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MAGMA MIXING IN UPPER CRETACEOUS PLUTONIC BODIES IN THE SOUTHWESTERN PARTS OF THE CENTRAL SREDNA GORA ZONE, BULGARIA

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Abstract

This paper considers petrographic and mineralogical data from some plutonic bodies in Central Sredna Gora zone. Microtextural features of the rocks and analytic data obtained for Elshitsa-Boshulia pluton support the idea of magma mixing and mingling processes. From selected samples were calculated P-T values at different stages of crystallization of both mafic and felsic magmas. According to these data we suggest an evolution model of the magmatic complex.

Key words: strike-slip deformation, mixing, mingling, Iskar-Yavoritsa Shear Zone, thermobarometry

The studied plutons (Plana, Gutzal, Varshilo and Elshitsa-Boshulia) are part of an elongated WNW-ESE complex belt of Upper Cretaceous intrusive granitoid bodies [1]. They are situated in the border area between the Rhodope massive to the south and central parts of Sredna Gora zone to the north (Fig. 1). Relatively large lenses and sheet-like bodies of mafic rocks (gabbro and gabbro-diorites) are embedded into the granitoid host. Numerous mafic fragments in the granites often accompany these mafic bodies.

PREVIOUS INVESTIGATIONS consider these plutons as products of magmatic activity during two magmatic epochs (Fig. 1): Variscan for Varshilo and Lesichovo plutons; and Late Cretaceous (or Late Cretaceous – Early Tertiary) for Plana, Gutzal and Elshitsa-Boshulia plutons. The latter have been interpreted as "fracture intrusions", formed in a rift setting [2,3] and as products of multiphase or double-phase normal basaltoid magma differentiation [4-9]. The mafic varieties are supposed to be older in age than the granites. The mafic fragments have been considered as xenoliths from the country rocks [8].

Some new structural, magnetostructural and petrological data [1], as well as radioisotope and geochronological studies [10] suggest that all these plutons (except Lesichovo one) are products of Late Cretaceous magmatic activity. All of them intruded the Pre-Upper Cretaceous basement of the Central Sredna Gora zone in dextral transpressional strike-slip regime.

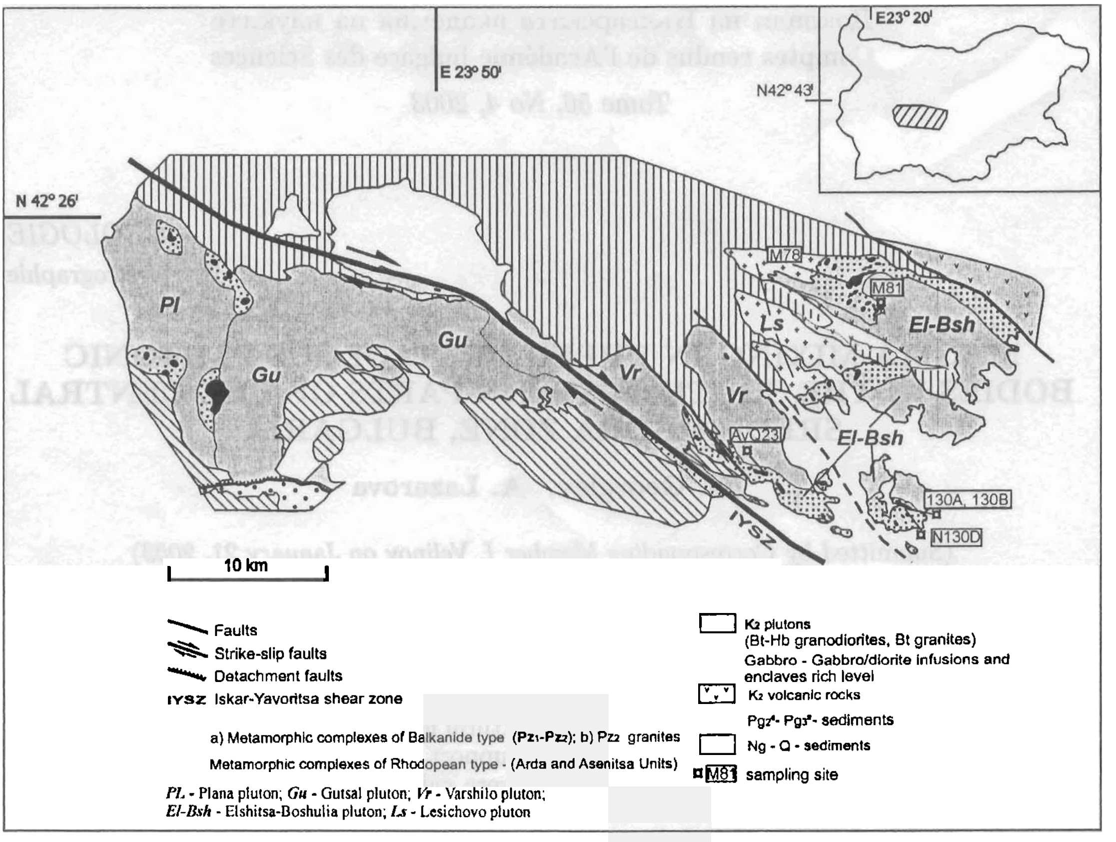

Fig. 1. Schematic geological map of the studied area

The main tectonic element that predetermined magma emplacement, structure of magma chamber and later imposed solid-state deformations is an NW-SE trending Iskar-Yavoritsa Shear Zone (IYSZ, Fig. 1). Some of the plutons (especially those situated in the northeastern block of the IYSZ) possess the characteristics of layered intrusions with well formed lower and upper parts: the lower part of magmatic chamber consists of crystal phase rich (most often porphyry) granodiorites; and the upper one – of felsic granites. At some places between these two parts are localized gabbro or gabbro-diorite lenses and sheet-like bodies (their thickness varies between 30–40 to 80–100 m and covers an area of several hundred square meters up to half square kilometer). Everywhere the mafic rocks are spatially connected with levels enriched in mafic enclaves. Chilled zones, load casts, flame structures and "pipe" structures along the lower parts of the basic sheet-like bodies testify to a sill-like manner infusion of gabbroic magma into partly crystallized layered granite magma chamber. IYSZ represented a main draining channel for both felsic and mafic melts.

The field relations described above correspond to the magma-mixing model proposed by [11] and give ground to consider the magmatic complex as a result of bimodal magmatism and magma mixing [1]. Such assumption is supported by zircon determinations [10]: 82.32 ± 0.5 Ma for gabbroic sheet-like bodies (Elshitsa-Boshulia pluton); 82.25 ± 0.3 Ma for granites of Varshilo pluton; 84.6 ± 0.3 Ma for the granodiorites of Elshitsa pluton.

The aim of this study is to reveal the conditions of magma crystallization and mixing processes using rocks petrography, textures and mineral compositions of representative samples from exposures in the area of the villages Velichkovo, Vetren, Boshulia and the Ganunitsa hill (Fig. 1).

We consider the wide compositional range of rocks in three general groups (gabbroic, granitic and dioritic) that represent respectively, mafic and felsic magmas and products of mixing. Our petrographic observations correspond closely to previous investigations [6-8] and, therefore, we focus our attention on details supporting the idea of magma mixing.

THE GABBROS have typical orthocumulate textures, very coarse-grained at some places (Vetren, Fig. 1). These rocks consist of plagioclase, hornblende, clinopyroxene and interstitial K-feldspar and quartz. Plagioclase and hornblende display concentric optical and chemical zoning (Table 1). Hornblende is presented by euhedral to subhedral grains and often replaces earlier clinopyroxenes. Hornblende composition changes systematically with decreasing AlIV from the cores (1.992–1.273) to the rims (1.552–0.872) of the grains. Two generations of plagioclase have been distinguished (Table 1). The first one (An_{92-88}) is found as inclusions in hornblende (along with clinopyroxene inclusions) or as corroded cores in the second generation of plagioclase (An_{54-31}). The latter one is presented often by zoned crystals with or without corroded cores. The latter indicates a temporary corrosion, marking a sudden change in the conditions of crystallization. The presence (of significant amount) of K-feldspar and quartz is an important feature of the gabbros. Both minerals include all earlier phases forming a poikilitic texture. K-feldspars impregnate, resorb, and replace earlier-formed plagioclase and hornblende crystals. These features suggest processes of mingling (mechanical mixing).

THE FELSIC ROCKS (granites and granodiorites) consist of plagioclase, K-feldspar, quartz and biotite and rarely hornblende. Plagioclase (An_{47-18}) is presented by a large euhedral to subhedral grains. Their features are specific oscillatory zoning (in some cases), optical inhomogeneity and "domain" structure. Quartz is presented mainly by large, euhedral to subhedral grains. K-feldspar (Or_{76-93}) forms interstitial anhedral grains.

THE HYBRID DIORITIC ROCKS mark levels of chemical mixing which crop out in the area of the village of Velichkovo and Ganunitsa hill. BOJADJIEV and CHIPCHAKOVA [8] have interpreted the same group of rocks as a hybrid type too, but the assumption has been related to granitoid melt influence on the first magmatic phase gabbroic rocks. The hybrid dioritic rocks consist of hornblende, plagioclase, K-feldspar, quartz, ± clinopyroxene or ± biotite. The hornblende grains are subhedral and smaller than in the gabbros. The compositional zoning is not so clear without distinct variation in AlIV from the cores to the rims of the grains. Plagioclases (An_{50-37}) often display oscillatory zoning (Table 1), marking fluctuations of the conditions of crystallization. This feature is another evidence of mixing processes and suggests an influence of the mafic magma on the felsic cumulate. K-feldspar and quartz define poikilitic texture of the rocks and confirm the operation of mixing processes.

Considering all microtextural features and mineral compositions we have assumed equilibrium between hornblende and second-generation plagioclase in most of the rocks studied. Using equations for hornblende barometry and hornblende-plagioclase thermometry [12-14] we have calculated P-T values of magma crystallization for selected samples (Fig. 1, Table 1). We have obtained three groups of results for the gabbros (Fig. 2): 900–800 °C/7–6.5 kbar for the central parts of hornblende grains and plagioclase enriched in anorthite that represent an earlier stage of mafic magma crystallization and correspond to 19–18 km depth; 800–700 °C/5–3 kbar calculated for the rims and intermediate parts of grains marked a later stage of magma crystallization and probably beginning of mixing at 15–9 km; 680 °C/2.5–1.8 kbar for rims probably reflecting

Table 1

Selected minerals (HB – hornblende; Pl – plagioclase; c – core; r – rim)

Rock	Gabbro				Diorite						Granite
Region	Velichkovo							Ganunitsa			Elshitsa
Sample	N130B				N130D			M78			M81
Hb	13 c	14 r	19 c	5 r	14 c	15 r	16 c	13 c	6 r	8 r	3 c
SiO_2	42.04	47.87	42.49	44.69	44.75	45.61	45.91	45.89	46.78	47.40	47.00
TiO_2	2.00	0.71	1.86	1.09	1.27	1.04	1.07	1.22	0.91	1.00	1.45
Al_2O_3	13.20	7.77	12.49	10.23	10.15	8.92	8.72	8.01	7.39	6.86	7.77
FeO	10.13	13.31	10.27	13.42	14.24	13.25	13.35	15.15	15.13	14.65	12.15
MnO	0.18	0.22	0.11	0.15	0.30	0.64	0.67	0.58	0.52	0.49	0.69
MgO	15.60	14.46	15.53	14.22	13.10	14.40	14.58	12.70	12.78	13.08	15.50
CaO	11.52	11.76	11.64	11.43	11.28	11.29	11.29	12.05	11.95	12.13	11.28
Na_2O	2.50	1.38	2.69	1.30	1.78	1.51	1.80	1.24	0.97	0.86	1.51
K_2O	0.37	0.40	0.51	0.20	0.46	0.63	0.60	0.89	0.99	0.87	0.44
H_2O	2.47	1.83	2.40	2.68	2.61	2.65	2.02	2.16	2.33	2.27	2.16
Sum	**100.01**	**99.71**	**99.99**	**100.01**	**99.94**	**99.94**	**100.01**	**99.89**	**99.75**	**99.61**	**99.95**
SiIV	6.008	6.882	6.108	6.448	6.511	6.589	6.598	6.754	6.886	6.971	6.707
Al^{tot}	2.221	1.315	2.115	1.738	1.732	1.518	1.476	1.388	1.281	1.188	1.306
Mg	3.323	3.099	3.328	3.058	2.841	3.101	3.124	2.786	2.805	2.868	3.298
Na^{tot}	0.693	0.385	0.750	0.531	0.503	0.422	0.501	0.354	0.277	0.246	0.418
Rock	gabbro		gabbro		gabbro				diorite		
Region	Vetren		Velichkovo								
Sample	AvQ023		N130A		N130B				N130D		
Pl	2 c	3 r	17 c	18 r	2 c	3 r	16 c	17 r	1 c	2 r	6 c
An	91.00	40.00	90.00	29.00	90.00	43.10	91.00	31.00	48.00	50.00	40.00
Ab	9.00	59.00	9.00	70.00	9.30	55.50	9.00	68.00	51.00	49.00	58.00
Or	0.00	1.00	1.00	0.00	0.00	1.00	0.00	2.00	1.00	1.00	2.00
Cn	0.00	0.00	0.00	0.00	0.60	0.40	0.00	0.00	0.00	0.00	0.00
Rock	diorite			gabbro-diorite				granite			
Region	Velichkovo			Ganunitsa				Elshitsa			
Sample	N130D			M78				M81			
Pl	7 r	12 c	13 r	9 c	10 r	14 c	15 r	6 c	7 r	8 c	9 r
An	43.00	39.00	46.00	41.00	46.00	39.00	37.00	38.00	37.00	35.20	25.20
Ab	54.00	59.00	54.00	58.00	52.00	60.00	62.00	58.00	60.00	60.70	69.30
Or	2.00	2.00	0.00	1.00	2.00	1.00	2.00	3.00	2.00	3.70	4.60
Cn	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.90

subsolidus re-equilibration of the magmatic system at depth of 5–3 km. The results for the hybrid dioritic rocks (represented by mafic fragment strongly affected by surrounding granite melt) in the area of Velichkovo (N130D, Fig. 1) are: ~ 800 °C/5–4 kbar for the cores and rims of the grain that probably mark a high-temperature stage of fast crystallization of the mixed rocks. Relatively constant values of the temperature

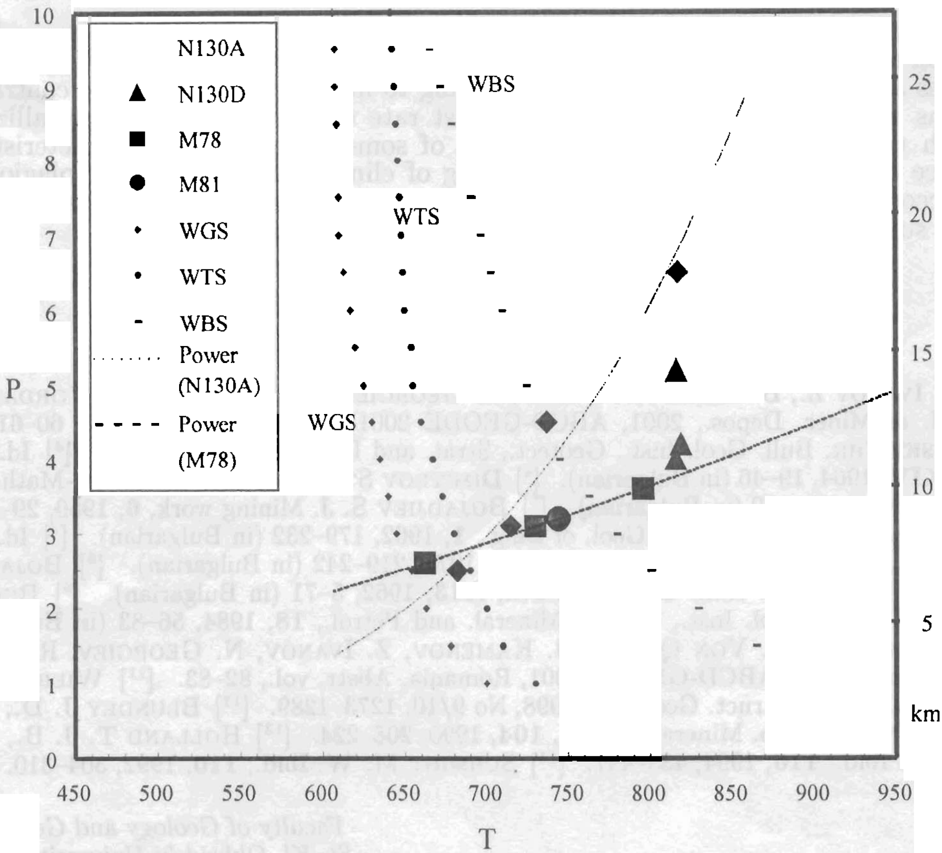

Fig. 2. P-T data from selected samples marking different stages of crystallization processes of different magma types. WGS, WTS, WBS represent granite, tonalite and basalt solidus

can be connected with an approximately fast crystallization during the decompression processes. The results for the diorites in the northern part of the Elshitsa-Boshulia pluton (M78, Fig. 1) mark a shallower level in the magma chamber: 800 °C/3.6 kbar reflect earlier stages of crystallization at depth around 10 km; 730 °C/3.1 kbar marked a later stage of crystallization at 9 km; 662 °C/2.6 kbar probably are connected with subsolidus processes. These dioritic rocks represent a lower part of mafic body where the mixing processes are get forward. The assumption for shallower level of crystallization in the magma chamber is supported by data obtained for the granitic rocks (N81, Fig. 1) in this part of the pluton: 750 °C/3.2 kbar at depth of 9 km.

As a conclusion we can propose an evolution model of the magmatic complex. High temperature partly crystallized gabbroic magma was carried up to the shallower levels of the crust and infused in partly crystallized granitic magma chamber at depth around 10–15 km. There were two levels in the granitic chamber formed as a result of partial crystallization and gravity differentiation processes. The lower level was rich of crystal phases ("mush") whereas the upper level was melt dominated. The infusing mafic magma passed through the lower parts of the chamber and reached the level of reological contrast. The gabbroic melt spreads along this boundary forming sill-like, lenticular or funnel-shaped bodies. Above mafic bodies a level enriched with mafic microgranular enclaves forms and the latter representing fragments of the mafic layers break off as a result of convectional movements. As a consequence all specific structures, textures and rocks (hybrid varieties), testifying to mixing processes of the contrastive magmas were formed. We can assume a fast rate of interaction and crystallization of both magmas because of a preservation of some unequilibrium characteristics – presence of chilled zones, not fully replacing of clinopyroxene and basic plagioclase, etc. According to age data all these processes are going through 86–82 Ma and these results support the idea of ± coexistence of mafic and felsic magmas.

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