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Geochemistry and origin of certain amphibolites, granofelses and related rocks from Romania

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Abstract

The metamorphic basic rocks from the Romanian crystalline schists belong to two tectono-magmatic cycles. Thus, the amphibolites and related rocks were formed during the Pre-Variscan tectono-magmatic cycle (820–717 Ma), while the granofelses resulted from igneous rocks erupted during the Variscan cycle (ca. 300 Ma). The amphibolites and the related rocks are associated with high-grade crystalline schists, while the granofelses and related rocks are associated with greenschist metamorphic rocks. Both of the igneous series from which the metamorphic basic rocks resulted originated in tholeiitic basaltic magmas of the MORB and IAV-types in the case of amphibolites, and of the WPB-type in that of granofelses. The tectonic setting of the protolith rocks shows that, along the current Carpathian Chain, a Pre-Variscan ocean preceded the Variscan one, while north of this mobile belt a stable tectonic plate was settled during the Variscan tectono-magmatic cycle.

Keywords: amphibolites, granofelses, occurrences, metamorphism, geochemistry, tectonic setting, origin.

Introduction

Around the middle of the previous century, there were vivid debates concerning the origin of the amphibolites and granofelses (term according to Fettes and Desmons, 2007) from the Romanian crystalline schists. The controversy spurred from the idea that some of these rocks could have originated in sedimentary deposits, other than the basic tuffs. Later on, chemical analyses proved that the granofelses from the Highiș-Drocea Mountains represented metabasalts (Giușcă, 1962; Savu, 1962). In the Southern Carpathians, it was also shown that the amphibolites and granofelses derived from igneous basic rocks (see Mureşan et al., 1974; Savu and Udrescu, 1975; Savu et al., 1978; Anton et al., 1981).

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Regarding the granofelses and the related acid rocks, several papers have been published on the Poiana Ruscă "basic and acid tuffogeneous rocks" (Mureşan, 1973), the granofelses from the Groşi Formation in northern Banat (Savu et al., 2006), and the metabasalts and other low-metamorphic basic and acid rocks from the Highiş-Drocea Mountains (Giuşcă, 1962; Savu, 1962, 1965; Savu and Udrescu, 1975; Savu and Tiepac, 1981). Other studies have been conducted on the metamorphic basic rocks from these regions, such as those by Savu et al. (1984a,b; 1990) and Liégeois et al. (1996). In 2003, Savu showed that the Drăgşan and Măru groups of amphibolites and related ultramafic rocks from the Danubian Domain (see Balintoni et al., 2009; Medaris et al., 2003), as well as the Getic Nappe of the Southern Carpathians, represent vestiges of a Pre-Variscan ophiolite suture.

The purpose of the present paper is to systematize the occurrences of metamorphic basic and related rocks from the mentioned areas, to show their geochemical peculiarities, to assess, through adequate methods, their origin, and to establish the tectonic setting of the igneous rocks they derived from.

Occurrences and petrography of the Pre-Variscan amphibolites from the Danubian Domain and the Getic Nappe; the Drăgşan and Măru groups

The Pre-Variscan amphibolites from the Danubian Domain are associated with crystalline schists metamorphosed mostly under the conditions of the almandine amphibolite series of the Lainici-Păiuş group and of other coeval metamorphic groups. The westernmost occurrence of amphibolites is related to the Ielova series (Codarcea, 1940), metamorphosed under the staurolite-quartz PT conditions. There, the amphibolites are associated with metamorphosed ultramafic and basic bodies (Mureşan et al., 1974). Thus, within the Cameniţa area, the metamorphosed basic rocks are represented by metagabbros, within which the igneous mafic minerals have been substituted by green hornblende, granules of titanite and epidote. Within the Urda Mare-Rudăria area, a transition from metagabbros like those previously mentioned to weakly metamorphosed gabbros occurs. In the latter, the hypidiomorphic texture of gabbros is preserved, as evidenced by the relations between plagioclase and diopside crystals. Diopside was partly substituted by uralite and green hornblende, which are associated with plagioclase (An_{40}), and by epidote, zoisite and sericite. The basic rocks are associated with serpentinites and pyroxenites, in which the initial minerals, represented by clinopyroxene and orthopyroxene, are noticeable. Dolerites with an ophitic texture are present, as well. This rock association appears to be a complex of basic-ultrabasic plutonic rocks.

Amphibolites also occur north of this area, at Muntele Mic (Gherasi and Savu, 1969; Savu et al., 1973). Eastward, along the northern margin of the Danubian Domain, amphibolites occur within the crystalline schists from the Ţarcu Muntain (Gherasi, 1937), the Vulcan Mountain (Liégeois et al., 1996) and, further on, in the Parâng Mountains, extending as a real complex up to the Latoriţa Valley, at Ciunget (see Ghika-Budeşti, 1937; Savu et al., 1973; 1974; 1984a; 1976; 1990), where they constitute the Drăgşan amphibolite group. In the amphibolite complex from the Vulcan Mountain, Berza and Seghedi (1975) described intercalations of kyanite gneisses.

In all of these areas, the metamorphosed basic rocks are represented by amphibolites *sensu stricto*, thin-layered amphibolites, amphibole gneisses, abyssal bodies of ultramafic rocks and quartzo-feldspatic gneisses, metaquartzkeratophyres being rarely associated with them. The amphibolites resulted from basaltic lavas and basaltic tuffs, metamorphosed under the conditions of the almandine amphibolite facies (see Winkler, 1970). The most representative mineral assemblage of these rocks is the following: plagioclase – green hornblende – almandine – quartz – magnetite – titanite.

The thin-layered amphibolites consist of layers rich in amphibole alternating with thin layers of leucocratic rocks comprised of plagioclase and small amounts of amphibole, quartz and magnetite. This structure may have resulted either from the metamorphic differentiation of a basic tuff (see Orville, 1969), or from metamorphic tuffites.

The amphibole gneisses which are sometimes associated with amphibolites are more leucocratic, consisting of plagioclase, quartz, amphibole and, rarely, biotite. They may represent metamorphosed acid-to-intermediate tuffs or greywakes.

It is worth mentioning that, sometimes, the amphibolite complexes are associated with bodies or layers of crystalline limestones and dolomites. Through high-temperature metamorphic reactions with their host rocks, these rocks often turn into silicate-carbonatic rocks known as reaction skarns or erlane, in which the following mineral assemblages occur:

1. Calcite–clinopyroxene–titanite–quartz–(feldspar).
2. Calcite–garnet–amphibole–clinopyroxene–titanite–quartz.

In the highly metamorphic crystalline schists of the Getic Nappe, amphibolites and related rocks occur in certain areas of the Southern Carpathians. Thus, in the western part of these mountains, amphibolites occur in the northern part of the Semenic Mountains, where they are associated with metamorphosed manganese deposits, consisting of Mn-silicates, Mn-carbonates and Mn-magnetite (Savu et al., 1964), metamorphosed together with the country rocks under the conditions of the almandine amphibolite facies. In the southern part of these mountains, amphibolites occur within the Miniş group, which has been metamorphosed under the conditions of the albite-epidote-amphibolite facies (Savu, 1969; 1973).

Amphibolites also occur along the area situated north of Muntele Mic, where they are located within the same high metamorphic crystalline schists of the Getic Nappe. There, they are known as the Măru amphibolite group, which extends between the Măru and Borlova villages, along the eastern margin of the Getic Nappe (Savu et al., 1984b).

The amphibolites show a thin-layered structure, in which the amphibolite layers alternate with layers of amphibole gneisses. Due to the granitoid solutions coming from depth, stromatitic migmatites and small bodies of pegmatites have formed in the Măru group. Apart from the amphibolites, the Măru series also includes layers of biotite amphibolites, amphibole gneisses, and, rarely, garnet amphibolites. As resulting from the microspore association determined by Visarion in Savu et al. (1978), the age of the Măru group is Upper Precambrian. The rock association from the Măru group is almost similar to that from the above-described Drăgşan group. It is note-worthy, however, that the amphibole gneisses contain, apart from plagioclase, green hornblende, biotite, apatite, and kyanite as poikilitic crystals. Layers of quartzo-feldspatic gneisses also occur in association with the amphibolite group.

Within the high-grade crystalline schists of the Getic Nappe, amphibolites also occur in the Căpăţâna Mountain from the Lotru Mountains (Savu, 1968), as well as in the Făgăraş Mountains. The more representative ones form the amphibolite complex occurring along the northern slope of the Făgăraş Mountains (see Dimitrescu, 1963; Anton et al., 1981; Gridan et al., 1989). This amphibolite complex consists of amphibolites and amphibole gneisses. The former consist mostly of green hornblende, occurring either in varieties rich in Na_2O or in varieties in which magnesium prevails over the iron content. The effects of the retrometamorphism affecting the crystalline schists of the Getic Nappe have determined the partial substitution of amphibole by epidote, biotite, chlorite and, rarely, calcite. Plagioclase occurs in fresh crystals. Garnet (up to 5%), titanite and magnetite occur as accessory minerals.

Occurrences and petrography of the Variscan granofelses of the Poiana Ruscă Mountains, the Groși Formation and the Highiș-Drocea Mountains

The granofelses resulted from the low-grade metamorphism of basic igneous rocks, mostly basic tuffs. Mureşan (1973) described the granofelses in the Poiana Ruscă Mountains as metamorphosed "tuffogeneous basic rocks," originating in basic tuffs and tuffites. The latter contain important amounts of arenaceous materials. Granofelses consist of albite, chlorite, calcite, epidote, magnetite, and, rarely, associated actinolite crystals. They occur mostly in Teliuc–Vadul Dobrei, Iazuri–Vârful Găuri, and around the Tomeşti village. It is worth mentioning that, in the crystalline schists of the Poiana Ruscă Mountains, metamorphosed acid tuffogeneous rocks are also present. This association of metamorphosed basic-acid rocks points to them originating in protolithic volcanic rocks engendered by bimodal volcanism.

North of the Poiana Ruscă Mountains, in the Groşi Formation from northern Banat, granofelses also occur (Savu et al., 2006). They are schistose rocks intercalated in the low-metamorphic phyllites of the Groşi Formation. The granofelses, which resulted from basic tuffs or basic tuffites, consist of cloudy albite crystals, included in a mass of the chlorite of pennine or clinochlore-type, resulting from volcanic glass. Lenticular knots occurring in this groundmass represent products of the transformation of clinopyroxene crystals, which consist of an aggregate of very fine chlorite lamellae and, sometimes, uralite fibers, associated with minute pistacite granules. A fine dust of iron and titanium oxides is present in the mass of the greenstones. Thin-layered greenstones occur frequently within the Groşi Formation.

Within the Highiş-Drocea Variscan low-metamorphic crystalline schists of the Păiuşeni group, granofelses are rare occurrences across the surface of these mountains, being concentrated in the Highiş and the Bârzava areas, in particular (Giuşcă, 1962; Dimitrescu, 1962; Savu, 1962, 1965; Savu, 2010; Tatu, 1998). In the last occurrence, they have been described thoroughly, as metabasalts, metadolerites, metagabbros, metagabbrodolerites, metadiorites and tuffogenous greenschists (Savu, 1965). The combination of these terms suggests the original rocks the granofelses derived from. Thus, the granofelses resulted from basic tuffs and tuffites are schistous rocks and they exhibit a blastocrystalloclastic or mostly granolepidoblastic texture. The rocks resulted from previous basaltic rocks display a blastoophitic or blastoporphyritic texture. They consist of albite (58%), chlorite, pistacite and accessories such as magnetite, pyrite and oligiste. The granofelses resulted from plutonic basic rocks display a blastohypidiomorphic texture, being more or less schistous. They consist of albite (50–33%), actinolite, uralite, biotite, chlorite, epidote, apatite, titanite and magnetite. According to the albite law, plagioclase (An $_{8-10}$) occurs as twinned crystals, packed with inclusions of acicular amphibole, fine biotite lamellae, and epidote. Sometimes, the entire plagioclase crystal was substituted by epidote. Like the granofelses from the Poiana Ruscă Mountains, the Highiş-Drocea granofelses are associated with porphyroid rocks, thus evidencing a bimodal volcanism that generated the protholitic rocks, as well.

Geochemistry of the metamorphic basic rocks

Given the fact that the metamorphosed basic rocks derived from igneous basic ones, their geochemistry will be discussed in terms of those rocks (see Moine and La Roche, 1968). The average chemical composition of the metamorphosed basic rocks is presented in tables 1 and 2. These tables point to a uniform composition of the metamorphic basic rocks occurring in different areas of the crystalline schists. Thus, SiO_2 remains below 52% in the rocks derived from basaltic and gabbroic rocks, and increases up to 55% in rocks resulted from dioritic rocks or equivalent volcanics. MgO and CaO display nearly equal contents in the basic rocks. What is interesting is the content of alkalies, which is a reminder of the content of these elements in the basic rocks that the metamorphic basic rocks derived from. What is also noteworthy is the variation of Na_2O, which displays contents consistent with those of basalts, but also ones which are similar to those from spilites. The variation of Na_2O clearly results from the diagram in Figure 1, on which the Pre-Variscan amphibolites have been plotted. This diagram was devised using the data from the basalt-spilite association of the Alpine Mureş ophiolitic suture (see Savu, 2002).

Table 1 Average chemical composition of the Pre-Variscan amphibolites and related rocks from the Danubian Domain and the Getic Nappe crystalline schists*

Area	1	2	3	4	5	6	7	8	9	10
SiO_2	50.32	54.87	48.09	47.87	54.58	67.38	47.93	49.23	46.77	46.85
Al_2O_3	12.07	15.74	15.40	17.16	16.73	16.76	16.96	15.58	14.03	15.90
Fe_2O_3	5.07	3.93	3.53	3.29	2.52	1.47	6.36	3.28	3.53	4.94
FeO	7.15	4.66	7.53	6.87	5.61	1.05	7.21	5.12	8.18	7.72
MnO	0.27	0.20	0.20	0.18	0.15	0.27	0.98	0.18	0.20	0.23
MgO	8.60	4.71	7.76	7.82	4.97	1.07	5.30	9.19	7.61	8.00
CaO	9.18	6.00	9.47	8.81	7.06	2.70	9.71	10.78	9.76	9.22
Na_2O	2.63	4.43	2.28	2.91	3.41	4.62	2.09	2.67	2.62	2.57
K_2O	0.76	2.19	0.87	0.87	1.03	1.76	1.23	0.65	0.36	0.79
TiO_2	1.37	0.93	1.32	1.64	1.04	0.33	1.57	0.95	2.22	1.91
P_2O_5	0.40	0.20	0.20	0.35	0.22	0.12	0.29	0.10	0.29	0.23
CO_2	-	0.55	-	0.50	0.27	0.65	0.61	0.31	0.33	-
S	0.51	0.07	0.16	0.13	0.15	0.118	0.18	0.05	0.10	-
H_2O	1.94	1.60	2.28	1.53	1.65	0.09	0.82	1.71	1.35	1.29
Total			09.79	99.93	99.58	98.37	100.00	99.80	99.35	99.65
Ni	-	-	112.30	96.33	39.50	24.00	55.00	139.0	143.40	140.80
Co	-	-	43.15	175.80	90.33	34.00	40.80	46.0	34.20	48.17
Cr	-	-	174.10	175.80	90.33	34	108.60	368	251.30	233.40
V	-	-	311.00	314.40	214	55.10	175.80	200	274.60	318.20
Sc	-	-	32.65	36.00	2.50	5.50	18.50	4.4	34	33.20
Y	-	-	24.85	35.30	24.50	11.67	-	17	31.50	34.78
Yb	-	-	-	2.33	-	-	-	1.8	2.37	2.75
Zr	-	-	141.39	182.80	136.80	134.10	-	43.33	186.60	216.70
Ba	-	-	218.60	191.60	376.80	805	122.50	315	96.60	-
Sr	-	-	367.45	524.40	495.50	474.60	515	386.6	268.10	-
Li	-	-	-	20.60	10.50	10.00	-	21.3	-	-
Cu	-	-	41.26	18.70	40.25	24	23.50	103.5	82.26	54.57
Ga	-	-	18.37	19.77	20.20	24.00	-	13.6	16.43	21.08
Sn	-	-	2.10	2.66	2.00	< 2	-	-	4.03	2.36
Pb	-	-	7.05	6.83	5.43	7.49	-	8	11.7	5.51
La	-	-	10.75	-	13.11	13.61	-	-	-	< 30
Ce	-	-	31.13	-	34.00	32.34	-	-	-	-
Pr	-	-	4.51	-	4.62	3.94	-	-	-	-
Nd	-	-	22.28	-	21.63	15.58	-	-	-	-
Sm	-	-	5.66	-	2.97	5.36	-	-	-	-

Area	1	2	3	4	5	6	7	8	9	10
Eu	-	-	2.01	-	1.02	1.66	-	-	-	-
Gd	-	-	6.38	-	2.85	5.68	-	-	-	-
Dy	-	-	5.81	-	2.27	5.17	-	-	-	-
Ho	-	-	1.20	-	0.47	1.06	-	-	-	-
Er	-	-	3.21	-	1.46	2.96	-	-	-	-
Yb	-	-	2.95	-	1.62	2.96	-	-	-	-
Lu	-	-	0.41	-	0.27	0.42	-	-	-	-
Hf	-	-	3.32	-	3.53	3.66	-	-	-	-
Ta	-	-	0.27	-	0.11	0.22	-	-	-	-
W	-	-	1.31	-	1.09	1.72	-	-	-	-
Th	-	-	0.53	-	2.61	1.73	-	-	-	-
U	-	-	0.31	-	0.93	0.67	-	-	-	-
Rb	-	-	21.34	-	7.43	22.13	-	-	-	-
Nb	-	-	5.90	-	6.40	2.85	-	-	-	-

* The average values represent the following: 1–average value based on 3 analyses of metabasalts from the Camenița-Urda Mare area (data from Mureşan et al., 1974); 2–average value based on 2 analyses of metadiorites from the Camenița-Urda Mare area (data from Mureşan et al., 1974); 3–average value based on 23 analyses of amphibolites from the Drăgşan group, Danubian Domain (data from Savu et al., 1984a; Liégeois et al., 1996); 4–average value based on 9 analyses of amphibolites from the Măru group, Danubian Domain (data from Savu et al., 1984b; Savu and Udrescu, 1975); 5–average value based on 6 analyses of amphibole gneisses from the Drăgşan and Măru groups (data from Savu et al., 1984a,b; 1990; Liegéois et al., 1996); 6–average value based on 2 analyses of metaquartzkeratophyres from the Drăgşan and Măru groups (data from Savu et al., 1984b; Liégeois et al., 1996); 7–average value based on 11 analyses of amphibolites from the Godeanu Mountain (data from Bercia, 1975); 8–average value based on 3 analyses of amphibolites from the Latorița Valley (data from Savu et al., 1982); 9–average value based on 19 analyses of amphibolites from the Făgăraş Mountains (data from Anton et al., 1981); 10–average value based on 26 analyses of amphibolites from the Suru Formation of the Făgăraş Mountains (data from Gridan et al., 1989).

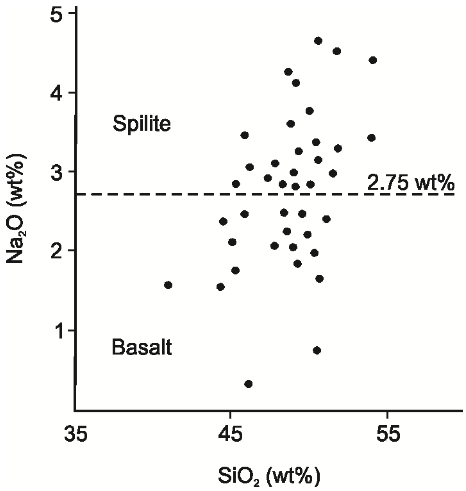

Fig. 1. Plot of the Pre-Variscan amphibolites from the Danubian Domain and the Getic Nappe on the Na_2O vs. SiO_2 diagram. Fields, according to Savu (2002). Data from Savu et al. (1984a,b) and Liégeois et al. (1996).

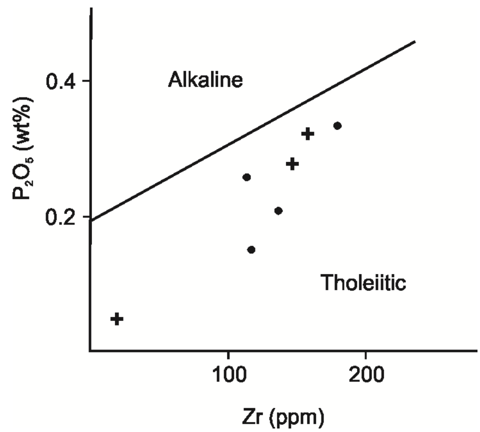

Fig. 2. Plot of the amphibolites and granofelses average contents from Tables 1 and 2 on the P_2O_5 vs. Zr diagram. Fields, according to Floyd and Winchester (1975). Dot–amphibolites; cross–granofelses.

Table 2 Average chemical composition of the Variscan granofelses*

Area	1	2	3		4		5	
SiO_2 (%)	45.45	-	La (ppm)	5.74	CaO (%)	6.39	Ti (ppm)	1.21
Al_2O_3	16.88	-	Ce	33.20	TiO_2	1.50	Zr	159.46
Fe_2O_3	6.01	-	Sm	2.26	Fe_2O_3	9.90		
FeO	6.91	-	Eu	0.94	K (ppm)	1.13		
MnO	0.218	-	Tb	0.95	Rb	48.59		
MgO	5.41	-	Yb	3.42	Sr	139		
CaO	8.19		Hf	3.00	Y	29.40		
Na_2O	2.84	-	Ta	1.38	Zr	159.40		
K_2O	0.80	-	Th	3.34	U	1.66		
P_2O_5	0.37	-	-	-	Th	4.82		
S	0.31	-						
CO_2	2.41	-						
H_2O	2.40	-						
Total	100.16	-						
Ni (ppm)	41.17	53						
Co	34	24.80						
Cr	31.75	232						
V	123.50	218						
Pb	8.75	18						
Cu	84	33.30						
Sn	5	2						
Ga	18	16.10						
Be	1.50	-						
Ba	300	96.40						
Sc	-	33						
Zr	-	53						
Y	-	17.10						
Sr	-	232						

* The average values represent the following: 1–average value based on 25 analyses of granofelses from the Poiana Ruscă Mountains (data from Mureşan, 1973); 2–average distribution of certain trace elements within 5 granofelses from the Groşi Formation (data from Savu et al., 2006); 3–distribution of REE within the granofelses from the Groşi Formation (data from Savu et al., 2006); 4–distribution of certain major and trace elements within 22 granofelses from the Drocea crystalline schists, Bârzava area (data from Savu and Udrescu, 1975; Savu and Tiepac, 1981); 4–average distribution of Zr and Ti within 13 Highiş-Drocea granofelses (data from Savu and Udrescu, 1975).

Given the average content of P_2O_5 and Zr (Tab. 1), the Pre-Variscan amphibolites and the Variscan granofelses are tholeiitic rocks (Fig. 2), a peculiarity inherited from the basic rocks they derived from.

Based on the variation of iron and magnesium oxides in most amphibolites from the Danubian Domain and the Getic Nappe, the tholeiitic character of these rocks is obvious, as illustrated by the diagram in Figure 3. Moreover, this diagram shows that several rocks plot within the domain of the calc-alkaline rocks. These rocks could represent the amphibolites resulted from spilitic rocks, real island arc volcanic rocks, or both. Otherwise, as suggested by Liégeois et al. (1996), the entire Drăgşan amphibolite group resulted from island arc volcanics. According to Savu (2003), the Drăgşan and Măru amphibolite groups represent vestiges of a Pre-Variscan ophiolitic suture.

The diagram in Figure 3 shows that the evolution of this ophiolitic suture was similar to that of the Alpine Mureş ophiolite suture from the southern Apuseni Mountains, in which ocean floor tholeiitic, partly spilitic, rocks are associated with island arc volcanics (see Savu, 2007). On the diagram, the granofelses from the Poiana Ruscă Mountains also plot within the tholeiitic domain.

Most intermediate rocks (SiO_2 > 52%) related to the amphibolites and granofelses are tonalitic rocks, as resulting from the diagram in Figure 4. One rock from the analyzed samples, which is associated with the amphibolites, plots within the trondhjemitic–quartz-keratophyric field, and another one occurs in the granite field. This proves, once again, the similarity between the Pre-Variscan ophiolitic suture and the Mureş ophiolitic suture. One metatuff related to the Poiana Ruscă granofelses occurs within the quartzkeratophyre field, as well (Fig. 4).

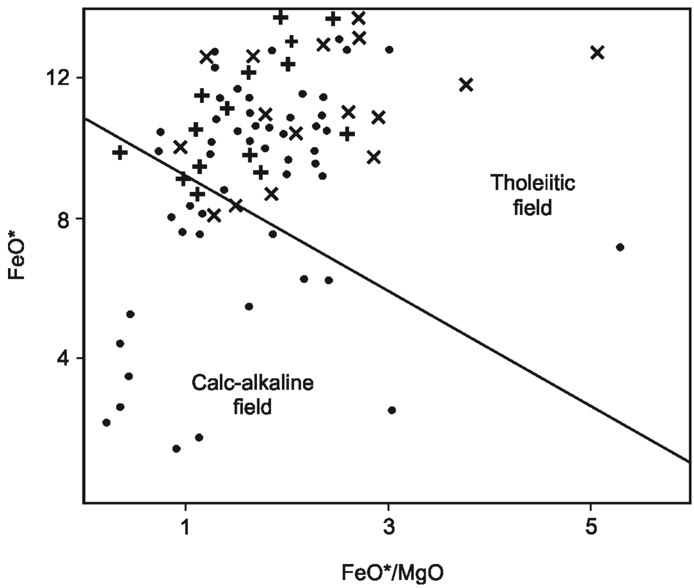

Fig. 3 Plot of the chemical analyses of Pre-Variscan amphibolites and Variscan granofelses on the FeO^* vs. Fe^*/MgO diagram. Domains according to Myiashiro (1974). Dot–amphibolites from the Danubian Domain (data from Savu, 1984a; Liégeois et al., 1996); cross–amphibolites from the Făgăraş Mountains (data from Anton et al., 1981; Gridan et al., 1989); eks–granofelses from the Poiana Ruscă Mountains (data from Mureşan, 1973).

The quartz-rocks associated with the Pre-Variscan amphibolites from the Southern Carpathians are typical island arc rocks (Fig. 5), and some of them exhibit obvious adakitic characteristics. These rocks most likely represent the acid differentiates of the magma generated by the island arc volcanism which manifested itself in the Pre-Variscan Carpathian Ocean.

Trace elements have been determined in a few of the rocks, like in the amphibolites from the Danubian Domain and the Getic Nappe. The variation of these elements is in agreement with that of the trace elements from the basaltic rocks, a relationship that was previously noticed in the variation of the major elements they are related to. The amphibolites and the granofelses display similar high contents of Ni, Cr and TiO_2, and low contents of K_2O. As the granofelses are most certainly derived from basaltic rocks, there is no doubt that all these rocks are orthorocks, an observation in agreement with the conclusion of Leake (1964) in this respect. In the metamorphosed quartzkeratophyres, the siderophile elements exhibit very low contents.

The variation of the REE from amphibolites and granofelses results from the diagram in Figure 6. On this diagram, the REE chondrite-normalized patterns of the Pre-Variscan amphibolites, which display an obvious Ce positive anomaly, are in agreement with the REE chondrite-normalized patterns of the MORB basaltic rocks (see Saunders, 1984). The REE chondrite-normalized pattern of the granofelses shows an important Ce positive anomaly, as well, but also strong negative anomalies for Sm and Eu. According to Cullers and Graf (1984), this indicates that the parental quartz-rocks differentiated from the basaltic magma through fractional crystallization.

Tectonic setting of the magmatic rocks the metamorphic basic rocks derived from

The association of the Pre-Variscan and Variscan metamorphic basic rocks with the crystalline schists of detrital origin shows that they erupted within marine basins, being metamorphosed together with the sedimentary rocks. Therefore, on the diagram in Figure 7, the plots of the average composition of the rocks from Tables 1 and 2 are situated within the plate margin basalt domain and, partly, within the within-plate domain. However, if the first type derived from basic rocks in the ocean basins, the second one derived from basic rocks erupted in epicontinental seas, under within-plate conditions.

The occurrence of the original basic rocks in an ocean basin is clearly pointed out by the diagram in Figure 8. On this diagram, the average chemical composition of the amphibolites from the Danubian Domain and the Getic Nappe plot along the line of the N-Type MORB basic rocks. Some rocks display a tendency of approaching the E-Type MORB. The metamorphosed basic rocks undoubtedly exhibit the characteristics of orthoamphibolites

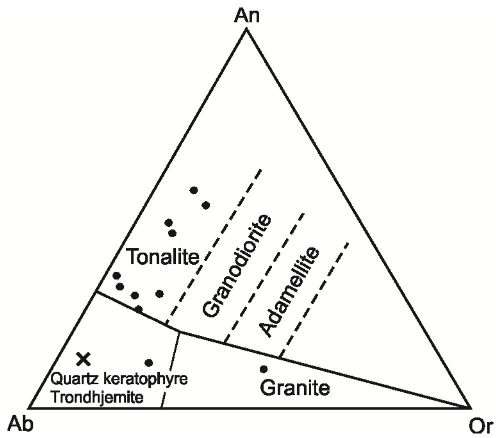

Fig. 4 Plot of quartz-rocks on the An–Ab–Or diagram. Fields according to O'Connor (1965). Dot–quartz-rocks associated with the amphibolites from the Danubian Domain and the Getic Nappe (data from Savu et al., 1984a,b; Liégeois et al., 1996); eks–quartzkeratophyres related to the granofelses from the Poiana Ruscă Mountains (data from Mureşan, 1973).

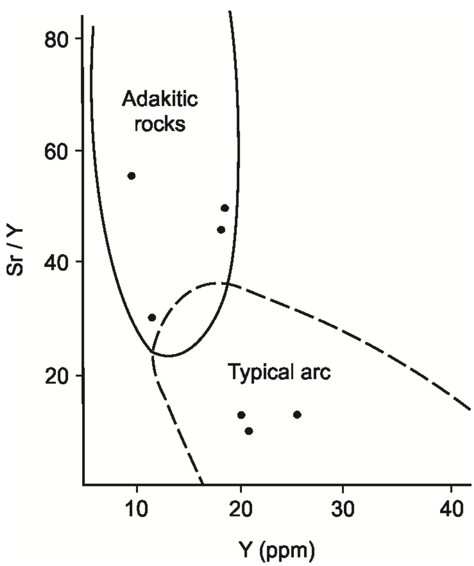

Fig. 5 Plot of the quartz-rocks related to the Pre-Variscan amphibolites from the Danubian Domain and the Getic Nappe on the Sr/Y vs. Y diagram. Fields according to Sajona (1965). Data from Tables 1 and 2.

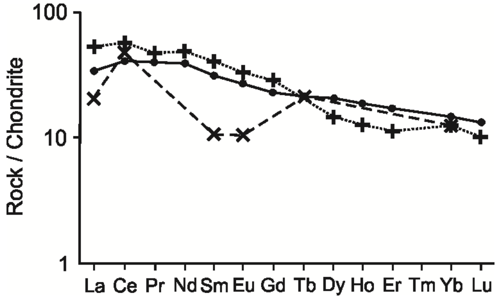

Fig. 6 REE chondrite-normalized patterns of the metamorphic basic rocks. Data from Tables 1 and 2. Dot and cross, patterns of the Pre-Variscan amphibolites and of the intermediate-to-acid rocks from the Danubian Autochthone (data from Liégeois et al., 1996); eks–pattern of the greenstones from the Groşi Formation (data from Savu et al., 2006).

The tectonic setting of the igneous rocks the metamorphic basic rocks resulted from ensues more clearly from the diagram in Figure 9, on which the chemical analyses of the metamorphic basic rocks have been plotted. There, the amphibolites from the Danubian Domain and the Getic Nappe plot within the MORB field. However, some samples from the amphibolites of the Danubian Domain, including the quartz-rocks, occur within the island arc rock field, proving, once again, that, in the Pre-Variscan Ocean, the igneous activity of the ocean floor was followed by island arc volcanism. The granofelses from the Highiş-Drocea crystalline schists are gathered within a restricted field situated in the within-plate domain.

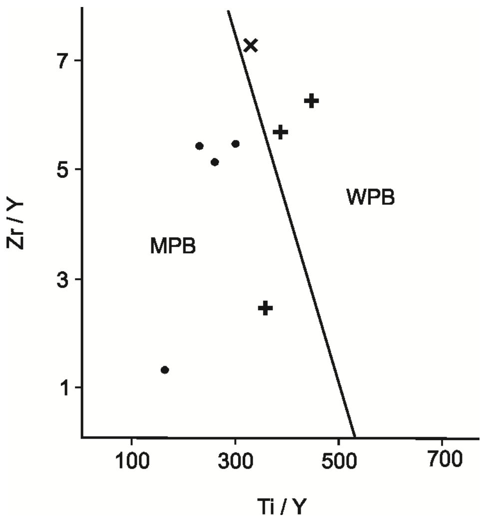

Fig. 7 Plot of the average composition of the amphibolites and granofelses on the Zr/Y vs. Ti/Y diagram. Fields according to Pearce and Gale (1977). Data from Tables 1 and 2. Dot–amphibolites from the Danubian Domain; cross–amphibolites from the Getic Nappe; eks–granofelses from the Highiş-Drocea Mountains.

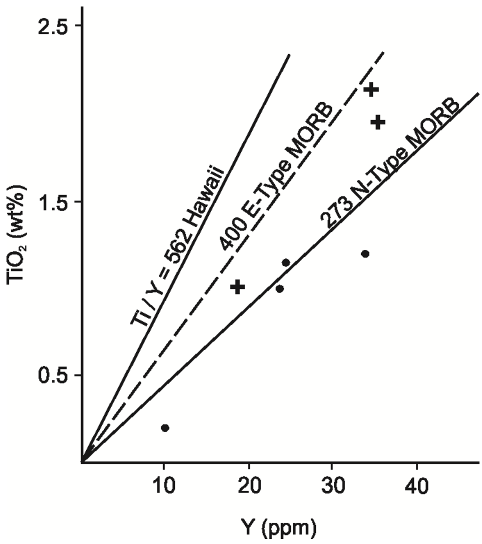

Fig. 8 Plot of the average chemical composition of the amphibolites from Table 1 on the TiO_2 vs. Y diagram. Characteristic lines according to Perfit et al. (1980). Dot–amphibolites from the Danubian Domain (data from Savu, 1984a; Liégeois et al., 1996); cross–amphibolites from the Getic Nappe (data from Savu et al., 1984b).

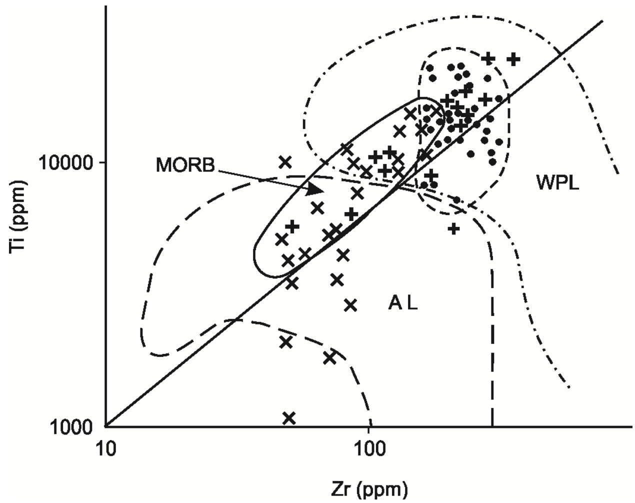

Fig. 9 Plot of the metamorphic basic rocks on the Ti vs. Zr diagram. Fields according to Pearce (1980). Eks–amphibolites from the Danubian Autochtone (data from Savu et al., 1984a; Liégeois et al., 1996); cross–amphibolites from the Getic Nappe (data from Savu et al., 1984b; Anton et al., 1991; Gridan et al., 1989); dot–granofelses from the Highiș-Drocea crystalline schists (data from Savu and Udrescu, 1975).

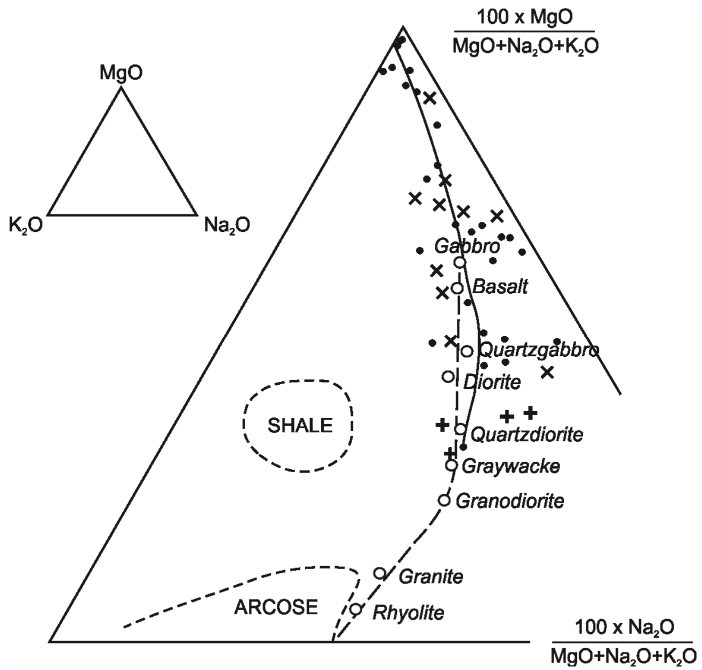

Fig. 10 Plot of the metamorphic basic rocks and the related quartz-rocks on the $MgO–K_2O–Na_2O$ diagram. Dot–amphibolites and three ultramafic rocks from the Danubian Domain (data from Savu et al., 1984a; Liégeois et al., 1996); cross–related quartz-rocks (data from Liégeois et al., 1996); eks–granofelses from the Poiana Ruscă Mountains (data from Mureșan, 1973).

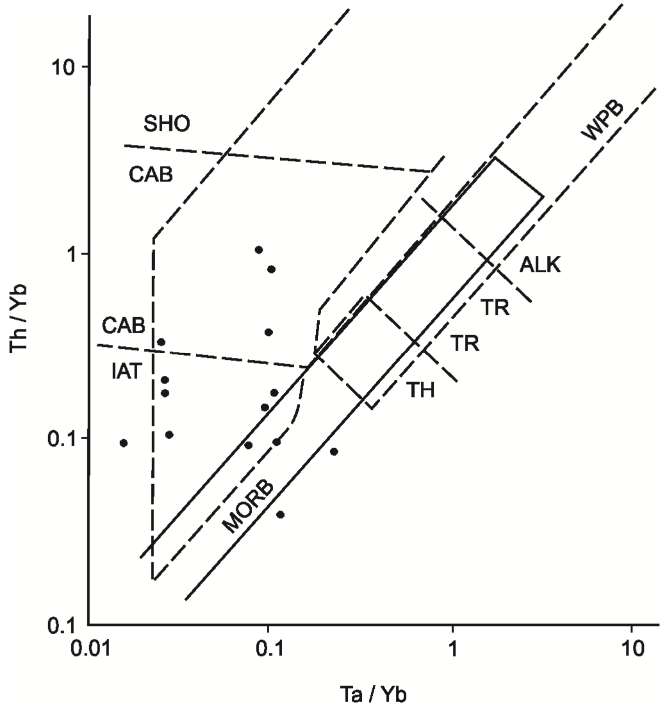

Fig. 11 Plot of the amphibolites and related rocks on the Th/Yb vs. Ta/Yb diagram. Fields according to Pearce (1980): SH–shoshonite; CAB–calc-alkaline basalt; Alk–alkaline; TR–transitional magmas; TH–tholeiite; MORB–mid-ocean ridge basalts (data from Liégeois et al., 1996).

A more detailed explanation for the origin of the metamorphic basic rocks results from the diagram in Figure 10, which is very suggestive in this respect (see Savu et al., 1978). This diagram shows that the plots of the amphibolites, the granofelses and their related rocks extend along nearly the entire distribution line of the igneous rock system. Thus, there occur ultramafic rocks associated with the amphibolites from the Danubian Domain and the Getic Nappe, followed, down on the distribution line, by the amphibolites derived from basaltic and gabbroic rocks, and, even further down, by the quartz-rocks related to the amphibolites, which derived from diorites, quartz-diorites and equivalent volcanic rocks. The protolithic basic rocks the granofelses derived from had a varied composition, therefore the resulting metamorphic rocks were distributed along nearly the entire distribution line, from the ultramafic rocks down to the dioritic rocks.

Origin of the metamorphic basic rocks and related quartz-rocks

Regarding the origin of the protolith of the metamorphic basic rocks and quartz-rocks from the crystalline schists of the Southern Carpathians and the Apuseni Mountains, unfortunately there are very few adequate chemical analyses. However, the results of the investigations carried out by Liégeois et al. (1996) on the amphibolites and related rocks from the Danubian Domain have proven useful in this respect. Thus, the rocks from these areas, which have been plotted on the diagram in Figure 11, show that the magmas from which the original basic rocks resulted were partly formed within an ocean ridge area, and partly within an island arc. The latter display an island arc tholeiitic (IAT) character, manifesting a tendency toward the calc-alkaline tholeiitic basalts.

Conclusions

Based on the distribution of the metamorphic basic rocks (amphibolites and granofelses) on the territory from western Romania, and their chemical composition and tectonic setting, the following general conclusions can be formulated:

During the Pre-Variscan period (820–717 Ma), the igneous activity manifested itself in a Carpathian Ocean, where the Pre-Variscan Carpathian ophiolitic suture occurred (Savu, 2003). This old ophiolitic suture included the products of both the ocean floor igneous activity and the island arc volcanism that followed. The area with such igneous rocks extended northward within the sedimentary basin from the current Getic Nappe domain.

At the beginning of the Variscan tectono-magmatic cycle, the old Carpathian mobile belt opened again, giving birth to an ocean trench from which a Variscan ophiolitic suture resulted (ca. 300 Ma). From this suture, some slabs of ultramafic rocks have been preserved (see Savu, 1989, 2005). Afterwards, the volcanism related to this tectono-magmatic cycle extended northward in the form of a within-plate volcanism which manifested itself in the Poiana Ruscă, Groşi and Highiş-Drocea areas, as shown by the diagrams above. Briefly, the igneous activity extended from the Southern Carpathian, where a mobile belt was active, northward, where a more stable plate was settled.

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