-13). The mineralographic study showed that the order of the formation of the minerals is olivine-chrome spinel ore. Olivine has been recrystalized before the chrome spinel ore. There are also noticed intercalations of the chrome spinel veilets in small dimensions in the olivine mass. Many other scholars have reached also the same conclusion on the relative later formation of chromite spinel ore and have proved this thesis in many publications (Çina A. et al. 1966, Çina A. 1970, Dede S. 1965).

Photo 6. Surrounding yellow olivine salbande on chrome spinel ore, Kepenek deposit. (Frashëri A. 1974).

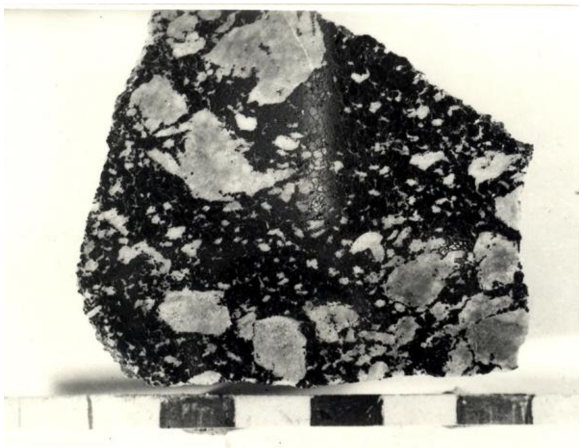

Photo 7. Chrome spinel ore has cemented irregular olivine pieces, Kepeneku deposit. (Frashëri A. 2008).

The reversal of the remnant magnetization vector has been also noticed in some other deposits, such as in Kam (Tropoja), Fushe-Kalt (Bulqia) etc.

In cumulate sequence and the surrounding dunite and hartzburgite rocks (for example in Cerruja deposit, Bulqize) have observed a normal vector of remnant magnetization. This vector has a downward direction and a dip angle of 40°. This shows that the ore bodies have been created at the same time with the cumulate sequence rocks.

Although these differences of the ophiolite magnetization, for some massifs is preserved approximate orientation of the vectors of remnant magnetization (Fig. 8). Predominant orientation of remnant magnetization vector have and azimuth D=284° for pillow lava and D=297° for volcanic basalts in central part of Mirdita zone. Azimuth D=267° of the magnetization vector have gabbro of Kurbneshi massif in this part of Mirdita zone.

In contrary with volcanic rocks and gabbros of central part of Mirdita zone, fig 4 are presented depandance the hartzburgites are represented by a dispersion of the azimuth of magnetization vectors in large limits in Bulqiza ultrabasic massif, D=60° – 300°, as well as preserve the positive sense of the vectors. This great variation of the direction of azimuth of magnetization vectors is conditioned by serpentinization process of he ultrabasic rocks, iven or low lewel of the serpentinization.

In the North-Erstern edge of the ophiolitic belt of Albanides, in he Komani site, the volcanic rocks have e clockwise rotation, analogue with External Albanides (Fig. 8).

Have been received interesting result from the thermal cleaning and demagnetization in the magnetic field of the alternative electrical currents of the sample from the gabbros massif in Qafzezi, South-Easter region of Albania (Fig. 8). The orientation of the magnetization of gabbros in Qafzez Massif in South-East of Albania, has an useful magnetic signal after cleaning and demagnization, has a vector with I_2=60.9° and azimuth D_2=282°. This direction is approximate with orientation of the magnetism vector of the gabbros massif in Chalkidiki, Greece, D_2=312° and I=68^O. The ophiolitic belt of the Chalkidiki was undergone two tectonic phases: first a counterclockwice rotation during Later Jurassic-Lower Cretaous and the second one a clockwise rotation during Terciary (Edel J.B. et al., 1991).

4. Conclusions

Based on petrophysical properties of the ultramaphic rocks and chrome ores it was concluded:

1. The physical properties of the ultramaphic rocks vary within broad limits and only in some cases a group of rocks can be differentiated by its physical properties from the surrounding rocks. The cumulate and the tectonic sequences are discriminated. These groups of rocks can create geophysical anomalies comparable with the ore body anomalies.
2. Fresh rocks are not magnetic. The magnetism of serpentinites changes within wide limits. They are usually magnetic and sometimes strongly magnetic. Non-magnetic serpentinites can also be found. The dunites of cumulate sequence are more magnetic than the other rocks.
3. The ultramaphic rocks can be distinguished from the surrounding rocks and from each other by their magnetism only if they have different degrees of serpentinization.
4. In some deposits and occurrences is observed inversed vector of magnetization. In these cases, the negative magnetic anomalies can observe over the magnetic chrome spinel ores.
5. The study of the orientation of the remnant magnetization vector of the ores and the surrounding rocks can be used as a supplementary information source about their formation conditions and consecutive changes in time.

6. Acknowledgments

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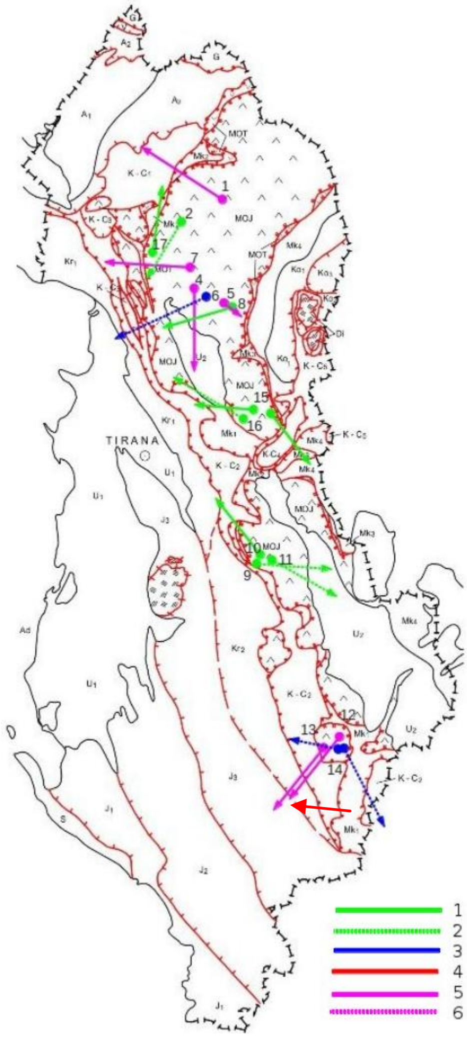

Fig. 8. Declination of the magnetization vectors of the ophiolite belt in Mirdita tectonic zone of the Albanides.

Tectonic zones:
Internal Albanides:
M- Mirdita zone
G- Gashi zone
Ko- Korabi zone

External Albanides:
A- Albanian Alps
K-C- Krasta-Cukali zone
Kr- Kruja zone
J- Ionian zone
S-Sazani zone
U- PeriAdriatic Depression

Magnetic declinations:
1- J > 0 Ultrabasic rocks
2- J < 0 Ultrabasic rocks
3- J < 0 Gabbro
4- J > 0 Gabbro, remnant magnetization after demagnetization
5- J > 0 Volcanic rocks
6- J < 0 Volcanic rocks

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