PETROLOGY, GEOCHEMISTRY AND ORIGIN OF CARPATHIAN ALKALINE PROVINCE, ROMANIA

HARALAMBIE SAVU

Geological Institute of Romania, 1 Caransebeş St., Bucharest

Abstract. The Carpathian alkaline province (CAP) occurs inside the Carpathian arc, where it extends from Banat up to East Carpathians. The alkaline province includes several occurrences of plutonic and volcanic alkaline rocks, distributed in five main areas. These rocks erupted during a distension period, starting by the end of the Triassic and continuing during the Jurassic. The parental magma (magmas) of these rocks derived from the long Carpathian mantle plume (CMP) or from five small mantle plumes. Several bimodal alkaline rock-series resulted from, which include different chemically equivalent plutonic and volcanic rocks. These rocks-series form characteristic petrographic associations, which run from ultramafic rocks by nepheline syenites up to leucogranites (alaskites) and alkaline rhyolites. These rocks resulted due to a very complicated magmatic process, in which magma differentiation and crustal contamination had the principal role. The magmatic activity, controled by these two factors, generated melanocratic and leucocratic rocks bearing a miyaskitic character, in which Na_2O prevailed on K_2O, so that the value of the Na_2O/K_2O ratio is usually higher than 1.

Key words: Carpathian Chain, alkaline province, plutonic rocks, volcanic rocks, petrology, geochemistry, origin.

Résumé. La province alkaline carpathique (CAP) se trouve à l'intérieur de l'arc carpathique, où elle s'étende de Banat jusqu'aux Carpathes Orientals. Cette province inclut plusieurs occurrences de roches alcalines plutoniques et volcaniques, qui sont distribuées dans cinq important régions. Les roches font éruption pendant une période de distension, en commençant vers lé fin de Triassic et continuant pendant le Jurassic. La magma (magmas) parentée des ces roches a derivé soit d'un long mantel plume (panache de manteau) ou de cinq mantel plumes plus petites. Nombreuses séries de roches alcalines bimodales ont resulté, qui comprendent tant de roches plutoniques que de roches volcaniques, qui sont equivalents du point de vue chimique. Ces séries de roches forment des associations pétrographiques characteristiques, qui commançent des roches ultrabasiques et vont par syénites à néphéline, arrivant à des leucogranites (alaskites) et à rhyolites alcalines. Ces roches représentent des produits d'un processus magmatique très compliqué, dans lequel la différenciation de magma et la contamination crustale ont eu le rôle principal. L'activité magmatique, qui a été contrôlée par ces deux facteurs, a engendré des roches mélanocrates et leucocrates, montrant un caractère myaskitique, dans lequel Na_2O prévaut sur K_2O, de sorte que la valeur du rapport Na_2O/K_2O est d'habitude plus grand que 1.

Mots-clés: chaîne carpathique, province alkaline, roches plutoniques, roches volcaniques, pétrologie, géochimie, origine.

INTRODUCTION

In a previous paper (Savu, 1962), I defined the Carpathian Alkaline Province (CAP) as being formed of several rock occurrences distributed in five main areas, included in a long bent zone situated inside the Romanian Carpathian Chain. The purpose of the present paper is to determine the main petrological and geochemical features and the origin of this alkaline province. Unfortunately, the different rock occurrences were incompletely documented with chemical data. All the rock occurrences presented enough chemical analyses of major elements, but some of them were not documented with analyses of trace elements, and a few of them presented REE analyses, and only one isotope analyses. In spite of all these deffects, I correlated the existent data to obtain a final general view on the petrological and geochemical aspects of the alkaline province as well as on its origin.

Rev. Roum. Géologie, Tomes **53–54**, p. 13–29, 2009–2010, Bucureşti

CAP AREA, ROCK OCCURRENCES AND PETROGRAPHIC ASPECTS

As shown in Figure 1, CAP extends along the inner part of the Carpathian Chain, running from Orşova, in Banat, up to Ditrău in the East Carpathian. It includes both plutonic and volcanic rock occurrences, distributed in five main areas. From these areas of alkaline rocks two of them (Nos 1 and 4) are located within the Danubian Autochthone, in Banat, and three occur in the Getic Nappe and its coevals from the East Carpathians, the Bucovinian Nappes, where the Ditrău pluton is emplaced. It results that the rock occurrences from the last three areas are now not in their original place, as the Orşova and Arjana rocks are.

PLUTONIC OCCURRENCES

The plutonic occurrences from the CAP are represented by the small stocks of nepheline syenites of Orşova and Mălaia in the South Carpathians and by the Ditrău alkaline pluton from the East Carpathians (Fig. 1).

1. Orşova alkaline stocks. West of Orşova, in the crystalline schists of the Neamțu series, nearby its contact with the Pre-Variscan Ogradena granitoid pluton, in Banat, three circular or ellipsoidal stocks of alkaline rocks do occur, the diameter of which does not exceed 400 m. Streckeisen and Giuscă (1932), Codarcea (1936) and Codarcea and Pavelescu (1963) studied the rocks from these occurrences.

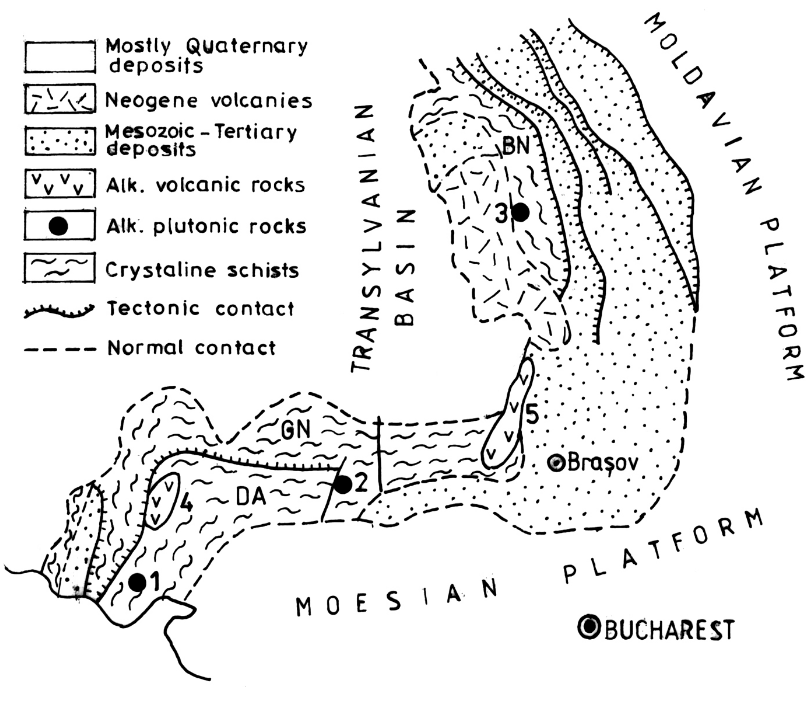

Fig. 1 – Sketch-map of the Romanian Carpathians, showing the actual position of the CAP alkaline occurrences. Plutonic rocks: 1, Orşova; 2, Mălaia; 3, Ditrău. Volcanic and dyke occurrences; 4, Arjana Zone; 5, Braşov district (Făgăraş Mountains, Codlea Basin, Perşani Mountains); DA, Danubian Autochthone; GN, Getic Nappe; BN, Bucovinian Nappes.

The recent studies carried out by Anastasiu (1973) and Stan and Tiepac (1996) showed that the three alkaline stocks (Cărbunăria, Strineac and Dealu Rău) from the Orşova region present a zonal structure, in which usually three concentric rock zones are to be remarked. These zones are more or less completelly developed. Around the nepheline syenite stocks some dykes of aplitic nepheline syenites or porphyritic microcrystalline nepheline syenites occur. The presence of nepheline syenite dykes around these alkaline rock stocks suggests that, both stocks and dykes originate in a NNE to SSW trending big alkaline pluton, concealed in the depth.

The nepheline syenites from the two inner zones of the alkaline stocks are represented mostly by foyaites. In their composition the following minerals are to be remarked: potash feldspar, nepheline, aegirine-augite and rarely cancrinite, sodalite, biotite and accessories. Nepheline was partly substituted by cancrinite and sodalite. The alkaline syenites from the marginal zone of the alkaline stocks consist of potash feldspar, albite, paragonite and accessories.

2. Mălaia alcaline stock. It was in the summer of 1962 when I discovered this syenitic body (Savu, 1962, unpubl. rep.). It intruded the high-grade crystalline schists of the Sebeş-Lotru series of the Getic Nappe from the Lotru Mountains, north of Ursu Summit on the Izvoru Rece Creek (Figs. 1 and 3), The stock is mostly covered by debris of syenitic rocks and crystalline schists. It has an ellipsoidal shape the longer diameter of which being of about 300 m (Savu, 1968). Like the mall syenite bodies of Orşova, it represents a stock that was initially merging in the depth into a large alkaline pluton. This syenitic body also shows a zonal structure, formed of three concentric zones (Fig. 3). The outer zone, representing a marginal facies, consists of alkaline syenite bearing biotite as melanocratic mineral. Then followed a zone of normal nepheline aegirine syenite (foyaite). The central area of the body is formed of pegmatoid nepheline syenite bearing aegirine, biotite and ilmenite. Both outer zones present a flow structure. Especially in the median zone melanocratic and leucocratic schlieren have been formed during the magma motion through the crust. This process is proved by the oriented (parallel) texture of both the nepheline syenites and the alkaline syenites (Savu, 1968).

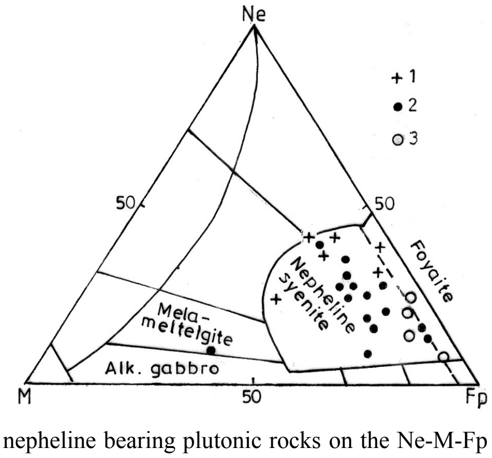

Fig. 2 – Classification of the nepheline bearing plutonic rocks on the Ne-M-Fp diagram (modal composition). Fields according to Eliseev *et al*. (1963). Nepheline syenites are from: 1, Orşova (data from Anastasiu, 1973); 2, Mălaia (data from Savu, 1968); 3, Ditrău (data from Codarcea *et al*., 1957).

The rocks of the median and central zones consist of microcline, albite, nepheline, aegirine and accessories. Sometimes nepheline was partly liebeneritized. The aegirine crystals show the following characteristics: Ng = greenish; Nm = greenish-yellow; Np = yellow-greenish; $c \wedge Ng = 2^o - 7^o$; (-) 2 v = 71°. The rocks of the central zone often show a massive, block texture, formed of portions of a hololeucocratic rock, separated one another by an aegirine net. It was shown (Savu, 1968) that the Mălaia rocks belong to an alkaline province.

On the Ne-M-Fp diagram (Fig. 2) the Mălaia nepheline syenites plot in the field of the normal foyaites. In contrast, the melanocratic schlieren occur within the melanocratic melteigite field and the leucocratic schlieren fall in the leucocratic foyaite domain (Savu 1968).

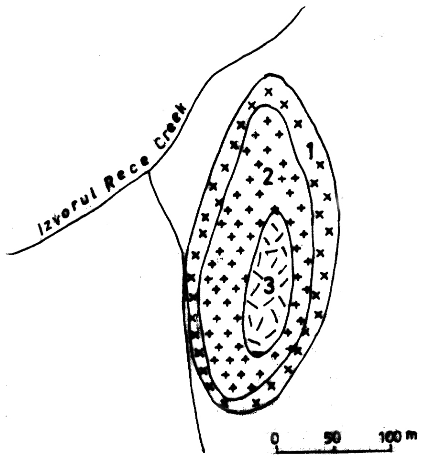

Fig. 3 – The zonal structure of the Mălaia syenite stock. 1, marginal zone formed of fine crystallized alkaline syenite; 2, median zone formed of normal crystallized nepheline syenite; 3, central zone formed of pegmatoid aegirine or biotite nepheline syenite.

3. Ditrău alkaline pluton. Among the plutonic alkaline bodies of the CAP, this alkaline body represents the most important and more complicated plutonic occurrence. It has a surface of about 270 km^2 and is located in the greenschist formation of the Tulgheş series of the Alpine Bucovinian Nappe from the East Carpathians (Fig. 1). According to Codarcea *et al.* (1957), this alkaline pluton was pointed out by Herbich who, in 1882, gave the name of 'ditroite' to the nepheline syenite rich in blue sodalite occurring on the Teascu Brook. Further on, the alkaline pluton was described in more than 100 studies regarding its structure, age and composition. These studies have been analysed by Codarcea *et al.* (1957) and by Jakab (1998), when referring to the pluton geology and by Kräutner and Bindea (1998) for the isotope age.

All the former authors considered the syenitic body as a magmatic intrusion (see for instance Ianovici, 1931 and Streckeisen, 1935). But in 1957 Codarcea *et al.* came forward with the hypothesis that this pluton could be a deep-seated anatectic-migmatic diapir. In the last studies realized by Anastasiu and Constantinescu, (1978); Jakab (1998) and Zincenco (1978, unpubl. rep.) the Ditrău alkaline body was considered as a magmatic intrusion, laterally extending in the depth. As the alkaline pluton shows an almost circular form on the surface, Földvary (1946) and Zincenco (1978, unpubl. rep.) considered it as a big stock, the last author suggesting a genesis by concentric intrusions of alkaline magmas, like in the Orşova and Mălaia zoned intrusions. According to the geological maps carried out by Streckeisen (1931), Földvary (1946), Codarcea *et al.* (1957), Zincenco (1978, unpubl. rep.) and Jakab (1998) the different rock-types in the pluton are rather randomly distributed than according to a concentric structure of a real stock. As I observed during the month of May 1953, when searching the alkaline pluton in the Jolotca area, along with M. Codarcea and S. Dăscălescu (unpubl. data), the eastern part of the pluton consists mostly of leucocratic alkaline rocks, while the western part is formed especially of melanocratic rocks. Therefore, it looks rather like a big unlayered laccolith.

The alkaline body was formed by successive intrusions of magma that reacted one another and with the country rocks, hybrid rocks occurring there. At the same time, hornfelses bearing cordierite, andalusite, sillimanite and garnet were formed at the pluton contacts. Arteritic migmatites of lit par lit-type resulted in the surrounding crystalline schists of the Tulgheş series, as I observed in 1953 at the sources of the Teascu Brook.

The Ditrău alkaline body consists of three plutonic rock series: 1) a series formed of SiO_2-unsaturated leucocratic rocks like nepheline syenites (Fig. 2), strongly differentiated from a 'dry' mantle plume magma (Savu *et al.*, 2000), 2) a series formed of melanocratic rocks like hornblendites, olivine hornblendites and meladiorites-hornblende gabbros (SiO_2 = 45 %), hybrid rocks like essexites being associated with, and 3) a crustal-contaminated series of SiO_2-saturated rocks (Fig. 4). On the diagram in Figure 2 the Ditrău nepheline syenites plot within the domain of the leucocratic foyaites, rich in alkaline feldspars and feldspathoids, like the foyaites from the small alkaline stocks of Orşova. The nepheline from the Ditrău rocks sometimes underwent the liebeneritization process, like the nepheline from the Mălaia rocks.

The SiO_2-saturated rocks, as shown on the diagram in Figure 4, are represented by quartz-monzonites, quartz-syenites, potash-granites and alaskites (leucogranites).

The pluton is accompanied by a large suite of dyke rocks like solvbergites, tinguaites, bostonites, syenite porphyries and syenite aplites (see Anastasiu *et al.*, 1983). Lamprophyres occur, too, being represented especially by camptonites and monchiquites. All around the region of the Ditrău pluton other types of lamprophyres like vogesites, odinites, spessartites, malkites and minetes are to be found, too (see Jakab, 1998).

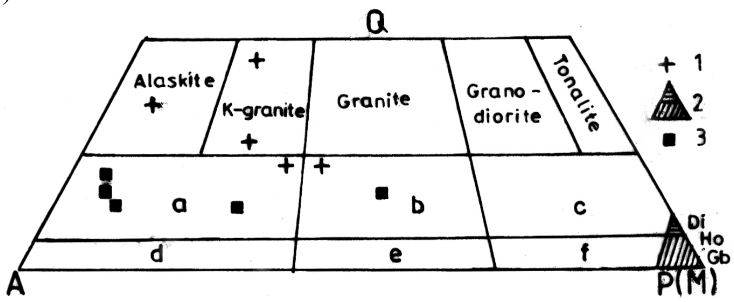

Fig. 4 – Classification of the SiO_2-saturated and ultramafic rocks (modal composition).associated with the nepheline syenites in the Ditrău pluton (data from Codarcea *et al.,* 1957) and of the Bârsa Fierului quartz-syenitic rocks (data from Savu, 1962) on the Q-A-P diagram. Fields according to Ginsbug *et al.* (1968, fide Streckeisen, 1967): a, quartz-syenite; b, quartz-monzonite; c, quartz-diorite; d, alkaline syenite; e, monzonite; f, diorite (Di) including ultramafics like hornblendite (Ho) and meladiorite-hornblende gabbro (Gb); 1, Ditrău quartz-bearing rocks; 2, Ditrău ultramafic rocks; 3, Bârsa Fierului quartz-syenites.

Concerning the age of the Ditrău alkaline pluton numerous studies have been carried out. In the oldest papers the authors hypothetically considered the age of the pluton going from Paleozoic up to Neogene. For instance Streckeisen (1931) considered this pluton as emplaced during the Upper Cretaceous, while Ianovici (1932) suggested a Jurassic age. Later on, numerous determinations of isotope age have been realized. Kräutner and Bindea (1998), who analysed all these data, concluded that this alkaline pluton was formed due to the magmatic processes, in which the magmatic activity manifesting itself during successive stages, starting from Carnian (230 Ma) and going up to the Berriasian (135 Ma), the rocks being also affected by the strain determined by the nappe motion, during the Aptian (115 Ma).

VOLCANIC AND DYKE ROCK OCCURRENCES

Within the CAP domain two large areas including occurrences of alkaline volcanic and dyke rocks are characteristic. Such rock occurrences are to be found in the Arjana Zone and in the Braşov district (Fig. 1, areas 4 and 5).

4. The Arjana Zone rocks. The Arjana Zone formations are situated on the outer margin of the western bend zone of the South Carpathians, in Banat. Its sedimentary deposits occurred within an epicontinental basin the Arjana Zone resulted from. It was studied by Schafarzik (1899), Codarcea (1940), Gherasi *et al.* (1970, unpubl. rep.), Năstăseanu (1980), Savu *et al.* (1986) and Russo-Săndulescu *et al.* (1994, unpubl. rep.). Năstăseanu (1980) showed that the Arjana Zone sedimentary deposits are Jurassic (Toarcian-Oxfordian) in age. These deposits represent, in fact, a volcano-sedimentary formation, since they are associated with alkaline volcanics and are intruded by dyke rocks of the same composition. The sedimentary deposits consist of silt and terrigeneous rocks associated with tuffogeneous rocks, sometimes affected by a weak anchimetamorphic process. Over these deposits lies an epiclastic formation with trachyte elements, which occurs within the Văratica and Pleşa areas. It is interesting that this formation includes exotic blocks of ultramafic rocks, mostly serpentinites, one of them including, in its turn, a block of very fresh dolerite, which suggests that these blocks could originate in an ophiolitic mélange (Savu *et al.*, 1986).

The volcanism had a bimodal character, its products being represented by melanocratic and leucocrateic volcanic rocks. Its activity started by lavas and pyroclastics of alkali basalts, which participate in the lower volcano-sedimentary complex of Piatra Dracului. As I was studying some thin section of volcanic rocks from the Arjana Zone, offered me by Fl. Codarcea and V. Codarcea, who searched the south of this zone during the last '60s, I discovered there the presence of trachytic rocks. The existence of these rocks and of other alkaline rocks was confirmed later on by Savu *et al.* (1986) within the northern part (Craiu Valley) of the Arjana zone. There, there were described pyroclastics and dykes of keratophyres, trachytes, quartz-syenites bearing an alkaline hornblende, bostonites, oligophyres and alkali basalts bearing Ti-augite phenocrysts the c∧Ng angle of which was of 45° to 48°.

The bimodal character of the alkaline volcanism results quite obvious from the way the rocks plot on the Na_2O+K_2O vs. SiO_2 diagram (Fig. 5). There the melanocratic rocks form their own large field (a) that extends over the picrobasalt, basalt and trachyandesitic fields, but also over the foidite, tephrite-basanite and trachybasalt fields, although any feldspathoide crystal was not yet observed in these high alkaline volcanic rocks. However, fact is that their average composition (M) falls on the diagram just in the tephrite-basanite field.

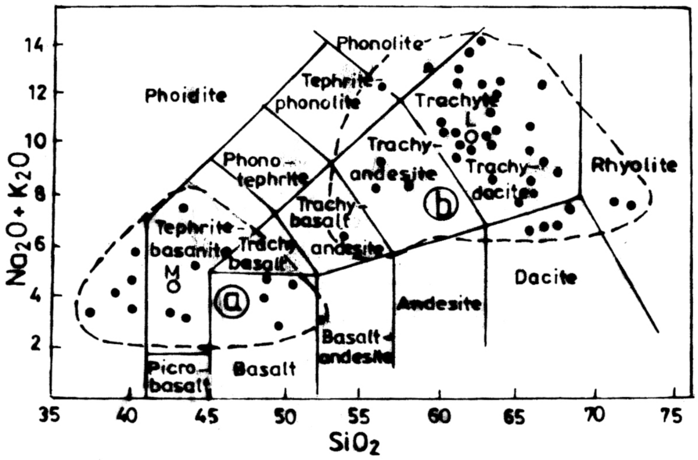

Fig. 5 – Classification of the alkaline volcanics and dyke rocks from the Arjana Zone on the $Na_2O + K_2O$ *vs.* SiO_2 diagram (data from Russo-Săndulescu *et al.*, 1994, unpubl. rep.). The original fields are according to Le Maitre *et al.* (1989). a, field of the melanocratic rocks; b, field of the leucocratic rocks; M and L average compositions of the melanocratic and leucocratic rocks, respectively.

The leucocratic rocks field (b) covers the dacite and rhyolite fields, but also the trachybasalt-andesite, trachydacite, trachyte and even the phonolite field, but so far any feldspathoid mineral was not observed in these rocks. Their average (L) plots on the diagram in the field of the trachyte-trachydacite field, once more underlining the alkaline character of this rock-series.

5. Alkaline rocks from the Braşov district. The alkaline rocks from this district of Transylvania are situated inside the angle formed by the Carpathian eastern bend zone. Within this district three areas of volcanic and dyke rocks occur: a) the swarm-dyke complex from the eastern extremity of the Făgăraş Mountains, b) Codlea Basin and c) Perşani Moutains.

5a. Făgăraş Mountains rocks. Meschendörfer (1860) mentioned first the presence of magmatic rocks in this area. Then there followed studies by Hauer and Stache (1863), Schmidt (1930) and Manilici (1956). The recent studies carried out by Savu *et al.* (1984) and Savu (1962) showed that within this eastern segment of the Făgăraş Mountains a swarm-dyke system occurs, that extends between Poiana Mărului, Holbav and Şinca Nouă. It seems that this area, along with the other two mentioned volcanic areas in the Braşov district, initially formed a single large zone of Mesozoic volcano-sedimentary deposits. But, as the Făgăraş Mountains, together with the rest of the South Carpathian segments, were exhumed at the beginning of the Tertiary era, their volcano-sedimentary superstructure was eroded, so that there occurred from the depth the infrastructure formed of the Pre-Variscan crystalline schists, intruded by the swarm-dyke rock system (Savu, 2004–2005). The volcano-sedimentary formations are now preserved in some syncline structures, only.

The swarm-dyke system consists of alkaline rocks of different composition, like basalts, dolerites, quartz-syenites, bostonites, quartz-bostonites, trachytes and alkali rhyolites. Among these dykes the Bârsa Fierului big dyke of quartz-syenites, 9 km long, is remarkable (Savu, 1962). The emplacement of the swarm-dyke system in the crystalline schist basement shows from the beginning the intra-plate and hotspot character of the rocks from this alkaline province (Savu *et al*., 1984). The NNE-SSW trending dykes are formed of melanocratic and leucocratic rocks (Fig. 6), which prove the bimodal character of the volcanism (Savu *et al*. 1984). It is coeval with the bimodal alkaline volcanism that engendered the Arjana alkaline rocks above described.

As shown in Figure 6, the melanoctatic rocks form on the diagram a separate field (a), that extends over the picrobasalt and basalt fields, but also over the foidite, tephrite-basanite, trachybasalt, trachybasalt-andesite fields and even over the phonolite field, rocks in whuch a feldspathoid mineral was not observed, yet. The average composition of the melanocratic rocks plots in the tephrite-basanite field, like that of the melanocratic rocks from the Arjana Zone. The leucocratic dyke-rocks (field b) cover the trachyandesite, trachydacite, trachyte and alkaline rhyolite fields. The average composition of the leucocratic rocks (L) falls within the trachyte-trachydacite field

The alkaline plutonic activity in the Făgăraş Mountains is represented by the Bârsa Fierului quartz-syenite dyke (Fig. 4) and by the quartz-syenite intrusion concealed under the crystalline schists from the Lupu Brook, which was evidenced by a drilling hole. Barkevikite lamprophyres (camptonites) are associated with.

5b. Codlea Basin. This basin is situated just east of the Făgăraş Mountains eastern extremity (Manilici, 1956), the crystalline schists of which are thrusting over its Mesozoic formations along a revers fault. The Liassic formations of this basin, which contain coal deposits, are located in a syncline – the Codlea syncline. The presence of coal deposits in these formations shows their epicontinental setting, in concordance with the Arjana Zone and the Perşani Mountains volcano-sedimentary formations. In the basin structure three rock complexes have been separated according to their coal deposits (Manilici, Vâlceanu, 1963). The lower complex formed of conglomerates was intruded by sills of porphyritic basalt. The second complex that unconformably lies over the former, contains a trachytic tuff bed of about 80 to 100 m thickness, that is associated with trachyte, keratophyre and bostonite rocks, which erupted during four stages. In the tuff composition there are present quartz and sanidine phenocrysts. Such rocks also occur as dykes, in the rocks of which phenocrysts of anorthoclase, sanidine, arfvedsonite, riebekite, apatite and opaque minerals occur. Phenomena of sericitization, chloritization, zeolitization and pyritization affected these dykes. Sometimes, there are to be found keratophyres bearing orthoclase and arfvedsonite or a brown hornblende. The third complex consists of sandstones in which the volcanic products are scarce. Dykes of basalts bearing basic plagioclase, Ti-augite, olivine and very rarely biotite intruded this complex. According to Manilici and Vâlceanu (1963) the chemical composition of these rocks (unpubl. data) is similar to that of the Făgăraş Mountains swarm-dyke rocks.

5c. Perşani Mountains rocks. The Mesozoic deposits and igneous rocks from the Perşani Mountains and neighboring areas have been studied by different authors like Szentpétery (1910); Wachner (1916), Dimirescu (1957), Cioflica *et al.* (1965), Săndulescu and Russo-Săndulescu (1981) and Nicolae and

Saccani (2005). Within this area two Mesozoic magmatic series are to be found: a tholeiitic series and an alkaline rock seies. The tholeiitic series is represented by olistoliths of serpentinites and tholeiitic basalts (Cioflica *et al.*, 1965; Săndulescu and Russo-Săndulescu, 1981) that originate in the Carpathian Ocean crust (Savu, 2005). These olistoliths are included in the wildflysch of the Bucovinian Nappe. Over this wildflysch nappe thrust the Olt Nappe, in the sedimentary deposits of which a seies of alkaline rocks is present. This alkaline series represents a coeval of the alkaline series from the Făgăraş Mountins, Codlea Basin as well as from Arjana Zone above described. Nicolae and Saccani (2005) analysed from this area alkali basalts and trachytes collected from Cuciulata Valley and Racoş area, rocks which show a porphyritic texture, determined by augite phenocrysts in basalts, and sanidine in trachytes. The alkali basalts plot, together with the Făgăraş Mountains basalts, in the melanocratic rock field (a) of the diagram in Figure 6, while the trachytic rocks plot in the leucocratic rock field (b) of this diagram. It is noteworthy that the average composition of all alkaline melanocratic rocks from the Braşov district falls in the tephrite-basanite field of the diagram, whereas the average composition of the alkaline leucocratic rocks (L) plots in the trachydacite-trachyte field, like the averages of the rocks from the Arjana Zone (Fig. 5).

GEOCHEMISTRY AND TECTONIC SETTING

As shown above, the volcanism from the CAP was a bimodal one (Figs 5 and 6). Accordingly, the geochemistry of the related rocks strongly supports this aspect. Thus, SiO_2 content is generally lower than 55 % in the melanocratic rocks and higher, up to 76 %, in the leucocratic ones (Table 1).

In the last rocks the most characteristic chemical components are the alkalies and Al_2O_3. Among the alkalies, Na_2O prevails on K_2O. For instance, the average content of Na_2O may reach more than 8 % in the nepheline syenites of Orşova and Ditrău intrusive bodies. Likewise, the K_2O average content increases up to 8.19 % in the nepheline syenites of Strineac stock, near Orşova, but it is lower in other rocks. The value of the Na_2O/K_2O ratio is always higher than 1, save the Perşani Mountains leucocratic rocks, in which it is of 0.57.

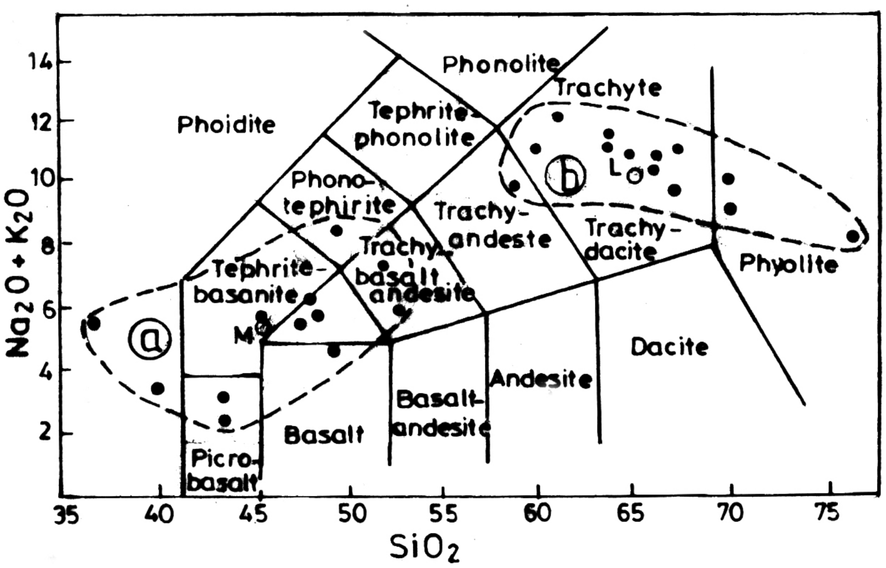

Fig. 6. Classification of the alkaline volcanics and swarm-dyke rocks from the Braşov district on the Na_2O + K_2O *vs.* SiO_2 diagram. Data from Manilici (1956), Savu *et al.* (1984) and Nicolae and Saccani (2005). The original fields are according to Le Maitre *et al.* (1989). a, field of the melanocratic rocks; b, field of the leucocratic rocks; M and L average compositions of the melanocratic and leucocratic rocks, respectively.

Not only the rock texture evidences the zonal structure of the stock bodies of Mălaia and Orşova, but it is also underlined by the rock geochemistry. Thus, Na_2O and K_2O are higher in the central facies of the Orşova stocks and in the normal facies of the Mălaia stock. On the contrary, Al_2O_3 shows an almost reverse behaviour. Its average content has higher values in the plutonic rocks than in volcanic rocks, in which it increases up to 26.10 % (Table 1), like in the nepheline syenites of Strineac stock. The lowest values of this component are to be found in the volcanic rocks.

Table 1

Average chemical composition of the CAP alkaline rocks*

Area	SiO_2	TiO_2	Al_2O3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	P_2O_5
A										
Mf	54.70.5	-	25.20	1.40	1.35	-	0.70	6.94	6.0 7.44	1.15
Cf	0.68	-	23.68	0.44	1.15	-	3.36	8.66		-
B										
Mf	58.25	-	24.70	4.0	-	-	1.01	2.12	8.19	-
Cf	56.50	-	26.10	5.29	0.16	-	1.24	4.84	3.27	-
C										
Mf	55.81	0.45	24.50	1.23	1.94	0.15	1.37	6.70	3.44	-
Nf	52.28	0.35	24,22	6.15	0.52	1.21	2.23	7.34	3.54	-
Cf	59.84	0.60	21.61	4.07	0.59	1.34	2.42	4.72	3.23	-
D										
Ho	36.59	4.24	13.45	6.47	7.57	8.31	13.87	3.89	1.56	0.87
Gb	44.51	2.31	11.78	5.38	5.52	6.79	10.54	2.87	1.37	0.69
Nsy	55.21	0.45	21.00	1.67	1.95	1.07	3.34	8.26	4.04	-
Msy	66.88	0.05	15.21	0.88	0.57	0.67	1.73	6.91	3.86	0.16
E										
Ml	43.30	2.88	16.40	3.18	8.02	7.57	5.67	3.32	0.89	0.41
Lc	62.86	0.66	16.72	2.92	1.72	0.90	0.98	6.25	3.79	0.06
F										
Fa										
Ml	45.38	2.79	16.51	2.75	7.02	3.97	6.14	4.13	1.89	0.57
Lc	64.85	1.15	17.60	1.15	2.82	0.63	1.13	5.51	4.50	0.11
Fb										
Ml	54.48	1.64	15.76	3.03	5.68	4.27	5.08	4.24	2.80	0.29
Lc	65.0	0/47	17.14	1.36	3.47	1.36	1.22	5.95	3.14	0.05
Fc										
Ml	46.61	2.02	15.81	1.18	6.07	5.95	10.61	3.04	0.89	0.30
Lc	67.72	0.40	14.98	0.47	3.16	1.03	0.72	3.55	6.16	0.05

* The average chemical composition data are referring to rocks from the following areas: A, Orşova – Cărbunăria (data from Anastasiu, 1973); B, Orşova – Strineac (data from Anastasiu, 1973); C, Mălaia (data from Savu, 1968); D, Ditrău (data from Jakab, 1998); E, Arjana Zone (data from Russo-Săndulescu *et al*., 1994, unpubl. rep); F, Braşov district: Fa, Făgăraş Mountains (data from Manilici, 1956, and Savu *et al*., 1984); Fb, Bârsa Fierului dyke (data from Savu, 1962b); Fc, Perşani Mountains (data from Nicolae and Saccani, 2005), Mf, marginal facies; Cf, central facies; Nf, normal facies; Ml, melanocratic rocks; Lc, leucocratic rocks; Ho, hornblendite; Gb, gabbro; Nsy, nepheline-syenite; Msy, microsyenite.

The agpaitic index – Na_2O+K_2O / Al_2O_3 (mol) (Sörensen, 1960) – which is lower than 1, except for the crustal contaminated Ditrău microsyenites (Table 4) shows that the alkaline rocks from the CAP are bearing a miyaskitic character (see also Savu, 1968).

In rocks of the melanocratic group characteristic are some chemical elements from the mafic minerals, like FeO, $Fe_2O_{3,}$ and TiO_2. In the plutonic rocks the highest contents of these components occur in the ultrabasic rocks from the Ditrău pluton. Thus, FeOtot increases up to more than 11 % in hornblendites, 17 % in gabbros and 11 % in essexites. The average contents vary in these rocks between 7 and 13 % (see Jakab, 1989). High contents of these elements also occur in the volcanic rocks plotting on the diagrams in Figures 5 and 6 in the picrobasalt field. For instance, in the Arjana Zone basic rocks Fe_2O_3 reaches 6 %.

Because the CAP rocks are of intra-plate-type, their TiO_2 average content usually is higher than in rocks of other tectonic settin. It varies between 2.53 % and 4.24 % in the Ditrău melanocratic rocks, and increases up to 5 % in the Arjana Zone basic tuffs.

The complete sets of trace elements from the CAP rocks have been determined in the Ditrău and Bârsa Fierului plutonic rocks and in the volcanic occurrences (Table 2). Their contents are characteristic for alkaline rocks, too. As in case of the major elements, the trace element contents separate the eruptive rocks into the melanocratic and leucocratic groups of the bimodal volcanism. Among the siderophyle elements Ni, Cr and V present higher values. But the highest contents among the trace elements from Table 2 are those of Zr, Sr and Ba, elements that are specific for alkaline suites. Nb is also high in these rocks.

Table 2

Average contents (ppm) of trace elements in the CAP alkaline rocks*

Area	Ditrău		Arjana Zone		Făgăraş Mountains.		Bârsa Fierului	Perşany Mountains.	
Type	Ml	Lc	Ml	Lc	Ml	Lc	Lc	Ml	Lc
Pb	-	-	4.61	5.42	9.15	10.8	8.5	7.2	12
Cu	-	-	26.9	9.76	38.14	9.08	11.0	24.9	-
Ga	-	0	26	26.6	19.0	23.0	24.2	21.8	27.0
Zn	75.0	79.3	-	-	-	-	-	92.2	130
Sn	-	-	5.83	4.32	3.22	4.08	2.6	-	-
Ni	129	8.90	83.9	12.15	59.9	4.66	21	77.5	4.5
Co	34.6	2.33	32.6	3.79	28.2	2.83	8.62	34.8	3.0
Cr	71	10.3	238.15	7.97	47.3	2.83	23.6	238.8	94.2
V	183.3	14.6	270.7	20.8	127.7	4.66	33.2	238.8	94.2
Sc	26	0.66	20.9	3.97	18.22	2.91	5.2	22.86	3.05
Yb	7.70	1.63	1.83	4.87	1.72	3.73	3.7	2.51	1.06
Y	7.7	25.8	29.69	51.46	26.7	39.16	40	25.0	85.5
La	97.9	37.31	63.38	124.4	45.5	105.6	55.7	23.98	75.3
Zr	17.25	50.9	203.0	877.9	208.3	615.8	657.5	152.8	798.5
Nb	137.5	96.4	25.8	145.8	28.22	118.8	142.5	30.0	111
Sr	1458.	817.7	400.4	114.4	682	120.8	340	286	27.0
Ba	-	655.3	476.5	240.6	703	571.6	480	259.2	93.5
Hf	1.56	14.2	3.23	20.76	-	-	-	4.38	21.3
Ta	7	8.6	-	-	-	-	-	2.66	5.5
Th	-	-	2.80	22.74	-	-	-	3.36	15.5
U	-	-	-	-	-	-	-	0.70	5.26

* The same sources as in Table 1; Ml, melanocratic rocks; Lc, leucocratic rocks.

According to the relationships of Nb and Y (Fig. 7) the alkaline plutonic rocks plot within the WPG field (see also Savu, 1962).

The value of Sr/Ba ratio (Table 4) shows that Ba usually prevails on Sr. Only in the Ditrău rocks and in the Perşani Mountains trachytes the values of this ratio are higher than 1.

The Zr contents present higher values in the leucocratic volcanics. The relationships between Zr and Y (Fig. 8) show that, like in the plutonic rocks, all of the CAP volcanic rocks are of intra-plate type. Otherwise, Savu *et al.* (1984) showed that the volcanic and dyke rocks from the Făgăraş Mountains area were hotspot rocks of WPB-type. The Zr/Nb ratio presents higher values in the Arjana Zone and the Făgăraş Mountains volcanic and dyke rocks.

Elements like Hf, Ta, Th and U have been determined in a complete set only in the Perşani Mountains volcanics by Nicolae and Saccani (2005). In these rocks the value of Th/U ratio is of 4.80 in melanocratic rocks and of 2.94 in leucocratic rocks.

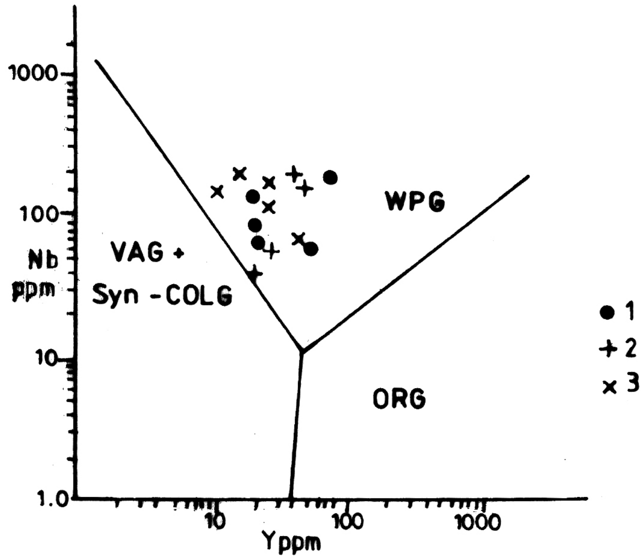

Fig. 7 – Plot of some plutonic rocks from CAP on the Nb vs. Y diagram. Fields according to Pearce *et al.* (1984): VAG + syn COLG, volcanic arc granites and syn-collision granites; WPG, intra-plate granites (and alkaline rocks); ORG, ocean ridge granites. 1, Ditrău nepheline-syenites (data from Jakab, 1998); 2, Bârsa Fierului quartz-syenites (data from Savu, 1962); 3, Orşova nepheline-syenites (data from Stan and Tiepac, 1996).

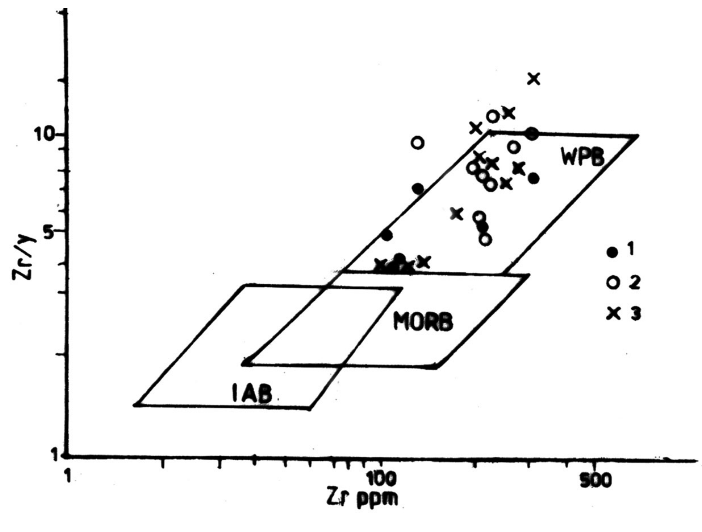

Fig. 8 – Plot of the melanocratic rocks from CAP on the Zr/Y *vs*. Zr diagram. Fields according to Pearce (1980): WPB, intra-plate basalts; MORB, mid-ocean ridge basalts; IAB, island arc basalts. 1, alkali basalts from the Perşani Mountains (data from Nicolae and Saccani, 2005); 2, basic rocks from the Făgăraş Mountains (data from Manilici, 1956 and Savu *et al*., 1984); 3, basic rocks from the Arjana Zone (data from Russo-Săndulescu *et al*., 1994, unpub. rep)

The REE contents have been determined in the Ditrău and Orşova plutonic rocks and in the Arjana Zone volcanic rocks (Table 3). Except for the Ditrău melanoratic rocks and Orşova syenites in which the value of Eu/Eu* = [(Eu)N/ ½ (Sm+Gd)N] ratio is higher than 1, in all of the other areas this value is lower, which indicates a process of differentiation of the parental magma. It is of note that when Gd was not analitically determine, it was estimated as (Gd)N by projecting this element on each rock pattern from the diagram in Figure 9.

Table 3

Average contents of REE in the CAP alkaline rocks*

Area	Arjana Zone		Perşani Mountains		Ditrău		Orşova
Type	Ml	Lc	Ml	Lc	Ml	Lc	Lc
La	34.66	70.1	23.98	75.3	97.9	37.31	39.96
Ce	56.66	132.5	44.4	166	172.4	49.7	105.9
Pr	-	-	5.87	15.7	-	-	-
Nd	-	-	24.34-	61.2	131	25.7	-
Sm	7.63	8.98	4.94	10.6	16.58	3.60	5.2
Eu	1.54	1.37	1.46	1.63	4.35	0.82	2.19
Gd	3.18^{+}	2.33^{+}	4.83	10.7	4.01	1.06	1.95^{+}
Tb	0.88	1.30	0.83	1.63	1.87	0.44	0.52
Dy	4.83^{+}	4.80^{+}	4.71	11.33	7.22	1.75	1.93^{+}
Ho	-		0.94	2.29	-	-	-
Er	-	-	2.07	7.58	-	-	-
Tm	-	-	0.33	1.12	-	-	-
Yb	1.60	3.37	2.51	6.92	7.70	1.63	1.4
Lu	-	-	0.33	6.92	0.33	0.27	0.22

* The same sources as in Table 1. Ml, melanocratic rocks; Lc, leucocratic rocks.

Table 4

Some characteristic geochemical values of the CAP alkaline rocks*

Area	Agpaitic index	Na_2O/ K_2O	Sr/Ba	Y/Nb	Zr/Nb	Eu/Eu*	Eu/Sm	ΣREE	LREE/HREE
A	0.67	1.01	-	-	-	1.27	0.42	162.82	13.5
B	0.58	1.80	-	-	-	-	-	-	-
C Ml Lc	0.54 0.84	2.29 1.91	- 1.24	0.56 0.26	0.12 5.28	1.17 0.98	0.26 0.22	325.26 121.11	11.77 20.03
D Ml Lc	0.39 0.12	1.64 3.73	0.84 0.47	1.15 0.35	7.86 6.02	0.71 0.49	0.20 0.15	110.98 244.95	8.22 16.06
E Ml Lc	0.56 0.79	2.18 1.22	0.97 0.21	1.73 0.33	10.26 6.30	- -	- -	- -	- -
F	0.73	1.82	0.70	0.28	4.61	-	-	-	-
G Ml Lc	0.38 0.89	3.41 0.57	1.10 2.35	0.85 0.15	5.9 7.9	0.59 0.46	0.29 0.15	377.89 162.8	5.74 6.65

* The same sources as in Table 1. Areas: A, Orşova; B, Mălaia; C, Ditrău; D, Arjana Zone; E, Făgăraş Mountains; F, Bârsa Fierului dyke; G, Perşani Mountains; Ml, melanocratic rocks; Lc, leucocratic rocks.

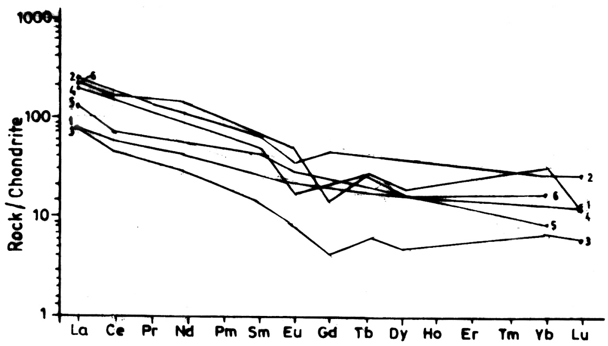

Fig. 9 – REE Chondrite-normalized patterns (average values) of the CAP rocks (normalizing values of Boynton, 1984). 1, pattern of the alkali basalts and 2, of the trachytes from the Perşani Mountains (data from Nicolae and Saccani, 2005); 3, pattern of the melanocratic rocks and 4, of the syenites from the Ditrău pluton (data from Jakab, 1998); 5, pattern of the melanocratic rocks and 6, of the leucoctatic rocks from the Arjana Zone (data from Russo-Săndulescu *et al*., 1994, unpubl. rep.).

Save the patters of the Perşani Mountains alkali basalts and Arjana Zone leucocratic rocks all the other patterns show an Eu or Gd negative anomaly, which indicates – the first one at least – a differentiation process underwent by the parental magma (see Haskin, 1984, and Boynton, 1984). In case of the Arjana Zone this process is much more obvious, since on the diagram in Figure 9 the Eu negative anomaly on the melanocratic rocks pattern is very clear. Since the contents of Yb and Lu were very low in the Orşova syenites (Table 3), thus contrastimg with the other rocks of CAP, their patterns were not represented on this diagram.

PETROLOGY AND ORIGIN

From the above data it results that the varied rocks from the CAP are intra-plate rocks (Figs 7 and 8), which form a characteristic petrographic province. These are hotspot rocks (Savu *et al.*, 1984; Savu, 1962) originating in a mantle plume – the Carpathian Mantle Plume (CMP) – as it results from the (Dy/Yb)N vs. (Ce/Yb)N diagram in Figure 10. On this diagram all of the CAP rocks are situated within an area occurring at the right of the 'plume line', which is characteristic for the hotspot rocks. Their averages delimit on the diagram a distribution field that is closely similar to that of the hotspot rocks from the Transylvania mantle plune (Savu, 2004). But the CAP rocks show a little lower values of the (Dy/Yb)N ratio than those originating in the Transylvania mantle plume. It is of note that when Dy was not analytically determined, it was estimated by the same way the (Gd)N was estimated, too.

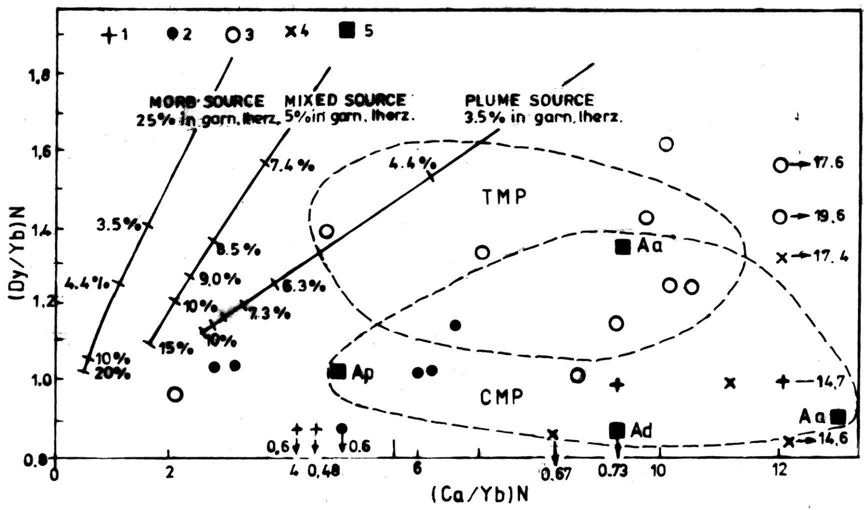

Fig. 10 – Plot of the CAP rocks on the (Dy/Yb)N vs. (Ce/Yb)N diagram. The lines with the melting-rate marks, are according to Haase and Devey (1996). 1, Ditrău plutonic rocks (data from Jakab, 1998); 2, Perşani Mountains volcanic rocks (data from Nicolae and Saccani, 2005); 3, Arjana Zone volcanic rocks (data from Russo-Săndulescu *et al.*, 1994, unpubl. rep.); 4, Orşova plutonic rocks (data from Stan and Tiepsc, 1996); 5, averages of the alkaline rocks from the four areas plotted on the diagram: Ad, Ditrău; Ap, Perşani Mountains; Aa, Arjana Zone; Ao, Orşova; TMP, Transylvania mantle plume field (according to Savu, 2004); CMP, Carpathian mantle plume field.

As shown before (Savu, 1962), the CAP hotspot structures occurred during the distension period evolving between the Paleozoic and the Alpine tectono-magmatic cycles, starting by the end of Triassic and continuing during the Jurassic. They have been generated either by a long mantle plume, or by five small separated coeval mantle plumes, present inside the arc made by the two main branches of the Carpathian triple junction (see Savu, 1998), along which the Carpathian Ocean opened a little later. It is noteworthy that this zone of hotspot occurrences was running in parallel with the rifting zone of the triple junction and with the Carpathian Ocean when it opened at the beginning of Liassic.

It is likely that during the rifting process along the Carpathian triple junction and the evolution of the Carpathian Ocean, the evolution of the CMP started, too, most probably by a rheomorphic intrusion of a mass of lower mantle into the upper mantle. Thus, there occurred either the long mantle plume, or the row of small five mantle plumes the hotspot rock occurrences of which extended from Banat up to the East Carpathians (Fig. 1).

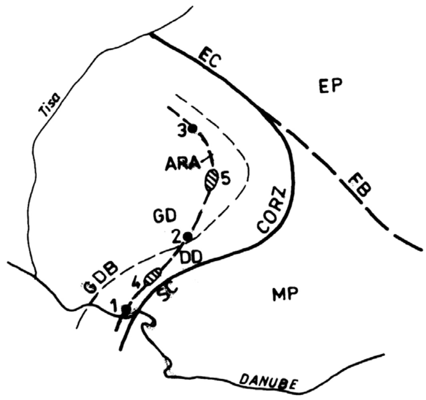

Fig. 11 – Skettch-map (not to scale) showing the initial distribution of the occurrences of hotspot alkaline rocks along an alignment, that was parallel to the Early Mesozoic Carpathian rifting zone. EP, East-European Plate; MP, Moesian Plate; GD, Getic domain; DD, Danubian domain; GDB, possible Getic/Danubian domains boundary; SC, South Carpathians; EC, East Carpathians; FB, Dobrogean failed branch of the Carpathian triple junction; CORZ, precursory rifting zone of the Carpathian Ocean; ARA, possible alkaline rocks alignment.

It is of note that two of the CAP hotspot occurrences (Nos 1 and 4) were initially emplaced within the Danubian domain and the other tree in the Getic Nappe domain (Fig. 11). When the Getic Nappe and its coevals from the East Carpathians – the Bucovinian Nappes – thrust over the autochthone structures in front of them, including the associated rock occurrences from Banat, the upper part of the three associated hotspot occurrences thrust, too, together with the crystalline schist basement of the nappes. Thus, they got into the actual position in the Carpathian Chain (Fig. 1). Consequently, the roots of these three hotspot structures remained somewhere beneath the Carpathian napes, in their autochthone, as the Orşova and Arjana Zone occurrences had been before the Getic Nappe would have been eroded. As the Getic Nappe from the western risen segment of the South Carpathians was eroded (Savu, 2004-2005), the Orşova and Arjana Zone rock occurrences came to the surface together with the Danubian Autochthone (Fig. 1).

The parental basic magma of the CAP rocks was formed at a depth of 70 to 100 km. as it results from the Ce/Yb vs. Ce and Ce/Yb vs. Sm/Yb diagrams (Fig. 12). This parental magma resulted by partial melting of less that 5 % of the peridotitic materials of the CMP substratum, as the (Ce/Yb)N *vs.* (Ce)N diagram in Figure 13 shows. On this diagram the CAP rocks plot within the field of the Hawaii, Azore, Réunion and Iceland rocks (see Saunders, 1984).

The parental magma (magmas) was a SiO_2-unsaturated magma, from which, by direct differentiation, the nepheline syenites resulted there (see Savu, 1968). When the parental magma got contaminated by crustal acid materials, there occurred more acid magmas the plutonic and volcanic quartz-bearing rocks resulting from. The contamination of the parental magma could have occurreed either at the base of the crust, or during its long-time ascending through. The last possibility is supported by the presence of the less alkaline rocks – the alkaline syenites – on the marginal zone of the zonal stocks of alkaline rocks, that was in direct contact with the crust (Fig. 3), thus contrasting with the nepheline syenites from the inner zones.

Due to these two factors – contamination and differentiation – the bimodal character of the alkaline magmatism resulted, too. The separation of the melanocratic and leucocratic magmas, it seems, started when the concentration of SiO_2 in the parental magma reached the value of about 55 % (see Figs. 5 and 6).

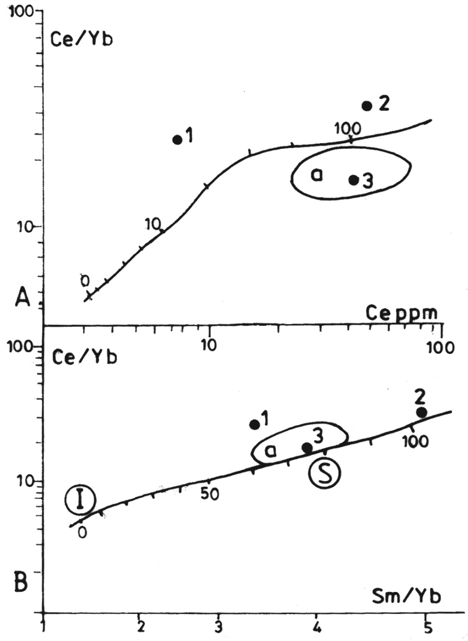

Fig. 12 – Plot of the average values of the CAP rocks on the Ce/Yb vs. Ce and Ce/Yb vs. Sm/Yb diagrams. The melting model and marks on its lines indicate the depth of the final melt segregation in 10 km increasement (Ellam, 1992). Simbols I and S represent the values of the lavas from Iceland and Skye; a, field of the Réunion island volcanics (according to the data from Ellam, 1992); 1, average of the Ditrău melanocratic rocks (data from Jakab, 1998); 2, average of the Arjana Zone alkali basalts (data from Russo-Săndulescu *et al.,* 1994, unpubl. rep.) 3, average of the Perşani Mountains alkali basalts (data from Nicolae and Saccani, 2005).

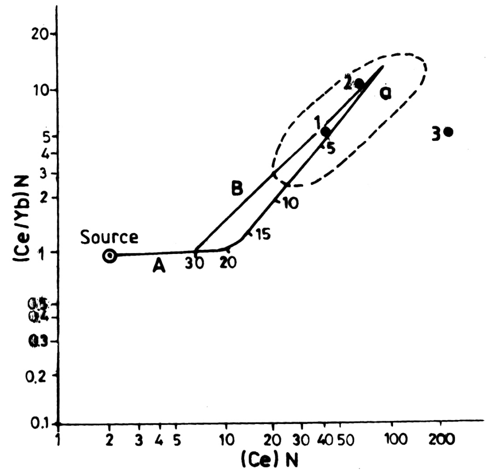

Fig. 13 – Plot of the average values of the alkaline rocks from CAP on the (Ce/Yb)N *vs.* (Ce)N diagram. Lines A and B according to Saunders (1984). A, equilibrium batch partial melting of a garnet lherzolite source with the marks of the partial melting rate; B, fractional crystallization line of an eclogite within an open system. 1, average of alkali basalts from the Perşani Mountains (data from Nicolae and Saccani, 2005); 2, average of alkali basalts from Arjana Zone (data from Russo-Săndulescu *et al.*, 1994, unpubl. rep.); 3, average of basic rocks from the Ditrău pluton (data from Jakab, 1998); a, field of the Hawaii, Azores, Réunion and Iceland intra-plate alkali basalts.

The plutonic and dyke occurrences in both the Făgăraş Mountains and the large area around the Ditrău intrusion are accompanied by sulfide, rare earth and radioactive element weak hydrothermal mineralizations (see Anastasiu, Constantinescu, 1984, and Jakab, 1998).

CONCLUSIONS

The magmatic activity in the CAP started by the end of the Triassic, at the same time with the rifting zone of the Carpathian triple junction, along which the Carpathian Ocean opened later on

The Ditrău pluton was formed by successive intrusions of differentiated magmas during a long period lasting from the Late Triassic (230 Ma) up to the Berriasian (135 Ma). The volcanic activity in the two volcanic areas of alkaline rocks (N^o 4 and 5 in Figure 1) manifested itself during the same period. It is of high interest the evolution, in parallel and during the same distension period, of two neighboring different magmatisms: an E-type MORB magmatism in the Carpathian Ocean, and the WPB-type alkaline magmatism in the CAP. In other words, the coexistence as neighboring structures of an ocean zone and a mantle plume or a row of mantle plumes.

The volcanism started by picrobasalts and basalts that corresponded to the melanocratic rocks (hornblendites, gabbros) from the Ditrău pluton. Otherwise, except for nepheline syenites, the other plutonic rocks from the Ditrău massif and the Bârsa Fierului big dyke have equivalents in the alkaline volcanics of CAP. The parental magma of all these alkaline rocks was a SiO_2-unsaturated magma, derived either from a single long mantle plume (CMP) or from five separate small mantle plumes. It had a miyaskitic signature. This magma differentiated from basic-ultrabasic to alkaline-acid magmas, a process in which the crustal contamination had an important role.

The differentiation process (including contamination) from basic-ultrabasic to quartz-syenitic magmas in the magmatic chambers of the plutonic rocks, and the differentiation process from picrobasaltic and basaltic to trachytic and alkali rhyolitic magmas in the magmatic chambers of the volcanic rocks were almost parallel and equivalent in both the magma evolution and the time of eruption.

REFERENCES

Anastasiu, N. (1973), *Corpurile de roci alcaline din cristalinul seriei de Neamțu (Carpații Meridionali).* An. Univ. București (Geol.), **XXII**, 53–72.

Anastasiu, N., Constantinescu, E. (1984), *Contribution à la connaisance pétrologique et structurale du massif de Ditrău – implications métallogenetiques*. An. Univ. București (Geol.), **XXXIII**, 43–49.

Bointon, W.V. (1984), *Geochemistry of the rare earth elements; meteorite studies.* In P. Henderson (Ed.) *Rare Earth Element Geochemistry.* Elsevier **2**, 13–14.

Cioflica, G., Patrulius, D., Ionescu, J., Udubașa, G. G. (1965), *Allochthonous Triassic ophiolites of the Perşani Mountains (Romania).* St. cerc. geol., geofiz., geogr. (Geol.), **19**, 161–183.

Codarcea, Al. (1940), *Vues nouvelles sur la tectonique de Banat méridional et du Plateau de Mehedinți*. An. Inst. Geol. Rom., **XX**, 1–74.

Codarcea, Al., Codarcea-Dessila, M., Ianovici, V. (1957), *Structura geologică a masivului de roci alcaline de la Ditrău*. Bul. St. Acad. Rom., **II**, 385–513.

Codarcea, Al., Pavelescu, L. (1963), *Considération sur la genèse des roches granitoids de l'autochtone danubien des Carpathes Méridionales*. Assoc. Geol. Carp.- Balk., Congr. V, **II**, 9–15.

Dimitrescu, R. (1957), *Asupra prezenței rocilor alacaline în partea nordică a Munților Perşani*, Com. Acad. Rom., **VII, 1**, 113–117.

Eliseev, N.A., Kusev, V.G., Vinogradov, D.P. (1963), *Proterozoiskii intrusivnii complex vostocinovo Priazovia.* AN SSSR, Moskva.

Ellam, M. (1992), *Lithosphere thickness as a control on basalt geochemistry*. Geology, **20, 3**, 153–160.

Földvari, A. (1946), *Age and contact-metamorphic effects of the nepheline-syenite stock of Ditró (Transylvania).* Rel. Inst. Geol. Publ. Hungary, B, **8, 1–2,** 11–32.

Haase, K.M., Devey, C.W. (1996), *Geochemistry of lavas from the Ahu and Tupa volcanic fields, Easter Hotspot, southeast Pacific: implications for intraplate magma genesis near a spreading axis*. Earth Planet. Sci. Lett., **157, (1–4),** 129–143.

Haskin, L.A. (1984), *Petrogenetic modelling – use of rare earth elements*. In P. Henderson (Ed.), *Rare Earth Element Geochemistry*, Elsevier **2**, 115–152.

Hauer, F., Stache, G. (1863), *Geologie Siebenbürgens*, Wien.

Herbich, F. (1872), *Die geologischen Verhältnisse des nordöstlichen Siebenbürgen*, Jb. ung. geol. Anstalt, Budapest, 1872.

Ianovici, V. (1931), *Étude sur le massif syenitic de Ditrău, région de Jolotca, district de Ciuc (Transylvanie*). Rev. Muz. Geol. Min. Univ. Cluj, **4, 2**, 1–53.

Jakab, G. (1998), *Geologia masivului alcalin de la Ditrău*, 298 p., Miercurea Ciuc.

Kräutner, H.G., Bindea, G. (1998), *Timing of the Ditrău alkaline intusive complex (Eastern Carpathians, Romania).* Slovak Geol. Mag., **4 (4)**, 213–221.

Manilici, V. (1956), *Studiul petrografic al rocilor eruptive, mesozoice, din regiunea Poiana Mărului – Şinca Nouă.* An. Com. Geol., **XXIX**, 5–75.

Manilici, V., Vâlceanu, P. (1963), *Beiträge zum Studium der Codlea Beckens*. Asoc. Geol. Carp. - Balk., Congr. V, **II**, 19–132.

Meschendörfer, J. (1880), *Die Gebirgsarten des Bürzenlandes*. Progrese des evangelischen Gymnasiums zu Kronstadt, 1880.

Năstăseanu, S. (1980), *Géologie des Monts Cerna*. An. Inst. Geol. Geofiz., **LIV**, 153–280.

Nicolae, I., Saccani, E. (2005), *Preliminary geochemical data on volcanic rocks from the Olt Nappe (Transylvanian Nappes, Romania); implications for their origin in the Transylvanides.* Ofioliti 2005, **30 (2)**, 103–106.

Pearce, J.A. (1979), *Geochemical evidence for the genesis and eruptive setting of lavas from Tethyan ophiolites*. In A. Panayiotou (Ed.) *Ophiolites*. Proc. Intern. Ophiol. Symp., Nicosia, Cyprus, 261–272.

Pearce, J.A., Harris, N.B.W., Tidle, A.G. (1984), *Trace element discrimination diagram for the tectonic interpretation of granitic rocks*. J. Petrol., 254, 956–983.

Saunders, A.D. (1984), *The rare earth element characteristics of igneous rocks from the ocean basins.* In P. Henderson (Ed.) *Rare Earth Element Geochemistry,* Elsevier **2**, 205–236.

Savu, H. (1962), *Origin of Bârsa Fierului quartz-syenite dyke and its affiliation to the Carpathian alkaline province, Romania*. Proc. Rom. Acad. Series B, 1, 23–30.

Savu, H. (1968), *Sienitele cu nefelin de la Mălaia şi poziţia lor în structura cristalinului Lotrului*. D.S. Inst. Geol., **LIII, 3**, 85–117.

Savu, H. (1998), *Origin and evolution of a Carpathian triple junction*. An. Univ. Bucureşti (Geol.), **XLVII**, 2–12.

Savu, H. (2004), *The Transylvania mantle plume and the related hotspot volcanic rocks, Romania.* Proc. Rom. Acad. Series B, 2004, **1**, 33–40.

Savu, H. (2004–2005), *Structure, metamorphism and origin of the dismembered thermal dome from the South Carpathians, Romania*. Rev. Roum. Géol., **48-49**, 41–58.

Savu, H. (2005), *Tectono-magmatic evolution of the Romanian territory and origin of its bent orogen structures*. Geo-Eco-Marina, ***9/10*,** 116–132.

Savu, H., Neacşu, V., Bratosin, I. (1984), *Petrological and geochemical study of the dyke rocks in the Şinca Nouă-Poiana Mărului-Holbav area (Făgăraş Mountains).* D.S. Inst. Geol. Geofiz., **LXVIII**, 151–219.

Savu, H., Horst, P. H., Udrescu, C., Neacşu V. (1986), *Ultrabasic rock olistoliths from the Jurassic formations on the Craiu Valley (Muntele Mic): petrology and geochemistry*. D.S. Inst. Geol. Geofiz. **70–71, 1**, 171–182.

Savu, H., Tiepac, I., Uscătescu, A. (2000), *Petrological and geochemical data concerning the mantle beneath the Perşani Mountains Quaternary basalt area, Romania*. Proc. Rom. Acad. Series B, 2000, **1**, 43–47.

Săndulescu, M., Russo-Săndulescu, D. (1981), *The ophiolites from the Rarău and Hăghimaş synclines – their structural position, age and geotectonic evolution.* D.S. Inst. Geol, **66**, 103–114.

Schafarzik, F. (1899), *Die geologische Verhältnisse der Umgebung von Borlova und Poiana Mărul*. Jb. Kgl. Ungar. G.A. f. **1897**.

Schmidt, O. (1940), *Cercetări geologice in ramificaţiunile nordestice ale Munţilor Făgăraş.* D.S. Inst. Geol. Rom., **XV**, 15.

Sörensen, H. (1960), *On the agpaitic rocks*. Intern. Geol. Congr. Report, 21st Sess. Copenhagen, **Part XIII**, Copenhagen.

Stan, N., Tiepac, I. (1996), *Petrochemical characterization of the syenites in Banat (Romania); REE and trace element contents; petrogenetic and tectogenetic consequences.* Rom. J. Petrology, **77**, 23–36.

Streckeisen, A. (1931), *Zur Differentiation im Nephelinsyenit Massiv von Ditró (Rumänien).* Lab. Miner. Univ. Bucureşti, **I**, 65–71.

Streckeisen, A. (1967), *Classification and nomenclature of igneous rocks*. N. Jb. Miner. Abh. 107**, 2–3**, 114–240.

Streckeisen, A., Giuşcă, D. (1932), *Das Nephelin-Cancrinit Syenit von Orşova*. Bul. Soc. Rom. Geol., **I**, 176–192.

Szentpetery, S. (1910), *Die mesozoischen Eruptivgesteine der südlichen Hälfte des Perşanyer Ggebirges*. Naturwiss. Müzeums Hefte, **IV**, 62 p., Cluj.

Wachner, H (1916) *Bericht über die im Sommer 1916 im Persányer Gebirge ausgefür geologischen Aufnahmen*. Jb. D. kgl. Ung. geol. R. A. f. **1916**, 259–284.

Received: 7.09.2010