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STRONTIUM ISOTOPE STUDIES OF THE LATE ALPINE EXTENSIONAL MAGMATISM IN EASTERN RHODOPES

Vladimir Georgiev[1], Petar Milovanov[2], Pavel Monchev[1]

[1]Geological Institute, Bulgarian Academy of Sciences, 1113 Sofia; vladogeo@geology.bas.bg
[2]Geology and Geophysics Ltd., 1505 Sofia

ABSTRACT. Significant differences in the character of distribution of the initial strontium ratios ($^{87}Sr/^{86}Sr$)*i* between the medium acid and the acid magmatic groups (subgroups) of the late extensional magmatism are not observed. This fact may be discussed as indication for a common origin of the initial magmas from the different regions of distribution of this magmatism and of the peripheral magmatic chambers, respectively. The relatively low values of the initial strontium ratios ($^{87}Sr/^{86}Sr$)*i* for this magmatism is an indication for mantle origin. The higher values of this ratio in the initial phases of magmatism are probably a result of more pronounced pollution of the initial magma with crustal material. The latest phases of the magmatism, however, are weakly enriched or barren of crustal material and thus their initial strontium ratios e close to 0.704, which correlates with the values of this ratio for the contemporary mantle.

СТРОНЦИЕВИ ИЗОТОПНИ ИЗСЛЕДВАНИЯ НА КЪСНОАЛПИЙСКИЯ ЕКСТЕНЗИОНЕН МАГМАТИЗЪМ В ИЗТОЧНИТЕ РОДОПИ

Владимир Георгиев[1], Петър Милованов[2], Павел Мончев[1]
[1]Геологически институт, БАН, 1113 София; vladogeo@geology.bas.bg
[2]Геология и геофизика АД, 1505 София

РЕЗЮМЕ. Не се наблюдават съществени различия в характера на разпределение на началните стронциеви отношения ($^{87}Sr/^{86}Sr$)i между среднокиселите и киселите магмени групи (субгрупи) от късноекстензионния магматизъм. Този факт може да се тълкува като указание за единен произход на родоначалните магми от различните ареали на разпределение на този магматизъм, респективно на периферните магмени камери. Сравнително ниските стойности на началните стронциеви отношения ($^{87}Sr/^{86}Sr$)i на този магматизъм са указание за мантийния му произход. По-високите стойности на това отношение в началните фази на магматизма вероятно са резултат на по-значително замърсяване на изходните магми с коров субстракт. Последните фази на магматизма обаче са слабо обогатени, или почти не са обогатени с коров материал и началните стронциеви отношения ($^{87}Sr/^{86}Sr$)i за тях са близки до 0.704, което е съизмеримо със стойностите на това отношение в съвременната мантия.

Geological structure

Traditionally, two major structural units are recognized in the Rodope Massif – pre-Paleogene metamorphic basement and a Paleogene volcano-sedimentary complex. The metamorphic basement crops out in the uplifted domes whereas the volcanogenic complex fills the superimposed depressions between them.

The Late Alpine extensional processes produced several metamorphic core complexes (domes) – Madan-Davidkovo, Byala reka, and Kesibir (Fig. 1). They comprise a migmatite metamorphic complex in the cores and a "variegated" one along their periphery (review in Georgiev, 2006). The Harmanli block was not affected by extension and at that time and was a passive structure. The superimposed depressions (Georgiev, 2005) developed between the individual domes of the core complexes and along their periphery. Terrigenous sediments and reefal limestones (Paleocene-Eocene) were deposited at the base of the Paleogene section followed upward by the products of abundant medium acid and acid volcanic structures (Eocene-Oligocene).

The extensional processes were accompanied by intensive magmatism of two types (Georgiev, 2004; 2005). The initial stage of extension is marked by the emplacement of granitoid intrusions in the upper brittle crust of the domes (Ivanov, 2000). Ages of 69-68 Ma have been determined for Chuchuliga and Rosino granites (Marchev et al., 2006) and of 53-52 Ma for Pripek granite (Ovcharova, 2005).

The magmatism of the late extensional stage is concentrated in Momchilgrad, Zlatoustovo and Northeastern Rhodope depressions. They merge in Kurdjali region and together form the East Rhodope Paleogene depression. Numerous medium acid volcanic structures are localized there, which are built of basaltic andesites and andesites to latites. Only acid volcanic products are found in Zlatoustovo depression (Kurdjali region) and Borovitsa caldera. The final phases of magmatism are

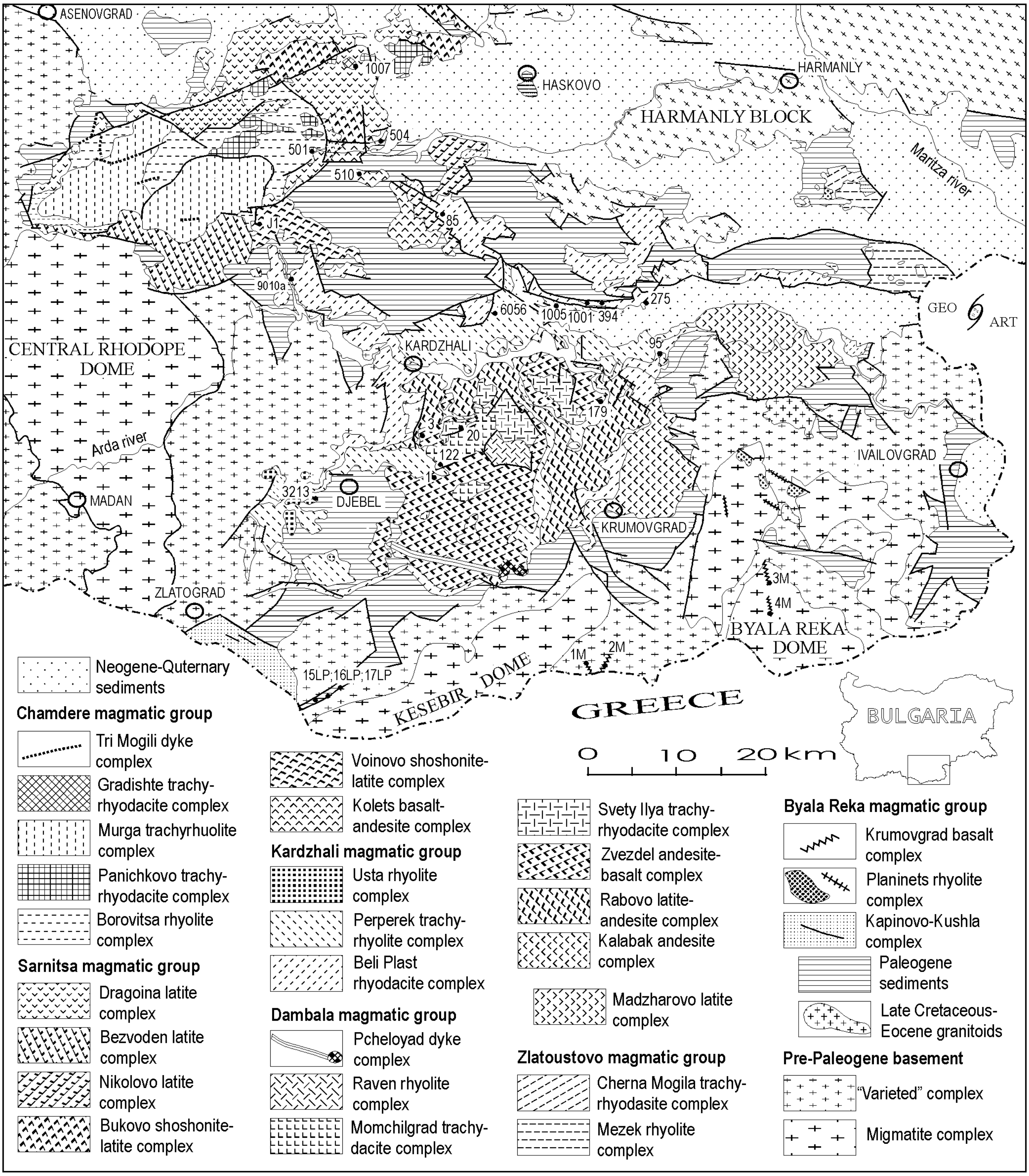

Fig. 1. Geological map of the Eastern Rhodopes

represented by acid and medium acid to basic subvolcanic bodies and dykes.

The products of the Paleogene magmatic activity in the Eastern Rhodopes have been subdivided into magmatic groups and complexes (Georgiev, Milovanov, 2003a; 2005; 2006a, b, c, d). The magmatic groups crop out in separate areas and result from the evolution of different peripheral magmatic chambers of medium acid to acid composition. The following groups, subgroups and complexes are distinguished.

In Momchilgrad depression: Dambala magmatic group, subdivided into Putocharka medium acid subgroup (Kalabak andesite, Rabovo latite-andesite, and Zvezdel basaltic andesite complexes), Zdravets acid subgroup (Svety Ilia trachyrhyodacite, Momchilgrad tracgydacite, and Raven rhyolite komlexes) and Pcheloyad dyke complex.

In Northeastern Rhodope depression: Sarnitsa medium acid group (with complexes separated with respect to order of formation as follows: Kolets basalt-latite, Voinovo shoshonite-latite, Nikolovo latite, Bezvoden latite and Dragoinovo latite ones) and Cham Dere acid group (with Borovitsa rhyolite, Panichkovo trachyrhyolite and Tri Mogili dyke complexes).

In Zlatoustovo depression: Madjarovo latite complex and Zlatoustovo acid group (Mezek rhyolite and Cherna Mogila trachyrhyodacite complexes).

In Kurdjali region develop rhyolite extrusions and explosive centers of acid volcanism assigned to Kurdjali acid group (Beli plast rhyodacite, Perperek trachyrhyolite, Stomanovo rhyolite and Ustren rhyolite complexes).

The last stages of magmatism are represented by acid and medium acid to basic subvolcanic bodies and dykes, as well as by acid minor intrusions localized in dyke swarms predominantly of WNW direction. They are intruded both in the depression and in its metamorphic framework. These latest phases in Byala Reka and Kesibir core complexes are united in Byala Reka magmatic group (Planinets rhyolite and Krumovgrad basaltic complexes).

K-Ar ages of the late extensional magnetism vary in the range of 40-28 Ma (Lilov et al., 1987; Yanev, Pecskay, 1997; Georgiev et al., 2003, Milovanov et al., 2005). $^{40}Ar/^{39}Ar$ datings are sporadic and possibly do not characterize the entire age interval of the magmatism. The published data are in the interval 33-31.5 Ma (Marchev, Singer, 1999; 2002) and mark the maximum of magmatic intensity.

Material and methods

Strontium isotope studies were performed during the geological mapping of the Eastern Rhodopes (scale 1:25000) conducted in the period 1993-1999. The method of laboratory investigations is described in Milovanov et al. (2003). Literature data for the Madjarovo latite and Krumovgrad basaltic complexes (Marchev, Rogers, 1998; Marchev et al., 1998; Marchev, Downes, 2002) have been also used (see Table 1).

The available data from the strontium isotope studies are rather irregularly distributed. For some magmatic groups, which unite 5-6 magmatic complexes (phases) with probable common magmatic chamber, only 2-3 analyses are available (Sarnitsa and Cham Dere groups). For other magmatic complexes (Krumovgrad, Madjarovo) there are 9-14 analyses. These complexes have a higher “weight” in the constructed diagrams. In order to avoid this inconsistency, apart from using all analyses, similar diagrams are presented for the mean values of the parameters for the respective magmatic groups and complexes.

Results

Data for the magmatism from the early extensional stage in the studied region are available only for Chuchuliga granite where the strontium ratios $(^{87}Sr/^{86}Sr)_i$ vary in the interval 0.706-0.708 (Table 1, Fig. 2).

The magmatic rocks from the late extensional stage show a wide range of values for the initial strontium ratios – from 0.700 to 0.710. The maximum frequency of these values is in the range 0.703-0.709, which corresponds to the interval of the mean values for the respective magmatic groups and complexes.

A distinct tendency is observed in the trend of $(^{87}Sr/^{86}Sr)_i$ values, which decrease with decreasing content of Sr. This tendency is even more pronounced for ^{86}Sr. At the same time there is an increase of the $^{87}Rb/^{86}Sr$ ratio with decrease of the $(^{87}Sr/^{86}Sr)_i$ values (Fig. 2A, B, C).

The trend of distribution of $(^{87}Sr/^{86}Sr)_i$ in the magmatic rocks from the late stage of extension is sub-horizontal with respect to SiO_2 (Fig. 2D). This shows absence of direct relationships between $(^{87}Sr/^{86}Sr)_i$ and the content of SiO_2. In addition, the most basic and most acid varieties are characterized by low values of $(^{87}Sr/^{86}Sr)_i$, whereas the medium acid varieties display highest values. The trend of distribution of $(^{87}Sr/^{86}Sr)_i$ in the magmatic rocks of the late stage of extension (about 0.706) has lower values than that of Chuchuliga granite (about 0.707).

The initial strontium ratios $(^{87}Sr/^{86}Sr)_i$ for the magmatism of the late extensional stage are directly proportional to the age (Fig. 2E). The younger phases are characterized by lower $(^{87}Sr/^{86}Sr)_i$ values. This tendency is typical both for this magmatism as a whole as well as for the individual depressions. In this sense the earlier medium acid Sarnitsa magmatic group from the Northeastern Rhodope depression shows mean $(^{87}Sr/^{86}Sr)_i$ values of 0.7085 while for the later acid Cham dere magmatic group this value is 0.7047. The situation is similar in the Momchilgrad depression. The earlier medium acid Putocharska subgroup of Dambala group has mean values of 0.7061 and for the later acid Zdravets subgroup this value is 0.7043. The lower end of the distribution trend of $(^{87}Sr/^{86}Sr)_i$ is about 0.704.

Discussion

The relatively low initial strontium ratios $(^{87}Sr/^{86}Sr)_i$ allow to suppose that the magmatism from the second part of the extensional stage is of predominantly mantle origin. Many researchers speak for mantle origin of the initial magmas. There are also different views about the mechanism of intrusion and enrichment with crustal material.

Mavrudchiev (1992) assumed mantle source of the initial magmas with generation of magma sources at three levels – root (57-35 km), intermediate (29-20 km) and peripheral (12-1 km). The magmas enter the peripheral chambers strongly differentiated and as partial magmas. The separation of these melts proceeds in intermediate magmatic chambers.

Marchev et al. (1998; 2004b) propose astenospheric source for the basaltic magmatism in the Eastern Rhodopes, accompanied by insignificant crustal pollution of the initial magma. These authors consider that the Paleogene metamorphic and magmatic evolution in the Rhodopes is well explained with convectional uplifting of the lithosphere and mantle diapirism.

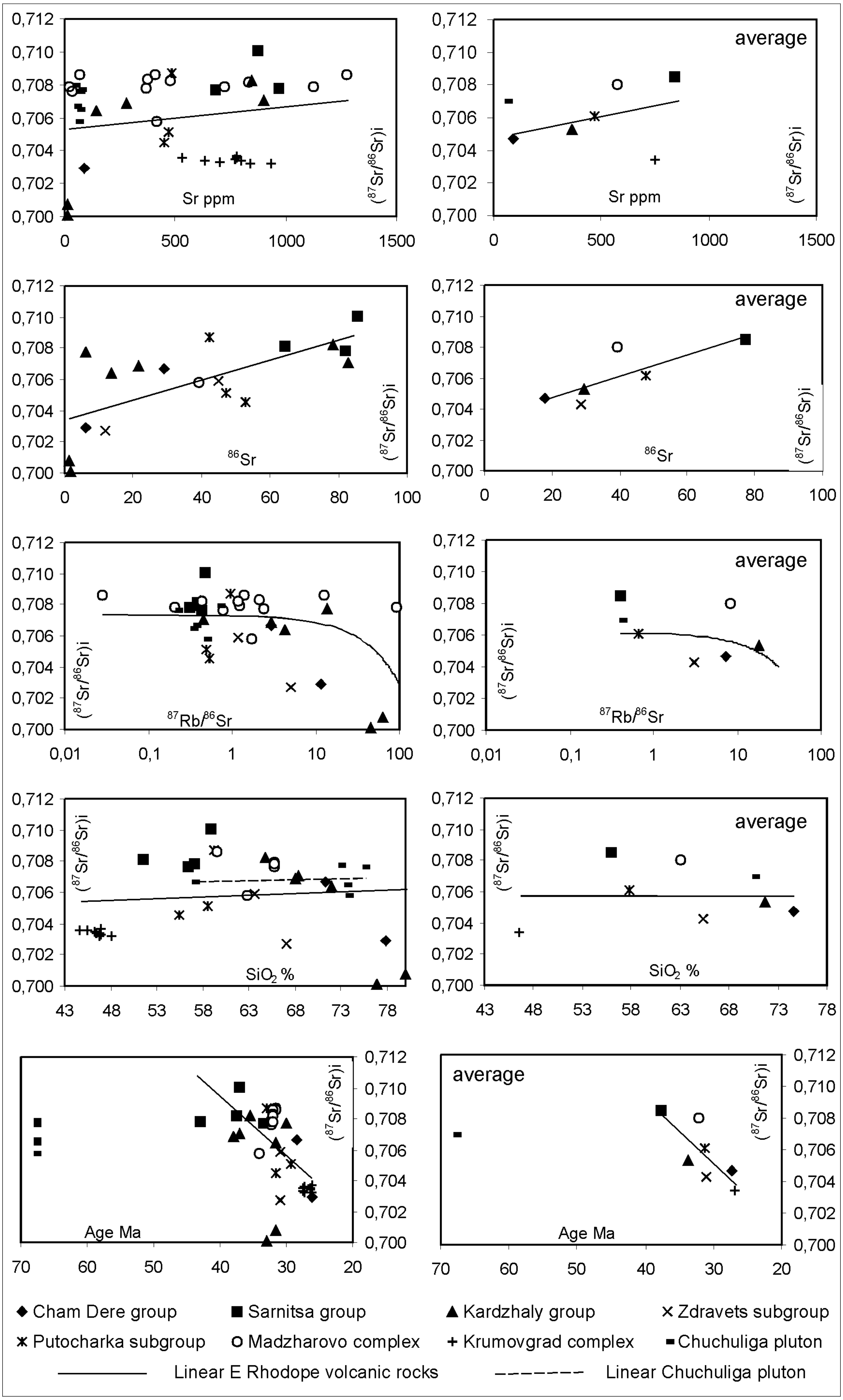

Fig. 2. $(^{87}Sr/^{86}Sr)i$ **variation diagrams**

Table 1.

$^{87}Sr/^{86}Sr$ composition for magmatic rocks in the Eastern Rhodopes

sample No	Rock	Localiti	SiO_2	$^{87}Sr/^{86}Sr$	Rb ppm	Sr ppm	^{86}Sr	$^{87}Rb/^{86}Sr$	time Ma	$(^{87}Sr/^{86}Sr)i$
CHAM DERE GROUP, Gradishte trachyrhyodacite complex										
1007	RD dm	v. Bryastovo	71,32	0,70783			29,04	2,910813	28,5	0,706652
CHAMDERE GROUP, Panichkovo trachurhyolite complex										
501	R dm	r. Velichka	77,79	0,70719	239,00	90,00	6,31	11,453249	26,2	0,702928
SARNITSA GROUP, Bezvoden latite complez										
9010a	Sh s	v. Dajdovnitsa	56,48	0,70789	119,00	680,00		0,431000	33,5	0,707685
SARNITSA GROUP, Voynovo shoshonite-latite complex										
J1	Ab l.f.	v. Jenda	51,50	0,70836			64,25	0,383813	37,5	0,708156
SARNITSA GROUP, Kolets basalt-andesite complex										
510	M I	v. Karamantsy	58,93	0,71032	143,00	874,00	85,68	0,480859	37,0	0,710067
504	HKA	v. Kolets	57,05	0,70798	88,00	970,00	82,05	0,309202	43,0	0,707791
KARDZHALY GROUP, Ustra rhyolite complex										
3213	R dm	v. Vodenicharsko	79,92	0,72878	298,00	13,00	1,42	62,676056	31,5	0,700739
KARDZHALY GROUP, Perperek trachyrhyolite complex										
275	R dm	v. Silen	76,86	0,72109	253,00	16,00	1,58	44,712696	33,0	0,700133
1005	R b	v. Miladinovo		0,71353			6,31	13,627140	30,0	0,707724
6056	R t	v. Chiflik	71,99	0,70834	195,00	145,00	13,81	4,262853	31,6	0,706427
KARDZHALY GROUP, Bely Plast rhyodacite complex										
85	HKD b	v. Minzuhar	64,80	0,70842	138,00	845,00	78,35	0,413019	35,5	0,708212
1001	RD	v. Sestrinsko	68,10	0,70846	223,00	280,00	21,45	2,964103	38,0	0,706860
394	RD b	v. Popovets	68,40	0,70729	148,00	903,00	82,76	0,459038	37,0	0,707049
DAMBALA GROUP, ZDRAVETS SUBGROUP, Momchilgrad trachydacite complex										
122	TD t	t. Momchilgrad	63,70	0,70640			44,87	1,167150	31,0	0,705886
DAMBALA GROUP, ZDRAVETS SUBGROUP, Svety Ilya trachyrhyodacite complex										
20	TRD l.f.	v. Chomakovo	67,00	0,70490			11,95	5,000000	31,0	0,702699
DAMBALA GROUP, PUTOCHARKA SUBGROUP, Zvezdel basaltic-andesite complex										
3	HKA l.f.	v. Sushevo	58,61	0,70530	85,00	469,00	47,27	0,489105	29,3	0,705096
1	HKBA l.f.	v. Bagryanja	55,42	0,70476	77,00	451,00	52,92	0,531633	31,5	0,704522
179	BA l.f.	v. Star Chal	59,20	0,70911	171,00	483,00	42,46	0,956901	33,0	0,708661
Madjarovo latite complex										
95mj	L b	v. D. Cherkovishte	62,84	0,70663	269,00	418,00	39,16	1,741062	34,0	0,705789
268Bi-MR	L l.f.	Madjarovo volc.	65,80	0,75017	642,90	20,20		92,192200	32,3	0,707875
268Sn-MR	L l.f.	Madjarovo volc.	65,80	0,70848	310,30	725,50		1,237400	32,3	0,707912
268Cp-MR	L l.f.	Madjarovo volc.	65,80	0,70799	8,90	32,50		0,793600	32,3	0,707626
268Pl-MR	L l.f.	Madjarovo volc.	65,80	0,70793	79,70	1124,40		0,205000	32,3	0,707836
202Bi-MR	QL l.f.	Madjarovo volc.	59,60	0,71422	290,60	67,10		12,529300	31,6	0,708597
202WR-MR	QL l.f.	Madjarovo volc.	59,60	0,70926	194,60	407,80		1,381100	31,6	0,708640
202Pl-MR	QL l.f.	Madjarovo volc.	59,60	0,70861	12,50	1276,50		0,028400	31,6	0,708597
1-MD	L l.f.	Madjarovo volc.		0,70925	194,60	407,80		1,380900	32,0	0,708626
2-MD	Mx l.f.	Madjarovo volc.		0,70839	123,10	831,90		0,428200	32,0	0,708195
3-MD	L l.f.	Madjarovo volc.		0,70930	277,00	373,00		2,148900	32,0	0,708321
4-MD	Mx l.f.	Madjarovo volc.		0,70877	197,80	479,30		1,194100	32,0	0,708222
5-MD	L l.f.	Madjarovo volc.		0,70884	300,80	366,50		2,374900	32,0	0,707760
6-MD	QL l.f.	Madjarovo volc.		0,70793	79,80	1124,40		0,205300	32,0	0,707836
7-MD	M I	Madjarovo volc.		0,70941	274,90	347,00				
Krumovgrad basalt complex										
Bz23-1-MV			44,70	0,70365	60,90	530,00			27,6	0,703542
IEG1-MV			46,44	0,70345	59,00	637,00			27,6	0,703345
Bz24-2-MV			46,33	0,70356	55,00	773,00			26,4	0,703480
IIEG1-MV			46,74	0,70349	75,00	801,00			26,4	0,703382
Bz26-1MV			45,50	0,70370	62,00	774,00			27,3	0,703606
GJ17-MV			46,75	0,70333	66,00	839,00			27,3	0,703234
Bz25-1MV			46,94	0,70379	73,60	778,00			26,1	0,703703
STR10-MV			48,03	0,70333	72,00	934,00			26,1	0,703240
Bz25-2-MV			46,94	0,70327	9,44	701,00			26,1	0,703254
Chuchuliga Pluton										
1	Gr I	v. Brusevtsy	72,80	0,70800	19,98	64,89		0,307840	68,0	0,707703
2	Gr I	v. Brusevtsy	73,45	0,70680	19,20	58,19		0,330000	68,0	0,706481
5	Gr I	v. Brusevtsy	73,65	0,70625	24,71	52,08		0,475600	68,0	0,705791
7	skarn	v. Brusevtsy	56,90	0,70700	16,42	45,96		0,357270	68,0	0,706655
3	Gr I	v. Chernichino	75,40	0,70784	13,08	59,76		0,218880	68,0	0,707629
6	pegmatite	v. Chernichino		0,70861	26,44	37,77		0,699970	68,0	0,707934

Sample number n-MR is data from Marchev, Rogers (1998), n-MD – Marchev et al. (2002), n-MV – Marchev et al. (1998). BA – basaltic andesite; RD – rhyodacite; R – rhyolite; HKBA – high-K basaltic andesite; HKA – high-K andesite; HKD – high-K dacite; Ab – absarokite; Sh – shoshonite; L – latite; M – monzonite; TD – trachydacite; TRD – trachyrhyodacite; QL – quartzlatite; Mx – mixed lava; Gr – granite; dm – dome; b – body; I – intrusion; l.f. – lava flow; t – tuff; s – sill

Yanev et al. (1998) accepted mantle source of the primary magma, which was heterogeneously enriched with components of the subducting lithosphere in the process of delamination.

The magmatism from the second extensional stage (localized mainly in the East Rhodope Paleogene depression and partly in the peripheral domes) is a product of several separate magmatic chambers. They are a result of uniform late post-extensional tectonomagmatic environment but have relatively independent evolution. The magmatism is of mantle origin but the separate magma chambers show specific composition and were possibly enriched to a different extent with crustal substrate. These chambers have similar but not identical and not synchronous evolution (Georgiev, 2004, 2005; Georgiev, Milovanov, 2005).

In the process of exhumation of the core complexes, a process of thinning of the lower plastic layer and of the crust as a whole took place between the separate domes and along the periphery of the Rhodope Massif. In these areas the upper mantle was uplifted and mantle substance penetrated in the crust (Georgiev, 2004; 2005). A differentiation was realized in the intermediate magmatic chambers and the peripheral magmatic chambers are of medium acid to acid composition. The magma of the peripheral magmatic chambers with medium acid composition underwent additional evolution and differentiation and the volcanism of some of them also evolved from medium acid to acid. The products of this magmatism – those predominantly in volcanic facies, are localized mainly in the framework of the East Rhodope depression. Separate monzonitoid intrusions as well as rhyolite and basic subvolcanic bodies and dykes were intruded also in the neighboring domes (sub-volcanic to hypoabysall facies).

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