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Geochemistry and origin of two magmatic rock associations from the banatitic magmatic-metallogenetic province in Romania

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Abstract: Within the Laramian (Upper Cretaceous) continental volcano-plutonic arc from the western part of the Romanian territory, the Lăpugiu Basin and the Vlădeasa Mountains are two areas with distinct associations of banatitic rocks. The first area is located in the northeast of Banat and the second is in the northern part of the Apuseni Mountains. These volcanic associations differ from one another by their general rock composition, since the rocks from the Lăpugiu Basin are more basic, being represented by andesites, while in the Vlădeasa Mountains the banatitic rocks consists especially of dacites, rhyolites and related plutonic rocks. All these volcanic and the associated plutonic rocks are calc-alkaline in composition, with some alkaline tendency, bearing an obvious continental arc signature. The Lăpugiu volcanics differ from the Vlădeasa ones by their high Sr, Ba and Zr contents and low Y contents, suggesting an adakitic tendency. The trace elements of the Vlădeasa volcanics are within a range normal for arc-related rocks. The andesitic (dioritic) parental magmas of the Laramian (banatitic) rocks in both areas resulted from the partial melting of a wedge of metasomatic mantle located above the subduction plane, at a depth of about 100 km. The Paleogene basalts, which cut the Laramian volcanics, are of within-plate type and their parental magmas resulted from the partial melting of a lherzolitic plume-source at about 50 km depth. The Lăpugiu volcanics are associated with Pb-Zn-Cu mineralizations, while uranium deposits are related to the Vlădeasa magmatic rocks.

Key words: Banatitic volcanics; andesites; arc magmatism; felsic rocks; within-plate basalts; Carpathians, Romania

1. Introduction

The Laramian Banatitic Province (Cotta, 1864) extends from the north of Romania through Serbia to the southeast of Bulgaria. Recently, this province was described by Berza et al. (1998) and Ciobanu et al. (2002) as the Banatitic Magmatic and Metallogenetic Belt, with a length of more than 1,000 km (Ciobanu et al., 2002). On the Romanian territory it includes mostly acid rocks (Giuşcă et al., 1966). However, the rock association from the Lăpugiu Basin makes an exception from this rule, consisting mostly of intermediate (andesitic) rocks. This review will compare the prevalently intermediate rocks of Lăpugiu Basin with the dominantly felsic rocks of the Vlădeasa region, as the

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geology of the two regions is better known compared with other banatitic zones in Romania. Moreover, each of these regions has its specific metallogeny.

2. Occurrences, petrography and metallogenesis

The two Laramian volcanic areas (Fig. 1) are situated on the bent zone of the Laramian continental volcano-plutonic arc (see also Rădulescu and Săndulescu, 1973; Savu et al., 1992; Savu, 2005a, Constantina et al., 2009), but occurring in somehow different geological setting. The Lăpugiu volcanics were formed near the Mureş ophiolitic suture, whereas the Vlădeasa volcanics occurred within the northern part of the Apuseni Mountains, formed of old crystalline schists. Necks and dykes of Paleogene hotspot basaltic rocks are crossing the banatitic volcanics in both areas. But these basalts have a different origin than the banatitic rocks.

2.1. The Lăpugiu volcanic rocks

In the Lăpugiu Basin the Laramian volcanics are lining the bottom of the basin, under the Neogene sedimentary deposits, so that they outcrop mostly on its margins (Fig. 1). On the northern margin of the basin these volcanics extend between Groşi, Bulza, Gurasada and Vorţa Valley. Kadić (1906), Pinkert (1907), Papiu (1954), Gheorghiu and Mareş (1964), Rădulescu and Borcoş (1968), Ianovici et al. (1976), Peltz et al*.*, (1970), Peltz and Urcan (1972), Savu et al. (1992, 1994), Roşu et al. (1993) and, recently, Constantina et al. (2009) studied these volcanics. The Laramian volcanics occurring on the southern margin of the basin, between Pietroasa, Roşcani and Ilia, have been investigated by Dittler and Kirnbauer (1933), Papiu (1956), Savu (1962) and Downes et al. (l995).

It is noteworthy that till 1974, in the absence of any precise dating, the Lăpugiu Laramian volcanics were considered as Neogene rocks. In 1974 a first Rb/Sr dating of 60 Ma was obtained (Herz et al., 1974) on a perlite from the Ilteu area. Later, Savu (1984) presented a K/Ar age of 59.6 Ma, obtained on a rhyolite tuff from Vica, and Vîjdea (unpublished data) determined an age of 70 Ma on a rhyolite from the Căpriorişca Valley. Concomitantly, Popescu (in Borcoş et al., unpublished report) determined the Upper Cretaceous age of these volcanics, studying the microfauna from the associated sedimentary deposits. These values have recently been confirmed by Constantina et al (2009), who obtained ages of 69 to 80 Ma on the Gurasada volcanics.

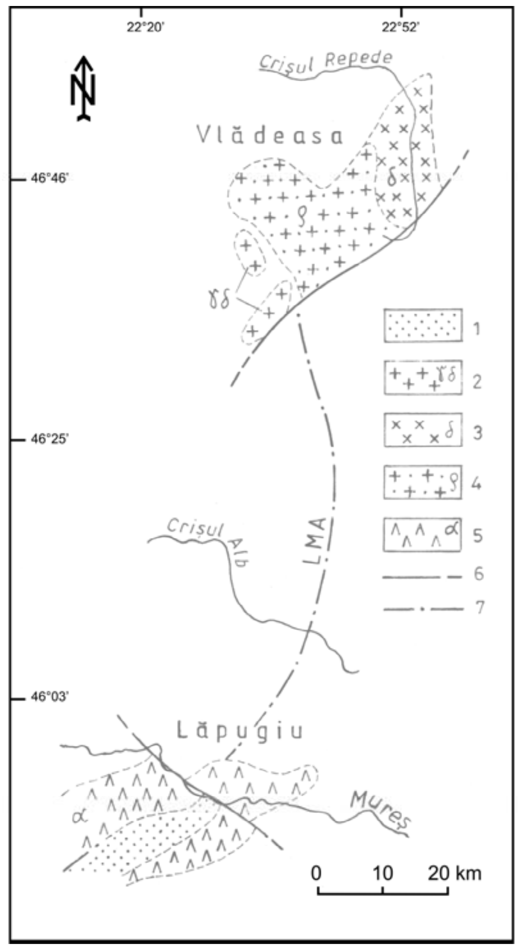

Fig.1. Sketch-map showing the position of the two areas of volcanics on the Laramian continental volcano-plutonic arc from the Romanian territory (after the Geological map of Romania, scale 1:1000000, Geological Institute of Romania, 1966, with the additions of the author). 1, Neogene deposits; 2, granodiorites and granites; 3, rhyolites and rhyodacites; 4, dacites and trachydacites; 5, andesites and trachyandesites; 6, fault; 7, inferred Laramian magmatic arc segment (LMA) of the Banatitic province.

As shown in Figure 2, in the Lăpugiu Basin the Laramian volcanics consist mostly of andesites and trachyandesites; the acid rocks like dacites, trachydacites, trachytes and rhyolites are scarce. Both the andesites and acid rocks occur mostly as pyroclastics, usually stratified. From a lithologic column made by Savu (1962) on the volcanics from the base of the Pietroasa volcanic sequence, in the southern margin of the basin, it results that the Laramian volcanics lie over a basement consisting of the Poiana Ruscă crystalline schists and Upper Cretaceous deposits. On the northern margin they lie on the Coştei Triassic intra-plate basalts and the Jurassic to Upper Cretaceous formations of the Mureş ophiolitic suture. They form an important pile of volcanics consisting of andesitic volcanic breccias, microbreccias, rarely lavas, and fine-grained to psammitic tuffs, which are often bearing plant impressions. The petrographic types include pyroxene andesites, hornblende biotite andesites, augite hornblende biotite andesites, hornblende andesites, hyperstene augite hornblende andesites and hyperstene augite hornblende biotite andesites, which are covered by Neogene gravels. These rock varieties can be found on both margins of the basin (Savu, 1962; Savu et al., 1992; 1994, Constantina et al. 2009). These are often associated with alkaline rocks such as trachyandesites (Fig. 2). The volcanic layers show a thickness of a few centimeters, in case of tuffs, and of up to 50 meters in case of the volcanic breccias.

The acid rocks from the Lăpugiu Basin, although rare, can be found on both margins of the basin, where they are associated with fine layers of sedimentary deposits.

On the northern margin of the basin they occur as layers of rhyolite tuffs intercalated in the lowermost part of the volcanic pile at Vica, on the Căpriorişca Valley and at Ilteu. At the last locality, the acid rocks are represented by perlites. On the Dineş creek, south of Mureş River, a trachyandesite dyke intruded Upper Jurassic limestones. On the southern margin of the basin, rhyolitic rocks occur in a volcanic neck, situated on the Bega Valley (Dittler and Kirnbauer, 1933). The respective rocks contain corroded quartz, sanidine and rarely albite and biotite phenocrysts. South of Pietroasa, acid pyroclastics are intercalated at the base of the volcanic sequence.

On the northern margin of the Lăpugiu Basin there are basic rocks, as well, such as basalts and basaltic andesites (Fig. 2), among which is the basaltic neck located south of Petreşti (see the map in Savu et al., 1992). The latter rocks show some geochemical peculiarities which place them (or at least a part of them), among the rocks of the Paleogene necks from the Mureş Rift (Savu et al., 1996), that originate in the Transylvanian mantle plume (Savu, 2004).

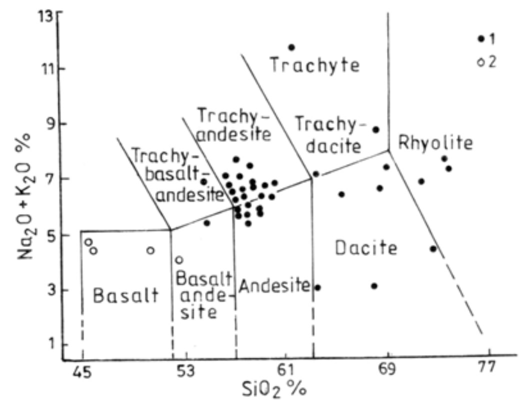

Fig. 2. Plot of the Laramian volcanics from the Lăpugiu Basin on the Na_2O+K_2O vs. SiO_2 diagram. Fields according to Le Maître et al. (1989). Data from Savu (1962), Savu et al. (1992; 1994) and Downes et al. (1995). 1, Lăpugiu volcanics; 2, Paleogene basalts.

2.2. The Vlădeasa magmatic rocks

As it was mentioned above, the acid rocks are prevalent among the Vlădeasa Laramian volcanics. They are associated with granodiorite and granite intrusions, resulting in a typical volcano-plutonic complex (Giuşcă et al., 1969). Geological data concerning these volcanics have been presented in numerous papers, summarized by Istrate (1978) and Ştefan (1980). A more documented paper was published by Ştefan et al. (1992).

The diagram in Figure 3 shows that these volcanics are represented especially by dacites, trachydacites and rhyolites (see also Fig 1). It is of note that Hauer and Stache (1863) introduced in geology the term "dacite", referring to the rocks from this region. Intermediate rocks like andesites and trachyandesites rarely occur. Giuşcă (1950), Istrate (1978) and Ştefan (1980) distinguished various types of andesites, dacites and rhyolites. At the same time, an ignimbritic formation was evidenced there by Giuşcă et al. (1969), extending over an area of about 400 km^2. Within the northern part of the Vlădeasa volcanic area, Istrate (1978) described a similar volcano-sedimentary formation.

The K/Ar dating (Bleahu et al., 1984) showed ages of 61 ± 3 Ma and 61.5 ± 5 Ma. These values show that the magmatic activity in the Vlădeasa area started a little later than in the Lăpugiu Basin.

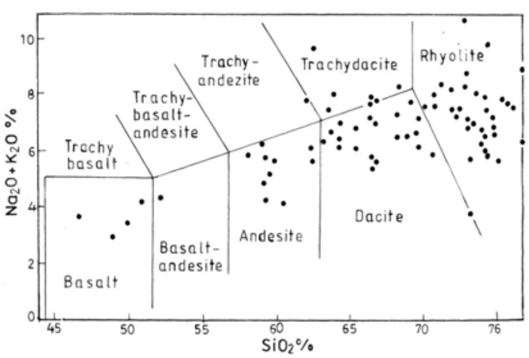

Fig. 3. Plot of the Laramian volcanics from the Vlădeasa area on the Na_2O+K_2O vs. SiO_2 diagram. Fields, according to Le Maître et al. (1989). Data from Giuşcă (1950), Istrate (1978), Ştefan (1980) and Ştefan et al. (1992).

The rocks occurring in the basaltic and basalt-andesite fields in Figure 3 are represented by lamprophyres *sensu stricto* (Ştefan, 1980) and Paleogene basalts (Istrate, 1978). The basaltic rocks occur as NW-SE trending dykes within the western part of the Vlădeasa volcanic area, where they are intruding the ignimbrite formation and the Senonian deposits (Istrate, 1978). They are very similar to the rocks from the Paleogene dyke swarm from the neighboring Bihor Mountains, which could originate in a Bihor mantle plume (Savu, 2005b), occurred during the extension period that followed the Laramian compression.

The two study areas are associated with different types of mineralization. According to the observations of Ghiţulescu and Socolescu (1941), Savu (1972) and Savu and Nicolae (1975), the Lăpugiu volcanics are associated with Pb-Zn-Cu hydrothermal mineralizations, occurring in the Căpâlnaş-Vorţa-Nevoiaş metallogenetic district (Savu, 2011).

The mostly acid magmatic rocks of the Vlădeasa area can be related with U mineralizations, occurring in the Băiţa-Avram Iancu (Bihor) metallogenetic district from the Apuseni Mountains uranium metallogenetic province. Based on the geological conditions, in this district there are two types of uranium mineralization. One is represented by the concentrations of uranium occurring in the Upper Paleozoic crystalline schists of the Păiuşeni series, such as the uranium concentrations occurring on the Păiuşeni river and Rănuşa, which are intercalated as lenses in the crystalline schists (Savu, 1993). The second one is related to the postmagmatic solutions released by the Băiţa granitoid pluton (Niţu, 2000). In both cases, the metal assemblage is U-(Co-Ni) of hydrothermal origin, being associated with enrichment in some other elements such as Fe, Pb, Zn, Cu and Mo. After their emplacement, the uranium deposits have been affected by the tectonics of the Apuseni Mountains Neogene rift (Niţu, 2008).

3. Geochemical features and tectonic setting

The average chemical composition of the Laramian volcanics from the two areas was presented in Tables 1 to 3. These data confirm that the Laramian volcanics from the Lăpugiu Basin, where SiO_2 varies from 50.78 to 68.47%, are more basic than the Vlădeasa rocks, in which this component increases from 49.54 up to 74.50%. The values of FeO_{tot} decrease from 9.26 to 0.16% in the first rock-series and from 8.23 to 2.08% in the second one. MgO varies from 9.76 to 0.66% in the Lăpugiu volcanics and from 7.02 to 0.52% in the Vlădeasa rocks. The sum of alkalies increases from 3.48 to 6.74% in the first series and from 4.29 to 7.55% in the second one, showing that the rock alkalinity is relatively higher in the Vlădeasa rock-series. Except for some alkaline and acid rocks, in both areas Na_2O prevails on K_2O.

The diagram in Figure 4 shows that in both volcanic areas rocks with an obvious alkaline tendency already remarked by Giuşcă et al. (1966) on the rocks of the banatitic province. The Paleogene basaltic rocks from both regions plot on the diagram in the tholeiitic field showing a different origin.

The trace elements presented in the same tables also show some peculiarities of the Lăpugiu volcanics compared to the Vlădeasa ones.Elements like Ni, Co, Cr, V and Sc have variable contents in both series, but they are higher in the Lăpugiu rocks than in the Vlădeasa ones. Among these elements Cr and V are remarkable, since in the Lăpugiu

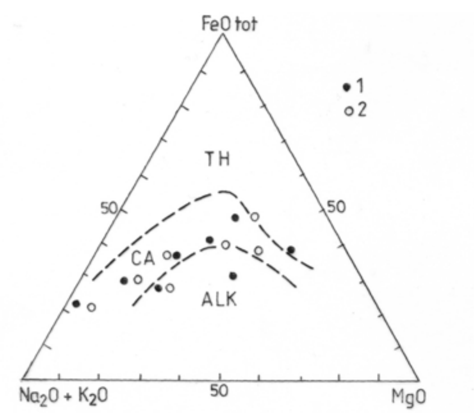

Fig. 4. Plot of the Laramian volcanics on the FeO_{tot}-Na_2O+K_2O-MgO diagram. Fields according to Irvine and Baragar (1971) and Hutchinson (1982). TH, tholeiitic; CA, calc-alkaline; Alk, alkaline. 1, Lăpugiu volcanics; 2, Vlădeasa volcanics, Data from the sources quoted in Tables 1 and 2.

volcanics Cr varies from 260 to 13 ppm and from 350 to 0 ppm in the Vlădeasa rocks. The V contents vary from 310 to 32.66 ppm in the first area and from 190 to 19 ppm in the second one.

The Zr contents in both series are high for calc-alkaline volcanics. The average Zr is

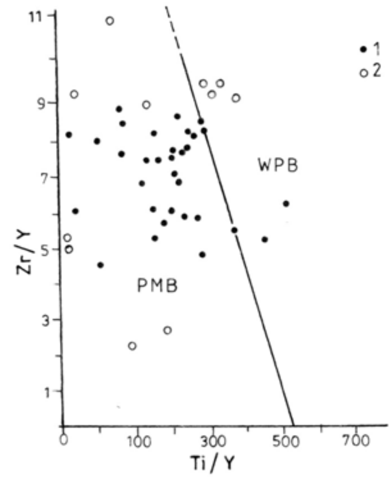

Fig. 5. Plot of the Laramian volcanics and the Paleogene basalts on the Zr/Y vs. Ti/Y diagram. Fields according to Pearce and Gale (1977): PMB, plate margin basalts; WPB, within-plate basalts. Legend as in Figure 4.

in the Lăpugiu rocks of about 125 ppm and of 257.6 ppm in the Vlădeasa ones; it is much higher in the more acid rocks of the second volcanic series. Accordingly, on the Zr/Y vs. Ti/Y diagram (Fig. 5) all the Laramian volcanics plot in the plate margin basalt (PMB) domain, namely, at higher values of the Zr/Y ratio. The basaltic rocks from both areas plot in the WPB field, which supports their affiliation to the Paleogene volcanic province.

The Y and Yb contents are variable, compared with those of the normal island arc volcanics. The average Y is of about 18 ppm in the Lăpugiu rocks and of 27 ppm in the Vlădeasa volcanics. The low Y content from the Lăpugiu rock series is characteristic for the volcanics with the adakitic features (Sajona et al., 2000). It could be supposed that it was determined by the fact that the Lăpugiu volcanics occurred within the Mureş adakitic province area (Savu, 2002), situated between the Southern Carpathians and the Apuseni Mountains.

The Sr and Ba contents are also variable in comparison with those from the normal island arc volcanics. The first element varies from 720 to 247.5 ppm. It has an average of

477 ppm in the Lăpugiu rocks and of only 113 ppm in the Vlădeasa volcanics. Ba presents an average of 478.5 ppm in the Lăpugiu rocks and of 459 ppm in the Vlădeasa ones.

The relationships between Sr and Y determined the plotting of the volcanics from both regions in the "Typical arc field" of the Sr/Y vs. Y diagram (Fig. 6). Nevertheless, due to their high Sr and low Y contents, some the Lăpugiu rocks plot on the diagram at higher values of the Sr/Y ratio, like those of adakitic rocks.

Table 1. Average chemical composition of the Laramian volcanics from the Lăpugiu Basin. Data from Savu (1962); Savu et al. (1992); 1994) and Downes et al. (1995)*

Element	1	2	3	4	5	6	7	8
SiO_2 %	50.78	52.90	55.75	58.26	60.33	66.43	66.47	68.47
TiO_2	1.50	1.04	0.66	0.88	0.75	0.13	0.27	0.33
Al_2O_3	15.24	13.92	17.17	16.45	17.10	14.77	18.05	16.05
Fe_2O_3	4.33	2.63	2.83	3.10	2.53	1.35	0.14	1.70
FeO	5.37	5.67	4.48	2.94	2.30	1.16	0.04	1.0
MnO	0.17	0.15	0.14	0.12	0.11	0.27	1.84	0.52
MgO	8.18	9.76	4.29	3.40	2.74	1.88	0.75	0.66
CaO	9.21	9.78	7.45	6.70	6.60	0.88	3.57	2.04
Na_2O	2.43	2.55	3.03	3..13	3.35	2.33	2.82	2.83
K_2O	1.53	0.98	2.80	2.55	2.49	2.48	3.92	3.72
P_2O_5	0.23	0.11	0.24	0.18	0.19	0.06	0.10	0.05
H_2O^+	1.05	0.75	0.64	1.54	1.13	1.52	1.95	4.15
CO_2	-	-	-.56	0.39	0.44	0.31	-	-
S	0.07	0.27	0.20	0.21	0.28	0.4	-	0.18
Total	100.1	100.51	100.24	99.84	100.34	94.01	99.95	100.70
Ni ppm	17	21	46	19	19.24	3.25	7.27	28
Co	34	25	30	16.77	14.26	2	4.7.33	
Cr	100	260	116	52.83	137.2	3.2.5	48.5	13
V	300	100	310	184	161.89	61.50	47	32.66
Sc	44	17	29.66	16.22	17.23	3.50	5.75	5.25
Zr	110	75	216.6	162.2	164	42.50	110	104.16
Y	21	121	27	19.88	25.3	15.50	12	13.16
Yb	2.8	1.3	2.56	2.11	2.48	0.75	1.35	1.71
La	-	-	42.66	32.88	38.73	41.50	41.50	36.83
Ba	280	300	556	494	650	220	650	480
Sr	440	720	496.6	570	642	192.5	470	247.5
Pb	7.5	11	19.66	15.27	35	20.20.5	6.71	
Cu	23	80	28	16	23.3	9.75	17.50	41.08
Zn	-	-	50	65	25.16	30	83.50	32.66
Ga	13	15	18.33	14.88	20	16	17.50	9.91
Sn	2	2	2	1.75	2.2	1	2.5	2
Nb	10	10	10	10	24.	16	10.20	
Mo	-	-	-	-	-	30	-	57

* The analyses in the table represent: 1, one basalt; 2, average of 2 basaltandesites; 3, average of 3 trachybasalt-andesites; 4, average of 9 andesites; 5, average of 15 trachyandesites; 6, average of 2 dacites; 7, average of 2 trachydacites; 8, average of 7 rhyolites.

On the contrary, the Vlădeasa rocks have values of the Sr/Y ratio lower than 10. The position of the Lăpugiu rocks on this diagram at higher values of Sr/Y ratio, as well as the fact that some rocks of this series plot even in the adakitic rock field (see also Savu, 2002), show their tendency toward rocks with adakitic characteristics. Therefore, it suggests that the Mureş adakitic province includes Upper Cretaceous, Paleogene, Neogene and

Quaternary volcanics. Because of the high Zr and low Y contents, on the Zr/Y vs. Zr diagram (Fig.7), most rocks from both study areas plot within or near the within-plate basalts field. The high Zr could have been induced by the contamination of the parental magmas and seems to be a characteristic of the rocks erupted along the continental volcanic arcs. The Lăpugiu and Vlădeasa volcanics could not be within-plate rocks as long as their Ti content is a normal one for the island arc volcanics (Fig. 5). On the Ti vs. Zr diagram (Fig. 8) the studied rocks plot within the IAB field, or near it. However, a difference occurs between the rocks of the two volcanic areas. The more basic Lăpugiu rocks, which are richer in Ti than those from the Vlădeasa area, plot on the diagram at values higher than 5000 ppm Ti, while most of the Vlădeasa rocks are situated at values lower than 2000 ppm Ti.

The high average contents of Ba and Sr in the rocks with adakitic tendency from the Lăpugiu Basin show that Ba and Sr usually make a characteristic pair in such rocks (Savu, 2001). Moreover, both the Laramian volcanics from the Lăpugiu Basin and the Neogene adakitic volcanics from the Mureş adakitic province have been engendered under the control of the fluids derived from oceanic crust slab subducted on the Benioff plane (Savu, 2001). These fluids generated a metasomatic wedge in the mantle, above the subduction plane, which was the source of the Laramian parental magmas. Other trace elements like Pb, Cu, Ga, Be and Li have varied contents in both volcanic series (Tables 1 and 2).

In Table 3, the contents of REE and other trace elements, as well as the values of some characteristic ratios from the Laramian volcanics were presented. The REE show similar average content in the two volcanic series. However, in the Lăpugiu rocks the REE values, excepting Yb, increase from the basic to the acid rocks. The REE from the Vlădeasa rocks display varied values within the range characteristic for the arc volcanics (Savu et al., 1992).

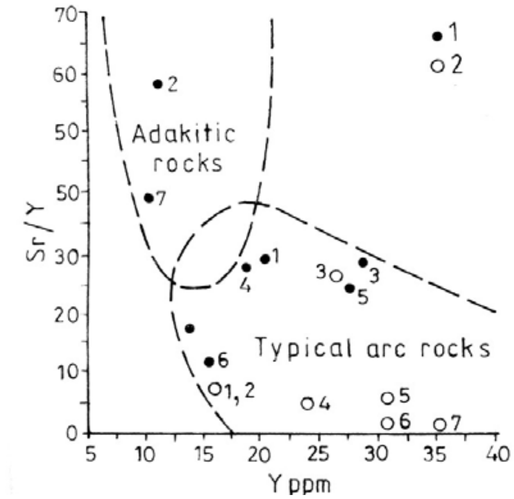

Fig. 6. Plot of the Laramian volcanics from both regions on the Sr/Y vs. Y diagram. Fields according to Drummond and Defant (1990), revised by Sajona et al. (2000). Legend as in Figure 4.

The chondrite-normalized REE patterns (Figs. 9 and 10) show some differences between the two rock series. The pattern of the acid volcanics from the Lăpugiu

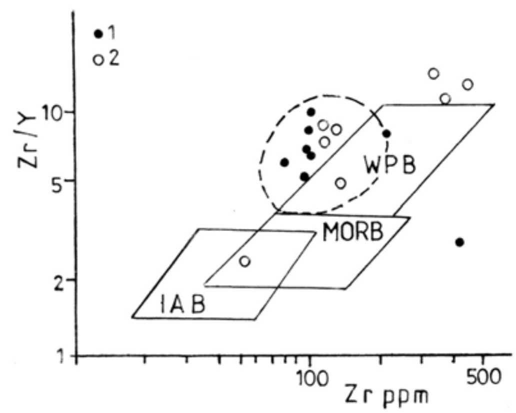

Fig. 7. Plot of the Laramian volcanics on the Zr/Y vs. Zr diagram. Fields according to Pearce and Norry (1979): WPB, within-plate basalts; MORB, mid-ocean ridge basalts; IAB, island arc basalts. Legend as in Figure 4.

Basin shows a weak Ce positive anomaly, as well as a strong Yb depletion (Fig. 9)The pattern of the acid rocks from the Vlădeasa area (Fig. 10) shows a strong Eu negative anomaly that is typical for the island arc rocks. The pattern of the intermediate rocks has the same significance, but it indicates a Tb negative anomaly, that is more. obvious at the Dumbrava hornblende biotite andesite (Ştefan et al., 1992).

Table 2. Average chemical composition of the Laramian volcanics from Vlădeasa. Data from Giuşcă (1950); Istrate (1978); Ştefan (1980) and Ştefan et al. (1992)*.

Element	1	2	3	4	5	6	7
SiO_2 %	49.56	52.74	59.88	62	65.86	68.63	74.59
TiO_2	1.31	0.85	0.18	0.7	0.22	0.25	0.13
Al_2O_3	17	15.62	16.72	19.4	15.42	12.51	13.20
Fe_2O_3	3.70	3.28	2.92	2.43	2.30	1.17	1.14
FeO	5.91	3.87	3.39	1.98	1.47	2.71	1
MnO	0.06	0.03	0.06	0.06	0.07	0.24	0.04
MgO	6.81	7.02	4.36	1.60	1.34	2.04	0.53
CaO	7.73	7.88	4.88	3.04	3.16	2.76	1.40
Na_2O	2.59	2.77	3.56	4.40	3.58	3.52	3.27
K_2O	0.81	1.52	1.46	3.20	2.93	3.42	4.28
P_2O_5	0.34	0.22	0.32	0.17	0.13	0.10	0.15
H_2O^+	2.58	2.59	1.33	0.88	0.70	0.45	0.53
CO_2	1.51	1.41	0.91	0.22	0.83	1.42	0.33
S	0.02	0.04	0.11	0.08	0.41	0.22	0.09
Total	100	99.65	100.08	100.18	98.42	99.46	100.74
Ni ppm	45.5	72	15	9	5.60	3	4
Co	32	37	14.5	14	7.75	5	-
Cr	250	350	29.5	-	12.25	-	-
V	205	190	99.5	66	25.80	30	19
Sc	30.5	29	18	17	9.10	-	14
Zr	150	120	54	375	126.6	420	450
Y	18	18	22.5	19	33	33	36
Yb	2.8	1.3	2.56	2.11	2.48	0.75	1.35
Ba	220	220	345	380	540	420	850
Sr	130	130	189	95	182	53	28
Pb	30	30	25	30	29.30	30	30
Cu	30	42	17	12	11.66	-	4
Ga	15.5	13	22.5	18	18.80	16.15	
Be	1.75	2	2	2	2.66	2	3
Li	-	-	37.5	43	46	-	-

* The analyses in the table represent: 1, average of 4 basalts and lamprophyres; 2, average of 2 basaltic andesites; 3. average of 10 andesites; 4, one trachyandesite; 5, average of 20 dacites; 6, average of 7 trachydacites; 7. average of 32 rhyolites and rhyodacites

For comparison, the pattern of the Paleogene basalts is characteristic for within-plate basic rocks. It is noteworthy that the relationships between the $(Dy/Yb)_N$ and $(Ce/Yb)_N$ ratios determined in a Paleogene basaltic rock from the Vlădeasa area, place it near the plume-source line on the diagram of Haase and Devey (1996), which confirms the supposition that the Paleogene dyke swarm of basic rocks from the neighboring southern area could originate in an inferred Bihor mantle plume (Savu, 2005b), a rock-series to which the basic dykes from the western part of the Vlădeasa area belong, as well. Other trace elements like Th, U, Rb, Hf and Nb (Table 3) were determined only in the rocks from the Vlădeasa area. It is obvious that the first three elements have the lowest contents in the basic

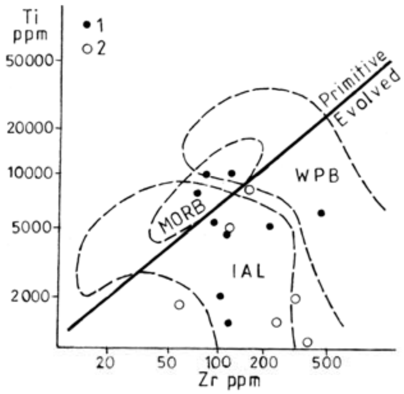

Fig. 8. Plot of the Laramian volcanics from both areas on the Ti vs. Zr diagram. Fields according to Pearce (1980): WPB, within-plate basalts; MORB, mid–ocean ridge basalts; IAL, island arc lavas. Legend as in Figure 4.

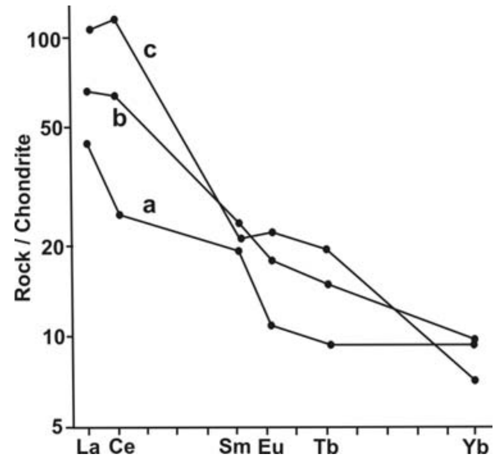

Fig. 9. Chondrite-normalized REE patterns (normalized values from Boynton, 1984) of the Lăpugiu rocks. a, basic; b, intermediate; c, acid. Data from Table 3.

Table 3. The average contents of the REE and of other trace elements from the Laramian magmatic rocks and the values of some of their characteristic ratios. Data from Savu et al., (1992) and Downes et al. (1995)*.

Area	Lăpugiu Basin			Vlădeasa		
Rock-group	Basic	Inter-Mediate	Acid	Basic	Inter-Mediate	Acid
La	14	22.6	33	27	19.6	33.8
Ce	21	55.8	100	25	30	68.46
Sm	3.85	4.74	4.30	5.6	4.13	7.63
Eu	0.82	1.34	1.70	1.29	1.23	0.87
Tb	2.05	2.06	1.5	3.2	2.3	3.10
Yb	2.05	2.06	1.5	3.2	2.3	3.10
Lu	0.21	0.32	0.58	-	-	-
Th	-	9.1	-	6.8	9.04	14.13
U	-	2	-	1.4	2.62	4.69
Rb	-	7.5	-	43.9	68.8	172.5
Hf	-	-	-	2.6	6.76	4.93
Nb	-	7.6	-	23.5	19.28	20.0
Sr/Y	21	29.5	22.38	7.22	6.84	2.57
Rb/Sr	-	1.3	-	0.14	0.21	1.75
Th/U	-	4.5	-	4.85	2.48	3.32
$(La/Yb)_N$	4.60	7.40	14.83	5.68	5.74	7.34
$(La/Ce)_N$	-	1.05	0.85	-	1.70	1.28

* The data in the table represent the averages of 27 analyses of andesites from the Lăapugiu Basin and 15 analyses on the acid rocks from Vlădeasa.

rocks and increase in the other rock groups. Among the ratios presented in Table 3, the values of Sr/Y ratio from the Lăpugiu rocks are in obvious contrast with those from the Vlădeasa volcanics, which are very low. The higher values of this ratio in the Lăpugiu rocks are in accordance with their adakitic tendency, as shown above. The Lăpugiu rocks show higher values of $(La/Nb)_N$ ratio than the Vlădeasa volcanics.

4. Origin of the magmatic rocks in the study areas

Referring to the genesis of the Lăpugiu rocks, Savu et al. (1992) and Savu (2005a) showed that these rocks originated in the continental volcano-plutonic arc from the western part of Romania, generated by the westward subduction of the Moesian Plate under the Transylvanian units (Savu, 1983). Indeed, as the diagram in Figure 11 shows, the Laramian volcanics from both volcanic areas plot in the "OROGENIC ANDESITE" domain. Most of these rocks occur in the High-K field, except for two of them that plot in the Medium-K field. The genesis related to subduction processes was also accepted by Ştefan et al. (1992) for the Vlădeasa magmatic rocks and more recently by Constantina et al. 2009) for the volcanics from the Gurasada area.

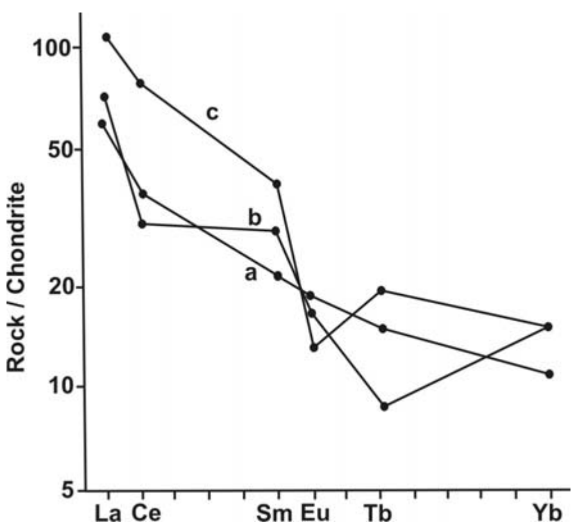

Fig. 10. Chondrite-normalized REE patterns (Boynton normalized values, 1984) of the Vlădeasa rocks. a, basic; b, intermediate; c, acid. Data from Table 3.

The parental calc-alkaline magmas of the Laramian volcanics were intermediate magmas, likely of andesitic (dioritic) composition. They were engendered at great depth in the mantle. According to the Ce/Yb vs. Ce (A) and Ce/Yb vs. Sm/Yb (B) diagrams (Fig. 12), these magmas were formed at a depth of about 100 km (diagram A) or shallower (diagram B).

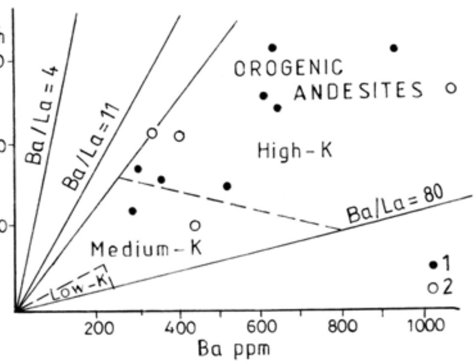

Fig. 11. Plot of the Laramian volcanics from both regions on the La vs. Ba diagram. Fields according to Gill (1981). Legend as in Figure 4.

Accordingly, the fields of the Laramian volcanics occur near the fields of the Réunion Island volcanics or overlap them. The fields of the Paleogene basalts on both diagrams suggest depths shallower than those of the Laramian magmas (ca. 50 km or deeper in Fig. 12A), near the field of the intraplate Deccan traps or partly overlapping it. This is consistent with, although somehow different from the depth of ca. 70 km estimated by Tschegg et al. (2010), based on geothermometric estimations on mantle xenoliths from the Paleogene mafic rocks. The origin at different depths and the geochemical similarities with the Deccan traps supports the origin of the Paleogene basalts in a geotectonic setting different from the one associated with the banatitic intrusions, and a possible lherzolitic source, as argued by Savu (2004, 2005b).

There are several models concerning the genesis of the calc-alkaline magmas in relation with a subduction plane. Taylor (1968) supposed that such magmas could have resulted from the melting of the subducted ocean crust, an opinion contradicted by Gill (1981). Other authors like Mysen and Boetcher (1975) and Green (1976) showed that the andesitic parental magmas resulted from the melting of a hydrated peridotite at a pressure of about 10 Kbar. Considering these ideas and those published by Minear and Toksöz (1970), Mysen (1979), Roden and Murthy (1985), Savu et al. (1992) and Kepezhinskas et al. (1995), it is reasonable to assume that the andesitic (dioritic) parental magmas of the Laramian volcanics from the Lăpugiu Basin and Vlădeasa Mountains were

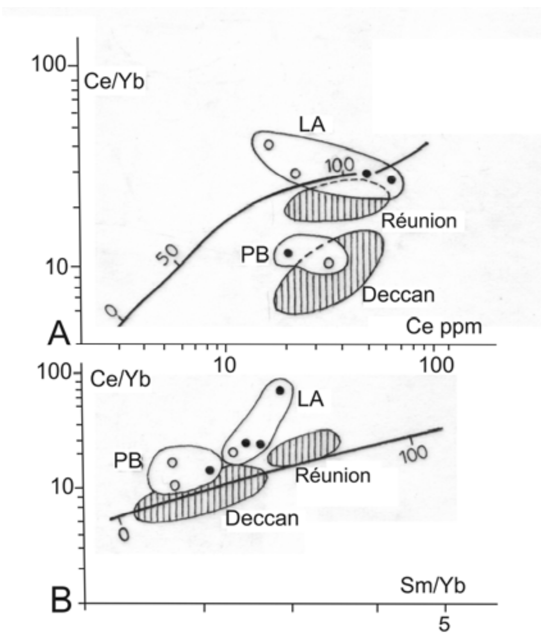

Fig. 12. Plot of the Laramian volcanics on the Ce/Yb vs. Ce (A) and Ce/Yb vs. Sm/Yb (B) diagrams. The depth lines and values, and the Réunion and Deccan rock fields were taken from Ellam (1992). LA, Laramian arc volcanics; PB, Paleogene within-plate basalts. Legend as in Figure 4.

produced by the partial melting of a mantle source. That mantle source should have been previously affected by metasomatism and contamination processes determined by the very hot fluids carrying various elements released by the subducted ocean crust slab in the process of eclogitization. In this respect, it must be emphasized that the subducted ocean crust was not a homogeneous basaltic one, since the Mureş ophiolitic suture contains, beside the ocean basaltic crust, intercalations of red argillites, limestones and sandstones. Moreover, the magmatic minerals from the ocean floor basalts were in most cases substituted by secondary minerals like uralite, chlorite, epidote, calcite and iron hydroxides; similarly, the plagioclase laths were altered into argillic minerals, calcite, zeolites and albite, depending on the temperature that controlled the process.Such minerals also occur in the basalt amygdales. All these materials, along with the water from the secondary mineral network and the water from the sediments contributed to the generation of a wedge of metasomatic and contaminated peridotite above the subduction plane, from which the parental magmas of the Laramian rocks derived by partial melting.

It seems that, before its emplacement in the upper crust, the parental magma underwent an intense differentiation. The low contents of Ni and related compatible elements like Cr, V, Mg etc. in the Laramian volcanics from both regions (Tables 1 and 2) indicate extensive fractionation of the mafic minerals during the differentiation of the parental magma. This process led toward the formation of a more basic magma/cumulate by the enrichment in mafic components, and toward a more acid/evolved magma that remained after the loss of a part of the mafic crystals. Concomitantly, an enrichment of the parental magma in alkalies took place, leading to the occurrence of some alkaline magma fractions, from which the alkaline and adakitic rocks resulted (Defant and Drummond, 1990). According to the low value of the $(La/Ce)_N$ ratio (Table 3) the metasomatic mantle source underwent LREE depletion during the mentioned processes.

The average isotope values of the Sr^{87}/Sr^{86} ratio are of 0.70703 - 0.70704 in the Lăpugiu andesites (Downes et al., 1995) and of 0.7059 to 0.7084 in the rocks from the Vlădeasa Mountains (Ştefan et al., 1992). These values show processes of contamination, both by metasomatism and contamination of the mantle source, as indicated by the low values of the $^{206}Pb/^{204}Pb$ ratio (Downes et al., 1995), and assimilation during the ascent of parental magma through the crust.

The parental magmas of the Paleogene tholeiitic basalts resulted from mantle plume sources, which were not affected by metasomatic processes (Savu, 2004; 2005b).

5. Conclusions

Two areas with distinct volcanic products are located along the Romanian segment of the Laramian (Banatitic) continental volcano-plutonic arc, extending from Banat to the Apuseni Mountains. The volcanics from these areas differ by their geochemical composition. The Lăpugiu rocks are mostly intermediate, being represented especially by andesites. The Vlădeasa rocks consist mostly of dacites, rhyolites and related plutonic rocks. All these igneous rocks are calc-alkaline in composition, with an obvious alkaline tendency. The Laramian volcano-plutonic rocks are bearing a remarkable continental arc signature, in contrast with the spatially-associated Paleogene basalts that are WPB rocks. The Lăpugiu volcanics show higher Sr, Ba and Zr and lower Y contents, in comparison with the Vlădeasa volcanics, where these trace elements are normal for island arc rocks. The first rock-series presents a slight adakitic tendency, consistent with their eruption within the Mureş adakitic province. The parental magmas of both Laramian volcanic series resulted from the partial melting of a metasomatic and contaminated mantle source, located at a maximum depth of ca. 100 km. In conclusion, the petrographic and geochemical differences between the two areas of Laramian continental arc rocks have been determined by several control factors, among which the most important could have been the mantle heterogeneity (see also Ringwood, 1979) and the degree of mantle source metasomatism and melting, as well as the magma contamination and differentiation.

The parental magmas of the Paleogene basalts resulted from the partial melting of a non-metasomatic lherzolitic mantle plume source, at a depth of about 50 km, like the magmas of the Deccan traps. The mineral deposits associated with the Lăpugiu volcanics are hydrothermal mineralizations of the Pb-Zn-Cu type, while the Vlădeasa magmatic rocks are associated with uranium mineralizations.

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