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Integrated interpretation of geophysical data in the South – Iaşi area

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Abstract

The limitations affecting the geological interpretation of geophysical data derived from measurements made using three methods relate mainly to the incompleteness of geological and drilling information, the volume and quality thereof, which is precarious in the region covered by this study, but also to the partial lack of confirmation of magnetometric results in the other geophysical maps available (gravimetric and telluric currents). These simple findings lead to the idea that the nature of these limitations is rather extrinsic than related to the potentiality of the magnetometric method. Obviously, in this context, this paper cannot propose reconsiderations and structural revisions of the previous opinions on this geological unit.
The petrophysical data, especially the magnetic ones, do not outline a rigorous premise regarding the interpretation of magnetic anomalies in the area under review, especially due to the peculiarity that the nearest drillings – Nicolina and Iași-Socola – have not revealed rock samples with special magnetic properties. Since the magnetometric method stands out primarily due to its petrographic resolution, the approach of an interpretation from the perspective of the structural content of geophysical information takes on a complex and difficult turn given the ambiguity of the situation.

Keywords: magnetic anomalies, gravimetric anomalies, intrusive granite bodies, crystalline basement, tectonic alignment, petrophysical parameters, density, magnetic susceptibility.

1. Introduction

This study is aimed at reconfiguring the interpretation of magnetic anomalies generated by endogenous bodies found in crystalline formations of the basement of the Moldavian Platform (applied on the South–Iaşi area), emphasising the main theoretical aspects related to the detailing of geological sources responsible for the occurrence of the mentioned anomalies, as well as the correlation of magnetometric

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data with those from other two important types of geophysical investigation. The paper presents data gathered as a result of magnetometric, gravimetric and telluric current surveys existing for the South–Iaşi area leading to a substantial reduction of the fundamental ambiguity regarding the deciphering of the geological structure of the subsoil, while highlighting the complementary character of information: gravimetric and electrometric information shows a pronounced structural content, while magnetometry information has a predominantly petrographic one.

2. General geological characteristics

The area in which the magnetothermal investigations that constitute the support of this paper were conducted belongs to the Moldavian Platform unit. We cannot therefore specify the geological framework of the smaller area that forms the background of our subject matter, without resorting to some broader references, covering the entire area of the Moldavian Platform, while being able to extrapolate the situation to our particular context.

The two components of the Moldavian Platform, the basement (the foundation) and the cover, reflect different stages of evolution, with the foundation representing the mobile, geosyncline stage, in which there were intense geodynamic processes (orogenesis, metamorphism, magmatism), completed in an orogenetic system, and the cover foundation representing the stability stage (small platform), where deposits accumulated in successive marine cycles were not deformed tectonically and remained quasi-horizontal. After consolidation, the first marine transgression took place in the Upper Vendian, and the newest deposits belong to the Meotian. In this long stratigraphic range there were several stages of rising above sea-level. On most of the Moldavian Platform, erosion acts in the Sarmatian deposits, from which only in the NE (along the Prut River) older deposits (Badenian and Cenomanian) have been exposed.

Next, we will consider only the lower level of the platform, the basement, since the cover deposits, due to the specific character of the magnetometric method and the contrasts of magnetic properties that justify the appearance of magnetic anomalies, do not include magnetically notable sources, which is why the chapter on this level would be irrelevant from the perspective of the content of the issue under review.

2.1 Formations of the crystalline basement

The lower level of the Moldavian Platform has a heterogeneous and heterochronous character, which was revealed by the drills in which it was intercepted. It displays features common to the Svekofenian – Karelian formations (2600–1750 Ma) that outcrop in the Ukrainian Massif. This is the case of meso-metamorphic gneiss and granitic – migmatitic gneiss formations, found in several drillings between Siret and Prut rivers. Compared to the formations of this age that alter in the south-western edge of the shield, it can be assumed that in some sectors of the platform basement formations metamorphosed in the granulite facies also develop, or that basic intrusions could be present – gabbro-anorthosite intrusions – of the same type as those known in the Ukrainian Massif and related to the Gothian cycle (1750 + 50 – 1200 Ma).

The structure specific to the basement of the Moldavian Platform is difficult to establish due to insufficient data. Compared to the portion of the basement that outcrops in the Ukrainian Massif, it can be admitted that the structures are mainly north-south oriented and show refolding in several planes. The basement of the platform takes the form of a monocline that descends in steps to the west and southwest. Drilling data have shown that this basement is immersed into a system of fault lines particularly oriented towards NW–SE (Fig. 1). Thus, in Soroca, on the bank of the Dniester River, the basement in Todireni currently appears at –950 m and in Iași at –1121 m.

On the territory of Iași County, similarly to the surrounding areas from north to south, the basement represents an old orogen brought to the stage of peneplain, of Podolic type, consisting mainly of crystalline shale, migmatite and eruptive rocks forming a rigid basement, subject to series of vertical oscillatory movements, resulting in marine transgressions and regressions. It was intercepted in a few deep drills at Iași (1121 m), Popești (1370 m), Bătrânești (1008 m), and Todireni (950 m). The longest core columns were extracted in Iași (270 m) and Todireni (483 m). Potassium-Argon (K–Ar) dating indicated the range of 1280–1500 Ma for feldspats. From the drills that brought information on the depth and petrographic nature of the basement, it appears that it consists predominantly of paragneiss and granitic rocks and that it lies at depths ranging between 808 m (Bătrânești) and 1216 m (Popești).

Massive quartz-diorite gneiss with biotite, hornblende, and pyroxenes are crossed by veins of feldspatic pegmatites. In areas adjacent to the veins, gneisses are enriched with metasomatic microcline. In parallel with these changes, there is also an appreciable increase in the content of apatite and magnetite. Hornfel enclaves also illustrate the existence of late granite injections.

On the meridian of Iași City, the crystalline formations were intercepted at depths between 900 and 1000 m. The crystalline complex consists, near the Iași town, of plagioclase paragneiss with garnet and sillimanite (Ianovici and Giuscă, 1961). In association with that, granitic gneiss were also highlighted. The crystalline shales from Iași form a migmatic complex involving the participation of in-situ mobilisations of metamorphic and anathectic origin, followed by granitic injections from deeper levels.

In the Iaşi–Socola drilling, which intercepted the basement within the 1121–1391 m interval, metamorphic rocks are very poor in metallic minerals – magnetite does not appear; however, only pyrrhotite is sporadically present. Rocks are typical metamorphic, resulting from an advanced metamorphism of sedimentological deposits. The rocks, devoid of metallic

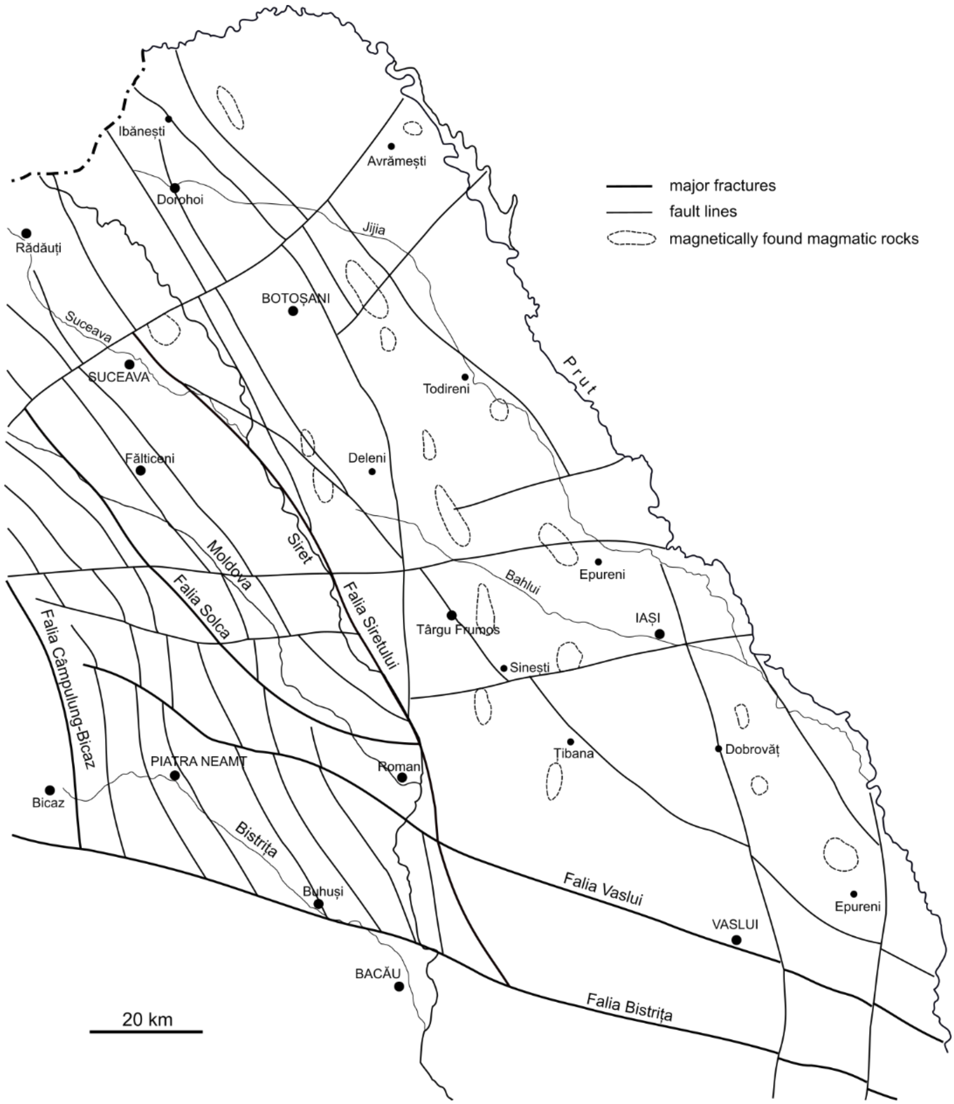

Fig. 1 The tectonic map of the Moldavian Platform (Visarion et al., 1987).

minerals would belong to granulite facies.

A special image was obtained due to the drilling in Todireni, where the entrance to the basement took place at approx. 950 m. Paragneiss described can be paralleled with granite-biotite gneiss from the old gneiss complex that are usually injected by pink granites, with migmatised muscovite and biotite. Near Jitomir, this gneiss contains sillimanite and graphite and in Volhynia there is a gneiss group with migmatic types and various Korzec intrusions, similar to the rocks found in the drillings made in the vicinity of Iași Municipality. Todireni gneiss is composed of microcline, oligoclase, quartz, biotite, hornblende, accessory apatite, titanite, and zircon, occasionally magnetite and pyrite.

The basalts intercepted in the Todireni drilling are probably Infra-cambrian (Riphean) of age, taking into account the frequency of the appearance of Infracambrian basalts in the Ukrainian Massif (Mutihac and Ionesi, 1974). It is also worth noting the presence of magnetite-bearing quartzites of the Krivoi Rog type in Todireni, which as a result of erosion processes, remained in the form of lenses in the depressionary areas of the basement. The magnetite and hematite-bearing rocks belong to the amphibolite facies.

In conclusion, from the known data, the basement of the Moldavian Platform represents an extension of the crystalline formations of the Ukrainian Massif regenerated in the mid-Proterozoic. The closest point to the Moldavian Platform, where the basement appears to date, is Cosăuţi, on the Dniester River, a place where old Rapakiwi granites appear under the unfolded Silurian formations.

Within the basement of the Moldavian Platform, four crystalline complexes can be differentiated, as follows:

– paragneiss with microcline (complex similar to some of the old formations, known in the Ukrainian Massif);

– mica shales with garnet, andalusite, and sillimanite, with interlayers of pyroxenic amphibolic shale and magnetite quartzites;

– epidotic mica shales, amphibolic shales with epidote, cris-crossed by pegmatites;

– low-grade metamorphic rocks.

It can be appreciated that the basement of the Moldavian Platform represents a peneplain that has been denuded. It consists of very old, medium-grade and low-grade metamorphic rocks, metamorphised in the third eon of the Precambrian, migmatised in the fourth eon of the Precambrian and injected and pierced by eruptive rocks at the end of the fourth eon of the Precambrian and the beginning of the fifth eon of the Precambrian. On the surface of the basement a syneclysis with relatively small structural closure is installed, which occupies an area that can be delimited by a contour passing through the localities of Vaslui – Iași – South Dorohoi – Botoșani – Hârlău – Deleni.

It follows from the corroboration of drilling data with geophysical data that, in the pre-Alpine periods, the consolidated basement in front of the present Carpathian domains has widened to the west, by incorporating a new area that has not suffered any folding, at least in the Alpine cycle. This led to discussions on the existence of two platform units in the region of the Eastern Carpathians, one is Eastern European with mesoproterozoic basement and the other is Central-European with Baikalian basement. As the consolidated area in front of the Eastern Carpathians functioned as a typical platform before the Alpine cycle, its designation, in its current structure, under the name of the Moldavian Platform is justified.

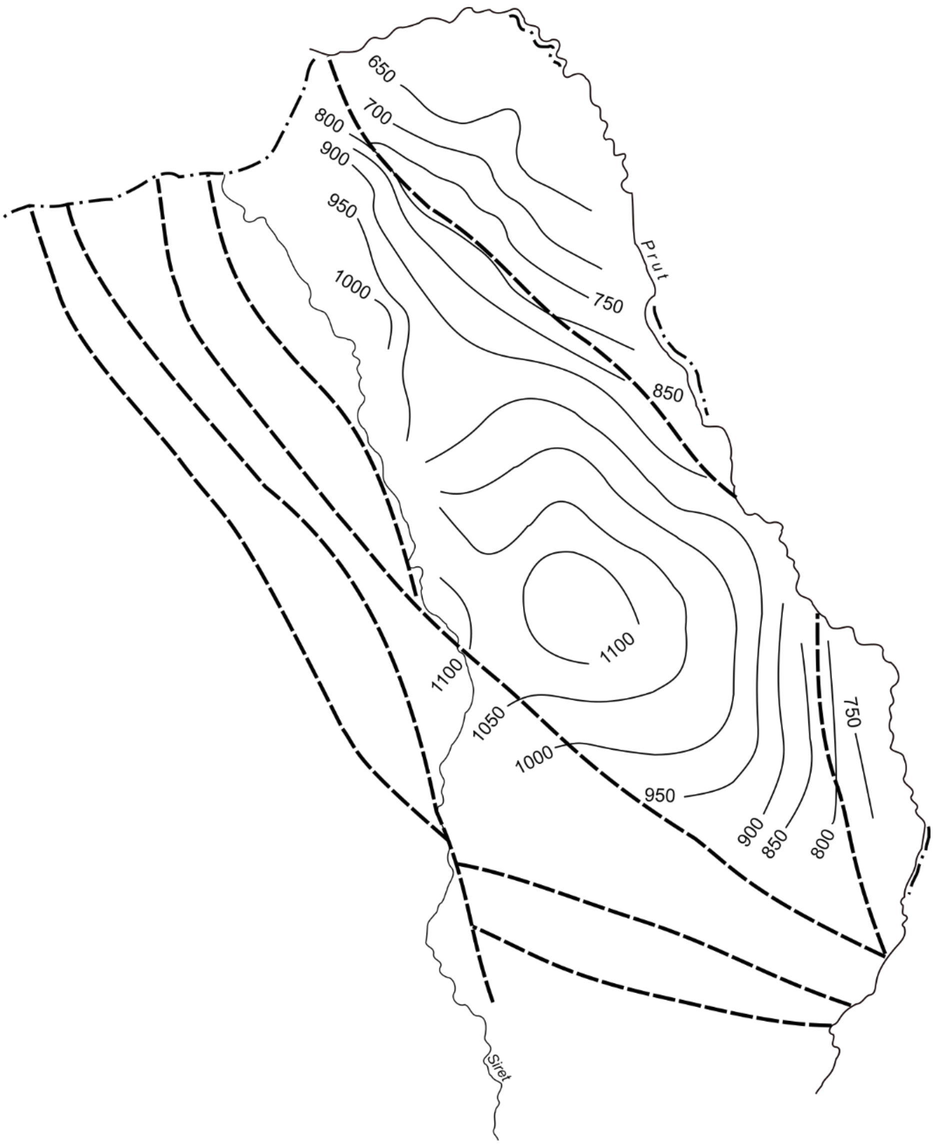

Fig. 2 Model of the surface morphostructure of the crystalline basement of the Moldavian Platform - isobates map (Nasser, 1977).

3. Petrophysical data

The idea of a unitary image of the basement of the Moldavian Platform requires the need to know the petrophysical parameters of the main types of rocks in the basement of this area. The petrophysical data for the platform area are quite inconsistent, as the vast majority of the information is associated with the determinations made on cores extracted from the classical drillings existing in the platform (Nicolina–Iași, Socola, Todireni).

As regards the perimeter studied in order to elaborate this paper, no determinations of magnetic susceptibility or density were made, as the current formations, on which the prospecting was carried out, are of Holocene–Pleistocene age, and thus do not constitute possible sources of magnetic anomalies.

3.1. Rock density petrophysical data from the Moldavian Platform

In the opinion of Botezatu (1982), the granitic crystalline basement – which, together with the old sediment, sinks to the west, to the Carpathian orogen and to the south, to the plain – is clearly differentiated in terms of density from the sedimentary surface, so that for crystalline, eruptive, Paleozoic and Mesozoic formations, densities between 2.55 and 2.95 g/cm^3 are allocated, and for Paleogene and Neogene formations densities between 2.20 and 2.45 g/cm^3 are allocated.

The gravity anomaly, on the entire surface of the Moldavian Platform, reflects the cumulative effect of mass contrasts and density, respectively, which are achieved at different levels in the basement (Fig. 2). On the East-European Platform area there are numerous local anomalies of gravity, with various morphologies and intensities. In the presence of a cover with no appreciable dimensions – especially in the central-eastern part of the platform, to which we refer in particular – and consisting of formations with relatively small inclinations, it can be considered that on the territory of the Moldavian Platform most of the local anomalies have their source in the mass inhomogeneities inside the basement.

The Moldavian platform consists of a basement of crystalline rocks that can be substituted laterally with varieties such as granogneiss and Precambrian granite rocks. This basement supports a sedimentary cover consisting of Paleozoic (Silurian), Mesozoic (Cretaceous), Paleogene and Neogene (Miocene and Pliocene) deposits. The almost horizontal position of the layers is specific for the above sequence, so the absence of folding phenomena, with large interruptions in sedimentation, corresponding to erosion surfaces formed under regional rising above sea-level.

Also taking into account the thickness of the formations leading to the creation of mass contrasts, it has been accredited that the anomaly of gravity in the platform area is mainly produced by a contrast between a lower level, consisting of crystalline rocks incorporating Paleozoic and Mesozoic formations, and a higher one, consisting of Paleogene and Neogene formations. The mean value of this density contrast was set at approximately 0.3 g/cm^3. In the previous statement, the term “level” has no structural significance, but refers to a series of formations belonging to the same area of densities, division that also has advantages in establishing and separating anomaly masses. Locally, there are mass contrasts located either in the platform basement or in cover deposits.

The crystalline basement appears to be particularly heterogeneous, built from a wide variety of rocks, a situation that will also determine an important variation of density values, from one basement sector to another, depending on the petrographic constitution, the degree of metamorphosis, the content in secondary minerals, the undergone transformation phenomena, among which the main role is played by granitisation.

The analysis of the information gathered on density leads to a constant conclusion regarding its dependence on the mineralogical composition of basement rocks. The mineralogical studies have shown that high density values are due to the presence of magnetite in combination with ilmenite, rutile, titanite, pyrite, chalcopyrite, and marcasite. The highly suggestive correlation coefficients clearly revealed that an increase in the concentration of magnetite within crystalline rocks led to a progressive increase in the values of density and magnetic susceptibility of the rocks.

The study of the distribution of density values highlights, for granogneiss rocks, mean values of about 2.72 g/cm^3. A feature observed in several cases in the basement of the Moldavian Platform was that densities with values lower than 2.70 g/cm^3, which were attributed to different types of granite, gneiss and migmatite (values ranging in most situations between 2.54 and 2.65 g/cm^3), as well as to quartzites. If these types of rocks are found in the masses of crystalline shale, they can generate minimal gravimetric anomalies, sometimes sufficiently expressive.

The development within crystalline complexes of rocks of the ultrabasic and basic type or amphibolic and amphibolic shales, with densities ranging from 2.88 to 3.00 g/cm^3 will condition the existence of maximum gravimetric anomalies. Magmatic bodies – diabases, gabbro-diabases – with average densities of 3.00 g/cm^3 and possible petrographic separations from the mass of crystalline formations with substantial intake in magnetite will also be reflected by maximum local anomalies. For the latter, however, it is also necessary to associate excess density with large volumes of rocks.

Since the data obtained by direct determinations are relatively small and refer to the top of the basement, in order to provide a more eloquent picture of the evolution of the petrophysical properties of the rocks of the basement, we will draw on information from the super-deep drilling FG-3 in the Kola peninsula. This information can also be extrapolated to the crystalline basement of the Moldavian Platform.

Proterozoic (0 – 4500 m)

▪ magmatic (diabases, gabbrodiabases, porphyrites, pyroxenites)	3.00
▪ volcanic-sedimentary and sedimentary (metamorphosed tuffs, metatufites, volcanogenic breccias, phyllite, aleurolites)	2.90

Proterozoic (4500 – 6835 m)

▪ magmatic (metadiabases, metaandesites)	2.89
▪ volcanic-sedimentary (various shales)	2.78

Archaic (6835 – 10500 m)

▪ gneiss	2.69
▪ amphibolites	2.93
▪ ultra-high pressure metamorphic rocks	2.98

The main conclusions drawn from the analysis of specific data for this drilling are that volcanic-sedimentary rocks have high density values due to the presence of metallic minerals (pyrrhotite, pyrite) and low porosity, while regional metamorphism leads to an increase in the density of crystalline rocks. The density determinations performed on samples taken from the drillings at Todireni and Bătrânești showed values of the same order of magnitude.

In relation to the sedimentary cover of the Moldavian Platform, histograms show mean densities and density contrasts made by various formations, compared to the value of 2.50 g/cm^3, considered to be the mean density of the sedimentary layer. Within the cover there may be mass deficits due to thickening of sand and marl deposits or excesses caused by the substantial development of lime and conglomerate deposits, which can locally influence the image of the gravity anomaly. In the case of sedimentary rocks, the density depends, in addition to the mineralogic composition, on porosity and the degree of cracking, since the porosity and cracking coefficients decrease due to the pressure exerted on the rocks.

Another aspect revealed following the interpretation of petrophysical data on sedimentary cover is the increase in density of sedimentary formations with depth and from east to west of the platform. Data retrieved in relation to the cover are quite limited and they have led to the establishment of the following ranges of density variation:

Pre-Silurian formations	2.66 – 2.71
Silurian formations	2.64 – 2.76
Cenomanian formations	2.04 – 2.54
Neogene formations	2.15 – 2.46

Overall, the Precambrian and Paleozoic sedimentary formations do not differ according to their density, so that a single average value of 2.66 g/cm^3 was adopted.

Table 1 presents the mean densities that can be attributed to the rock deposits belonging to the main geological periods found in the Moldavian Platform, based on the analysis of the petrophysical density data.

By default, the main density contrasts are derived:

+ 0.22 g/cm^3 between the formations of the crystalline basement and deposits of Cretaceous–Paleozoic age;

+ 0.20 g/cm^3 between Neogene-Paleogene and Cretaceous–Paleozoic deposits.

Table 1 Mean densities of the rock deposits identified in the Moldavian Platform

Neogene and Paleogene deposits	2.30
Cretaceous and Paleozoic deposits	2.50
Crystalline formations of the basement	2.72

3.2. Magnetic petrophysical data

The image of the aeromagnetic map highlights a relatively large number of regional anomalies, with intensities sometimes reaching hundreds of nanotesla and a marked diversity of orientations in different directions. Against the background of these regional aeromagnetic anomalies, there are numerous local anomalies, some with circular shapes (Todireni), others with elliptical contours (Șesul Jijia–Grozești, etc.), located on the flanks of regional anomalies. The variation range of volume magnetic susceptibility, as well as density, is vast, with variations even within the same type of rock, depending on the more diminished or more consistent intake of ferromagnetic minerals. Anisotropy of magnetic susceptibility is generated both by the form of constituent ferromagnetic granules, disseminated in the rock matrix, as well as by the structure of the crystalline network.

In terms of magnetic susceptibility, the main constrast is that between the crystalline basement containing some magmatic and metamorphic rocks with magnetic properties, on the one hand, and the sedimentary cover formations, almost devoid of magnetic properties – except for the levels of Cenomanian glauconitic sandstones with phosphatic nodules, on the other hand. In the case of the magnetic anomaly in Bătrânești, the maximum intensity in the apex area of the anomaly amounts to values greater than 400 nT. The obvious increase in magnetic susceptibility with depth – in the range of 1008–1049 m – indicates an ascending percentage of magnetite in rocks. Table 2 illustrates that with values of magnetic susceptibility and remanent magnetisation intensity.

Descending to the center of the Moldavian Platform, in Todireni, the source of the magnetic anomaly could be considered the more or less important enrichment of paragneiss in magnetite, as the analysed samples present magnetite contents of approx. 3.8 % and, in rare cases, even of 10–20 %. The hypothesis has been advanced that the magnetic anomaly would be determined by the wide development of gneiss with biotite within the basement, with mean magnetic susceptibility values for this type of rock oscillating around 5500 ucgs. An important fact is the presence, in the Todireni drilling, of Krivoi Rog magnetite quartzites. As a result of erosion processes, the formations that belong to the mineralisation-bearing quartz facies remained lens-shaped in the depressionary areas of the crystalline basement. The magnetite- and hematite-bearing rocks belong to the amphibolite facies, found in Bătrânești and Todireni.

Table 2 Magnetic susceptibility and remanent magnetisation intensity

Type of rock	Depth of sampling (m)	Susceptibility (ucgs)	IR
Granogneiss with biotite–magnetite (opaque minerals: pyrite, chalcopyrite)	1020	12–14	55–56
Granogneiss with biotite (opaque minerals: ilmenite, magnetite, pyrite, chalcopyrite, pyrrhotite)	1036	6327–6669	364–395
Granogneiss with altered biotite (opaque minerals: ilmenite, magnetite, hematite, titanomagnetite)	1029	1378–1384	85–146
Granogneiss with biotite and green hornblende (opaque minerals: magnetite, ilmenite, pyrite, chalcopyrite, rutile, titanomagnetite, pyrotine)	1035–1040	2728–8021	126–1359

In the area of Iași Municipality the lowest magnetic susceptibility values were determined for the rocks that belong to the crystalline basement, which confirms the development of the weaker magnetized complex in this area, presenting the characteristics of a granulite facies (Iași–Socola), a complex in the composition of which migmatites prevail.

Drilling No 3503 was carried out in Nicolina–Iași perimeter, in a region that corresponds on the magnetic map to an area with low field strength values (100–120 nT), located to the south-east of the wave of the maximum high expansion anomaly. The drilling penetrates the crystalline basement over a range of 184 m, between 1117 and 1301 m. The absence of minerals with magnetic properties leads to low magnetic susceptibility values, which usually range from 0.1 to 30 ucgs, except for some muscovite, biotite, and garnet-bearing granogneiss and some sillimanite-bearing granogneiss. It is clear that these types of formations cannot influence the magnetic map.

The same coordinates are found in the case of the drilling performed in Iași–Socola, where the metamorphic rocks are very low in metal minerals – magnetite is absent, and only pyrrhotite is present, but rarely, since they are specific to an advanced degree of metamorphism of sedimentogenic deposits. A synthetic image of mean values of the magnetic susceptibility for the prevalent rocks found in the sedimentary cover and the crystalline basement of the Moldavian Platform is presented in table 3.

Newer petrophysical data, derived from complex measurements made in the laboratory of the Institute of Oil, Gas and Geology in Bucharest, were used as basic material samples that belong to crystalline formations found in the drills from Bătrânesti, Nicolina–Iași and Todireni.

Three of the petrophysical parameters were determined, namely: volume magnetic susceptibility, remanent magnetization and density. Table 4 shows the ranges of variation of the values of these parameters, by rock types.

4. Interpretation of geophysical data

4.1. Preliminary considerations on the possibilities of a geophysical method in deciphering platform structures

The depth of investigation in magnetometry allows to address any problems of investigation and subsequently interpretation of results for platform areas, regardless of the development of sedimentary deposits. If magnetite – the mineral with the most intense magnetic properties – is taken as a reference value, the depth of investigation oscillates around 20 km. Such an order of magnitude can be associated, in the case of the crystalline basement of the Moldavian Platform, to the granitic layer of the terrestrial crust. The theory shows and practice has confirmed that magnetometry is one of two basic geophysical methods – while the

Table 3 Mean values of the magnetic susceptibility of the cover and crystalline basement rocks of the Moldavian Platform

Rock	Magnetic susceptibility (ucgs)
Lime and dolomites	0.3–2.0
Dacite tuffs	3.0
Quartzites and sandstones or quartz sands	0
Marls and clays	2–200
Sandstones	2–200
Sands	2–300
Sandstones or andesitic marls	200–700
Andesitic tuffs	400–1200
Granites	3–70
Magnetite-bearing Rapakiwi granites	100–1500
Basalts	500–5000
Mica shales	3–80
Gabbros	5000
Dacites	870
Granodiorites	4700
Diorites	12500
Magnetite ore	1500–40000
Serpentine	1600–5300

Table 4 Variation of magnetic susceptibility, remanent magnetization and density by rock type

Type of rock	Susceptibility (ucgs)	Remanent magnetization	Density (g/cm^3)
1. Gabbros, metagabbros	202–8091	2–1082	2.58–2.73
2. Granite, leucogranite	1–5039	85–1082	2.58–2.72
3. Granitoid and migmatic granogneiss, eye-gneiss and mica gneiss	22–3840	5–2354	2.64–2.72
4. Microblastic quartzite with magnetite and biotite (sample extracted from 1 166 m, from Todireni drilling)	19122	10218	3.05–3.06
5. Pegmatite	2400–5284	1639–1966	2.70–2.72

other is gravimetry – that brings information from the basement, regardless of the depth at which it is placed, and even below, but highly qualitative. If the sedimentary layer intervenes with particularly favorable physico-geological parameters – as is the case with the sedimentary cover of the Moldavian Platform, which only shows very weak magnetic properties and which cannot, however, constitute a screen for those of the rocks in the basement – the model offered by the interpretation of magnetic data can be improved and can provide a much clearer and coherent image.

The magnetometric method which, due to the much more limited number of magnetic sources compared to that of the sources of gravimetric anomalies, is significantly restricted, can also be correlated with this favorable situation, provided by a virtually non-magnetic sedimentary cover. This advantage stems from the physico-geological characteristic of the fact that rocks with important magnetic properties are in unlimited numbers. On the other hand, magnetic anomalies are generally anomalies of a maximal or dipolar nature, so that cumulation by addition is the most common form of cumulation of this type of geophysical anomalies.

Another major aspect, which must be converted into a premise for structuring the assessments and interpretative hypotheses of magnetic information, is that of the accentuated petrophysical – and only structurally subordinate – content of magnetic data.

As a result, the magnetically characteristic rock formations often coincide with the geological reference object that we want to identify and locate through prospecting. In terms of competence, regional magnetometry is the best-resolution method in surveying platform basements.

In platform areas, with dislocated and generally not too deep basements, magnetic boundaries can also coincide with fractures if they separate major structural units with distinct tectonic evolution. Most of the times fractures are responsible for the strips of maximal magnetic anomalies, as they are active in various orogenic phases when they allowed the circulation of magma, and their consolidation took place later, in the platform stage of the basement. On these fractures, important volumes of intrusive rocks, with sometimes notable magnetic properties, were deposited. An information with significant structural content, obtained by correlation of magnetic and gravimetric data, refers to the link between deep fractures, which are predetermined elements of the position of first rank structures within platforms, conditioned by vertical displacement along them of the various constituent blocks of the earth's crust.

The geophysical research of the Moldavian Platform has posed and continues to pose problems that are difficult to solve. The configuration of the geomagnetic field at the level of the crystalline basement reflects a series of anomalies – determined mainly by the petrographic nature of the rocks – that do not show a differentiation in the age of these rocks.

4.2 The principle underlying the telluric current method

Most of the time in the activity of surveying itself, only the information provided by the telluric field is used, as the ones of the magnetic field are not always necessary. Thus, it was found that in the areas of elevation of the crystalline basement the telluric currents reach maximum values, and in those of immersion they reach minimum values, sometimes immeasurable. These general observations have led to the conclusion that it is possible to determine variations in the depth of the crystalline basement by appropriate measurement of the electric field produced by the telluric currents circulating between the observation surface and the basement.

The strength of the telluric field at an observation point is obtained from the composition of its components on the two orthogonal directions corresponding to the measurement lines M_1N_1 and M_2N_2. The telluric field component on direction M_1N_1 is calculated based on the following relation:

$$E_1 = \Delta V_1 / M_1N_1$$

where E_1 is the telluric field component on direction M_1N_1, ΔV_1 is the potential difference between sockets M_1 and M_2 (in mV) and M_1N_1 is the distance between the sockets (in km).

Numerous field and observer measurements made at different points on the Earth's surface have highlighted a number of regularities in the distribution of the telluric field as well as its dependence on the geological structure. There have also been oscillations with very long periods of annual or even decennial periods. In addition to these long periods on telluric records (tellurograms), short-term oscillations between 15 and 60 seconds, which are used in the prospecting activity, are always present.

At the same time, the direction of the telluric field is maintained sensibly constant over large surfaces. Distortions that appear in the general direction of the telluric field lines are related to the geological structure.

From a prospecting point of view it is particularly important to note that the orientation and intensity of the telluric field depend on the geological structure in the investigated area.

The telluric current method is based on the assumption that the electric field values measured at the surface are degraded by a direct current layer circulating between the surface and the basement. Although this is not the reality, it is still conceivable that at very low frequencies, i.e., between 0.1 and 0.01 Hz, the distribution of the telluric field can be well described by the laws of direct current. Under these circumstances, the current conservation law requires that the current density be inversely proportional to the depth of the basement or the thickness of sedimentary formations. Therefore, the electric field measured at the surface is directly proportional to its thickness. In summary, it follows that the electric field strength is inversely proportional to the total longitudinal conductance of the sedimentary rock package.

The application of the laws of direct current to substantiate the prospecting method principle is also based on the finding that at periods between 15 and 60 seconds, under the conditions of an insulating basement, the input impedance is a frequency independence and is inversely proportional to conductivity. Therefore, everything runs as if a direct current flows into the basement.

The depth of the basement can be determined at a point A if its value is known at a reference point B. Following this path, one could even draw maps with isobaths of the basement. However, given that the structures are not rigorously two-dimensional, the resistivity is not constant and the telluric current is not continuous, it follows that such maps can only be of an informative-qualitative nature.

In the field, measurements are carried out simultaneously at two different points (base and station), using recording devices with two measuring lines each. During field operations, one recording device remains permanently in the same position (base) and the other is moved to different observation points (mobile station or, simply, station).

The so-called J invariant is frequently used in the prospecting activity, which represents the square value of the mean square values of the telluric field strengths in the station and base. According to this definition, it can be written:

$$\mathrm{J} = \left(\frac{Es}{Eb}\right)^2$$

where Es and Eb are the mean square values of the telluric field in the station and the base, respectively.

4.3. Presentation of the main magnetometric data and their interpretation

The aspect of the magnetometric map ΔT on the ground in the South–Iaşi area, the northern boundary of which is located about 15 km south from the municipality of Iași and which is limited to the east by the Prut River, reveals the existence of five main maximal anomalies. They have different extensions and orientations, outlined on a calm background of the isodynamic regime of the total field, somewhat similarly to the perimeter of the North–Iași. Here, we encounter a progressive decrease in field values towards the Prut River, a slightly more pronounced decrease, probably due to the steep, almost vertical contact between magnetically inferred intrusive bodies located in the N–NE part of the perimeter and the crystalline basement which is non-magnetic or has very limited magnetic properties.

Comparing this image with that shown by the aeromagnetometric map, made for a flight ceiling of h=500 m above the surface of the ground, it can be observed that the abnormal high-intensity area of the N–NE perimeter appears here only in the form of a horizontal magnetic gradient, significant but not eloquent for the mode of manifestation of the bodies existing in the mass of the crystalline basement. There can only be a tendency to close the isodynamic lines towards Prut River, but the information is visibly affected by the surface on which the flight took place, limited by the borderline.

An important feature, common to both maps, is the preservation of the NW–SE trend of orientation of the main maximal magnetic anomaly axes, as well as the existence of anomalies (the Armaş Hill case) the configuration and contextual location of which provide sufficient elements to consider that they are most likely due to the existence of a source of the type responsible for the Roșcan anomaly found in the northern perimeter. These different trends of orientation of anomalies are associated to different geological causes, as the N–S direction is generally found in lower intensity, isolated anomalies with forms relatively subsumable to the isometric one, located in the flanks of important areas of the regional anomalies. As regards the tectonic nature of the magnetometrically investigated territory in the South of Iaşi, it also belongs to the Botoșani–Huși block, characterized by the presence of an epi-Karelian basement (Visarion et al., 1988). The tectonic and geological framework can be considered approximately identical, even though the formations revealed by erosion are older in this part (Meotian, Kersonian, and Bassarabian, unlike only the Holocene, Pleistocene, and Bassarabian formations found in the north), which has no magnetic relevance whatsoever.

As with the North Iași perimeter, based on the interpretation of the primary magnetic data, we believe that the depth level at which the sources of the main magnetic anomalies are positioned attests as unquestionably their placement inside the crystalline basement, and it is only in the case of Cozia–Șesul Voloaca that it is possible to locate the intrusive body in close proximity to the crystalline basement-sedimentary cover contact. Obviously, as there is no possibility of confirmation, this claim must be given credit only from a hypothetical perspective.

Let us take a look now at the external, formal elements that define the maximal magnetic anomalies highlighted by the magnetic map ΔT on the ground, trying to emphasize the features of each of them.

The anomaly of Armașului Hill, named this way because there is no other more significant topographical landmark overlapping with the apex area of the magnetic effect, is located in the south-western part of the perimeter, being framed to the north by the limit of the prospected area, to the west by the course of the Dobrovăț stream, to the south by Pribești settlement, and to the east by Coropceni and Ciortești settlements. In the north the anomaly remains open, with values of isodynamic lines marking the passage to the minimal area. The dimensions of the anomaly are 7 × 5.5 km2, while the intensity in the apex reaches about 70–75 nT (0 nT in the background), and the morphostructure reveals a slightly elliptical development in the N–S direction. By the depth estimation procedures also used for magnetic anomalies in the North Iași area, 1295 m (Sharma) and 1315 m (Kunaratnam) values were calculated according to the D–D_1 profile, which implies a localisation of the upper surface of the source of this anomaly at a level of approx. 1300 m, comparable to that of the body that generates the Roșcani anomaly. The similarity could extend to the configuration of the magnetic profile curve based on which the estimates were made, this being almost symmetrical (Fig. 3). Moreover, the conditions in which the two anomalies occur, determinable in the context of the map, lead to a series of parallelizations or even analogies.

The anomaly of the apex located to the south-east of Covasna and which we will simply call the Covasna anomaly, has a slightly smaller expansion compared with the previous one, of approx. 3 × 5 km^2. It has a more poignant shape elongated in the NW–SE direction, which reveals a geological cause of another nature, diminished to the north and extended to the south, probably due to the larger development of the intrusive body in that area.

The maximal intensity in the apex is less than 90 nT (approx. 20 nT in the back-

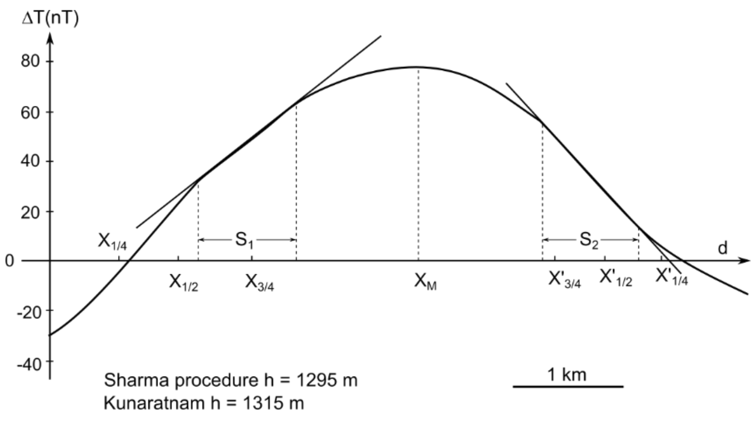

Fig. 3 Profile D–D_1 estimating the depth of the source body of Armașului Hill anomaly, with specific morphostructural and geometrical landmarks.

ground), as the anomaly is delimited to the north by the Costuleni settlement, to the west by the limit of the perimeter of the magnetometric prospection, to the south by the upper course of the Bohotin stream and to the east by the Cozia settlement. The E–E_1 profile, used to determine the depth of the source, has an orientation perpendicular to the direction of maximal development of the magnetic effect. By using the Sharma process, a value of approx. 150 m deep is obtained, while the Kunaratnam process offers a slightly lower level of 1100 m (Fig. 4). This depth may have higher values, as in the case of anomalies located to the east of the Covasna anomaly, comparable to those of the depth of the source of Armașului Hill anomaly, if we also take into account the fact that a normal field correction was not performed. According to placement and appearance, the Covasna anomaly could be caused by the existence of somewhat deeper endings of large intrusive magmatic masses, the magnetic effect of which also extends on the territory of the Republic of Moldova, as well as to the north, towards Iași. The situation is somewhat comparable to that of the anomaly of a lesser extent located in the north of the Deleanu anomaly, in the North–Iași perimeter. These anomalies placed on the periphery of the large abnormal alignments (the case of Stejarii or Cozia–Şesul Voloaca and Șesul Jijia–Grozești for the South–Iași perimeter) could be caused not so much by obvious descents of the surface of the basement, but by a displacement on these fractures of the blocks (compartments) in which the intrusive bodies were fragmented and by a possible weaker intake of mineralizing solutions, carrying ferromagnetic

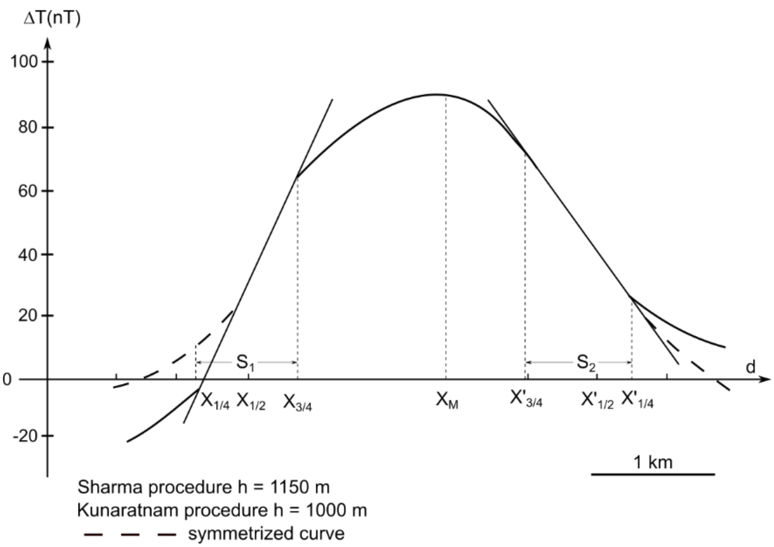

Fig. 4 Profile E–E_1 estimating the depth of the source body of Covasna anomaly, with specific morphostructural and geometrical landmarks.

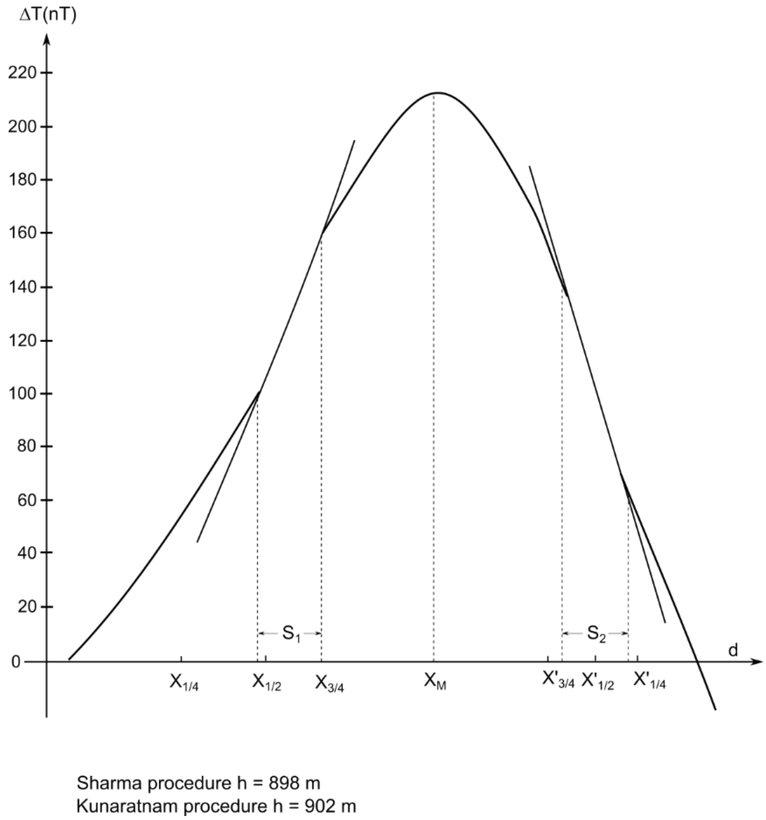

Fig. 5 Profile F–F_1 estimating the depth of the source body of Cozia-Șesul Voloaca anomaly, with specific morphostructural and geometrical landmarks.

minerals, in these areas of the bodies.

The Cozia-Şesul Voloaca anomaly, named this way because it is located approximately between these topographical landmarks, retains an orientation similar to that of the Covasna anomaly, and is extended in a NW–SE direction. Its maximum intensity exceeds 210 nT, but it is worth noting the high magnetic background on which this anomaly is found, representing approx. 160 nT, which could be produced by a large intrusive magmatic mass placed deeper. The extent of this anomaly is smaller and can be assessed at 2 × 4 km2. With regard to the depth of the source generating this anomaly, determined by the above-mentioned procedures and using the geometrical characteristics of the magnetic profile F–F1 (Fig. 5), the results provide figures that would indicate the highest source and the existence in the two perimeters that are the subject of this discussion and analysis. The Sharma method indicates 898 m and the Kunaratnam method indicates 902 m, which is a very good similarity. However, as in other cases specified at the appropriate time, the determinations could be affected by the interference of magnetic effects, produced between the western flank of the Cozia–Șesul Voloaca anomaly and the eastern flank of the Covasna anomaly. Using the symmetry curve as well, we sought to attenuate this distortion. The anomaly has an elliptical morpho-structure, suggesting the development of the intrusion in this direction, but what is interesting is the horizontal magnetic gradient, very accentuated for a magnetic platform effect, present on the ENE flank of the anomaly, the values of which exceed 100 nT/km. The significance could be represented by the near vertical contact of the intrusion with the formations of the crystalline basement, but also by a passage, over a very small interval, from a type of rock with remarkable magnetic properties for this area to one devoid of magnetic properties or having paramagnetic properties.

Șesul Jijia–Grozești anomaly, the apical area of which is almost symmetrically crossed by the Jijia River, is the most intense and at the same time extended magnetic anomaly of the South–Iași perimeter. Its elliptical configuration, open to the east, where it continues beyond the Prut River, can be traced this time in an almost perfect W–E direction, unique for the investigated regions and which constitute the factual support of this paper. It denotes an indisputable change in the orientation of intrusions and implicitly of the fractures that divide the platform basement. It also suggests the possibility that in this part of the perimeter an intersection of the alignment by major fractures, in the NW–SE direction occurs, which can be traced approximately through the apex of magnetic maximal anomalies, by a longitudinal fault lines relatively oriented towards W–E and the route of which could extend to Bazga and north of Rotăria. The Șesul Jijia–Grozești anomaly reaches the apex at an intensity of 260–265 nT (160 nT in the background), sized of 4 × 9 km2 (incomplete assessment because the eastern term of the anomaly is not fully specified), which recommends it as remarkable. In terms of depth there are some amendments, as in the case of its northern continuation, Cozia–Șesul Voloaca, supported by the trenchant contact with the basement, contact made on the northern flank, and by the much slower immersion of the body in the south, where the effect of Ursu Forest is also cumulated. The depth calculation performed after the symmetrized curve provides a value of 1375 m by the Sharma method and 1314 m by the Kunaratnam method, respectively, the G–G1 profile being the one for which the geometrical and intensity characteristics of the anomaly were the basis of the estimates (Fig. 6).

Finally, the fifth expressive magnetic anomaly has the visible apex in the Ursu Forest, with an intensity of approx. 80 nT (60 nT in the background), an area of 4.5 × 2 km^2 and could be due to a cause identical to that allegedly responsible for the Covasna anomaly, but to a smaller extent.

A maximal value of low importance and magnitude can be found to the east of Rotăria settlement, which could be generated – in the case of monocline sedimentary deposits – by weak positive vaults of

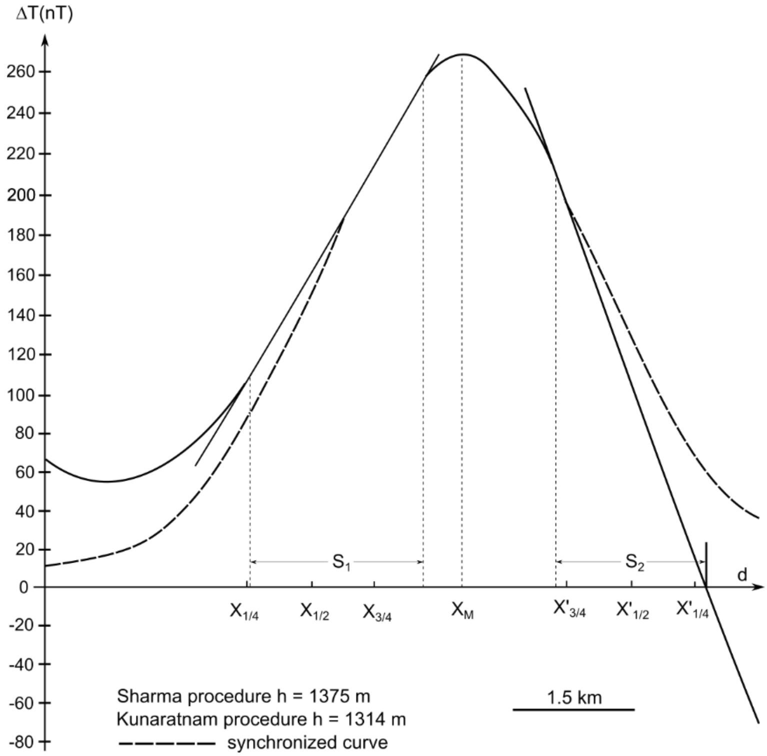

Fig. 6 Profile G–G1 estimating the depth of the source body of Șesul Jijia–Grozești anomaly, with specific morphostructural and geometrical landmarks.

the crystalline basement, of the kind that, under certain conditions, can become favorable to the accumulation of hydrocarbons.

4.4. Quantitative interpretation of geophysical data from the South–Iași perimeter

In the light of the processing of magnetic information existing in the North–Iași area and in view of the restrictive feature of the absence of certain petrophysical data from the investigated perimeters, as well as of drilling data, clarifying on some structural aspects and relationships, a very complex processing could not be addressed for this area either. The latter consists of: the analytical continuation in the lower semi-space, made at a plane located at 500 m depth from the observation plane; two-dimensional modelling for the main four anomalies of the region; magnetic vertical gradient profiles for a more precise location of the boundaries of source bodies and possible approximation of the form of sources to that of a regular geometric body; a hypothetical interpretative section, supplemented with gravimetric data and telluric currents (profile of invariant J).

The image of the analytical continuation in the lower semi-space (h = –500

m) (Peters, 1949 procedure) does not provide any relevant additional information on the sources of the four anomalies. This demonstrates that the surface of these intrusive bodies is highly unlikely to be affected by irregularities, such as apophyses, which are of a unitary nature. The intensity of the anomaly of the Armaş Hill increases from 70 to 100 nT, an accentuation which is unspectacular, but is justified by the rather large depth of the body. A relatively similar proportion is recorded for the Covasna anomaly where the increase is from 90–95 nT on the ground to 140 nT in the analytic continuation map. Here too, there are no separations from sources manifesting on the surface by a cumulative effect. More notable increases occur for the Cozia–Șesul Voloaca anomaly (from 210 to 260 nT) and Șesul Jijia–Grozești (from 260 to 340 nT), but the nature and regime of isodynamic lines are preserved in the same terms.

An interesting conclusion regarding the intervals of variation of depths stems from consulting the residual map resulting from the difference of the local magnetic effect on the ground and the local aeromagnetic effect, corresponding to the flight ceiling h = 500 m. The identity of the residual effects overlapping the anomalies of Armaşului Hill and Covasna (–20 nT) validates our assumption relating to the possibility that the depth of the source body of the Covasna anomaly is greater than the one resulting from the determinations made, especially since the susceptibility assigned to it is greater than that of the body responsible for the Armaşului Hill anomaly.

An important information deficit can be observed especially in cases of Cozia–Şesul Voloaca and Șesul Jijia–Grozeşti anomalies, which can be explained by diminishing the reference area in the situation of the maps obtained by weighted mediation – the side used for the device was L = 2 km and the displacement step of the device was d = 0.5 km – and which makes it virtually impossible for the most intense anomaly in the perimeter Șesul Jijia–Grozeşti to manifest itself in the residual map. Moreover, the restrictive factor consists in the absence of an indication of the above-mentioned aeromagnetic anomalies, since their placement in immediate vicinity of the border area has decisively affected the integrity of this image. The detail that the Armașului Hill anomaly is not found in the aeromagnetic map of the local effect (obtained by weighted mediation) denotes, however, the great depth at which the source body is positioned and its magnetic properties, insufficiently expressive. As they appear on the map of the local magnetic effect, the local aeromagnetic map being irrelevant in this respect, it is clear that the sharper decrease in the intensity of the Cozia–Şesul Voloaca anomaly (from approx. 200 nT to approx. 100 nT) can be attributed to the higher magnetic background on which this anomaly is found. That is similar to Șesul Jijia–Grozeşti anomaly and is probably due to a zone of the crystalline substrate richer in ferromagnetic minerals or to a large magnetic mass, located much more deeply. The route of the major fracture affecting the basement can be noted, as its route is traceable by the abnormal minimal trends found on the Cozia trajectory, which is parallel to the north with the course of the Bohotin stream.

Another stage of the quantitative interpretation of the results of magneto-metric prospecting in the South–Iași area is the development of two-dimensional models for the sources that generate the reference anomalies of this perimeter (through the procedure suggested by Talwani and Heirtzler, 1964). This type of modelling was used because the elongated morphostructure of magnetic anomalies – with the relative exception of Armașului Hill anomaly – of this region reflects the existence of bodies suitable for two-dimensional modelling. For the Armașului Hill anomaly an illustrative overlap takes place, in the direction of the D–D_1 profile, between the measured and the calculated magnetic effect produced by the model, considering a body with asymmetric trapezoidal vertical section, with the eastern flank less steep and with the upper surface slightly inclined from west to east and placed at the determined depth of

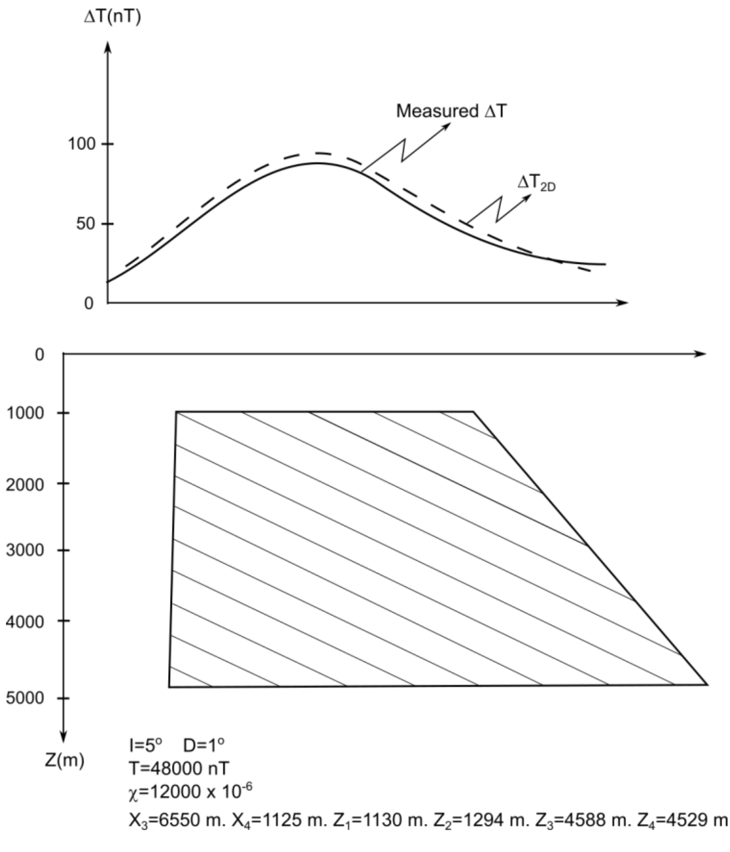

Fig. 7 Two-dimensional modelling of the source of Dealul Armașului magnetic anomaly (according to profile D–D_1).

approx. 1300 m. This body was assigned a magnetic susceptibility of 1200 × 10^{-6}, because the intensity of about two and a half times the anomaly generated by this body recommends it as possessing superior magnetic properties (Fig. 7). The other magnetic data remain the same, which is also the case for the intrusive bodies from Covasna, Cozia–Şesul Voloaca and Șesul Jijia–Grozeşti, meaning that the magnetic

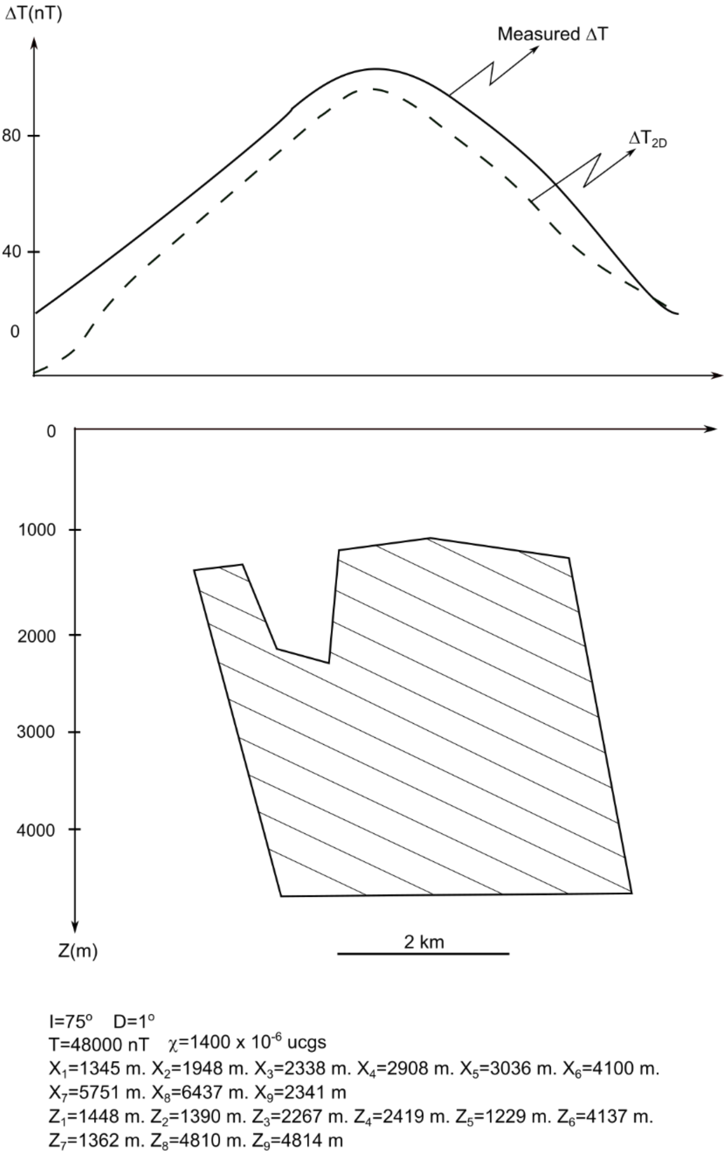

Fig. 8 Two-dimensional modelling of the source of the Covasna magnetic anomaly (according to profile E–E_1).

inclination is I = 75º, the magnetic declination D = 1º, and the geomagnetic field strength is 48,000 nT. The source of this anomaly can be assimilated to a body of granogneiss or granitic origin, with possible variations in the petrographic composition.

The two-dimensional modelling of the $E–E_1$ profile, which crosses the apex of the Covasna anomaly, shows the appearance of a body with an upper surface affected by irregularities, with a small apophysis being noted on the south-western flank of the body. The magnetic probability granted is 1400×10^{-6} (Fig. 8), with the more intense effect possibly due to slightly lower depths of the source, but more probably to the higher magnetic background. The petrographic nature is comparable to that of the source of Armașului Hill anomaly.

For the two more intense and obviously elongated anomalies located in the E–NE part of the South–Iași perimeter, the two-dimensional modelling started from common premises. The vertical section of both bodies reflects shapes generally of a trapezoidal appearance, with the placement depths in accordance with those determined by the Sharma and Kunaratnam procedures (Figs. 9 and 10). The slightly increased magnetic suscep-tibility was set at 2000×10^{-6}, which would correspond to granitoids and granogneiss, but also to Rapakiwi (magnetite) granites. These two bodies with an elongated appearance in the horizontal plane may be close to the form of dykes, the integrity of which was subsequently disrupted by displacements caused by tectonic accidents of the type of fracture that could be drawn approximately between Colțu Cornii and Roșu.

4.5. Assumptions on the interpretation of the configuration of vertical gradient curves for the main magnetic anomalies in the South–Iași perimeter

Outstanding qualities recommend the preferential use of the vertical gradient in interpreting the anomalies of potential geophysical fields, both for the more rigorous location of the causes of such anomalies and for the separation of sources of cumulative anomalies, as well as for estimating the depth of source bodies. As far as out paper is concerned, we will approach this type of magnetic information processing on the one hand for qualitative considerations, related to the comparison of magnetic vertical gradient curves obtained with those of known geometric bodies, and on the other hand, in order to have an additional control element certifying the horizontal expansion of the body, as it appears from the two-dimensional modelling.

One of the possibilities of approximation of the vertical magnetic gradient, in the space domain, is to combine the continuous upwards and downwards values of the magnetic field. This category also includes the procedure proposed by Constantinescu and Eldaiem (1963), which approximate the vertical magnetic gradient by the mean gradient of the values continued analytically upwards and downwards at equal distances:

$$T_Z \cong (T_{(-d)} - T_{(d)}) / 2d$$

Combining expressions of continued values upwards $T_{(d)}$ and downwards $T_{(-d)}$ it results:

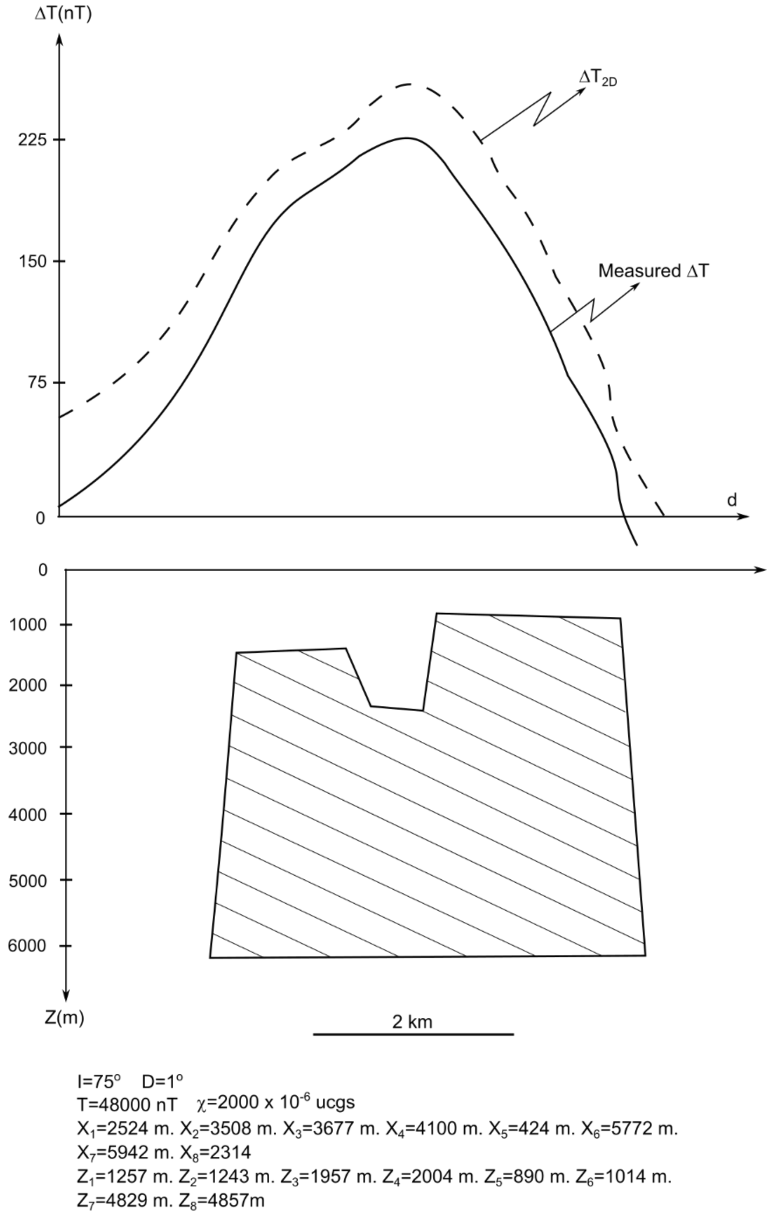

Fig. 9 Two-dimensional modelling of the source of Cozia–Șesul Voloaca magnetic anomaly (according to profile F–F$_1$).

$$T_Z = \frac{1}{d}\left[-13.969267 \cdot T_{(0)} + 8.69351 \sum_{i=1}^{4} Ti_{(d)} - 5.16367 \sum_{i=1}^{4} Ti_{d\sqrt{2}}\right]$$

where “d” is the side of the square grid when the values of the geomagnetic field T are known.

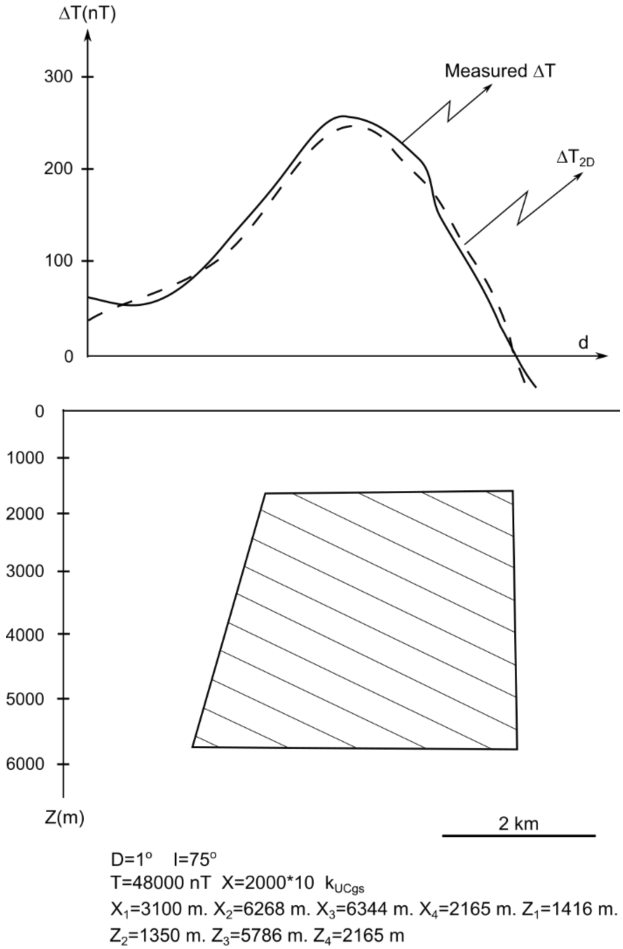

Fig. 10 Two-dimensional modelling of the source of Șesul Jijia–Grozești magnetic anomaly (according to profile G–G_1).

What is important in considering this method of determining the vertical gradient of the geomagnetic field is the correct determination of the size of the sampling interval (d), which makes the resolution of any of the gradient's calculation procedures comparable to that of the others. As a general rule it is recommended that "d" is between 0.1 × h and h, where h is the depth at the top of the source, and tends preferably towards low range values. In the case of the perimeter under review, this condition is met and, in addition, we also benefit from compatibility with the level of depth at which the analytical continuation is carried out in the lower semi-space and with the flight level from which the aeromagnetic map was made (500 m for both, as well as the value of the interval "d"). Another remarkable feature refers to the approximation allowed by the formula proposed by Constantinescu and Eldaiem (1963), which is better for the apex areas of anomalies – as we did in the case of the four anomalies for which the vertical gradient profiles were represented – namely those situations that are of greater interest.

By analyzing separately the images of the vertical magnetic gradient curves obtained for each anomaly and having also the representations of the source bodies of the four main maximum anomalies in South–Iași area, a series of hypotheses arise, applicable mainly to the limits of the source bodies.

Thus, given the vertical magnetic gradient curve performed on the same profile as the depth determinations, as well as the two-dimensional modelling for the Armașului Hill anomaly (Fig. 11), we can infer approximately the positions of the slopes of the intrusive body. That is based on the distance separating the two gradient maximal values appearing on the flanks of the anomaly profile, its extension horizontally and on the path of the profile with which it was studied, being approx. 3 km, information that is in full agreement with the one revealed by the two-dimensional modelling (Fig. 7), where the same value of body width is highlighted. The minimum area of the vertical magnetic gradient, located in the central part of the profile, i.e., just above the intrusive body, which coincides with the apex of the anomaly curve ΔT, could be dued to a decrease in the magnetic susceptibility of the body to its upper part, possibly caused by a degree of metamorphosis of the mas-

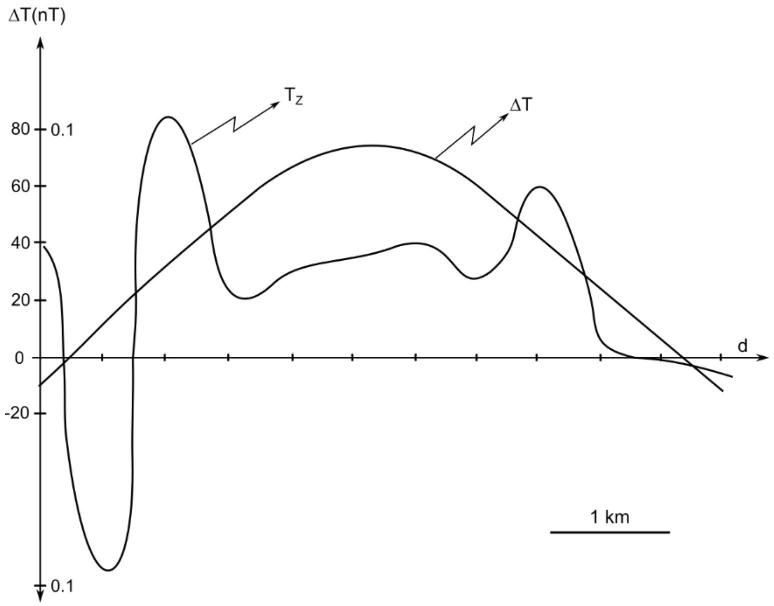

Fig. 11 Profile of vertical magnetic gradient T_Z and geomagnetic field ΔT for Armașului Hill anomaly (profile direction D–D_1).

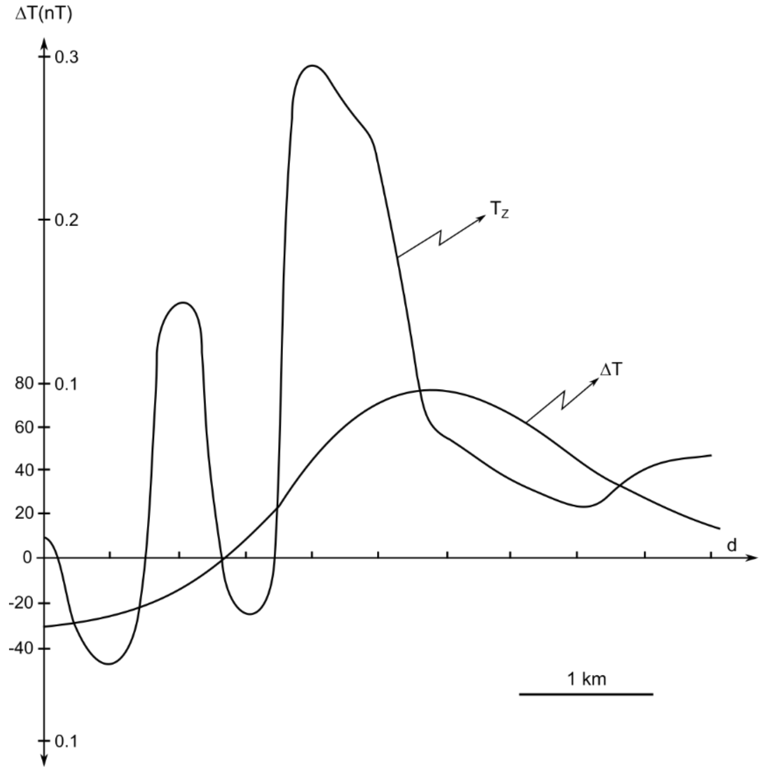

Fig. 12 Profile of vertical magnetic gradient T_Z and geomagnetic field ΔT for Covasna anomaly (profile direction E–E_1).

sif in this area. It is highly unlikely that the appearance of the magnetic anomaly curve could be partly attributed to a landform effect – it is worth recalling that the apex of the anomaly largely overlaps the raised landform area called Armaşului Hill. That is because the geometric influence of the landform – the rocks that make up it do not have magnetic properties, which eliminates the possibility of a petrophysical component of the manifestation of landforms in the ground anomaly – does not decisively distort the morphostructure of magnetic anomalies when the geological bodies responsible for their presence are located at relatively large depths. Moreover, this influence can become important only when the topo-graphical level variations of landforms have a size comparable to that of the vertical distances between the measuring points and the source.

By going further and analyzing the vertical magnetic gradient and total geomagnetic field curves related to the Covasna anomaly, we can see a number of features that clearly differentiate the behavior of the geomagnetic field from the previous case (Fig. 12). First, the configuration of the vertical gradient curve suggests from the very beginning the assimilation of the form of the source of magnetic anomaly with a geometric body of the type of an infinite horizontal cylinder (Fig.13). That is because between the apical areas of the gradient curve and that of the magnetic anomaly on the ground there is a gap of about 750–800 m, an effect that could be explained by the existence of irregularities of the upper surface of the body, combined with the presence of a reduced remanence. The analysis of the images in Figure 12 shows a good correspondence between the apophysis on the south-western flank of the intrusive body and the maximal vertical magnetic gradient, both of which are placed at approx. 1 km from the origin of E–E_1profile. As regards the location of the boundaries of the body in the horizontal plane of the E–E_1 profile, the extension would be of about 0.5 km for the south-western limit, and 4 km for the north-eastern one, respectively, resulting in a source width of around 3.5 km, which partly corresponds with the information

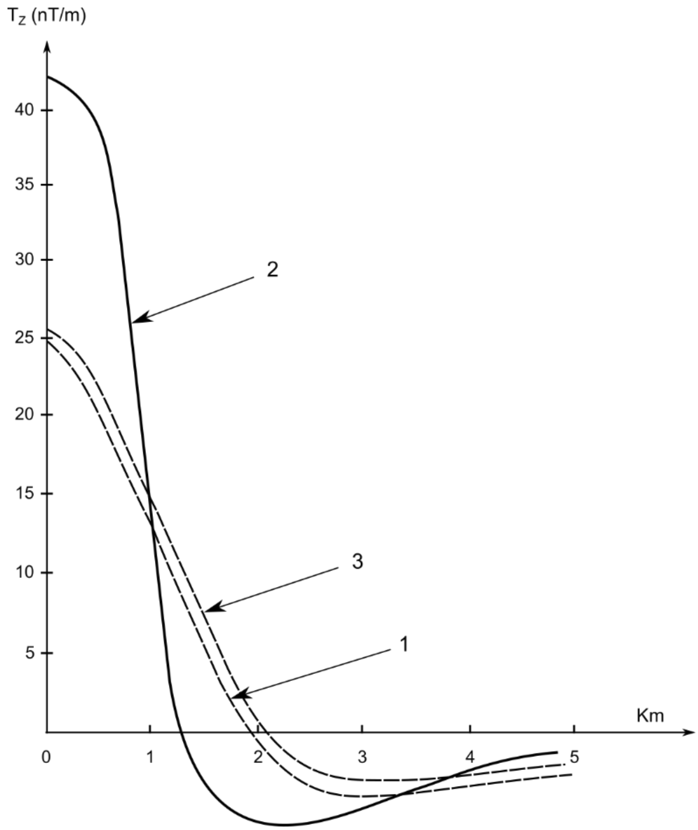

Fig. 13 Profiles of vertical magnetic gradient above an infinite horizontal cylinder (according to Constantinescu and Eldaiem, 1963).

from the two-dimensional modelling where the extension is over 4 km. The higher gradient values for the Covasna magnetic anomaly compared to those found at Dealul Armașului anomaly might suggest more agitated surfaces of the source body of this anomaly. The slower decrease oriented more towards the northeast of the anomalous effect compared to that of the vertical gradient could be correlated to the lower expansion of the body in reality, relative to the one resulting from the two-dimensional modelling, apparently affected by the interference between the magnetic effect on the north-eastern flank of the anomaly and that given by the southwestern flank of Cozia–Șesul Voloaca anomaly.

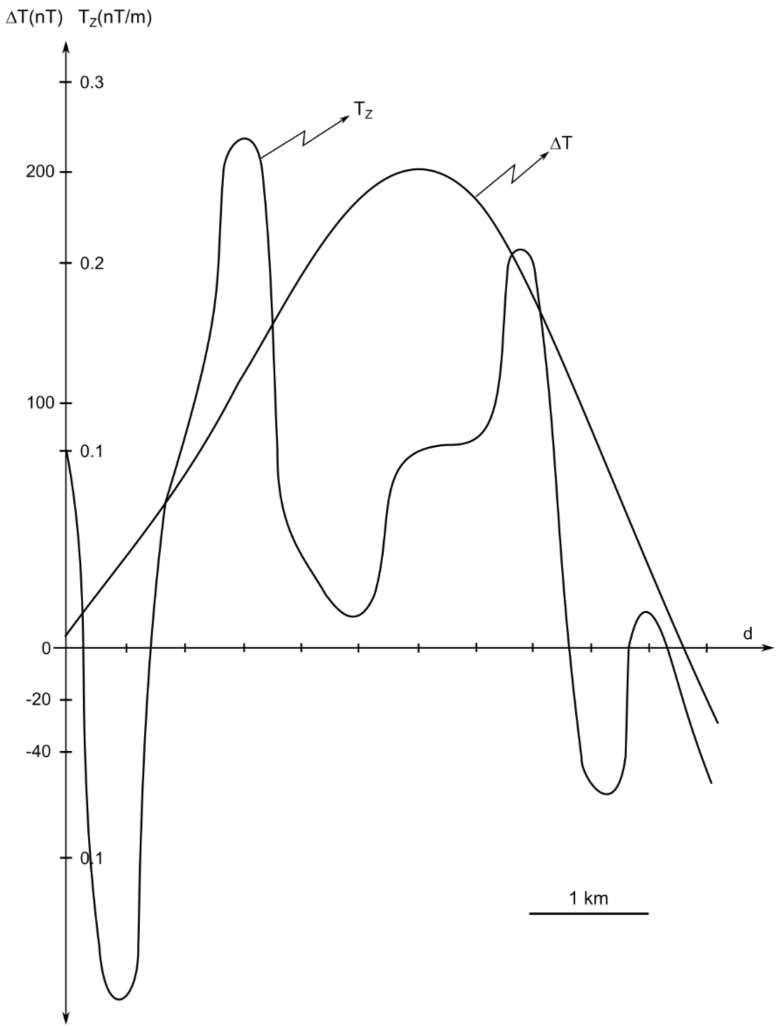

Fig. 14 Profiles of vertical magnetic gradient T_Z and geomagnetic field ΔT for Cozia–Șesul Voloaca anomaly (profile direction $F–F_1$).

For the Cozia–Şesul Voloaca anomaly the curve of the vertical magnetic gradient reflects the image of an effect similar to that produced by an infinite horizontal cylinder (Figs. 13 and 14). Obviously, the gradient maximal value located on the south-west flank of the ground magnetic anomaly profile (estimated at approx. 0.27 nT/m) is very likely to be associated with the apophysis visible in the bi-dimensional modelling of the source of this anomaly (Fig. 9). The apophysis could actually be larger in size if the high magnitude of the effect on the gradient curve is taken into account. As for the limits of the source body, we can also note a good correlation between the data provided by the two-dimensional modelling and those resulting from the interpretation of the vertical magnetic gradient curve, as the extremities placed on the F–F_1 profile, in the horizontal plane, define an interval of about 3.5 km, corresponding to the expansion of the intrusive body.

In the case of Șesul Jijia–Grozeşti anomaly, the source of which seems to have a genesis common to that of Cozia–Șesul Voloaca anomaly, the correspondence between the curve of the vertical magnetic gradient and that generated by a theoretical body of the type of an infinite horizontal cylinder is even more obvious (Fig. 15). We can also note here a good coincidence of the maximal areas of the two curves, gradient and that of the profile of the total geomagnetic field anomaly. The difference from the theoretical curve is revealed on the flanks, where small-extent minimal tendencies are found, while for that on the southern flank of the anomaly, there might be a fracture of secondary importance, which affects this slope of the body, in its deep part. The higher gradient values on the northern flank of the profile highlights the almost vertical trenchant contact with the metamorphosed formations of the crystalline basement. In relation with the information we can obtain on the development of the body at its upper part, both the vertical magnetic gradient curve and the appearance of the two-dimensional modelling reveal a width of approx. 3.5 km, with the southern boundary of the body placed at about 1–1.5 km from the extremity of the G–G_1 profile, and the northern one at approx. 5 km from the same end (south).

Even though they do not provide special information from a quantitative point of view, the conclusions that can be drawn from the analysis of the configuration of vertical gradient curves are, as we found, in accordance with the geometric and structural characteristics revealed by the two-dimensional modelling. In addition, they give the possibility to make some local corrections with a view to approaching the actual form and the defining features of the source bodies responsible for the existence of maximal magnetic anomalies in the South–Iași area.

4.6. Presentation of the hypothetical interpretative section North Pribești–Coropceni–North Bazga–North Roșu–South Colțu Cornii

Based on the corroboration of the data accumulated from magnetometric, gravimetric, and telluric current investigations existing for the South–Iași area, a hypo-

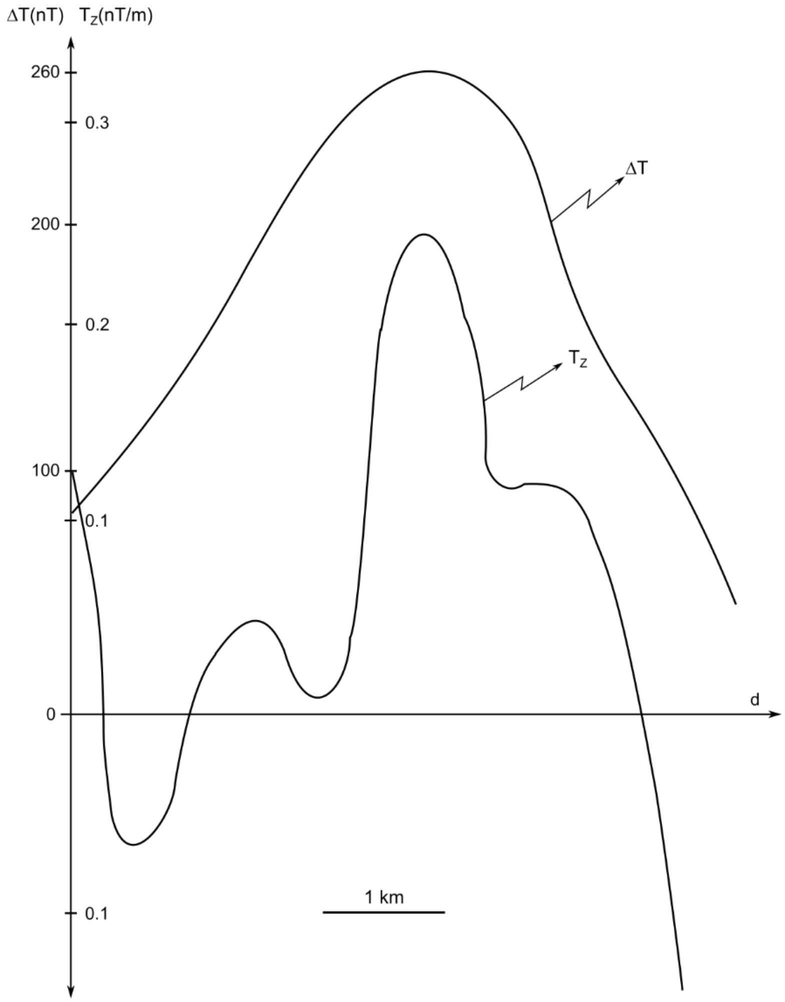

Fig. 15 Profiles of vertical magnetic gradient ΔZ and geomagnetic field profiles ΔT for Șesul Jijia–Grozești anomaly (profile direction G–G_1).

thetical section was conceived, crossing the perimeter from south-west to north-east and thus intercepting much of the area with the most expressive geological and geophysical significances. It was shaped following the construction of maps of the total geomagnetic field, Bouguer gravimetric anomaly, and the invariant J specific to the telluric currents method (Fig. 16).

In order to develop that section, both the two levels of the sedimentary surface and the intrusive bodies and formations of the crystalline basement have been assigned average values of the petro-physical parameters in accordance with the stan-

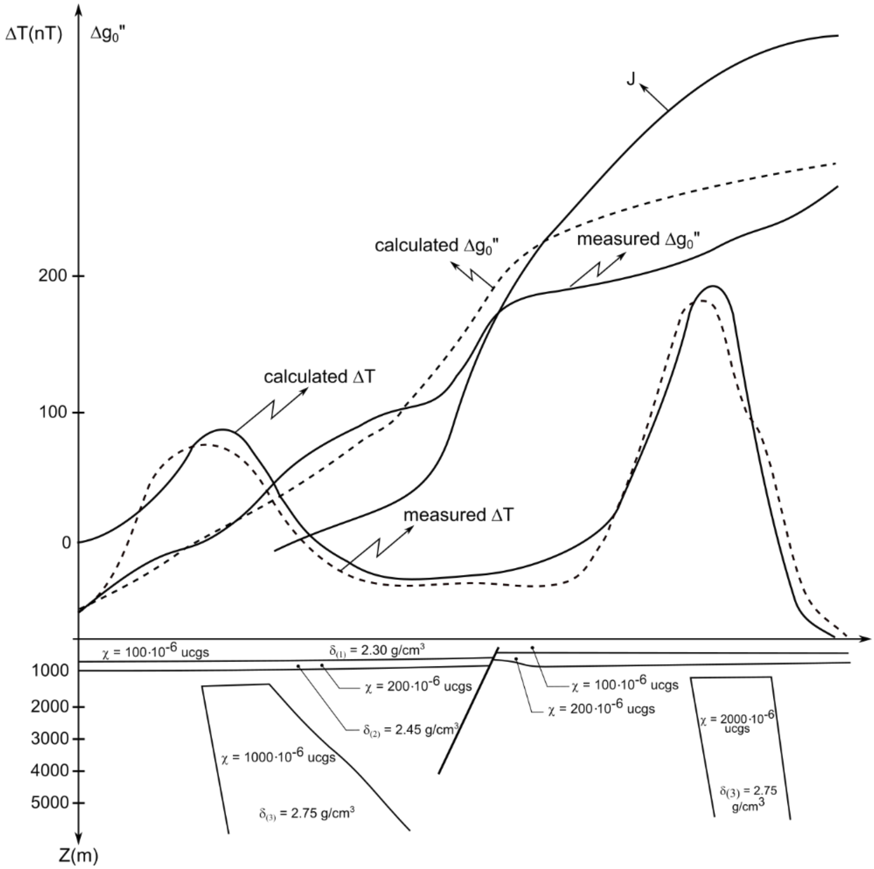

Fig. 16 Hypothetical geological section on the path North Pribești–Coropceni–North Bazga–North Roșu–South Colțu Cornii, from the perimeter of South–Iași, scale 1:200,000 (Δg_0" – curves of gravimetric anomalies; ΔT – curves of magnetic anomalies; J – invariant curve specific to the telluric current method.

dards outlined in the tables presented in section 3, regarding the petrophysical data. Thus, as regards the density values for the upper level of the sedimentary cover (generally corresponding to the geological formations of Neogene and Paleogene age) a mean value $\delta_{(1)}$ = 2.30 g/cm^3 was accepted, while for the other level of the cover, which is basal and subsumes approximately the formations of Cretaceous and Paleozoic age, the mean value $\delta_{(2)}$= 2.45 g/cm^3 was proposed. For the same two levels of the cover, the mean magnetic susceptibility was valued at $\chi_{(1)}$ = 100·10^{-6}, values denoting very weak magnetic properties or, at most, weak magnetic properties such as paramagnetic ones. However, towards the base of the cover it is possible that some sedimentary levels, suffering a process of low metamorphism, also have some magnetic properties that are irrelevant in the context of the magnetometric map ΔT at ground level.

As regards the formations of the crystalline basement, a mean value of 2.72 g/cm^3 was considered appropriate for their $\delta_{(4)}$ density, which would correspond to a predominantly paragneiss structure, while the mean value considered appropriate for the magnetic susceptibility was $\chi_{(4)} = 400 \cdot 10^{-6}$.

For intrusive bodies, it was considered that a mean density value, almost identical to that of crystalline formations (2.75 g/cm^3), would explain on the one hand the absence of their manifestation in the field of gravity and, on the other hand, this value would also be justified by the petrographic type predominantly represented by granites, granogneiss or gabbrodiorites. The magnetic susceptibility associated to these bodies is $1200 \cdot 10^{-6}$ for the one determining the Armașului Hill anomaly, a perfectly possible value for a granite with magnetic properties (of the Rapakiwi type) and $2000 \cdot 10^{-6}$ for the source body of Cozia–Șesul Voloaca anomaly, which would correspond to a type of granogneiss with important magnetic properties.

Obviously, referring to how to reflect the structure of the basement in magnetic information (Fig. 16), the magnetic maximal value of Cozia–Şesul Voloaca anomaly appears to be much more accentuated (approx. 3 times) compared to the one of the Armașului Hill. That is due to the more consistent magnetic properties of the first body and its significantly lower depth, but also to the fact that in this area the formations of the crystalline basement are approximately 350–400 m higher than those located to the south-west (which implies a much smaller thickness of the sedimentary cover deposits). They are also shallower than part of those located east of the fracture highlighted magnetically, but also gravimetrically and electrometrically; there might have been a transition from a predominantly granulite facies of the platform basement formations to an amphibolite one, with certain magnetic properties. In relation to the major tectonic accident that affects the crystalline basement and can be seen in the South–Iași area, this is of the type of a regional fault line, on which the basement progressively immerses to the south-west and which constitutes an unquestionable access route for magmas stabilised in the form of intrusive bodies at various depth levels. The regional fault line can be represented along a route approximately through Piciorului Hill – Ursoaiei Forest – Mitoc – Curățitura Forest – Zberoaia, a path along which the isodynamic regime and the tendency of a sharp decrease in the geomagnetic field values are symptomatic. It should also be specified that the magnetic calm range stabilised against a background of low values (approx. –25 nT) placed in the central area of the hypothetical section, between the two maximal values, should not be attributed exclusively to the appearance of the above mentioned tectonic accident, but, also given its expansion (approximately one third of the profile), to a non-magnetic basement developed in the central area of the map (Fig. 16).

The appearance of the profile of the gravimetric anomaly in Bouguer's reduction (Δg_0) (Fig. 16) leads to the identification of characteristics common with the way in which the deep geological structure manifests in the magnetic profile of the given section. Overall, the information provided by the gravity profile is fewer and more ambiguous, especially with regard to the location of intrusive bodies, as they are limited only to the relationship with the type of evolution of the basement surface in depth. Thus, the area of high values corresponds to the basement section with the lower depth, positioned to the east of the regional fault line the path of which was mentioned above and is due only to a small extent to the intrusion in the subsoil of the Cozia–Șesul Voloaca area. Given the absence of an illustrative density contrast between the body and the mass of the rocks in the platform basement (the mean values attributed are almost identical), the behavior of the gravity field is perfectly justified. Instead, a high-quality fracture is found, as opposed to the more relative one materialized in the image of the total geomagnetic field anomaly. Further, the progressive decrease in Bouguer's anomaly values on the west side of the major fracture is explained by the continuous descent of the crystalline basement, a phenomenon occurring in a NE–SW direction.

What is remarkable is that in both the gravity and magnetic profile there is a very good correlation between the graphic representations of measured and calculated effects. The image of intrusive bodies, as shown on the section, differs from that resulting from individual two-dimensional models, which can be argued by a change in the direction of the magnetic profile in the case of the hypothetical section. The procedure of obtaining the image from Fig. 16 is also the one developed by Talwani and Heirtzler (1964).

The profile of the invariant J placed on the section under review reveals a predominantly structural significance of its configuration, somewhat in a situation similar to gravimetric information (Fig. 16). In this regard, the positioning of the regional fault line that affects the crystalline basement in one NW–SE direction and implicitly the separation of the two basement sections is visible at a very good resolution. Since the interpretation of isoline maps of invariant J takes into account an electrical resistivity of constant value for the deposits of the sedimentary cover, it is therefore easy to explain the configuration of its curve, which has high values in the north-eastern part, where the basement is found at lower depths – the current is less thick – and low values to the south-west, where the basement is deeper, therefore the current wave propagates through a more developed sedimentary rock package.

The correlation of the geophysical data available in the South–Iași area, derived from the 3 methods analysed, leads to a substantial reduction in the fundamental ambiguity regarding the understanding of the geological structure of the subsoil, highlighting the complementary nature of the information: gravimetric and electrometric information shows a pronounced structural content, while the information provided by magnetometry has a predominantly petrographic one.

5. Elements of geological interpretation for the South–Iași perimeter

A synthetic approach of magnetic results supplemented by the context provided by geophysical information obtained through the contribution of other geophysical methods – especially gravity and electrometry in the form of telluric currents – reveals the essential weight of magnetic prospecting in deciphering the structure of the platform basement in the South–Iași area. Seismometry, as we could find in the introductory chapter dedicated to previous geophysical research, is not compatible with magnetometry in terms of depth of investigation and resolution. Logically, a comparative analysis of the images built by interpreting magnetic data and those enshrined by the other methods may be a prerequisite for the coincidence and agreement of the hypotheses presented - in particular as regards the position of the surface of the crystalline basement in the underground and the existence of regional fault lines. It also may represent a stage of integration of information with a complementary content, the juxtaposition of which, in the absence of mutual confirmation, still validates a higher systematization of the perspective on the deep subsoil of that area.

The source of the regional gravimetric anomaly, as can be noted on the map in Figure 17, seems to be represented by the thickening of the deposits of the sedimentary cover by approx. 300–350 m, in a NE–SW direction, in which regard the main argument consists in the appearance of the quasilinear variation of the value of gravity in this direction. What is interest-

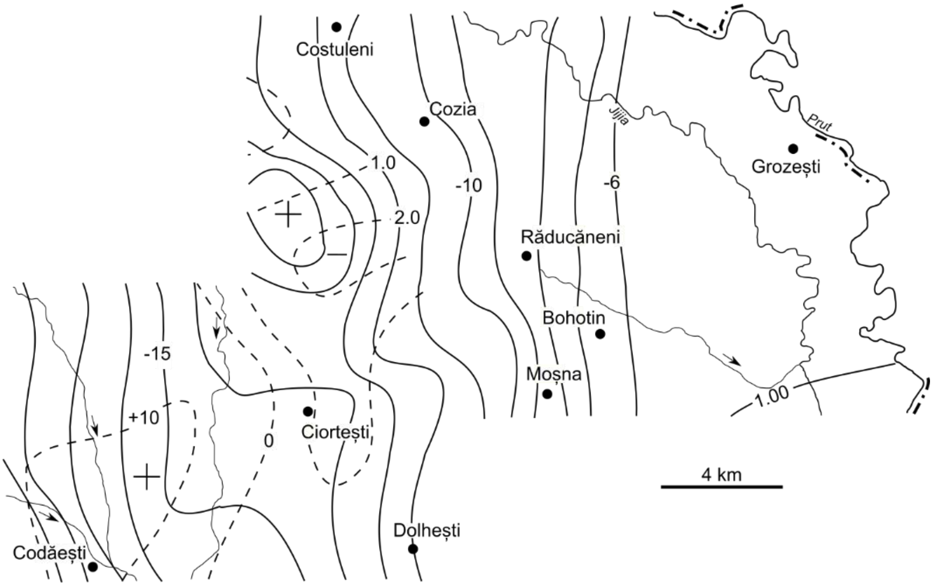

Fig. 17 Map of the Bouguer's gravity anomaly (H = 0; δ = 2.2 g/cm^3) for the South–Iași perimeter (according to Gorie and Hanu, 1990).

ing here, unlike the perimeter located north of Iași, is the orientation on a N–S direction of the regional abnormal isogal maps of the gravity in Bouguer's reduction and the non-disturbing of their straight route as a consequence of the manifestation of the regional fault line signalled on the ΔT map on the ground. In the sector located south of Covasna magnetic anomaly and further up to Ciortești settlement, there is a strong minimal gravimetric trend that appears very clearly outlined in the form of an anomaly in the residual map (Fig. 17). The image probably reflects a mass deficit created by a thickening of sedimentary deposits in a depressionary zone located at the level of the crystalline basement. On the magnetic map, the area is characterised by negative field values, values that may suggest the presence of a common cause with that proposed by the interpretation of the gravimetric effect, although the more plausible explanation in this case would be the reflection of a basement devoid of magnetic properties

The north-eastern frame of this anomaly trend is boarded by a horizontal gradient area of higher gravity, with a NW–SE orientation (approximately 2 mgal/km), which is symptomatic for the likely existence of a fault line at the level of the crystalline basement. That is also highlighted by the ΔT map on the ground which places here the western extremity of Piciorului Hill – Ursoaiei Forest – Mitoc – Curățitura Forest – Zberoaia regional fault line. The residual peak located to the north of Codăești presents a fairly illustrative overlap with the magnetic one from the Armașului Hill, which could suggest a petrographic nature with an evolving chemistry towards the base. On the image provided by the regional map of Bouguer anomaly, this maximal value is correlated with a notable horizontal gradient section, while the possibility of a fracture on which eruptive intrusion occurred is not excluded (Fig. 18). The existence of a maximal value of gravity on the southwestern flank of the maximal magnetic anomaly from Covasna, not signaled magnetically, may be due to the presence of both an apophysis (termination) of the source body of the magnetic anomaly, higher in position, but devoid of magnetic properties, and also an another body, independent of it, with a higher density. However, the general lack of correlation between the image elaborated on the basis of gravimetric data and that resulting from magnetic data justifies the fact that all these intrusive bodies do not pass beyond the surface of basement-cover contact.

It is obvious that the route of major tectonic accidents, followed approximately in a direction marked by the topographical landmarks mentioned above, but also the trend that can be seen in the Costuleni – West Cozia – Răducăneni – Moșna direction represent the continuation in the area of the South–Iaşi perimeter of the main trends outlined in the northern part of the Spineni – Jijia River – Vlădeni – Jija River route. Those tendencies are characterized by horizontal gradient strips of the very intense gravity field and marked by the distribution of important magnetic bodies. In the image of the map for invariant J, obtained by the

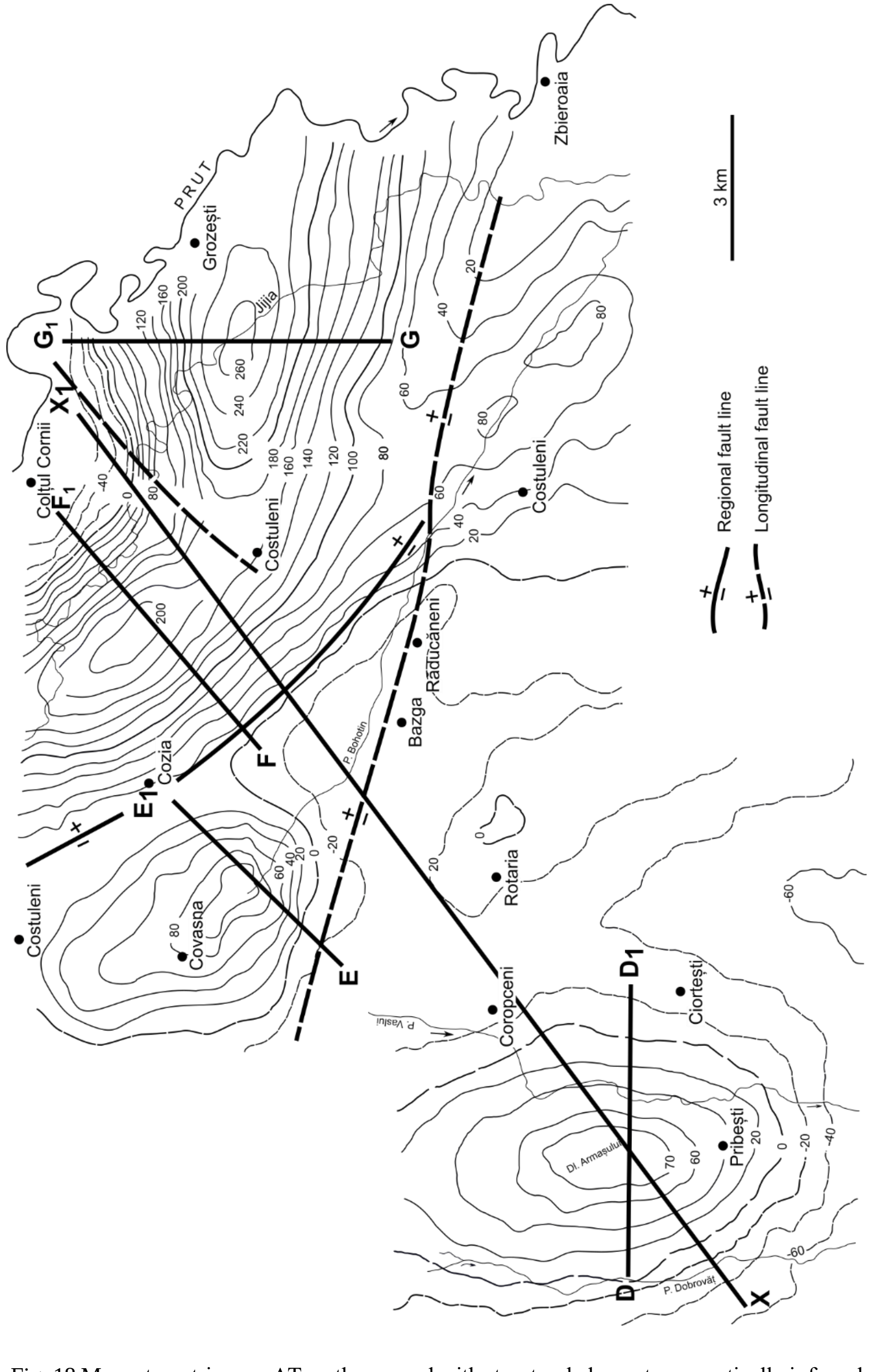

Fig. 18 Magnetometric map ΔT on the ground with structural elements magnetically inferred within the South–Iași perimeter.

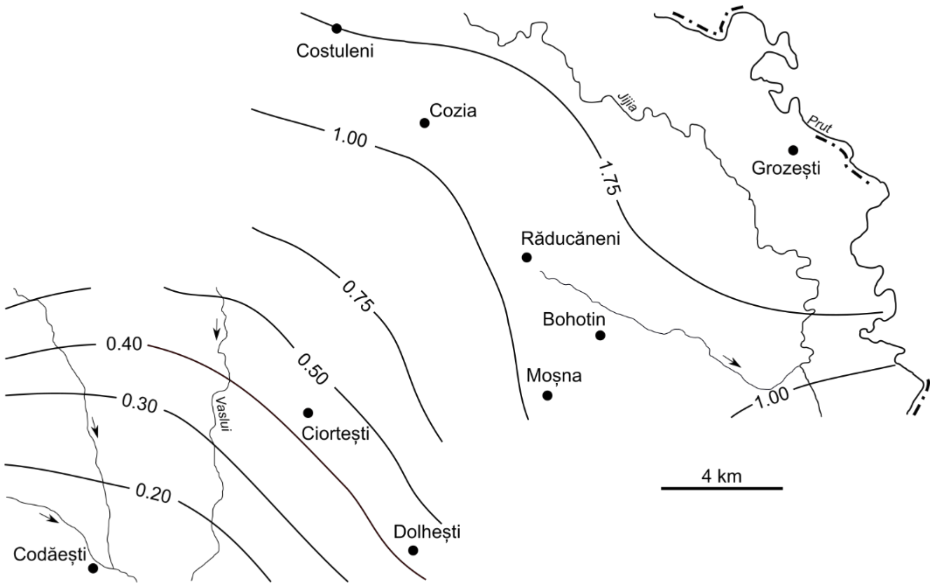

Fig. 19 Map of invariant J (telluric current method) for the South–Iaşi perimeter.

telluric current method (Fig. 19), the only notable element for the South–Iași area is this continuous decrease in the values of the isolines from NE to SW, the cause of which, as in the case of the interpretation of gravimetric and magnetometric maps, lies in the contact between the basement sections with significantly differentiated electrical properties. That is based on the the hypothesis that the paleorelief of the Cretacic deposits does not behave like an electric horizon of reference, as the electrical properties of the sedimentary deposits below are not differentiated from those of the crystalline basement.

The existence of large regional or local fracture networks in NW–SE and W–E directions favored the movement of mineralized solutions, probably after the settlement of the intrusive bodies. The correlation between the presence of these fractures and the distribution of the main magmatic bodies, inferred in the vast majority of situations from magnetic data, makes it unlikely for the magnetic anomalies to be generated by accumulations of residual magnetite in the depression zones, at least in the South–Iaşi area, while the depths of sources are relevant in this respect.

6. Conclusions

From the interpretative premises referring to the contrasts of physical properties, outlined in the "Petrophysical data" chapter and from the hypotheses and models proposed in the chapter dedicated to the processing and interpretation of the existing magnetic data for the two perimeters under investigation, the advanced availability of magnetometric surveys stands out with sufficient eloquence – in relation to the other geophysical prospecting methods – in the structural and petrographic deciphering of the Moldavian Platform area.

There are no interpretative impediments in the sedimentary formations, meaning that we have no reason to believe that sources of magnetic and even gravimetric anomalies can manifest within this range of depths. The arguments in support of these assumptions are presented in the sections where the geological problem of the origin of sources is approached. The usual complementary balanced character, specific to the relationship between the magnetic and gravimetric information, is outweighed for this particular situation, by the fact that the magnetic image of these areas offers quite remarkable possibilities in order to also give it credit for a good resolution in terms of accurately revealing structural aspects, which used to be a preserve of gravimetry.

This status of magnetic information is favored by the absence of an expressive contrast of density between the formations of the crystalline basement and eruptive intrusive bodies, the values attributed by us, in accordance with the petrophysical data regarding the surrounding areas, being 2.72 g/cm^3 versus 2.7 g/cm^3. That leads to a situation in which, due its characteristics, gravimetric information does not allow discrimination between the two petrographic types and reduces its scope only when reflecting the progressive immersion of the basement in a south-western direction.

In terms of magnetic properties, even in the area of development of a granulite facies, which highly lacks in ferromagnetic elements, the magnetic susceptibilities of those bodies may be regarded as sufficiently conclusive to enable them to differentiate undisputedly in the existing geological context.

The variability effect on the position of the crystalline basement surface, present in the magnetic information, is blunted by the petrographic component, which controls the obvious changes in the isodynamic regime. Moreover, the values of the geomagnetic field decrease very sharply, which is inconsistent with the gravimetric maps and could be attributed to the absence of magnetic properties of the formations of the crystalline basement on these areas. It is very likely for the magnetic background to be enriched in ferromagnetic elements, with magnetic susceptibilities not so clearly differentiated from those of the source intrusive bodies.

The correlation between these anomalies and their sources consisting in the important accumulations of iron mineralization arranged in the depressed areas of the platform basement, since the structural closure of the negative undulations of the surface of the basement is reduced, and the analysis of the magnetic properties of the main magmatic rock intercepted in the nearby drillings (Socola, Popești, Nicolina) are insufficient to justify the quite consistent intensities of magnetic anomalies, especially since the probable depth of placement of sources is also important, and it ranges from 900 to 2400 m. Cozia – Şesul Voloaca – Şesul Jijia – Grozeşti, from the South–Iaşi perimeter, may represent a possible cause of the very particular image of the two magnetic anomalies positioned here. It means that the reflection of intrusions in the geomagnetic field seems to be disturbed by the presence of an accumulation of magnetic effects from the formations of the basement, which is also noted on the map of the local magnetic effect.

In fact, it highlights with enough clarity the routes of the main tectonic accidents affecting the crystalline basement, in Dealul Piciorului – Ursoaiei Forest – Mitoc – Curățitura Forest – Zberoaia perimeter. The trend of shifting the direction of orientation of the main major fractures – from a predominant NW–SE character in the northern part to one with a visible predominantly W–E orientation in the south – most likely marks the contact between different basement sections both petrographically and in terms of age.

The much stronger manifestation of the regional fracture in the geomagnetic field than in the gravity field (Fig. 17) seems to be correlated with the fact that its magnitude is not so large instead. The contact of the two basement zones it separates is also doubled by a differentiation in terms of magnetic properties. All these arguments, plus other results stemming from the interpretation of the material set out in the previous chapters and whose contribution to the coagulation of a coherent overall picture is undeniable, offer the magnetometric prospecting the full legitimacy to be considered as the main geophysical method of deciphering the structure of the crystalline basement of the platform areas, in particular for the central area of the Moldavian Platform.

References

Botezatu, R., 1982. Geophysical models of the geological structure of Romania. Publisher Editura Tehnică, Bucharest.

Botezatu, R., 1987. Bases of the geological interpretation of geophysical information. Publisher Editura Tehnică, Bucharest. (in Romanian).

Bradu, M., 1987. Procedures for estimating the depths of sources of magmatic anomalies. Archive of the Enterprise of Geological and Geophysical Survey (IPGG), Bucharest. (in Romanian).

Constantinescu, L., Eldaiem, M., 1963. A practical formula for approximating vertical gradients of the geomagnetic field. Probleme de geofizică, **II**, 27-44. (in Romanian).

Gorie, J., Hanu, D.B., 1990. Report on gravimetric and magnetometric survey for iron ores, in the Costuleni-Prut-Micleşti-Dobrovăţ perimeter, Iași county. Archive of the Institute of Oil, Gas and Geology, Bucharest. (in Romanian).

Gorie, J., 1996. Geological map of Romania, scale 1:200,000. Iași and Ștefănești sheets. State Committee of Geology, Bucharest.

Ionesi, L., 1994. Geology of the platform units and orogenic formations in Northern Dobrogea. Publisher Editura Tehnică, Bucharest. (in Romanian).

Ianovici, V., Giuşcă, D., 1961. New data on the crystalline basement of the Moldavian Highland and Dobrogea. Academia Republicii Populare Romane, Studii şi cercetări geologice, **VI**, 153-159. (in Romanian).

Ivan, M., 1994. Magnetic survey. Publishing House of the University of Bucharest, Bucharest. (in Romanian).

Maxim, G., 1988. Synthesis of geophysical data on the presence of alkaline basal massifs and their associated Ni concentrations in the Moldavian Platform. Archive of the Institute of Oil, Gas and Geology, Bucharest. (in Romanian).

Nasser, A.A., 1977. Geological and geophysical study of the central sector of the Moldavian Plateau. PhD thesis, University of Bucharest, Bucharest. (in Romanian).

Mutihac, V., Ionesi, V., 1974. Geology of Romania. Publisher Editura Tehnică, Bucharest. (in Romanian).

Mutihac, V., 1990. Geological structure of the Romanian Territory. Publisher Editura Tehnică, Bucharest. (in Romanian).

Peters, L.J., 1949. The direct approach to magnetic interpretation and its practical application. Geophysics, **14**, 290–320.

Sharma, P.V., 1978. Geophysical methods in geology, Elsevier, New York.

Talwani, M., Heirtzler, J.R., 1964. Computation of magnetic anomalies caused by two-dimensional structures of arbitrary shape. Computers in the Mineral Industries, **I**, 9, 464–480.

Talwani, M., 1985. Computation with the help of a digital computer of magnetic anomalies caused by bodies with arbitrary shape. Geophysics, **XXX**, 5, 797–817.

Telford, W.M., Geldard, L.P., Sheriff, R.E., Keys, D.A., 1976. Applied geophysics. Cambridge University Press, Cambridge.

Visarion, M., Polonic, P., Atanasiu, L., 1987. Geological and geophysical research regarding the deep structure in the Eastern Carpathians foreland. Archive of the Romanian Geological Institute, Bucharest. (in Romanian).

Visarion, M., Săndulescu, M., Stănică, D., Atanasiu, L., 1988. An improved geotectonic model of the East Carpathians. Rev. Roum. Geol. Geophys et Geogr., Serie Geophysique, **32**, 43–52.