The SEG International Exposition and 79th Annual Meeting being held in Houston, Texas
25-30 October 2009.

THE USE OF GEOPHYSICAL METHODS IN SEARCH FOR CHROME DEPOSITS

The Geophysical methods, as a part of geological complex in search for chrome deposits, have to solve two main problems:

1. To conduct direct exploration for ore bodies.
2. To help in the geological-structural mapping in order to study the factors that control the mineralization.

In Albania was gained a good experience for the geophysical exploration of chrome deposits and were set up integrated methods to be used in ground and underground surveys. These are achievements of a collective body of geophysicists and geologists. These achievements have been published and presented in scientific sessions, dissertations, and in many geological and geophysical studies and projects (see references). In this monograph are generally presented the best achievements, especially those of the last ten years, carried out by specialists of the Geophysical-Geochemical Exploration Centre of Tirana.

The geophysical complex for direct search includes surface mapping by gravity, magnetic and IP methods, 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.

4.1. View on the geology of chrome ore deposits in Albania

The big ophiolitic belt of Albanides, with ultramaphic massifs, is the main belt of chrome ore deposits in Albania. In 1984 Albania was ranked at the third place in the world for exploitation of chrome ore, reaching an amount of 960,000 ton/year.

Chrome ore deposits are concentrated in the eastern ultramaphic belt (Figs. 4.1, 4.2, 4.3), with two sequences of different geological-petrological-geochemical and metallogenic sequences, 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. 4.4).

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. Podimorf ore bodies as pseudostratos folded, lens, and column types, have rather big dip angle.

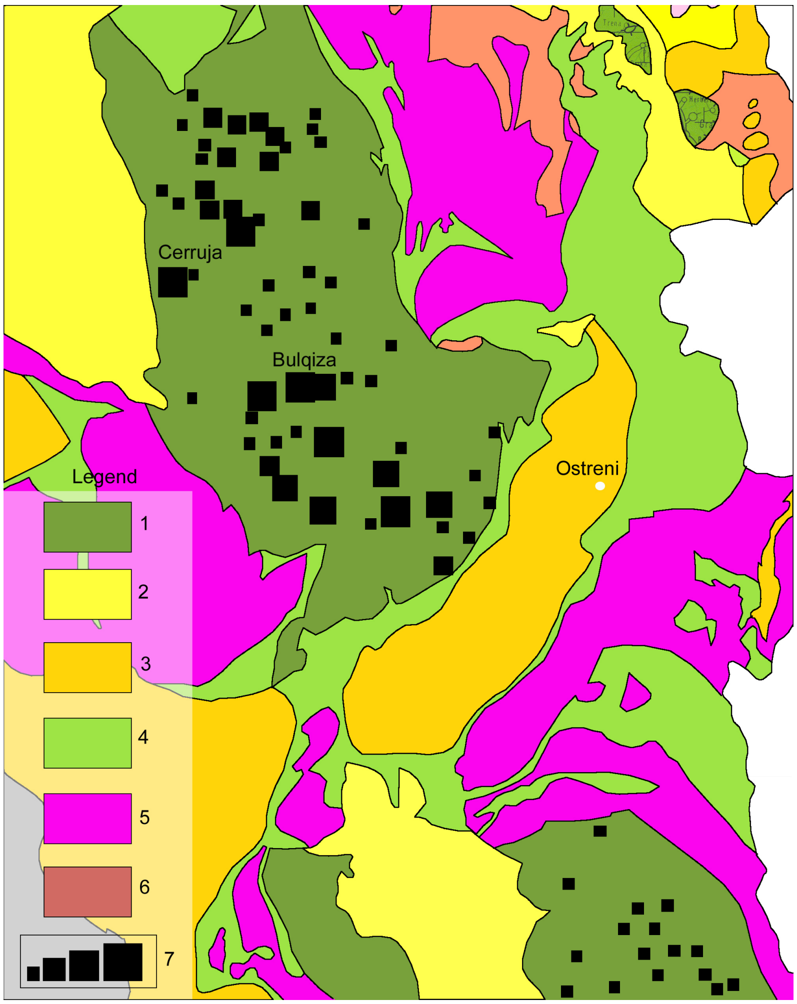


Fig. 4.1. Chromite ore deposits in Bulqiza ultrabasic massif.

(After Metalogenic map of Albania, at scale 1:200.000, 1999)

1-Ophiolitic formation; 2- Neogenic molasse formation of the post frontal depressions; 3- Maastrichtian-Eocene flysch formation; 4- Upper Tithonian-Cenomanian Early flysch formation 5- Middle Triasic-Lower Jurassic Carbonate formation; 6- Terrigeneous metamorphosed Paleozoic formation; 7- Chromites ore deposits (occurrence, small, medium, and big deposits.

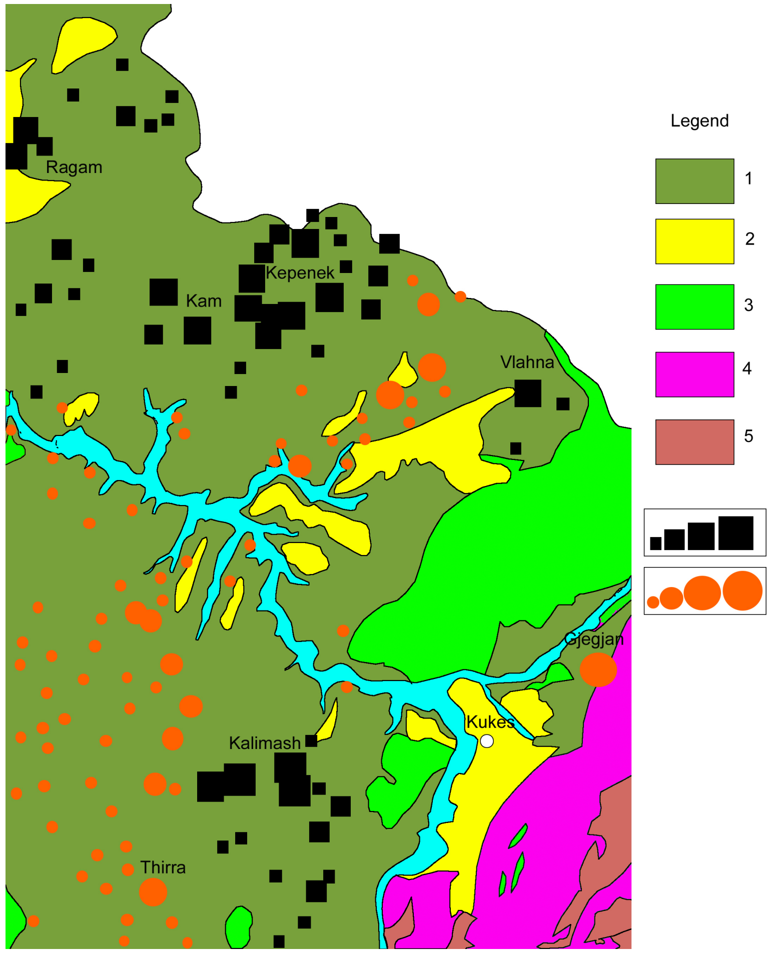


Fig. 4.2. Chromite and copper ore deposits in Tropoja-Kukësi ultrabasic massif. (After Metalogenic map of Albania, at scale 1:200.000, 1999) .

1- Ohiolitic complex; 2- Neogenic molasse formation of the post frontal depressions; 3- Barremian-Upper Cretaous carbonate formation; 4- Middle Triasic-Lower Jurassic carbonate formation; 5- Terrigeneous metamorphosed Paleozoic formation; 6-7- Chromites and copper ore deposits, respectively (occurrence, small, medium, and big deposits).

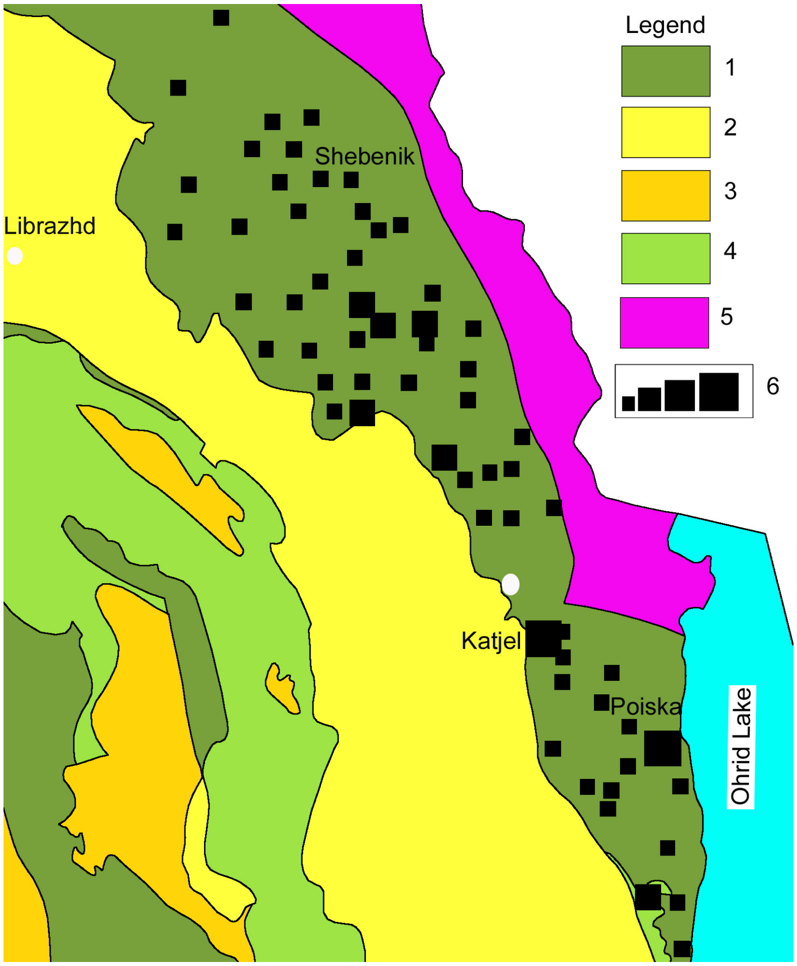


Fig. 4.3. Chromite ore deposits in South Bulqiza and Shebenik-Pogradeci ultrabasic massif. (After Metalogenic map of Albania, at scale 1:200.000, 1999). 1- Ohiolitic complex; 2- Neogenic molasse formation of the post frontal depressions; 3- Maastrichtian-Eocene flysch formation; 4- Barremian-Upper Cretaous carbo-nate formation; 5- Middle Triasic-Lower Jurassic carbonate formation; 6- Chromites ore deposits, respecti- vely (occurrence, small, medium, and big deposits).

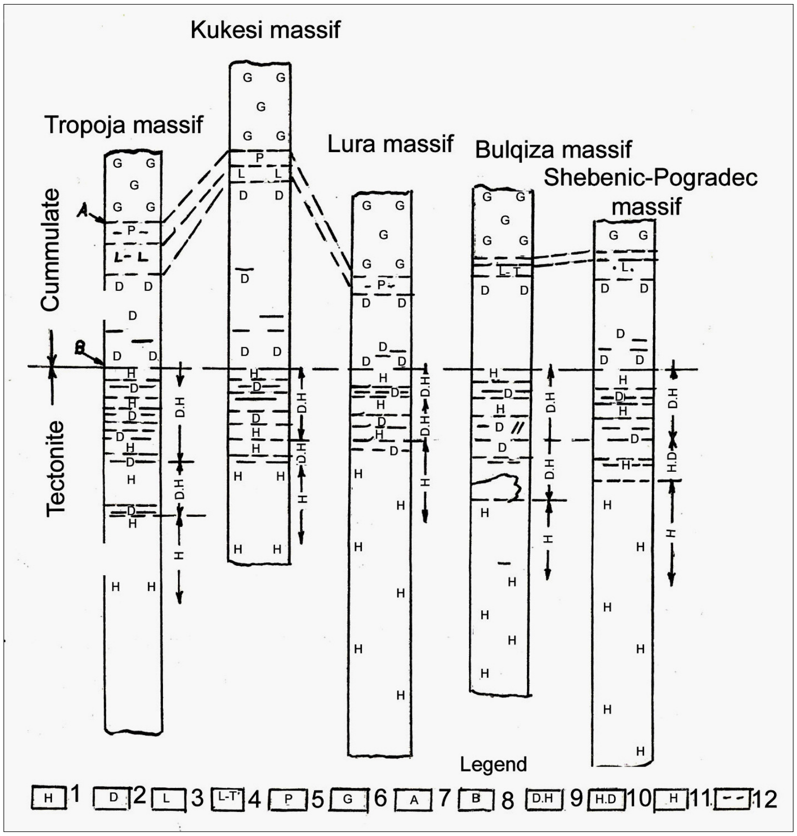


Fig. 4.4. The correlation scheme of the schematic geo-logical sections of the eastern belt of ultramaphic rocks (Hallaçi H. et al, 1989).
1- Hartzburgite; 2- Dunite; 3- Lherzolite; 4- Lherzolite-troctolite; 5- Pyroxenite; 6- Gabbro; 7- MOHO velocity discontinuity; 8- MOHO petrological discontinuity;
9- Dunitic-hartzburgite facies of tectonites;
10- Hartzburgite-dunitic facies of tectonites;
11- Hartzburgite facies of tectonites;
12- Mineralization levels.

In some deposits, the horizons of the mineralization are represented as anticlines or synclines. In some others as overlapped monoclines in different hypsometric levels are observed. Their dunitic envelopes have a thickness of some centimetres up to some tens of meters. The borders between the dunite and ore bodies are very well defined. The chrome-ore content is characterised by big amounts of Mg and little amounts of Al and Fe. The values of the ratios Cr/(Cr+Al) are 0.76-0.84 and those of Fe/(Fe+Mg) are 0.28-0.35. The ore's texture is represented as massive, nodular and disseminated one. The content of chrome oxide in high grade chromite is about 42-44 % and about 20 % in low grade chromite. It depends on the thickness of the ore body, as well. Massive texture ores are mainly situated in the central part of their bodies, as in Bulqiza, Kalimash, Kepenek and Zogaj deposits (fig. 4.5).

The dunite-hartzburgite facies is step by step situated over the hartzburgite-dunitic ones. The content and the number of dunitic alternations increases from the bottom to its top in dunite – hartzburgite facies.
The mineralization is connected with these dunitic alternations, and these ore alternations represent the main level of the mineralization.

The thickness of the ore bodies, stretching from some tens of meters to some hundreds of meters, (in some cases up to 1550 meters) varies from 0.5 up to 5-10 meters, dipping down to 200 - 400m.

The cumulate sequence is situated with angular unconformity over tectonite (petrological MOHO). The dunite with rare alternations of hartzburgite and lherzolite are predominant inside this sequence**.** Chromite in its lower levels becomes more aluminite than in higher levels.

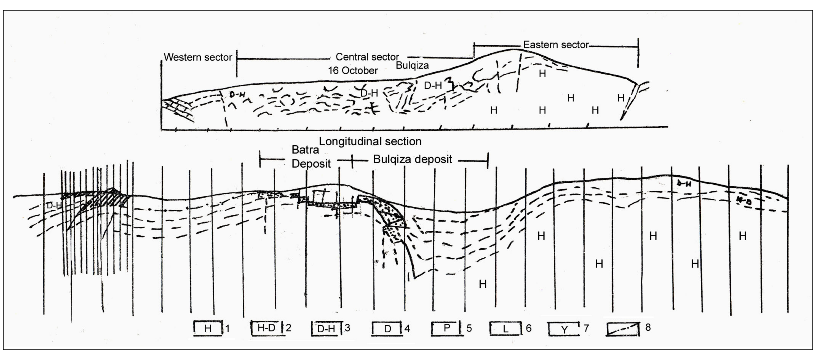


Fig. 4.5. Geological transversal (EW) and longitudinal (NS) sections in the Bulqiza ultramaphic massif (Hallaçi H. et al.1989).
1- Hartzburgite; 2- Hartzburgite-dunite; 3- Dunite-hartzburgite; 4.-Dunite; 5. Mineralization levels.

Metamorphic chromite is characterised by high content of Mg and lower contents of Fe and AL. The values the of the ratio Fe/(Fe+Al) are 0.30 - 0.40 and those of Cr/(Cr+Al) are 0.81 - 0.84. Refractory ore as alumo-chromite has a ratio value Cr/(Cr+Al) = 0.55. They are characterised by belt texture up to disseminated. Ore bodies belt morphology is presented by the alternations of chromite with dunite and they have the form of small angle dipping lens, stretching some hundreds of meters.

In figure 4.6 is shown a cross-section of Krasta deposit in the Bulqiza ultramaphic massif.

For geological-structural mapping purposes, electric soundings have been used simultaneously with gravity and magnetic surveys. The place and the role of each of these methods depend on the geology of the site, on the contrast of the physical properties between the ore bodies and the surrounding media and on the geological problem to be solved by geophysical methods.

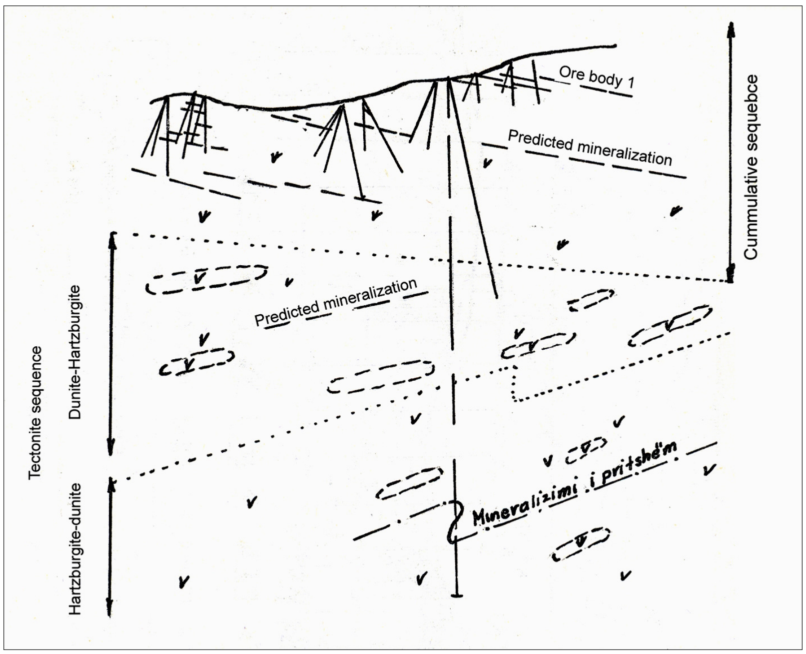


Fig. 4.6.Geological section at Krasta-Lugu Thellë deposit, Bulqiza district (Stërmasi Sh. et al. 1989).

4.2. PHYSICAL PROPERTIES OF CHROME ORES AND ULTRABASIC ROCKS

The geophysical methods in search for chrome ore deposits are mainly based on the distribution of gravitational, magnetic and electrical fields, which depend on the density, magnetism, IP and the electrical resistivity changes of the ore bodies and the surrounding rocks, and on the geology of the site, as well.

Petrophysical studies are carried out for the ultrabasic rocks of some massifs (especially those of the eastern belt) and for chrome ores, in some deposits of Albania. There are analysed the results of petrophysical studies on the density (1490 samples), magnetic (727 samples) resistivity and induced polarization (374 samples) (Frashëri A., 1974, 1989) and thousands samples by other geophysicists (Bushati S. 1997, 1998, Leka P. et al. 1988, 2002, 2004, etj.) of ultrabasic rocks and chrome iron ores.

4.2.1 Density

Iron chrome ores density

Iron-chrome ores of hartzburgites and dunite-hartzburgite of the tectonite sequence, have a density value from 2550-4380 kg/m^3. The ore's density of Kam Tropoja deposit is mostly influenced by its contain of Cr_2O_3, according to the relation:

$$\sigma = 40.C + 2000 \quad (kg/m^3) \qquad (4.1)$$

where **σ** is the density of chrome ore, in kg/m^3
C is the ore contain of Cr_2O_3 in percentage,
with a correlation coefficient of 0,92 (Fig. 3.1-a)

This relation is not a universal one. It changes from one deposit to another deposit, from one body to another body. In Vlahna deposit (Fig. 3-1-b) the correlation has following relation:

$$\sigma = 27.C + 2430 \quad (kg/m^3) \qquad (4.2)$$

Many factors are conditioned such changes of the ore density. As can be seen from figure 4-7 these regularities are different depending by contain of chrome-spinel grains.

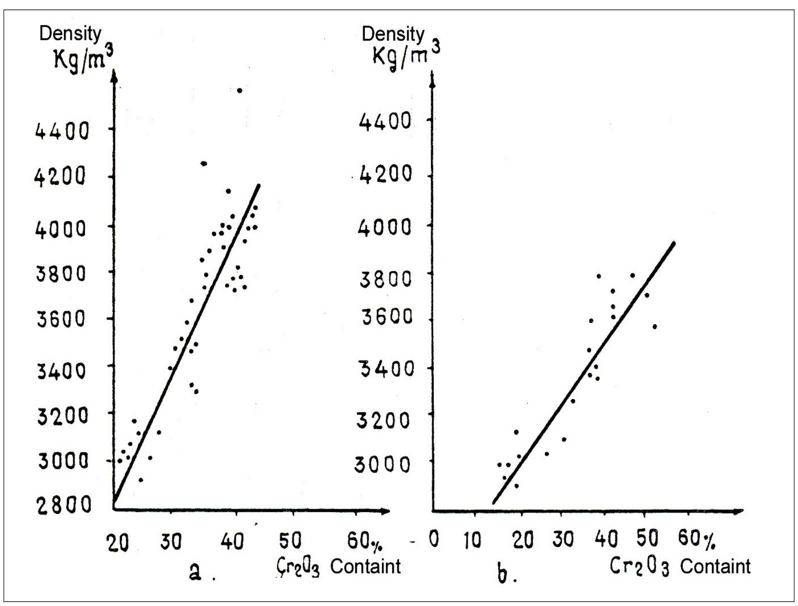


Fig. 4-7. The dependence of the chromite ore density by Cr_2O_3 contain, in Kami (1) and Vlahna (2) deposits, Tropoja ultrabasic massif (Frashëri A., 1974, 1989).

Fig. 4-8 shows the plot of the density versus the ratio Cr_2O_3/FeO value. Relation (4.1) and (4.2) show that they depend by contain of Cr_2O_3, which is the main factor, and the density of chrome spinel as well.

Table 4-1

Physical properties of chrome ores and ultramafic rocks.

(Pumo E., Frasheri A., Tashko A. 1994)

No	Sample	Density, in kg/m^3			Magnetic properties in $\times 10^{-5}$ SI Units: Suscept	
		Min	Max	Mode	Min	Ma
1	Chrome	2450	4380	3700	10	50 / 300
2	Dunite	2700	3340	3020	10	100
3	Serpentinized dunite	2600	2800	2700	40	300
4	Harzburgite	2800	3300	3050	10	70
5	Serpentized Harzburgite	2700	2900	2800	20	100
6	Serpentinite	2240	2650	2550	10	800
7	Pyroxenite	2900	3200	3080	10	32

* Ores with high content of secondary magnetite.

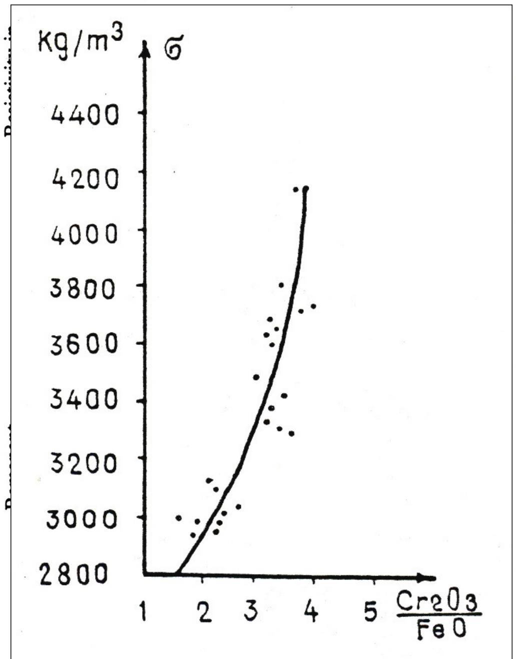


Fig ... ore by Cr_2O_3/FeO ratio

th... the ore, also conditions of ... present in the tables 4.2, 4.3

Density of iron chrome ores from different deposits and occurences in Tropoja utrabasic massif (Frashëri A., 1974)

Table 4.2

Deposit or occurrence	Ore structure	Density In g/cm^3	Contain (atomic units)			
			Cr	Fe^{+3}	Fe^{+2}	Magne-tic Compo-nents
Ragam	Nodular	4.3714	1.942	0.867	2.348	5.40
Tplanë	Nodular	4.4413	12.835	0.576	2.646	3.60
Pac-Çorraj	Nodular	4.4741	11.748	1.129	3.815	7.05
Pac-Çorraj	Compact	4.5902	10.974	1.524	4.713	9.50
Kam	Compact	4.4340	11.358	0.904	2.998	5.65
Kam	Compact	4.4819	11.634	1.228	3.526	7.70
Kam	Nodular	4.4294	12.062	0.862	2.705	5.40

The dependence of chrome ore density by the structure, Vlahna deposit (Frashëri A., 1974, 1989).

Table 4.3.

Ore structure	Predominant density values, kg/m^3	Cr_2O_3 contain, in %	Chrom-spinel contain, in %
Rare disseminates	2960	19.97	10
Medium disseminates	3480	37.94	50
Dense disseminates	3800	47.89	72.5
Massive ore	4140	61.44	96
Nodular ore	3410	38.13	40
Banded ore	3040	27.49	40

Fig. 4-9 shows distribution curve of the density of chrome spinel ore from different parts of ore body Nr.6, Kam deposit.

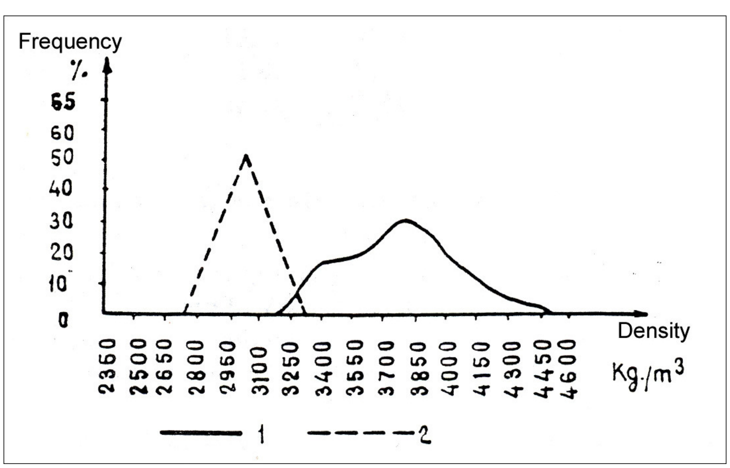


Fig. 4-9. Variation curve of the density of chrome spinel ore from different parts of ore body Nr.6, Kam deposit. (Frashëri A., 1974). 1- Rich ore (123 samples); 2- Average contain ore (96 samples)

The density of the chrome ore is conditioned by the degree of the serpentinization of its olivine. As higher is the degree of serpentinization, the smaller are the density values (fig. 4-10).

Due to all those factors, ore density values are different not only in the same deposit but in the same kind of ore as well (fig. 4-11).

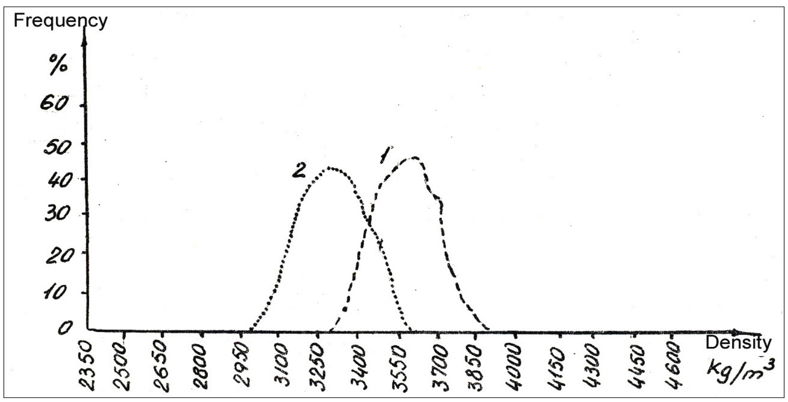


Fig. 4-10. The density variation curves of the chrome ore in the tectonic sequence, which contains olivine with different degree of serpentinization.
1- Ore between dunites, 2- Ore between serpentinized dunites.

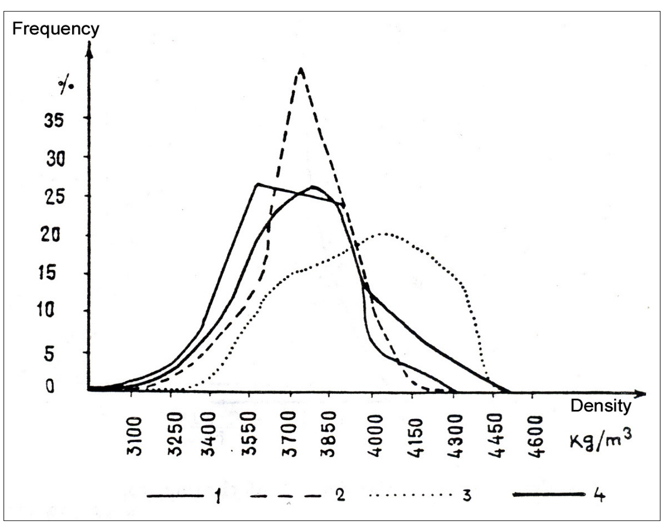


Fig. 4-11. The density variation curves of the chrome ore in different parts of the ore body, Tplanë occurrence. (Frashëri A., 1974, 1989).

1- Northern part (110 samples), 2- Central part (103 samples), 3- Southern part (101 samples),
4- Generalised curve.

The high value of the Tplanë occurrence ore's density, with high percentage of Cr_2O_3 contain, can be explained by the great density of chrome spinel (4441.3 kg/m^3) (Table 4.1.) and by the lack of the metamorphism of the studied ore body in which the olivine is not serpentinized.

The density of chrome-iron ore, which is connected with cumulate sequence of the rocks, changes in a wide range (Table 4.3).

The mode of the chromite from Kepeneku deposit, with dense disseminates structure up to massive, is 3,62 g/cm^3 (Fig. 4-12). The density of the chromite ores among the serpentinized rocks has a mode 3,28 g/cm^3, because the olivine of the ores is serpentinized.

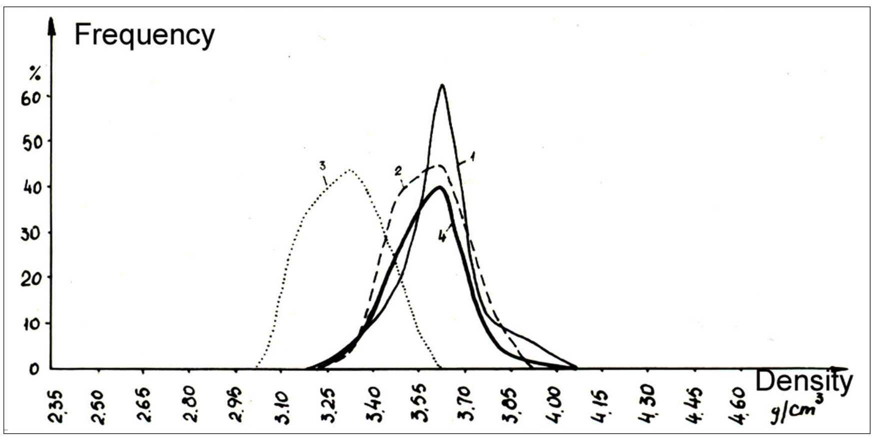


Fig. 4-12. The density variation curves of the chrome ore in Kepenek deposit. (Frashëri A., 1974, 1989).

1 - Ore of the body No. 1 (40 samples); 2- Ore among the dunites, body No. 7 (27 samples); Ore among the serpentinized rocks, body No. 7 (30 samples); 4- Generalized curve of the ore among the fresh dunites.

The chromite ores ore body 1 of the Ragami deposit have a structure by average disseminates and nodular of body Ragam. The nodules are disseminated in the partial seprpentinized mass of the olivines (seprentine of the chryzotil kind). As shows the fig. 4-13, the chromite ores from these deposits have smaller density, in comparison by the chromites from other deposits, in Tropoja ultrabasic massif.

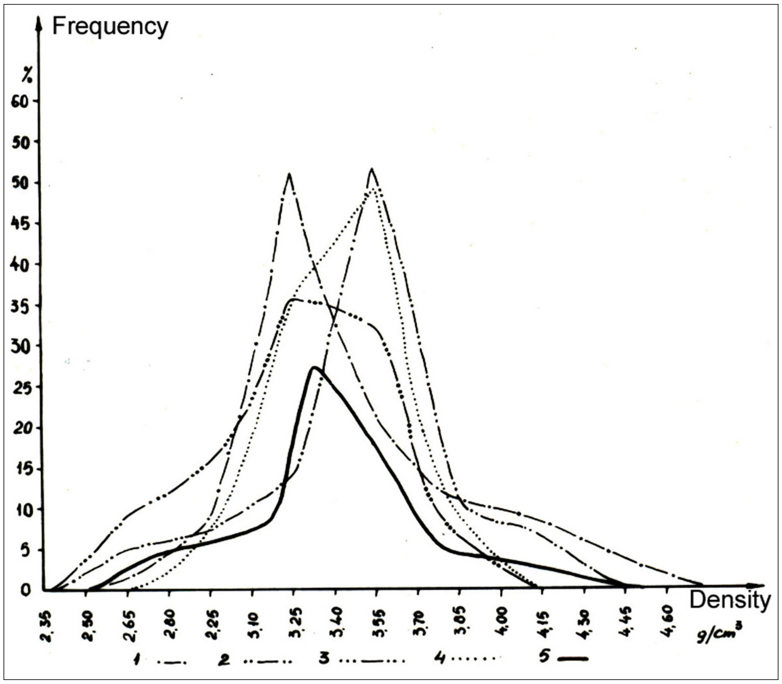


Fig. 4-13. The density variation curves of the chrome ore in different parts of ore body, Ragami deposit. (Frashëri A., 1974, 1989).
1- Ore of the body No. 1 (Ragami II) (57 sampes); 2- Ore of the body No. 2 (Ragami II) (29 samples); 3- Ore from body No. 3 (Ragami II) (31 samples); 4-Ore from Ragami I (25 samples); 5- Generalised curve.

Comparing the generalized distribution function for rich chromite of different deposits, it is noticed that density has its characteristics distribution in every deposit (fig. 4-14).

In fig. 4-15 and 4-16 are shown the density distribution curves of the chrome ore in some deposits of Tropoja and Bulqiza ultramaphic massifs.

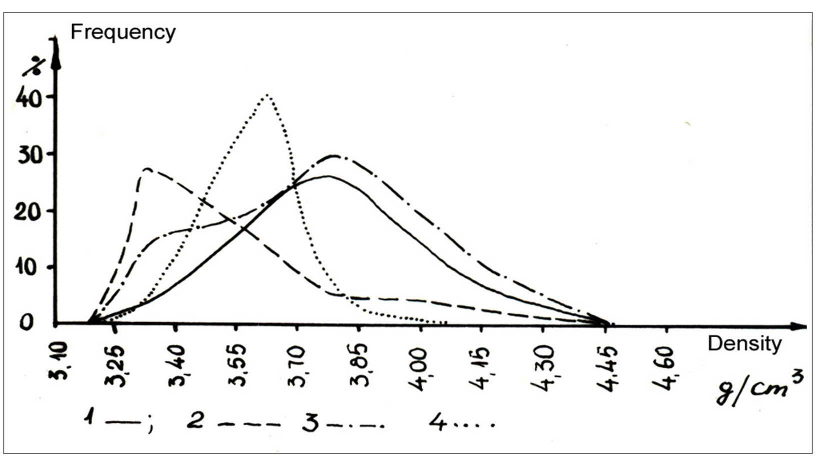


Fig. 4-14. Generalized variation curves of the density of rich chrome spinel ores of different deposits. (Frashëri A., 1974, 1989).

Characteristic of the petrodensity of chrome spinel ore and ultrabasic rocks.

(Frashëri A., 1974, 1989).

Table 4.4

Kind of ore and rocks	Nr. of samples	Density, in kg/m^3		
		Min.	Max.	Mode
1. Rich chromite, δ >3250 kg/m^3	720	3260	4380	3730±20
2. Chromite with average contain 2800< δ >3250 kg/m^3	136	2830	3250	3040±40
3. Poor chromite 2500< δ >2800 kg/m^3	13	2550	2790	2700±80
4. Dunites	101	2820	3340	2910±40
5.Serpentinized dunites	46	2650	2790	2620±20
6. Serpentinites from dunites	182	2220	2640	2570±30
7. Hartzurgites	164	2800	3330	3000±40
8. Serpentinized hartzburgites	33	2660	2800	2690±80
9. Serpentinites from hartzburgites	31	2200	2650	2580±50
10. Pyroxenites	4	2640	3320	3080±260
11, Gabro-pegmatites	10	2560	3150	3070±160

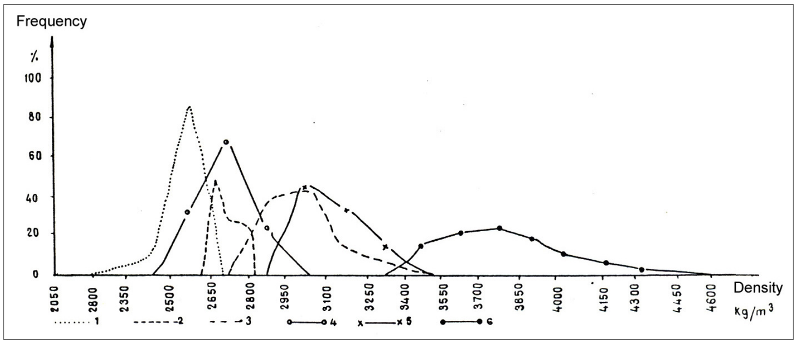


Fig. 4-15. Generalised curves of the density variations of the chrome ore and the ultramaphic rocks of the Tropoja massif tectonic sequence. (Frashëri A., 1974, 1989).

1- Serpentinite, 2- Serpentinized ultra-maphic rocks,
3- Dunites and fresh hartzburgites, 4- Ore of rare disse-minated structure, 5- Ore of medium disseminated structure, 6- Ore of dense disseminates or massive.

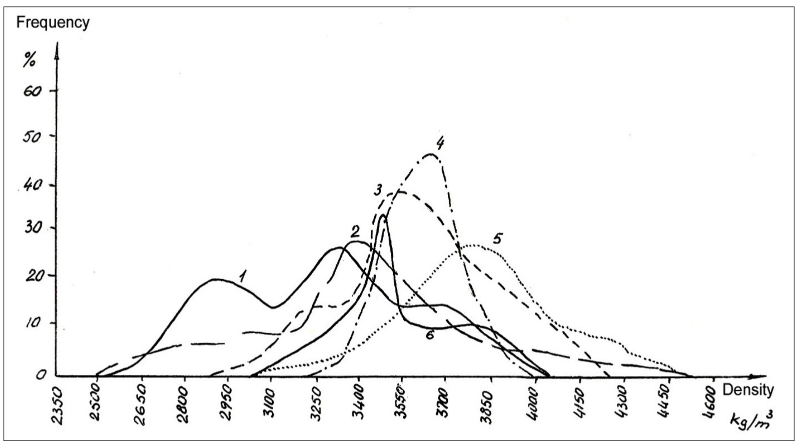


Fig. 4-16. The density variation curves of the chromi-te ores in deposits of Bulqiza and Tropoja ultra-maphic massifs. (Frashëri A., 1974, 1989, Pumo E. et al. 1994).

1- Bulqiza (plotted according to the data given by Bushati S., Karcanaj P. 1988) 2- Ragami, 3- Kami, 4- Kepeneku, 5- Tplanë, 6- Cërruja.

Based on generalised results of the study on chrome ore density in Albanian deposits, we can divide them into three categories, which have different density values:

1. Rich chromites, with 42% of Cr_2O_3 contain and with the highest density value, which varies form 3260 - 4380 kg/m^3. The predominant density value is 3730 kg/m^3 corresponding to chrome ores with 42% of Cr_2O_3.
2. Chromites with average contain of chrome oxide Cr_2O_3 of 32-42% and density values of 3200 - 3680 kg/m^3. The predominant density value is 3300 kg/m^3 corresponding to chrome ores with 32.5% of Cr_2O_3 contain.
3. Low contain of chromites, with 12.5-30.0% of Cr_2O_3 contain and low-density values of 2550 - 3200 kg/m^3. The predominant density value is 2700 kg/m^3 corresponding to chrome ores with 17.5% of Cr_2O_3 contain.

Ultrabasic rocks density

The study of the density of the ultrabasic rocks was carried out according to their classification in fresh and serpentinized dunites and hartzburgites, pyroxenites and the kinds of vein series (Dede S. 1865, Dobi A. 1981, Ndoja I. Gj. 1961, 1988, Shallo M. et al. 1989).

The density values of the ultrabasic rocks of tectonic sequence of hartzburgites and dunitic hartzburgites are between 2200 and 3340 kg/m^3.

The studies dunites have simple mineralogical composition. Mainly olivine and chrome spinel takes part as accessory. The highest density value of 3340 kg/m^3 is characteristic for fresh compact dunites (Photo 4.1). In figure 4.16 is shown the density distribution curve of the dunites in the ultramaphic massif of Tropoja. In the dunites group, besides the fresh rocks (with 0-5% of serpentine) are also included little serpentinized rocks (with 10-15% serpentine) with a predominant density value of 2910 kg/m^3.

Serpentinized dunites can be distinguished by the predominant density value of 2680 kg/m^3. For this types of rocks the contain of serpentine ranges from 15-20% up to 50%.

This decrease of density values can be explained by the fact that chrysotile and antigorite, created during the transformation of the olivine in the process of the serpentinization, have density values from 2500-2700 kg/m^3, which are lower than the density values of the olivine from 3300-3500 kg/m^3. The high number of cracks in the rocks can also explain such decrease of the density.

In the figs. 4-17 and 4-18 is also shown the distribution curves of the density values of the ultrabasic rocks of Bulqiza and Tropoja massifs, particularly and rocks of cumulate sequence in Cerruja area (Bulqiza). The density values of the hartzburgites and the serpentinized hartz-burgites are the same with those mentioned above. The studies hartzburgites have an average composition of 60-70% olivine, 30-40% rhombic pyroxene, 1% chrome spinel, serpentine and very rarely some grains of monoclyne pyroxene (Photo 4-2).

Though the density of hartzburgites varies within the sae limits as the density of dunites we notice that the maximum in the distribution curve of hartzburgites density shifts on the right, i.e. they have a density mode of 3000 kg/m^3, which is greater than that of dunites.

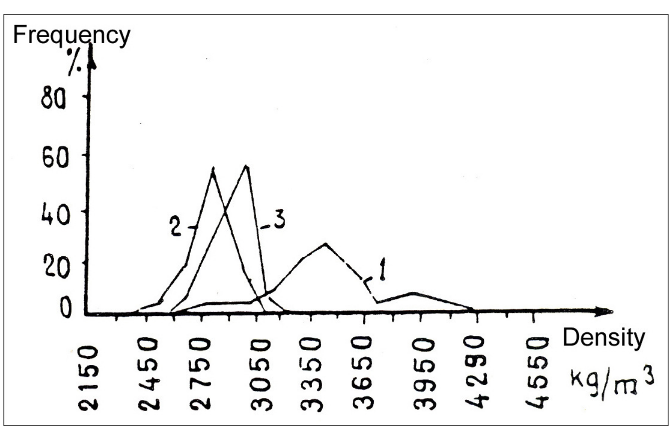


Fig. 4-17. Variation curves of the density of chrome spinel ore
(1), dunites
(2) and hartzburigites
(3), Ragami deposit. (Frashëri A., 1974).

As it can be seen from the distribution curves in figures 4-15 and 4-18, it seems that the dunites of tectonic sequence have a predominant density value of 1500 kg/m^3 lower than the hartzburgites. This shows that the dunites are more serpentinized than the hartzburgites, even though they are situated in the same conditions.

The average densities of dunites and hartzburgites of cumulate sequence are almost even, but however, the densities of hartzburgites are characterised by a higher variation factor, which indicates that these rocks have different degrees of serpentinization. The top density value of 3180 kg/m^3 shows about the existence of lower serpentinized hartzburgites than dunites. There were no defined density borders between dunites and hartzburgites of cumulate sequence in Cerruja deposit.

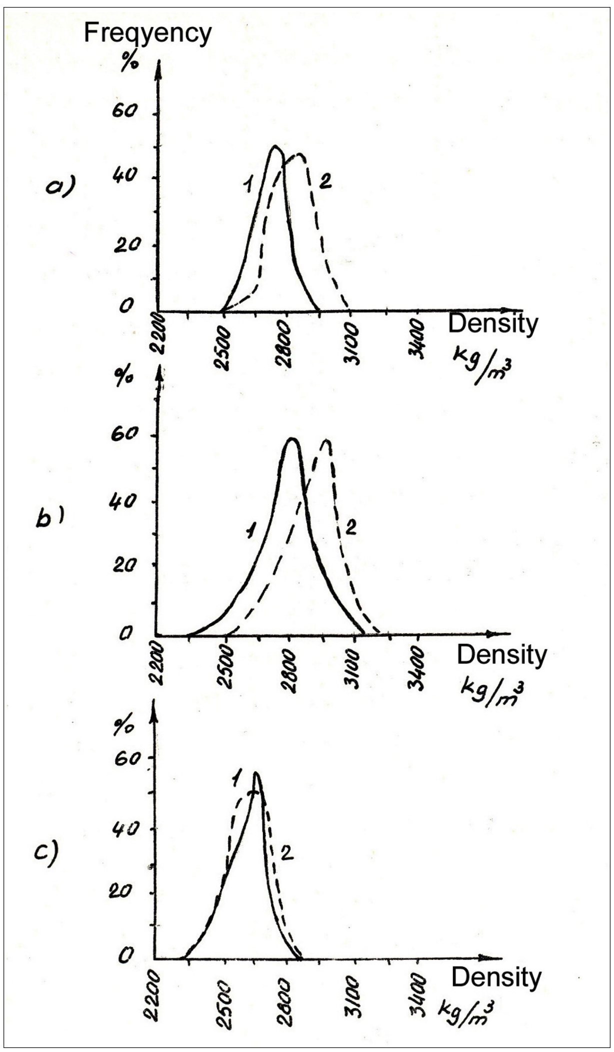


Fig. 4-18. The density variation curves of the dunite (1) and hartzburgite (2) of tectonic hartzburgite sequence and dunitic-hartzburgite one of the Bulqiza massif (a) (Bushati S. etc.), of Rragami massif (Tropoja) (b) and of cumulate sequence in Cerruje (Bulqiza) (c) (Frashëri A. 1974).

Petrographic studies have demonstrated that the dunite rocks, which the fissures constitute 10-15% to 20% of the rock volume, has a density values of 3000 kg/m^2, though they may be unserpentinized.

The pyroxenites and gabbro-pegmatites have high density values. The predominant density values of pyroxenites and gabbro-pegmatites are respectively 3080 kg/m^3 and 3070 kg/m^3

The serpentinites have lower density values than all the kinds of ultramaphic rocks even if they are of dunite or hartzburgite origin (fig. 4-15). The predominant density value of serpentinite is 2570 kg/m^3 (Photo 4-3). Serpentinite with smaller density values than chrysotile and antigorite (2200 kg/m^3), which represent 90% of rock mass, can be found as well. The porosity and the fissures, especially in the serpentinites that are formed during the process of dynamo-metamorphism, can explain the decrease of density values.

Very important is comparison of the density of ultrabasic host rocks and density contrast among chrome spinel and surrounding rocks in different deposits. Dunites and hartzurgites in Tplanë deposits have the most higher values of the density, with respectively modes 3000 and 3070 kg/m^3 (Fig. 4-19).

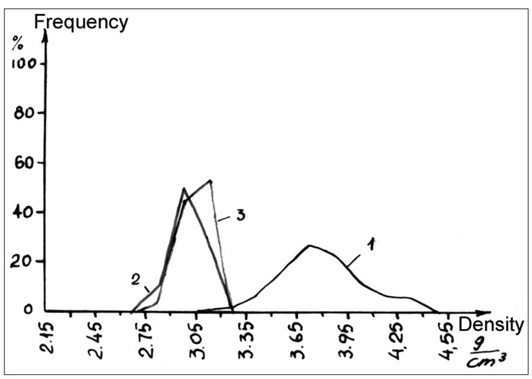


Fig. 4-19. The density variation curves of the chromites (1), dunites (2) and hartzburgites (3) in Tplanë deposit, Tropoja ultrabasic massif. (Frashëri A., 1974).

In the Ragami deposit are located also the serpentinized dunites and hartzburgites, with density smaller 2800 kg/m^3, and serpentinites (Fig. 4-20). The mode of the dunites density is 2820 kg/m^3, and of the hartzurgites 2950 kg/m^3.

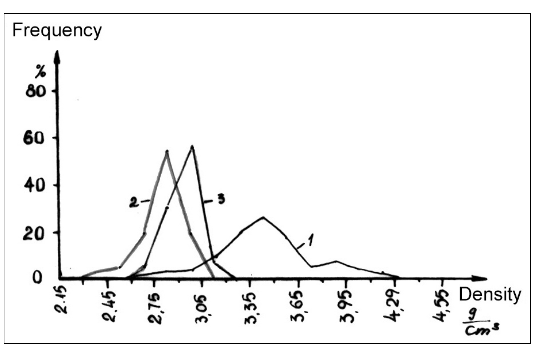


Fig. 4-20. The density variation curves of the chromites (1), dunites (2) and hartzburgites (3) in Ragami deposit, Tropoja ultrabasic massif. (Frashëri A., 1974, 1989).

Consequently, in Ragami area the dunites are most serpentinized that hartzburgites.

The density of the dunites in Kepenek deposit change from 2900 to 3040 kg/m^3, and hartzur-gites from 2550 up to 3100 kg/m^3, with a mode 3040 and 3010 kg/m^3, respectively (Fig. 4-21). Hartzburgite individualisations, near of the zone of disjunctive tectonics are presented more serpentinized.

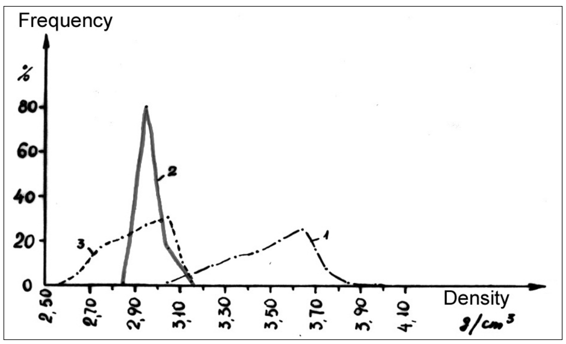


Fig. 4-21. The density variation curves of the chromites (1), dunites (2) and hartzburgites (3) in Kepenek deposit, Tropoja ultrabasic massif. (Frashëri A., 1974).

In the other deposits or occurrences in the Tropoja ultrabasic massif, the density distribution of the different kinds of the surrounding rocks, has another character. In the Kami deposit, there are extended a ultrabasic rocks with a density mode of 2530 kg/m^3, which shows the present of serpentinites.

The density of the dunites and apodunitic serpentinites change from 2480 kg/m^3 up to 3050 kg/m^3, and mode 2530 kg/m^3 (Fig. 4-21).

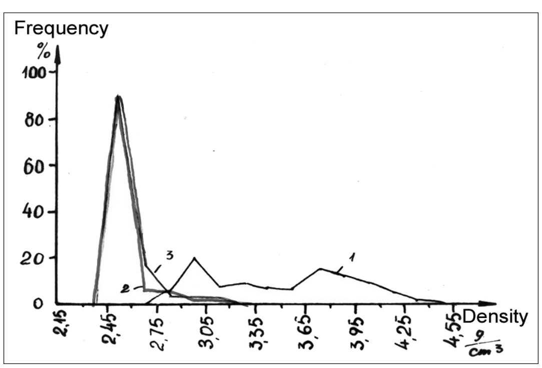


Fig 4-22. The density variation curves of the chromites (1), dunites (2) and hartzburgites (3) in Kami deposit, Tropoja ultrabasic massif. (Frashëri A., 1974).

The hartzburgites and apoharzburgitic serpentinites have a density varies from 2380 up to 2940 kg/m^3 , with mode 2540 kg/m^3.

In the Vlahna deposit, in Paci and Gzhima occurrences, predominate serpentinites with average density 2560 kg/m3 (fig 4-23, 4-24, 4-25). Only in the great depth, are located also the fresh ultrabasic rocks.

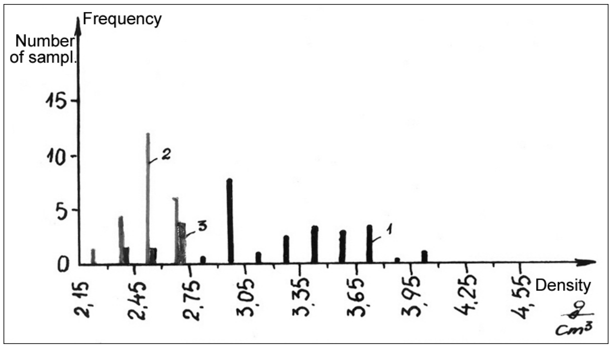


Fig. 4-23. The density variation curves of the chromites (1), dunites (2) and hartzburgites (3) in Vlahna deposit, Tropoja ultrabasic massif. (Frashëri A., 1974).

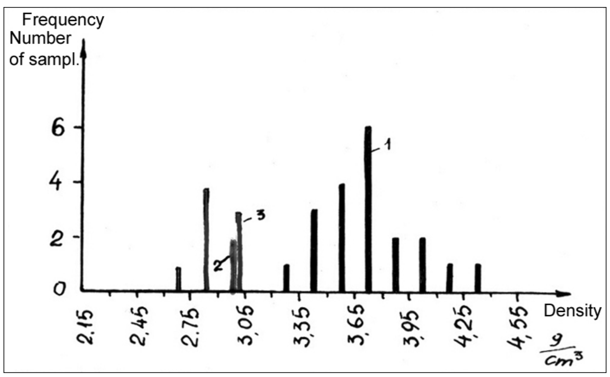


Fig. 4-24. The density variation curves of the chromites (1), dunites (2)
and hartzburgites (3) in Paci occurrence, Tropoja ultrabasic massif. (Frashëri A., 1974).

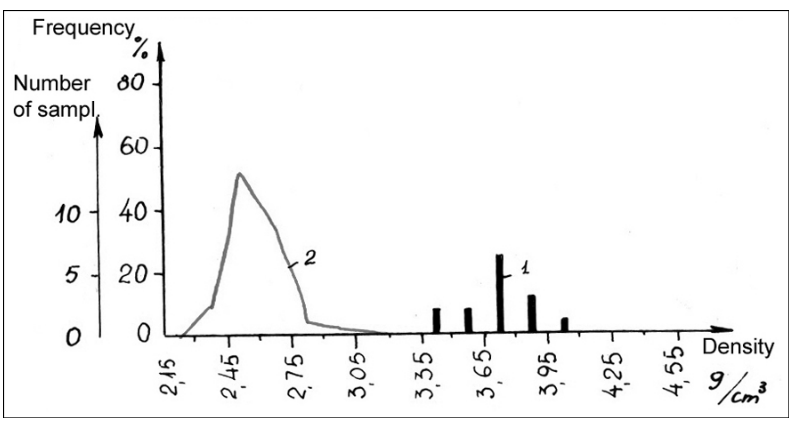


Fig. 4-25. The density variation curves of the chromites (1), dunites (2) and hartzburgites (3) in Gzhima occurrence, Tropoja ultrabasic massif. (Frashëri A., 1974).

Based on above-mentioned analyse it is possible to take some geological conclusions about the ultrabasic massif of Tropoja: Ragami deposit, Tplanë and Paci occurrences are located in the western part of the massif. Kami, Kepenek and Vlahna deposits are located in the eastern part of the massif. The density mode of the ultrabasic rocks in the western part of the massif is averagely 2980 kg/m^3, in eastern part 2550 kg/m^3. This situation shows that in western part of the massif are extended mostly fresh ultrabasic rocks. Serpentinized dunites and hartzburgites also and the serpentinites are presented in general eastern part of the massif rocks. Consequently, from west to the east is increased the level of the serpentinization and dynamo-metamorphism. In the same time, serpentinization intensively of dunites and hartzburgites are different in these both side of the massif. Dunites of the western part of the massive are most intensively serpentinized that hartzburgites. Par counter, in the eastern part, there are hartzburgites most serpentinized. In the vertical direction, the density of the geological section rocks, in the deposits, in general, is homogeneous. Density space distribution peculiarities of the ultrabasic rocks of the Tropoja massif are expressed geological-textural settings of the massif.

Figs 4-15, 4-16, 4-19 up to 4-25 and tab. 4.5 shows the value of the density contrast among chromite spinel ores and ultrabasic rocks of the Tropoja massif.

Residual density of chromite spinel ore and ultrabasic rocks of Tropoja massif

Tab. 4.5.

Ore or rock individualisation	Surrounding rocks	Residual density and confidence borders, g/cm^3
Rich chromites	Fresh dunites and hartzburgites	800±40
	Serpentinized dunites and hartzburgites	1000±20
	Serpentinites	1100±40
Average contain of chrome spinel	Serpentinized dunites and hartzburgites, serpentinites	400±50
Piroxenites	Serpentinized dunites and hartzburgites, serpentinites	40±260
Gabbro-pegmatites	Serpentinized dunites and hartzburgites, serpentinites	400±180
Fresh dunites and hartzburgites	Serpentinized dunites and hartzburgites, serpentinites	400±40

Based on petrodensity studies, it results that chrome ores have different density values from those of the surrounding ultramaphic rocks. Massive ores are very well distinguished from surrounding rocks; medium disseminates chromites can be distinguished by serpentinized rocks and serpentinites and poor chromites are different from the last ones. Dunites and fresh hartzburgites, pyroxenites and also gabbro-pegmatites are differentiated from all kinds of serpentinized ultramaphic rocks.

4.2.2. Magnetism

The magnetism values of the chrome ore and the ultrabasic rocks is unstable and change in a wide range. The magnetism is the most variable property of them. This is due to the quantity changes of iron-magnetite minerals and their forms inside the ore or minerals. The variation of their residual and chemical magnetism strongly depends on the chemical transformations, recrystallization and redistribution of the mechanical stresses. Therefore, chrome ores and ultrabasic rocks can be classified as nonmagnetic, weakly magnetic, and strongly magnetic ones.

Iron chrome ore magnetism

Massive texture iron-chrome ore, situated inside fresh ultrabasic rocks, has an induced magnetization (I_i) predominant value of $(500\pm50)\cdot10^{-5}$ SI units (fig. 4-26, tab. 4.6).

The remanent magnetization of those chromites varies between $(100\text{-}8100)\cdot10^{-5}$ SI units. In Kepenek deposit are found very powerful magnetic ores with a predominant remanent magnetization value of $5300\cdot10^{-5}$ SI units (Photo 4-4), and also non-magnetic ores, with I_r values $(150\text{-}70)\cdot10^{-5}$ SI units. The ores of average disseminates structure have smaller induced magnetization levels than the massive ores. The remanent magnetization in massive ores has almost equal values (Table 4.6).

From this table it can see that the ore in serpentinized rocks differs from the others. Unlike the ore i the fresh rocks, those in the serpentinized rocks are generally not magnetic.

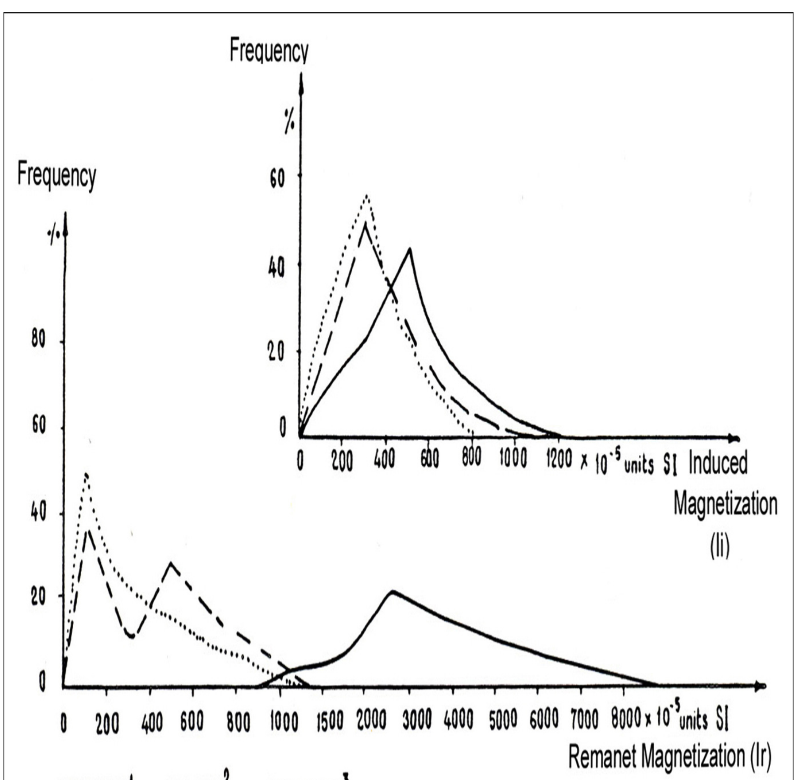


Fig. 4.26. The variation of induced magnetization (I_i) and remanent magnetization (I_r) of chrome ores and ultramaphic rocks of tectonic sequence (Frashëri A. 1974, 1989).
1- Dunites, 2- Hartzburgites, 3- Massive structure chromites.

The magnetic properties of the chrome spinel ore and the ultrabasic rocks.
(Frashëri A, 1974, 1989)

Table 4.6.

Kind of ore or rock	Quantity of samples	Induced magnetization I_i, $*10^{-5}$ units (SI)			Remanent magnetization I_r, $*10^{-5}$ units (SI)		
		Min.	Max.	Mode	Min.	Max.	Mode
Chromite with structure of dense disseminated up to massive among dunites	25	100	1250	500±150	10	8100	100 700 3200
Massive magnetic chromite among dunites	8	2400	10000	3700	2400	10000	5300
Chromite with structure of average disseminated among duntes	25	100	1000	300±100	1200	6500	2500± 900
Chromite among the serpentines	27	100	10000	300±100	10	900	100±80
Dunite	85* 32**	0	700	10±10 50±30 200±80	10	1800	300±70
Serpentinized dunite	20	38	1000	350			
Harzburgite	109* 56*	0	700	15±15 300±100	20	1000	300±100
Serpentinized harzburgites	87* 14**	40	1000	300	20	1300	350±150
Serpentinites from dunites	82	0	3700	150±70	5	70000	300±90
Serpentinite from harzburgites	68	0	1100	250±50	5	9500	150±60
Pyroxenites	102	10	720	350±60	10	71000	150±90
Gabbro pegmatites	21	0	270	50	170	250	

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

The strong magnetic chromites, represent ores with 90-95% chrome spinel and 10-5% olivine contain. Their chrome-spinel appears splitted and corroded by olivine. Many thin belts of broken ores can be observed on polished sections. The quantity of secondary magnetite is rather big in these ores. This secondary magnetite is found in the form of small spots and narrow and long veinlets almost parallel with each other, inside chrome spinel grains and in the fissures. Their induced magnetisation can be determined by the quantity contain of secondary magnetite. Due to the typical crystalline structure of spinel and to chemical formula (Mg, Fe)(Cr, Al, Fe)$_2$O$_4$, the chrome spinel represent the ferrite and magnetic moment of the molecule is created by bivalent atom of the iron Fe^{2+} (table 4.7).

The dependence of chromite magnetism by FeO contains.

Table 4.7

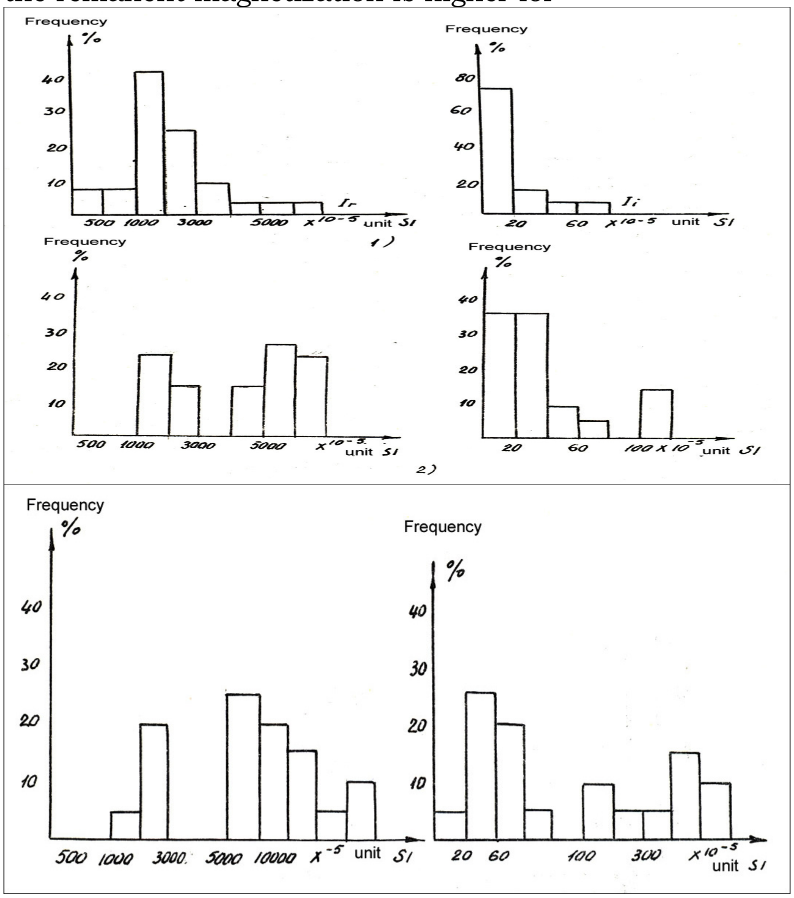
FeO contain 15%	Induced magnetization, in x10^{-5} SI units	Remanent magnetization, in x10^{-5} SI units
11.31	140	3517
16.07	270	3153

Chrome spinelides, behaving like ferrites have induced magnization which varies in broad limits, that depend on contain of bivalent of iron (Fe^{+2}) in their spinelic structure and on the contain of the secondary magnetite as well. Beside the contain of bivalent atom of iron (Fe^{+2}), which for the chrome spinel of the studies massif reaches averagely 3,3 atoms (Çina A., 1966), there is another characteristic linked with the contain of titanium oxide TiO (averagely 0,08 atoms) which is in just proportion with the contain of three valent atom of iron (Fe^{+3}) (Çina A. et al. 1966, Çina A. 1970, 1987). The presence of TiO_2 influences its magnetic features, as well. In general, it is proved that, the magnetization gets higher together with the increase of the number spinel grains inside the ores. Besides the induced magnetization in the chrome spinelides there exists the phenomenon of hysteresis, as the result of which there might appear remanent magnetization. So, it is natural, that the remanent magnetism has gained values with broad limits, but with maximal values smaller than the remanent magnetization of the magnetic minerals and especially of magnetite.

The larger magnetism of the massive structure ore compared with that with disseminates, is influenced even by the larger contain of Fe in massive ores.

The remanent magnetization (I_r) marked reduction down to 100x10^{-5} units SI, and the induced magnetization (I_i) reduction down to 300x10^{-5} units SI for the ores in the serpentinized rocks was accompanied by a Q_n ratio change (from $Q_n>1$ to $Q_n<1$) as well (Table 4-6). The decrease of the remanent and induced magnetization of the ores situated between serpentinized rocks can be explained by the magnetization changes of the ferrite. Elastic strain effects due to the redistribution of mechanical stresses and the chemical-mineralogical changes occurring during the serpentinization process cause these changes (Photo 4-5, 4-6).

Nevertheless the ore magnetism is not the same for different deposits. For example, the disseminated texture ore in Fushe Kalt deposit in Bulqiza ultrabasic massif has a predominant induced magnetization value of 20x10-5 units SI, while the remanent magnetization is higher for



Remanent magnetization Induced magnetization

Fig. 4-27. The histograms of the variation of the remanent (I_r) and induced (I_i) magnetization of the chrome ores in Fushe Kalt deposit in Bulqiza ultrabasic massif (plotted by data of Sharra Xh. et al. 1987, according to the measurements of Kosho P., Dema Sh., Rrenja A.).
Ore structure: 1- Average disseminates, 2- Average-Dense disseminates, 3- Massive ore.

the chromite of medium disseminates up to dense disseminates, or massive structure (Fig. 4-27). Massive chromites are not magnetic ones.

Disseminated structure ores with high values of induced magnetisation up to 850.10^{-5} units SI are located in areas, which have been under a powerful dynamic action, where a lot of secondary magnetite is created within the serpentine mass and even in the chrome spinel grains. On the contrary, the massive ores of the same zone due to small contain of magnetite in the main mass have a smaller value of induced magnetization (Ii).

In the 45% of the analysed samples remanent magnetization observed is $1<I_r/I_i<3,5$ and in special cases up to 12,5.

Remanent magnetization vacillates in broader limits than the induced magnetization; especially, for particular samples it reaches up to 97000x10^{-5} units SI.

Mineralographic studies have proved that magnetism is strengthened alongside with the increase of the chrome spinel grains in the ore.

Figs. 4-28, 4-29, and 4-30 show the distribution of the magnetization of chromite spinel ores of the Kepenek, Kam, Vlahna deposits.

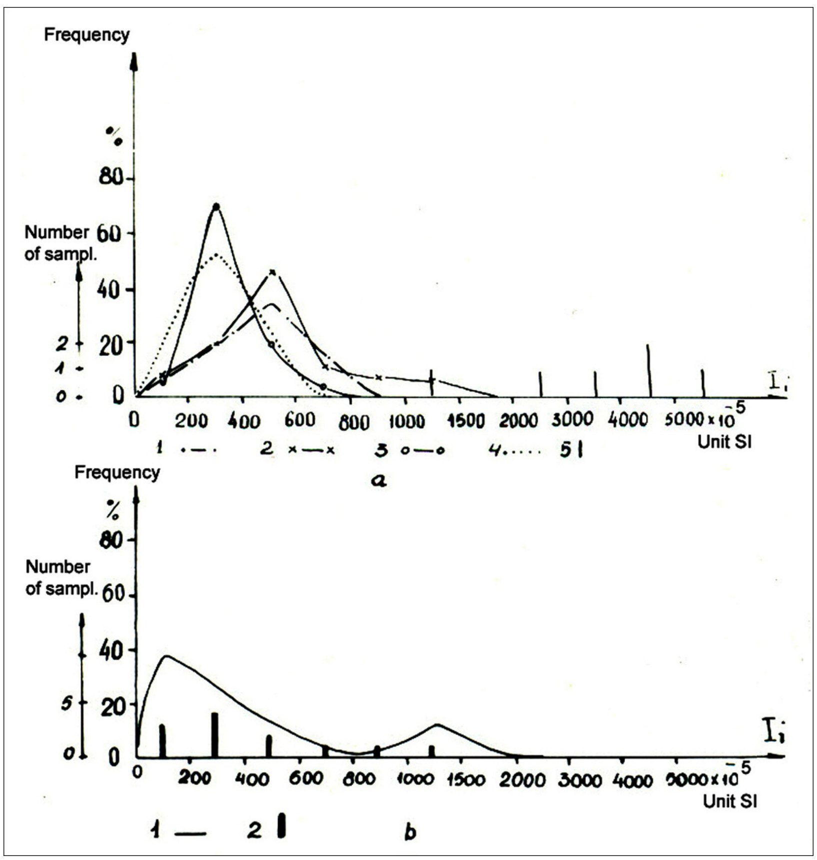


Fig. 4-28. Variation curves and histograms of the induced magnetiza-tion (I_i) of the Kepenek deposit ore (a), and Kam, Vlahna deposits and Pac occurrence (b). (Frashëri A, 1974).

1- Massive ore of the No. 1 body, which is located among the fresh dunites (26 samples); 2- Massive ore of the No. 7 body, among the fresh dunites (27 samples); 3- Ore among serpentinized rocks of Nr. 7 body (27 samples); 4- Average disseminates, among the fresh dunites (25 samples); 5- Magnetic massive ore of the No. 1 body (5 samples).

1.Rich chromite ore from Kam, Vlahna deposits and Pac occurrence (generalized curve, 33 samples);

2. Poor-average disseminated ore from Kam and Vlahna deposits (common graphic, 12 samples).

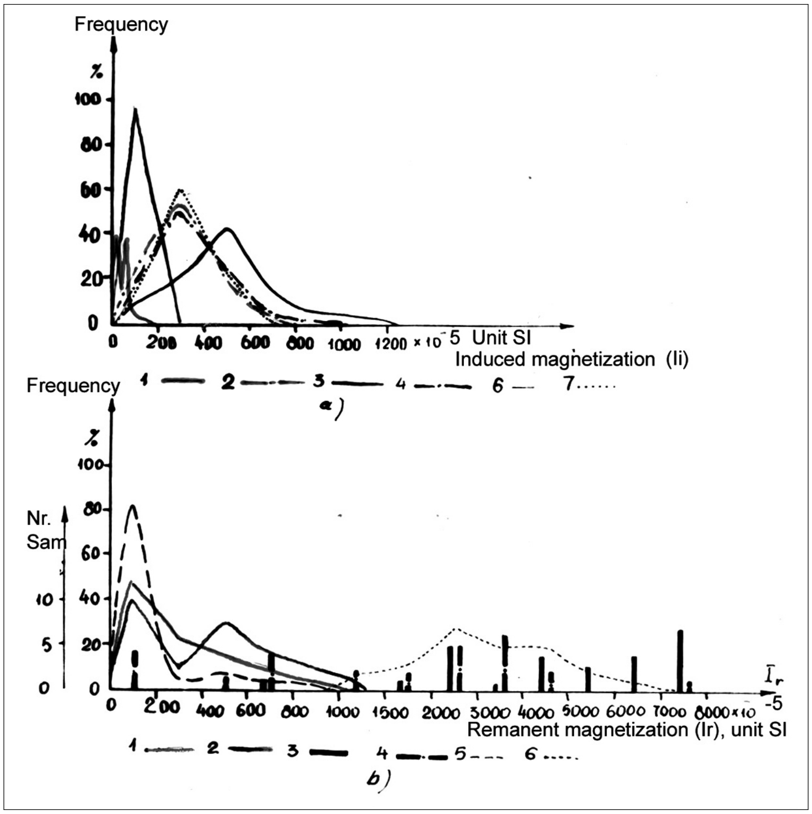


Fig.4-29. Variation curves and histograms of the induced magnetiza-tion (I_i) and remanent magnetization (I_r) for chrome spinel ores and ultrabasic rocks of the Kepenek deposits, and fresh rock of the Ragami deposit. (Frashëri A, 1974)

1- Dunites, Ragami deposit (45 samples);

2- Dunites, Kepenek deposit (30 samples); 3- Hartzburgites, Ragami deposits (58 samples); 5- Massive chrom spinel ore among the fresh dunites, Kepenek deposit (48 samples); 6- Chrome spinel ore among the serpentinized rocks, Kepenek deposit (52 samples).

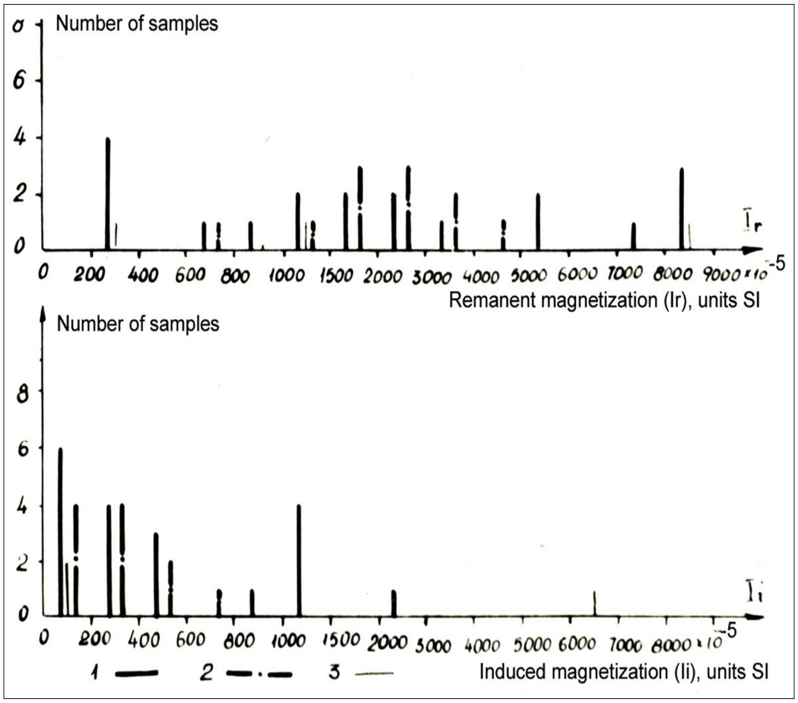


Fig.4-30.Histogrames of the induced (I_i) and remanent (I_r) magnetization of the rich chrome spinel ores from Kam (1), Vlahna (2) deposits, and Pac occurrence (3). (Frashëri A, 1974).

Magnetism of the rocks

The ultrabasic rocks have a magnetism, which changes in a broad band, conditioned by the presence of the ferromagnetic minerals, mainly by secondary magnetite and less by the magnetized accessory chrome spinel. 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 remanent magnetization (I_r). In this way the ultrabasic rocks can be considered from partially unmagnetic to strong magnetic.

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 (Fig. 4-26, table 4.5). The magnetic properties of these two kinds of rocks vary within almost the same limits. Remanent 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 cataclasised. 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 remanent magnetization. With the increasing of the activity of cataclases, magnetism is strengthened, especially the natural remanent magnetization. The fresh rocks have unequal magnetic properties in different regions.

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 (Fig. 4-31, 4-32, 4-33).

With the increase of the serpentinization process, the magnetization (in particular the remanent magnetization) of dunites and hartzburgites gets stronger. This can be explained by the increase of the secondary magnetite and the thermoremanent 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.

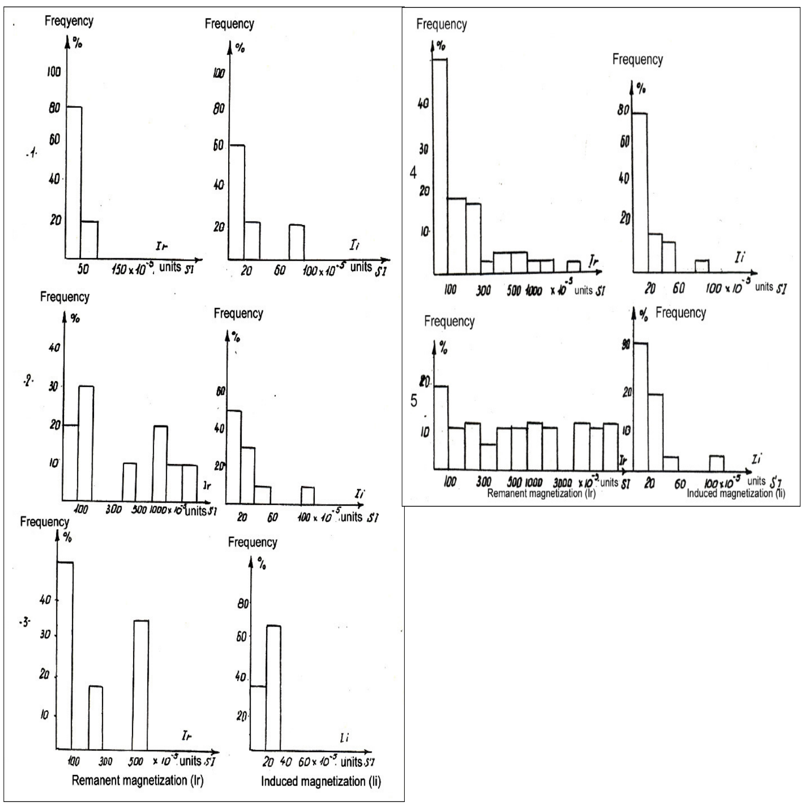


Fig. 4-31. The histograms of the variation of remanent (I_r) and induced (I_i) magnetization of the rocks in Fushe Kalt (Bulqiza) deposit (Plotted by data Sharra Xh. Et al. 1987, accorded to the measurements of Kosho P., Dema Sh., Rrënja A.).

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

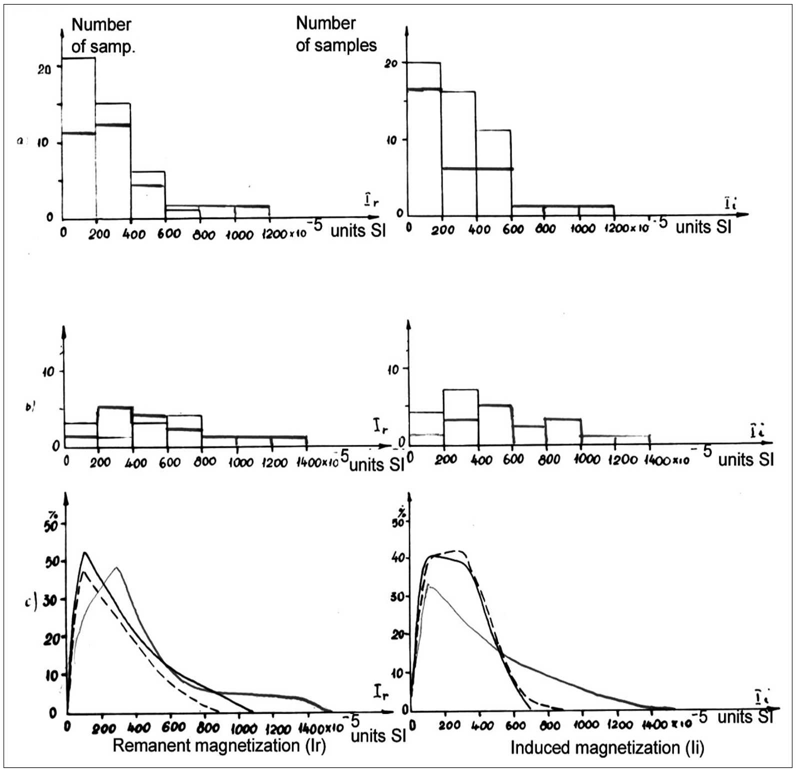


Fig. 4-32. The histograms of the variation of remanent (I_r) and induced (I_i) magnetization of the rocks in Kami (a), Vlahna (b) and variation curves (c)(Frashëri A., 1974).
1. Serpentinites from dunites (55 samples); 2. Serpentinites from hartzburgites (59 samples); 3. Piroxenites (102 samples).

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 (Photo 4-7, 4-8, 4-9, 4-10). 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.

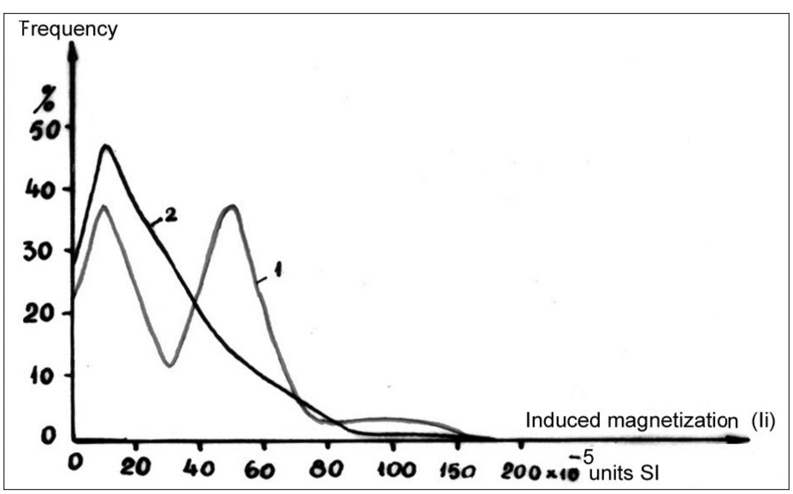


Fig. 4-33. The variation curves of induced (I_i) magnetization of the dunites (1) and hartzburgites (2), Ragami deposit. (Frashëri A., 1974).

These great changes of the remanent 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 4-5). 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 remanent magnetization has a thermal nature, under the influence of the magnetic field of the earth and surrounding rocks.

The gabbro-pegmatite are magnetic only in the cases when there is primary magnetite in their composition, like in the cases of cumulate sequence (Tab. 4.5).

Petromagnetic studies have shown the presence of inverse magnetization phenomenon for chrome spinel ores in some deposits (fig. 4.34).

From this picture, it can be seen that the ores in Kepenek deposit (Tropoja ultrabasic massif), are characterised by vectors of remanent magnetization oriented in the average azimuth $\Phi=356°$ and with dipping angle $\theta=-70°$, i.e. opposite to the direction of the vector of remanent magnetization for surrounding rocks. The surrounding dunites the dipping angles of the I_r vector is averagely $\theta=60^0$, where as the azimuth $\Phi=42^0$.

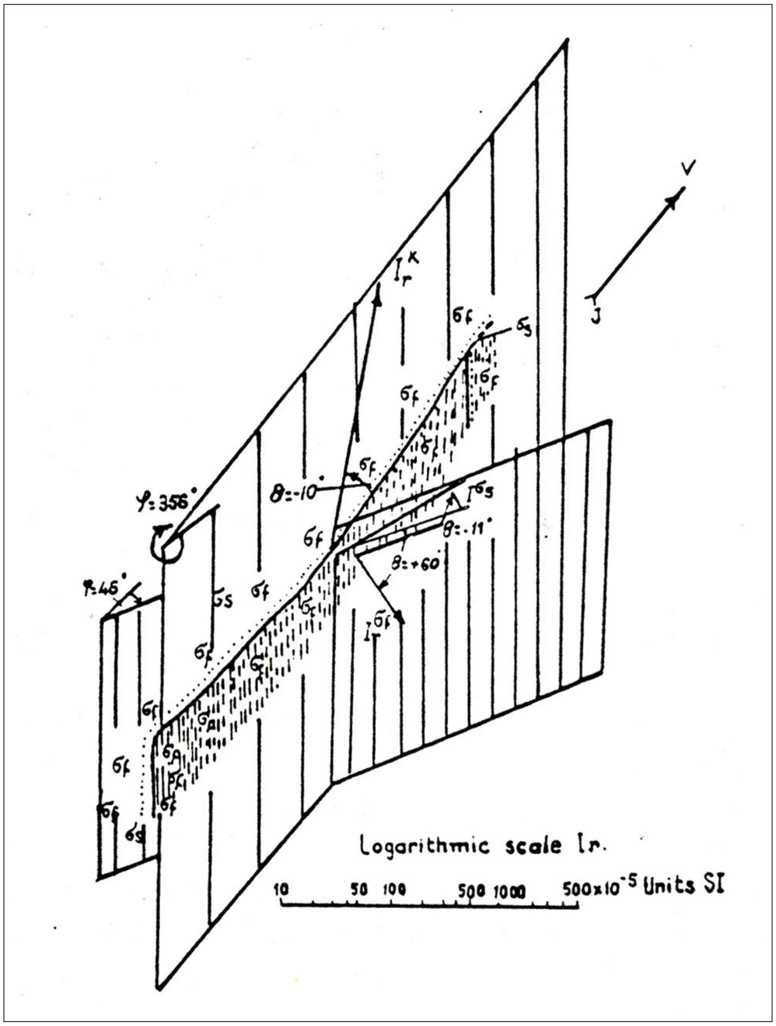


Fig. 4.34. The inverse remanent magnetization (I_r) for a chrome ore in Kepenek deposit, Tropoja ultrabasic massif. (Frashëri A. 1974, 1989).

The sample from the dunitic envilope 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 cataclisis 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).

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 remanent 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. 4.35). Under the thermal influence of the ore matter, in the dunitic envelope of the ore body the direction of the I_r inclination has changed.

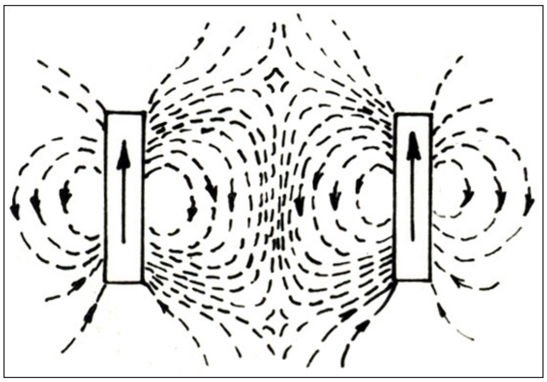


Fig. 4.35. Distribution of magnetic lines in the space between two bodies near each other, with the magnetization vectors in the same direction and sense.

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).

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

In cumulate sequence and the surrounding dunite and hartzburgite rocks (for example in Cërruja deposit, Bulqizë) have observed a normal vector of remanent 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 of the rocks.

Petromagnetic studies carried out for chromites and ultramaphics rocks demonstrated that:

- Massive structure ores of many deposits are more magnetic than the surrounding rocks.
- Disseminates structure ores are more magnetic than the surrounding rocks.
- There are some nonmagnetic chrome ores.
- 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. 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.
- 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.

Tab. 4.8 presents the values of the contrast of the magnetism between the chrome spinel ores and ultrabasic rocks;

Contrast of the magnetism between chrome spinel ores and surrounding ultrabasic rocks in Tropoja massif (Frashëri A. 1974)

Tab. 4.8

7

Kind of the		Deposit or occu-rrence	Student para-meter (t) after I_r	Difference between the values of the magnetism, in $x10^{-5}$ units SI		
Chromite ore	Surrounding rocks			I_r	I_i	$\lvert I_r+I_i \rvert$
Rich ore	Serpentinite	Pac Vlahna	2,5 22,2	1000 2000	0 100	1000 2100
	Dunite	Kepenek	10,0	2300	100	2400
Power up to average contain ore	Serpentinite	Kam Vlahna	5,5 8,3	300 1800	130 140	430 1940

4.2.3. Induced polarization (IP)

Polarizability of the ultrabasic rocks and the chrome spinel ores was determined on samples of regular geometrical shape (parallelepiped) with the dimension 100 x 80 x 50 mm. Measurements were carried out in the time domain. The effect of induced polarization was expressed with the coefficient η, which is given:

$$\eta = \frac{dU_{IP}}{dU_p} \cdot 100\%$$

where: dU_{IP} – the difference of IP potentials, measured 500 ms after the switch off of the charging pulse.

dU_P – the difference of the charging pulse potentials.

In some characteristic samples were studies the IP decay curve in three windows. The first window with integration from 260-520ms. For such measurements, IP chargeability is expressed in mV/V, and given:

$$M = \frac{V_s}{V_p} \cdot 1000$$

where: V_p- primary voltage

V_s – IP (secondary) voltage

According to our measurements of same samples with both techniques we found that M/η≈4,5.

The chrome spinel ores and the ultrabasic rocks are characterised by IP coefficient values from 0.2 -60%. They may be from unpolarizable to strongly polarizable (Tab. 4-9).

Coefficient of Induced Polarization (IP) of chrome spinel ores and ultrabasic rocks.(Frashëri A. 1974)

Tab. 4.9

Kind of ores/rocks	The scale of polarization	Number of samples	IP Coefficient, in %		
			Min.	Max.	Average
Rich chromite	Low	14	0,7	3,0	2±0,5
	Average	57	3,0	18,0	13±1,0
	Strong	19	18,0	30,0	25±1,0
Chromite with average contain up to massive	Unpolarizable	18	0,2	2,0	1±0,5
	Average	39	2,0	18,0	6±1,0
Dunites	Unpolarizable And low	18	0,2	2,0	1±0,5
Serpentinite from dunites	Low	26	0,4	6,0	2±1,0
	Average	8	6,0	19,0	12±3,0
	Strong	6	19,0	41,0	32±5,0
Hartzburgites	Unpolarizable	51	0,2	2,0	1±0,3
Serpentinized hartzburgite and serpentinite from hartzburgites	Low	20	0,5	6,0	3±1,0
	Average	23	6,0	19,0	11±2,0
	Strong	34	19,0	51,0	35±4,0
Fresh pyroxenites	Unpolarizable	2	0,1	0,2	
Gabbro-pegmatites	Unpolarizable	2	0,3	1,0	

Chrome spinel ores polarizability

The rich chrome spinel ores has an IP coefficient (η) which varies from 0,7 to 30%. The polarizability is divided into three groups:

- Chrome ores with small IP values (0.7-3%) and a predominant IP value of 2%.
- Chrome ores with average IP values (3-18%) and a predominant IP value of 13%.
- Chrome ores with high IP values (18-60%) and a predominant IP value of 25%.

Ore bodies with high IP values have been found in some deposits (Fig. 4-36). Polarisable ores in Kepenek deposit are situated between fresh rocks.

The chromites of cumulate sequence (for example Cërruja deposit) have IP values from 2% up to 4%. The ores of average and dense dissemination have the highest IP values. This feature is not very high for massive chromites. Low up to medium IP values have been observed in Kami and Vlahna deposit, (Tropoja massif) where chrome ores are situated between serpentinized rocks, and also in Tri Gjepra zone (Bulqiza) (fig. 4.37, 4.38).

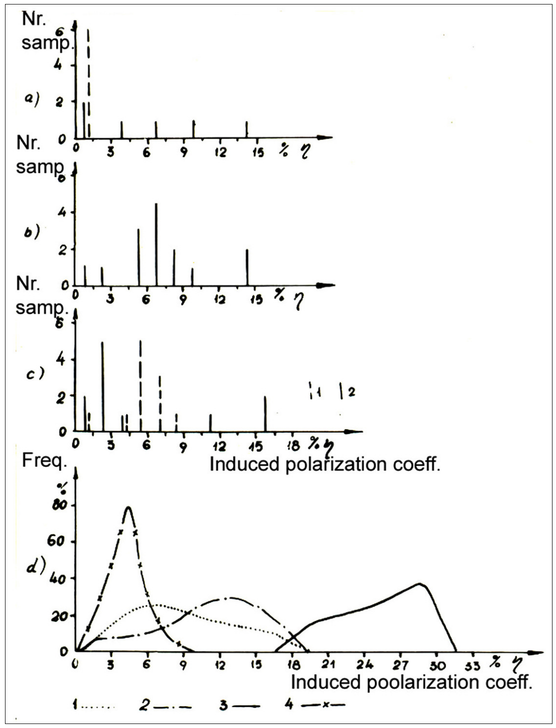


Fig. 4-36. Variation curves and histograms of IP coefficient of chrome spinel ores in Kam deposit (a), Paci occurrence; c) Vlahna deposit; d) Kepenek deposit. (Frashëri A. 1974).

c) 1- Rare up to average disseminates ore; 2- Rich ore.

d) 1- Disseminates ore among the dunites (27 samples); 2- polarizable massive ore among the dunites (39 samples); 3- strongly polarizable ore among dunites (19 samples); 4- ore among the serpentinized rocks (28 samples).

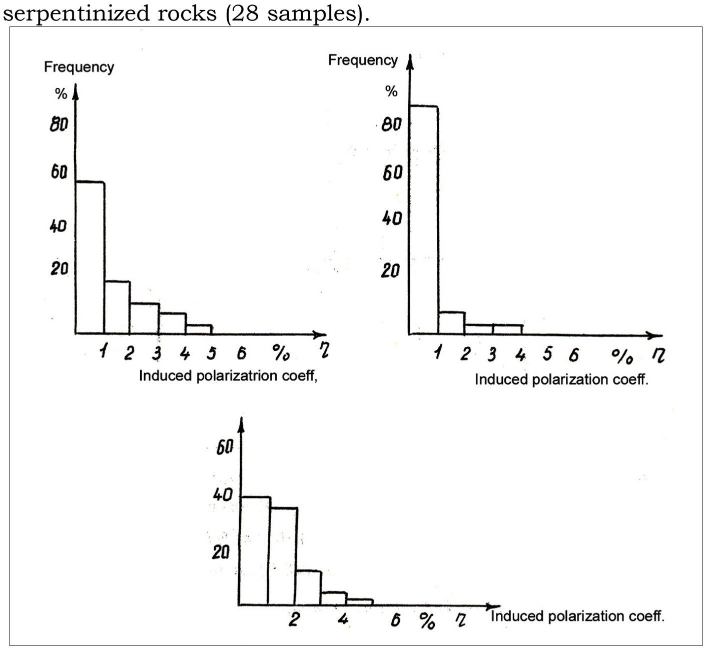


Fig. 4-37. Histograms of the IP coefficient variation in Tri Gjepra zone (Bulqiza massif), (plotted according to data presented by Prenga Ll. et al. 1986).

1. Chromites; 2. Dunites; 3. Hartzburgites.

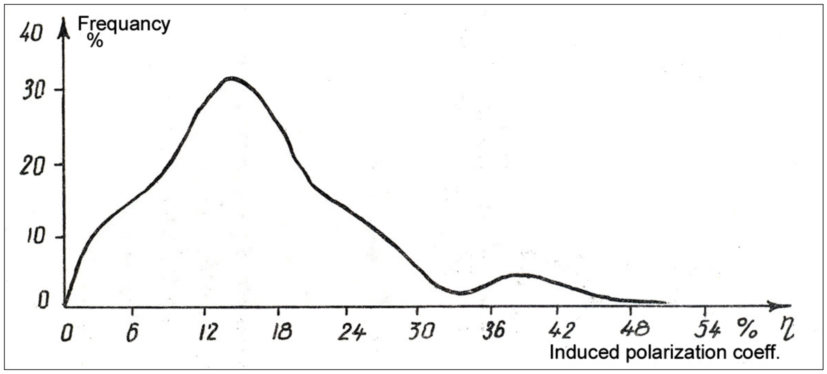


Fig. 4-38. The variation curves of the IP coefficient of the chrome ores in Cërruja deposit (Bulqiza massif).

In some deposits of average and high grade chromites except for chromite with average contain and sometimes rich chromites with average IP values, unpolarized ores exist as well (0.2 - 2%).

Fig. 4-39 present variation curves of IP coefficient for chrome ores of deposits in the Tropoja massif.

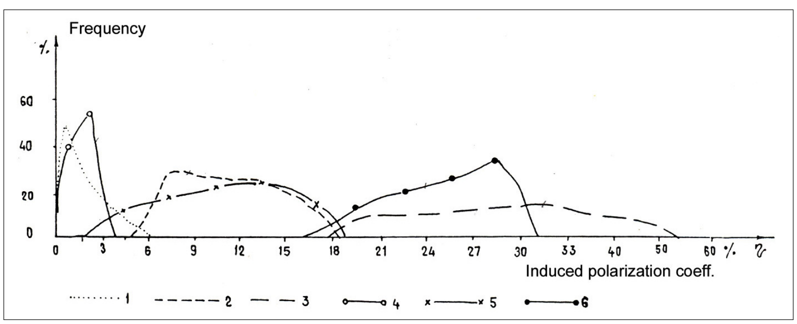


Fig. 4-39. The variation curves of the IP coefficient for the chrome ores and ultramaphics rocks of the Tropoja massif. (Frashëri A. 1974).

1. Unpolarizable average contain and poor ores (7 samples); 2- Polarizable average contain and poor ores (39 samples); 3- Unpolarizable rich ore (14 samples); 4- Polarizable rich ore (57 samples); 5- Strongly polarizable rich ore (19 samples); 6- Weak polarizable ultrabasic rocks (115 samples); 7- Polarizable ultrabasic rocks (31 samples); 8- Strongly polarizable ultrabasic rocks (40 samples).

The study of the polarization of massive chrome ores, in the majority cases, shows that high grade of IP polarization ores have higher levels of polarization than those with rare up to average disseminates.

As can be seen from the IP coefficient variation curves (figs. 4-36 up to 4-39), the ability of chromites to get polarised is not the same, not only for different deposits but even for particular ore bodies of the same deposit and in side of the same ore body as well.

Polarizability of the ultrabasic rocks

The IP coefficient of cumulate sequence ultramaphic rocks varies in a wide range than in the chromites (fig. 4-40). If the maximal value of this IP coefficient reaches in 30% for the chromites, in the investigated rocks this one reaches up to 51% (Table 4-8).

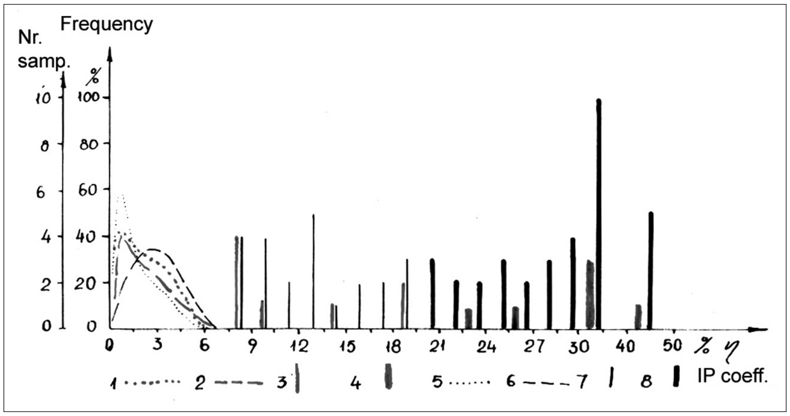


Fig. 4-40. Histograms and variation curves of the induced polarizability. Of ultrabasic rocks. (Frashëri A. 1974).

1- Dunites; 2- Weakly polarizable serpentinites from dunites; 3- Polarizable serpentinites from dunites; 4- Strongly serpentinites from dunites; 5- Hartzburgites; 6- Weakly serpentinites from hartzburgites and serpentinized hartzburgites; 7- Polarizable serpentinites from hartzburgites and serpentinized hartzburgites; 8- Strongly polarizable serpentinites from hartzburgites and serpentinized hartzburgites.

The secondary magnetite, in the cumulative sequence dunite, is present in the form of veinlets. The magnetite is higher especially where there is chrysotile-asbestos banding. The distribution curve of the IP coefficient of dunites has two maximums in Cerruja deposit. This indicates the presence of nonpolarisable dunites and strongly polarizable ones (fig. 4-41). The polarization values of the Cërruja deposit hartzburgites, vary in wider range than the chromites and dunites. Their IP coefficient varies from 0.2-51% and only one maximum point with a coefficient value of 3.2 % can be observed.

Strong polarisability is characteristic for magnetic dunite and hartzburgite. The IP polarization of cumulate sequence rocks changes not only in horizontal plane but also in vertical section. Alternations of nonpolarisable rocks with strongly polarisable ones can be observed.

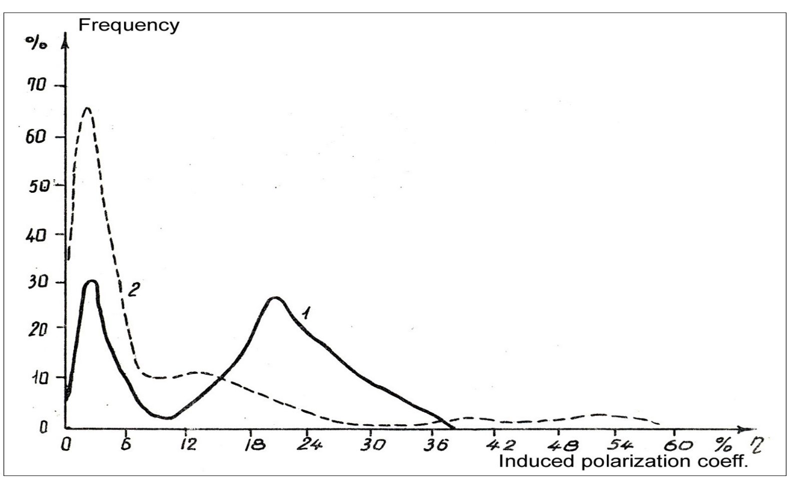


Fig. 4-41. The variation curves of the IP coefficient of the Cërruja deposit, Bulqiza ultramaphic rocks. (Frashëri A. 1974)
1 - Dunite, 2 - Hartzburgite.

Based on the level of polarizability, rocks can be classified as low, average and strong polarisable ones.

The dunites, hartzburgites and a kind of serpentinites can be considered as rocks with low polarization. Their predominant IP coefficient value is about 1%.

The polarisability of the ultramaphic rocks increases with the increase of the serpentinization. According to the petrophysical studies, the polarization of chrome ores and ultramaphic rocks is mainly determined by contain and the shape of the secondary magnetite and in some cases by the small disseminates of the pentlandite, when they are present. Greater effect can be observed in cases when the secondary magnetite is present in the shapes of fine chains, very thin veinlets or lattice (Photo 4-14 and 4-15). There are many rocks with strong polarization more than the chrome spinel ore. No difference noticed between the serpentinites from dunites and serpentinites from hartzburgites.

In order to know the nature of so changeable and strong polarizability of chrome spinel ores and the ultrabasic rocks we have studied the relation of the IP coefficient to the induced magnetization, electrical resistivity, the contain of the minerals with electronic conductivity or as semiconductors, the humidity and to the technical survey parameters like the density of the polarizing current and the time of charging pulse. The form of the decay curve of the IP effect was also studied.

For other equal conditions (resistivity, rock soakness and the technical survey parameters) there exists the linear relation between the IP coefficient and the induced magnitization, for the ores and the ultrabasic rocks, too (fig. 4-42, 4-43). The relations with greater slope are those of the strongly polarized rich chromites, and of serpentinites. Since the induced magnetization of chrome spinel ores and the ultrabasic rocks depends on the presence of the secondary magnetite within, the induced polarizibility of the chrome spinel ore and the ultrabasic rock as well is determined by the contain of this semiconducting mineral that can be strongly polarized. These conclusions were fairly well proved by petrographic and mineralogical studies.

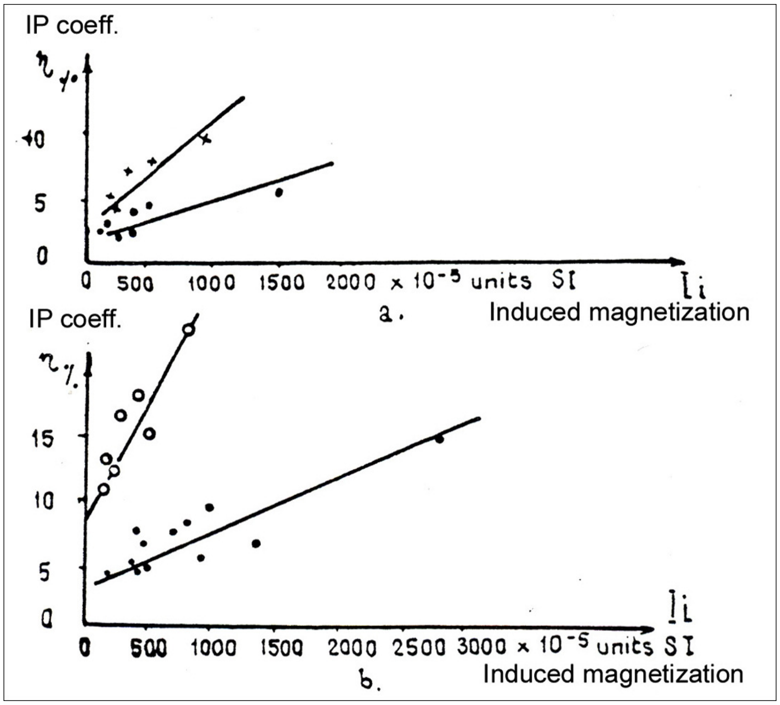


Fig. 4-42. The dependence of the IP coefficient by induced magnetization (I_i) for the ore with average disseminates (a) and rich ore (b). (Frashëri A. 1974, 1989).

1- Polarizable rich ores and disseminates ores;

2- Average disseminates ores; 3- Strongly polarizable massive chromites (resistivity about 20 000 Ohmm).

The ore cannot be polarized does not contain secondary magnetite. The ore has a polarizability up to 4% when it has small quantities of secondary magnetite in the form of detached spots. The polarizability is increased many times, not only when the quality of magnetite is increased but also when it is placed very thin chains and veinlets (their thickness may be 0,00064-0,0032 mm). The polarizability assumes values over 20% in the cases when the secondary magnetite is in a net-structure in the massive ore. The presence of other minerals with electronic conductivity or semiconductivity such as petlandit, have influences on the polarizability. It is very often found, though in small quantities, in chrome spinel ores in the form of very fine-grains crystalline individuals.

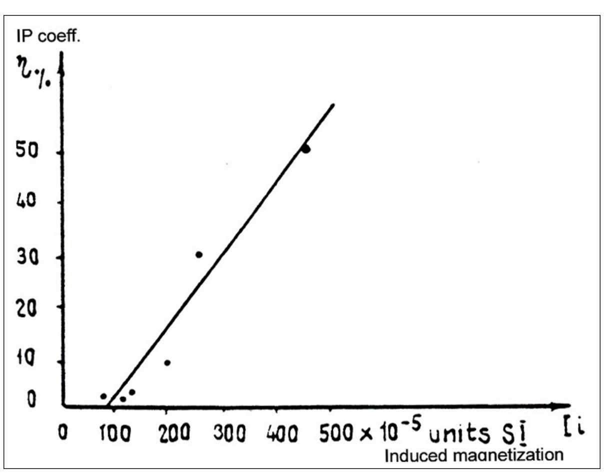


Fig. 4-43. The dependence of the IP coefficient by induced magnetization (I_i) of the serpentinites (resistivity about 50 000 Ohmm).(Frashëri A. 1974, 1979).

The fresh and the serpentinized rocks that do not contain secondary magnetite practically are not polarized ($\eta<0,2\%$). With the increase of the quantity of magnetite the IP coefficient is also increased. Where the secondary magnetite is the form of the fine chains and veinlets, the coefficient of IP has maximal values.

In this way it is proved that the induced polarizability of the chrome spinel ore and the ultrabasic rocks first of all depend from the quantity of the secondary magnetite and the other minerals with electronic conductivity, as well as on the geometric of the grains of these minerals and the manner of their placing in the ore or in the rock.

There are also defined the dependence of polarizability on the resistivity of the ore and the ultrabasic rock (fig. 4-44). With the increase of the resisivity, polarizability is increased and reaches the maximal values in the samples with a resistivity of 100 000 Ohmm. With the further increase of resistivity, the polarizability begins to decrease.

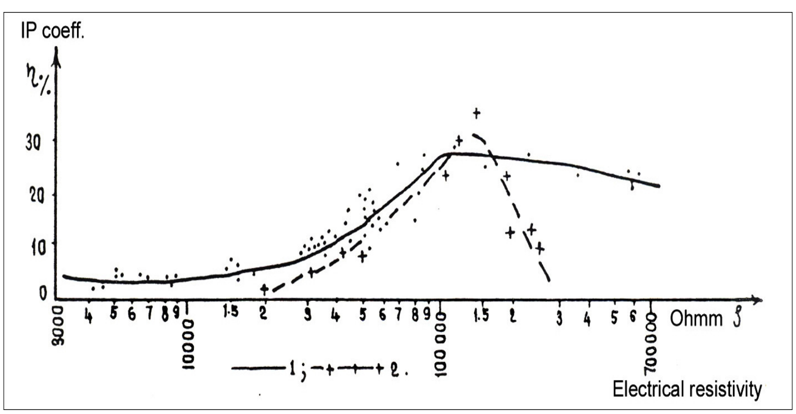


Fig. 4-44. The variation of the IP coefficient on the resistivity of the chrome ore (I_i=500.10^{-05} SI units) (1) and on the resistivity of the tectonic sequence serpentinite (I_i = 150 10^5 units SI) (2). (Frashëri A. 1974, 1989.

We have studied the relationship between IP coefficient and humidity, in order to better know the dependence of polarization on resistivity. Both these dependences (the dependence of the induced polarizability by resistivity and by the rock soakness) show that the IP effect depends from the level of saturation with water in the porous space of the ore or rock. When rock soakness is decreased to a certain level, the majority of the general polarizing current flows through the pores, which are blocked by the grains of magnetite, so the effect of IP become greater. The quantity of the IP effect greatly decreases for very small quantities of water. This reduction happens because, the surface of magnetite grains has a smaller affinity for water than the surface of the other neighbouring silicate grains for small contains of water, so the surface of the magnetite is the first to be dried. The same happens with the dependence of the IP effect on the resistivity. With the increase of resistivity to a certain limit, in analysed case equal to 100000 Ohmm, the part of the current that flow in the empty pores is reduced and the density of the polarizing current that penetrates into the magnetite grains is increased, the effect of IP is strengthened. The reduction of the IP effect for the samples with an extraordinarily large resistivity, over 100000 Ohmm, is connected with the general reduction of the density of the current that the flow through the sample, particularly through the magnetite grains.

This regularity is not observed everywhere. An example of this are the ores located in the cumulate sequence of the Cërruja chrome deposit (Bulqiza massif). For this ores it has been observed that with the increase of resistivity the IP coefficient decreases.

The amplitude of the induced polarization also depends on the density of the polarizing current (Fig. 4-45). For the averagely polarized ore, the IP potential varies linearly only in the initial interval, for a density of the polarizing current of 0,015-0,15 μA/cm². The ore that is weakly polarized retains the linearity of the variance of the potentials of IP from the density of the polarizing current for many times greater values (up to 6,5 μA/cm²). This shows that this kind of ore is polarized as the environment with ionic conductivity.

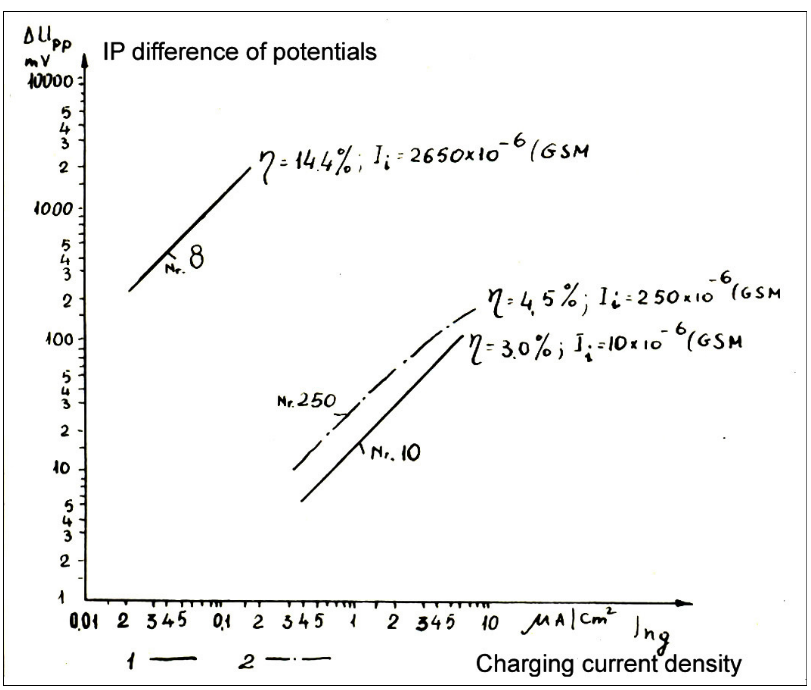


Fig. 4-45 IP potential (U_{pp}) dependence by the polarizing current density (j_{po1}). (Frashëri A. 1974).

1 – Chrome spinel ore; 2) Dunite.

In dunites, linearity is destroyed after the density of 3 μA/cm² of the polarizing current. The curve of the rocks, which have a magnetite in the form of thin veinlets placed in a lattice shape, is different from the one where the magnetite is present as homogeneously distributed dust. In the first case, the IP potential changes are linear up to the point where the density of polarised current reaches the value of 6 μA/cm². The curve is characteristic for the metal-electrolytic interface. Therefore those rocks are strongly polarisable (the IP coefficient is 22.3%). Some of serpentinites cannot get a polarizibility (IP coefficient is 1.8%) because their magnetite is distributed like dust. In this case we have to do with a straight line, characteristic for the polarization of the ionic conductivity rocks, which is smaller than that of the metallic-electrolytic interface.

The above-mentioned factors, related with nature of polarization, find reflection even in the charge and decay curves of the later phase of IP effect (Fig. 4-46). The more prolonged charge and decay curve is found in the ores that the strongly polarized. In these ores the decay of the IP effect continues as long as the charge. About 50% of the potential of IP decay is observed averagely 20 seconds after the switching off of the polarizing current. In the ores and dunites that are weakly polarized, the decay of the effect of IP is almost three times quicker than in the above-mentioned case. The quantity of the potentials of IP is reduced 50% after 12 seconds for the ore and 8 seconds for dunites, since the moment of switching off of the polarizing current.

A short decay like this is characteristic for the polarizability of the environment with ionic conductivity. Analysing all the data related with the nature of the polarizability of the chrome spinel ore and the ultrabsic rocks, we reach the conclusion that their average and strong polarization is a voluminous polarization developed in the metal (magnetite)-electrolyte interface. The absence of distinctions between the anodic and cathodic polarization speaks of the volume's nature of polarization, too.

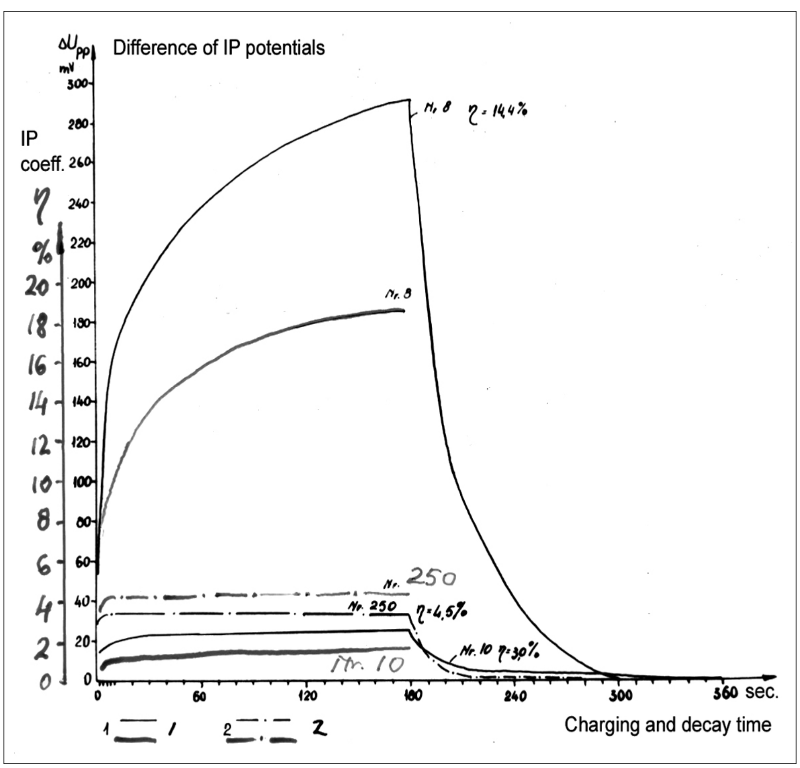


Fig. 4-46. The charging and decay IP curves of the chrome spinel ore (1; 2) and dunites (3; 4). (Frashëri A. 1974).

Beside the facts mentioned above, another phenomenon has been observed in some kinds of ores (for example, in Cërruja deposit). In some zones has been found chromite without secondary magnetite which can be polarized up to 20%, and chromite with less than 0.2% of secondary magnetite in dust form, with an IP coefficient up to 40.6%. These kind of polarisable ores are different from the nonpolarizable ones (IP coefficient is 2%) only by contain and homogeneous distribution of the chrome spinel aggregates inside the serpentine mass. These last ones have less chrome-spinel (35-40%) and can get polarized more than the massive ores.

From the correlation of the IP coefficient with the density, can be understood that the polarization is increased with the decrease of the density. This phenomenon shows that the IP of the ores is affected by the ore structure, the serpentinization degree of the olivine, the development of its capillary system and by contain of the metallic mineral.

For the tectonic sequence rocks with the same contain of metallic grains, it has been observed that, the rocks of low porosity are more polarisable than the ones of greater porosity. This means that the IP effect is connected with the rock's structure, and especially with its compaction and with contain and the form of the metallic grains.

Residual polarizabilities of the chrome spinel ores and ultrabasic rock in Tropoja massif are presented in the tab. 4-10.

The polarization study of the chrome ores and the ultrabasic rocks shows that :

1. Strongly polarisable rich chrome ores, can clearly be distinguished from the dunite, hartzburgite and serpentinite with low and average polarisability.

2. Rich and poor ores of average polarisability can be distinguished from the fresh ultramaphic rocks of low polarisability.

3. Serpentinized rocks and serpentinite with secondary magnetite are strongly polarisable and can be clearly distinguished from the fresh ultramafic rocks.

Residual polarizabilities of the chrome spinel ores and ultrabasic rock in Tropoja massif
(Frashëri A. 1974)

Tab. 4-10

Kind of ores and rocks	Surrounding rocks	Student parame-ter (t)	Residual IP coeff. in %
Strong polarizale rich chromite	Dunite, hartzburgite	8,8	24
	Average polarizable rocks	3,9	14
Average polarizable rich chromite	Weak polarizable rock	3,9	11
Averagely polarizable of chromite with average contain	Weak polarizable rock	6,7	5
Stron polarizable seprpentione	Weak polarizable rock	12,9	30
Averagely polarizable serpentine	Weak polarizable rock	4,2	9

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

1. The density is a more stable and typical physical property, which can be used for distinguishing chromites from the surrounding rocks. Therefore the gravity method is the basic geophysical method for the search for chrome deposits.
2. The gravity, as the main geophysical method of the search, can not substituted by magnetic surveying and either of them can not be substitute geoelectrical methods (as IP). There are strongly polarisable or magnetic ores whose density values have very small differences or no differences from the surrounding rocks. The bodies created by these ores, especially when they are situated between fresh rocks, are objects for the magnetic and geoelectrical surveying.
3. There are chrome ores, which have the same or similar features with the surrounding rocks. These ore bodies cannot create local anomalies of physical fields and cannot be studied by geophysical methods. For example the disseminated structure ores, which have an average density value of 3300 kg/m^3 and 32% of Cr_2O_3 contain, cannot be discriminated from the fresh dunite of the same density value.
4. 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.

5. The study of the orientation of the remanent 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.

4.3. APPLICATION OF GEOPHYSICAL ME-THODS IN SEARCH FOR CHROME DEPOSITS

Many geophysical studies carried out in the ultrabasic massifs of Albania (as in Bulqiza, Tropoja, Kukësi, Shebeniku, Pogradeci etc) for the search for chrome deposits, which have been successful in many cases. They demonstrated that the geophysical methods are a part of the integrated methods for the search for this mineral ore. A long list of many scientific publications, on this item, is presented in the references.

4.3.1. Exploration for chrome ore bodies

The main principle for the application of the geophysical methods for the search for chrome ores, has been to start with the mapping in well known zones of the mineralization and to extend this mapping further to unknown zones, on surface and in the depth.

The works carried out only in Bulqiza ultrabasic massif can illustrate the effectiveness of the geophysical search for chrome ores. Geological and geophysical mappings, at scale 1:2000 have been conducted in total over 65 km^2 or in 15% of surface of the Bulqiza massif (Ll. Langore tec. 1989). There are observed 215 geophysical anomalies have been fixed. Among them, 191 anomalies have been observed by only of one geophysical method, and 24 ones present complex anomalies: gravity, magnetic or IP. From 64 anomalies, 51 anomalies were fixed over the known chromite bodies/occurrences and have contributed for their development in the strike direction. Thirteen anomalies have been discovered buried chromite bodies without surface outcrops, which have been explored by trenches, galleries and drill holes. Thirty-five anomalies have been evaluated as very important for exploration and development works. Based on them the possibility of following their extension was achieved. Hundred fifty-one have been non-mineralised anomalies; but they are caused by particular rocks, tectonic faults, and topographic effects or by the change of the thickness of the deluvion.

Based on these integrated geological-geophysical studies, industrially useful bodies (or deposits) were discovered in Ternovë, Liqeni i Sopeve, 10 Korriku, Lugu i Gjatë, Jugu i Batrës (M-5 anomaly), Qafë Lame etc. Important results were achieved in other zones such as in Liqeni i Dhive, Maja e Thekrës, Kaptinë , 80 Vjetori, Tri Gjepra, Bishti i Kalit etc.

The efficiency of geophysics is still relatively low in comparison with copper deposit exploration. By integrated geological-geophysical surveys in the 35 objects in the Bulqiza ultrabasic massif to check the anomalies have projected 356 boreholes. From these boreholes, 145 have discovered chromite ores, and 211 have been negative. The ratio of the success was 1/1,4. Many studies must performed before can be reached proper results for chrome exploration.

a) <u>Ore anomalies</u>

Geophysical anomalies caused by ore bodies have been observed in several areas.

Over the ore bodies, weak gravity anomalies are observed, with amplitude, about 0,1-0,2 mGal (fig. 4-47, 4-48, 4-49, 4-50). These anomalies are more evident after the field transformation (fig. 4-53, 4-55, 4-56).

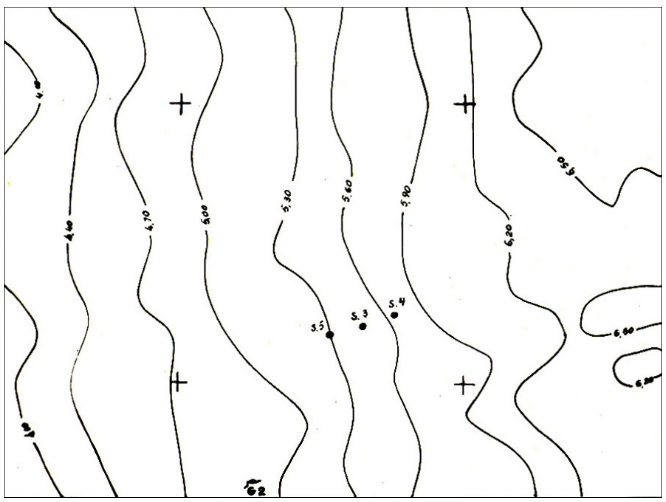


Fig. 4-47. Gravity anomalies map, Bouguer reduction, Kami deposit, and boreholes projected to check residual gravity anomaly. Iso-anomalies every 0,3 mGal. (Mihajllovsky Ja. M. 1960).

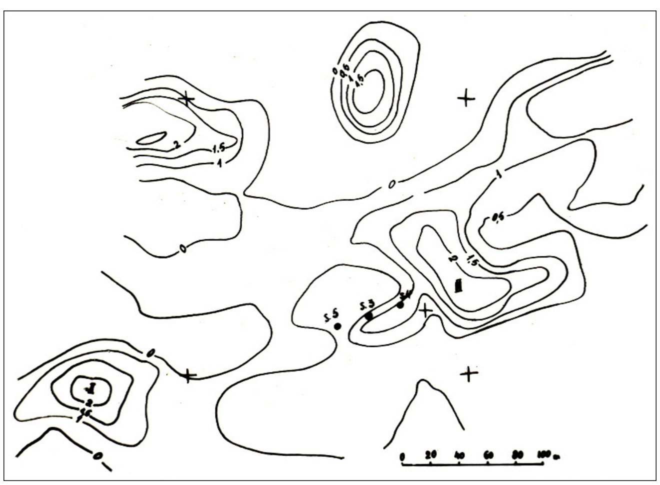


Fig. 4-48. Gravity residual anomalies map, Kami deposit, and boreholes projected to check residual gravity anomaly. Iso-anomalies every 0,5x10-8 mGal/cm. (Lubonja L. et al. 1973).

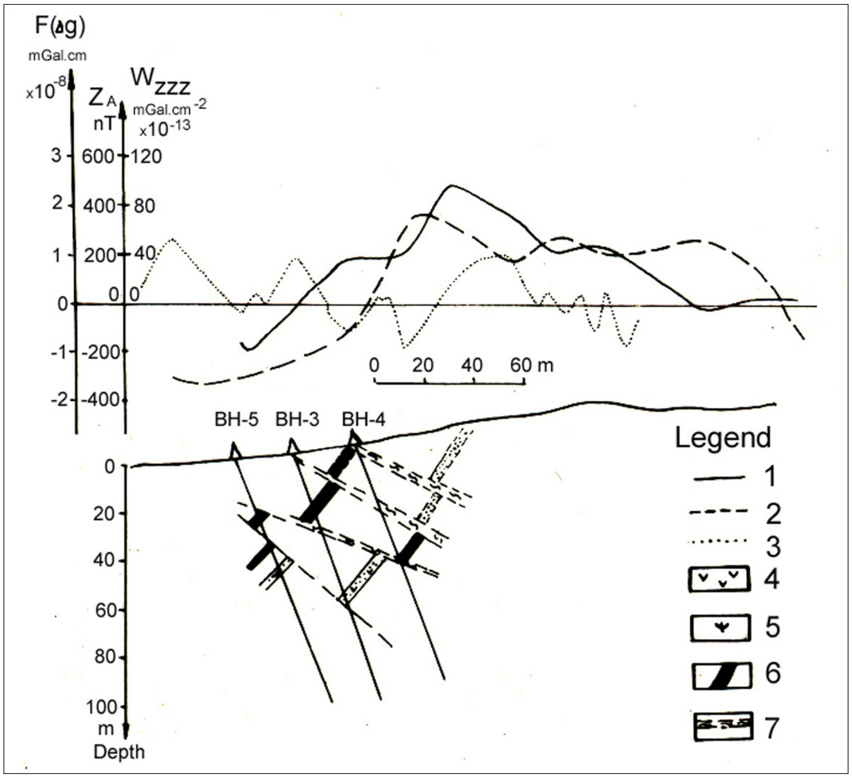


Fig. 4-49. Geological-geophysical section III-III for projecting of the boreholes to check the residual gravity anomaly, Kam deposit. (Lubonja L. et al. 1973).

1- Wzzz profile; 2- F(Δg) profile; 3- ΔZ profile; 4- Dunites; 5- Hartzburgites; 6- chromite ore body discovered by projected boreholes; 7- Disjunctive tectonics.

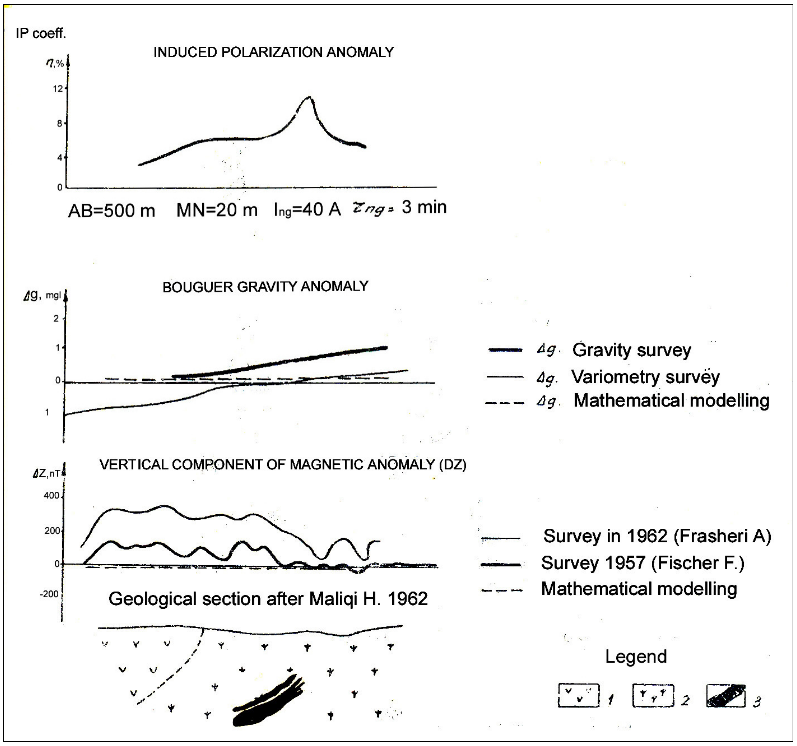


Fig. 4-50. Geological-geophysical section, Kami chromite deposit, Tropoja ultrabasic massif. (Frashëri A. et al. 1971).

1- Peridotites; 2- Dunites; 3- Chrome spinel ore body.

The gravitational anomaly is expressed in the Bouguer anomaly graph but it is better expressed in the residual gravity anomaly calculated by Saxov-Nygard formula F (Δg) and in the residual local anomaly (Δg) plots. In this cross section, the gravitational and magnetic anomalies were fixed not only on the ore body but also around it (for example in the point 128-142 on particular rocks).

Field transformation of Bouguer gravity anomalies (Δg) in vertical derivatives of second (W_{zz}) and thirty (W_{zzz}) orders of the gravity field potential in the Krasta and Surroi deposits have presented the anomalies with greater amplitudes (fig. 4-9, 4-10).

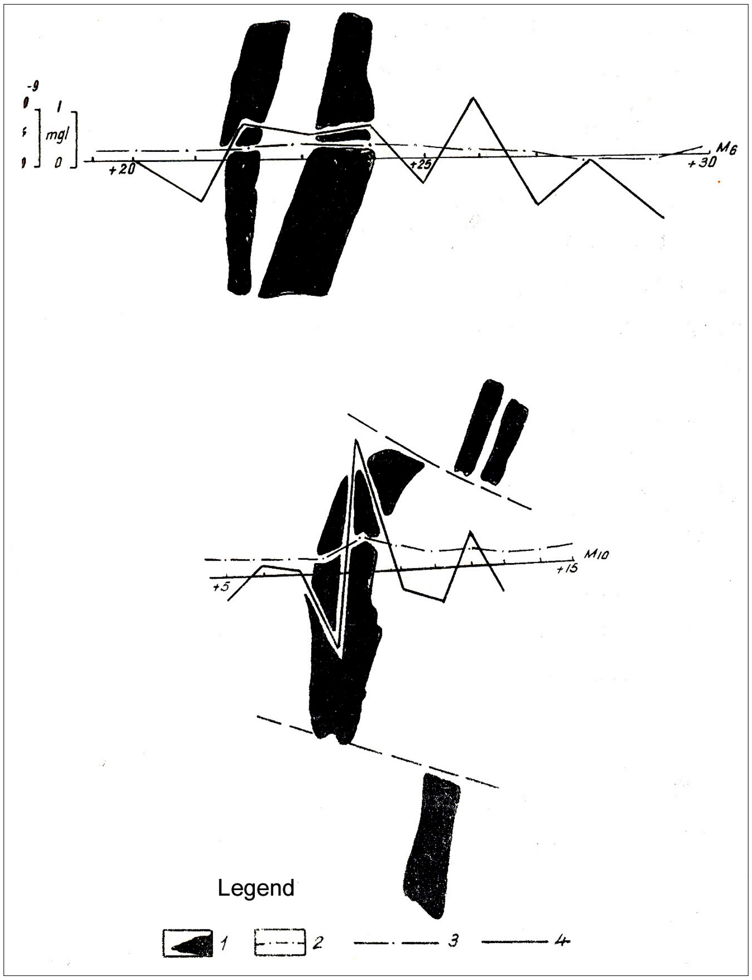


Fig. 4-56. Map of the Bouguer gravity anomalies (Δg) transformation in vertical derivatives of second and thirty orders W_{zzz} of gravity field potential, Surroi deposit, Kukësi ultrabasic massif (Lubonja L. & Frashëri A. 19676).

1- Chromite ore body; 2- disjunctive tectonics; 3- (Δg) profil; 5- W_{zzz} profil.

In the W_{zzz} graphics can detect not only ore bodies, but their apophyses, too. Such transformations are created possibilities not only to amplify weak Bouguer anomalies, but also to select superimposed anomalies over bodies, which are located near each other.

Transformations of the Δg anomalies in vertical gradients of the gravity potential W_{zz} and W_{zzz} must not create the wrong impression that through recalculations is possible to get anomalies even in the cases where there are no Δg anomalies over the chromite body. Transformations and recalculation of the W_{zz} and W_{zzz} only may show up some peculiarities of the Bouguer gravity anomalies map and in the same time diminish and eliminate some peculiarities that don't permit to read the map.

The distribution of the magnetic field in the Kami deposit is turbulent. With great attention have been possible to select the anomalies over the chromite ore bodies (fig. 4-51). Fig. 4-52. Ore body Nr.6 of the Kami deposit has created very clear IP anomaly (fig. 4-50).

Figs. 4-57 and 4-58 shows the result of the geophysical exploration in the Tërnova deposit in the tectonic sequence, Bulqiza ultrabasic massif.

Fig. 4-57. Integrated geological-geophysical map of Tërnova deposit. (Langora Ll. et al. 1989).

1- Overburden; 2- Serpentinized dunites; 3- Serpentinized hartzburgites; 4- Pyroxenite veiny serie; 5- Gravity and magnetic anomalies; 6- Chromite ore body; 7- Serpentinized, schistized and brachiated tectonic zone; 8- Textural elements in the pyroxenite bands; 9-0 Boreholes.

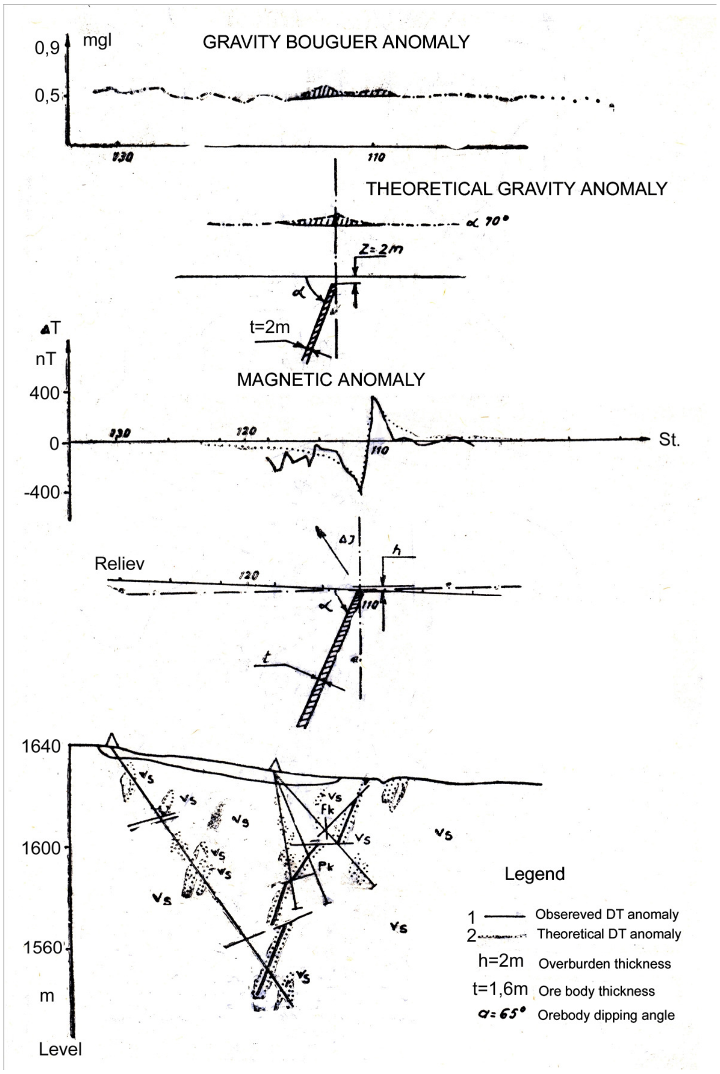


Fig. 4-58. Integrated geological-geophysical section, Tërnova deposit. (Langora Ll. et al. 1989).

1- Observed magnetic anomaly (ΔT); 2- Mathematical modelling magnetic anomaly (ΔT); 3- Overburden thickness h=2 m. ; 4- Ore body thickness t=1,6 m.; 5- Ore body dipping angle, α=65°.

In the map, presented in the fig. 4-11, in Tërnova area are outcropped two chrome spinel occurrences. Over the northwestern occurrence were observed complex gravity and magnetic anomalies, with amplitudes respectively 0,15-0,20 Mgal and 400-600 nanoTesla. Over other outcropped body is observed only magnetic anomaly. The fig. 4-58 shows that under the overburden were discovered massive chromite ore body, with thickness about 1,6 m, and 220 m long, which presents the one of ore bodies of the Tërnova deposit.

South Batra area is characterized by absence of chromite mineralization outcrops. In the total intensity of magnetic field (ΔT) there are observed a negative anomaly with amplitude –650 up to –670 nanto Tesla, 320 m long and 80 m width (Fig. 4-59, 4-60, 4-61).

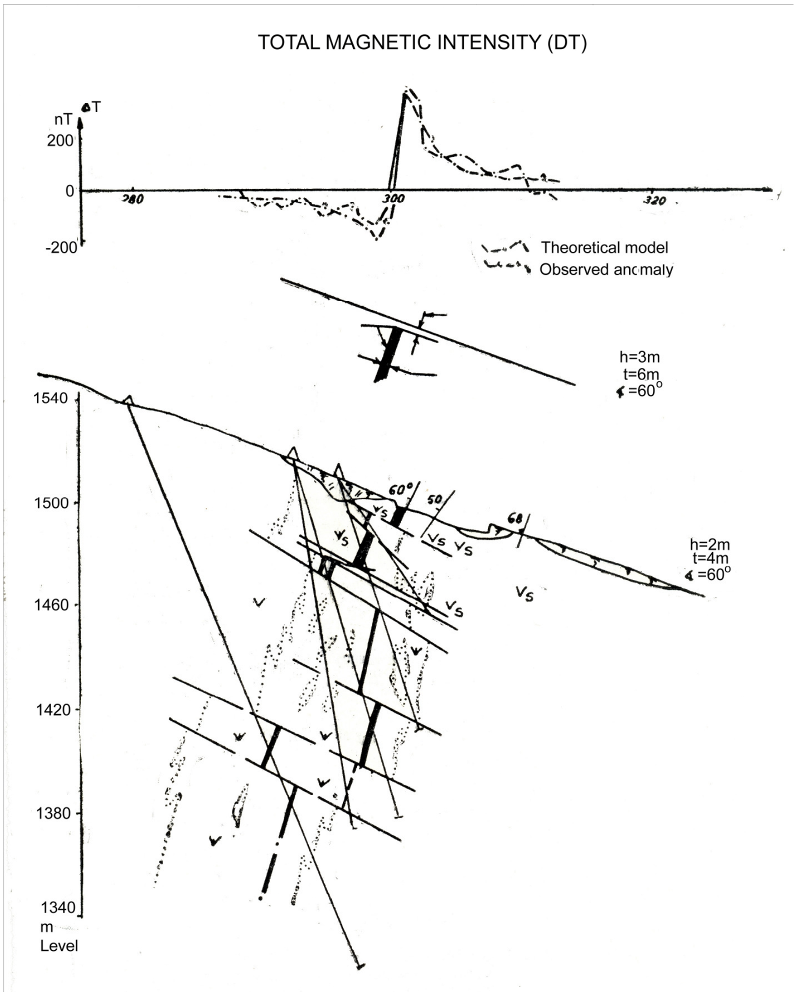


Fig. 4-61. Geological-magnetic section, South Batra area, anomaly M-5. (Langora Ll. et al. 1989).

In the case of the South Batra area, because of inverse remanent magnetization of the chrome ore body, anomaly is very complicated: anomaly presents a negative minimum together with a positive maximum (fig. 4.15). The lowest intensity values for the anomaly were observed where the depth of the ore body was 8 m (fig. 4.61). A horizontal displacement of the extremities of the axis of an anomaly and two maximums were observed in the profile No. 224 (fig. 4.60). This anomalous behaviour can be explained by the existence of a transverse tectonic fault, which divides the body into two parts along its strike. The southern extremity of its northern part and the northern extremity of its southern part are shown in the profile No 224. That means that there were two ore bodies and consequently two maximum points.

As can be seen from the map on figure 4.59, all trenches performed to verify the anomaly, intersected ore bodies, except those presented in the profiles 224, 228. The ore bodies in the profiles No. 224 and 228 were intersected by bore holes in great depths. In the axis of this anomaly 23 bore holes and 3 galleries were projected at different topographic levels. All bore holes and galleries have intersected the ore body, which runs alongside the anomaly, with a strike about 400 m. The thickness of the body is 2-3 m and its Cr_2O_3 content reached 30-40 %. Dipping ore body has a length of 180 meters.

The search for chrome ore body in the M-5 anomaly, South Batra zone, illustrates the high effectiveness of magnetic surveying.

Intensive and wide magnetic anomalies has been observed over a chromite ore body in the Leshnica and Vlahna deposits, at Kukësi and Tropoja ultrabasic massifs (Fig. 4.62, and 4.63).

The chromite spinel ore of the Leshnica deposit is very magnetic. But, there don't existing IP anomaly. Such absence of the IP anomalies is conditioned by very high

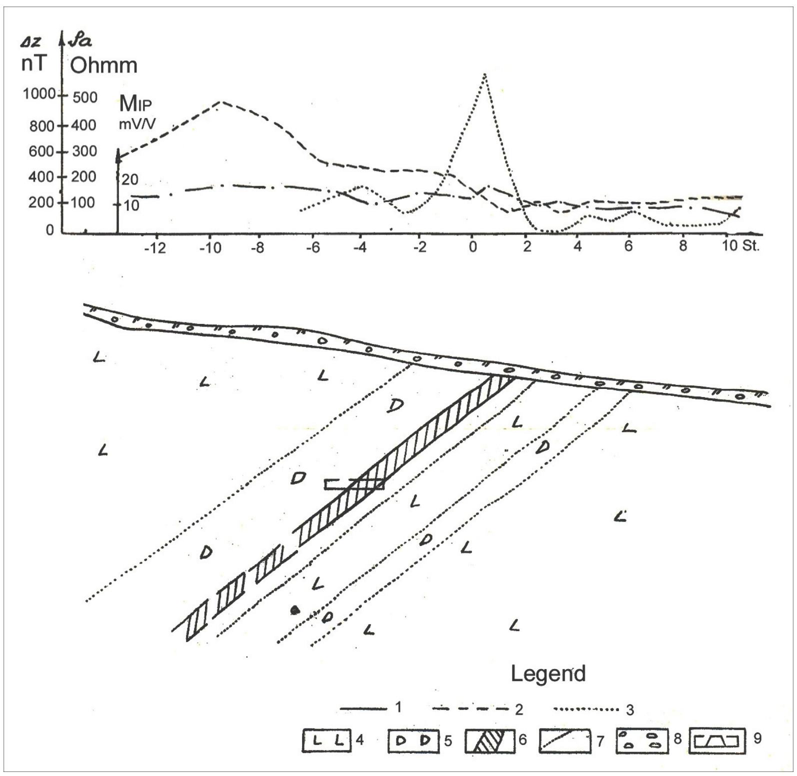


Fig. 4.62. Geological-geophysical section with a positive magnetic anomaly over a chromite ore body, Leshnice area, Kukesi ultrabasic massif (Frashëri A. et al. 1963).

1- IP coefficient profile; 2 - Apparent resistivity profile; 3 - Vertical component (DZ) of magnetic field profile; 4 – Hartzburgites; 5 – Dunites; 6 - Ore body; 7 – Gradual geological boundary; 8 – Deluvion; 9 - Gallery.

humidity of chromites, which are located in the disjunctive tectonic zone, with intensive underground water flow. In such conditions, the magnetic chromite ore is non-polarizable.

Negative magnetic anomaly of the vertical component (ΔZ) of –540 nanoTesla amplitude, and a clear IP anomaly, with amplitude of 35 - 50 mV/V, which is about 3 times over the background level, have been observed over the Vlahna chromite ore body (Tropoja massif) (fig. 4.17).

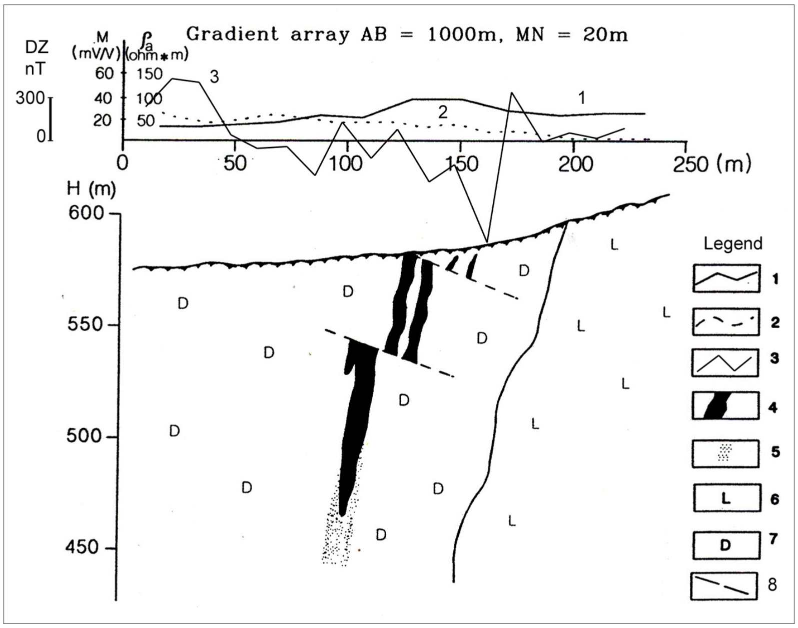


Fig. 4.63. Magnetic and IP anomalies over the Vlahna deposit (Tropoja massif) (Frashëri A. et al. 1963, Lubonja L. & Frashëri A. 1966).

1- IP coefficient profile; 2 - Apparent resistivity profile; 3- Magnetic anomaly (ΔZ); 4 – Masive chromite ore body; 5- Disseminates chromite; 5 – Hartzburgites: 6 – Dunites; 7 - Disjunctive tectonics.

In Tri Gjepra area (Bulqiza ultrabsic massif) has observed IP anomaly (fig. 4.64).

From the IP sections shown in fig. 4-18, can be seen that the IP anomaly is contoured by a line with value of 1.4% over the background level. This level is 1-1.2% for hartzburgites and 1.5-1.8% for dunites. The anomaly has amplitude of 1.5-2.5% at the width of 30-40m. Since the ore body layout is underneath the shallow deluvion, these anomalies can be discriminated better by using of pol dipole array A20M20N,B→∞. Many boreholes and trenches intersected this anomaly, which a length about 280 m.

The chromite ore in the Qafe Gjelas deposit in the Bulqiza massif has a predominant density value of 4000 kg/m^3, which is higher than the density of the surrounding rocks. This is a magnetic ore and has a predominant IP coefficient value of 1.7%. The dunites and hartzburgites have an IP coefficient of 0.7% and 1.2% respectively. For this reason clear gravitational, magnetic and IP anomalies have been observed over this ore body (fig. 4-656).

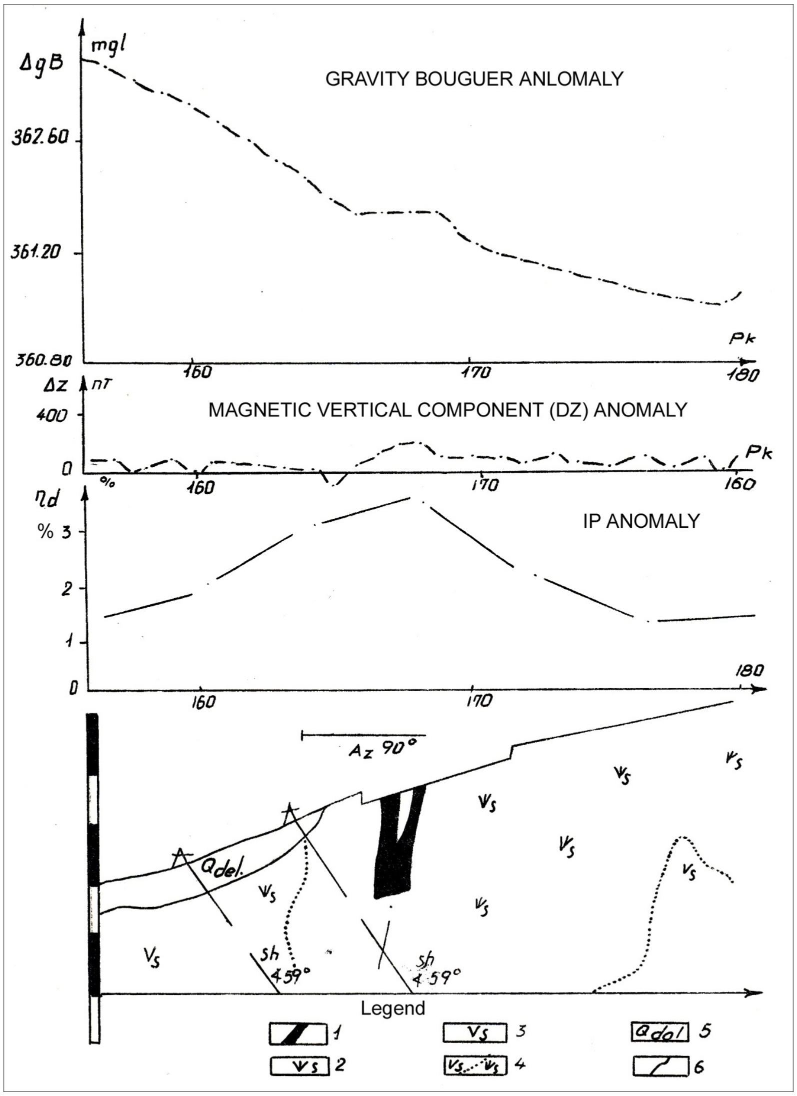


Fig. 4.65. Geological-Geophysical section in Qafe Gjela deposit
(Bulqiza massif) (Prenga Ll. Et al. 1983).
1 - Ore body, 2 - Serpentinized dunite,
3 - Serpentinized hartzburgite, 4 - Smooth-rock border, 5 - Deluvion, 6 - Tectonic fault.

From this section can be seen that the IP anomaly is a rather wide one. This is due to the influence of ore body and its dunite envelope (fig. 4.66). Consequently a complicated wide anomaly is observed.

In fig. 4-67 is presented a magnetic anomaly over chromite ore in the Tplanë area.

b) Non-ore anomalies

During the geophysical mapping for the search for chrome ores, have been observed a lot of non-ore anomalies, due to many factors such as:

- Fresh rock inclusions between serpentinized rocks, which may create gravitational anomalies.
- Serpentinized rocks with high content of magnetite which can create magnetic anomalies, or induced polarization.

For example a magnetic anomaly of the amplitude -200 and +200 nT was caused by highly serpentinized dunites (fig. 4.68). IP anomalies can be observed, in these zones, as well.

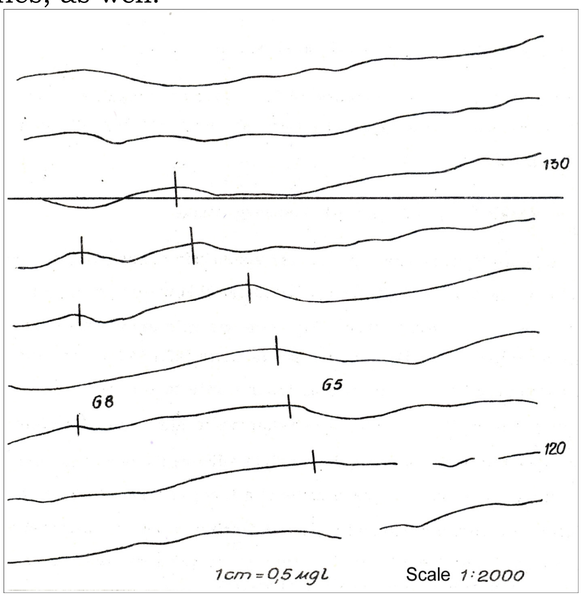


Fig. 4.68. The map of profiles of the total magnetic field intensity (ΔT) at Fushë Kalti zone (Bulqiza massif), where magnetic anomaly is observed over highly serpentinized belt and crushed dunitic inclusions have been observed (Sharra Xh., Rrënja A. et al. 1987).

Gravitational anomalies have been observed in zones with thin cover of soft overburden and compact bedrocks close to surface (fig. 4.69).

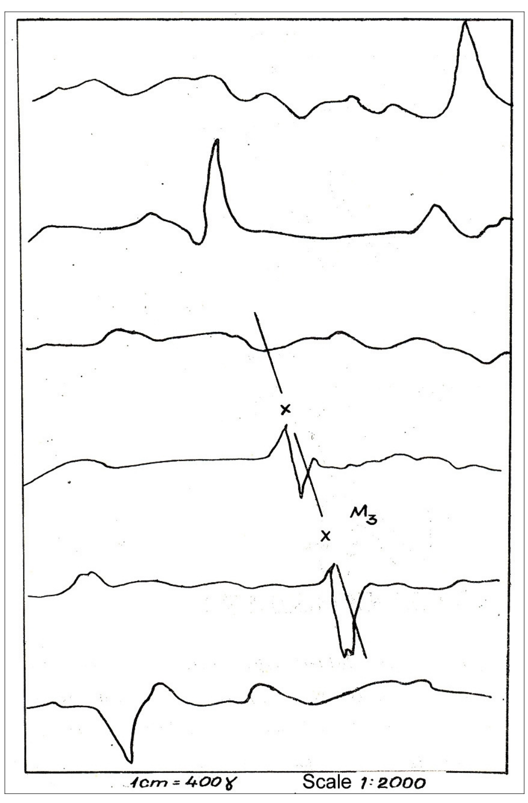


Fig. 4.69. The map of profiles of the Bouguer anomaly in Fushë Kalti (Bulqiza massif), in a sector where are decreased the thickness of the soft overburden. (According to the Sharra Xh., Rrënja A. et al. 1987).

Prior to Bouguer anomaly interpretation, the thickness of soft sediments (deluvion and eluvion) was determined by apparent resistivity soundings. The main task of the interpretation was to selected the anomalies caused by ore bodies.

In fig 4-70 and 4-71 are presented magnetic anomalies over a non-magnetic rock individualisation between magnetic seprentites and pyroxenite vein , respectively, in Kam Tropoja deposit.

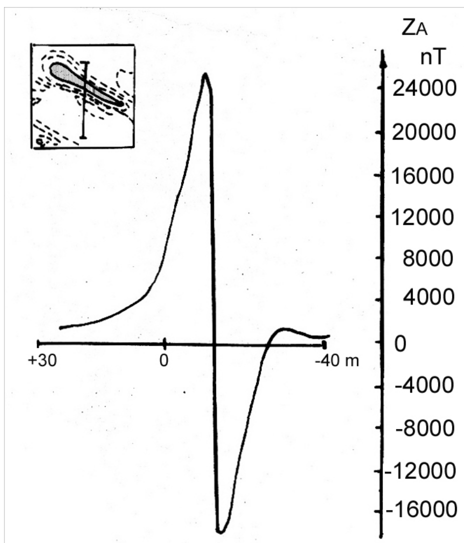


Fig. 4-71. Magnetic anomaly (ΔZ) over a pyroxenite vein, Kami deposit. (Fischer F., 1957).

4.3.2. Underground geophysical surveys

Underground geophysical surveys have been carried out in boreholes, in galleries and other mine works to solve the following problems:

a) <u>The search around mine works</u>

The search around mine works has been conducted in order to contour known ore bodies, especially those that are effected by tectonic faults, and to search for new ore bodies located around mine works. The goal was to increase the search depth and to get the available information for a sparse network of mine works at the first stage of the exploration.

Underground surveys can be made by all geophysical methods, which are used also by surface mapping. Radio wave floodlighting method can be used as additional ones.

The experience gained, especially during the eighty years period in Albania showed that the three components magnetic borehole method can be implemented successfully and efficiently for the search for magnetic chrome ore bodies. Typical example is presented the underground magnetic surveys in four boreholes in the Shkalla area, Bulqiza ultrabasic massif (Fig. 4-72) (Gjovreku Dh. 1984, Langora Ll. et al 1988). In the borehole No. 141 are observed two anomalies, at the depth 100 m and 140-180 m. The anomalies respectively have amplitudes: ΔZ=7 500 nT, ΔH=8 500 nT, and ΔZ=5000 nT, ΔH=8000 nT.

Fig. 4.72. Geological-geophysical section in L-L 5 underground magnetic survey line, Shkalla deposits, Bulqiza ultrabasic massif. (Langora Ll. et al. 1989)

According to the geological-geophysical interpretation of the data in the L-L 5, and L-L 6 lines result following conclusions:

- Chromite ore body must located about 30-40 m from line L-L 6.
- Northern prolongation of the ore body is about for 40 m.
- Other ore body causes second anomaly.

Projected boreholes have discovered ore bodies.

Fig. 4-73 shows the underground magnetic surveys in boreholes at Bulqiza deposit. The observed magnetic field in the borehole Sh. 4 represents an anomalous field above and underneath levels.

Borehole Sh.3 has intersected the ore body. The interpretation of the plots of the three component magnetic component Z and total magnetic component T showed that the ore body intersected by the bore hole Sh.2 in the forms of flexure is connected with the ore body intersected by the bore hole Sh.3.

In borehole S-17, which did not interest any orebody, an anomalous sector of the total magnetic field vector T at a depth of 190-330 m was observed (fig. 4-74). This anomaly was interpreted as being caused by a magnetic chromite ore body between the boreholes S-17 and S-16. The shallow boreholes S-1, S-2, S-3 and S-4 drilled at the end of gallery G-5 intersected the predicted ore body.

The outputs of the radio wave floodlighting and radio wave profiling give good results when the chrome ore is magnetic and has dense up to massive structure (fig. 4.29) The absorption coefficient values of electromagnetic waves of frequency 1 - 10 Hz for this area is b = (0.02-0.04) Neper/m, which is greater than for ultrabasic rocks (b = 0.0012-0.0015 Neper/m). The hologram of the fig. 4-75 show that maximal values of the image intensity are presented magnetic chromite ore body.

IP methods can be used for the search of polarised ore bodies around boreholes by using the pole-dipole array N5M5A,B$\to\infty$ and N10M100A,B$\to\infty$, which can investigate a zone of a radius 7m and 60m, respectively.

The results of underground survey are not affected either by complicated topography, or by alternated rock inclusion nearly to surface. Mine works, metallic equipment and geological heterogeneity have an effect on these results. To avoid these influences, underground surveying is carried out by a special methodology and prior to the interpretation; the results are subjected to different mathematical processing.

b) <u>Well logging</u>

The geophysical methods have been used for geological documentation of the borehole trunk, ore bodies, tectonics faults and rock inclusions of different serpentinization degrees. Ore body thickness, deep layout, Cr_2O_3 content and the ratios Cr_2O_3/FeO, Cr/Al have been determined at a rather high accuracy.

The density is the more stable physical property, which in most cases is used for the selection of ore bodies from the surrounding media. The main method used for documentation of the borehole is the density and selective gamma-gamma logging (fig. 4.76.).

In the borehole log of the diffused gamma radiation (I_{gg}) the ore bodies can be outlined by radiation minimum, because they have higher density values than the surrounding rocks.

From this figure can be seen that a detailed description of the borehole geological section and more accurate evaluation, together with partial drill logs, can be made according to well logging data interpretation.

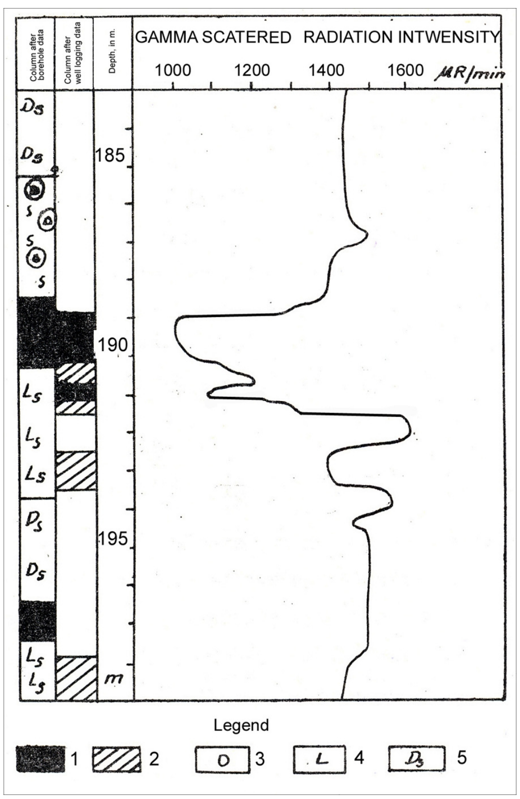


Fig. 4.76. Diffused gamma radiation log (I_{gg}) in Luçiane deposit, Bulqiza massif (after Nakuçi I. well logging).

1- Massive ore body; 2- Ore body with disseminated structure; 3- Dunites; 4- Hartzburgites; 5. Serpentinized dunites.

Minimum points have been also observed in fresh, non-serpentinized, rocks individualizations, situated between serpentinized rocks. For discriminating them can be is used a selective gamma-ray logging. The intensity of smoothed component of scattered gamma rays, which is determined by heavy element content (as chrome) in the borehole section, is recorded by this logging.

Data on density gamma-ray logging can be used for the assessment of Cr_2O_3 content in the ores, for the computation of the ratios Cr_2O_3/FeO and Cr/Al, because it exist a correlation between the ore density and the Cr_2O_3 content, and between Cr_2O_3 and FeO and Al. Magnetic and polarisable ore bodies are very well distinguished through magnetic and IP well logging. Serpentinized rock inclusions with secondary magnetite situated between fresh rocks give clear anomalies. These last ones can be used as geophysical indicators to distinguish tectonic sequences from cumulate ones, etc.

Chrome ore bodies can also be discriminated from ultramafic rocks by other parameters such as the effective atomic number 19, cross-section capture 0.054 cm^{-1}, which are greater for hartzburgite and dunite (effective atomic number 12.5 and cross-section 0.0015 cm^{-1}), and characteristic gamma ray spectrum (for high energetic levels 8.5 and 8.9 MeV). Based on these characteristics different kinds of logs, such as the neutron-gamma spectrometric, neutron-neutron, thermal and overthermal neutron logging can successfully be used for geophysical documentation. Ore bodies can be distinguished by higher logging values than those of the surrounding rocks.

As it was mentioned above, it can be seen that, for the geophysical documentation of the borehole in chrome deposit, the basic method to be used should be the radiation logging (density, gamma-gamma, selective gamma-gamma, aluminium neutron-activation, neutron-neutron, thermal neutron and overthermal neutron logging). The magnetic, the IP and conventional resistivity logging can be used as additional methods.

4.3.3. Geophysical applications for geological mapping

Geophysical methods contributing to geological structural mapping purposes, aimed at successfully solving some regional and local problems. The structure of ultramaphic rocks massifs and their relationship with the surrounding media have been studied. Serpentinized and fresh rocks, tectonic and cumulate sequences have been discriminated by their serpentinization degree. Tectonic faults and deep elements of primary structures such as flow and banded structures, S, L and Q system of primary fissures, the individualisation of fresh and serpentinized rocks were mapped in the ore fields. The conditions of rock formation and their changes in space and time during the geological history have been studied for the mapped regions. During the exploration-developing stage have been studied, at a more detailed scale, the factors controlling the mineralization.

For accomplishing geological-structural mapping tasks, have been used different kinds of geophysical methods such as gravitational, magnetic, micromagnetic mappings; magneto-telluric and electromagnetic soundings; low and high frequency seismic prospecting for big and shallow depths studies, respectively. These works have been accompanied by petrophysical studies

Valuable information about the geology of Bulqiza ultramaphic massif and about other massifs has been received by gravitational mapping at the scale 1:25000 (Kosho P.). In the figure 4.77 is shown a geological geophysical line in Klos-Bulqizë-Shpuzë (Frashëri A. et al. 1990).

According to the interpretation of the Bouguer anomaly, the massif has an inverted conic shape. Its thickness is smaller at the edges and increases towards the centre (up to 5.5 km). Based on the distribution of the magnetic field, the serpentinized sector of the ultramaphic rocks and the flanks where re massif is covered by the Neogene molasses sediments (especially the western flanks) have been mapped. The intensity of the magnetic field in these sectors is high due to the content of secondary magnetite. In plane, the anomalies have a mosaic picture, due to heterogeneous distribution of secondary magnetite. In these zones are also found some local minimums.

These characteristics can be used as features for the discrimination of cumulate sequences. Magnetic anomalies of cumulate sequence have high amplitude and high frequency.

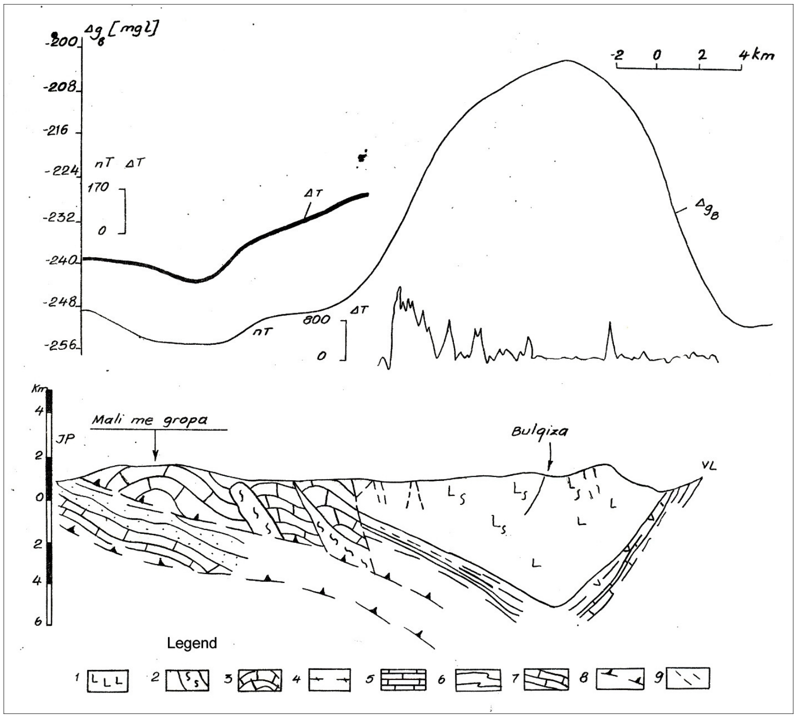


Fig. 4-77. Geological-geophysical line in Klos-Bulqizë-Shpuzë (Frashëri A. et al. 1990).
1 - Hartzburgites, 2 - Serpentinites, 3 - Triassic limestone, 4 - Volcano-sedimentary series, 5 - Jurassic limestones, 6 - Cr^2 - Pg^3 flysch, 7 - Pg^2 limestone, 8. Cover tectonics, 9 - Disjunctive tectonics.

Anomalies on dunite-hartzburgite tectonic sequences are characterised by smaller amplitudes and lower frequencies, meanwhile the intensity of the magnetic field is smaller than for hartzburgite-tectonite sequences. The correlation of different geophysical parameters, determines different perspective levels of ultramaphic cross sections, which help the search for mineralization.

Micro magnetic survey has given good results in determining the primary textural elements in zones covered by 2-3 m thick soft sediments and in zones where these elements cannot be seen. This is possible because the axis of the magnetic micro anomalies have two directions, one parallel with the fissures systems L, S and flow and banded textures, and the second one which coincides with Q fissure system.

The picture of the distribution of magnetic micro anomalies can be explained by the layout of the secondary magnetite mainly according to flow, banded textures and the fissures system L,S and C (fig. 4.78) and to the

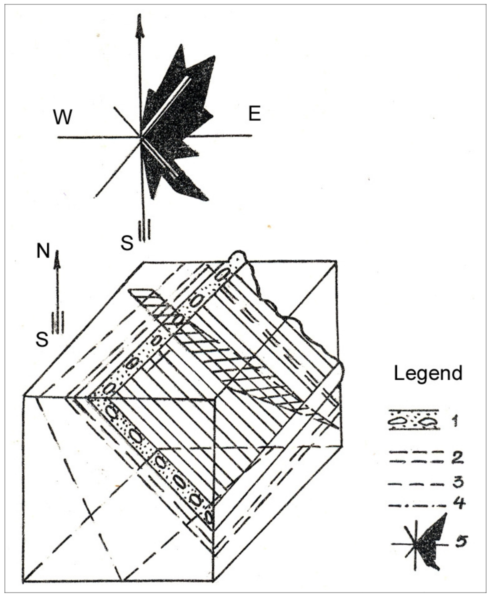


Fig. 4.78. Primary structural elements and the direction of the axis of magnetic micro anomalies. (Frashëri et al. 1969).
1 - Banded texture, 2 - Primary fissure system L, 3 - Primary fissure system S, 4 - Primary fissure system Q, 5 - Rose diagram and vectors of the direction of the magnetic micro anomalies axis.

direction of the vector of thermoremanent magnetization, which coincide with the direction of primary structural elements.

From the performed magnetic micro surveys, it seems that the axes of magnetic micro anomalies are the same for the dunitic rocks and the hartzburgite. That means that different kinds of rocks of tectonite-hartzburgite-dunite sequence have had the same development during the geological history. Dunites and hartzburgites can only be distinguished by unequal degrees of the serpentinization. The difficulty in distinguishing them is explained by the fact that these rock have physical properties which vary in a wide range and sometimes overlap each other.

Serpentinites, generally, have high contents of secondary magnetite and are magnetic. Therefore the magnetic surveying can be used to study the weathering layer for the search of nickel-silicates.

Geological geophysical studies of chrome ore fields have been carried out simultaneously with regional geological-geophysical mappings and petrophysical studies. These last ones have been used as a supplementary information source about the rock formation conditions, their composition and their changes in space and time. Such data are given in studies about the rock magnetism and its nature.

In the Tropoja ultramaphic massif has been observed an increase of the rock's density values, from the eastern part to the western one (particularly after Kami). That indicates that the rocks in the western part of this massif are less serpentinized than the ones in the eastern part. In the same direction can be distinguished the dunites from the hartzburgites of tectonic sequence. The hartzburgites have higher density values than the dunites. In the western part of the massif, is observed an increase of the content of pyroxenites inside hartzburgites and the degree serpentinization for these two kinds of rocks is different.

4.4 Some important conclusions and recommendations

Based on the results of geophysical investigations for the search of chromite in Albania and in other countries of the world, some conclusions can be made:

Geophysical anomalies are fixed on ore bodies and on rock inclusions. That means, not every anomaly may indicate about the presence of an ore body.
On chrome ores there are not always geophysical anomalies. That means that the lack of anomalies does not necessarily indicate about the absence of ore bodies.

The wide variation of the ore's physical properties and those of the surrounding rocks can explain these, by the small differences between these physical properties, by the shape and the small dimensions of ore bodies compared with their layout depth. Therefore, a geophysical anomaly can indicate only about the possibility of the existence of an ore body.

This anomalous situation is presented in the table 4.11.

In figs. 4-79 and 4-80 are presented a theoretical dependences of gravity anomalies (Bourguer reduction and vertical gradients) by mass/radius and depth of the ore body centres for a model in the sphere shape or horizontal cylinder, to have the possibilities to observed the anomalies, respectively with amplitudes 0,2 and 0,4 mGal, and 20 Oetvesh.

The characteristics of the anomalous geophysical picture, in the regions where chrome ore deposits are searched.

Table 4.11

Chromite ore and surrounding rocks	Gravity anomalies	Magnetic anomalies	Induced Polariza-tion anomalies
Massive chromites,	+	+	+
magnetic and polarizable	+	+	-
Massive chromites,	-	+	+
magnetic, unpolarizable	-	-	+
Disseminates chromites,	+	-	-
magnetic and polarizable	-	+	+
Disseminates chromites, nonmagnetic,	+	+	+
polarizable Fresh ultramaphic rocks Individualization Serpentinized ultramaphic rocks individualization Serpentinites intersected by gabbro-pegmatite dykes of cumulate	+	-	-

sequence Gabbro pegmatite dykes or frech pyroxenites			

According to these calculations, by gravity surveys is possible to discover chromite bodies in different depth, from tens to hundred meters, if will exist necessary mass of the ore body. For example, the ore body with radius 14,5 m and mass 50.000 tons, is possible to explorer up to 23,5 m depth of location, because the Bouguer anomaly will has an amplitude about 0,2 mGal. The mass about 3.500.000 tons can be explored at 200 m depth of location, by survey such anomaly, 0,2 mGal.

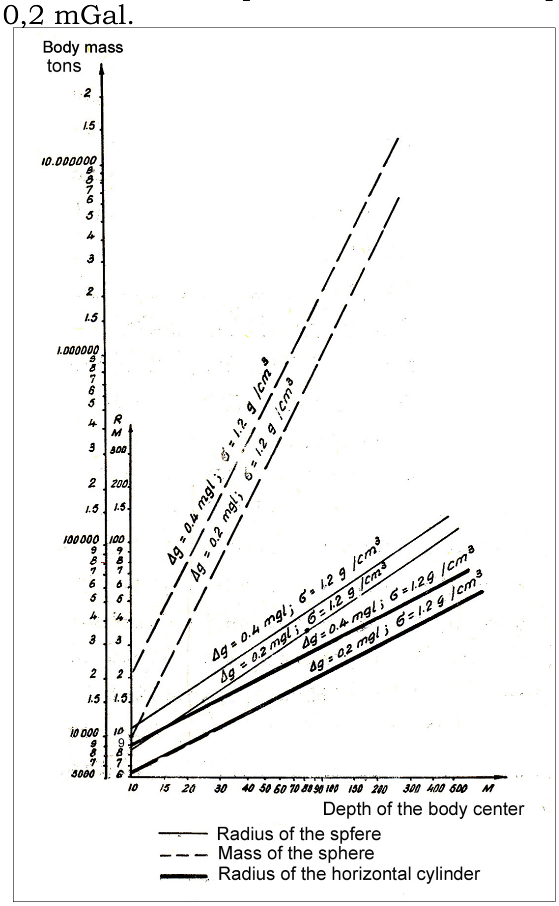


Fig. 4- 79. Theoretical limits of the ore body mass, for constant Depth of location of ore body, which will created an Bouguer anomaly of an amplitude Δg- 0,2 and 0,4 mGal. (Frashëri A. 1968, 1974)

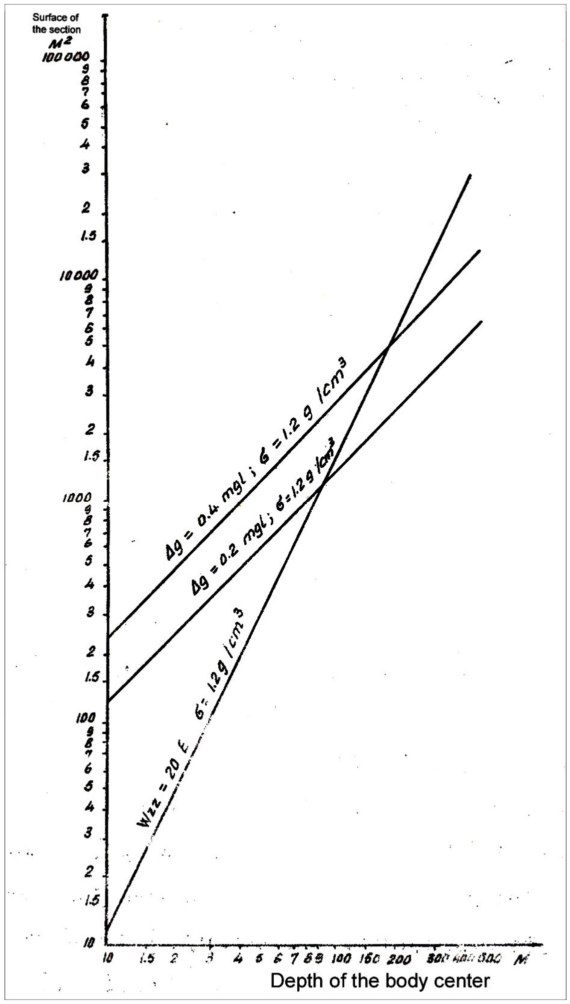


Fig. 4-80. Theoretical limits of the horizontal cylindrical ore body section surface, for constant depth of location of ore body, which will created an Bouguer anomaly of an amplitude Δg- 0,2 and 0,4 mGal and Wzz= 20 Oetvesh. (Frashëri A. 1968, 1974)

These limitations create the need for the implementation of some measures to increase the effectiveness of geophysical search:

Direct search for chrome ore bodies should be carried out simultaneously with the geophysical-structural mappings and petrophysical studies in order to know the factors controlling the mineralisation.

Surface and underground geophysical surveys (gravity, magnetic, geoelectrical ones) should be carried out in complexity. In the interpretation of the results should be considered all other existing geological information. This will make possible the determination of the nature of an anomaly, so that the ones caused by ore bodies can be selected. Better combination of surface with underground surveys leads to the increase of the search depth of the geophysical methods.

Geophysical works can achieve better results when perspective zones are the exploration objects. The work should start from well-known ore bodies and not from small sectors.

Geophysical studies should be carried out in the framework of complex geological studies. Only in this way can better be studied the geology of the ultramaphic massifs, the premises for the search of ore deposits and ore bodies underneath the surface of the Earth.

Since the number of shallow or near- surface ore deposits is decreasing, the implementation of geological methods, at present, is a necessity in order to increase the search depth for chrome deposits.