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Exhumation of the South Carpathians (Romania) and their block structure

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Abstract The present paper is dealing with the post-collision, disjunctive tectonics of the South Carpathians. The exhumation of this mountain chain started by the end of the Middle Cretaceous, but this process ended during the Upper Cretaceous, culminating with the Getic Nappe thrust. During this uplifting process and especially after it, during the Early Tertiary, the raising Carpathian Chain was affected by some longitudinal, transverse and diagonal faults, which separated it into several blocks.

***Keywords*:** South Carpathians, exhumation, fault, block tectonics, Romania.

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1. Introduction

A not-advised geologist who would have a look at any geological map of South Carpathians would wonder why in the western part of this mountain chain the Danubian Autochthon occurs from under the Getic Nappe and in the eastern part it is still covered by this huge nappe. Moreover, while the SemenicAlmăj, Poiana Ruscă and Sebeş-Cibin massifs look like lower plateaus, the axial massifs of the South Carpathians, such as Cerna, Retezat, Vulcan, Parâng, Căpăţâna and Făgăraş are comparatively higher, being separated one another by faults or systems of faults. The greatest difference of altitude between the axial zone of the South Carpathians and the surrounding areas occurs between the Făgăraş Mountains and the Transylvanian Basin, which is of about 2000 meters. Besides, within the South Carpathians, intramontane sedimentary basins were formed, and outliers of the Getic Nappe are still preserved over the outcropping Danubian Autochthon, sometimes together with Mesozoic sedimentary deposits. All these aspects suggest that the different segments of the South Carpathians moved vertically with different amplitudes, generating a block structure of this mountain chain (see also Savu, 2005).

Contributions to the post-collision young tectonics of the South Carpathians have been presented by numerous authors: Berza and Drăgănescu (1988), Ratschbacher et al. (1993), Stănoiu (2004), Moser et al. (2005), Stănoiu et al. (2006), Schmid et al. (2008) and others. Nevertheless, a detailed approach of the block structure of South Carpathians was not published, yet. In the present paper I try to show the main blocks into which the South Carpathians are separated and to mention the fractures along which these blocks moved.

2. Alpine evolution of the South Carpathians

By the end of Paleozoic and the beginning of the Mesozoic the European continent was undergoing a strong peneplanation process, owing to which the Variscan orogens have been intensely eroded. This erosion process affected the South Carpathians, too. Nonetheless, by the end of Triassic, an incipient continental rifting process started almost parallel with the eroded Variscan sutures (Savu, 2009). By the beginning of the lower Jurassic (ca. 180 Ma), along that continental rifting zone, a process of spreading started, so that the Carpathian Ocean opened along the rifting zone.

The spreading of the Carpathian Ocean lasted up to the end of Jurassic, when its closure started, with the convergence of the Moesian Plate and the Transylvanian Plate. Consequently, the crust of this ocean was shortened either by subduction or by obduction, the latter generating the olistostromes from the Carpathian ophiolitic suture, as for instance, that from the Mehedinţi

Plateau. The closure of the Carpathian Ocean was accomplished in the Middle Cretaceous, when the suture formed by the Severin ophiolites were covered by the Getic Nappe (Săndulescu, 1984). At the end of the upper Cretaceous, the huge Getic Nappe was thrust over the Danubian Autochthon, covering the formations and structures of the Carpathian suture. The resulted Carpathian Chain was covered by sedimentary deposits; subsequently, the main exhumation stage of the South Carpathians took place.

3. Exhumation of the South Carpathians

Exhumation of South Carpathians can be inferred for the Middle Cretaceous period, when a slow uplift of the old basement induced erosion, as shown by the exotic blocks of granitoid and crystalline schists present in the conglomerate deposits from two areas: the Mureş Couloir and the Haţeg Basin.

In the Barremian-Aptian deposits situated near the Tisa Village from the Mureş Couloir, exotic blocks of crystalline schists and large porphyritic granites with microcline megacrysts occur in a red horizon of conglomerates (Savu *et al*., 1996). The porphyritic granites remind of the shoshonitic granites from the Voineasa area (Savu, 2008). These exotic blocks most probably came from the Sebeş crystalline schists, in which such granitoid occur south of Orăştie (I. Stelea, oral communication), a place situated near the Mureş Couloir. Berbeleac (1968) also reported exotic blocks of granitoid rocks from the Cretaceous conglomerates occurring southeast of the Metaliferi Mountains, north of the Orăştie area.

Another area with exotic blocks of granitoids occurs in the Haţeg Basin, where such blocks are present in the upper Cretaceous conglomerates (Berza, 2004). These blocks must have come from the granitoid plutons of the Danubian Autochthon (which is exposed in the proximity of this sedimentary basin) during the postcollision exhumation and erosion.

The above observations show that there were uplifting phases of the crystalline basement of the South Carpathians as early as the Barremian-Aptian period, i.e. before the Getic Nappe thrust. The collision of the Moesian Plate with the Transylvanian Plate determined the thrust of the Getic Nappe (shear nappe) over the Danubian Autochthon (Murgoci, 1905; Codarcea, 1940; Săndulescu, 1984). By the end of the Cretaceous, after the Getic Nappe thrust, owing to some fault systems of east-west and northeast-southwest orientations, in the Carpathian Chain *sensu stricto*, the main exhumation stage began (see also Matenco and Schmid, 1999 and Moser et al., 2005), thus exposing the granitoid plutons to erosion, as the granitoid blocks from the Haţeg conglomerates showed. It is possible that the big granitoid plutons from the Danubian Autochthon, the mass of which was lighter than that of the surrounding crystalline schists, would have hade an important role in the uplifting process. During this process or later, in the Early Tertiary, because of several diagonal and transverse fault systems (Savu, 2004-2005; Stănoiu, 2004; Stănoiu et al., 2006), the South Carpathians chain was divided into several blocks (Fig. 1) and several intramontane sedimentary basins were generated, as well.

4. The main faults and blocks from the South Carpathians

First of all, regarding the structure of South Carpathians, it must be underlined again that west of the Ciunget – Polovragi fault (7, in Fig. 1) the Danubian Autochthon occurs from under the Getic Nappe and that east of this important fault the Danubian Autochthon is still covered by the Getic Nappe. This shows that the western segment of the South Carpathians was uplifted with respect to the eastern one, so that its tectonic cover consisting of the Getic Nappe was eroded, except for some outliers of this nappe (Savu, 2005).

Another feature of the South Carpathians structure is given by the Rusca Montană-Lotru-Loviştea fault (9), which extends east-west on almost the entire length of the South Carpathians. The Rusca Montană-Lotru-Loviştea divides the South Carpathians into a northern domain, mostly including the outcropping area of the Getic realm, and a southern domain, which mostly contains the outcropping area of the Danubian realm (Savu, 2005), as shown in Fig. 1. Moreover, along this fault, three intramontane sedimentary basins (Rusca Montană, Petroşani and Loviştea (Brezoi-Titeşti) line up. The northern and southern domains are generally formed of pre-Variscan and Variscan medium- to high-grade and low-grade metamorphic rocks. More information on these rocks and their outcropping areas are contained by the Geological Map of Romania, scale 1:1,000,000, which constituted the base on which the sketch-map from Fig. 1 was drawn. Yet, the map does not show clearly the block structure, excepting for the intramontane sedimentary basins, which formed as an effect of the post-collisional fault systems. I evidenced myself, alone or together with co-workers, some of these faults, such as the Lotru fault (Savu, 1968), Vârciorova-Craiu fault (Savu et al., 1973), Isverna fault (Savu, 1985), Ilova fault (Savu et al., 1973) and Muntele Mic fault (Savu, Hann, 1982), and checked in the field the presence and geometry of other major faults identified by other authors. An important contribution to the knowledge of the fault systems from the western part of the South Carpathian had Stănoiu (2004) and Stănoiu et al. (2006).

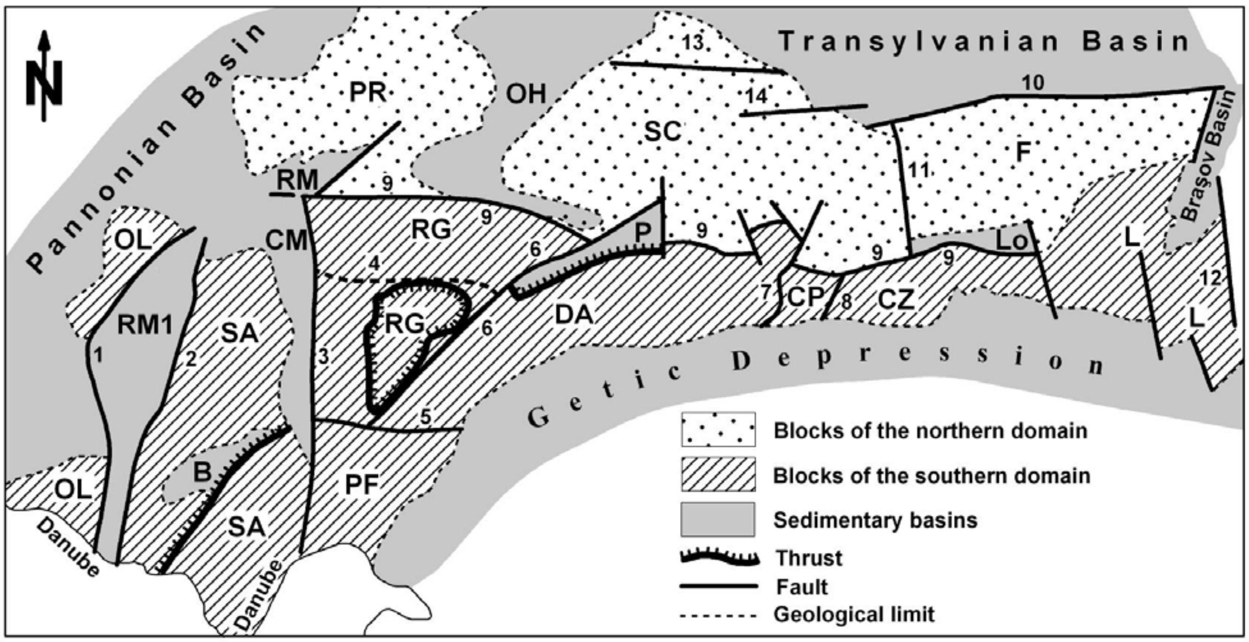

Fig. 1. Sketch-map showing the major faults and blocks of the South Carpathians. *Faults:* 1, Kujazevac – Pirot; 2, Cuptoare-Secul – Sicheviţa; 3, Oţelu Roşu – Orşova; 4, Vârciorova – Buta (it was figured by dash line because it crosses the Retezat-Godeanu block, thus, it does not mark a block boundary); 5, Mehadia – Isverna; 6, Cerna; 7, Ciunget – Polovragi; 8, Valea lui Stan; 9, Rusca Montană – Lotru – Loviştea; 10, North Făgăraş; 11, Olt Valley; 12, East Leaota; 13, North Sebeş; 14, Cărpiniş. *Blocks:* CP, Căpăţâna; CZ, Cozia; DA, Danubian (Vulcan-Parâng); F, Făgăraş; L, Leaota; OL, Ocna de Fier – Locva; PF, Porţile de Fier; PR, Poiana Ruscă; RG, Retezat – Godeanu; SA, Semenic – Almăj; SC, Sebeş – Cibin;. *Intramontane basins:* B, Bozovici; CM, Caransebeş – Mehadia; LO, Loviştea (Brezoi-Titeşti); OH, Orăştie – Haţeg; P, Petroşani; RM, Rusca Montană; RM_1, Reşiţa – Moldova Nouă.

4.1 Blocks from the northern domain of the South Carpathians

In the northern domain of the South Carpathians there are fewer blocks, but they are larger than those from the southern domain. In the westernmost part of this domain there is the Poiana Ruscă block (PR). This block is surrounded by the Cretaceous and younger sedimentary deposits of the Rusca Montană Basin (RM) and Orăştie – Haţeg Basin (OH). At the north it gets in contact with the Mureş Couloir deposits, and at south it is delimited from the Retezat – Godeanu block (RG) by the long fault Rusca Montană – Lotru – Lovіştea (9). This block consists of low-grade and medium-grade metamorphic rocks, inclusively crystalline limestones and greenstones (Mureşan, 1973). Numerous east-west trending secondary faults are crossing this block (Kräutner *et al*., 1969).

East of the Poiana Ruscă block there is the Orăştie – Haţeg Basin (OH), formed due to some local faults (see also Rotschbacher et al. 1993), in which Mesozoic and Tertiary sedimentary deposits accummulated. East of Orăştie – Haţeg Basin, there is the large block of Sebeş – Cibin (SC), which is surrounded by the sedimentary basins Orăştie – Haţeg at the west, and the Transylvanian Basin at the northeast. At its south margin it gets in contact with the blocks of the southern domain of the South Carpathians, from which it is delimited by the Rusca Montană – Lotru – Loviştea fault (9). At the east, the Sebeş – Cibin block is delimited from the Făgăraş Block by a system of north-south trending faults (11), as shown by Dumitrescu and Săndulescu (1970), which extends along the Olt Valley zone. A branch of this fault system is running along the Vasilatu (Valea lui Stan) Valley, and continues southward as the Vasilatu (Valea lui Stan) fault (8), which is associated with gold mineralizations. These faults are reverse faults, steeply dipping eastward (see the map by Savu *et al*., 1977). Therefore, they support the idea of some thrusting, despite the fact that they are perpendicular on the dominantly E-W trend of the East Carpathians structures. Like the Poiana Ruscă block, the Sebeş – Cibin block was also affected, along its northern part, by some east-west trending tectonic accidents. One of them is the Căpâlna incipient shear zone, where the crystalline schists and the hosted dykes of acid rocks have been deformed. In 1960, I observed south of the Cărpiniş Village an east-west trending fault in the crystalline schists, along which, the rocks had been transformed into a fault argillite with a thickness of about 1 meter.

The easternmost block of the northern domain is the Făgăraş block (F). This block is delimited by the fault (10) from the Transylvanian Basin, along which, the greatest difference of altitude (2000 m) occurs, as mentioned above. At the south, this block is contiguous with the Loviştea sedimentary basin, and is separated from the Cozia block (CZ) by the Rusca Montană – Lotru – Loviştea fault (9). The northeastern extremity of this block is delimited from the Jurassic and Cretaceous sedimentary deposits of the Braşov Basin by an almost north-south trending system of reverse faults dipping west (12), as shown by Savu and Schuster (1971). The limit between this block and the Leaota block (L) is represented either by faults or by normal lithological contacts. This limit could represent the northeastern extension of the longitudinal fault Rusca Montană – Lotru – Loviştea (9), but this possibility was not investigated so far. Transverse faults are crossing this block (Stelea et al. 2004; 2009, unpublished reports).

4.2 Blocks from the southern domain of South Carpathians

The southern domain of South Carpathians contains several blocks (Fig. 1). The westernmost block from this domain is the Ocna de Fier – Locva block (OL), which is separated from the rest of the South Carpathians by faults generated since the end of the Upper Cretaceous, like the Kujazevac – Pirot fault (1), which runs from Romania southward through Serbia (Giuşcă *et al*., 1966). Along this main fault, important banatitic intrusions, like those of Ocna de Fier and Moldova Nouă, were emplaced. Toward the west, this block is contiguous to the Pannonian Basin. The block consists of low-grade crystalline schists (Maier, 1974), partly covered by sedimentary deposits.

East of the Ocna de Fier – Locva block, there is the Reşiţa – Moldova Nouă Basin (RM_1), which subsided between the Kujazevac – Pirot fault (1) and the Cuptoare-Secul – Sicheviţa system of faults (2). Therefore, this basin looks rather like a graben, in which Paleozoic and Mesozoic sedimentary deposits were preserved (Răileanu *et al*., 1959). It is worth showing that some of these faults formed also since the end of Upper Cretaceous, because along them, dykes of banatitic acid rocks were intruded in the Văliug area.

The Semenic – Almăj block (SA) follows toward east, which is located between the last sedimentary basin and the Caransebeş – Mehadia Basin (CM). This block includes rocks from both the Getic Nappe and the Danubian realm. In this block, the Getic Nappe consists of the medium to high-grade crystalline schists ± manganese silicates and crystalline dolomites of the Sebeş-Lotru Group and numerous granitoid (granitic and trondhjemitic) plutons (Savu, 1970; 2008; Stan and Tiepac, 1996). The Danubian Autochtonous consists of crystalline schists, granitoid plutons and ultramafic rocks (Codarcea, 1940; Bercia and Bercia, 1975; Anastasiu, 1976; Stan et al., 1985). In the southern part of this block, the Bozovici Neogene sedimentary basin (B) was formed along local faults.

The Caransebeş – Mehadia Basin (CM) (Fig.2), containing Neogene sedimentary deposits, extends, on the north-south direction, between Semenic–Almăj block (SA) and the Retezat - Godeanu block (RG). The Oţelu Roşu – Orşova fault system (3) marks the limit between the Caransebeş – Mehadia Basin and the Retezat - Godeanu block. It is obvious that the faults from the Oţelu Roşu – Orşova system, and probably from other associated systems, have been open faults, because, along them, Paleozoic formations (Savu, Hann, 1982), Mesozoic limestones (Gherasi, Savu, 1968) and the Paleozoic formations from the granitoids near Orşova occur as tectonically-included wedges. An example in this respect is the Piatra Ilovei (Ilova Stone), which is a limestone wedge tectonically included in the pre-Variscan granitoid pluton of Muntele Mic (see the picture in Savu et al., 1973). On the western margin of the basin, it seems that its Neogene deposits transgressivelly lie on the crystalline schists from the Semenic–Almăj block, although, near the Slatina Timiş, some north-south short faults are separating the two structural units.

The Retezat – Godeanu block (RG), which follows toward the east, in the Danubian Autochthon area, exhibits more complicated aspects, both by position and structure. It is delimited, toward the west, by the Oţelu Roşu – Orşova fault system (3), toward the southeast, by the Cerna fault (6), and toward the north, by the Rusca Montană – Lotru – Loviştea fault (9). According to Berza and Drăgănescu (1988), the Cerna fault extends further away, toward the northeast. The Mehadia – Isverna fault (5) intersects the Cerna fault at its southern extremity. Around the crossing of the two faults there are the famous Băile Herculane thermal water springs, known since the Roman period. In the structure of the Retezat – Godeanu block, an infrastructure and a superstructure can be distinguished. The infrastructure is formed by the Jurassic sedimentary formations of the Arjana Zone (Codarcea, 1940), which include alkali volcanics, and of Cretaceous sedimentary deposits, over which the superstructure of the Godeanu outlier of the Getic Nappe is placed (Gherasi, 1937; Bercia, 1975), being formed of the crystalline schists from the Sebeş-Lotru Group. The west–east trending Vârciorova–Buta fault (4) cuts the Retezat – Godeanu block. Along this fault, the Muntele Mic granitoids have been strogly sheared.

Southeast of this block, the Danubian (Vulcan-Parâng) block (DA) follows, which extends from the Isverna –Mehadia fault (5) round up to the Ciunget – Polovragi fault (7), which delimits at the same time the two big segments of the South Carpathians (Savu, 2005).

On the old geological maps of Romania, the Ciunget-Polovragi fault (7) was represented as a margin of the Getic Nappe, thus part of the Getic thrust. If it had been so, the Danubian Autochthon should have extended like a ‘V’, downstream, along the Lotru Valley, which is a dip valley. Nevertheless, the representation of this tectonic zone on the geological maps as an almost straight line, indicates a very steep dip to the east, thus its fault nature, with a north-south strike. Therefore, the Ciunget-Polovragi fault (7) cuts the South Carpathians chain, so that the western Danubian (Vulcan-Parâng) block (DA) was uplifted and the eastern Căpăţâna block was subsided, the latter still preserving the Getic Nappe formations (see also Savu, 2005). At the same time, it determined the displacement toward north of the Danubian (Vulcan-Parâng) block (DA) and of the plane of the long fault (9), as shown in Fig. 1.

The Danubian (Vulcan-Parâng) block (DA) consists of the Lainici-Păiuş and Drăgşan metamorphic rock series (Manolescu, 1933) and numerous granodioritic-granitic, throndhjemitic and shoshonitic plutons (Savu, 2008) and Mesozoic sedimentary deposits over which some Getic Nappe outliers are lying. Between this block and the Retezat – Godeanu block is situated the intramontane sedimentary basin of Petroşani (P), which includes coal deposits among its formations.

The possible involvement of east-west longitudinal faults at the transition from the South Carpathians to the Moesian Platform it is very difficult to check because of the foredeep cover. Nevertheless, in some places, such as Stăncesti (Savu et al., 1972) and Mănăstirea Crasna (Savu et al., 1973) such faults are visible. These are reverse faults dipping northward, which catch along them deposits of the Schela Formation.

At the southwestern extremity of the Danubian (Vulcan-Parâng) block (DA) the Porţile de Fier block (PF) is located, which extends from the Mehadia-Isverna fault (5) down to Danube. It consists of Mesozoic sedimentary deposits overlain by the Getic Nappe outlier of Porţile de Fier. This block and the Mehadia-Isverna fault (5) are situated in front of the Wallachian spur (Stille, 1953) of the Moesian Plate, which advanced from the east.

East of the Danubian (Vulcan-Parâng) block (DA) and the Ciunget-Polovragi main fault (7), the Căpăţâna block (CP) is located. It is delimited at the north by the Rusca Montană – Lotru – Loviştea fault (9) and by the Vasilatu (Valea lui Stan) fault (8) at the east. This block consists of the medium- to high-grade metamorphic rocks of the Sebeş-Lotru Group. The Cozia block (CZ) follows to the east and extends eastward to the Leaota block (L). The Cozia block is delimited from the Făgăraş block by the Rusca Montană – Lotru – Lovişţea fault (9) and from the Leaota block (L) by the northwest-southeast trending Câmpulung fault system. It consists of the medium- to high-grade crystalline schists of the Făgăras Mountains, the Cozia ocular migmatites and by Eocene sedimentary deposits (Dimitrescu, 1962; Savu, Schuster, 1971; Balintoni, 1975). The easternmost block of the southern domain of South Carpathians is the Leaota block (L). This has a more complicated structure compared with the other blocks of the southern domain, consisting of metamorphic rocks (Gherasi, Dimitrescu, 1974) and patches of Mesozoic sedimentary deposits, which extend eastward to the Bucegi Mountains, from which the Leaota block is delimited by the fault system (12) consisting of reverse faults with westward dip (Savu and Schuster, 1971), in the opposite sense to the fault system (11) from the western boundary of the Făgăraş block (F), which are dipping eastward. Both these structural features support the bilateral uplifting of the Făgăraş block (F).

Like the other blocks from the southern domain of the South Carpathians, the Leaota block is in contact with the young sedimentary deposits of the Getic Depression.

5. Conclusions

The exhumation of South Carpathians took place along some longitudinal, marginal faults and its inception goes as far back as the end of the Middle Cretaceous, as shown by the exotic blocks of Carpathian granitoids occurring in the sedimentary deposits of this age. The most important uplift of the South Carpathians occurred during the Upper Cretaceous, culminating with the Getic Nappe thrust. By the end of the Upper Cretaceous and during the Early Tertiary, besides the mentioned longitudinal faults, transverse and diagonal faults played an important role, determining the separation of the South Carpathians into several blocks. It seems that, during the exhumation of the South Carpathians, owing to the inner longitudinal Rusca Montană – Lotru – Lovişţea fault (9), the Carpathian Chain was divided into a northern domain and a southern domain. Then, the transverse fault Ciunget-Polovragi (7) separated the southern domain into a western segment and an eastern segment, displacing the western segment northward. The western segment was more uplifted than the eastern one, so that its cover of Getic Nappe was almost completely eroded, save for some outliers, while over the subsided eastern segment the Getic Nappe is still present. Concomitantly with this process and after it, the mentioned fault systems achieved the separation of South Carpathians into several blocks. This study points to the importance of faults, beside thrust nappes, in the construction of the present edifice of the South Carpathians.

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