GENESIS OF THE CARPATHIAN OPHIOLITIC SUTURE AND ORIGIN OF ITS VARIED MAGMATIC ROCKS, ROMANIA

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The Carpathian ophiolitic suture (COS) represents a long structure, which extends from the Eastern Alps toward east, then running all around the Apuseni Mountains-Trasylvanian block (plate) and finally getting into the Serbian territory, where makes junction with the main branch of the Alpine ophiolitic suture. To get to the actual bent COS, the region in which it is located went through four evolution stages. During the first stage, which started by the end of Triassic, a rifting bent zone occurred within the European peneplane, in which a system of transcrustal faults was engendered, through which a system of within-plate basaltic rocks was emplaced. At the beginning of Jurassic, probably in Liassic, the rifting process got into a spreading process, so that the Carpathian Ocean *sensu stricto o*ccurred along the rifting zone. At the same time this phenomenon reactivated the old neighboring East European, Moesian and Transylvanian tectonic plates. Within this ocean a classical ocean crust was generated, which consisted of MORB-type rocks. Probably during the Oxfordian, the closure of the Carpathian Ocean started under the influence of the motion of the three convergent plates above mentioned, which finally modelled the actual bent COS. During the closing process there was generated an immature island arc, in which a calc-alkaline volcanism manifested itself. During the ocean closure the ocean crust was entirely consumed by subduction or by the obduction of the ocean crust slabs in front of the obducting Transylvanian Plate, where a subduction basin with wildflysch deposits was formed. Some slabs of ocean crust underwent a retro-obduction process, being pushed back over the obducting Transylvanian Plate like in the Mehedinți Plateau from the South Carpathian segment of COS. The three convergent tectonic plates got into collision and the actual bent Carpathian Chain was modelled. During the post-collision stage the COS tectonics was achieved, which was of different style in the two segments of COS. Thus, in the South Carpathian segment a large-nappe orogen manifested itself, while in the East Carpathian segment an overlapped orogen was active.

Key words: Rifting stage; Ocean stage; Ocean closure stage; Post-collision stage; Tectonics.

INTRODUCTION

Some time ago I presented a comparative study on the two ophiolitic sutures from the territory of Romania – the Carpathian Ophiolitic Suture (COS) and the Mureş Ophiolitic Suture (Savu[1]). On this occasion I showed the main characteristics of the two structures. Later on, I realized a detailed study on the Mureş Ophiolitic Suture (Savu[2]). But, for a complete picture of the ophiolitic sutures and their relationships with the neighboring convergent tectonic plates from the Carpathian area, it is necessary a special study on the COS, too.

By searching the genesis of the Mureş Ophiolitic Suture I found out that, to get to an end, such a structure must get through four main evolution stages, as follows: 1, pre-ocean continental rifting stage; 2, ocean opening stage; 3, ocean closure-collision stage; 4, pos-collision stage. In the light of these conclusions, I will try to present the genesis of COS and of associated rocks with, keeping in mind that ophiolites are real ocean floor formations.

Referring to the studies on the Romanian Carpathians, along which COS extends, it results that numerous authors studied their geology. Thus, from west to east, the geology and tectonics of these formations were studied by Codarcea[3], Băncilă[4], Rădulescu and Săndulescu[5], Bleahu[6], Săndulescu[7,8], Savu[9] and more recently by Hoeck *et al.*[10]. Savu[11], Savu *et al.*[12,13], Dimitrescu[14], Cioflica *et al*[15], Săndulescu and Săndulescu[16] and recently Grinea[17] studied the magmatic rocks of COS, including its ophiolites. More recently, I studied the Romanian segment of COS in relation with its triple junction and the North Dobrogea failed branch (Savu[18]).

POSITION OF COS IN THE CARPATHIAN AREA AND ITS GENERAL STRUCTURAL ELEMENTS

The Carpathian Ophiolitic Suture represents a long Alpine structure, which extends from the Eastern Alps toward east, running all around the Apuseni Mountains-Transylvanian block (plate). It is running through the West Carpathians, East Carpathians and South Carpathians up to the western extremity of the Moesian Plate, then going southward, where it joins the Vardar Zone in Serbia (Fig. 1).

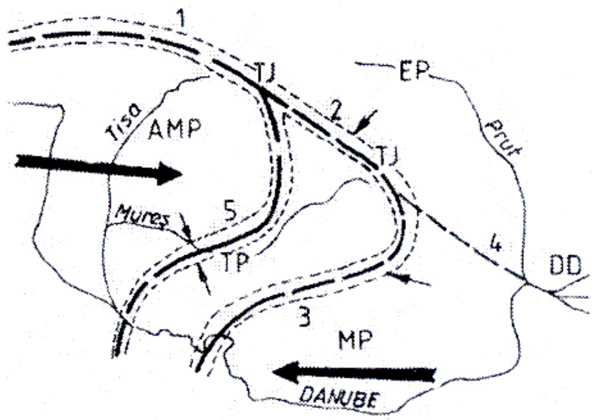

Fig. 1. Position of COS in the system of tectonic plates and ophiolitic sutures from the Carpathian area, and its extension through the West Carpathians (1), East Carpathians (2) and South Carpathians (3); 4, the failed branch of North Dobrogea; TJ_1, triple junction related to North Dobrogea failed branch; TJ_2, triple junction related to the Mureş Ocean; 5, Mureş Ophiolitic Suture; EP, East European plate; MP, Moesian Plate; AMP, Apuseni Mountains Plate including the Transylvanian Plate; the thick lines mark the ophiolitic sutures. The broken thin lines mark the flysch zones ($J_3 – K_2$) with or without ophiolitic olistoliths. The arrows show the direction of the Alpine subduction of the convergent plates. DD, Danubian Delta.

This ophiolitic suture (Fig. 2) evolved between three convergent tectonic plates (Figs. 1 and 2). These plates are represented by the East European Plate (EP) and the Moesian Plate (MP) as outer convergent plates subducting under a third inner plate, the Apuseni Mountains Plate (AMP), including the Transylvanian Plate (TP), as it was shown in Figure 1. The motion of these convergent plates modelled the bent shape of COS (Fig. 2), as it did before with the old Pre-Variscan and Variscan ophiolitic sutures (see Savu[9]).

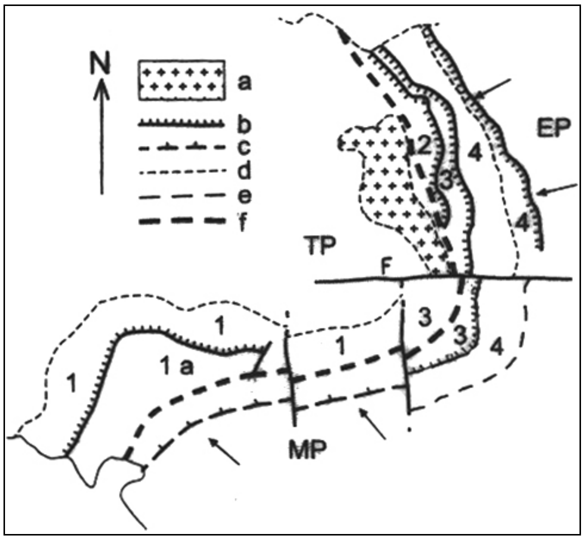

Fig. 2. Scketch-map (addapted after the Geological Map of Romania, scale 1:5 000 000) showing the main tectonic units from COS. South Carpathian segment: 1. Getic Nappe; 1a, Danubian Autochthone. East Carpathian segment: 2, Crystallino-Mesozoic Nappe representing the eastern margin of the obducted Transylvanian Plate, now mostly subsided in the Transylvanian Basin; 3, Wildflysch Nappe; 4, Paleogene-Miocene formations Nappe; a, Neogene volcanic arc; b, thrust; c, possible extension of the Getic Nappe; d, boundary of the geological formations; e, fault; f, possible position of the collision plane beneath the nappe structure of COS (drawn in accordance with the Carpathian electronical conductivity anomaly by D. Stănică and M. Stănică[19]); TP, obducted Transylvanian Plate; EP, subducted East European Plate; MP, subducted Moesian Plate; F, the South Transylvanian transcrustal fault. The short arrows mark the direction of the plate subduction.

As shown in Figure 1, on the Romanian segment of COS there occur two triple junctions like TJ_1 and TJ_2. TJ_1 represents the place from which the North Dobrogean failed branch separated. And TJ_2 indicates the place from which the Mureş Ocean detached to get finally into the Mureş Ophiolitic Suture.

PRE-OCEAN CONTINENTAL RIFTING STAGE AND THE RELATED WITHIN-PLATE ROCKS

By the end of Paleozoic and during the Triassic the entire European continent represented a large peneplain. The mountain chaines resulted from the Pre-Variscan and the Variscan orogenies were strongly eroded and peneplanized, epicontinental formations being deposited over the continent. But during the Middle Triassic (ca. 200 Ma), due to a thermo-tectonic process, in the vast peneplane a convexity occurred in the crust along the actual COS zone. The convexed crust cracked, a succession of transcrustal faults occurring there (Fig. 3), which engendered a rifting zone. It is of note that this rifting zone was running parallel with the scars of the old Pre-Variscan and Variscan ophiolitic sutures and with the respective orogens (Savu[9]).

Along the transcrustal faults from the rifting zone a within-plate volcanisn started manifesting itself, mostly by basic rock dykes, the volcanic products of which, together with the sedimentary formations, deposited on the Pre-Triassic basement of the COS zone and of the North Dobrogea failed branch.

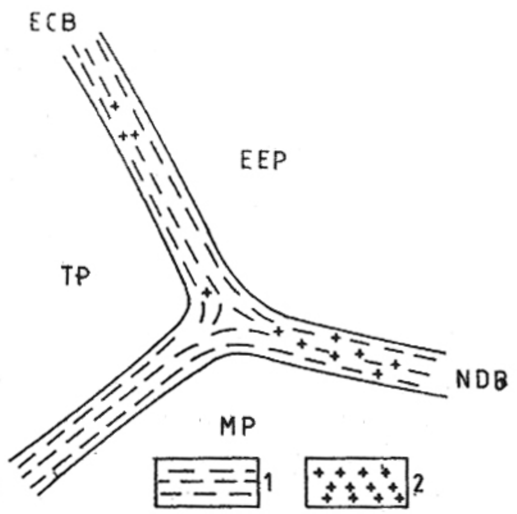

Fig. 3. Model showing the pre-ocean rifting zone with three branches, in which dykes and lavas of within-plate basalts occurred. 1, longitudinal transcrustal faults and basaltic dykes occurred along the faults; 2, remnants of Triassic lava flows and pyroclastics; EEP, East European Plate; MP, Moesian Plate; TP, Transylvanian Plate; ECB, East and West Carpathian branches of the rifting zone; SCB, South Carpathian branch; NDB, North Dobrogea failed branch.

As the North Dobrogea branch was not affected by the opening of any ocean zone and by the related tectonic movements, as the COS area did, an almost complete sequence of the Triassic formations were preserved in this region. There occur volcanic rocks as lavas and dykes and sedimentary deposits as detritic formations, limestones and red argillites, formed in an epicontinental sea (Savu *et al.*[20]). The volcanism started in Spathian by a bimodal volcanism, which produced basalts, quartz-keratophyres and rhyolites (Savu *et al.*[21]), followed in Spathian-Anisian by flood basalts and in Ladinian by basaltic dykes (Savu[22]). Because of the absence of an ocean zone, gabbros and ultramafic rocks are missing from the Triassic magmatic association.

Similar formations are to be found in the COS area either as dykes crossing the Crystallino-Mesozoic zone or as olistoliths of within-plate basic rocks in the Barremian-Albian wildflysch from the East Carpathians. In the South Carpathian branch these formations are scarcelly represented by dykes of basic rocks. Basaltic dykes have been described by Grinea[17] in the Bucovinian crystalline schists basement and olistoliths of within-plate basalts have been presented by Hoeck *et al.*[10]

The most important rocks are the basalts, which have been analysed in different papers (see Savu[23]; Hoeck *et al.*[10]; Grinea[17]). In the North Dobrogea failed branch they occur as tholeiitic pillowed basalts, which erupted in an epicontinental sea. They show a within-plate signature, as it was shown in Figure 4 (Savu[23]). According to the new chemical data obtained by Grinea[17], the Triassic basalts from the dykes cutting the Bucovinian crystalline schist basement plot in the within-plate field of the diagram in Figure 4, too, and in the same field plot the "ocean island basalts (OIB)", analysed by Hoeck *et al.*[10]. Not only plot these basalts in the within-plate field of the diagram in Figure 4, but also they fall just in the field of the Triassic basalt dykes and lavas from the Crystallino-Mesozoic zone of the East Carpathians and North Dobrogea (Savu[23]). Moreover, on a Hf/3-Th-Ta diagram made by Hoeck *et al.*[10] the last rocks fall in the same (WPB) field.

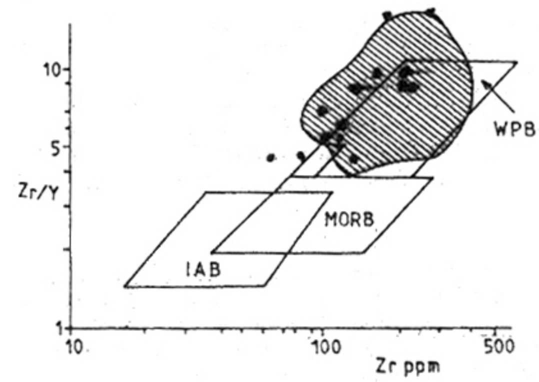

Fig. 4. Distribution area (hashures) of dykes and lavas of Triassic basaltic (diabasic) rocks from the East Carpathians, South Carpathians and North Dobrogea (data from Savu[23]) on the Zr/Y vs. Zr diagram of Pearce[24]. WPB, within-plate basalts; MORB, mid-ocean ridge basalts; IAL, island arc lavas. Dots represent the plots of basalt dykes from the Bucovinian crystalline schists (data from Grinea[17], Table 15) and of "OIB" olistoliths from the Barremian-Albian of the East Carpathian wildflysch (data from Hoeck *et al.*[10]).

All these data show that during the Triassic rifting stage no ocean zone occurred along the actual COS and in the North Dobrogea failed branch. Therefore, the "OIB" rocks above mentioned must be considered as olistoliths of within-plate basalt dykes crossing the crystalline schists from the East Carpathians, which have been reworked in the wildflysch together with olistoliths of Triassic sedimentary rocks and Jurassic ophiolites.

OCEAN OPENING STAGE AND GENESIS OF ITS OCEAN FLOOR MAGMATIC ROCKS

The rifting stage lasted up to the beginning of Jurassic. During the Liassic (ca. 180 Ma) the rifting process changed into a spreading process, which led to the opening of the Carpathian Ocean *sensu stricto* along a spreading axis. As the ocean floor magmatic rocks–ophiolites – obducted from this ocean and the associated Liassic deposits show, this ocean extended all along the rifting zone (Fig. 5). This figure also shows that the ocean trench opened in the East Carpathian segment along the outer margin of the rifting zone, and in the South Carpathian segment it opened along the inner margin of the rifting zone. This situation would explain why the magmatic products of the Triassic rifting zone erupted along this branch are now located in the basement of the northern margin of the Moesian Plate, where they are covered by the post-Triassic deposits of the Pericarpathian Depression.

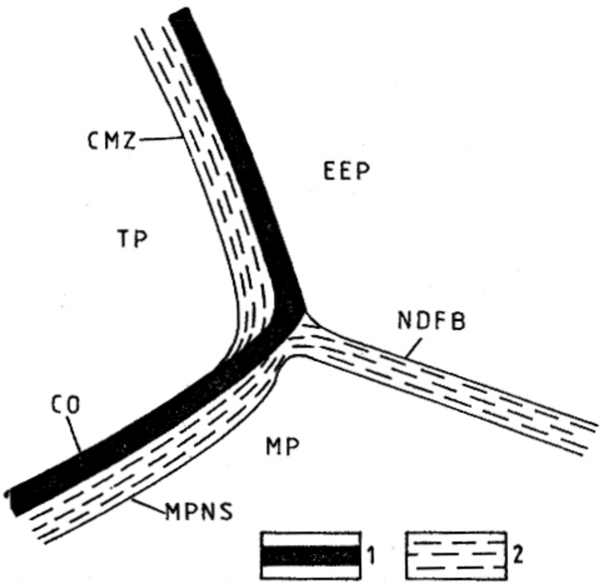

Fig. 5. Opening of the Carpathian Ocean (CO) along the Triassic rifting zone. CMZ, Crystallino-Mesozoic zone of the East Carpathians; MPNS, northern part of the Moesian Plate; NDFB, North Dobrogea failed branch; EEP, East European Plate; TP, Transylvanian Plate including the Apuseni Mountains Plate (according to Savu[1]); 1, Carpathian Ocean; 2, volcanic remnants from the pre-ocean rifting zone. The same legend as in Figure 3.

All the ophioltes produced by the Carpathian Ocean are now not *in situ*. They are to be found in an alochthonous position, occurring as olistoliths and olistolplates included in the Mesozoic flysch formations. Usually, they occur together wuth olistoliths of Triassic magmatic and sedimentary rocks included in the Barremian-Albian wildflysch. This situation engendered the confusion as regards the age of the Carpathian Ocean, which was considered as a Triassic ocean (see Hoeck *et al.*[10]).

As the Carpathian Ocean crust was completely consumed either by subduction or by obduction, many geologists who studied the East Carpathian geology, for instance, supposed that the ophiolite slabs of basic and ultramafic rocks occurring in the wildflysch or in other occurrences from these mountains originated in the Transylvanian realm ophiolites i.e. in the Transylvanian Basin (see Turculeţ[25]). But the Mesozoic magmatic rocks occurring on the bottom of the Transylvanian Basin are represented, as it is known so far, by island arc volcanics, which are similar to those from the Mureş ophiolitic suture (Savu *et al.*[26]). It does not exclude the possibility that ocean floor ophiolites could be present under the island arc volcanics, like in the Mureş ophiolitic suture, where they are represented by basalts and gabbros, and very little by ultramafic cumulate rocks (Savu[27]). Therefore, the Mureş Zone ophiolites could be considered as deprived of ultrabasic rocks, if it would not be only for the small Gealacuta serpentite slice of a few square meters pushed up through a tectonic line (Savu *et al.*[28]). Besides, ultramafic rocks were found neither in the volcanic rocks from the bottom of the Transylvanian Basin, nor in the olistolits from the Maramureş area (Bombiţă, Savu[29]). In conclusion, the big exotic blocks of Alpine ultramafic rocks from the East Carpathian segment of COS do not originate in the Transylvanian realm ophiolites.

But there is another explanation of the origin of the ophiolite slabs present on the obducted plate of the COS, namely, the explanation accorded by Savu *et al.*[30] to the ophiolitic olistoliths from the olistostrome on the Mehedinți Plateau in the South Carpathian segment of COS. These authors showed that these ophiolitic slabs are occurring there due to a retro-obduction process, represented in Figure 5. It shows that under the conditions of the subduction-obduction process, during the subduction of the Carpathian Ocean crust under the obducting Transylvanian Plate, some slabs of ocean crust of basic and ultramafic composition escaped the obduction manifested itself in front of the obducting Transylvanian Plate, thus being pushed back over this plate.

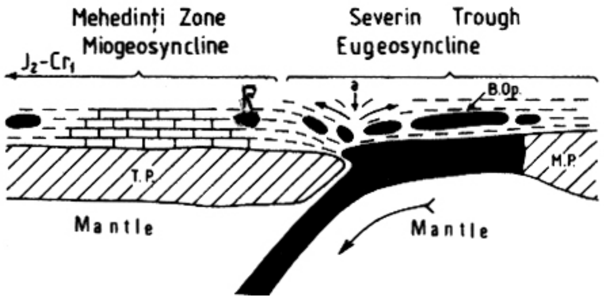

Fig. 6. Model showing the retro-obduction of ophiolitic slabs on the obducting Transylvanian Plate (Mehedinți Plateau ophiolites from the Danubian Autochthone) (Adapted after the models of Dewey and Bird[31,] and of Christensen and Salisbury[32]): TP, obducting Transylvanian Plate; MP, subducting Moesian Plate; B Op, basaltic ophiolite olistolith; R, retro-obducted slab.

In the South Carpathians the ocean floor rock slabs of basalts and ultramafic rocks, as well as of blocks of ophiolitic mélange, occur as olistoliths and olistolplates in the olistostrome of the Severin Nappe from the Mehedinți Plateau (Fig. 6). As shown by Savu *et al.*[13], these formation underwent a Late Kimmerian very low regional metamorphism, the age of which was of ca. 130 Ma (see also Savu *et al.*[33]). Among these slabs an important basaltic olistoplate occur, which is hosting a stratiform copper deposit of Cyprus-type (Savu *et al.*[34]).

As shown above, the ophiolites consist of basic and ultramafic rocks. According to their composition, the last rocks are represented by Alpine-type peridotites (Fig. 7), which consist of harzburgites and rarely of lherzolites. Sometimes, in the structure of the peridotitic olistoliths there are to be observed bands of wehrlites with diallage laminae. During the Late Kimmerian metamorphism the ultramafic rocks have been deformed and almost entirely serpentinized.

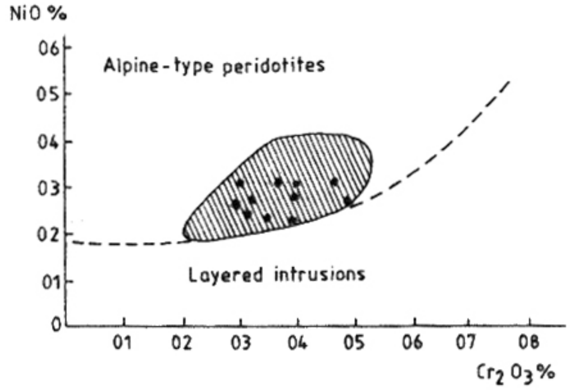

Fig. 7. Distribution field of the ultramafic rocks from the COS on the Ni *vs*. Cr_2O_3 diagram fields according to Malpas and Stevens[35]. Hashures, field of the ultramafic rocks from the Mehedinți Plateau in South Carpathians (data from Savu *et al.*[13]; dots, plots of the ultramafic rocks from the East Carpathians (data from Hoeck *et al.*[10]).

The basaltic olistoliths consist of pillowed variolitic and amygdaloidal basalts; dolerites rarely occur there. Intercalations of black shales, abyssal red argillites and jaspers with flattened radiolaria occur in a pyroclastic horizon from the basaltic olistoplate, which is hosting the copper deposit.

In the southern part of the East Carpathians ophiolitic rocks obducted from the Carpathian Ocean are to be found in the wildflysch of the Perşani Mountains (Dimitrescu[14]; Cioflica *et al.*[15]). It is of note that in the East Carpathian wildflysch, including that from the Perşani Mountains, there are to be found olistoliths belonging to three petrographic provinces, namely: 1, olistoliths of Triassic within-plate basalts and sedimentary formations, mostly limestones, formed during the rifting stage; 2, Late Triassic to Jurassic olistoliths of alkaline rocks and sedimentary deposits reworked from the Carpathian alkaline province area (Savu[36]); 3, olistoliths of Jurassic ophiolites obducted from the Carpathian Ocean.

As the wildflysch represents such a mélange of rocks of different age and origin, it is difficult to separate them from one another. However, according to their features, I considered that the Jurassic ophiolites are represented there by pillowed basalts, dolerites, gabbro-dolerites and gabbros, and without any doubt, by ultramafic rocks. Concerning the basaltic rocks, in the paper by Cioflica *et al.*[15] it is not clear which basalts are within-plate rocks and which are the basalts obducted from the Carpathian Ocean. Otherwise, at the time when the paper was published such a question had not yet occurred. In this respect it is noteworthy to show that in the basaltic rocks analysed by these authors the TiO_2 content varies from 3.0 to l.63 %, values which are characteristic for the within-plate basalts. Anyhow, the volcanic rocks presented in the paper are pillowed basalts with amygdaloidal structure and ophitic texture. Some rocks underwent the spilitization processes. Without any doubt, these last basalts are ocean floor rocks.

The gabbros, gabbro-dolerites and dolerites, which occur either as isolated olistoliths or associated in groups, consist of basic plagioclase, which occurs together with diopside crystals, often altered into uralite. Sometimes the gabbros were saussuritized, in which case plagioclase was partly substituted by secondary minerals. Some gabbro olistoliths contain Ti-magnetite and ilmenite in a higher amount then in normal rocks.

The olistoliths of ultramafic rocks, mostly serpentinites, have a lenticular shape and consist of an aggregate of fibrous chrysotile and antigorite lamellae. Relicts of olivine are seldom occurring in these rocks. Sometimes talc is also present.

Both basic and ultramafic rocks have been described as olistoliths in the wildflysch formation from the "Wildflysch Nappe" (Barremian-Albian) of the East Carpathian segment of COS in the Rarău and Bicaz areas. Hoeck *et al.*[10] and Grinea[17] showed that the volcanic rocks occur as pillowed basalts, exhibiting an ophitic up to porphyritic and even glomeroporphyritic texture. In the massive basalts there occur phenocrysts of plagioclase and clinopyroxene included in a groundmass consisting of plagioclase, pyroxene and magnetite microcrystals. Rarely, there occur basalts with variolitic structure, in the varioles of which the plagioclase laths are radially disposed. Dolerites also occur as olistoliths in the wildflysch deposits. They show an intergranular-doleritic texture.

Olistoliths of gabbros are rarely observed. Usually, they are represented by Ti-magnetite gabbros, like the gabbros from the Mureş ophiolitic suture (Savu[37]). The gabbros of Pojorâta consist mostly of diopside, showing very fine crystals of amphibole on the clivage planes, and plagioclase. Frequently, the pyroxene crystals have been altered into a green hornblende (Hoeck *et al.*[10]), probably uralite, associated with epidote, chlorite and possible calcite. Plagioclase shows a large variety of composition, the more basic samples being of labrador (An_{50}). Often the mineral was highly altered, but a slight normal zoning is still observed

The ultramafic rocks from these areas of COS are mainly represented by olistoliths of lherzolites, those of harzburgites rarely occurring. On the diagram in Figure 7 they plot, together with those from the South Carpathians, in a restricted field situated in the "Alpine-type peridotites" domain.

Taking into account that the ocean floor basic and ultramafic rocks originated in the same gabbroic parental magma, on the diagram in Figure 8 there have been plot the clinopyroxenes from the olistoliths of such rocks from the East Carpathians wildflysch, analysed by Hoeck *et al.*[10] It results from the diagram that the most represented clinopyroxenes derived from tholeiitic rocks of ocean floor origin. Only few clinopyroxenes fall in the calc-alkaline field of the diagram, which derived from the andesites described by Hoeck *et al.*[10] Evidently, they represent island arc volcanics.

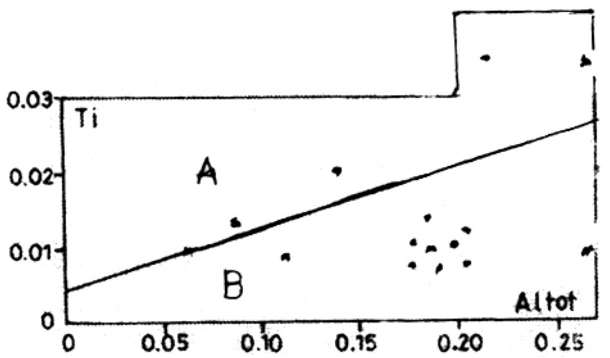

Fig. 8. Plot of clinopyroxenes from the olistoliths of ocean floor and island arc rocks from the East Carpathians wildflysch on the Ti *vs*. Al tot diagram. (Addapted after Leterrier *et al.*[38]): A, field of clinopyroxenes from the calc-alkaline rocks; B, field of clinopyroxenes from the tholeiitic rocks.

Ophiolites from COS occur also as pebbles in the Lower Miocene Pietricica conglomerate from the East Carpathians (Savu[39]), where they are associated with pebbles of rocks of different origin and age. The pebbles of ocean floor rocks consist of ultramafic rocks like harzburgites and pyroxenites. The first rocks are made up of olivine, partly substituted by antigorite, and orthopyroxene. The last mineral occurs in light pleochroic elongated crystals, which include spinel crystals and are bastitized along the clivage planes. Sometimes, harzburgites have been altered into serpentinites, rocks consisting of antigorite, bastite pseudomorphoses formed on orthopyroxene crystals, talc lamellae, chrome spinels and fine granules of secondary iron oxides. The pyroxenites consist of diopside and hyperstene. A brown hornblende occurs in the interstices between the pyroxene crystals. As I observed in 1978, during an expedition in the Polar Ural, pyroxenite dykes were usually cutting the obducted slabs of "Alpine-type" ultramafic rocks. This fact can well explain the association of peebles of the two rock-types from the Pietricica conglomerates.

With the view to show the relationships between the ocean floor rocks from the COS and those from the Mureş ophiolitic suture as regards their N-type and E-type characteristics, many rocks from these ophiolitic sutures have been presented on the diagram in Figure 9.

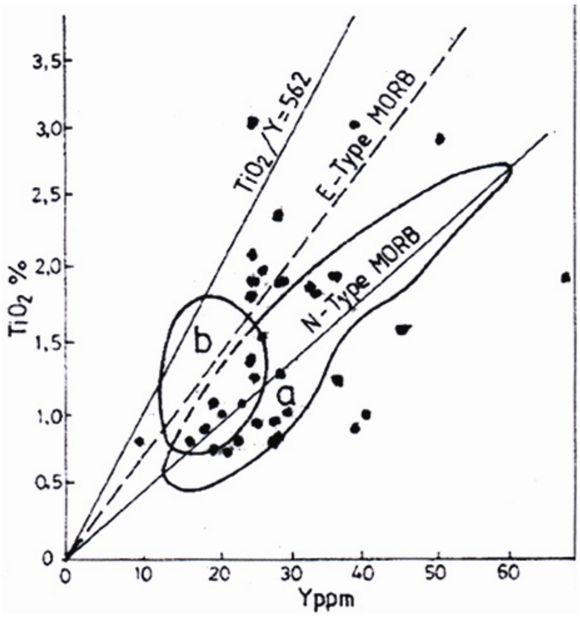

Fig. 9. Distribution of the ocean floor rocks from the Mureş and Carpathian ophiolitic sutures on the TiO_2 *vs*. Y diagram. Fields drawn according to Perfit *et al.*[40]: a, field of ocean floor rocks from the Mureş ophiolitic suture (data from Savu *et al.*[41]); b, field of the ocean floor rocks from COS, the Mehedinți Plateau in the South Carpathian segment (data from Savu *et al.*[13]); dots, ocean floor rocks from the East Carpathian segment of COS (data from Hoeck *et al.*[10] and Grinea[17]).

This diagram exhibits important differences between the ocean floor rocks of the two Alpine ophiolitic sutures. Thus, the ophiolitic rocks from the Mureş ophiolitic suture are clear N-type MORB rocks (field a). On the contrary, the ophiolites from the COS are very variate under this aspect. For instance, the ophiolites from the Mehedinți Plateau in the South Carpathian segment are rather E-type MORB rocks (field b). The plots of the ophiolitic rocks from the wildflysch of the East Carpathian segment are very dispersed, as they are distributed all over the diagram. However, it seems that these plots are gathered into two groups: one group is situated at the upper part of the E-type MORB line of the diagram and the other is located at the lower part pf the N-type MORB line of the diagram.

Moreover, in contrast with the Mureş ophiolitic suture, in COS there are not known so far any remnants of a sheeted dyke complex or of trondhjemitic granophyres and plagiogranites. Instead, slabs of ultramafic rocks are frequently occurring there.

CARPATHIAN OCEAN CLOSURE STAGE AND OCCURRENCE OF THE ISLAND ARC VOLCANICS

The closure of the bent fosse of the Carpathian Ocean was determined by the motion of the two converagent plates – the East European Plate and the Moesian Plate – toward west, thus being subducted under the Transylvanian Plate (Figs. 1 and 2). Due to this process the Carpatian Ocean crust was entirely consumed, partly by subduction and partly by obduction. The subduction process determined the occurrence of two geological structures. First of all, it engendered a subduction sedimentary basin with flysch deposits, in which an immature island arc was formed. The associated volcanism manifested itself along this immature island arc, which is evident in the East Carpathian segment of COS. In the South Carpathian segment the subduction basin, together with its sedimentary deposits and island arc volcanics, was covered by the Getic Nappe; even the Danubian Autochtone was a little moved southward over these geological formations (see Fig. 2).

The better-known island arc volcanics engendered by the closure of the Carpathisn Ocean are those associated with the Tithonian-Berriasian flysch deposits from the Bratocea tectonic unit located at the southernmost part of the East Carpathian segment, around the Prahova Valley (Savu *et al.*[42]). There, in the Azuga Beds, occur lava flows of calc-alkaline porphyritic basalts, hyalobasalts and amygdaloidal basalts, occasionally in pillow lava shapes. These volcanics are associated with basic tuffs and jaspers, intercalated in the flysch deposits. The island arc characters of these volcanics clearly result from the way they plot on the diagram in Figure 10.

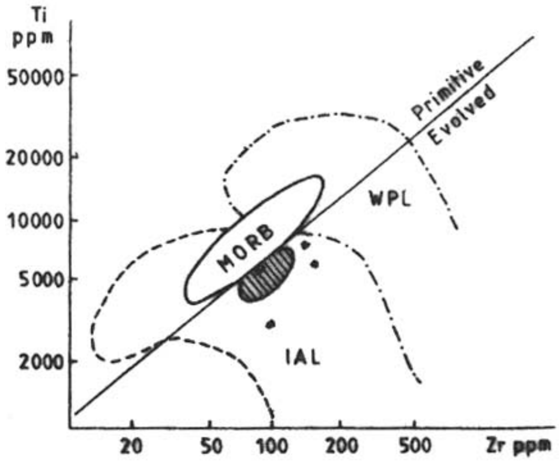

Fig. 10. Plot of the calc-alkaline volcanics from the immature island arc on the Ti *vs*. Zr diagram. Fields according to Pearce[24]: WPL, within-plate lavas; MORB, mid-ocean ridge basalts; IAL, island arc lavas; hashured field represents the island arc volcanics from the Bratocea tectonic unit (data from Savu *et al.*[42]); dots represent calc-alkaline basalt-andesites from the East Carpathian wildflysch (data from Hoeck *et al.*[10]).

On this diagram the plots of the calc-alkaline volcanics gather in a restricted field situated in the island arc domain, near the limit between the primitive and the evolved magmas.

Another occurrence of similar volcanics to those above presented have been recorded by Cioflica *et al.*[15] in the Neocomian deposits from the Carhaga Valley from the Perşani Mountains. There these authors described basic tuffs associated with jaspers.

Hoeck *et al.*[10] also presented several chemical analyses of calc-akaline basalts and andesites collected from the Hăghimaş, Rarău and Perşani Mountains wildflysch, which they described as highly porphyritic and glomeroporphyritic rocks, in which plagioclase and augite occur as phenocrysts, included in a groundmass formed of small crystals of plagioclase, clinopyroxene and iron oxides. Four rocks of this group fall in the island arc lavas field of the diagram in Figure 10. In the same calc-alkaline rocks field have been ploted these volcanics on the diagram in Figure 8, too.

In the Bicaz region of East Carpatians Băncilă and Papiu[43] identified a tuffogenous horizon associated with the black schists of the Lower Cretaceous from the Cârnu anticline. They supposed that the pyroclastics could represent andesites and rhyolites.

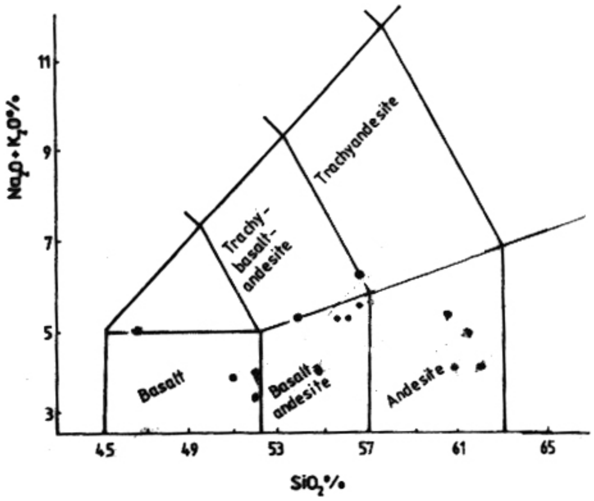

Fig. 11. Rocks from the Valea Rece area plotted on the $Na_2O + K_2O$ *vs*. SiO_2 diagram. Fields according to Le Maître *et al.*[44]. Data from Grinea[17].

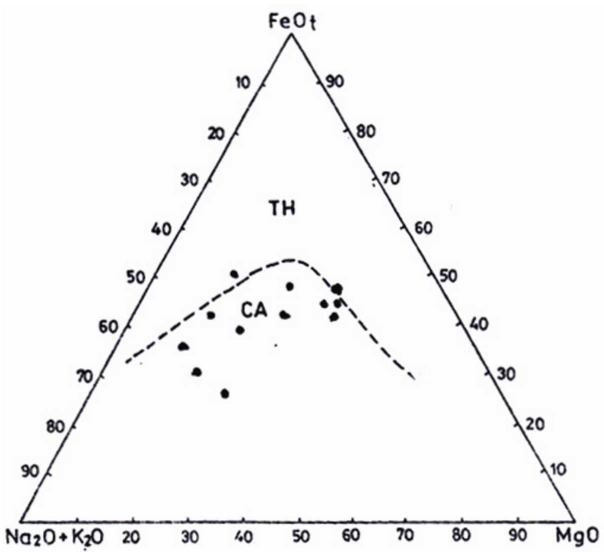

Fig. 12. Rocks from the Valea Rece area plotted on the FeOtot-$Na_2O + K_2O$-MgO diagram. Fields according to Irvine and Baragar[45]: TH, tholeiitic; CA, calc-alkaline. Data from Grinea[17].

In the same region Grinea[17] described agglomerates and tuffs, jaspers being associated with. These rocks are comprised in the "Tuffogenous Formation" from the Valea Rece–Trotuş (Culmea Fagului). The formation is intercalated in the Kimmeridgian-Tithonian Lunca Formation, which contains remnants of Aptychus. The SiO_2 content from the 12 chemical analyses obtained by Grinea[17] (Table 18) on these rocks shows values varying from 45.06 to 66.01 %. These analyses have been used in the present paper to realise the diagrams from the Figures 11 and 12. The first diagram shows that the rocks plot on it from the basalt field up to that of andesitas.

Moreover, as the diagram in Figure 12 shows, all rocks plot in the calc-alkaline field, indicating their origin in a volcanic island arc, like the rocks from the Prahova Valley, above presented.

POST-COLLISION STAGE AND OUTLINES OF THE COS TECTONICS

The purpose of this chapter is not to discuse the different Alpine tectonic units of COS. because these have been studied by different authors. It aims to present the outlines of the tectonics of the two segments of COS, dwelling on their style, in which there are important differences.

The Alpine tectonics of COS was determined, like for the older sutures, by the motion of the two convergent plates – the East European and the Moesian Plates. The Alpine tectonics of the South Carpathian segment was discused by Munteanu-Murgoci[46], Codarcea[3] and Săndulescu[47], to quote the most important referring to papers. As it results from Figure 2, the main element of the tectonics of these mountains is the large Getic Nappe, which covers all the previous tectonic structures of this segment. Therefore, it could be defined as a large nappe–style orogen. This tectonics could have been determined by the fast west-northwestward subduction of the Moesian Plate under the southern margin of the Transylvanian Plate.

The Alpime tectonics of the East Carpathian segment was discused by Băncilă[4] and Sandulescu[47], among others. As shown in Figure 2, the tectonics of this segment consists of numerous nappes, which are overlapping one another from west toward east. Therefore, this structure could be defined as an overlapped (*imbriqué*)-style orogen. It could have been determined by a westward slow subduction of the East European Plate under the eastern margin of the Transylvanian Plate.

The collision plane of the three tectonic plates is situated now somewhere under the nappe units of the Carpathian Chain, as shown in Figure 2 (see also Grintyman[48]).

The two convergent plates, the East European Plate and the Moesian Plate, were both moving westward, but with different speeds. Therefore, they must have tangentially touched under the obducting Transylvanian Plate, rubbing one another. At the Earth surface the touching plane of the two plates could be marked by the South Transylvanian transcrustal fault (see Fig. 2). A strong argument in this respect could be the fact that the two Neogene continental volcanic arcs from the northern block of the Transylvanian Plate, separated by this fault, stop just in front of this transcrustal fault, as the East Carpathian volcanic arc shows (Fig. 2). This fault could also mark a least resistance plane in the mantle, through which the Transylvanian mantle plume was emplaced, which engendered the hotspot volcanics along the transcrustal fault (see Savu[49]). Another argument concerning the process of the rubbing plane between the two subducted tectonic plates could be the presence of shear mantle xenoliths in the Racoş hotspot trachybasaltic volcanics related to the transcrustal fault (Savu *et al.*[50]), the more so as, according to the new mineral assemblages, the shear process manifested itself at about 100 kilometers depth and at high temperature, which favoured the recrystallization of the component mantle minerals.

A last evident motion of the Moesian Plate under the South Carpathian Chain took place during the Upper Cretaceous. It generated an island arc volcanism, the products of which, represented by basaltic and andesitic tuffs, are to be found in the Upper Cretaceous wildflysch of the Peri-Carpathian Depression, between Balta and Curpenu northwest of Târgu Jiu (see Savu *et al.*[51]). After this episode the Getic Nappe covered all the COS structures.

CONCLUSIONS

To get to the actual bent COS, the region from the European peneplain where it was located, got through four evolution stages.

At the beginning, during the last part of the Triassic, along the actual COS a zone of continental rifting process was active, generating a system of transcrustal faults. Along these faults a dyke system of within-plate basaltic rocks took place. This zone was running parallel with the old Pre-Alpine sutures, between the East European, the Moesian and the Transylvanian tectonic plates.

During the second stage, at the beginning of Jurassic, probably in Liassic, the rifting process got into a spreading process, which manifested itself along the rifting zone. By this process the Carpathian Ocean resulted, in which an ocean crust was engendered, which consisted of ocean floor (MORB) rocks like tholeiitic basalts, gabbros and ultramafic rocks,

Later on, probably in the Oxfordian, there started the motion of the three convergent plates, alredy mentioned, which determined the process of subduction–obduction and the closure of the Carpathian Ocean. By this process the ocean crust was entirely consumed. During this process an immature island arc occurred, along which a calc-alkaline (IAV) volcanism was active, producing volcanic rocks consisting mostly of porphyritic basalts, sometimes accompanied by more acid rocks.

The subduction process led to the collision of the three convergent plates, which modelled the bent COS with its two segments, each of them getting a specific tectonic style. Thus, in the South Carpathian segment a large-plate orogen occurred, while in the East Carpathian segment an overlapped orogen was engendered.

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