ON THE PLUME-SOURCE ORIGIN OF SHOSHONITIC GRANITOIDS AND RELATED ROCKS

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The shoshonitic granitoid plutons the present paper is referring to are very different in age and are located far away to one another. They occur in the south of Finland, being located in the old Fennoscandian shield, in the Late Precambrian Romanian crystalline schists of the South Carpathians and in the south of the Alpine Mureş ophiolitic suture. In spite of all these differences of age and high distance between them, these granitoid plutons exhibit similar or very close features. The shoshonitic granitoid plutons and the related rocks occurred after the emplacement of the syn-orogenic granitoid plutons *i.e.* toward the end of the respective tectono-magmatic cycle. According to the petrographic and geochemical characteristics of their rocks these plutons represent post-collision or late orogenic to paulo-post orogenic intrusions of intraplate-type. The granitoids are calc-alkaline rocks with alkaline tendency. They are K-feldspar or alkali-feldspar megacryst large porphyritic rocks with shoshonitic signature. There are the following relationships between the main alkaline elements and aluminium oxide: K_2O+Na_2O > 5 %; K_2O/Na_2O = 0.5 up to more than l.O; Al_2O_3 > 10 %. These granitoids belong to the ferriferous granitoid series. Above all the shoshonitic granitoids and the related rocks are very rich in LREE, especially Ce and La. Accordingly, the value of (Ce/Yb)N ratio is higher than 2 and that of Ce/Yb ratio is also higher, exceeding the value of 12. These values show their shoshonitic character and the plume-source origin. Their parental magma derived from a contaminated pyrolite that resulted from a metasomatic mantle plume, which was coming from the lower mantle and reacted with the host metasomatic upper mantle. This contaminated pyrolite differentiated into a shoshonitic magma and a lamproitic magma, from which derived the different components of the shoshonitic granitoid plutons.
Shortly, the hotspot shoshonitic granitoids may be defined as post-collision rocks very rich in K_2O, eventually K_2O = Na_2O (shoshonitic signature) and very rich in Ce (plume-source origin).

Key words: Shoshonitic granitoids, Mantle plume, Petrography, Geochemistry, Origin.

1. INTRODUCTION

In 2008, while searching for the origin of the lamprophyres from the Pre-Variscan South Carpathian granitoid province (Savu, in press), I was impressed by the very high Ce content of the Tismana post-collision shoshonitic granitoids from this petrographic province. This fact reminded me of the Tertiary hotspot volcanics related to the Transylvanian mantle plume (Savu, 2004). A preliminary information on the literature showed that other shoshonitic granitoids presented such high contents of Ce. Therefore, I decided to work out a more thorough study on this subject. The results of these investigations are presented in the present paper.

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2. OCCURRENCE AND PETROGRAPHY OF SHOSHONITIC GRANITOIDS AND RELATED ROCKS

In order to achive this study three representative shoshonitic granitoid occurrences have been selected, which were very different in age and area of emplacement. These are the Svecofennian shoshonitic granitoids from the south of Finland (Eklund *et al*., 1998), the Romanian South Carpathian shoshonitic granitoid pluton of Tismana (Duchesne *et al*., 1998) and the Romanian Săvârşin shoshonitic granite laccolith (Savu *et al*., 1996), which were presented in Fig. 1.

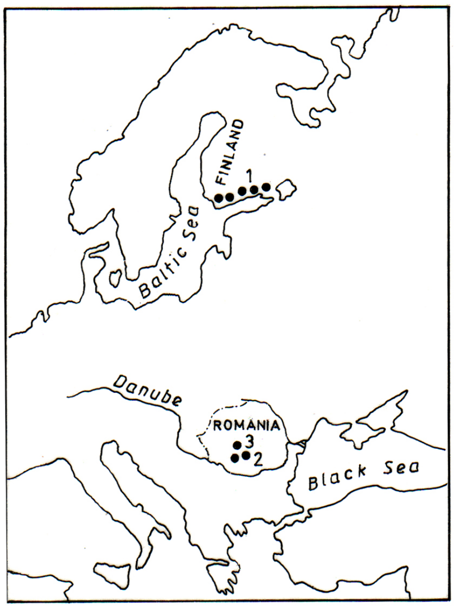

Fig. 1 – Emplacement of the selected shoshonitic granitoid occurrences and related rocks on the Europe sketch-map. 1, Svecofennian granittoid plutons; 2, Romanian South Carpathian granitoid pluton of Tismana; 3, Romanian Săvârşin shoshonitic granitoid pluton.

1. Svecofennian shoshonitic granitoid plutons. According to the map by Eklund *et al*. (l998), the Svecofennian granitoid plutons (1803–1770 Ma) occur all along a belt situated in the south of Finland, extending from the Lemland intrusion, in the southwest, up to the border of the Russian Karelia, in the southeast, and a little further into it (Fig.1). They are emplaced in the old Fennoscandian basement consisting of crystalline schists, migmatites and older granites. These rock occurrences consist of large K-feldspar porphyritic granites, monzonites, ladogites and nevoites, and are accompanied by lamprophyres. These plutons have been intruded by rapakivi granitoids, which I visited in 1973, east of Helsinki, in the company of dr. Haapala. They have been studied by numerous geologists among which more recently by Eklund *et al*. (1998).

The southwest Lemland intrusion consists of K-feldspar porphyritic shoshonitic granitoids and is cut by the anorogenic Åland rapakivi granite. The porphyritic granite was invaded by basic to intermediate magmas in several pulses, that generated rocks with pillowed structures. On a discriminant diagram the basic and intermediate rocks plot in the monzonite field, whereas the K-feldspar porphyritic granitoids are occurring in the monzo- and syenogranite fields. These two rock-groups represent the end numbers of a magma mingling – magma mixing system (see Eklund *et al*., 1998)

It is interesting that the pillowed monzonitic rocks are carrying ultramafic rock 'fragments' regarded as autoliths. However, their melanocratic minerals show higher Mg# values than the similar minerals from the host monzonitic rock. This intrusion is accompanied by the Åva ring complex, consisting of K-feldspar porphyritic granite mingled with monzonitic magma. The ring complex is cut by numerous radial lamprophyre dykes; nevertheless, it was shown that some lamprophyres were intruded before the ring dyke complex. Lamprophyres are represented by spessartites, vogesites and minettes.

Within the southeast of Finland the rounded Luonteri intrusion is a polyintrusive stock, in which five magmatic pulses took place. It consists of syenodiorites, monzonites and quartz-monzonites.

To the same magmatic belt belong the intrusions from the neighbouring Russian territory, which occur within the northwest of Ladoga area. There are the intrusions of Vuoksi, Ajajärvi, Elisenvaara and the Kalto dyke swarm, which consists of basic and intermediate rocks.

2. South Carpathian shoshonitic granitoid plutons. The Pre-Variscan crystalline schists basement (580 Ma) of the Danubian Autochthone from the South Carpathians is housing along its southern margin two characteristic shoshonitic granitoid plutons, as shown in Fig. 1: the Tismana and Novaci plutons (Savu *et al*., 1973; Duchesne *et al*., 1998: Savu, in press b). Whereas the first pluton shows an almost laccolitic shape, the second occurs as an elongated intrusion situated along the southern margin of the Cărpiniş bigger syn-orogenic calc-alkaline granitoid pluton. Both shoshonitic intrusions consist of K-feldspar large porphyritic granite which present a massive structure.

The Tismana post-collision granitoid pluton (567 Ma) was recently studied by Duchesne *et al*. (1998), who established its shoshonitic character too. This pluton represents a late orogenic to paulo-post orogenic intrusion. The massive structure of the granitoid rocks supports this tectonic setting. However, some of its structural elements exhibit an orientation parallel to the lineation of the host crystalline schists. But the almost rounded shape of the pluton suggests rather a laccolith structure, which evidently differs from that of the syn-orogenic elongated plutons from the South Carpathian granitoid province (Savu, in press b). A regional-contact metamorphism in the amphibolite facies extends from the syn-orogenic Cărpiniş pluton by the Şuşiţa pluton up to the Tismana shoshonitic pluton (Savu, 2005).

The characteristic rock of the Tismana shoshonitic pluton is represented by a K-feldspar (microcline-pertite) megacryst large porphyritic granitoid, which contains melanocratic autoliths. There occurs a northern marginal equigranular facies consisting of diorites and gabbros up to tonalites and granodiorites. Xenoliths of a few hundred meters long coming from a hydrous metasomatic mantle plume (Savu, in press a) occur in a restricted area. According to Duchesne *et al*. (1998), these xenoliths consist of 40-45 % olivine oykocrysts, 15-20 % orthopyroxene, 10 % phlogopite, 5 to 10 % brown hornblende and less than 10 % basic plagioclase and accessories like pyrrhotite with pentlandite exsolutions. These minerals do not show any mechanical deformations, but are partly altered under the influence of the metasomatic processes that affected the original mantle plume when reacted with the metasomatic upper mantle and the magmatic chambers of the precursor syn-orogenic granitoids, still present there (Savu, in press a). It is noteworthy to show that from more than 20 granitoid plutons present in the South Carpathian granitoid province (see the general map by Savu, in press b) such mantle plume xenoliths occur in the Tismana shoshonitic granitoid pluton only.

Lamprophyres are also occurring in the South Carpathian granitoid province. They have been studied in a previous paper (Savu, in press a), in which it was shown that the lamprophyre dykes consist of spessartites, malkites and kersantites, rarely camptonites and minettes which originated in a plume-source.

3. Săvârşin shoshonitic granitoid pluton. This pluton (128 Ma) occurs near the southern margin of the Alpine Mureş ophiolitic suture (Savu *et al*., 1996; Savu, in press c). It represents a post-collision asymmetrical laccolith (Fig.1), which constitutes the southern part of the Săvârşin composite granitoid pluton, the northern Temeşeşti calc-alkaline twin intrusion of which is formed of diorites and granodiorites.

The Săvârşin shoshonitic intrusion has a rather rectangular shape, the long side of which is of 3.75 km. and the short one of 2.5 km. The tectonic researches on the pluton (Savu, 1995) showed that the granitic magma ascended through a funnel situated at the northeast extremity of the pluton, where it is marked by a gravity negative anomaly, and extended southwestward through the ophiolitic rock pile in which the laccolith is located.

The laccolith consists of two main rock-types of shoshonitic nature: a large porphyritic granite which forms the inner and main facies of the intrusion and a porphyritic microgranite that makes the marginal facies of it, which extends all along its northern contact with the ophiolitic host rocks.

A kersantite dyke cuts the northern Temeşeşti part of the composite pluton, but it could originate in the same shoshonitic magma as the Săvârşin laccolith.

Both granitoid facies of the Săvârşin laccolith consist of a groundmass which contains quartz, oligoclase and biotite, rarely a green hornblende, in which phenocrysts of alkali-feldspar occur. In the large porphyritic inner facies these occur as megacrysts of 4-5 cm long. Some megacrysts have been included in the melanocratic autoliths beside biotite, hornblende and plagioclase crystals. Such melanocratic autoliths frequently occur in the large porphyritic inner facies of the shoshonitic laccolith, where they helped to the determination of the direction of the magma intrusion and implicitly of the granite tecyonics (Savu, 1995).

The alkali-feldspar megacrysts show a zonal structure, in which zones of orthoclase-anorthoclase and albite-oligoclase alternativelly succed to one another. This structure was favoured by the almost equal content of K_2O and Na_2O in the shoshonitic magma (see Table 1) and by the variation of the vapour tension in this magma (Savu, 2008).

3. GEOCHEMICAL DATA AND TECTONIC SETTING

The average chemical composition of the shoshonitic granitoid rocks from the three selected occurrences was presented in Table 1. According to their SiO_2 content these rocks are represented by basic terms like Kalto and Åva lamprophyres and intermediate and acid plutonic rocks.. The last are represented by porphyritic monzonites, monzo-granites, granites and leucosyenites.

As it was remarked by Eklund *et al*. (1998) and as it results from Table 1, the chemical composition of these shoshonitic rocks could be generaly characterized by the following contents and relationships of their main major chemical alkaline elements and aluminium oxide as rocks in which $K_2O + Na_2O > 5$ %; $K_2O / Na_2O = 0.5$ up to more than 1.0 (see Table 2) and $Al_2O_3 > 10$ %. FeO_{tot} is variable, it being higner than 8 % in lamprophyres and decreasing in the other rocks from almost 7 % down to 2 %. Almost the same trend show the contents of MgO and CaO. The shoshonitic rocks are calc-alkaline rocks with an obvious tendency toward the alkaline rocks, as it results from the diagram in Fig. 2. It shows that the South Carpathian shoshonitic granitoids are real calc-clkaline rocks since they plot along the calc-alkaline array of the diagram. The Svecofennian granitoids manifest an obvious tendency toward the alkaline domain, a feature supported by the presence among them of the syenitic rocks. and other rocks in which the sum of alkalies is higher than 10 %. But the most leucocratic shoshonitic rocks are those of Săvârşin, in which the sum of alkalies is of 8.90 % and the average content of MgO is only of 0.66 % (Table 1 and Fig. 2). It is noteworthy to show that, according to their average composition, the two mantle plume xenoliths from the Tismana shoshonitic granitoid pluton plot on this diagram (No 7) far away from the area of the shoshonitic rock association.

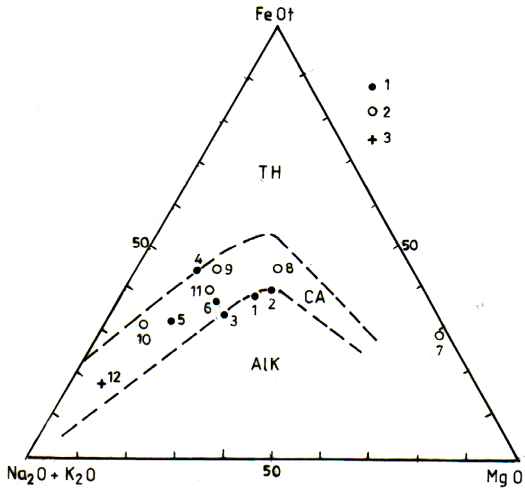

Fig. 2 – Plot of the shoshonitic granitoids and related rocks on the FeO_{tot} - $Na_2O + K_2O$ – MgO diagram. Fields according to Irvine and Baragar (1971) and Hutchinson (1982): TH, tholeiitic; CA, calc-alkanine; Alk, alkaline; 1, Svecofennian shoshonitic rocks; 2, South Carpathian Tismana rocks; 3, Săvârşin shoshonitic rocks (all data are from Table 1).

Table 1

Average chemical composition of the hotspot shoshonitic granitoid plutons and related rocks*

Plut-on	1 (1)	2 (2)	3 (4)	4 (2)	5 (2)	6 (13)	7 (2)	8 (7)	9 13)	10 (11)	11 (31)	12 (2)
SiO_2	40.75	49.0	50.0	58.31	64.0	55.32	43.36	50.67	58.27	68.98	59.30	70.78
Al_2O_3	10.59	14.0	14.59	15.11	15.12	14.76	6.09	17.08	15.27	14.47	15.60	14.74
Tio_2	3.41	1.73	1.78	1.86	1.44	1.84	0.31	1.51	1.49	0.48	1.16	0.35
FeO*	8.68	8.53	7.85	7.31	4.75	6.03	11,11	9.01	7.75	3.47	6/74	2.18
MnO	0.15	0.16	0.15	0.06	0.09	0.12	0.16	0.16	0.12	0.04	0.10	-
MgO	6.57	6.78	5.82	2.15	1.85	4.15	28.15	5.71	2.44	0.87	3.0	0.66
CaO	11.90	7.79	6.81	4.32	4.03	6.57	3.58	7.07	4.28	1.57	4.30	1.28
Na_2O	2.37	2.66	3.46	3.39	2.96	3.10	0.40	2.54	2.69	2.58	2.60	4.06
K_2O	5.47	4.11	4.96	3.55	4.84	4.58	0.45	2.64	3.98	5.86	4.16	4.84
P_2O_5	4.14	1.51	1.81	0.51	0.63	1.80	0.25	0.70	0.65	1.03	0.79	0.23
H_2O^+	0.40	1.11	0.24	-	0.24	0.53	-	-	-	-	-	0.60
H_2O^-	0.04	0.21	0.4	-	0.56	0.30	-	-	-	-	-	0.35
CO_2	2.70	0.13	0.32	-	0.11	0.82	-	-	-	-	-	0.5
Loi	3.46	1.45	0.79	0.74	0.76	1.44	5.71	2.22	1.35	1.15	1.57	-
Total	99.43	99.17	98.97	97.76	101.9	101.9	99.62	99.32	98.38	100	100.1	100.5
Ba	9513	4711	6679	2227	3336	5283	963	1302	1506	1212	1340	908
Rb	85	94	76.7	130	102.2	97.5	31.5	113	150.2	118	155.4	196
Sr	7018	2374	4599	1536	1346	3374	126	922.8	534.6	281.9	679.7	328
Cr	90	190	80	35.5	23.6	83.65	23.19	44.28	11.0	11.5	22.26	-
Ni	81	90.7	70.5	8	13.16	50.6	-	-	-	-	-	-
Ta	1.6	1.26	0.75	1.4	1.4	1.28	-	-	-	-	-	1.34
Nb	32	39.8	18.0	43	24.16	31.3	2	61.5	68	33.11	54.2	20
Hf	3.7	9.9	1.47	13.3	8.4	7.6	1.5	6.6	13.3	8.08	9.39	0.9
Zr	242	407.2	126	606	374	351	25.73	284	542	337.4	387.4	172
Y	59	29.2	33.7	14.5	31	33.4	11.5	33.5	45.2	23.5	34.0	22.5

Table 1 (continued)

U	8	3,5	3.5	4.5	2.4	4.3	0.4	0.85	1.62	2.17	1.54	-
Th	23	7.2	16	11.5	10.6	13.6	6.3	7.78	14.4	23.65	15.27	1.5
La	608	218	394.5	187	116.8	304.8	11.5	87	100.6	79.9	89.1	99.5
Ce	1206	485	750	386	262.7	470	14	150.5	201.3	149.5	166.9	175
Nd	520	152.2	302	140.5	97.0	242.3	8	62.7	87	56.18	68.96	-
Sm	67.4	19.6	36.4	19.1	13/42	31.18	1.9	10.4	14.33	8.65	11.12	7.05
Eu	15.97	5.0	8.92	4.04	3.05	5.73	0.47	2.77	2.87	1.69	2.44	1.41
Gd	47.2	7.42	4.04	29.15	11.8	19.92	2.3	8.44	11.82	6.4	8.88	-
Dy	13.25	6.88	7.14	5.12	5.80	6.30	1.58	5.64	7.87	3.84	5.78	4.84
Er	6.56	3.45	3.94	1.95	3.05	3.63	0.93	2.96	5.64	4.11	4.23	-
Yb	3.10	2.60	2.77	1.15	2.55	2.96	0.93	2.77	3.85	2.06	2.89	2.3
Lu	0.93	-	-	-	-	-	-	0.44	0.54	0.31	0.43	0.69

* The average chemical analyses in the table are referring to the following shoshonitic granitoid occurrences: Svecofennian occurrences; data from Eklund *et al*. (1998): 1, Kato lamprophyres; 2, Åva lamprophyres; 3, Elisenvaara rocks; 4, Luonteri rocks; 5, Lemland intrusion; 6, average of the Svecofennian leucocratic rocks; South Carpathian Tismana granitoid pluton; data from Duchesne *et al*. (1998):7, mantle xenoliths; 8, melanocratic rocks; 9, intermediate rocks 10, felsic rocks; 11, average of the Tismana shoshonitic granitoids; 12, Săvârşin shoshonitic granitoid pluton (Romania); data from Savu *et al*. (1996). FeO* = $FeO_{tot;}$ 1(1), the first figure represents the order number of the occurrences; the figure in parantheses represents the number of calculated chemical analyses.

The shoshonitic character of all these granitoids is pointed out by the diagram in Fig. 3, on which, according to their average composition, the rocks plot within the shoshonitic domain, characterized as the domain of rocks with very high content of K. According to their chemical composition the two mantle plume xenoliths from the Tismana pluton do not occur on the diagram.

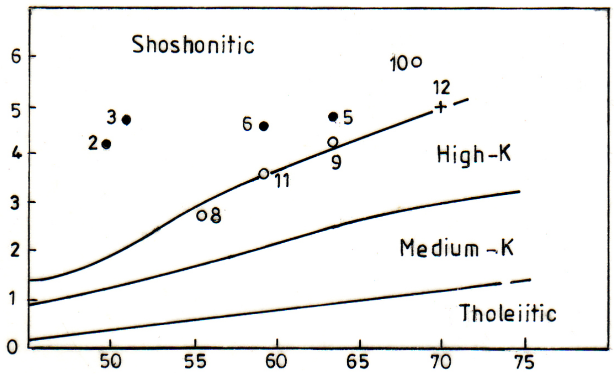

Fig. 3. Plot of the shoshonitic rocks on the K_2O vs. SiO_2 diagram.
Fields according to Rickwood (1983). Legend as in Figure 2.

The value of the MgO / FeOtot ratio (Table 2) is higher than 1 only in lamprophyres; it culminates by the value of 4.49 in the mantle plume xenoliths. This value is lower than 1 in the leucocratic rocks. Therefore, all the shoshonitic granitoids and the related plutonic rocks belong to the ferriferous series of granitoids. It is clearly shown by the diagram in Fig. 4. This feature could have been inherited during the differentiation of the shoshonitic granitoid magma from the parental mantle plume pyrolite.

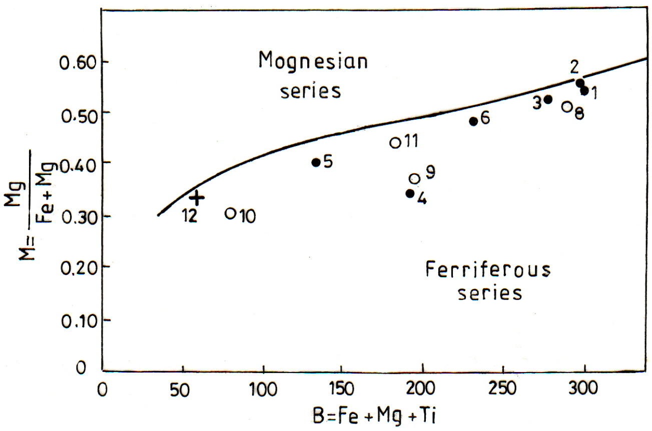

Fig. 4 – Plot of the shoshonitic granitoids on the Mg /.Fe + Mg vs. Fe + Mg + Ti diagram, in which Fe was taken as Fetot. Fields according to Debon and Le Fort (1988). The same legend as in Figure 2.

The average content of the trace elements from the shoshonitic granitoids (Table 1) underlines some more features of these rocks. As for instance, the relationships between Rb and Y+Nb, represented in the diagram from Fig. 5, show that all the shoshonitic granitoids and their related rocks are intraplate rocks. This tectonic setting is consistent with their character of post-collision and paulo-post orogenic intrusions.

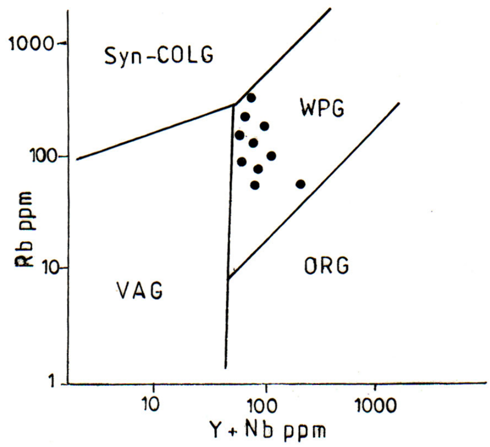

Fig. 5 – Plot of the average content of the shoshonitic granitoids and related rocks on the Rb vs. Y+Nb diagram. Fields according to Pearce (1996): syn-COLG, syn-collision granites; WPG, within plate granites; VAG, volcanic arc granites; ORG, ocean ridge granites.

The siderophile elements like Cr and Ni show higher contents only in lamprophyres and other basic and intermediatee rocks.

It is notable that the average values of the Sr/Y and (La/Yb)N ratios from Table 2 are very high in the Svecofennian shoshonitic granitoids like in the adakitic rocks, and are lower in the younger shoshonitic granitoids, like those of Săvârşin. But, because of the high values of Y and (Nb)N, the average values of these rocks plot at random on the discriminant diagram of Martin (1999).

As shown above, according to their content in K, all the rocks from the three selected granitoid occurrences presented in this paper are shoshonitic rocks This character is confirmed by the relationships between Ce/Yb and Ta /Yb ratios used to the construction of the diagram in Fig. 6. On this diagram the rocks plot in the shoshonitic field.

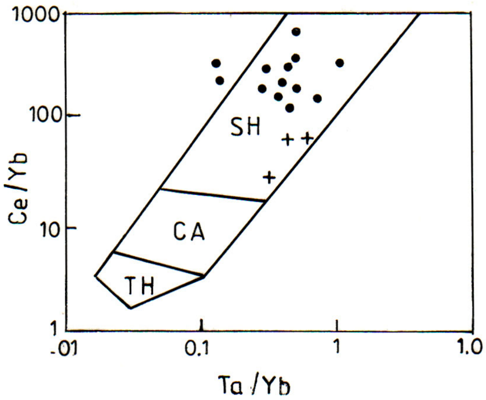

Fig. 6 – Plot of some shoshonitic granitoids on the Ce/Yb vs. Ta/Yb diagram. Fields according to Pearce (1982): SH, shoshonitic rocks; CA, calc-alkaline rocks; TH, tholeiitic rock. The same legend as in Figure 2.

The REE average contents are also higher in the old Svecofennian granitoids and lower in the Mesozoic Săvârşin rocks (Table 1). These aspects clearly result from the variation of the ΣREE (Table 2), which is very high in the Svecofennian rocks, especially in some lamprophyres in which the value of ΣREE reachs 2488 ppm. From this sum the values decrease down till that of the Săvârşin pluton, in which the ΣREE is only of 292 ppm. But the values of the LREE/HREE ratio from the shoshonitic granitoid series are variable.

The chondrite-normalized REE patterns (Fig.7) of the shoshonitic granitoids are very close to one another by their form. They very well characterize the shoshonitic granitoids, showing that these rocks are very rich in LREE, especially La and Ce, and have very low contents of HREE. The rock patterns strongly decrease from LREE toward HREE. A small Eu negative anomaly occurs only in case of the South Carpathian Tismana granitoid patterns.

Table 2

Some characteristic ratios from the shoshonitic granitoids (data from Table 1)*.

Pluton	1	2	3	4	5	6	7	8	9	10	11	12
(Dy / Yb)N	2.7	1.7	1.73	2.84	1.85	2.13	1.10	1.32	1.27	1.21	1.26	1.36
(Ce / Yb)N	100.	48	70	86.8	26.3	37.7	3.90	14.	13.5	16.7	15.4	19.6
Eu / Eu*	0.8	1.0	1.20	0.58	0.72	0.83	1.09	0.89	0.68	0.90	0.82	0.79
K_2O / Na_2O	2.3	1.5	1.43	1.04	1.63	1.32	1.12	1.03	1.47	2.27	1.59	1.14
Y / Nb	1.8	0.7	1.87	3.27	1.29	1.79	5.75	0.54	0.66	0.70	0.63	1.02
Sr / Y	119	81	136	1o6	43.4	76.8	1.09	37.5	11.6	12	20.2	14.5
Ti / Eu	0.1	0.2	0.11	0.27	0.23	0.20	0.38	0.40	0.31	0.16	0.20	0.14
Ce / Yb	389	186	270	335	103	208	15	54.3	52.2	56.2	54.2	76
Ta / Yb	0.5	0.4	0.27	1.21	0.54	0.67	-	-	-	-	-	1.58
Mg / Mg+Fe	0.57	0.3	0.58	0.56	0.40	0.58	0.81	0.53	0.34	0.30	0.34	0.35
Mg / Fe	1.3	0.5	1.42	1.32	0.7	0.53	1.40	1.12	0.56	0.43	0.78	0.55
ΣREE	2488	900	151	774	516	1086	41.6	333.	436	306	361	292
LREE / HREE	28.	37	49.4	17.6	18.8	27.5	5.76	13.5	12.2	24.5	134	28.2
(La / Yb)N	148	57	231	48.6	39.4	6.97	-	21.2	17.6	26.1	20.8	29

* The same legend as in Table 1.

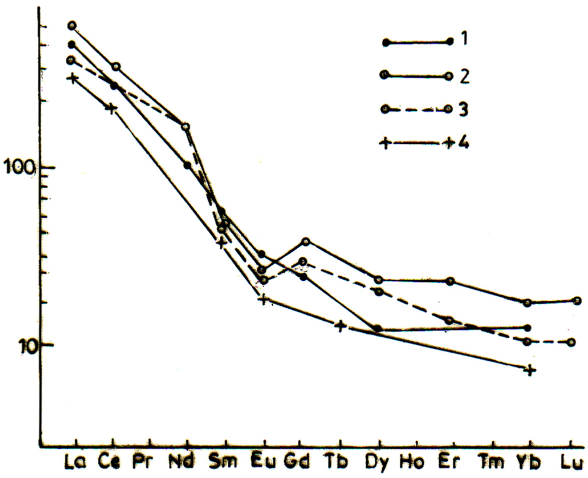

Fig. 7 – The chondrite-normalized REE patterns of the shoshopnitic granitoids (normalizing values of Boynton, 1984). 1, pattern of the Svecofennian shoshonitic granitoids; 2 and 3, patterns of the Tismana shoshonitic granitoids; 4, pattern of the Săvârşin shoshonitic granitoids. All patterns were caculated on the average element contents from Table 1.

The values of the Eu/Eu* ratio are variable all along the shoshonitic granitoid series (Table 2). Taking into account that Gd, which was needed in the relation Eu* = (Eu)N / 1:2 (Sm+Gd)N, and its neighbouring REEs show very close contents, in cases when this element was not analitically detrmined, (Gd)N was directly estimated by projecting it on the rock pattern from Fig. 7.

4. ORIGIN OF THE SHOSHONITIC GRANITOIDS

In two previous papers (Savu, in press b, c) the parental granitoid magma of the shoshonitic granitoid plutons was considered as a special magma, but derived from the same initial pyrolite formed in the metasomatic upper mantle, from which the other granitoids from the South Carpathian granitoid province and from the Săvârşin composite pluton resulted. In this respect see also Janousek *et al* (2000). In contrast, the above presented data showed that the shoshonitic granitoids are particular rocks which differ from the normal calc-alkaline and trondhjemitic syn-orogenic granitoids. Therefore, one may suppose from the beginning a different origin for these rocks.

The essential genetic elements regarding the origin of the shoshonitic granitoids and related melanocratic rocks are to be found in the Tismana pluton. As shown above, this pluton is carrying big ultramafic xenoliths. These xenoliths are chemically similar to the mantle plume xenoliths from the young hotspot trachybasalts from the Perşani Mountains, in Romania, as the diagranm in Figure 8 shows (see also Savu, in press a).

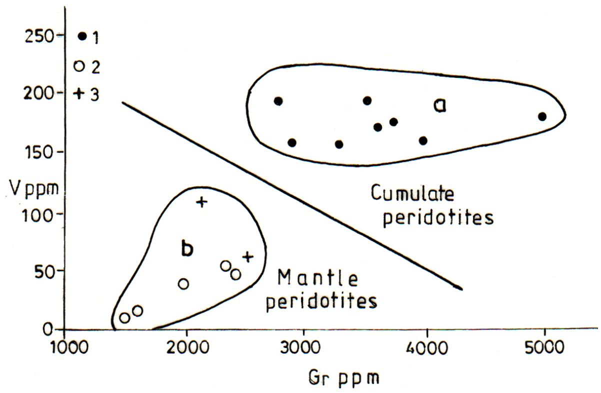

Fig. 8 – V vs. Cr discriminant diagram between cumulate and mantle plume peridotites. Fields according to Savu (in press a): a, field of the cumulate peridotites; b, field of the mantle plume peridotites. 1, cumulate peidotites from the Mureş ophiolitic suture (data from Savu et al., 1986); 2, mantle plume peridotitic xenoliths from the young hotspot trachybasalts from the Perşani Mountains (data from Savu et al., 2000); 3, mantle plume xenoliths from the Tismana shoshonitic granitoid pluton (data from Duchesne et al. 1998).

Taking into account that the melanocratic minerals from the ultramafic 'fragments' from the Lemland shoshonitic granitoid intrusion, in Finland, differ by the value of the Mg# from the similar minerals from the host pillowed monzonitic rocks, it is possible that these 'fragments' also represent xenoliths torn by the shoshonitic magma from a strongly metasomatized mantle plume, in wich the parental shoshonitic magma of the shoshonitic rocks originated too. Unfortunatelly there are not global chemical analyses on these rocks.

On the other hand, both the mantle plume xenoliths fron the Tismana shoshonitic granitoid pluton and the granitoid rocks of this pluton itself plot on the diagram in Fig. 9 within an area situated to the right of the plume-source line of the diagram and even on this line. According to Haase and Devey (1996) such a behaviour of any rocks indicates their plume-source origin. Moreover, all the shoshonitic granitoids and the related lamprophyres presented in this paper also plot on this diagram within the same area of the plume-source rocks (see also Savu, in press a).

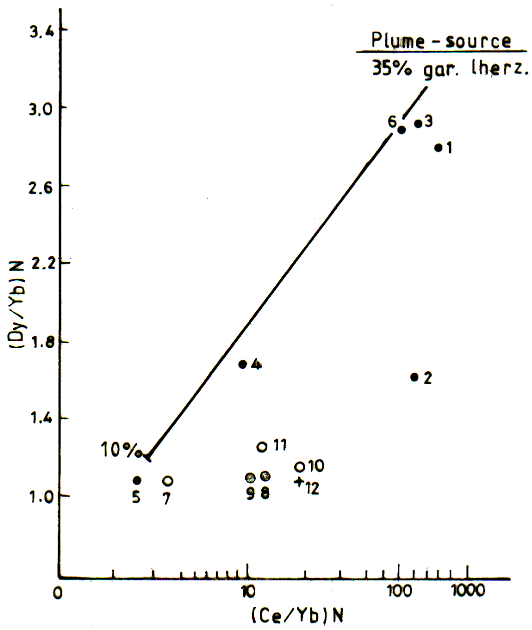

Fig. 9 – Plot of the average values of the shoshonitic granitoids and related rocks and the mantle plume xenoliths from the Tismana shoshonitic pluton on the (Dy/Yb)N vs. (Ce/Yb)N diagram, adapted after Haase and Devey (1996). Legend as in Figure 2.

According to the diagram in Fig. 10, the original mantle plume from which all these rocks derived must have been a hydrous metasomatic mantle plume, as the plume-source xenoliths from the Tismana shoshonitic pluton plot on the diagram below the level of the chondrite ratio, one of them just in the field of the hydrous mantel field. This mantle plume came from the lower mantle as a rheomorphic intrusion in the metasomatic upper mantle, there reacting with it and getting metasomatic too (see Savu, in press a). From this metasomatic mantel plume a pyrolite was generated by anatexis, which reacted with the host metasomatic upper mantle and the residual magmatic chambers from which the parental magmas of the precursor syn-orogenic granitoid plutons derived, and got contaminated. In this contaminated pyrolite both the shoshonitic and lamproitic parental magmas of the shoshonitic granitoid and of different components of the Tismana shoshonitic granitoid pluton originated.

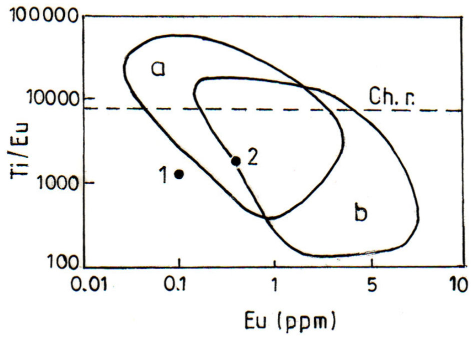

Fig. 10 – Plot of the mantle plume xenoliths from the Tismana shoshonitic granitoid pluton on the Ti/Eu vs. Eu diagram. Fields drawn after the data of Donough and Frey (1989) a, anhydrous mantle; b, hydrous mantle; Ch. r., chondrite ratio level.

And, since the rocks from the Tismana shoshonitic granitoid pluton and those from the other shoshonitic granitoid plutons, presented in this paper, show similar or very close petrographic and geochemical characteristics, and plot within the plume-source field of the diagram in Fig. 9, this show that all these plutons and the related rocks originated in similar plume-sources. All these observations show that the initial basic and intermediate materials from which Duchesne *et al*. (1998) and Janousek *et al*. (2000) derived shoshonitic magmas have been of plume-source origin.

The genesis of these shoshonitic granitoid plutons and of their related rocks evolved according to the following model (Fig. 11).

SPGM--------------------→ shoshonitic granitoid trend.
/
MMP--------→ CPPy
\
LPM---------------------→ lamprophyres and other basic and intermediate rocks trend.

Fig. 11 – Model showing the genesis of the plume contaminated pyrolite and its differentiation into shoshonitic granitoid and lamproitic parental magmas of the rocks from trhe shoshonitic granitoid plutons. MMP, metasomatic mantle plume; CPPy, contaminated plume pyrolite; SPGM, shoshonitic parental granitoid magma; LPM, lamproitic parental magma.

This model shows that the initial plume pyrolite differentiated into two magmas: a shoshonitic parental magma from which the shoshonitic granitoids derived and a lamproitic parental magma in which the basic and intermediate rocks that follow the intrusion of the shoshonitic granitoid plutons like lamprophyres, monzonites, basalts, basaltandesites etc.originated (see also Savu, in press a).

5. CONCLUSIONS

The shoshonitic granitoid plutons and their related rocks usually occur after the syn-orogenic granitoid pluton emplacement, *i.e.* at the end of the tectono-magmatic cycle. Therefore, the petrographic and geochemical features characterize them as post-collision or late-orogenic to paulo-post orogenic intrusions of intraplate-type.

The granitoids are calc-alkaline rocks with an alkaline tendency. They are very rich in K_2O and Na_2O, so that they occur as K-feldspar or alkali-feldspar large porphyritic rocks. This composition determines their shoshonitic character. There are the following relationships between the major alkaline elements and aluminium oxide: $K_2O + Na_2O > 5$ %; $K_2O / Na_2O = 0.5$ up to more than 1.0; $Al_2O_3 > 10$ %.

The shoshonitic granitoids belong to the ferriferous granitoid series. Above all the shoshonitic granitoids and the related rocks are very rich in LREE, especially Ce and La. Therefore, the values of (Ce/Yb)N ratio are higher than 2 and those of Ce/Yb ratio are always higher than 12. Both values are characteristic for the plume-source rocks. Even in case when some features differ from one rock to another, the shoshonitic and plume-source characteristics are constant.

These conclusions were based on the actual geochemical data; further more thorough investigations maybe will bring new data on this subject.

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