Summary:

A half a century history of the application of geophysical methods in exploration of chrome ores deposits in Albania is presented in the paper. There are analyzed the best results and problems, which have solved the Albanian geophysicists, in the framework of integrated multi-disciplinary geological search of for chromite deposits.

Introduction:

The geophysical methods, as a part of integrated geological search for chrome ore deposits, have been applied in Albania to solve two main problems: 1) Direct exploration for ore bodies, and 2) Help in the geological-structural mapping in order to study the factors that control the mineralization.

Albania was ranked at the third place in the world for exploitation of chrome ore, reaching an amount of 960,000 ton/year. There was gained a good experience for the geophysical exploration of chrome deposits and were set up integrated methods for ground and underground surveys. These are achievements of a complex team of geophysicists and geologists.

Field Description

Geologic Setting

The ophiolites of Albanides a rich chromite-bearing belt represent. Chrome ore deposits are concentrated in the ultramaphic massifs, which have tectonic and cumulate sequences. 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. Podimorf ore bodies as pseudostratos folded, lens, and column types, have rather big dip angle (Hallaç, H., et al. 1989). The ore's texture is represented as massive, nodular and disseminated one. The content of chrome oxide varies from 20% to (42-44) %. 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 ones. 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.

Geophysical exploration

The geophysical complex for direct chrome ore search includes surface mapping by gravity, magnetic and IP methods, and underground surveying. Underground surveying was carried out for the exploration 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 (Frashëri, A., 2008,

Lubonja, L. and Frashëri, A.,, 1966, Pumo, E. et al. 1993). Gravity and magnetic mapping have been performed in the complex with geological mapping in the ore field zones. Micro-magnetic survey has been a part of the geological-structural mapping. Petrophysical studies are carried out for the ultrabasic rocks of some massifs and for chrome ores, in some deposits of Albania: density, magnetic susceptibility and remanent magnetization, electrical resistivity and induced polarization (Frashëri, A., 1974, Leka, P., and Vinçani, F. , 2004).

Physical properties of chrome ores and ultrabasic rocks

Density

Iron-chrome ores have a density value from 2550-4380 kg/m^3. The ore's density of Kam Tropoja deposit is mostly determined by its contain of Cr_2O_3, according to the relation, with a correlation coefficient of 0,92 (Frashëri, A., 1974):

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

where σ is the density of chrome ore, in kg/m^3

C is the ore contain of Cr_2O_3 in percentage,

This relation changes from one to another deposit, and from one body to another body. The density of the chrome ore is conditioned also by the degree of the serpentinization of its olivine. The density values of the ultrabasic rocks of tectonic sequence of hartzburgites and dunitic hartzburgites are between 2200 and 3340 kg/m^3. Serpentinized dunites can be distinguished by the predominant density value of 2680 kg/m^3. Massive ores are very well distinguished from surrounding rocks; medium disseminates chromites can be distinguished by serpentinized rocks. 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.

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. Therefore, chrome ores and ultrabasic rocks can be classified as nonmagnetic, weakly magnetic, and strongly magnetic ones (Frashëri, A., 1974).

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. The remanent magnetization of those chromites varies between $(100\text{-}8100)\cdot10^{-5}$ SI units. 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. This decreasing can be explained by the magnetization changes of the ferrite. Remanent magnetization vacillates in broader limits than the induced magnetization; especially, for particular samples it reaches up to $97000x10^{-5}$ units SI.

The ultrabasic rocks have a magnetism, which changes in a broad band, conditioned mainly by the presence of the secondary magnetite and less by the magnetized accessory chrome spinel. The fresh dunites and hartzburgites of tectonic sequence are not magnetic. With the increase of the serpentinization process, the 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 $I_r = 70{,}000 \cdot 10^{-05}$ SI units and $I_i = 3100 \cdot 10^{-05}$ SI units.

Petromagnetic studies have shown the presence of inverse magnetization phenomenon for chrome spinel ores in some deposits. The ores in some deposits 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 in the Albanian territory location.

Induced polarization chargeability (IP)

The chrome spinel ores and the ultrabasic rocks are characterised by IP chargeability values from 2-600 mV/V. They may be from unpolarizable to strongly polarisable. The rich chrome spinel ores has an IP chargeability which varies from 7 to 300 mV/V. The ores of average and dense dissemination have the highest IP values. The ore cannot be polarized does not contain secondary magnetite. The ore has a polarizability up to 40 mV/V 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, with a thickness about 0,00064-0,0032 mm.

The IP coefficient of cumulate sequence ultramaphic rocks varies in a wide range than in the chromites. If the maximal value of this IP coefficient reaches in 300 mV/V for the chromites, in the investigated rocks this one reaches up to 510 mV/V. The secondary magnetite, in the cumulative sequence dunite, is present in the form of veinlets. The fresh and the serpentinized rocks that do not contain secondary magnetite practically are not polarized ($\eta<20$ mV/V). There are also defined the dependence of polarizability on the resistivity of the ore and the ultrabasic rock. 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.

The amplitude of the induced polarization also depends on the density of the polarizing current..

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. 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.

Application of geophysical methods in search for chrome deposits in Albania- case studies

Exploration for chrome ore bodies

The gephysival explorations carried out in most important 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 (Langora Ll. et al.. 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. Fifty one 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. Thirty-five anomalies have been evaluated as very important for exploration and development works. Hundred sixteen have been non-mineralised anomalies; which are caused by particular rocks, tectonic faults, and topographic effects or by the change of the thickness of the deluvion.

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. 1). These anomalies are more evident after the field transformation in vertical gradients of the gravity potential W_{zz} and W_{zzz} (fig. 2). Intensive and wide magnetic (positive or negative), and IP anomalies have been observed over a chromite ore bodies (Fig.3, 4).

Underground geophysical surveys

Underground geophysical surveys in boreholes and galleries have been performed to solve the following problems:
1)The search around mine works.
2)The outputs of the radio wave floodlighting and radio wave profiling give good results when the chrome ore is magnetic.
3) IP methods can be used for the search of polarised ore bodies around boreholes by using the pole-dipole array N5M5A,B→∞ and N10M100A,B→∞, which can investigate a zone of a radius 7m and 60m, respectively.

Well logging

The main method used for documentation of the borehole is the density and selective gamma-gamma logging.

Geophysical applications for geological mapping

Geophysical surveys for geological structural mapping purposes have contributed, 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 (fig. 5).

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.

Conclusions

1) 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 alternatives. A geophysical anomaly can indicate only about the possibility of the existence of a chrome ore body.

2) According to mathematical modllings, 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. These limitations create the need for the implementation of some measures to increase the effectiveness of geophysical search:

3) 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 and geophysical anomalies.

4) 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.

5) 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.

6) Geophysical studies should be carried out in the framework of complex geological research. 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.

7) 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.

Bibliography

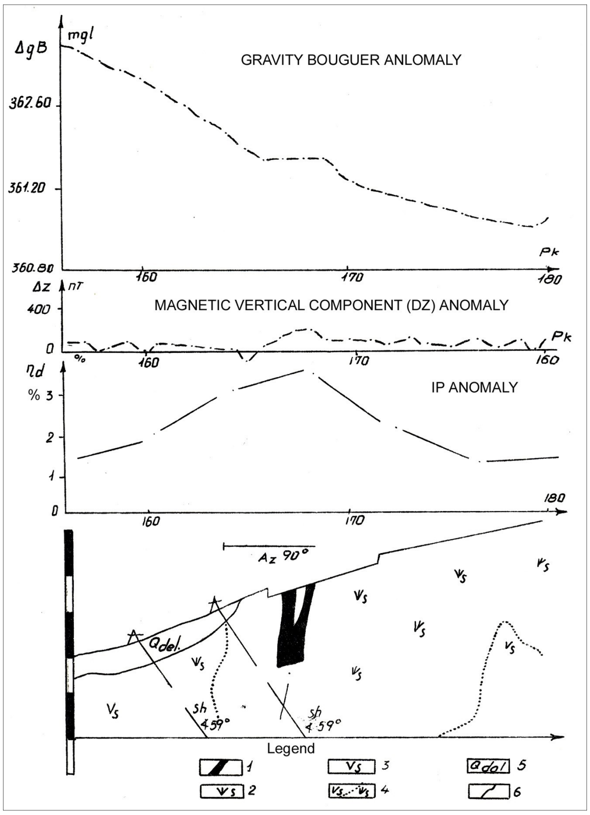

Fig. 1. Geological-Geophysical section in Qafe Gjela deposit (Bulqiza massif) (Frashëri A, 2008, after Prenga Ll. et al. 1983).

1 - Ore body, 2 - Serpentinized dunite, 3 - Serpentinized hartzburgite, 4 - Smooth-rock border, 5 - Deluvion, 6 - Tectonic fault.

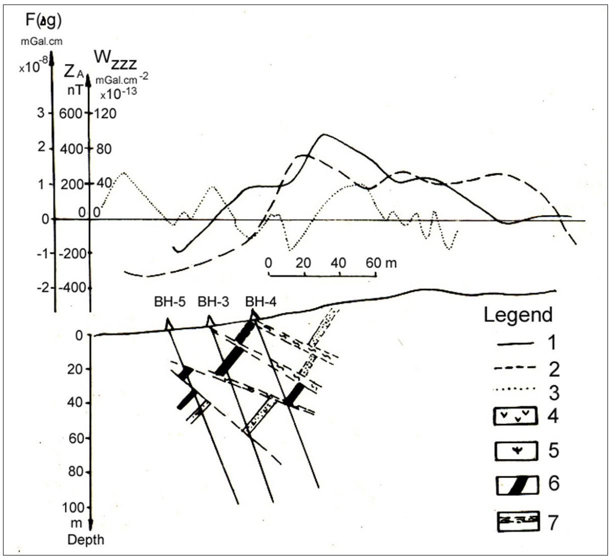

Fig. 2. Geological-geophysical section III-III for projecting of the boreholes to check the residual gravity anomaly, Kam deposit. (Frashëri A, 2008, after Lubonja L. et al. 1973).

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.

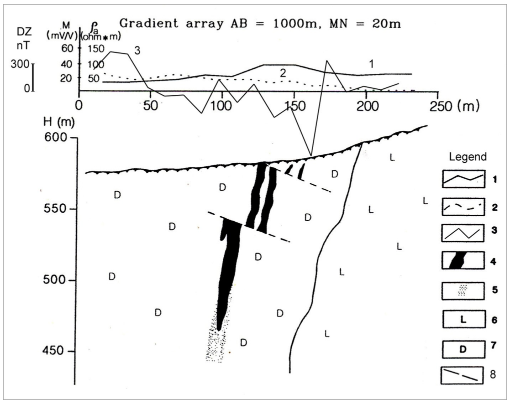

Fig. 3. Magnetic and IP anomalies over the Vlahna deposit (Tropoja massif) (Lubonja L. et al. 1966).

1- IP anomaly; 2- Apparent resistivity profile; 3- Magnetic anomaly (ΔZ); 4 – Masive chromite ore body; 5- Disseminates chromite; 5 – Hartzburgites:

6 – Dunites; 7 - Disjunctive tectonics.

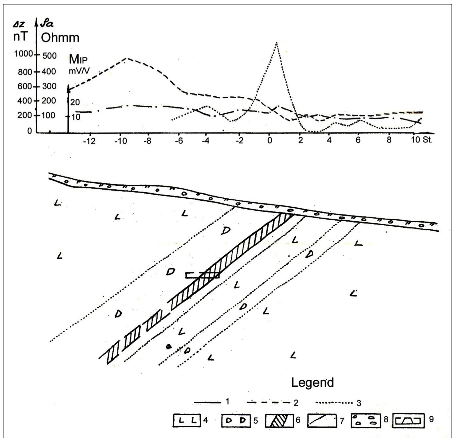

Fig. 4. Geological-geophysical section with a positive magnetic anomaly over a chromite ore body, Leshnice area, Kukesi ultrabasic massif (Frashëri A. 2008.

1- IP anomaly; 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.

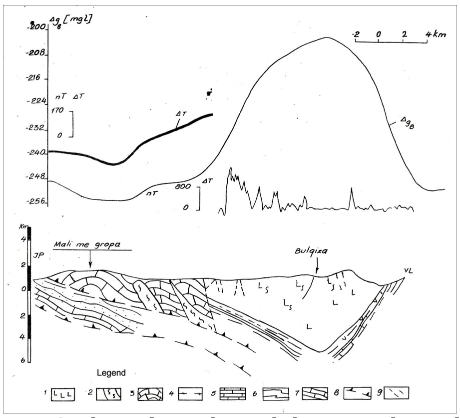

Fig. 4. Geological-geophysical line in Klos-Bulqizë-Shpuzë (Frashëri A. et al. 1990).

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.