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On the application of geophysics in the exploration for copper and chrome ores in Albania[1]

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Abstract

Some generalized results of geophysical exploration for copper sulphide and chromite ores in Albania are presented. The most important geophysical methods used are electrical prospecting, gravity, magnetics and electromagnetics. Physical properties of the ores, genesis and geological problems to be solved have determined the proper choice of any of these methods in the complex exploration.

Introduction

The search for copper and chrome ores in Albania, as well as for other solid minerals, oil and gas included is carried out using a wide complex of geophysical and geochemical methods.

In mineral exploration geophysical methods have contributed to the search for ore bodies or mineralized zones and in geological mapping.

Electrical prospecting and sometimes magnetics, EM and gravity have been the main methods used in the search for copper sulphide deposits. Exploration to a depth of 600–700 m has been performed with the induced polarization (IP) method.

Chromite ore exploration has been carried out using gravity, magnetics and induced polarization methods. Many good results have been obtained but in comparison with copper exploration, chromite exploration is more complicated and more problematic.

Physical and geological bases for geophysical exploration of copper and chrome deposits

Copper ore deposits in Albania are mainly connected with an ophiolitic belt in the Mirdita zone. Mineralization is present in the form of sulphides such as pyrite and chalcopyrite located in volcanogenic rocks (diabase, spilite, keratophyre) and in

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Table 1. Physical properties of copper sulphide ores and surrounding rocks.

	Sample	Chargeability,* in mV/V			Resistivity, in ohm * m			Density, in kg/m^3			Magnetic susceptibility in $\times 10^{-5}$ SI Unit		
		Min	Max	Mode	Min	Max	Mode	Min	Max	Mode	Min	Max	Mode
1	Pyrite-chalcopyrite ore of different sulphide content and textures	18	900	250	0.1	1200	30	2600	4100	3200	10	5000	20† 1000‡
2	Quartz-pyrite-chalcopyrite	5	354	130	15	1650	—	2610	3680	3100	30	2000	50† 1000‡
3	Diabase	4	15	6	320	7000	1200	2700	3200	2800	15	160	75
4	Altered diabase	3	18	7	20	300	200	—	—	—	—	—	—
5	Gabbro	6	16	8	280	5800	450	2700	3200	2800	30	320	150
6	Quartz diorite	5	12	8	150	3000	600	2360	2750	2670	70	1800	220
7	Schistose detritus overburden with clays and silica	3	10	5	4	180	20	2200	2500	2400	10	200	40

* Chargeability amplitude, calculated as spectral IP parameter (m).
† Ores without pyrrhotite.
‡ Ores with pyrrhotite.

effusive rocks of volcano-sedimentary formations, and in the form of quartz-sulphides in gabbro rocks. The mineralization in volcanogenic media forms either concentrated orebodies or simply disseminated sulphide zones or both. The mineralized zones range from some metres to some hundreds of metres wide and from some tenths of metres to kilometres on strike. Massive or veinlet orebodies are often present inside these mineralized zones. In volcano-sedimentary formations, mainly massive orebodies are found.

In Table 1 the results of a petrophysical study of copper sulphide ores and the surrounding rocks are given (Avxhiu 1979; Alikaj 1989). Several hundreds of examples have been tested for every physical parameter included in the study.

The most typical and distinctive physical properties are chargeability and resistivity which are conditioned by mineral content, structure and degree of rock alteration. The surrounding rocks are characterized by a low value of chargeability and a higher resistivity than sulphide ores.

The sulphide ores have a higher density than the surrounding rocks and when they contain pyrrhotite and/or magnetite they exhibit magnetic properties.

These four properties serve as bases for the application of IP, resistivity, EM, self-potential and mise-à-la-masse in copper deposit exploration. Occasionally, magnetic and gravity methods have also been used.

The chrome ore deposits are linked mainly to the upper part of a harzburgite-dunite-tectonite sequence, as well as to the lower part of a dunite cumulate sequence of ultramafic massifs. Most chrome-bearing deposits are of podiform type, less are stratiform.

Dunites and harzburgites are often serpentinized and contain secondary magnetite in a fine-grained disseminated form or thin veinlet.

These orebodies occur as sparsely-to-densely disseminated, nodular, belted or massive chromites. The type of ore is chromespinelid, mainly magnesian and sometimes ferrous. Its chemical composition is simple and the content of olivine and serpentine varies. In some cases the chromite grains are enclosed by secondary magnetite membranes, which are crystallized as a result of intense dynamic processes. Secondary magnetite is also present in chromite and serpentine.

In Table 2 the physical properties of various kinds of chrome ores and ultramafic rocks are presented (Frasheri 1974; Lubonja and Frasheri 1966).

The chrome ore density is determined by the Cr_2O_3 content and, in general, for a simple case, the following dependence is observed (Frasheri 1968):

$$\delta = 40X + 2000,$$

where δ is the ore density in kg/m^3 and X is the percentage of Cr_2O_3 in the ore.

This relationship is not unique, because the ore density is dependent on the degree of serpentinization of the olivine and also on the microfissures.

Large chargeability values are characteristic of chromites which contain secondary magnetite in veinlet or network form. Due to chemical and thermal remanant magnetization, some chromite ores are magnetic.

Table 2. Physical properties of chrome ores and ultramafic rocks.

No	Sample	Density, in kg/m^3			Magnetic properties in $\times 10^{-5}$ SI Units: Susceptibility			Magnetic properties in $\times 10^{-5}$ SI Units: Remanant magnetization			Chargeability in mV/V			Resistivity in ohm-m	
		Min	Max	Mode	Min	Max	Mode	Min	Max	Mode	Min	Max	Mode	Min	Max
1	Chrome	2450	4380	3700	10	500	150	70	8100	2800	5.5	720	78	700	3600
						3000*	300								
2	Dunite	2700	3340	3020	10	1000	250	10	900	150	3	60	8	2200	7000
3	Serpentinized dunite	2600	2800	2700	40	3000	250	10	800	700	5	643	12	100	650
													94		
													517		
4	Harzburgite	2800	3300	3050	10	700	200	10	1300	100	3	15	6	2400	7100
										500					
5	Serpentized Harzburgite	2700	2900	2800	20	1000	400	10	100	250	4	814	22	120	680
													76		
													591		
6	Serpentinite	2240	2650	2550	10	8000	1100	10	70000	300	3	950	15	35	100
													92		
													605		
7	Pyroxenite	2900	3200	3080	10	320	100	10	71000	150	2	6	4	170	1800

* Ores with high content of secondary magnetite.

The petrophysical properties of ultramafic rocks are mainly subject to the degree of serpentinization and the physical and mechanical conditions. From Table 2, the following conclusions can be drawn:

1. Density is the most stable and typical property used to differentiate between chromite ores and ultramafic rocks, thus gravity is the basic method used in our chrome exploration.
2. The values of geophysical anomalies over orebodies depend on the physical contrast between the chromite and the surrounding rocks.
3. Sometimes the physical property contrast between chromite and ultramafic rocks is very low, and thus no geophysical anomaly of this parameter can be observed.
4. Over some areas of ultramafic rocks, some geophysical anomalies can be fixed, due to a physical property contrast with the surrounding rocks.

Based on these conclusions we can state that geophysical anomalies reveal some targets which have a high probability of indicating the presence of chrome orebodies. Their lack shows only that within the depth of investigation, orebodies exhibiting a sufficient contrast to ultramafic rocks do not exist. Thus, geophysical exploration for chrome ore is rather complicated, and an integrated interpretation of geological, geophysical and geochemical methods should be used.

Geophysical exploration for copper ore deposits

During the 1960s the main electrical prospecting method used in copper exploration in Albania was the self-potential (SP) method. Resistivity and magnetic surveys were also carried out, and occasionally the gravity method was used. Good results were obtained from this integrated interpretation for shallow depths, some tenths of metres (Fig. 1) (Frasheri 1963).

After rapid development in the early 1970s, the IP method became the major surveying method for copper sulphide exploration, while the other methods served as complementary or follow-up methods. In this period the depth of investigation increased to 200 m (Fig. 2) (Avxhiu 1979).

In the last decade our copper exploration was extended to greater depths, to 400–700 m. For this purpose we used the following procedures:

1. New IP instrumentation consisting of a high-power transmittter and a high-sensitivity receiver was used (IPC-7/15KW, IPR-10A, IPR-11), produced by SCINTREX.
2. The surface-to-hole IP responses were studied theoretically and experimentally to investigate the orebodies around the boreholes, especially at great depths (Lubonja *et al.* 1985).
3. The possibility of separating low amplitude and frequency IP anomalies was also studied (Lubonja *et al.* 1984).

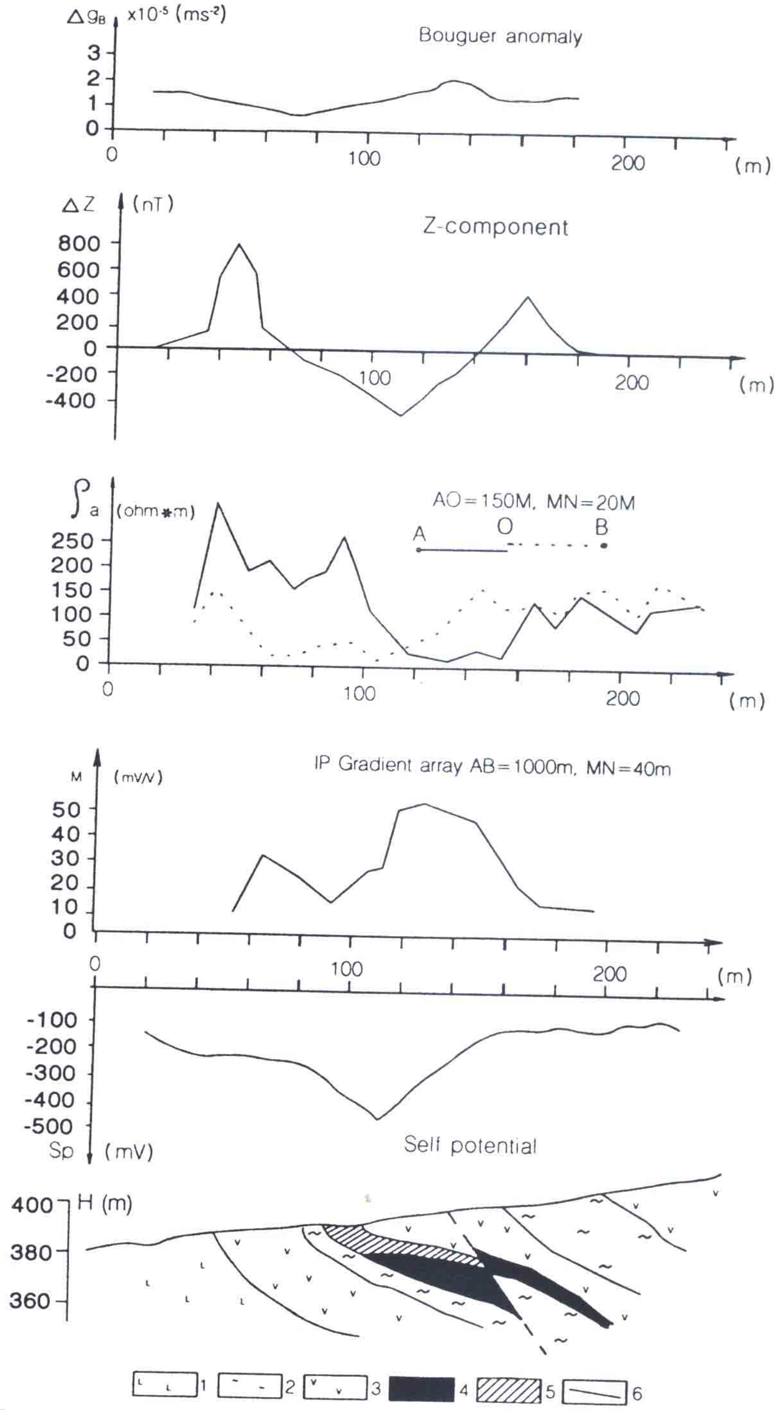

Figure 1. Geophysical profiles and geological section of a copper sulphide ore deposit. (1) Ultrabasic rock. (2) Argillaceous schists. (3) Diabase. (4) Massive orebody. (5) Disseminated mineral zone. (6) Tectonic faults.

4. The results from direct mineral exploration and geological mapping by geophysical methods were coordinated (Avxhiu, Bushati and Alikaj 1984).

In theoretical studies, the IP field distribution in heterogeneous geological media, with a lithological boundary of any shape, over a rugged relief was investi-

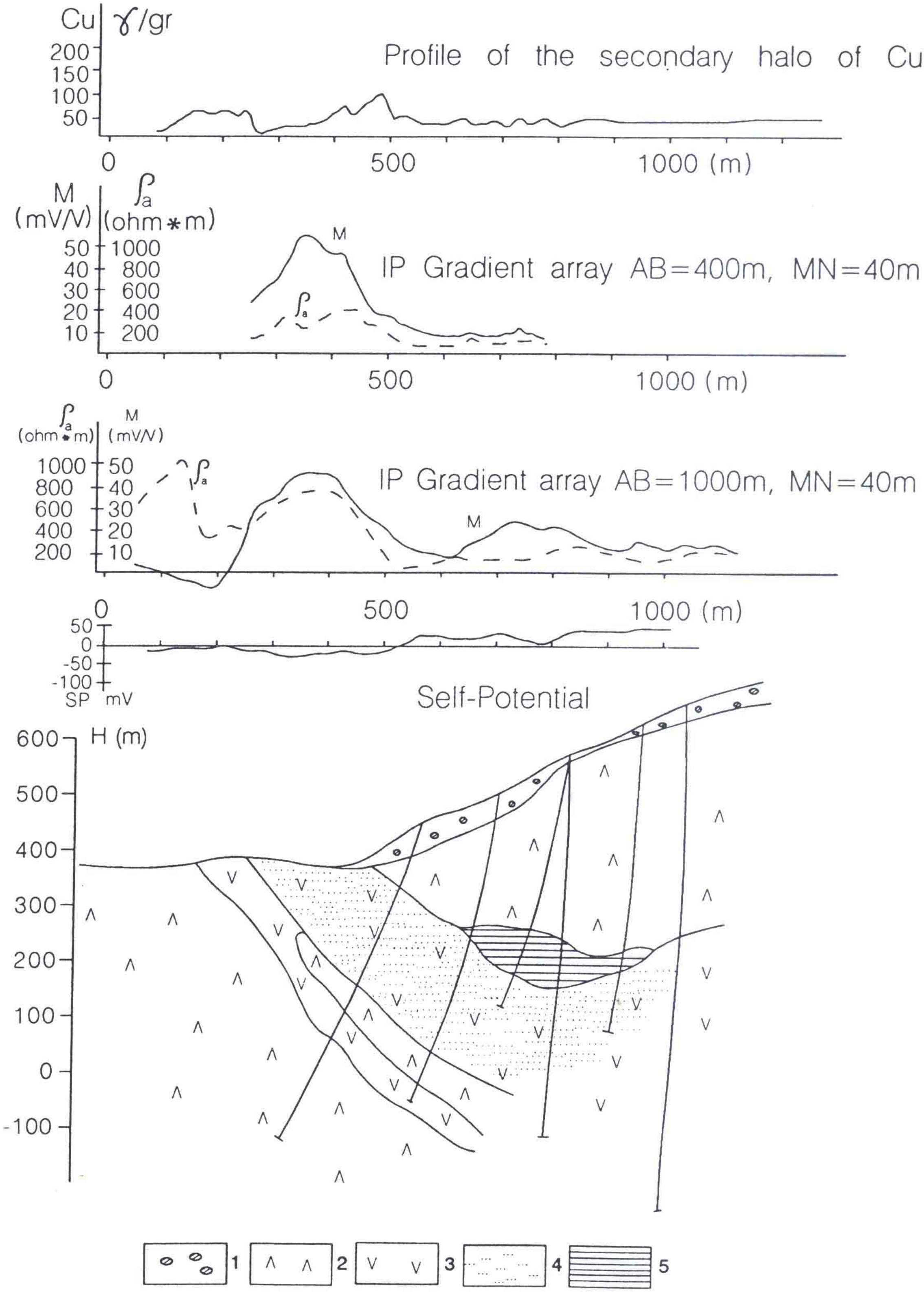

Figure 2. Geophysical and geochemical profiles over the cross-section of a copper sulphide ore deposit. (1) Overburden. (2) Keratophyre rocks. (3) Spilites. (4) Disseminated sulphides. (5) Massive sulphide orebody.

gated. Applying the finite-element method and other techniques, the proper algorithm and software were developed for computation of synthetic IP anomalies (Frasheri, Tole and Frasheri 1984; Frasheri 1987; Frasheri 1989). Mathematical models were computed for polarizable bodies of any geometrical shape, with or without resistivity contrast, in 3D, 2.5D and 2D. The current electrode could be set on the surface or underground.

As a result of theoretical and experimental studies in different geological media, the depth of investigation using the IP method in copper sulphide exploration has increased markedly, to 600–700 m. Figure 3 shows such a case in a volcano-sedimentary formation in north-east Albania. The survey was carried out using deep IP soundings with a maximum separation of current electrodes of AB = 4400 m.

Chargeability responses for every separation are plotted at points located at the approximate depth of investigation, Hi. The geological data are plotted on the same

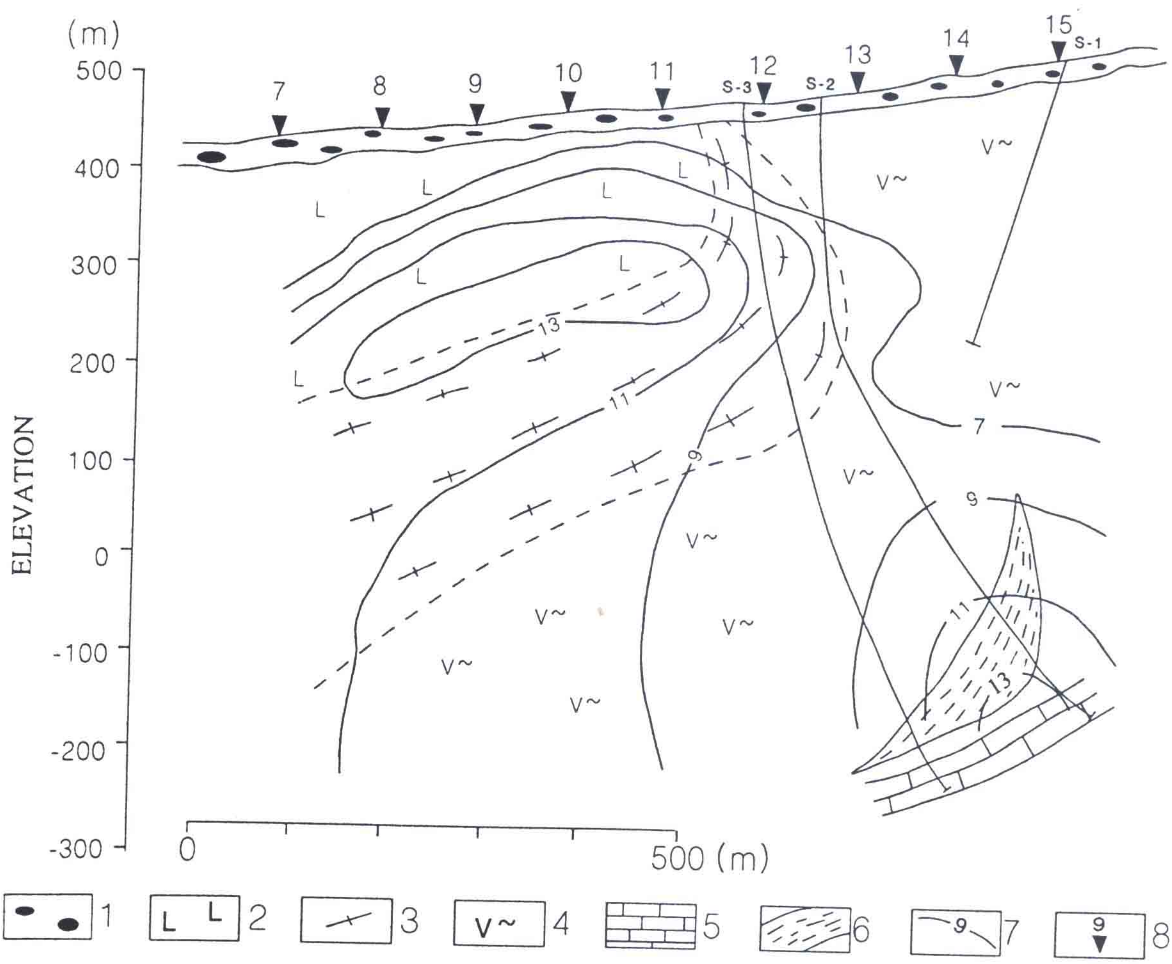

Figure 3. Real section of chargeability (M4) according to the VES-IP measurements in volcano-sedimentary formations. (1) Overburden. (2) Ultrabasic rocks. (3) Amphibolites. (4) Volcano-sedimentary rocks. (5) Limestones. (6) Disseminated and veinlet sulphides. (7) Chargeability contours in mV/V. (8) Centre and the number of VES-IP.

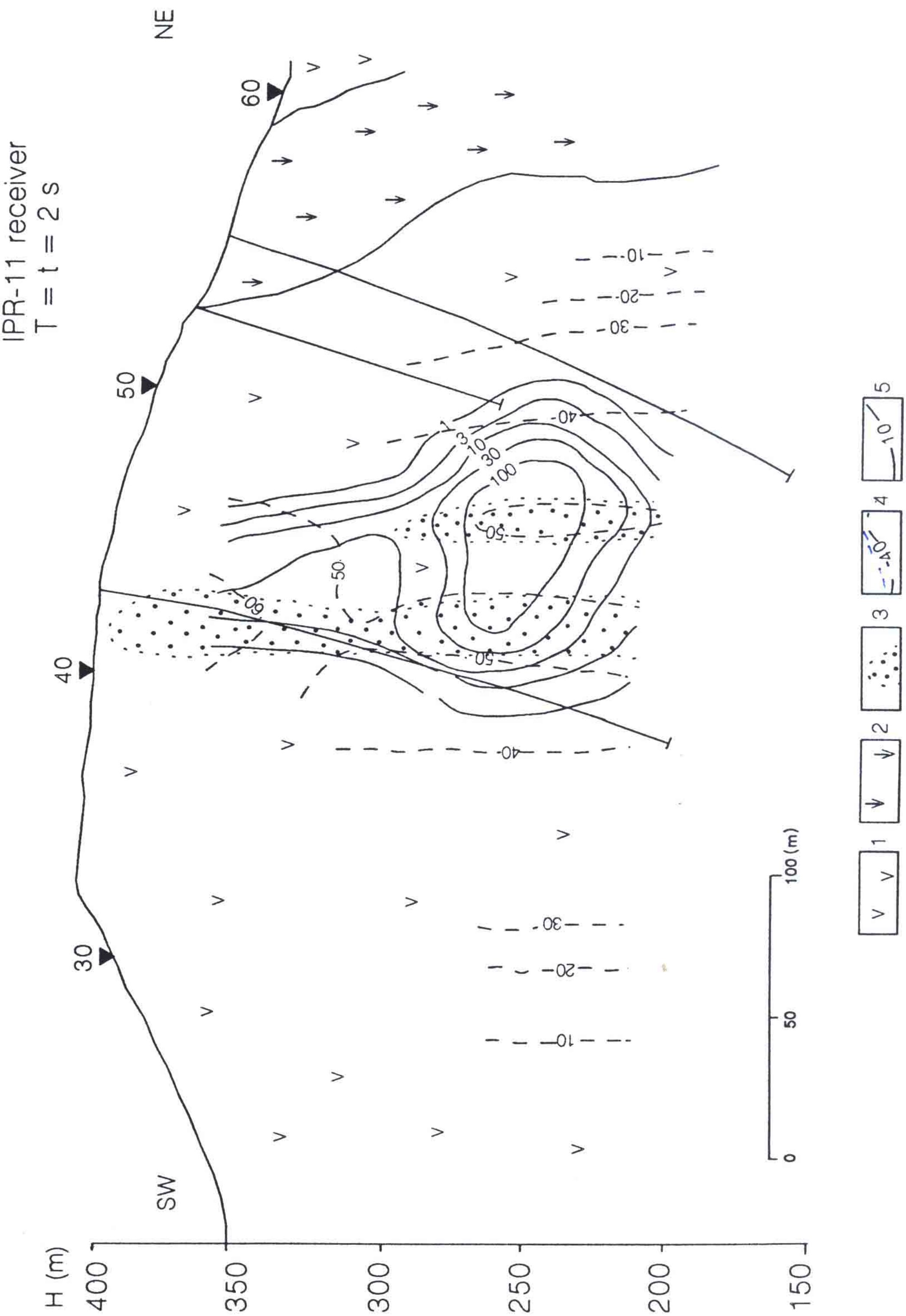

Figure 4. 'Real section' of the chargeability (M4) and apparent time constant spectral IP parameter (τ) over a mineralized sulphide zone. (1) Diabase. (2) Harzburgite. (3) Mineral zone. (4) Chargeability in mV/V. (5) Spectral time constant τ in sec.

section. This type of presentation is called a 'real section' (Alikaj 1989; Langore *et al.* 1989a). Chargeability contours show an anomaly at a depth of 500–700 m. This was confirmed by drilling which crossed a thick sulphide zone at this depth. The shallow chargeability anomaly is connected with the contact zone between ultrabasic and amphibolite rocks, which contain magnetite and scattered sulphides.

Another important problem of the IP method is to discriminate between high- and low-grade sulphide ores. Recently, spectral IP parameters have been investigated (Alikaj 1989; Langore *et al.* 1989a). We used the Cole–Cole model (Pelton *et al.* 1978) in the time domain to derive the synthetic spectral IP parameters m, τ and C, according to Johnson (1984).

The study of spectral IP parameters was carried out in samples, at test sites and under field conditions. The main conclusion of the study was the good differentiation between massive or veinlet sulphide ores and disseminated sulphide ores. In Fig. 4 a field case history of a spectral IP survey in Derveni volcanogenic rocks is presented. Within the chargeability 'real section' of the M4 window, a strong anomaly of the apparent time constant τ was observed. The first borehole drilled nearby intersected a thick mineralized zone with some intervals of concentrated sulphide belts. However the centre of the anomaly has not yet been verified.

Some results and problems in chrome exploration using geophysical methods

Geophysical investigation, consisting of gravity, magnetic, resistivity and induced polarization methods has provided good results to support the geological mapping of ultramafic rocks and their relationship to the surrounding formations, in order to determine the geology of the mineralized belts and the primary textures of rock massifs (Frasheri 1974; Langore *et al.* 1989b). We present some results of chrome exploration, below.

Over the orebodies, weak gravity anomalies are observed, which are more evident after the field transformation. Figure 5 shows a case study from north-east Albania (Frasheri 1974). It must be noted that such anomalies can also be caused by fresh rock isolations settled among serpentinized rocks. Magnetic surveys may help in some cases to solve this problem. Depending on the orientation of the magnetization and the susceptibility contrast of the orebody, magnetic anomalies can be either negative or positive (Figs 5 and 6) (Lubonja and Kosho 1974; Frasheri 1974). Positive magnetic anomalies have been also recorded over the magnetic serpentinites which contain secondary magnetite due to dynamometamorphism. But these cases differ from those of orebodies because of the lack of gravity anomalies.

In many cases IP anomalies are observed over orebodies consisting of polarizable chromite (Fig. 7) (Lubonja and Frasheri 1966). These anomalies are often wider than orebodies due to a dunitic envelope which presents the same IP parameters as chromite ore. In some cases IP anomalies are also caused by polarizable ultramafic

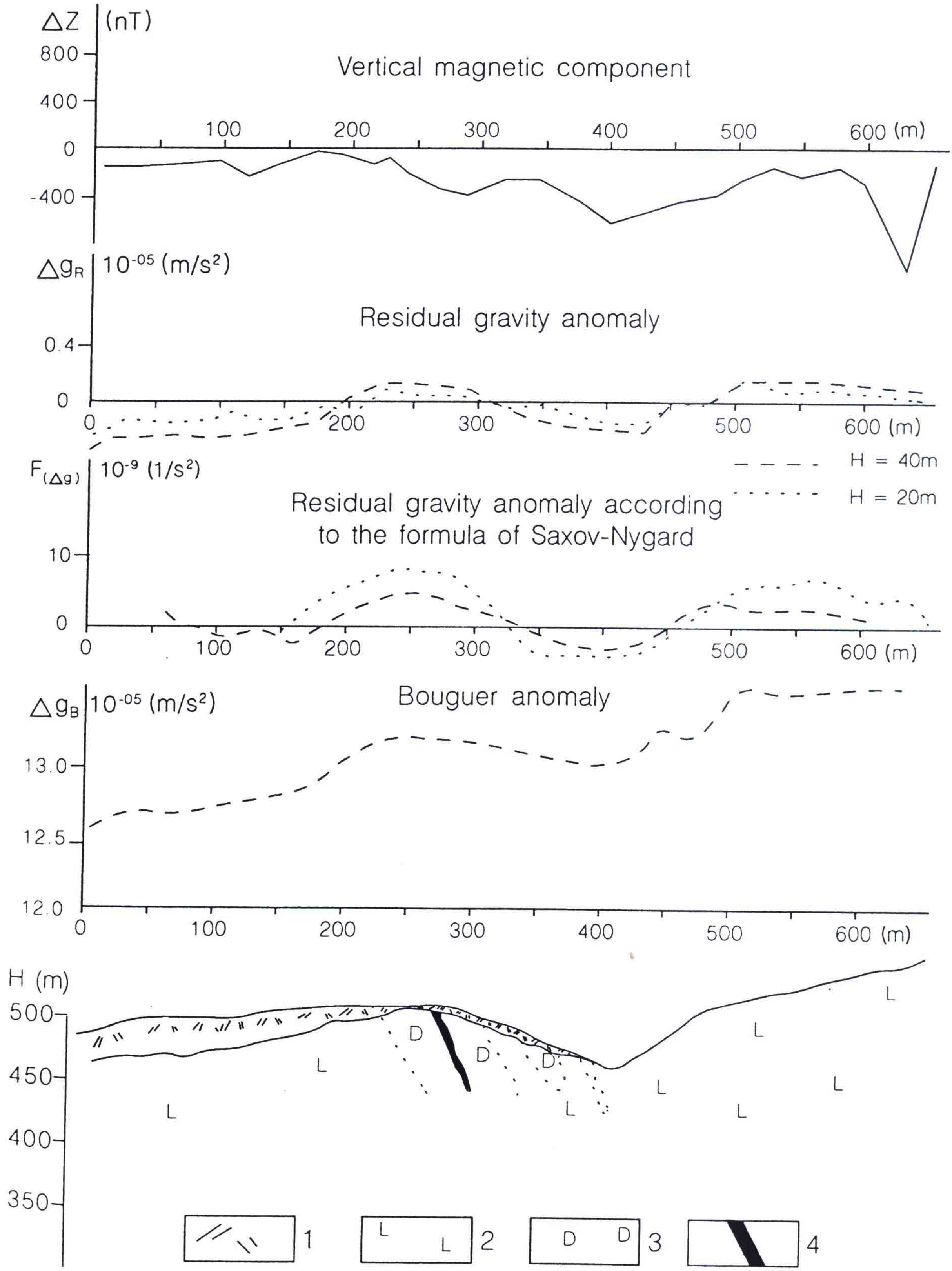

Figure 5. Gravity and magnetic profiles over a chromite orebody. (1) Overburden. (2) Harzburgite. (3) Dunite. (4) Chromite ore.

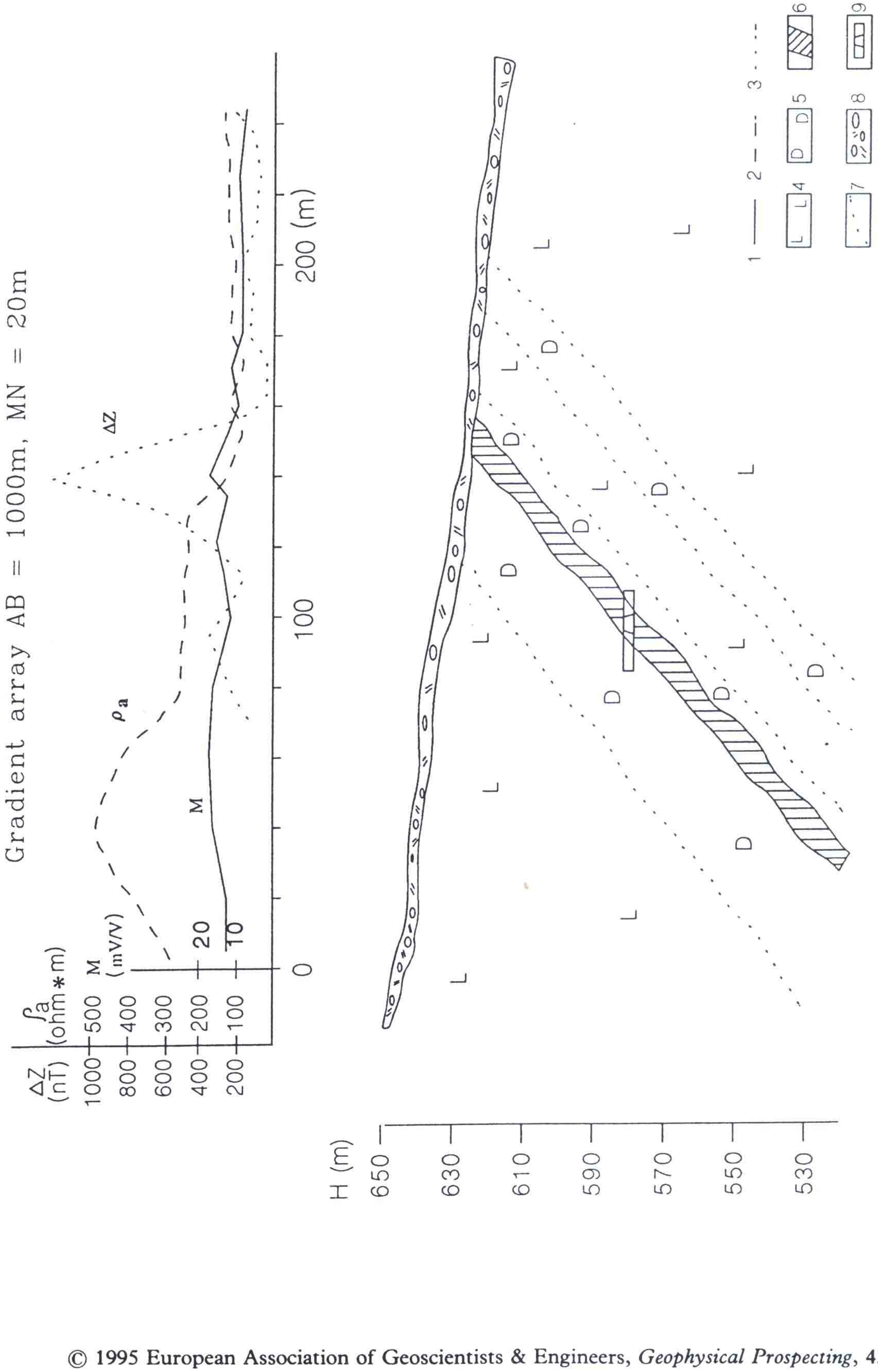

Figure 6. Geophysical profiles and geological section over a chromite ore deposit. (1) IP profile. (2) Resistivity profile. (3) Anomaly of the vertical component of the magnetic field profile. (4) Harzburgite. (5) Dunite. (6) Chromite ore. (7) Gradual geological boundary. (8) Overburden. (9) Mine working.

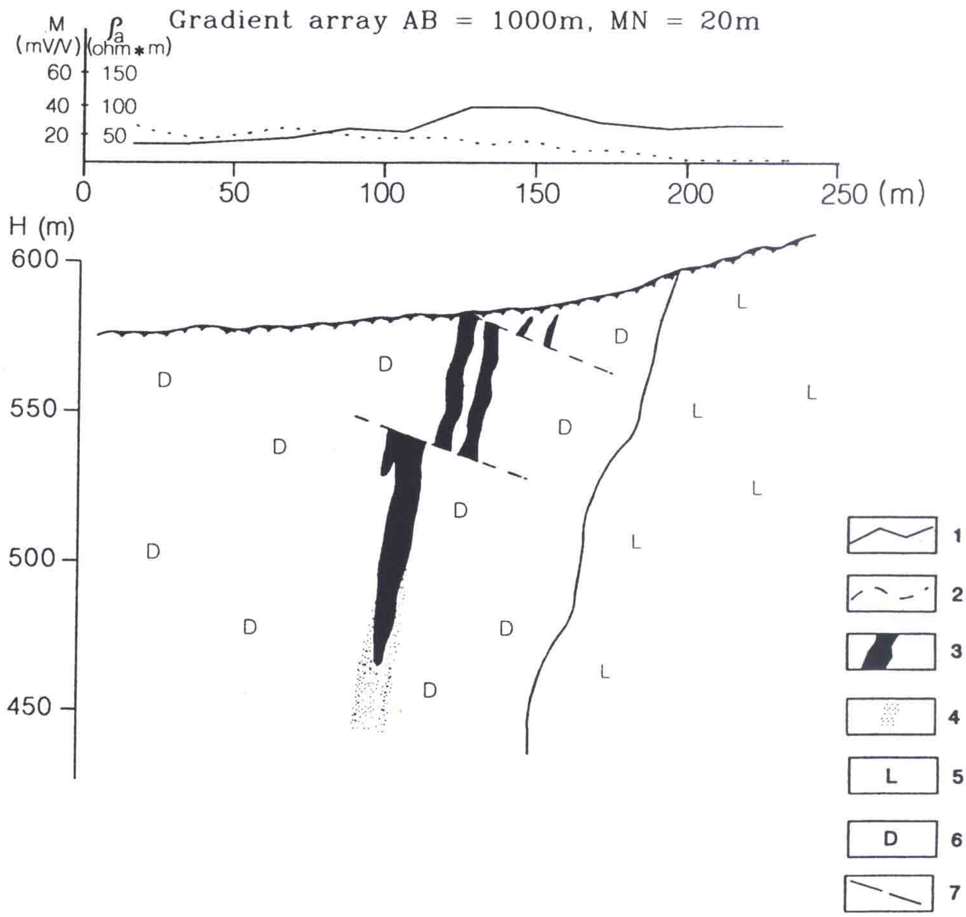

Figure 7. IP and resistivity profiles over a cross-section of a chromitic ore deposit. (1) IP profile. (2) Resistivity profile. (3) Massive chromite. (4) Disseminated chromite. (5) Harzburgite. (6) Dunite. (7) Tectonic fault.

rocks. Some laboratory tests of chromite samples with spectral IP have shown no correlation between Cole–Cole parameters and chrome-bearing.

In our experience of chrome exploration, we have found examples where the distribution of physical fields is very complicated, because the ultramafic rocks are very heterogeneous. In these cases, the 'ore' anomalies may be detected using an integrated interpretation of geophysical and geological data. However, the complicated physical fields render more difficult the data interpretation and decrease its reliability.

In order to increase the depth of exploration for chromite ores, we have successfully used the borehole magnetic survey and hole-hole radio-wave method (Fig. 8) (Gjovreku 1986). In borehole S-17 which did not intersect any orebody, an anamalous sector of the total magnetic field vector **T** at a depth of 190–330 m was observed. This anomaly was interpreted as being caused by a magnetic chromite orebody 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 orebody.

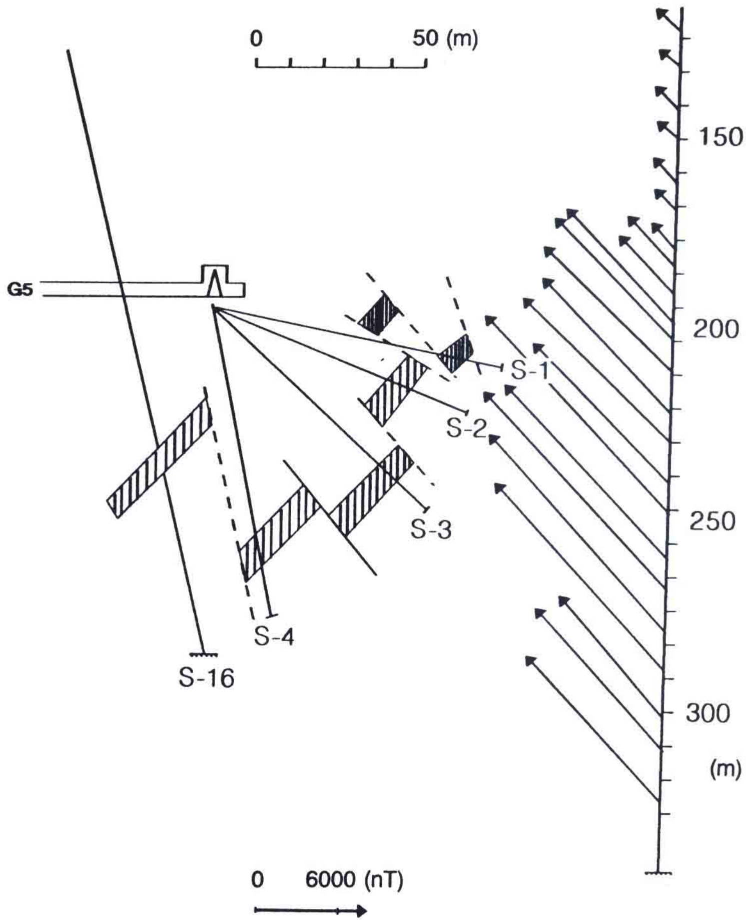

Figure 8. Results of a three-component borehole magnetic field survey in the search for chromite ores. (Anomaly of total magnetic field **T**).

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