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Amphiboles from the Plana pluton, Bulgaria

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Introduction

The Plana pluton is a part of a NW-SE elongated Upper Cretaceous magmatic complex (Plana, Gutsal, Varshilo, Elshitsa-Boshulja etc.), that borders on the Srednogorie zone to the north and the Rhodopian massif to the south. All the plutonic bodies from the complex are interpreted in literature as fracture intrusions controlled by the Maritsa shear zone structures (Dabovski, 1980; Dabovski, 1988; Georgiev, Lazarova, 2003). The pluton intruded mainly high-grade metamorphic rocks and partially the Diabase-Phyllitoid Complex and Mesozoic sediments and andesites (Boyadjiev, 1971). It provoked contact changes in the country sedimentary rocks, producing Px-hornfelses. First information about the Plana pluton gives Nikolov (1921). Boyadjiev (1971) makes detailed characteristics of the intrusive rocks.

The field observations show gradually ranging in composition from the periphery to the core of the pluton rock types, from gabbro-pyroxenite (GbPxt), gabbro (Gb) and subalkaline Gb, through quartz-diorite (Qd), monzodiorite (Md), quartz-monzodiorite (Qmd), granodiorite (Gd) and granite (Gr). Mafic to mesocratic dykes and abundant pegmatite-aplite veins cut the plutonic body. Processes of magma mixing in the pluton were recorded (Georgiev, 2003; Georgiev, Lazarova, 2003) but not studied. The latest field research shows the presence of melanocratic to mesocratic microgranular enclaves, indicating such phenomena (more detailed petrographic characteristic and mineral composition definition for the different rock types in Bidzhova, Nedialkov, 2006).

Brief characteristics of the amphiboles from the different rock types

As good indicators of crystallization environments and being almost omnipresent in the rocks of the Plana pluton, amphiboles (Amph) are of particular interest for the interpretation of magma evolutionary history.

In the porphyritic Gb (GbP) and GbPxt, amphiboles were found as subhedral to anhedral and rare euhedral crystals with clear pleochroism. They mostly replace and form overgrowths on pyroxene crystals, and sometimes enclose smaller plagioclase grains. Their composition corresponds to tschermakite (Tsch) with Mg# 0.77—0.84 and magnesiohornblende (MHb) with higher Mg# (0.79—0.83) for the GbPxt and lower (0.6-0.63) for the GbP (table 1 and fig. 1a). The silica content increases in general from the core to the periphery of the grains. Regarding the pressures estimated (see bellow), it seems that Tsch crystallized early in depth (and was cumulated after the magma emplacement in the outer parts of the magmatic chamber), while later "in situ" crystallization produced MHb.

With the progressing magma differentiation, after the emplacement of the melt in the magmatic chamber, Amph crystallization increases at the expense of clinopyroxene growth. Further differentiation led to a gradual decrease in Amph content along with the raising silica in the melt. In the intermediate rocks, Amph are small subhedral to anhedral MHb crystals, which often replace and form overgrowths on clinopyroxene. Where no pyroxene occurs, as well as in the more evolved rocks (Gd and Gr), euhedral to subhedral MHb crystals were established. The Mg# for these Amph is within 0.62—0.84 increasing towards the more evolved rocks. (fig. 1a).

Amph richer in sodium were found in most of the enclaves (table 1), which is consistent with their relatively raised alkalinity. They mainly plot as MHb and edenite (Ed) with transitions to ferroedenite, magnesiohastingsite (MHas) and pargasite (Parg) in one of the enclaves (fig. 1b). More Na-rich clinopyroxene was also found in the later. Comparatively to Amph from the main rock types, some of the enclaves are relatively more ferrous (fig. 1a, b), which corresponds to the high iron content in those samples. The Amph is fine-grained to medium-grained and vary in size within a single enclave. Euhedral to subhedral Amph with clear pleochroism was established, but also skeletal crystals indicating rapid crystal growth as a result of the fast cooling of injected more primitive and hot mafic magma.

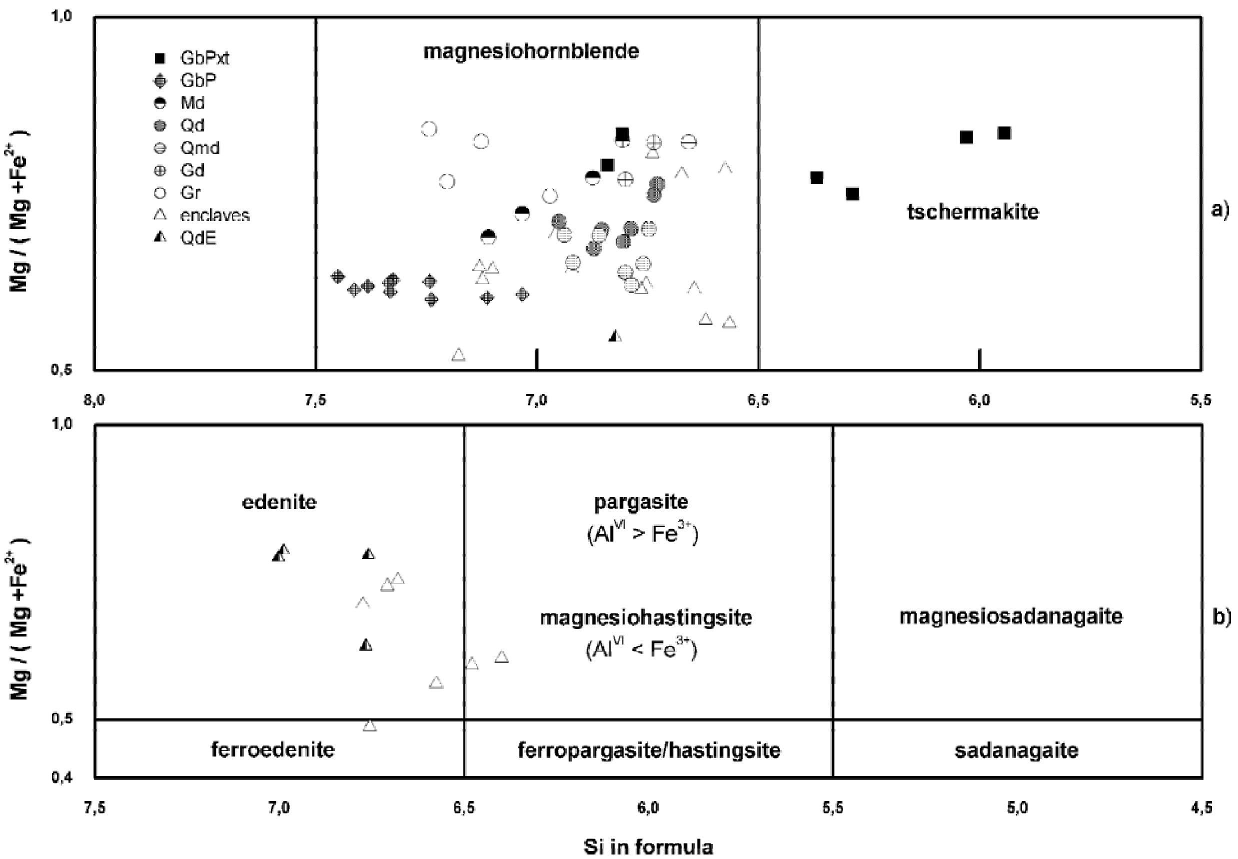

Fig. 1. Classification diagram after Leake et al. (1999) for the amphiboles in the Plana pluton. Parameters for **a)** $Ca_B \geq 1.5$; $(Na + K)_A < 0.5$; $Ti < 0.5$; **b)** $Ca_B \geq 1.5$; $(Na + K)_A > 0.5$; $Ti < 0.5$. Abbreviations: GbP, porphyritic Gb; QdE, quartz-diorite near the contact with an enclave

Significant variations of the $Mg/(Mg+Fe^{2+})$ ratio (possibly indicating interaction processes between the two different melts) were recorded in the enclaves (0.52—0.74), but the range within a single enclave does not vary a lot.

Some Amph from host rocks near the contacts with the enclaves are also more sodium rich. There are crystals with MHb core and Ed periphery, and such of thoroughly edenitic composition. The later possibly crystallized in the enclave and then moved in the hosting magma, while the first ones may have nucleated in the host melt and were later influenced by the enclave magma.

Thermobarometry

On the basis of the total Al content in the Amph and the existence of amphibole-plagioclase equilibrium, the pressures (after Schmidt, 1992) and the temperatures (after Blundy and Holland, 1990) estimated for the Amph crystallization in the different rock types are as follows: 230—400 MPa (6—10 km) and 660—800°C for the main differentiates; 620—800 MPa (17—21 km) and 900—1000°C for Tsch in the GbPxt (cumulates); 350 MPa (9.5 km) and 850°C for MHb in the GbPxt ("in situ" crystallized); 230—280 MPa (6—7.5 km) and 660—710°C for MHb in the porphiroid Gb; 260—690 MPa and 710—800°C for the enclaves (the pressure range within a single enclave does not vary more than 140 MPa).

Conclusions

The Amph in all of the rock types are calcic. Two stages of Amph crystallization could be distinguished. The first one took place in depth before the magma emplacement and produced Amph of Tsch composition at 620—800 MPa (17—21 km) and temperatures within 900—1000°C. The second stage was after the melt emplacement in the magmatic chamber and produced "in situ" crystallized MHb (230—400 MPa (6—10 km) and 660—800°C). The Mg# of the Amph increases parallel to the progressing magmatic differentiation as the mafic mineral content decreases towards the more evolved rock types. More sodium and iron rich Amph were found in the enclaves. Their composition is relatively more variable, due to the interaction between the host melt and the more primitive injected magma. They crystallized at pressures within 260—690 MPa and temperatures

Table 1. Chemical composition of amphiboles from the Plana pluton (structural formula based on 22 oxygen atoms)

Rock	GbPxt		GbP		Md	Qd		Qmd		Gd		Gr		QdE	Enclaves					
Sample	21/P		10d'/P		8"/P	15/P		18/P		27/P		4/P		7xr/P	7x/P	31x/P	17x/P	40x/P		
Analysis	Hb_2-c	Hb_5	Hb_{14}-c	Hb_{16}-p	Hb_{54}-p	Hb_{22}-c	Hb_{23}-p	Hb_{33}-c	Hb_{34}-p	Hb_{46}-m	Hb_{47}-p	Hb_{30}-c	Hb_{31}-p	Hb_{49}-c	Hb_{51}-c	Hb_{39}-p	Hb_{60}-p	Hb_{66}-p	Hb_{73}-c	Hb_{74}-p
SiO_2	42.08	48.09	47.86	50.34	47.8	48.09	46.82	46.81	45.92	47.53	47.46	50.62	49.87	48.28	46.1	45.15	45.61	42.95	43.76	45.14
TiO_2	1.55	0.21	1.68	0.91	0.75	0.49	0.60	0.66	0.78	0.83	0.53	0.30	0.25	0.61	0.81	0.93	0.55	1.65	0.53	0.72
Al_2O_3	14.19	8.32	8.45	6.28	7.27	7.67	8.36	7.82	7.89	8.41	7.68	7.40	6.06	5.83	6.89	8.72	8.87	10.76	12.10	9.55
FeO	14.00	14.51	13.78	14.21	13.81	14.8	15.08	15.8	16.15	13.48	13.02	11.17	11.57	12.83	15.01	15.18	16.39	16.21	16.94	18.92
MnO	0.19	0.19	0	0.28	0.71	0.49	0.28	0.49	0.52	0.91	1.18	1.63	1.89	0.73	0.92	1.13	0.57	0.41	0.24	0.34
MgO	14.60	15.61	11.97	12.55	15.21	14.67	14.80	13.32	13.24	15.35	16.05	16.48	17.31	15.94	14.24	14.38	11.54	11.51	10.69	9.45
CaO	10.36	11.04	12.53	12.71	10.84	10.45	10.52	10.77	10.67	10.22	9.55	8.73	8.90	10.47	10.51	10.24	12.14	10.40	10.37	11.92
Na_2O	0.05	0.04	1.07	0.54	0.97	0.44	1.11	0.82	1.38	0.92	1.70	0.94	1.20	2.30	3.12	0.85	0.92	2.95	1.94	1.25
K_2O	0.96	0.17	0.42	0.21	0.84	0.97	0.88	0.76	0.90	0.89	0.69	0.58	0.42	0.53	0.69	0.83	0.90	1.20	1.20	1.22
Si	6.029	6.841	7.034	7.332	6.874	6.951	6.729	6.861	6.748	6.801	6.807	7.203	7.127	7.003	6.775	6.575	6.765	6.398	6.479	6.756
^{iv}Al	1.971	1.159	0.966	0.668	1.126	1.049	1.271	1.139	1.252	1.199	1.193	0.797	0.873	0.997	1.193	1.425	1.235	1.602	1.521	1.244
T	8	8	8	8	8	8	8	8	8	8	8	8	8	8	7.968	8	8	8	8	8
^{vi}Al	0.424	0.236	0.498	0.410	0.106	0.257	0.145	0.212	0.114	0.220	0.106	0.444	0.147	0	0	0.072	0.316	0.287	0.590	0.440
Ti	0.167	0.022	0.186	0.100	0.081	0.053	0.065	0.073	0.086	0.089	0.057	0.032	0.027	0.067	0.090	0.102	0.061	0.185	0.059	0.081
Fe^{3+}	1.038	0.848	0	0	0.700	0.506	0.832	0.637	0.743	0.636	0.839	0.267	0.592	0.548	0.475	0.993	0.438	0.346	0.470	0.143
Mg	3.118	3.310	2.623	2.725	3.261	3.161	3.171	2.911	2.901	3.275	3.432	3.496	3.688	3.447	3.120	3.122	2.552	2.556	2.359	2.108
Fe^{2+}	0.253	0.584	1.694	1.731	0.851	1.022	0.787	1.167	1.156	0.781	0.566	0.761	0.546	0.938	1.315	0.711	1.595	1.625	1.522	2.225
Mn	0	0	0	0.035	0	0	0	0	0	0	0	0	0	0	0	0	0.039	0	0	0.003
C	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Fe^{2+}	0.387	0.295	0	0	0.109	0.260	0.193	0.132	0.086	0.196	0.157	0.301	0.244	0.070	0.054	0.144	0	0.048	0.105	0
Mn	0.023	0.023	0	0	0.086	0.060	0.034	0.061	0.065	0.110	0.143	0.196	0.229	0.090	0.115	0.139	0.033	0.052	0.030	0.041
Ca	1.590	1.682	1.973	1.983	1.670	1.618	1.620	1.691	1.680	1.567	1.500	1.500	1.500	1.627	1.655	1.598	1.929	1.660	1.645	1.911
Na	0	0	0.027	0.017	0.134	0.061	0.153	0.116	0.170	0.127	0.233	0.171	0.164	0.214	0.177	0.119	0.038	0.241	0.220	0.048
B	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Na	0	0	0.278	0.136	0.136	0.062	0.156	0.117	0.223	0.129	0.240	0.088	0.168	0.433	0.712	0.121	0.227	0.611	0.337	0.314
K	0.175	0.031	0.079	0.039	0.154	0.179	0.161	0.142	0.169	0.162	0.126	0.105	0.077	0.098	0.129	0.154	0.170	0.228	0.227	0.233
A	0.175	0.031	0.357	0.175	0.291	0.241	0.318	0.260	0.392	0.291	0.366	0.193	0.245	0.531	0.842	0.275	0.397	0.839	0.564	0.547
Mg#	0.83	0.79	0.61	0.61	0.77	0.71	0.76	0.69	0.70	0.77	0.83	0.77	0.82	0.77	0.69	0.78	0.62	0.60	0.59	0.49
Type	Tsch	MHb	MHb	MHb	MHb	MHb	MHb	MHb	MHb	MHb	MHb	MHb	MHb	Ed	Ed	MHb	MHb	MHas	Parg	FerroEd

Abbreviations: Tsch, tschermakite; MHb, magnesiohornblende; Ed, edenite; Mhas, magnesiohastingsite; FerroEd, ferro-edenite; Parg, pargasite. The indexes **c**, **m** and **p** represent the average composition respectively of core, medium part and periphery of the crystal.

710—800°C. May be some of the Amph crystallized earlier and were later partially reequilibrated, hence the big pressure interval for the enclaves.

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Амфиболи от Планския плутон, България

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Резюме. Амфиболите са чувствителни към условията на кристализация и дават възможност да се определят особеностите на процесите на магмена еволюция. В Планския плутон амфиболи се установяват в почти всички скални разновидности (габро и габропироксенити с нормална алкалност, кварцдиорити, монцодиорити, кварцмонцодиорити, гранодиорити, гранити и магматични включения). Те липсват единствено в субалкалното габро. Всички анализирани амфиболи са калциеви. В габропироксенитите са установени Tsch и MHb, докато в порфирното габро и останалите диференциати — само MHb. Предполагат се два стадия на амфиболова кристализация. Първият, в дълбочина, с кристализация на амфиболи с Tsch състав при налягане 620—800 MPa и температура 900—1000°C, а вторият с „in situ" кристализация на магнезиев обикновен амфибол при 230—400 MPa и 660—800°C. С напредване на диференциацията и намаляване количеството на мафични минерали с изкисляването на топилката, магнезиалността на амфиболите расте. По-високи съдържания на Na и Fe се установяват в амфиболи от включенията. Те попадат предимно в полетата на Ed и MHb с преходи към фероеденит, MHas и Parg. Вариациите в състава вероятно се дължат на взаимодействие между инжектираната по-примитивната топилка и вместващата магма. Отчетените налягания за включенията са в голям диапазон (260—690 MPa) а температурата на кристализация е 710—800°C.