INTRAMOESIAN FAULT IN THE FĂGĂRAŞ MOUNTAINS AREA

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In memoriam Mircea Săndulescu

Abstract. It is considered that the Intramoesian Fault on the Romanian territory is not topographically expressed. Although there is evidence that the fault plane is close to the surface in the Moesian Platform area, the assumption that the fault does not cross-cuts the upper crust in the orogenic area of the Făgăraş Mountains is currently accepted. The geophysical fault trace in this region coincides with the geological trace of the Scara Fault. The tectonic movements along the two (?) faults during the Cretaceous and the Miocene contributed to the achievement of the Alpine structures in the eastern part of the South Carpathians, connected to Vrancea bend of the Carpathian orogen. Both faults are seismically active, the earthquakes hypocenters in the Făgăraş Mountains area being localized both in the upper and middle crust. Accordingly, the presence of the Intramoesian Fault at the topographic surface in the Făgăraş Mountains, on the NW-SE direction of the Scara Fault, is taken into account.

Keywords: Intramoesian Fault, Scara Fault, Făgăraş Mountains.

Rezumat. Falia Intramoesică în aria Munţilor Făgăraş. Se consideră că Falia Intramoesică nu apare la zi pe teritoriul României. Deşi există dovezi că planul faliei este aproape de suprafaţă în aria Platformei Moesice, în prezent este acceptată ipoteza neargumentată că falia nu traversează crusta superioară din aria orogenică a Munţilor Făgăraş. În această regiune, traseul geofizic al Faliei Intramoesice coincide cu traseul geologic al Faliei Scara. Mişcările tectonice în lungul celor două (?) falii în timpul Cretacicului şi Miocenului au contribuit la realizarea structurilor alpine din partea estică a Carpaţilor Meridionali, conectată la curbura Vrancea a orogenului carpatic. Ambele falii sunt active seismic, focarele cutremurelor din aria Munţilor Făgăraş fiind localizate atât în crusta superioară cât şi în crusta medie. În consecinţă, prezenţa la zi a Faliei Intramoesice în fundamentul cristalin al Munţilor Făgăraş, pe direcţia NW-SE a Faliei Scara, este luată în consideraţie.

Cuvinte cheie: Falia Intramoesică, Falia Scara, Munţii Făgăraş.

INTRODUCTION

The Intramoesian Fault (IMF) separates the eastern sector of the Moesian Platform with low-grade metamorphic basement, of Dobrogea type, from the western one with granitic and medium-grade metamorphic basement, of Danubian type according the petrographic drilling data (BARBU & DĂNEŢ, 1970). The fault stretches on NW-SE direction from the Black Sea continental platform to the Făgăraş Mountains area. VISARION & SĂNDULESCU (1991) consider that the fault does not cross the upper level of the crystalline basement in this region, the fault plane being buried under the Getic Nappe body, at 10 km depth.

On the territory of Bulgaria, the IMF is clearly expressed in the surface topography by two subparallel branches at 5-6 km away from each other on the Silistra Town-Shabla Cape lineament. Both branches are represented by en echelon fault sets, morphologically expressed by linear and narrow valleys with the slopes affected by active landslides (ROGOZHIN et al., 2009). The tectonic block between the two branches suffered recent downward movements of 8-12 m, the resulted graben being filled with tectonically disturbed Quaternary loams.

For the Romanian territory, there are no cartographical data regarding the IMF occurrence at surface, perhaps because detailed geological maps lack in the Moesian Platform area. It is known that, after the subcrustal earthquake of March 4, 1977 in Vrancea, hot water emerged from the depth on the fault plane at Fierbinţi, near Urziceni Town (CORNEA & POLONIC, 1979). This is a proof that the fault plane is very close to the surface.

The geophysical IMF trace in the Făgăraş Mountains (SOCOLESCU et al., 1964; VISARION & SĂNDULESCU, 1991) is coincident with the lineament of an active dextral strike-slip fault which cross-cuts the crystalline basement on the NW-SE direction (DIMITRESCU et al., 1985; GHEUCA, 1988; STELEA, 1992), called herein Scara Fault, after the saddle name through which the fault crosses the main crest of the mountains. The dextral movement on this fault has contributed to the Alpine regeneration of the basement on the northern border of the Făgăraş Mountains. In this paper, we bring into question geometrical, kinematical and seismic arguments, in order to demonstrate that the Scara Fault actually is the Intramoesian Fault correspondent at the topographic surface.

INTRAMOESIAN FAULT

History of knowledge. Kinematically undefined, the Intramoesian Fault appears for the first time on the tectonic map of Romania at scale 1:1000000 (DUMITRESCU & SĂNDULESCU, 1970), as a short tectonic line crossing the Moesian Platform and the outer foredeep between the localities Călăraşi and Fierbinţi. Based on seismic data, RĂDULESCU et al. (1976) prolonged the fault over the inner foredeep up to Câmpulung Muscel Town. In order to explain the subduction of the eastern sector of the Moesian Platform beneath the Carpathian orogen in Vrancea bend,

the authors deduced a sinistral slip on the Călăraşi-Fierbinţi Fault, correlated with the dextral slip on the Peceneaga-Camena Fault.

Investigating the seismicity of the eastern sector of the Moesian Platform, CORNEA & POLONIC (1979) found that almost the entire seismic activity of the region is localized on the Călăraşi-Fierbinţi Fault, which they define as active transcurrent fault. The sinistral slip on the fault plane was argued by the more rapid movement of the eastern compartment due to its sinking beneath the orogen. SĂNDULESCU (1984) is the author of the name Intramoesian Fault, with dextral slip during the Cretaceous followed by sinistral slip from the Miocene till now.

Intramoesian Fault kinematics. SĂNDULESCU (1984, 1994) argued the important geodynamic role played by the Intramoesian and Peceneaga-Camena faults in the achievement of the Carpathians geometry and structure during the Cretaceous phases of the Alpine orogenesis. According to the author, the two sectors of the Moesian Platform separated by IMF moved toward northwest with different motion rates, the higher motion rates of the western sector inducing a relative dextral displacement on the fault plane.

During the Miocene, only the eastern platform sector moved toward the orogen, the displacement on the fault plane becoming sinistral as it is today (SĂNDULESCU, 1984, 1994). The western sector immobility would explain the lack of the Neogene magmatism related to the subduction process in the South Carpathians, as well as the narrowing of the Miocene nappes west of the IMF. The nappes inside the Miocene thrusts belt gradually disappear west of the Dâmboviţa Valley so that, west of the Olt Valley, only the Subcarpathian Nappe appears.

Even less developed, the Miocene thrusts in front of the central South Carpathians show that the western IMF compartment also moved toward the orogen during the Miocene. In our opinion, the Miocene thrusts narrowing and thinning in the central South Carpathians area reflects a change in the tectonic regime on the contact between platform and orogen, induced by the collision angle reduction with the progressive double bending of the orogen. As the two Carpathians bends had already formed at the end of the Cretaceous (SĂNDULESCU, 1984, 1994), the drift direction of the western platform sector was no longer perpendicular to the orogen during the Miocene, but oblique. Consequently, the Miocene tectonic regime at the contact between the Moesian Platform and the orogen in the Făgăraş Mountains area became transpressive.

At the same time, the tectonic regime on the platform/orogen contact east of the IMF remained compressional, proof being the large development of the Cretaceous and Miocene thrusts belts, as well as the current platform subduction beneath the orogen in Vrancea bend. The compressional regime in this region is the result of the Moesian Platform drift to west and northwest synchronous with the Foreapulian crustal block drift to east and its subsequent clockwise rotation (SĂNDULESCU, 1984, 1994).

Both the Miocene nappes and the covering Mio-Pliocene molasse in front of the Făgăraş Mountains are dextral displaced along the IMF. The subsequent down dip movement of the western fault compartment (SĂNDULESCU, 1984) took place during the Upper Miocene, after the nappes emplacement.

Seismic activity of the Itramoesian Fault. The IMF is seismically active, the focal depth of earthquakes covering the entire thickness of the crust (CORNEA & POLONIC, 1979). After the subcrustal earthquake of March 4, 1977 in Vrancea region, an intense seismic activity was recorded on this fault in the region localized northeast of Bucharest, where 13 earthquakes occurred between March 26 and June 6, 1977 (CORNEA & POLONIC, 1979).

Historical earthquakes related to IMF in the Moesian Platform took place at Urziceni on November 25, 1897 and October 26, 1898, both at depth of 2 km (CONSTANTINESCU & MÂRZA, 1980). Most earthquakes on the territory of Bulgaria is related to the tectonic activity of the Intramoesian Fault (ROGOZHIN et al., 2009). The current crustal earthquakes along the fault are concentrated on the Black Sea coastal area and 30-100 km offshore.

SCARA FAULT

Scara Fault geometry. The Scara Fault is in fact a fault zone consisting of parallel or braided vertical faults which crosses the Făgăraş Mountains on the same direction with the Intramoesian Fault between the localities Sebeşul de Jos (Sibiu County) on the northern slope and Nucşoara (Argeş County) on the southern one. The fault zone has a width of 1-2 km on the southern slope and branches northwestward reaching a width of 6-7 km on the northern slope (Fig. 1). The lithological markers show dextral fault displacements of 1.5-4.5 km on the southern slope (DIMITRESCU et al., 1985; GHEUCA, 1988) and of 0.5-3 km on the northern one.

In its western compartment, the Scara Fault is accompanied by NW-SE secondary fractures (Fig. 1) probably representing the surface expression of a deep arborescent structure, asymmetrically branched (half flower structure). Many sectors of rivers valleys in this tectonic compartment are oriented on NW-SE fractures direction (e.g. Jibra, Moaşa Sebeşului, Tătaru, Strâmba, Scara, Cumpeniţa). Such fractures also affect the Cretaceous and the Tertiary sedimentary formations within the Brezoi-Titeşti Basin and Călimăneşti Basin (e.g. ŞTEFĂNESCU et al., 1982).

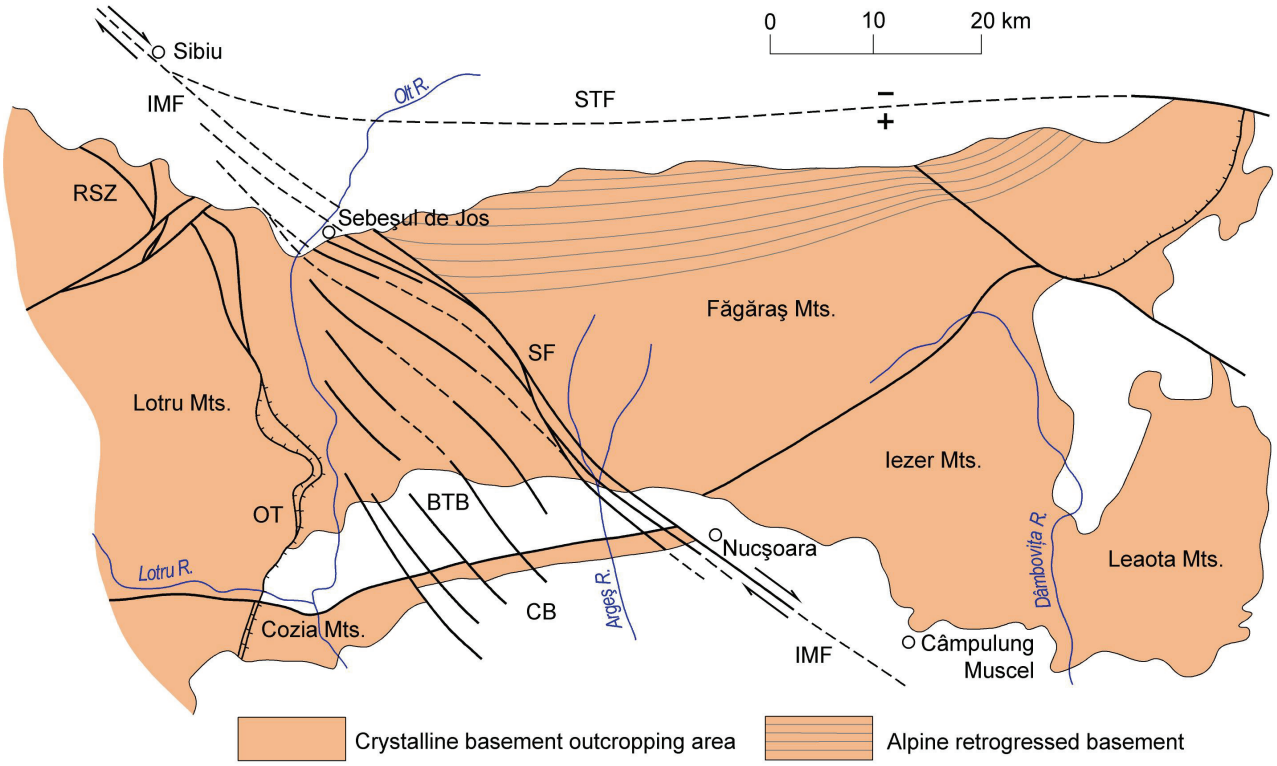

Figure 1. Scara Fault (SF)/Intramoesian Fault (IMF) in the Făgăraş Mountains area and related secondary faults suggesting a deep half flower structure in the western compartment. Abbreviations: STF-South Transylvanian Fault; RSZ-Răşinari Shear Zone; OT-Olt Valley thrust faults; BTB-Brezoi-Titeşti Basin; CB-Călimăneşti Basin.

At the present erosion level, the metamorphic rocks along the Scara Fault are deformed through frictional sliding and cataclastic flow. The deformation is homogeneous in the gneissic rocks, large volumes of rock being brecciated (Fig. 2a). Strain concentrations locally occur, marked by planes of cataclastic flow and hydrothermal fluids circulation (Fig. 2b). In the micaceous rocks, the deformation usually is localized on the foliation planes transposed on the fault direction (Figs. 2c, d).

Scara Fault kinematics. The Scara Fault corresponds to a major structural discordance in the crystalline basement of the Făgăraş Mountains, obvious on their northern slope especially. The eastern tectonic compartment was tightly folded, strongly retrogressed and completely restructured during the Cretaceous phases of the Alpine orogenesis. The Pre-Alpine (Hecynian) foliation was transposed on a penetrative axial plane cleavage associated with low-grade mineral parageneses (chlorite). This compartment has a monoclinal general structure with northern dip close to the vertical. By contrast, the basement in the western fault compartment is not affected by penetrative Alpine deformations so that it preserves the Pre-Alpine foliation associated with medium-grade mineral parageneses (staurolite, kyanite). The general structure of the western compartment on the northern slope is that of a large antiforme with western plunge.

These field data show the Scara Fault accommodated the isoclinal folding of the crystalline basement in the Făgăraş Mountains area during the Cretaceous. The fault limited to the west the Alpine retrograde metamorphism of the basement in the manner in which the Intramoesian Fault limited the westward development of the Miocene thrusts in the foredeep area (SĂNDULESCU, 1984). Situated next to Vrancea bend, the eastern fault compartment was folded under the action of the compressional forces exerted by the southeastward drift of the Foreapulian crustal block. At the same time, the tectonic regime in the western compartment was transpressive, with en echelon dextral displacements on the secondary faults related to the Scara Fault and non-penetrative deformations, strictly localized on them.

According to SĂNDULESCU (1984, 1994), the Carpathians bend in Vrancea region is the result of the southeastward movement of the Foreapulian block in concurrence with the northwestward movement of the Moesian Platform during the Cretaceous, accommodated by dextral displacements on the IMF and sinistral displacements on the Peceneaga-Camena Fault. Therefore, the movements along the IMF during the Cretaceous had the same sense with the movements on the Scara Fault, which accommodated the crust shortening in the crystalline basement on the northern border of the Făgăraş Mountains.

Land instability along the Scara Fault. In the southern area of the Făgăraş Mountains, the present-day tectonic movements on the Scara Fault are manifested through the permanent instability of the Argeş Valley slopes in Vidraru Lake area, as well as the active landslides in the eastern extremity of Cozia Mountains (Nucşoara-Slatina region). Landslides frequently occur on the related fractures in the western fault compartment in the Brezoi-Titeşti Basin (Perişani-Titeşti-Boişoara region). Toward southeast, the landslides affect the sedimentary cover in Poiana-Pripoare region, as well as the crystalline horst of Cozia Mountains, strongly brecciated and almost completely eroded in this area.

Not far from the northwestern Făgăraş Mountains, in Aciliu-Apoldu region, there are active landslides with detachment surfaces on NW-SE tectonic planes representing prolongations of the Scara Fault. These are visible in the Pannonian sedimentary deposits on the Transylvania Depression southwestern border. In this region, where the Intramoesian Fault intersects the South Transylvanian Fault, the land instability seriously affect the road infrastructure.

Here are also mentioned recent phenomena of mud volcanoes type, on the NW-SE lineament Apoldu-Sibiu-Avrig (CIUPAGEA et al., 1970).

SEISMIC ACTIVITY IN THE FĂGĂRAŞ MOUNTAINS AREA

Figure 2. The Scara Fault in outcrops. a, b) Brecciated augen gneisses on the Argeş Valley (Vidraru Lake area) with hydrothermal circulation on cataclastic flow planes (b). Support structure for the slope are seen in (a).
c, d) Chloritized biotite gneisses and fault gouge on the Cumpenița (c) and Moaşa Sebeşului valleys (d).

The active character of the NW-SE fault zone in the Făgăraş Mountains area is reflected in the high crustal seismicity of the region. In this region, there are registered numerous earthquakes aligned on the NW-SE direction, with hypocenters localized in the middle crust, as well as in the upper crust. The earthquakes along the Intramoesian Fault are concentrated in the western fault compartment (VISARION & SĂNDULESCU, 1991), namely in Vidraru Lake and Câmpulung Muscel areas (VISARION et al., 1988). Vidraru Lake area is located exactly on the Scara Fault lineament. If we accept two different faults on the same tectonic lineament in the orogen area, the earthquakes with depths greater than 10 km should be assigned to the IMF plane and those with depths less than 10 km to the Scara Fault plane, which is a nonsense.

A destructive earthquake was registered in the Făgăraş Mountains area on January 26, 1916, at 21 km depth, followed by a long series of aftershocks, from January to May, with hypocenters at depths of 10-15 km (CONSTANTINESCU & MÂRZA, 1980). According to the macroseismic data synthesized by ATANASIU (1961), the replies from January were recorded at Titeşti (Brezoi-Titeşti Basin), Cumpăna and Piscu Negru (Argeş Valley), the following replies migrating to the southeast at Arefu, Muşeteşti and Nucşoara, localities on the southeastern border of the Cozia Mountains. By correlating these seismic data with the tectonics of the region, it is found that most replies have occurred along two NW-SE lineaments, i.e. Cumpăna-Nucşoara along the Scara Fault and Titeşti-Arefu-Muşeteşti along the fault branches in its western compartment.

Another shallow earthquakes was recorded in the Câmpulung Muscel region January 5, 1940 at 5 km depth (ATANASIU, 1961), on November 21, 1943 at 2 km depth and on April 12, 1969 at 8 km depth (CONSTANTINESCU & MÂRZA, 1980). A question arises: if the Intramoesian Fault plane lies at 10 km depth not far to the northwest, on which fault these earthquakes occurred?

DISCUSSIONS AND CONCLUSIONS

The data presented in the text, some of them contradictory, can be summarized as follows:

a) in the Moesian Platform area, the Intramoesian Fault is active from the Cretaceous until the present, with dextral displacement during the Cretaceous and sinistral displacement starting with the Miocene (e.g. SĂNDULESCU, 1984, 1994);

b) in the Făgăraş Mountains area, the Scara Fault is active with dextral displacement from the Cretaceous until the present, which means that the Scara Fault kinematics was identical to the Intramoesian Fault kinematics during the Cretaceous;

c) starting with the Miocene, the horizontal displacements on the two faults become contrary, sinistral on the Intramoesian Fault in the platform and dextral on the Scara Fault in the orogen;

d) both faults played a determinant role in achieving the Alpine structures in the eastern part of the South Carpathians, connected to Vrancea bend of the Carpathian orogen;

e) the seismic activity of the Intramoesian Fault in the Făgăraş Mountains area cannot be separated from the seismic activity related to the Scara Fault.

The movement toward the orogen of the eastern IMF compartment from the Cretaceous until the present was conjugated with the movement in the same sense of the western fault compartment from the Cretaceous until the Sarmatian, when there took place the last thrusts on the inner flank of the foredeep. The higher dextral movement rate of the western compartment (SĂNDULESCU, 1984) explains the large Cretaceous thrusts in the western South Carpathians. The Cretaceous dextral fault displacement has also made possible the crust shortening by folding in the eastern South Carpathians basement on the northern border of the Făgăraş Mountains.

Starting with the Miocene, the displacement on the IMF became sinistral in the Moesian Platform area, the eastern fault compartment moving faster due to its subduction under the orogen in Vrancea region (RĂDULESCU et al., 1976; CORNEA & POLONIC, 1979; SĂNDULESCU, 1984, 1994). But the horizontal fault displacements in the inner foredeep and the Făgăraş Mountains basement are dextral. How is it explained?

Our explanation is that the current sinistral movement on the IMF in the Moesian Platform area disappears at the contact with the orogen by the subduction of its eastern compartment. Starting with the Miocene, the subduction plane splits the eastern fault compartment into two blocks with opposite movements, the platform block sinking below the orogen and the orogen block overthrusting the platform. The eastern IMF compartment moving toward NW does not collide with the eastern Scara Fault compartment moving toward SE on the same vertical tectonic plane. Therefore, the horizontal movement sense on the Intramoesian Fault-Scara Fault lineament can be simultaneously sinistral in the platform area and dextral in the orogen area.

In the western IMF compartment corresponding to the central-eastern South Carpathians there is no subduction plane. The platform comes in contact with the orogen through vertical and subvertical faults, possible thrust faults, related to the Tertiary foredeep subsidence (SĂNDULESCU, 1984). The Moesian Platform presses the orogen at low angle inducing en echelon dextral displacements in the crystalline basement. The tectonic instability of the western compartment in the Făgăraş Mountains is evidenced by its high crustal seismicity (VISARION & SĂNDULESCU, 1991) and the land instability. The seismic activity of the Intramoesian Fault in this region coincides with that of the Scara Fault. The depth range of earthquakes focus covers both the upper and middle crust, being localized on the same transcrustal tectonic plane belonging to the same fault, i.e. the Intramoesian Fault.

Now we can understand why ATANASIU (1961) could not explain why the earthquake of October 31, 1894 was simultaneously felt in the localities Câineni, Câmpulung Muscel and Brăila. The line Câineni-Câmpulung Muscel coincides with the Intramoesian Fault, active in conjunction with the Peceneaga-Camena Fault, where Brăila Town is seated. At that time, the author did not know about these geodynamic connections at regional scale.

REFERENCES

ATANASIU I. 1961. *Cutremurele de pământ din România*. Edit. Academiei. Bucureşti. 194 pp.

BARBU C. & DĂNEŢ T., 1970. Asupra fundamentului Platformei Moesice din zona Balş-Optaşi. *Petrol şi Gaze*. Edit. Tehnică. Bucureşti. **21**(7): 391-396.

CIUPAGEA D., PAUCĂ M., ICHIM T. 1970. *Geologia Depresiunii Transilvaniei*. Edit. Academiei. Bucureşti. 256 pp.

CONSTANTINESCU L. & MÂRZA V. I. 1980. A Computer-Compiled and Computer-Oriented Catalogue of Romania's Earthquakes during a Millenium (984-1979). *Revue Roumaine de géologie, géophysique et géographie / Géophysique.* Academia României. Bucureşti. **24**(2): 193-234.

CORNEA I. & POLONIC G. 1979. Date privind seismicitatea şi seismotectonica părţii de est a Platformei Moesice. *Studii şi cercetări de geologie, geofizică, geografie. Seria geofizică*. Academia României. Bucureşti. **17**(2): 167-176.

DIMITRESCU R., HANN H. P., GHEUCA I., ŞTEFĂNESCU M., SZASZ L., MĂRUNŢEANU M., ŞERBAN E., DUMITRAŞCU G. 1985. *Harta geologică a României scara 1:50000, foaia Cumpăna*. Institutul Geologic al României. Bucureşti.

DUMITRESCU I. & SĂNDULESCU M. 1970. *Harta tectonică a României, scara 1.1000 000*. Institutul Geologic al României. Bucureşti.

GHEUCA I. 1988. Versantul sudic al Munţilor Făgăraş, litostratigrafie şi tectonică. *Dări de seamă ale Institutului de Geologie şi Geofizică*. Bucureşti. **72-73**(5): 93-117.

RĂDULESCU D., CORNEA I., SĂNDULESCU M., CONSTANTINESCU P., RĂDULESCU F., POMPILIAN A. 1976. Structure de la croûte terrestre en Roumanie - essai d´interprétation sismiques profonds. *Anuarul Institutului de Geologie şi Geofizică*. Bucureşti. **L**(50): 5-36.

ROGOZHIN E. A., KHARAZOVA Y. V., GORBATIKOV A. V., SHANOV S., STEPANOVA M. Y., MITEV A. 2009. The Structure and Contemporary Activity of the Intramoesian Fault in Northeastern Bulgaria Obtained through a Complex of New Geological-Geophysical Metods. *Izvestiya, Physics of the Solid Earth*. **45**(9): 794-801.

SĂNDULESCU M. 1984. *Geotectonica României*. Edit. Tehnică. Bucureşti. 336 pp.

SĂNDULESCU M. 1994. Overview on Romanian Geology. *Romanian Journal of Tectonics and Regional Geology*. Institutul Geologic al României. Bucureşti. **75**(2): 3-15.

SOCOLESCU M., POPOVICI D., VISARION M., ROŞCA V. 1964. Structure of the Earth' crust in Romania as based on gravimertic data. *Revue Roumaine de géologie géophysique et géographie / Géophysique*. Academia României. Bucureşti. **8**: 3-11.

STELEA I. 1992. Considerations upon the lithostratigraphy and metamorphism of the Făgăraş Series. *Romanian Journal of Petrology*. Institutul Geologic al României. Bucureşti. **75**: 183-188.

ŞTEFĂNESCU M., HANN H. P., GHEUCA I., SZASZ L., ŞTEFĂNESCU M. 1982. *Harta geologică a României scara 1:50000, foaia Titeşti*. Institutul Geologic al României. Bucureşti.

VISARION M., SĂNDULESCU M., STĂNICĂ D., VELICIU Ş. 1988. Contribution à la connaisance de la structure profonde de la Plate-forme Moesienne en Roumanie. *Studii Tehnice şi Economice*. Institutul Geologic al României. Bucureşti. Seria D. **15**: 211-222.

VISARION M. & SĂNDULESCU M. 1991. Elemente rupturale majore în Munţii Făgăraş şi Transilvania de Sud. *Studii şi cercetări de geologie, geofizică, geografie. Seria geofizică*. Academia României. Bucureşti. **29**: 3-11

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