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Pre-ocean and post-collision intraplate basalts from Romania: A comparative study

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Abstract

In the present paper, the intraplate pre-ocean Triassic Dobrogean basalts and the post-collision Paleogene Transylvanian basalts have been comparatively studied. Although the two basaltic rock series show the same tectonic setting, they, nevertheless, display peculiarities in terms of their texture. The rocks of the first basalt series erupted along continental rifting faults during the distension period preceding the opening of the Carpathian Ocean, whereas those of the second basalt series erupted along the faults which appeared during the distension period that followed the collision of the Alpine tectonic plates. The first basalt series shows a WPB-to-MORB transition character, while the second series exhibits an IAV-to-WPB transition character. The parental magma of the first basalt series came from a depleted mantle source, while that of the second basalt series derived from an enriched mantle source, under the influence of a mantle plume. It seems that both parental magmas have been formed in the mantle, at a depth of about 30–50 kilometers. At the moment of the eruption, they had evolved as basaltic magmas, in which the olivine fractionation had already reached about 15%.

Keywords: intraplate basalts, pre-ocean basalts, post-collision basalts, geochemistry, origin.

Introduction

In a previous paper (Savu, 2005), a comparative study of the pre-ocean and post-collision hotspot alkali basalts from the Alpine tectono-magmatic cycle occurring on the territory of Romania was carried out. However, within this area, tholeiitic and calc-alkaline intraplate basalts occur, as well. Although these two basalt series have the same tectonic setting, their geochemistry displays certain differences, making a comparison between them, along with an estimation of the origin of these geochemical discrepancies as shown further on within the present paper, necessary.

Occurrences of rocks from the two intraplate basalt series

To begin with, it is necessary to clarify the geotectonic significance of the two magmatic

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processes taking place during the evolution of the Alpine tectono-magmatic cycle, as well as their position in relation to the Alpine ocean. During the evolution of the Alpine tectono-magmatic cycle, the two magmatic activities had clear positions and functions (Savu, 2012). Thus, the pre-ocean intraplate volcanism launched the magmatic activity of the cycle, before the opening of the Alpine ocean, while the post-collision intraplate volcanism closed the magmatic activity of the Alpine cycle, after the closing of the ocean. Both manifested themselves through continental tectonic plates.

The two types of intraplate basalts that the present paper deals with occur on the territory of Romania in different areas spreading from the Apuseni Mountains down to North Dobrogea (see the Geologic Map of Romania, scale 1:1000000).

1. *Pre-ocean intraplate basalt occurrences.* The pre-ocean basalts occur within two areas: in the Noth Dobrogea aulacogen, and in the north of Banat. In the first case, the intraplate basalts erupted during the Triassic, in the following three phases: the Spathian (Scythian), the Spathian-Anisian and the Ladinian (Savu, 1986; Savu, 2011). During the first eruption phase, the magmatic activity manifested itself under two aspects, namely as a bimodal dyke swarm, crossing the crystalline schists of the Măcin Unit (Nicolae and Seghedi, 1996), and as volcanic activity (Mirăuţă, 1982; Baltreş, 1993), the products of which crop out in the Isaccea-Somova area, also as bimodal volcanics (Savu et al., 1985; Savu, 1986).The basalt flows overlie the Variscan anchimetamorphic formations and granitoids of the Tulcea Unit (Savu et al., 1985; Savu, 1986).

During the Late Spathian and the Anisian, the intraplate volcanism manifested itself through large basalt flows, resulting in the Niculiţel flood basalt complex, which is about 200 m thick. The flood basalts directly overlie the Variscan anchimetamorphic formations and granitoids of the Tulcea Unit. These relations can be easily observed on the Pârâul Viilor creek, at Sarica, and west of Mânăstirea Cocoş, where basalt flows unconformably overlie the same Variscan formations of the North Dobrogea aulacogen infrastructure (Savu, 2011). This stratigraphic unconformity has been regarded as forming a tectonic thrust, such as, for instance, on the Geological Map of Romania, sc. 1:50000, the Niculiţel sheet.

The last phase of Triassic basic rocks manifested itself in the North Dobrogea aulacogen through dykes trending N40°W, near the Izvoarele village, intruding the Ladinian deposits, and through those crossing the flood basalts from the Niculiţel complex, in the Asan hill, and the Mesozoic deposits on the Armanu valley, at Somova. There, the basalts occur as multiple dykes, as well.

All these volcanics and dykes from North Dobrogea aulacogen erupted along the failed branch of the Carpathian triple junction (Savu, 1986). This structure evolved during the Upper Triassic, up to the beginning of the Jurassic, when the Carpathian Ocean opened and the North Dobrogea branch was aborted as an aulacogen.

In the north of Banat, intraplate basalts occur around the Coştei village, south of the Mureş ophiolitic suture (Savu et al., 1992). North of Coştei, under the Laramian (banatitic) volcanics of the Lăpugiu Basin, Triassic quartz sandstones and intraplate volcanics occur. The basaltic rocks consist of pillowed basalts, hyalobasalts and amigdaloidal basalts, which are associated with quartz keratophyre tuffs, suggesting bimodal volcanism. Between the basalt flows, layers of Triassic limestones and red argillites often occur. The general features of the basalts, along with their association with Triassic sedimentary deposits, indicate that these basalts erupted in an epicontinental sea, like the intraplate basalts from North Dobrogea, described above. The Coştei basalts erupted along the pre-ocean rifting zone along which the Mureş Ocean opened at the beginning of the Liassic.

2. *Post-collision intraplate basalt occurrences.* The basalts in this category erupted during the Paleogene (48-30 Ma, K/Ar, M. Lemne, unpublished data). They occur within two areas from the inner part of the Carpathian Orogen. One of these areas is located in the Bihor Mountains. There, the

basalts form a dyke swarm oriented on the N35°W general direction (Savu, 2000), like other dyke swarms around the world, such as, for instance, those from the Thulean province (see Tyrrell, 1960, Fig. 9). A second occurrence of post-collision intraplate basalts is present south of the Petreşti village, in the south of the Southern Apuseni Mountains, slightly north of the Mureş River, where a volcanic neck crossed the Mureş ophiolitic suture formations. It is located in the same obducted plate of the Alpine system of the Carpathian Orogen (Savu et al., 1991).

Petrography and classification of the basaltic rocks

As shown above, the pre-ocean basalts appear under two forms: as dykes and as volcanics. The dykes mostly occur in the Măcin Unit, where they form the previously-mentioned dyke swarm, which crosses the Pre-Variscan and Variscan crystalline schists of the Moesian Plate. The dykes form a bimodal series, the basic sequence of which consists of basalts, dolerites and, rarely, gabbro-dolerites (Nicolae and Seghedi, 1996). The texture of these rocks varies from intersertal and intergranular to medium-granular. The rocks are formed of basic plagioclase, partly altered, clinopyroxene, and, rarely, olivine partly substituted by serpentine.

The most representative basic volcanics from the North Dobrogea aulacogen are those from the flood basalt complex in the Niculiţel formation. These rocks often occur as pillow lava, showing a hyalobasalt crust (Savu et al., 1980; 1982). The rocks consist of basalts, hyalobasalts and anamesites. The melanocratic mineral in the flood basalts is a reddish-violet prismatic titan-augite, which is associated with anortite-rich laths of plagioclase. Rare sills of gabbro-dolerites are also present. Spilitic rocks occur, as well, showing that the eruptions of flood basalts manifested themselves in an epicontinental sea, like the flood basalts from the Deccan trap complex (Sukheswala, 1977), where spilites are also present. The basic sequence of the Somova bimodal volcanics consists of porphyritic basalts and tuffs.

The basic rocks from the Coştei basalt complex consist mostly of basalts, which show an intersertal texture and are formed of basic plagioclase laths, partly substituted by argillaceous minerals, augite and glass affected by chloritization. Hyalobasalts occur, as well, the vitreous component of which is almost completely substituted by chlorite, in the mass of which nests with a variolitic texture are to be observed. Apart from these types of basalts, amygdaloidal basalts also occur, the amygdals of which are usually filled with calcite and chlorite or only with chlorite.

The post-collision basaltic rocks from the Bihor area mostly occur as dykes of basalts and dolerites, often affected by the process of autometamorphism. However, some remnant fresh rocks, which consist of plagioclase microcrystals, clinopyroxene and serpentine pseudomorphoses formed on olivine crystals, in association with magnetite, pyrite and, rarely, apatite, indicate more melanocratic terms. It is noteworthy that augite exhibits a weak, light red and violet, pleochroism.

The Petreşti rock is an instance of aphanitic olivine basalt, consisting of a hyalopilitic-to-pilotaxitic groundmass, in which augite and olivine phenocrysts occur, the latter being crossed by veinlets of iddingsite.

For the classification of the basaltic and related rocks, the diagram in Figure 1 is very suggestive. It shows that, although all of the basic rocks consist of intraplate basalts, there are obvious differences between the pre-ocean and the post-collision ones. The pre-ocean basalts are more varied; one rock is more basic, plotting in the picrobasalt field; other two rocks show a weak tendency toward alkaline basalts, plotting in the trachybasalt field. The post-collision basalts are close to one another, being, thus, gathered into a restricted field.

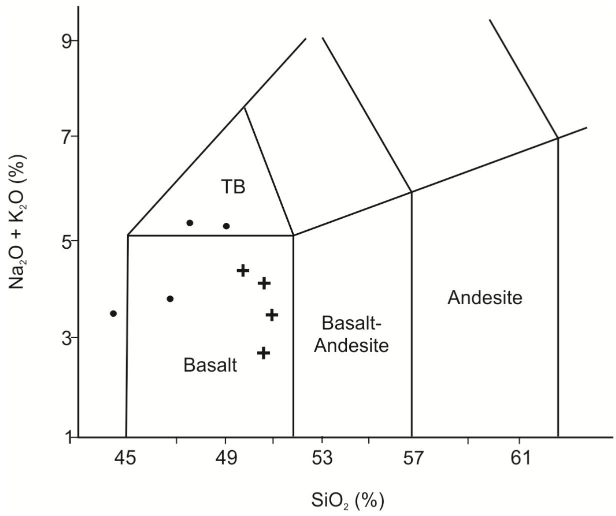

Fig.1.Plotting of the average values of basalts and related rocks from the two rock series on the Na_2O + K_2O vs. SiO_2 diagram. Fields according to Le Bass et al. (1986). Dot – pre-ocean basalts; cross – post-collision basalts. Data from Tables 1 and 2.

Geochemistry of basaltic rocks and their tectonic setting, inferred from the chemical elements

The average chemical composition of the rocks from the two basic rock series is illustrated in Tables 1 and 2. The latter indicate that all the rocks are consistent with the definition above, as their SiO_2 varies from 44.46 to 49.42% in the pre-ocean basaltic rocks, and from 44.33 to 52.90% in the post-collision rock series. In both series, TiO_2 shows higher contents than in other basalts, being characteristic for intraplate basalts. A small difference between the two basalt series is related to the value of Fe_2O_3, which is slightly higher in the pre-ocean basaltic rocks, where its general average is 9.76%, compared to that of the post-collision rocks, which is 9.40%. An obvious difference between the two basaltic rock series is indicated by the values of MgO, with a general average of 8.65% in the pre-ocean rocks, and one of 6.84% in the post-collision basaltic rocks. The CaO average value of the post-collision basalt series (9.21%) is higher than that of the pre-ocean basaltic rocks (7.62%). The general average, 4.39%, of the calc-alkaline compounds from the pre-ocean basalts series is higher than the general average value, 3.68%, of the calc-alkaline compounds from the post-collision basalt-series. Dominant among these compounds is Na_2O, the average of which is 3.45% in the pre-ocean basalt series, and 2.32% in the post-collision basalt series.

The plotting of the average values of the two basalt series from Tables 1 and 2 on the diagram in Figure 2 has revealed the main petrochemical characteristics of the two rock series. Thus, the pre-ocean basalts are mostly tholeiitic, showing a tendency toward the calc-alkaline series. The rocks of the post-collision basalt series are, on the contrary, mostly calc-alkaline, with a weak tendency toward the tholeiitic domain.

All the rocks from the two basalt series display an intraplate signature. There are, nevertheless, differences from one series to another, as shown in Figure 3. The pre-ocean basalts plot on the diagram in the domain of the evolved magmas, while the post-collision basaltic rocks plot in the domain of the primitive magmas.

Table 1 Average chemical composition of the pre-ocean basalts*

Oxides/elements	1	2	3	4	Ratios	Values
SiO_2	47.40	49.42	48.35	44.46	Mg#	72.99
TiO_2	1.77	2.32	2.75	1.85	Na_2O/K_2O	3.67
Al_2O_3	15.52	16.65	14.63	14.61	CaO/Al_2O_3	0.50
Fe_2O_3	9.37	7.55	10.39	11.75	FeO*/Mg	1.58
MnO	0.20	0.10	0.20	0.21	FeO*/FeO*+MgO	0.61
MgO	9.22	6.58	5.50	6.06	Ti/Y	350
CaO	8.26	6.41	7.78	8	Zr/Y	4.37
Na_2O	2.57	3.75	4.15	3.33	Sr/Y	5.07
K_2O	0.99	1.44	0.96	0.39	Ba/Sr	0.50
P_2O_5	0.28	0.25	0.64	0.16	K/Sr	39.86
LOI (H_2O, CO_2, S)	1.34	1.73	1.23	1.42	Ti/V	51.10
Sum	100.24	99.86	99.0	99.53	Eu/Sm	0.31
Ni	243	95.75	65.81	64.66	(La/Yb)N	2.03
Co	46.91	38.15	40.8	28.4	Tb/Yb	0.25
Cr	379	243.5	135.3	97.5	Eu/Eu*	0.92
V	242.5	217.8	260.6	245.0	(La/Sm)N	1.40
Sc	34.66	29.5	28.46	33.5	(Ce/Yb)N	1.70
Ba	133.16	109.7	149.13	126.2	LREE/HREE	8.31
Sr	212.08	283.5	149.13	137.5	Sum of REE	169.5
Zr	179.75	223.3	197.76	174.4	-	-
Y	38.33	36.87	54.90	24.8	-	-
Zn	-	-	-	37.2	-	-
Cu	49.50	33.47	34.67	55.0	-	-
Pb	7.50	5.06	3.44	2.77	-	-
Ga	15.57	15.75	18.23	11.5	-	-
Sn	2.53	2.0	3.46	-	-	-
La	5.4	13	10.47	9.33		
Ce	15.55	27	24.55	16.67	-	-
Pr	2.7	-	-	-	-	-
Nd	13.45	-	-	-	-	-
Sm	3.85	5.1	5.0	3.17	-	-
Eu	1.35	1.79	1.6	0.73	-	-
Gd	4.05	-	5.09	-	-	-
Tb	0.77	-	0.95	0.70	-	-
Dy	4.77	-	5.0	-	-	-
Ho	1.06	-	1.23	-	-	-
Er	2.63	-	3.22	-	-	-
Tm	0.4	-	0.41	-	-	-
Yb	2.47	4.2	3.01	3.0	-	-
Lu	0.35	-	0.45	-	-	-
Mg#	79.5	77.72	67.66	67.1	-	-

* The analyses in the table represent: 1–average of 14 basalts from the Măcin area (data from Nicolae and Seghedi, 1996; Saccani et al., 2004); 2–average of 14 basalts from Somova area (data from Savu et al., 1985); 3–average of 3 basalts from the Niculiţel basalts (data from Saccani et al., 2004); 4–average of 9 Coștei basalts (data from Savu et al., 1992).

Table 2 Average chemical composition of the post-collision basalts*

Areas	1	2	3	4	Ratios	Values
SiO_2	50.78	52.90	44.33	49.55	Mg#	70.5
TiO_2	1.50	1.04	2.65	1.36	Na_2O/K_2O	1.35
Al_2O_3	15.24	13.92	13.84	14.57	CaO/Al_2O_3	0.89
Fe_2O_3	9.26	8.03	11.11	9.1	FeO*/MgO	1.19
MnO	0.17	0.15	0.17	0.13	FeO*/Fe*+MgO	0.54
MgO	6.18	9.76	10.30	8.49	Ti/Y	481
CaO	11.21	9.78	7.93	7.83	Zr/Y	5.43
Na_2O	2.43	2.55	2.01	2.30	Sr/Y	18.29
K_2O	1.53	0.98	0.76	2.17	Ba/Sr	1.17
P_2O_5	0.23	0.11	0.42	0.28	K/Sr	24.1
S	0.07	0.27	0.24	0.35	Ti/V	53.8
H_2O	1.05	0.75	LOI, 5.37	3.30	Eu/Sm	0.39
Sum	100.11	100.51	99.66	99.83	(La/Yb)N	10.57
Ni	17	21	35.22	25.60	Tb/Yb	0.11
Co	34	25	22.77	25.60	Eu/Eu*	0.56
Cr	100	260	133.75	102.20	(La/Sm)N	0.45
V	300	100	193.11	171.60	(Ce/Yb)N	3.97
Sc	44	17	22.33	25.20	LREE/HREE	11.12
Y	21	12	25.66	24.60	Sum of REE	86.05
Yb	2.8	1.3	2.03	1.2	-	-
Zr	110	75	90.55	128.20	-	-
Ba	280	300	473.88	585	-	-
Sr	440	720	351.11	362	-	-
Pb	7.5	11.0	10.22	17.20	-	-
Cu	23	80	24.44	24.20	-	-
Ga	13	15	15.11	18.40	-	-
Sn	2	2	-	-	-	-
Zn	-	-	219.44	232.0	-	-
La	12	17	-	-	-	-
Ce	16	26	-	-	-	-
Sm	4.1	3.6	-	-	-	-
Eu	0.64	1.0	-	-	-	-
Tb	0.46	0.47	-	-	-	-
Lu	022	0.20	-	-	-	-
Mg#	74.63	85.86	64.53	64.68	-	-

* The analyses in the table represent: 1–one basalt from Petrești (data from Savu et al., 1991); 2–one basalt-andesite from Petrești (data from Savu et al., 1991); 3–average of 4 melanocratic basalts from the Bihor dyke swarm (data from Savu, 2000); 4–average of 9 basalts from the Bihor dyke swarm (data from Savu, 2000).

Although the rocks from the two basalt series plot as intraplate basalts, a character determined both by their occurrence and the diagram in Figure 3, the diagram in Figure 4 shows that some rocks exhibit a tendency toward the plate margin domain (MPB). It is, however, known that the rocks occurring on the margins of tectonic plates are either ocean floor or island arc volcanics. This shifting of some rocks toward the MPB domain marks the ambiguous character of these rock series. Otherwise, as shown by Savu (2011), according to their geochemistry, the Dobrogea Triassic basaltic rocks represent WPB-to-MORB transition rocks, while the post-collision basaltic rocks occur as IAV-to-WPB transition rocks (Savu, 2000). These aspects suggest the weak hybrid character of the parental magmas of the two rock series.

The pre-ocean basaltic rocks are slightly more basic than the post-collision ones, as indicated by the values of the magnesium number Mg# [= 100 × mol. MgO/(MgO + 0.9 × FeOtot)] of the two basalt-series (Tabs. 1 and 2). This is clearly highlighted by the diagram in Figure 5, on which the magnesium number of all rocks was plotted. On this diagram, the plots of the pre-ocean basalts are situated in a higher position than the level of 65 Mg#, whereas most of the post-collision basaltic rocks occur in a position lower than this level.

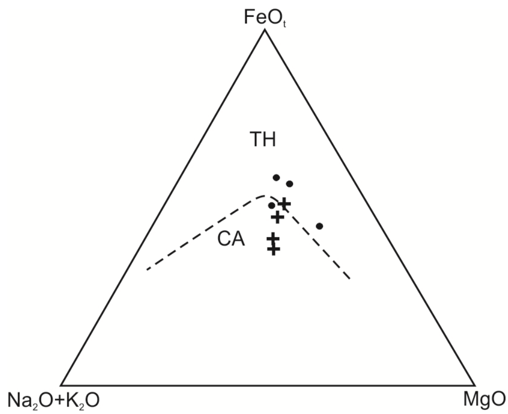

Fig. 2 Plotting of the average values of the rocks from the two basalt series in the FeOtot–(Na_2O+K_2O)–MgO diagram. Fields according to Irvine and Baragar (1977). Data from Tables 1 and 2. Legend as in Figure 1.

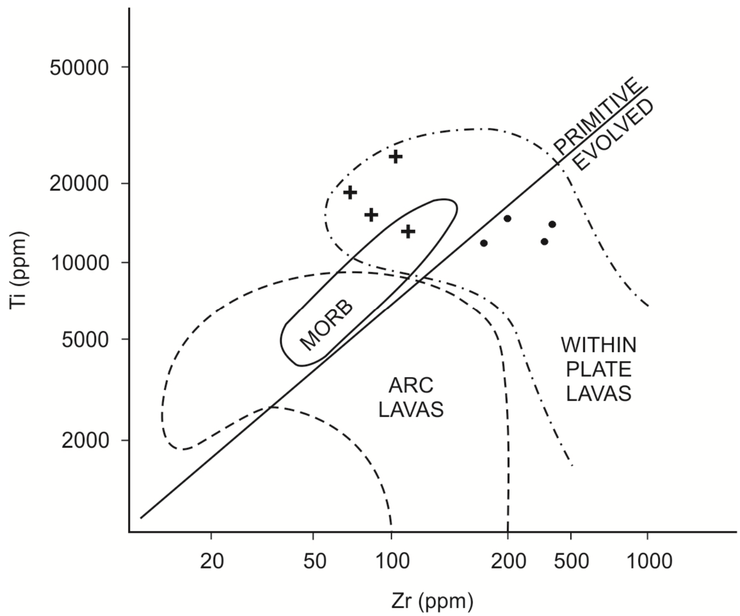

Fig. 3 Plotting of the average values of the basaltic rocks from the two basalt series on the Ti vs. Zr diagram. Fields according to Pearce (1980). Data from Tables 1 and 2. Legend as in Figure 1.

The average values of the trace elements from the two basalt series have been included in Tables 1 and 2, as well. Depending on the data from the literature, for the pre-ocean rocks, these elements have been presented in complete sets, whereas in the post-collision rock series the REE have been determined in only two groups of basalts. The contents of trace elements from the siderophile group like Ni, Cr and Co are higher in the pre-ocean basalts, while those of V and Sc are higher in the post-collision rocks. The trace elements related to the alkaline major elements, such as Ba and Sr, are generally higher in the post-collision basalts than in the pre-ocean ones. Other trace elements display variable contents in the two basalt series.

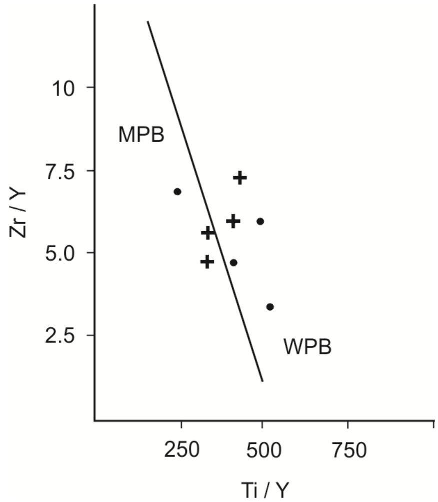

Fig. 4 Plotting of the average values of the rocks from the two basalt series on the Zr/Y vs. Ti/Y diagram. Fields according to Pearce and Gale (1977). Data from Tables 1 and 2. Legend as in Figure 1.

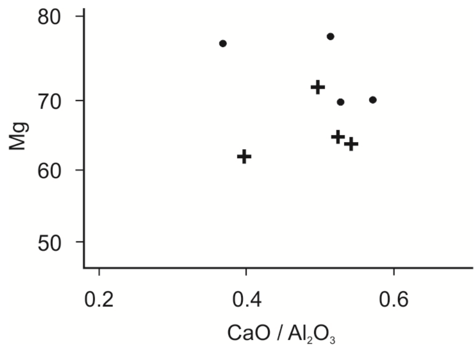

Fig. 5 Plotting of the magnesium number (Mg#) of the rocks from the two rock series on the Mg# vs. CaO/Al_2O_3 diagram. Data from Tables 1 and 2. Legend as in Figure 1.

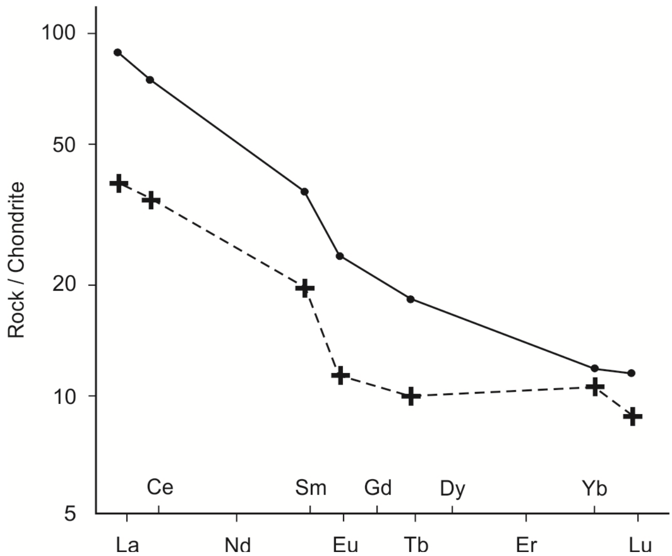

Fig. 6 The chondrite-normalized REE (normalizing values of Boynton, 1984) of the two basaltic rock series. Data from Tables 1 and 2. Legend as in Figure 1.

As highlighted by Tables 1 and 2 and Figure 6, the average sum of REE is higher in the pre-ocean basalt-series. The LREE/HREE ratio, on the other hand, is higher in the post-collision rocks. The average value of the Eu/Eu* ratio (Eu/Eu* = Eu/radical of [$(Sm)_N$. $(Gd)_N$]) is also higher in the pre-ocean basal-tic rocks than in the post-collision ones – in the first rock series it is 0.92, while in the second one it is 0.52. As Gd was not analytically determined, like in the case of the post-collision basalts, $(Gd)_N$ was directly estimated by projecting this element on the curve of the respective rock series from Figure 6.

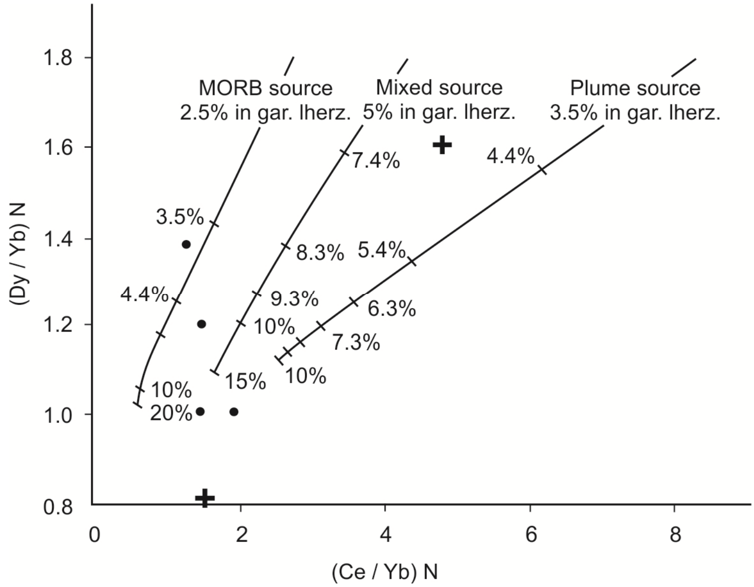

Fig. 7 Plotting of the average values of the two basaltic rock series on the (Dy/Yb)N vs. (Ce/Yb)N diagram. The source lines according to Haase and Devey (1996). Data from Tables 1 and 2. The same legend as in Figure 1.

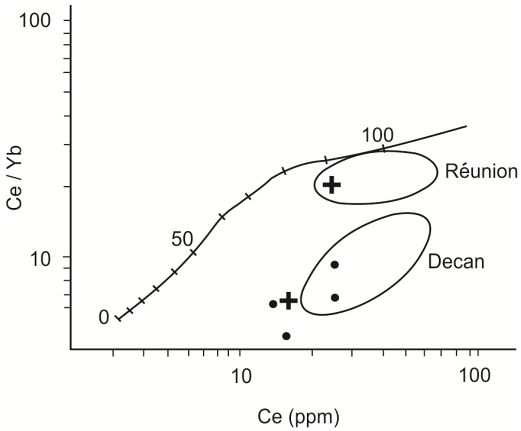

Fig. 8 Plotting of the average values from the pre-ocean and post-collision rocks on the Ce/Y vs. Ce diagram. Fields and depth curve according to Ellam (1992). Data from Tables 1 and 2. Legend as in Figure 2.

It is noteworthy that all of the ratios in which major elements have been used (see Tables 1 and 2) are higher in the pre-ocean basalts than in the post-collision ones. The Na_2O/K_2O ratio is also significant from this point of view, as it is also higher in the pre-ocean basalt-series.

Origin of the rocks from the two basaltic rock series

Although the rocks from the two basaltic rock series have the same tectonic setting, as intraplate rocks, their mantle sources must have been somewhat different, as indicated by the differences between their component rocks. As the diagram in Figure 7 shows, two plots of the average values of the pre-ocean rocks occur along the MORB source line, this position being consistent with the conclusion reached by Savu (2011), according to which the North Dobrogea Triassic basalts are WPB-to-MORB transition rocks. The other plots are rather close to the mixed-source line, which allows us to infer that the parental magmas of these rocks originated in a mantle source, as well, but were probably contaminated by crust materials.

Only two plots of post-collision rocks are situated between the mixed-source line and the plume-source line. Their real source must have been in the upper mantle, as well, but the genesis of the parental magma could have been influenced by a mantle plume which was very active at depth in the region during the Paleogene period, when the post-collision volcanics erupted (Savu, 2004). Otherwise, it was previously shown that the parental magmas of these rocks bear the IAB-to-WPB signature (Savu, 2005).

On the Ce/Y vs. Ce diagram, with the exception of one post-collision rock, which occurs in the Réunion island rock field, all of the pre-ocean and post-collision rocks plot either inside the Deccan trapps field or near it (Fig. 8). This suggests that the parental magmas have been formed through the partial melting of the upper mantle, at a depth of about 30 to 50 km.

For the genesis of the parental magmas of the two rock series, the mantle source was partially melted, at a rate of about 10 to 15%, as shown on the diagram in Figure 9. The latter also indicates that the partial melting rate was higher in the case of the post-collision magmas, as most of the plots of these rocks are located near the 15% rate on the melting curve.

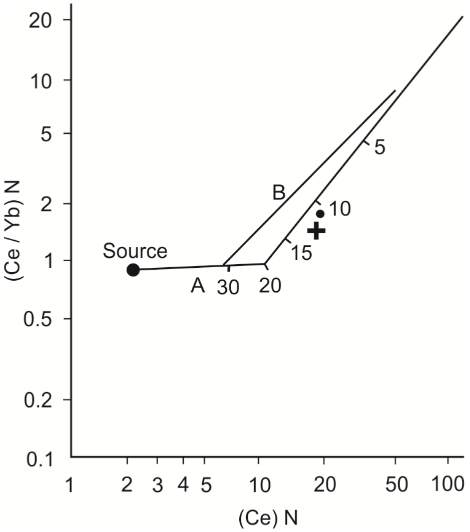

Fig. 9 Plotting of the average values of the rocks from the two rock series on the $(Ce/Yb)_N$ vs. $(Ce)_N$ diagram. Melting curve and melting rate values according to Saunders (1984). Data from Tables 1 and 2. Legend as in Figure 1.

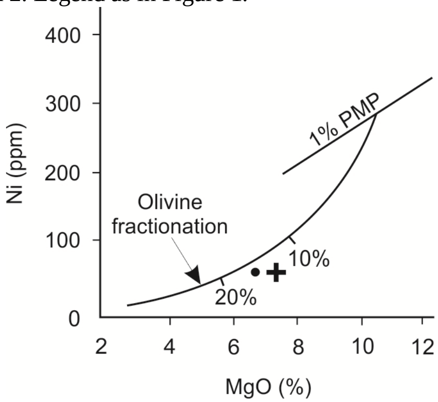

Fig. 10 Plotting of the general average of the rocks from the two volcanic rock series on the Ni vs MgO diagram. Partial melting line (PMP) of 1% pyrolite and olivine fractionation curve according to Volker et al. (1992). Data from Tables 1 and 2. Legend as in Figure 1.

The basaltic parental magmas of both rock series had reached a certain degree of evolution at the moment of the volcanic eruption, as indicated by the diagram in Figure 10, where the plots of the general average of the two rock series show that the olivine fractionation in both magmas reached around 15%.

Conclusions

The comparison of the two basalt series occurring in North Dobrogea and Transylvania, respectively, has yielded a series of conclusions. Firstly, the Triassic rocks of the pre-ocean basaltic series erupted along continental rifting faults during the distension period which preceded the opening of the Carpathian Ocean and the Mureş Ocean. The Paleogene rocks of the post-collision basaltic series erupted along faults formed during the distension period that followed the Laramian compression, when the Transylvania mantle plume was emplaced. Consequently, their geochemical characteristics show that the Triassic basalts bear a WPB-to-MORB transition signature, while the Paleogene basaltic rocks display an IAV-to-WPB transition character.

Although both rock series erupted in a continental tectonic setting, each of them exhibits its own petrographic peculiarities. Thus, the Triassic pre-ocean basalts show an intersertal-to-doleritic texture, while the Paleogene post-collision basalts are mostly porphyritic rocks.

The parental magma of the pre-ocean basaltic rocks originated in a depleted mantle source, whereas the parental magma of the post-collision basalts was formed in an enriched mantle source, which evolved under the influence of a mantle plume. Both parental magmas were formed in the mantle, at a depth of about 30–50 km, as in the case of the Deccan traps, which are also intraplate rocks. The basaltic rocks of both series resulted from evolved parental magmas, in which the olivine fractionation had reached about 15% at the moment of the eruption, with some differences between the two parental magmas.

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