100 YEARS OF THE GEOELECRIC AND ELECTROMAGNETIC RESEARCHES IN ROMANIA

Dragoş Armand STĂNICĂ[1] and Dumitru STĂNICĂ[2]

Rezumat. *In această lucrare sunt evidențiate etapele principale privind dezvoltarea și promovarea la nivel național a metodelor geoelectrice și electromagnetice, aplicate în ultimii 100 de ani de către specialiști din instituțiile de stat și din companiile private, pentru prospectarea substanțelor minerale solide, a apelor subterane și a zăcămintelor de petrol și gaze. De asemenea, sunt prezentate studiile și cercetările electromagnetice utilizate la investigarea structurilor geologice de adâncime, la elaborarea hărților naționale de curenți telurici, precum și pentru obținerea semnalelor electromagnetice precursoare cutremurelor de adâncime intermediară generate în zona geodinamic activă Vrancea.*

Abstract. *In this paper are emphasized the main stages regarding the development and promotion at the national level of the geoelectric and electromagnetic methods applied in the last 100 years, by the scientists from the state institutes and private companies, for solid mineral substances, underground waters and oil and gas fields prospection. The electromagnetic studies and researches used to investigate the deep geological structures, to elaborate the national telluric current maps, as well as to obtain the electromagnetic precursors of the intermediate depth earthquakes generated in the geodynamic active Vrancea zone are presented, too.*

Keywords: Geoelectric and electromagnetic methods, ore deposits and oil and gas fields, deep structure investigation, electromagnetic precursors, intermediate depth Vrancea earthquake

1. Introduction

Three main stages are distinguishing in the geoelectric and electromagnetic research methods development in Romania: 1925-1947, 1948-1989 and 1990-present. ***The first stage*** started by promoting at national level of the geoelectric and electromagnetic methods by the Geological Institute of Romania and private companies belonging to the extractive industry, especially, the oil industry [1].

A remarkable event in the evolution of the geoelectric methods have taken place in 1927, when Ștefănescu S. was promoted head of the Prospecting and Applied Geophysics Section, organized in the frame of the Geological Institute. His theoretical papers, published between the 1927-1947 years [2], have brought a

[1]PhD, Senior Researcher, affiliation: Institute of Geodynamics of the Romanian Academy, Bucharest, Romania, (e-mail: armand@geodin.ro).
[2]PhD, Senior Researcher, affiliation: Institute of Geodynamics of the Romanian Academy, Bucharest, Romania, full member of the Academy of the Romanian Scientists, (e-mail: dstanica@geodin.ro).

high reputation to the institute and mark the entrance of the young Romanian geophysical school into the worldwide. In this interval, the geoelectric method - vertical electrical sounding version (VES), was experimented in mining prospecting to delimit and extend the interest zones for the ore deposits and hydrocarbon structures [3, 4].

The 1948 year represents entrance in ***the second stage*** of geoelectric methods development, when all the human and technical potential was concentrated under State control, by nationalization of the extractive industry. In this framework, the entirely geologic and geophysical activities where organized by setting up the Geological Comity, which had subordinated the Enterprise for Prospecting and Laboratories. Thus, beginning with 1951, the geoelectric prospecting for useful mineral substances was realized by this enterprise and the Mining Ministry (in the period 1955-1972) and, by the Geological and Geophysical Prospecting Enterprise for Hydrocarbons (GGPEH), founded in 1953 under the direct coordination of the Ministry of Oil Industry, as well. Starting with 1960, the Geological Institute accomplished studies and researches related to the elaboration of national geological and geophysical maps, deep structure investigation, new geoelectric methodology development to elaborate the telluric maps (scale 1:200.000) and achievement of the specific equipment. After 1966, these activities belong to Institute of Applied Geophysics (IAG) and, from 1974 to the Institute of Geology and Geophysics, founded by the fusion of the IAG with Geological Institute.

It is to mention that the geoelectric researches played a prominent roll through the geophysical methods applied in hydrocarbons prospection in the 1930-1965 interval, after that the main domains of investigation were for the solid mineral substances, subterranean water, geothermal resources, and starting with 1975, for deep geological structure investigation by using magnetotelluric method. Since 1996 up to now, the both Geological Institute of Romania and Institute of Geodynamics of the Romanian Academy (founded on 1990) are involved in such activities, representing in fact the entrance in ***the third stage*** of the geoelectric and electromagnetic (EM) researches in Romania.

The actual level of the geoelectric methods was possible by the consequent politics promoted by the Romanian State after 1948, regarding to the geophysical researches intensification and, the constant support of the following scientific personalities: L. Mrazec, G. Macovei, Al. Codarcea, V. Ianovici, S. S. Ştefănescu, R. Botezatu, T.P. Ghiţulescu, I. Gavăt, L. Constantinescu, P. Georgescu and so on. However, the most important contribution in the geoelectric and electromagnetic methods development was due to the excellent results obtained by the geophysicists that have used these researches in a creative mode, to increase the knowledge level related to the both mineral resources and deep geological structure in Romania.

2. Geoelectric researches for the solid mineral substances, subterranean water and oil and gas structures

2.1. Ore deposits and subterranean water investigation

Between 1925 and 1948 years, the Prospecting and Applied Geophysics Department of the Geological Institute of Romania used the geoelectric methods for to investigate the ore deposits and underground water. These studies had an experimental character due to the low level of their theoretical development and investigation techniques in the worldwide and, the most used being the following techniques: the spontaneous potential (SP), Elbof, VES and Turam [1, 2].

The studies realized by Ştefănescu S. at the Geological Institute, between 1927 and 1948, brought important contributions for solving multiple base theoretical problems of the geoelectric research methods, including the quantitative interpretation of the vertical electric soundings, applied on the horizontal stratified layers and, various electromagnetic methods that knew a large development after 1950 year. On the interval 1948-1964 are used the geoelectric methods (SP and resistivity techniques) to investigate ore deposits associated to Neogene magmatic and metamorphic structures in Eastern Carpathians, and with magmatic rocks, graphite and barite accumulations in Southern Banat. While, in order to study the sedimentary basins and hydrology (including geothermal areas) was applied the resistivity method – VES version. Beginning with 1964 year, was applied the induced polarization method (IP), what represented for the next six years the main methodology for geoelectric researches of the disseminated mineralization (Cu, Pb, Zn, Au, Ag, Mo) and, those of "porphyry copper" type cantoned in volcanic rocks (Stoica *et al.*, 1988).

Since 1970, have been successfully applied the electromagnetic method in the time domain – with a single turn version, that had a better resolution versus IP for the large ore bodies and, from 1976 year, is used the radio waves attenuation method to study the space between the mining works and/or between these and the surface of investigated medium. The elaboration of the „alpha centers" theory and the implementation of some mathematical models based on Green functions, Ştefănescu S. had an important contribution to the modelling of the conductive heterogeneities of 2D and 3D type, by the DC geoelectric methods [5].

2.2. Hydrocarbon structures investigation

In the period 1925-1948, the foreign companies applied resistivity methods (VES version), to investigate oil and gas fields, thus being studied the areas of Muntenia, Oltenia and Southern Moldavia aiming at the identification on Neogene deposits of some new anticlinal structures and to extend of those already existing.

The majority of the geoelectric researches for hydrocarbon investigation were made in the period 1930-1939, when the VES measurements were applied simultaneously with the inductive methods - Sundberg and Cagniard [4].

After 1948 year, the Geologic and Geophysical Prospecting Enterprise for Hydrocarbons used geoelectric methods in the frame of the Ministry of Oil Industry.
Thus, in the interval 1954-1968, are used VES, telluric currents and cross-transmitters methods to investigate, at the scale 1:100.000, the following geologic units: North Dobrogea Promontory, Southern Dobrogea, Southern of the Moldavian Platform, Transylvanian Basin, Pannonian Depression and Moesian Platform.
It is also to mention that the geoelectrical prospecting for hydrocarbons after 1950 had a preliminary character, its main purpose being to supply useful information for the placement of the seismic prospecting networks, and after 1968 year it was stopped due to the difficulties appeared at the interpretation of the geoelectric data carried out in unexplored areas, in a very rugged relief, and because the resolution power of the seismic methods enhanced substantially.

3. Electromagnetic researches for the deep geological structure investigation and to obtain pre-seismic signals related to Vrancea earthquakes

Electromagnetic (EM) researches of the deep geological structure were accomplished by the specialists from the Institute of Applied Geophysics in the interval 1968-1974, the Institute of Geology and Geophysics (1974-1995), the Geological Institute of Romania (1996-2001) and Institute of Geodynamics of the Romanian Academy (2002 - present) using the natural electromagnetic induction methodologies (magnetotelluric, telluric currents and geomagnetic methods).

3.1 Magnetotelluric and telluric current researches

Between 1979-2001 years, over 2000 magnetotelluric soundings placed along some profiles (see Figure 1), chosen in order to make the investigation of the deep geological structure of the following major units: Eastern, Meridional and Western Carpathians, Carpathian Foredeep, East-European and Moesian Platforms, North-Dobrogea Orogen, Pannonian and Transylvanian Depressions, were made [6-9].

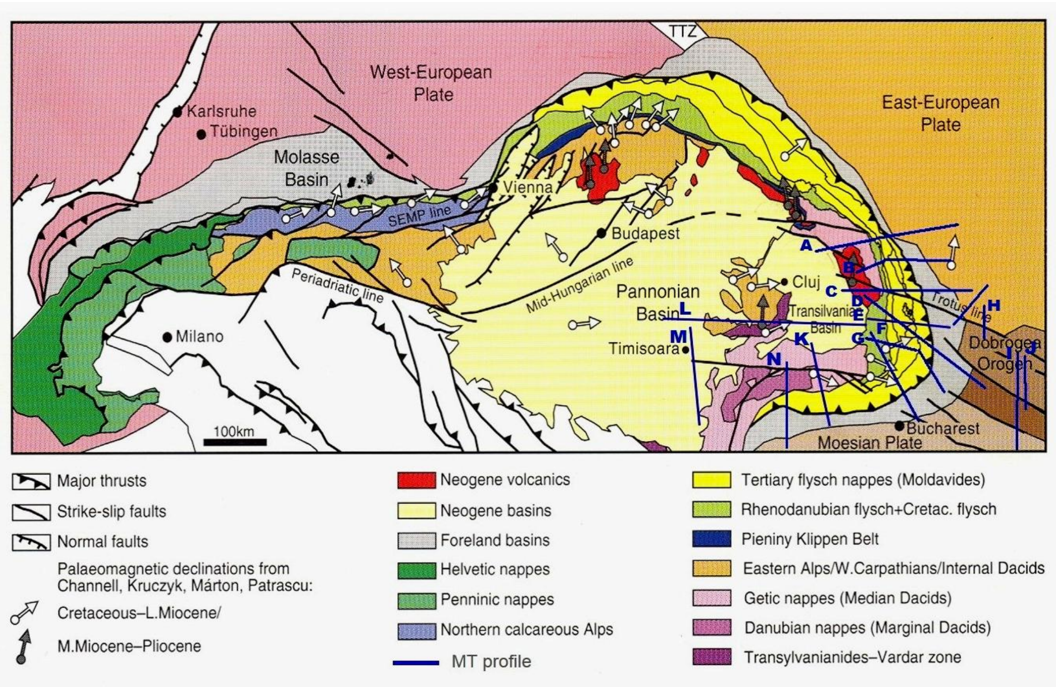

Fig. 1. Magnetotelluric profiles (blue line) placed on the Romanian territory.

It is to mention that the EM methods are the most sensitive for detecting partially interconnected, volumetrically minor yet tectonically important conducting phases such as partial melt, fluids and graphite. EM methods can therefore provide models on lithosphere/upper mantle conductivity, which are complementary to other geophysical data and aid at defining constraints to other geophysical and geological models, such as seismic tomography or reflection seismic models, temperatures or fraction of melt or volatiles.

In the class of EM methods, the magnetotelluric sounding method (MTS) can provide information on electrical properties of deep crust and upper mantle, by using sufficiently long data recordings of the Earth's electromagnetic components (Ex, Ey, Hx, Hy and Hz), in several sites, placed on profiles crossing the main geotectonic units from Romania, such as:

- resistivity models obtained by using 2-D forward modeling-finite element code, see Figure 2 and Figure 3;
- a map at the brittle-ductile transition zone in the lower crust, including the alignment of the Trans-European Suture Zone (TESZ) which separate the East European Platform by the Phanerozoic terranes, see Figure 4;
- 3-D resistivity tomographic images of the Vrancea upper mantle, see Figure 5;
- 3-D geodynamic model for the Vrancea zone, see Figure 6.

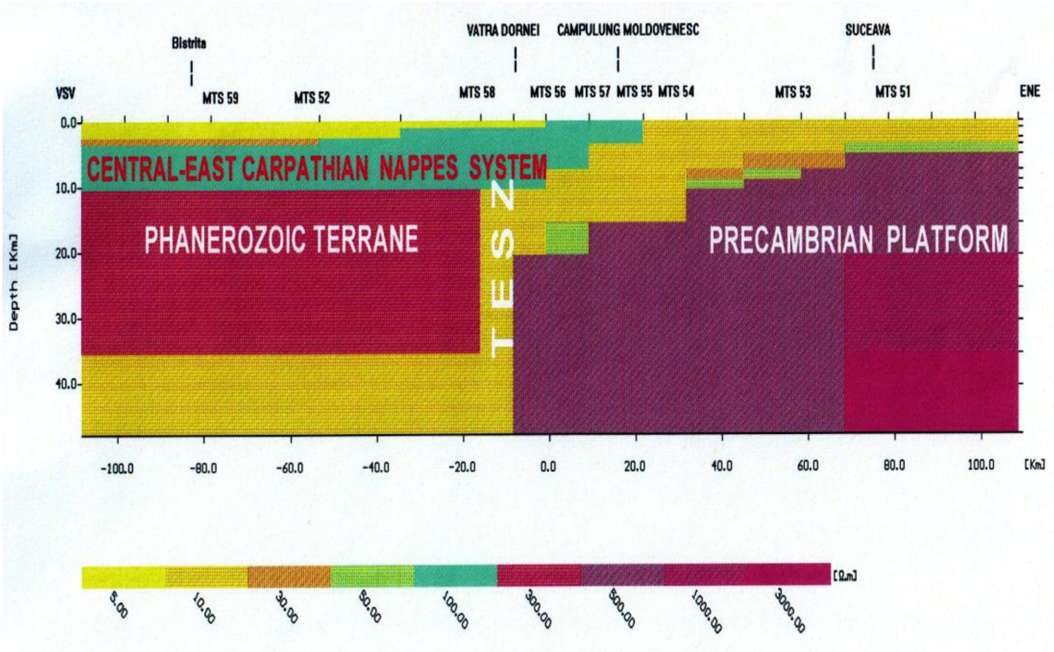

Fig. 2. Magnetotelluric crustal resistivity model on the profile A (Bistriţa - Vatra Dornei – Suceava). MTS51 – magnetoteluric sonding, TESZ – Trans European Suture Zone.

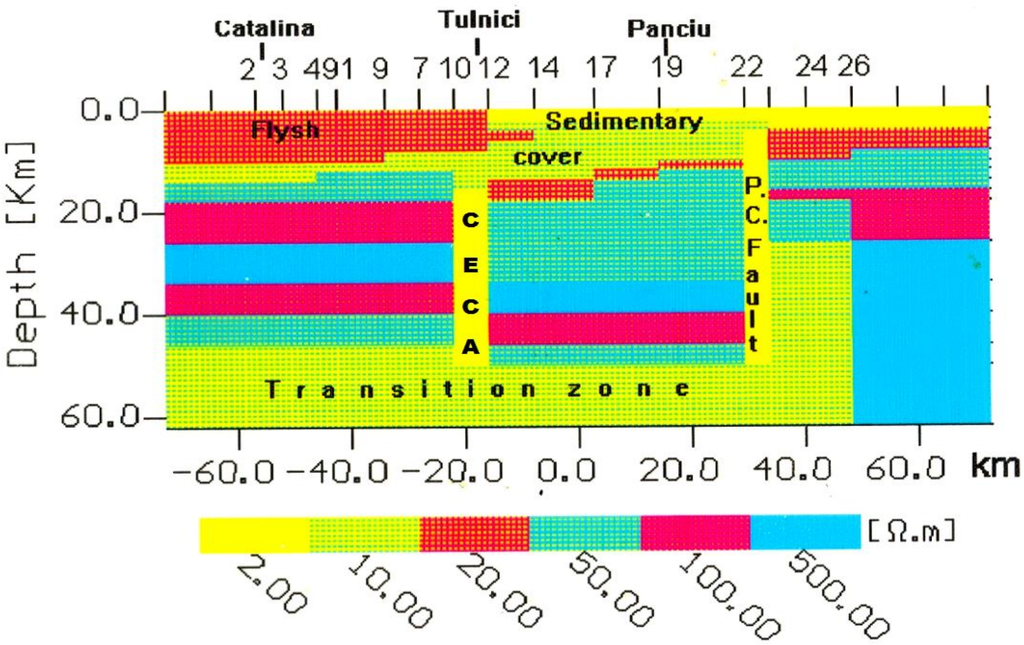

Fig. 3. Magnetotelluric crustal resistivity model on the profile E (Vrancea zone) obtained by using 2-D forward modeling-finite element code. 12 is magnetoteluric sonding, CECA is Carpathian Electrical Cponductivity Anomaly, P.C.Fault is Peceneaga Camena Fault.

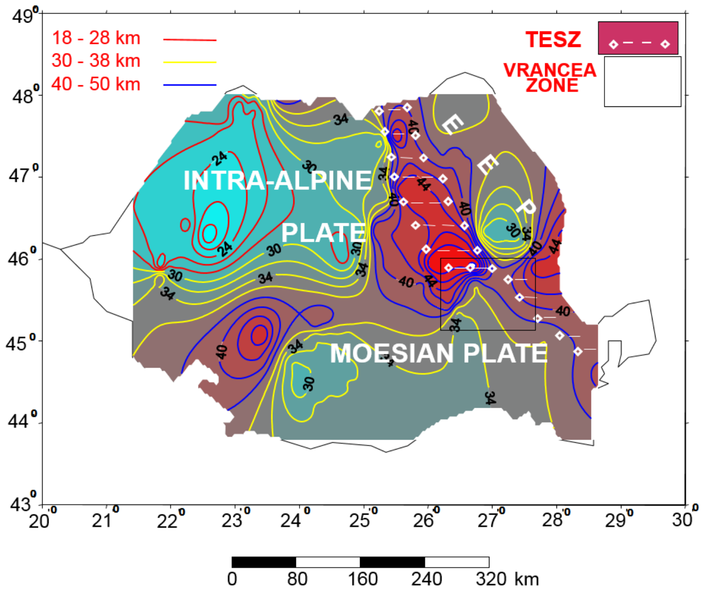

Fig. 4. Map with isobaths (red, yellow and blue lines) at the brittle-ductile transition zone in the lower crust. EEP is East European Platform.

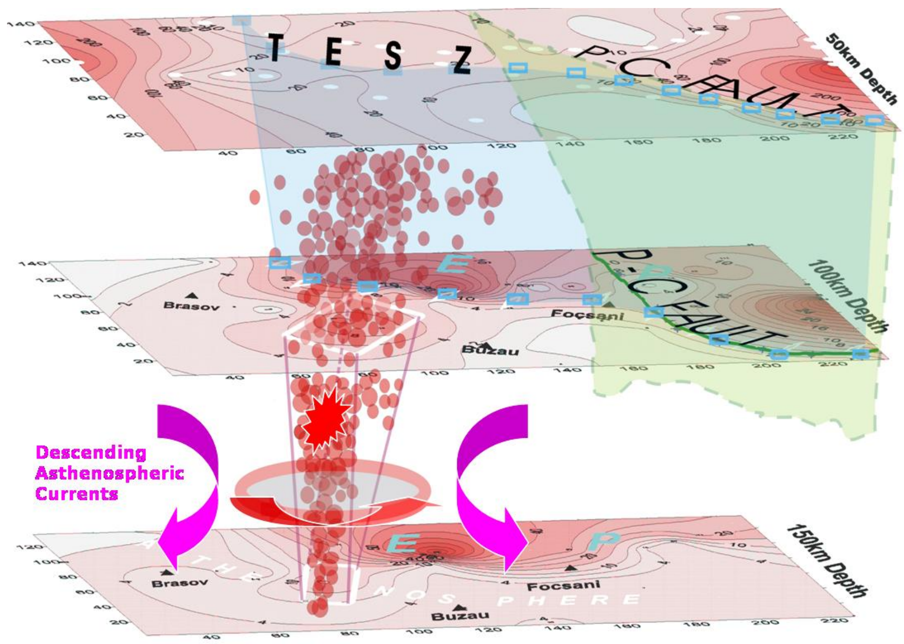

Fig. 5. 3-D resistivity tomographic image of the Vrancea upper mantle, realized at the tree levels (50 km, 100 km and 150 km). Red full circles are intermediate depth earthquakes; white square shows the two strike directions of the relic slab at 100 km and 150 km, demonstrating the existence of the torsion process (red arrow) generated by the descending asthenospheric currents (pink arrows).

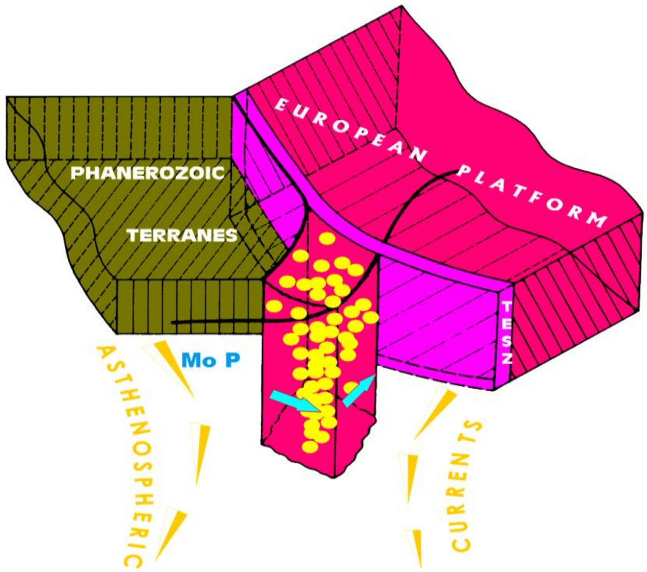

Fig. 6. 3-D geodynamic model for the Vrancea zone. Mo P is Moesian platform; pink color delineates the TESZ; blue arrows indicate the direction of the torsion process generated by the descending currents in asthenosphere; yellow arrows are descending asthenospheric currents.

Three lithospheric models for the East European Platform (EEP), Moesian Platform (MP) and Transylvanian Depression (TD) have been obtained by using 1-D resistivity inversion [9], see Figures 7, 8 and 9.

East European Platform
1-D resistivity model (ρ) in lithosphere

Layers	ρ[Ωm]	H [km]	Observations
1	10	10	Sedimentary cover of the platform
2	1000	35	Crystalline basement
3	10	10	Crust-upper mantle transition zone
4	500	120	Upper mantle
5	10		Asthenosphere

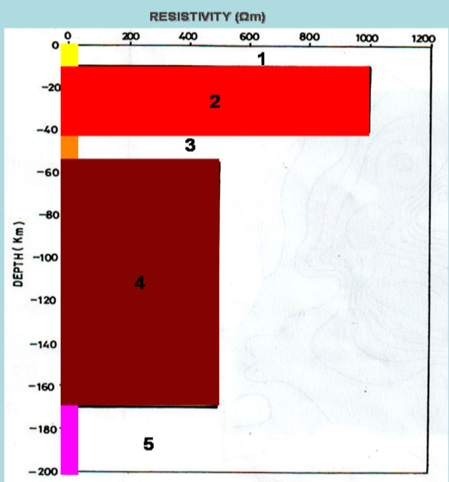

Fig. 7. 1-D lithospheric resistivity model for the East European Platform.

Moesian Platform

1-D resistivity model (ρ) in lithosphere

Layers	ρ [Ωm]	H [km]	Observations
1	10	10	Sedimentary cover of the platform
2	1000	30	Crystalline basement
3	10	10	Crust-upper mantle transition zone
4	500	80	Upper mantle
5	10		Asthenosphere

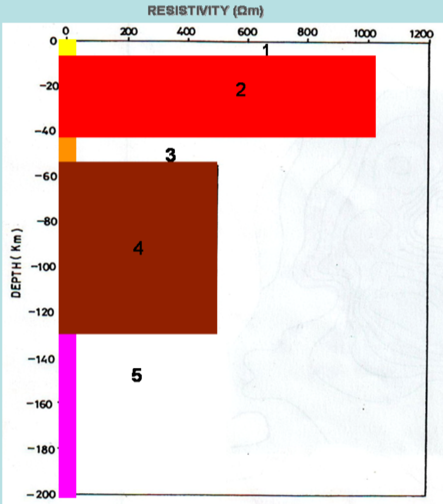

Fig. 8. 1-D lithospheric resistivity model for the Moesian Platform.

Transylvanian Depression

1-D lithospheric resistivity (ρ) model

Layers	ρ [Ωm]	H [km]	Observations
1	5	5	Post-tectogenetic sedimentary cover
2	500	2	Central-East Carpathian Nappes Systems
3	700	24	Crystalline basement
4	10	10	Crust-upper mantle transition zone
5	500	40	Upper mantle
6	10		Asthenosphere

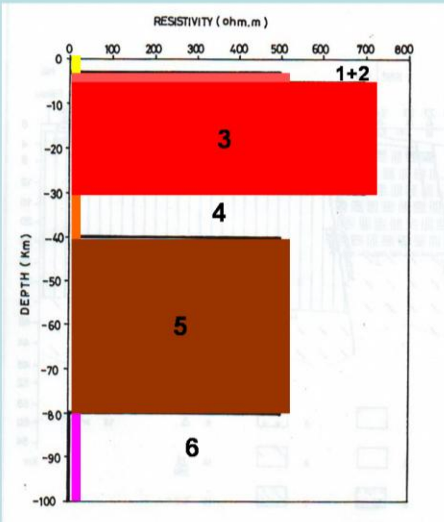

Fig. 9. 1-D lithospheric resistivity models for the Transylvanian Depression.

Finally, the 2D models and 2D and 3D tomographic images emphasizing the resistivity distribution at different levels of depth, gave information regarding:

- the thickness of the East Carpathians flysch nappes systems and their over-thrust lineament with sedimentary cover of the EEP;
- the thicknesses of the volcano-sedimentary formations, platforms sedimentary cover and Carpathian Foredeep;
- the thicknesses of the crust and upper mantle for (EEP, MP, TD and Pannonian Depression);
- the major suture alignments (TESZ and Tethyan) and of the crustal and lithospheric faults (Intra-Moesian, Trotuş and Peceneaga - Camena).

The researches realized by using telluric currents method have been obtained in the frame of the national program on the interval 1969-2006 and, consequently, a number of 48 sheets map (scale 1:200.000) have been elaborated for the parameters J and μ on the entirely Romanian territory, see Figure 10.

Some of them were assembled to emphasize the deep structure of the Moesian Platform [10, 11] and the others telluric maps are archived at the Geologic Institute of Romania.

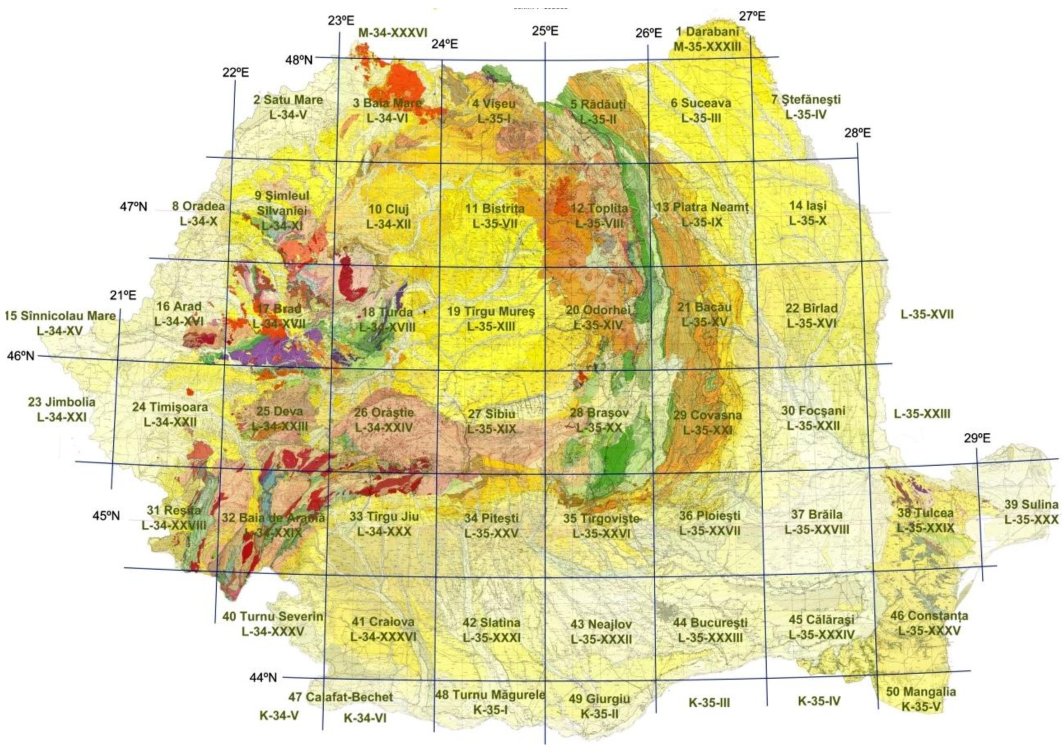

Fig. 10. Squares on geological map of Romania at the scale 1:200.000 (48 sheets map were used as support for the telluric parameters J and μ).

3.2 Pre-seismic geomagnetic signals related to Vrancea earthquakes

Since 2001 year up to now, the Institute of Geodynamics of the Romanian Academy have realized electromagnetic researches in the frame of the Priority Program with the theme: "*The study of the natural variations of the electromagnetic field for a better knowledge of the terrestrial crustal structure and the establishment of the evolution of some parameters related causally to the strain release in the geodynamic active Vrancea zone*".

In compliance with the methodology elaborated by [9, 12-15], the following parameters have been used to emphasize geomagnetic pre-seismic signals related to Vrancea intermediate depth earthquakes:

- the normalized function Bzn which is time invariant in non-geodynamic conditions and it becomes unstable due to the geodynamic processes generated by the intermediate-depth seismicity, being associated with the resistivity changes along the high conductivity faults in the crust and upper mantle;
- the parameter Bzn* obtained by using a statistical analysis based on standardized random variable equation.

An example haw this methodology works is presented for the earthquake of Mw5.7 generated in 24 September 2016, in Vrancea zone [15], see Figure 11.

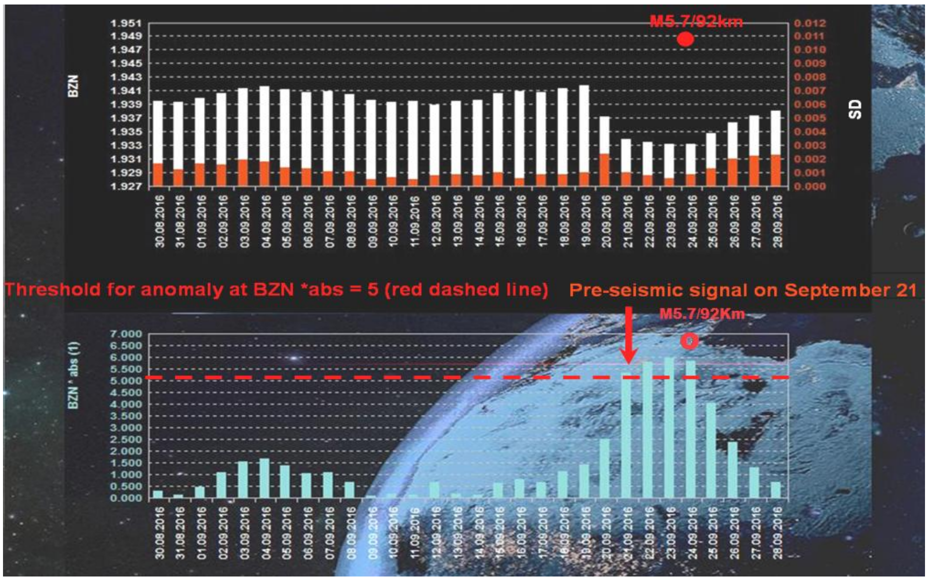

Fig. 11. Daily distribution of the geomagnetic parameters Bzn and Bzn* (photo image captured from the web site of the Institute of Geodynamics of the Romanian Academy, related to Mw5.7 earthquake, generated on September 28, 2016), the ratio M5.7/92 is earthquake magnitude/ hypocenter depth.

Conclusions

Romania is one of the countries where the geoelectrical and electromagnetic methods have been used on a large scale, from the beginning of their theoretical and experimental development, in both the economic geological investigations (for mineral ore deposits, hydrocarbons, underground waters, geothermal resources) and to improve the knowledge regarding the deep geological structure on the entirely territory. Especially, due to the Sabba Ştefănescu' contributions, the Romanian geophysical school have brought important role in the theoretical base development of the geoelectrical methods and, their applications being closely connected to the geological activity. However, the most important contribution of the electromagnetic methods development was due to the excellent results carried out by the geophysicists which have used these researches in a creative mode, with the aim to promote them at the national and international levels.

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