

Metasomatic gabbroids – markers in the tectono-metamorphic evolution of the Eastern Rhodopes

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Е. Кожухарова – Метасоматические габброиды - реперы в тектоно-метаморфической эволюции Восточных Родоп. Пегматит-аплитовые жилы пересекают серпентиниты докембрийской офиолитовой ассоциации в Белоречком поднятии и вызывают биметасоматические реакции. В результате образуются дайкоподобные тела из метасоматитов, внешне похожие магматическим габброидам. Эти тела согласные сланцеватости серпентинитов. Габброиды крупнозернистые, пятнистые, местами приобретают сланцеватой текстуры. В минеральном составе преобладают цоизит, эпидот, плагиоклаз (от альбит-олигоклаза до анортита). Устанавливаются еще диопсид, кварц, тальк, хлорит, амфибол (актинолит и гастингсит), гроссуляр, К-полево шпат, титанит и доломит. Часто наблюдаются псевдоморфические, коррозионные, симплектические и диаблестические структуры. Химический состав метасоматических габброидов отличается от основных магматических пород своей изменчивостью. С другой стороны, они различаются от ранее метаморфизованных основных габброидов, которые являются составной частью офиолитовой ассоциации по своей структуре, текстуре, химическому составу и характеру деформации. Метасоматические габброиды являются синметаморфическими постдеформационными реакционными продуктами, связанными с дифференциатами поздней глубинной мигматизации Прародопской супергруппы, проявленной во втором событии второго метаморфического цикла. Возможно, что они синхронны гнейс-гранитам, обнаженным на вершине Орловый верх. Хронологически они следуют этапу синдеформационного метаморфизма офиолитов и отмечают начало их ассимиляции. Метасоматические габброиды один из важнейших реперов в метаморфической эволюции кристаллического фундамента Родопского массива.

Abstract. Metasomatic gabbroids - markers in the tectono-metamorphic evolution of the Eastern Rhodopes. Pegmatite - aplitic veins cut the serpentinites of Precambrian ophiolite association in Byala Reka anticline. As a result, bimetasomatic reactions took place and dyke-like bodies of metasomatic rocks, similar to gabbros appear. The bodies are concordant with the schistosity of the serpentinites. The rocks have coarse-grained, spotted or slightly schistose structure. Their mineral composition is dominated by zoisite, epidote, and plagioclase ranging between albite-oligoclase and anorthite. The other common minerals are diopside, quartz, talc, chlorite, amphibole (actinolite and hastingsite), grossular, K-feldspar, titanite, dolomite. The texture is commonly pseudomorphous, corrosional, symplectitic, diablastic. The varying chemical composition of the metasomatites distincts them from the petrochemical group of the basic magmatic rocks. On the other hand, they differ in structure, texture, character of the deformation, and chemical and mineral composition from the earlier metamorphosed basic magmatic rocks which are components of the ophiolitic association. The metasomatic gabbroids are synmetamorphic, postdeformation reaction products related to the differentiates of later deep level migmatization of the Prarhodopian Supergroup. They were formed during the second metamorphic event of the second metamorphic cycle. Probably, the metasomatic gabbroids were synchronous to the gneiss-granites from the Orlov vrh peak. Temporally they follow the stage of syndeformation metamorphic recrystallisation and mark the beginning of the ultrabasic rock assimilation. The metasomatic gabbroids are important markers in the evolution of the metamorphic basement of the Rhodope massif.

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Introduction

The rocks of the Precambrian ophiolitic association have been affected by the regional metamorphism in the Rhodope massif, and as a result, eclogites, garnet serpentinites, amphibolites, talc-chlorite and actinolite schists, amphibole gneisses have been produced. The sequence of their formation marks phases in the metamorphic evolution of the rock complex (Кожухарова, 1984b). The alteration in the chemical composition of the protoliths depends on the temporal and local conditions of the metamorphism varying from isochemical to allochemical one. During the migmatization intensive chemical reactions took place in at the zones where rocks with contrast composition were in contact. Instructive example is the pegmatization of the ultrabasic rocks where the processes of hybridisation led to a partial or full assimilation of the ultrabasites and appearance of metasomatic gabbroids. They resemble magmatic gabbros and sometimes were mistakenly regarded as such during the field mapping. In addition in different places in the Rhodope massif, mainly in the Byala Reka dome, three types of basic dykes are distinguished: metamorphosed dolerites, metasomatic gabbroids and late postkinematic non-metamorphosed basic rocks. They mark different episodes in the geodynamic development of the Rhodope massif. Therefore, they should be known and correctly distinguished in the field.

The metasomatic gabbroids were examined for the first time in the Byala Reka dome (Кожухарова, 1984a, Кожухаров и др., 1984) as dyke-like epidotised and migmatized gabbroids. D. Kozhukharov (Кожухаров, 1987) considered them as parts of the Zhulti Chal and Gnesdare Formations from the Prarhodopian Supergroup, and related their origin to the granitization. The presence of metabasic dykes in the region of the village Zhulti Chal is noted by other authors (Macheva, Kolcheva, 1992) but because of the lack of appropriate petrologic information it is not clear which kind of dykes are spoken about.

In the present paper two types of metabasites are described: dyke-like metasomatic gabbroids and metamorphosed doleritic dykes from the north-eastern periphery of the Byala Reka anticline in Eastern Rhodope. The aim is to determine the features of the two genetic types, the conditions of their formation, and the relative place they occupy in the tectono-metamorphic evolution of the metamorphic basement of the Rhodope massif. The results exposed were obtained since 1982, and the existence of metasomatic gabbroids was reported almost at the same time (Кожухарова, 1984a).

Geological setting

The Byala Reka structure is one of the largest positive structures in Eastern Rhodopian block described as Byala Reka dome (Иванов, 1961). It is slightly elongated to northwest and deformed by several generations of second-order folds (Боянов, Русева, 1984). The north-eastern margins are cut by the Byala Reka dislocation (Иванов, 1961), marked by a row of faults (Боянов, Русева, 1984). The central part of the structure is composed by leptites, porphyroblastic and migmatized gneisses (Боянов и др., 1963), nominated as the Strazhets Group of the Prarhodopian Supergroup (Кожухаров, 1987), cut by gneiss-granites (Кожухарова и др. 1988). The mentioned rocks are covered by the Boturche Group (Кожухаров, 1987), composed of mica schists, quartzites, rare marble layers and conformable bodies of metamorphosed ophiolites. The later along with the basic magmatites are supposed to had been obducted on the active margins of an ancient Precambrian continent during carbonate-pelite sedimentation (Кожухарова, 1984a). Later on, all rocks were regionally metamorphosed and transformed to different kind of amphibolites, eclogites, talc-chlorite and actinolite schists (Кожухарова, 1984b).

Along the north-eastern periphery of the Byala Reka dome, the gneissic complex of the Strazhets Group is covered by the rocks of the Boturche Group consisting of the Zhulti Chal and Gnesdare Formations which are overlain by beds of the Tintyava Group (Кожухаров, 1987). The geological relationships of the three groups are subject of discussion. According to recent views (Боянов и др., 1963, 1990; Боянов, Русева, 1984; Кожухарова, 1984a; Кожухаров 1987), the three groups formed a normal stratigraphic successions, and the contacts between them were consolidated during the metamorphic alteration. In some recent publications (Burg et al., 1996), the boundaries between the groups are considered as tectonic zones. The authors cited do not present any concrete facts about the geological situation, and the notion for a system of thrusts is deprived of arguments. Other authors (Macheva, Kolcheva, 1992) examine the contacts of Strazhets, Boturche and Tintyava Groups as intrusive ones. According to them, the Strazhets and Tintyava Groups are composed of metagranites because of mineralogical and geochemical similarities between the compositions of the porphyroblastic gneisses of the Punovo Formation and granites. But far not all of the gneisses of the Strazhets and Tintyava Group allow to be interpreted in such a simplified way. The statement that the mentioned gneisses intruded the Boturche Group that is partly composed by metaophiolites is

not acceptable. It is possible that the authors mistakenly assume some of the dyke-like metasomatic gabbroids as metagranite apophyses. The current investigations on the north-eastern periphery of the Byala Reka dome (Kozhoukharova, 1996) have shown that the rocks of the Boturche Group form a closed, inclined to south-west synclinal fold reworked by second order folding (Fig. 1), the hinge line being oriented 300-320°. The beds from the south-western limb dip 30-40° and those from the north-eastern one, 45-70°. In the cores of second and third-order folds well developed rodding structures are visible. A later major fold system with axial planes striking 30-40° was found, too. It seems as if it is the same fold system spotted by Боянов et al. (1990) northeast of the Byala Reka dome. Thanks to the action of the two fold phases, a macroboudinage inside the varied formations was formed. The serpentinite bodies which are components of the Boturche group represent big boudins (Кожухарова, 1984a) conformable to the host mica schists and amphibolites as everywhere in the Rhodope massif where their primary stratigraphic position has not been modified by late tectonic movements. Nowhere in the Rhodope massif serpentinite rocks mark sutures, thrust surfaces or deep faults as some authors consider (Dercourt et al., 1987; Burg et al., 1990; Dobretsov, 1991; Sokoutis et al., 1993). The serpentinites have always a stable stratigraphic position in the lower levels of the varied formations, and are covered by Proterozoic well-stratified mica schists and marbles. This fact excludes the possibility that they have been involved as ocean crust during the collision between two tectonic continental units. Even less plausible is the statement that there is a piling of allochthonous sheets (Burg et al., 1996). In the examined region, the varied complex of the Boturche Group, that contains ophiolites, has a normal and laterally persistent metamorphic contact with the rocks of the Strazhets and Tintyava Groups without thrusting or injection of intrusive masses. Some movements had been concentrated during the first major stage of synmetamorphic folding, along the rheologically contrast boundary between the gneissic and the varied complex. Along shear zones eclogitisation of ophiolites and blastomylonitisation of porphyroblastic gneisses took place. The last have been transformed to fine-grained gneisses, and in the zones of the most intense deformation, to garnet-mica schists with phengite. This synmetamorphic deformation accompanied by crystallisation is distinct from the later, mainly brittle type deformations, with restricted recrystallisation of the quartz and micas that is concentrated along zones of Alpine diaphoresis. A third system of open folds trending 0-10° can be

seen in a small number of exposures not accompanied by metamorphic recrystallisation.

The stratigraphic sequence of the Strazhets, Boturche and Tintyava groups also needs clarification. The establishment of a recumbent synclinal fold at the north-eastern margins of the Byala Reka dome indicates that the Tintyava and Strazhets groups are the limbs of a syncline and belong to a single lithostratigraphic unit. Their petrographic similarity is another evidence in favour of their unification. On the other hand, the Zhulti Chal and Gnezdare Formations of the Boturche Group also may be considered to be one unit with identical composition to that of the Rhodope Supergroup (Kozhoukharova, 1996) exposed in central and western Rhodope Mountains.

Metasomatic gabbroids

Country rocks

The bodies of the metasomatic gabbroids have been found inside the serpentinite megaboudins (Fig. 1, 2), that belong to the Boturche Group. Two types of rocks compose the Boturche Group: 1. Parametamorphites, represented by mica schists and gneiss-schists with thin layers of quartzites and marbles; 2. Metaophiolites - serpentinites and amphibolites.

1. Parametamorphites

1.1. Mica schists. In the studied region garnet-muscovite and chlorite-garnet-muscovite schists were encountered, with two, and at some places, with three successive mineral parageneses, separated by evidences for deformation phases. The first paragenesis is composed by:

- relics of garnet (coarse-grained, 2 to 3 mm in diameter porphyroclasts) embracing quartz, chlorite, titanite and idiomorphic inclusions of needle like rutile; frequently an "atoll" structure is observed, or semi-corroded skeletons with high grossular content (Table 1);
- staurolite: prismatic, often broken, rotated, indicates an early lineation distorted by later folds;
- biotite: light brown flakes replaced by muscovite and chlorite;
- muscovite: relatively large, bended flakes, included in a second generation muscovite with low phengite content (Table 1);
- plagioclase: oligoclase to andesine;
- quartz: with strong undulatory extinction;
- kyanite: deformed and altered by muscovite;
- small grains of tourmaline, rutile and chloritoid.

The second paragenesis forms a new schistosity, which flows around the garnet, porphyroclasts and crystallised in the pressure shadow areas. It is represented by:

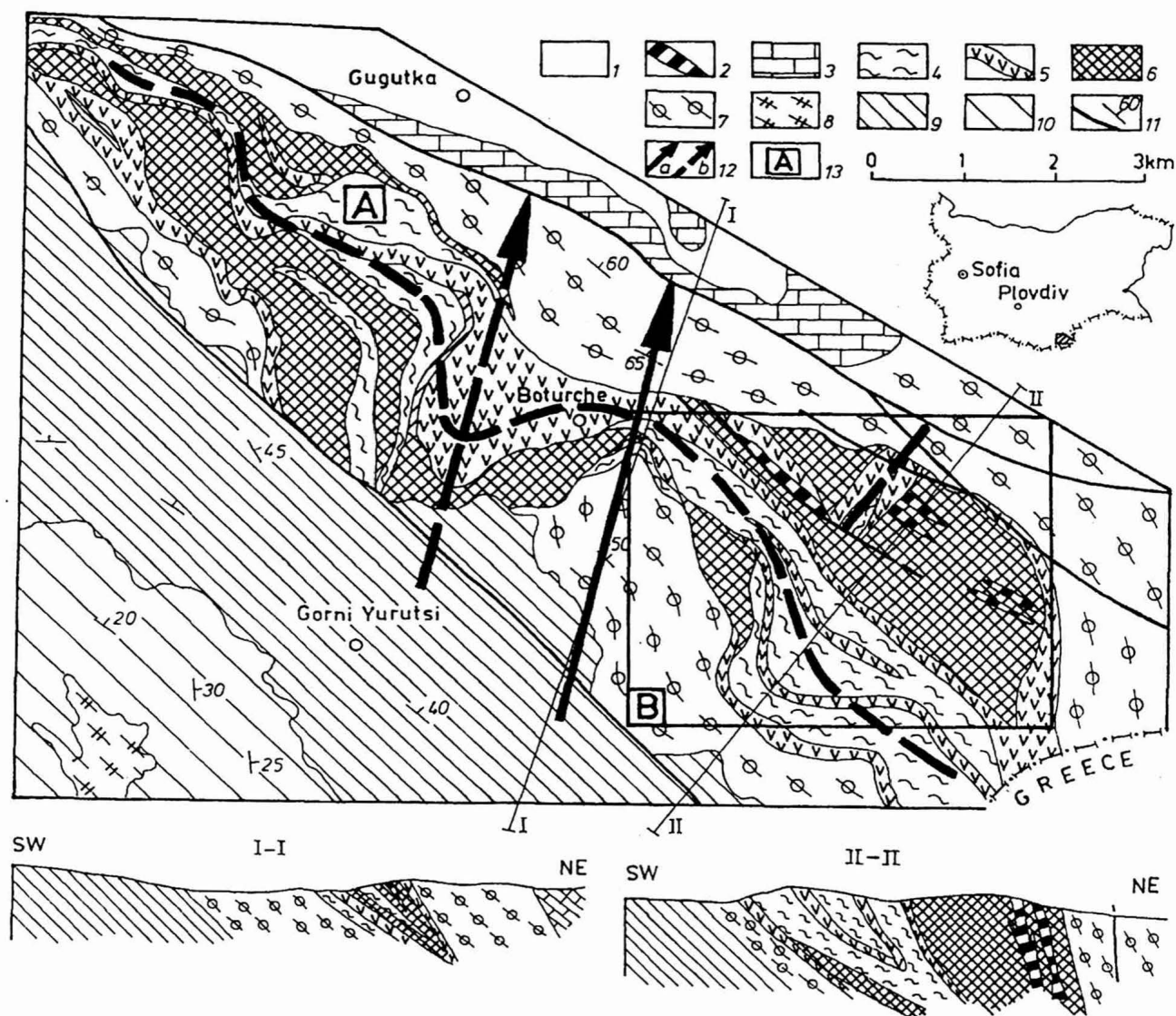


Fig. 1. Geological map of north-eastern periphery of the Byala Reka dome (after Д. Кожухаров, 1987 with some addition and interpretation of the author). Symbols: 1 – Quaternary and Pliocene; Boturche Group: 2 – beds of metasomatic gabbroids; 3 – marbles; 4 – mica schists; 5 – amphibolites; 6 – serpentinites; Prarhodopian Supergroup: 7 – porphyroblastic gneisses; 8 – metagranites; 9 – leptynite gneisses; 10 – biotite gneisses; 11 – tectonic zone and mode of occurrence of beds; 12 – a. anticlinal axis; b. synclinal axis; 13 – A. detailed map of Fig. 7; B. detailed map of Fig. 2

- chloritoid: large laminated individuals with polysynthetic twins and pleochroism from blue-greenish (γ) to grey-greenish (β) and light-yellowish (α) shades; a helicitic structure is common with numerous rutile needles oblique to the elongation of the mineral, possibly indicating earlier schistosity;

- garnet₂ is developed as rims around the garnet₁ grains or is represented by small independent grains; it is clear (without inclusions), its grossular and spessartite content is low, but is enriched in almandine while the pyrope content is unchanged (Table 1);

- muscovite: small flakes along with the chlorite, form ribbon aggregates that surround the garnet₁ porphyroclasts enriched with phengite component (Table 1);

- chlorite: tiny flakes of ripidolite with high Al content (Table 1);

- quartz: clear, filled with rutile inclusions often crystallized in the pressure shadows of the garnet porphyroblasts along with chloritoid, chlorite, garnet, muscovite (second generation) and albite-oligoclase.

1.2. Quartzites. They are composed mostly of quartz (80%) and variable amounts of garnet, plagioclase, graphite, muscovite and hematite.

2. Metaophiolites. The main rock varieties are serpentinites, pyroxenites, eclogites and amphibolites.

2.1. Serpentinites. They constitute megaboudins with a lenticular form, and exceeding 1 km in length, or small lenses and thin plates alternating with amphibolites (Figs 1, 2). All bodies are deformed. They are concordant to the country layers and follow the general configuration of the varied formations. Their stratigraphic position and

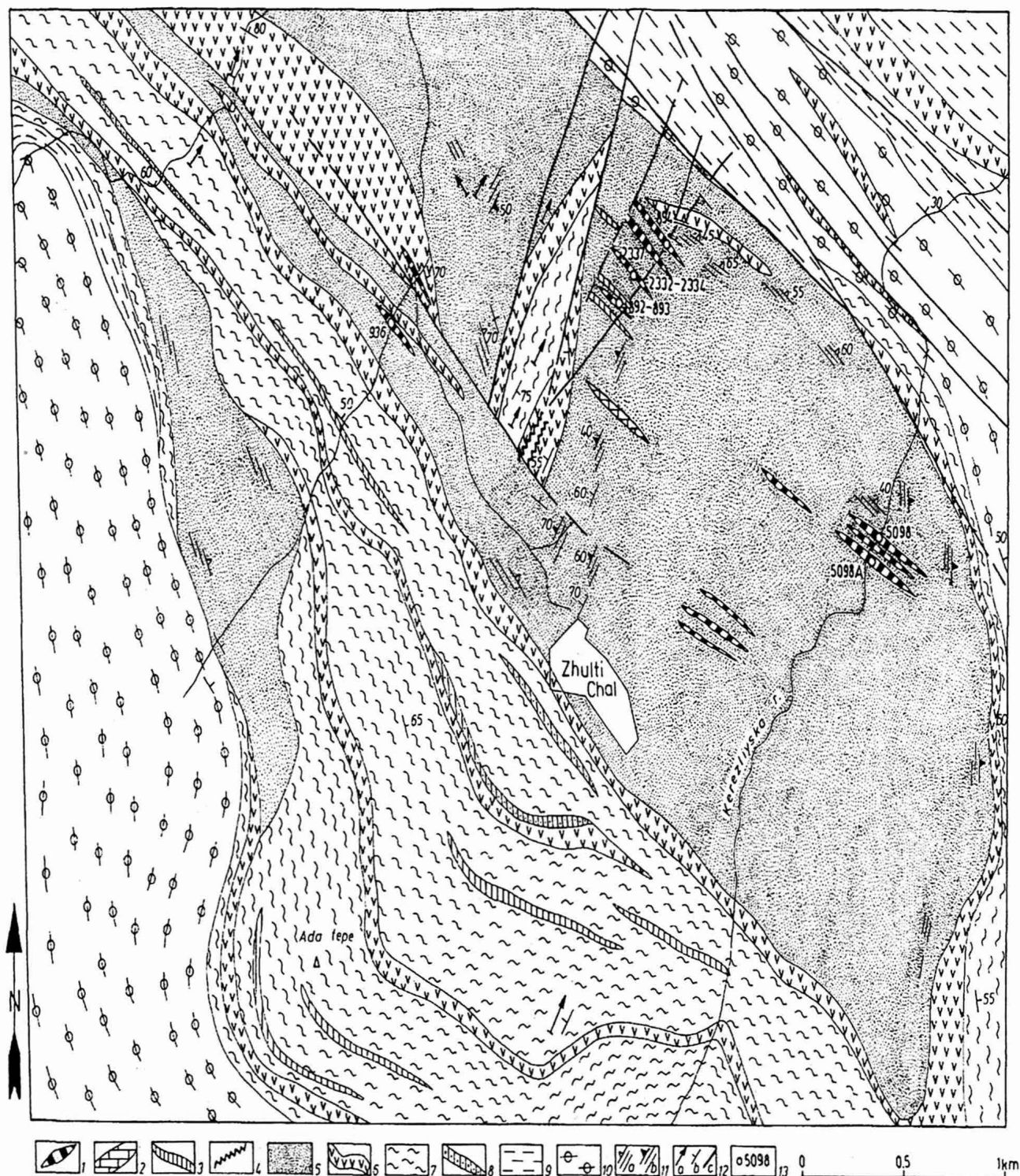


Fig. 2. Geological map of the region of Zhulti Chal. Symbols: 1 - dyke-like bodies of metasomatic gabbroids; 2 - pyroxenite veins; 3 - talc-chrysotile veins; 4 - quartz veins; 5 - serpentinites; 6 - amphibolites; 7 - mica schists; 8 - quartzites; 9 - leptynite gneisses; 10 - porphyroblastic gneisses; 11 - a. first schistosity; b. second schistosity; 12 - a. fold axis; b. mode of occurrence of beds; c. fault; 13 - location and number of sample

association with the rocks of the varied formations is persistent. The rock-forming minerals are chrysotile, lizardite and antigorite (80-95%) with rare relics of olivine, pyroxene and chromite. The serpentine minerals are replaced by talc, tremolite, chlorite, calcite and magnetite. In the central parts of the big boudin near the village Zhulti Chal the serpentine is predominantly of a lizardite-chryso-

tile type but at the margins of the boudin it is antigorite. The antigorite with tiny octahedral magnetite marks the foliation planes of two schistosities: S_1 (parallel to the elongation of the megaboudin striking to NW-SE and folded), and S_2 (formed by later antigorite, oblique to S_1 and striking north-east). Often at the periphery of the body a 30 cm wide reaction zones of talc-chlorite and chlo-

Table 1

Representative microprobe chemical analyses of minerals from garnet-chloritoid-chlorite schists - sample 5012

	garnet	garnet	musk-I	musk-I	musk-I	musk-II	musk-II	musk-II	Chl	Chld
	1-core	2-rim	3	4	5	6	7	8	9	10
SiO ₂	36,04	36,46	46,04	46,74	46,98	47,12	48,71	50,53	25,02	24,92
TiO ₂	0,06	0,20	0,27	0,38	0,28	0,57	0,40	0,51	0,00	0,11
Al ₂ O ₃	22,54	22,41	37,79	35,21	36,25	33,06	31,38	28,44	41,34	24,42
FeO	27,32	31,33	1,25	1,56	1,38	2,63	2,66	2,15	20,62	22,09
MnO	7,05	5,09	0,00	0,06	0,19	0,00	0,00	0,00	0,78	0,00
MgO	2,69	2,63	0,78	1,15	1,15	1,94	2,70	3,08	4,66	15,74
CaO	4,17	1,80	0,08	0,10	0,03	0,00	0,01	0,00	0,08	0,00
Na ₂ O	0,13	0,08	1,56	1,01	1,37	0,76	0,60	0,43	0,06	0,33
K ₂ O	0,00	0,00	7,98	8,40	8,61	8,84	9,75	9,81	0,00	0,03
H ₂ O	0,00	0,00	4,24	5,37	3,77	5,07	3,79	5,05	7,44	12,38
Total	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00
Basis	O-24	O-24	24	24	24	24	24	24	14	36
Si	5,791	5,864	6,064	6,108	6,232	6,321	6,530	6,666	2,02	5,078
Al ^{IV}	0,209	0,136	1,936	1,892	1,768	1,679	1,470	1,334	3,95*	2,922
Al ^{VI}	4,059	4,111	3,929	3,528	3,899	3,547	3,486	3,086		2,941
Ti	0,007	0,024	0,021	0,037	0,028	0,057	0,040	0,050	0,000	0,017
Fe	3,666	4,207	0,137	0,169	0,152	0,294	0,298	0,236	1,393	3,757
Mn	0,958	0,693	0,000	0,006	0,021	0,000	0,000	0,000	0,053	0,000
Mg	0,644	0,630	0,152	0,223	0,227	0,387	0,538	0,605	0,562	4,778
Ca	0,717	0,310	0,011	0,014	0,004	0,000	0,001	0,000	0,006	0,000
Na	0,038	0,025	0,397	0,255	0,351	0,196	0,154	0,109	0,004	0,130
K	0,000	0,000	1,340	1,400	1,456	1,512	1,666	1,650	0,000	0,007
OH	0,000	0,000	3,723	4,670	3,330	4,530	3,380	4,440	4,020	16,82
Alm	60,87	71,73								
Sp	15,91	11,82								
Pyr	10,69	10,74								
Grs	12,53	5,71								

rite-actinolite schists had been developed. Lenticular or glomeroblastic segregations of coarse-grained octahedral magnetite are visible.

2.2. Pyroxenites. Mainly dyke-like bodies have been observed in the internal part of Zhulti Chal body (Fig 2). The predominant strike of the dykes is NW, preserving parallelism with the elongation of the megaboudin. The pyroxene is a prismatic enstatite, reaching 5-6 cm in length. It is developed on the serpentine and on its turn is replaced by needle-like amphibole.

2.3. Eclogites. They form lenses and thin layers among garnet-bearing amphibolites between the Punovo and Boturche Group. The best exposures of amphibolitised eclogites have been found in the vicinity of the village Kazak (Kожухарова, 1984⁶). In the eclogites two clearly distinguishable metamorphic parageneses were established separated by deformation phase: a) eclogitic paragenesis - omphacite (Jd₃₅₋₃₆), garnet (Alm₄₄₋₄₅Py₃₋₁₁Sp_{0,6-10}Grs₂₂₋₃₁And₂₂₋₃₁), rutile, ilmenite; P - 9 kbars, T - 400-500°C; b) post-eclogitic, transitional paragenesis (decomposition of omphacite): diopside, plagioclase An₁₋₁₂; c) diaphthoretic paragenesis: almandine, plagioclase An₂₆₋₃₅, amphibole, zoisite, T - 400-500°C, P - 4-6 kbars.

2.4. Amphibolites. They are the most abundant metamorphic products of the ophiolites, and form layers alternating with mica schists, quartzites and

serpentinites. Two fold generations and three petrographic types are recognised: garnet amphibolites, epidote amphibolites and migmatized amphibolites. The garnet amphibolites are exposed at the north-eastern part of the Zhulti Chal megaboudin. The first paragenesis consists of low-alumina hornblende, andesine, garnet, epidote, rutile and apatite crystallised in P-T conditions corresponding to 480-540°C and 4-5 kbars. The mineral crystallisation is followed by breaking and rotation of the minerals. The second paragenesis is marked by the same minerals forming coronas or replacing the earlier ones. The higher alumina content in the hornblende and the more anortitic feldspar testify for a temperature increase up to 560-580°C. During the migmatization of the amphibolite layers, quartz-feldspatic segregations and a new paragenesis of quartz, oligoclase-andesine, amphibole, biotite, barite, epidote, chlorite, titanite, and idiomorphic magnetite had been formed. The measured crystallisation temperature is in the range of 560-620 °C.

Petrographic features of the metasomatic gabbroids

Along the north-eastern periphery of the Byala Reka dome to the north of the village Zhulti Chal

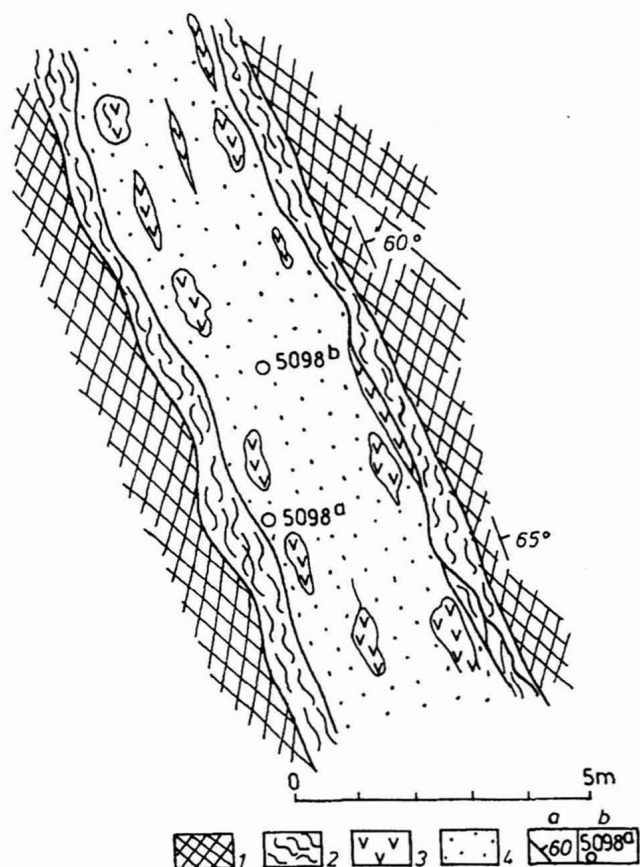


Fig. 3. Draft of a body of metasomatic gabbroids, valley of Kerezliyska Reka. Symbols: 1 - serpentinites; 2 - chlorite and actinolite-chlorite schists; 3 - amphibolites; 4 - metasomatic gabbroids with agglomerate and spotted structure; 5 - a. schistosity and shearing of serpentinites; b. location and number of sample

and along the valleys of the rivers Kavashka and Kerezliyska a number of dykes and lenses of pegmatoid gabbroids are exposed cutting the serpentinites of the Zhulti Chal megaboudin (Figs 1, 2). The prevailing strike of the bodies is NW-SE (290-330°). They are subvertical or dipping 60-70° to the SW. The thickness of the bodies varies from several cm to 4-5 m. Xenoliths of partially assimilated serpentinites, chlorite schists and garnet amphibolites are visible in their marginal parts where a zonality of the bodies appeared (Fig. 3). At the contact the serpentinites are altered to talc-chlorite schists and amphibolites.

The metasomatic gabbroids have a varied appearance and irregular structure (Plate I). In some locations the structure is massive, equigranular and fine-grained, whereas in others it is block, agglomeratic, streaky, lenticular or schistose (Plate I, 1, 2). Often in the internal parts of the bodies pegmatoid segregations of coarse-grained (1-2 cm) plagioclase, amphibole, epidote, etc. are formed. Often slight schistose "leopard" structure of grey-greenish and light grey stains 2-4 × 1-2 cm in size is seen resembling that of the augen gneisses. Some parts of the rock are almost monomineral with textures varying from granoblastic to nematoblastic or ophitic. The most common are reaction textures: coronas, corrosion relationships, different kind of pseudomorphs, symplectites and diablastic intergrowths. The textures reflect a complicated process of metasomatic crystallisation, replacement and assimilation

Table 2

Representative microprobe chemical analyses of minerals from metasomatic gabbroids - sample 5098a

	1 - alb	2 - kfl	3 - zs	4 - chl	5 - chl	6 - ms	7 - grt	8 - czs	9 - czs
SiO ₂	63,13	63,91	38,50	35,67	27,70	45,33	39,67	38,21	38,31
TiO ₂	0,00	0,09	0,02	0,00	0,00	0,07	0,11	0,24	0,30
Al ₂ O ₃	35,70	19,60	34,19	20,10	24,70	38,17	22,39	27,87	28,82
FeO	0,10	0,12	0,38	1,16	8,31	0,00	2,37	7,47	6,02
MnO	0,00	0,00	0,01	0,15	0,20	0,14	0,44	0,09	0,15
MgO	0,00	0,00	0,00	30,23	26,82	1,51	0,06	0,00	0,00
CaO	0,22	0,00	24,55	0,19	0,00	0,17	34,82	22,70	22,20
Na ₂ O	10,85	0,12	0,07	0,32	0,29	0,19	0,00	0,14	0,28
K ₂ O	0,00	16,16	0,00	0,10	0,03	9,81	0,14	0,15	0,07
H ₂ O	0,00	0,00	2,28	12,08	11,95	4,61	0,00	3,13	3,84
Total	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00
basis	32(O)	32(O)	13(O)	36(O)	36(O)	24(O)	24O	13	13
Si	11,066	11,820	2,914	6,625	5,362	5,959	5,995	2,974	2,932
Al ^{IV}	5,311*	4,271*	0,086	1,375	2,638	2,041	0,005	0,026	0,068
Al ^{VI}	-	-	2,965	3,027	2,999	3,873	3,983	2,531	2,533
Ti	0,000	0,012	0,001	0,000	0,000	0,006	0,012	0,014	0,017
Fe	0,013	0,017	0,023	0,171	1,275	0,000	0,283	0,460	0,365
Mn	0,000	0,000	0,001	0,023	0,032	0,015	0,056	0,005	0,010
Mg	0,000	0,000	0,000	8,367	7,738	0,295	0,013	0,000	0,000
Ca	0,041	0,000	1,991	0,038	0,000	0,024	5,638	1,893	1,821
Na	3,687	0,043	0,010	0,116	0,055	0,047	0,000	0,020	0,041
K	0,000	3,813	0,000	0,022	0,003	1,645	0,025	0,015	0,006
OH	0,000	0,000	1,150	14,960	15,430	4,039	0,000	1,624	1,960
Or	0,00	98,88				Alm	4,70		
Ab	98,90	1,12				Sp	0,93		
An	1,10	0,00				Pyr	0,22		
						Grs	94,15		

Symbols: alb - albite; kfl - K-feldspar; zs - zoisite; chl - chlorite; ms - muscovite; grt - garnet; czs - clinozoisite

Table 3
Representative microprobe analyses of minerals from metasomatic gabbroids

	5098g zoisite	5098g epidote	5098g diopside	2334v anorthite	2334g garnet	2334d actinolite	5098g chlorite
SiO ₂	38,02	36,82	53,25	43,53	34,47	53,91	28,60
TiO ₂	0,00	0,14	0,00	0,00	0,26	nd.	0,00
Al ₂ O ₃	34,08	29,11	2,07	35,37	20,20	4,36	22,96
Fe ₂ O ₃	0,79	6,93	0,90	0,00	2,76	11,76	7,62
FeO	-	-	-	-	28,92	-	-
MnO	0,00	0,10	0,25	nd	0,60	nd	0,16
MgO	0,14	0,13	17,14	0,00	3,76	17,42	28,49
CaO	24,45	23,78	25,43	20,03	9,02	11,01	0,00
Na ₂ O	0,00	0,00	0,54	1,06	0,00	0,00	0,00
K ₂ O	0,00	0,00	0,29	0,00	0,00	1,53	0,08
H ₂ O	2,52	2,99	0,13	0,00	nd	nd	12,08
Total	100,00	100,00	100,00	99,99	99,99	99,99	99,99
basis	13/O,OH	13/O,OH	6 (O)	32 (O)	24 (O)	24 (O)	36(O)
.Si	2,874	2,834	1,922	8,094	5,635	7,700	5,439
Al ^{IV}	0,126	0,166	0,078	7,754	0,365	0,300	2,561
Al ^{VI}	2,911	2,476	0,011	-	3,527	0,434	2,586
Ti	-	0,016	-	-	0,031	-	-
Fe ³⁺	0,045	0,402	0,024	-	0,338	1,263	1,090
Mn	-	0,006	0,008	-	0,082	-	0,025
Fe ²⁺	-	-	-	-	3,746	-	-
Mg	0,015	0,015	0,923	-	0,915	3,708	8,075
Ca	1,980	1,962	0,984	3,989	1,579	1,685	-
Na	-	-	0,038	0,191	-	0,251	-
K	-	-	0,013	-	-	-	0,018
OH	1,269	1,535	-	-	-	-	15,33
			Q-1,906	Or-0	Al-59,25	F	0,118
			J- 0,076	Ab-2,00	Sp- 1,30		
			mg-1,00	An-98,0	Pr-14,47		
					Gr-16,80		
					Ad-8,18		

between the basic-ultrabasic rocks and the pegmatitic solutions (Plate I, 3-6).

The mineral composition of the rocks varies, too. Ca-Al minerals from the epidote group and the basic plagioclases predominate. At the margins of the bodies (Fig. 3) compact porcelain-like masses are observed composed by tiny prismatic crystals of zoisite forming radiated or disordered aggregates (Plate I, 1, 2). The zoisite shows lamellar, zonal, sometimes hour-glass crystal structure with anomal low blue interference colours, parallel extinction and negative optical character. In the same porcelain masses microcrystalline individuals of albite, K-feldspar, chlorite and talc are found (Table 2). The fine-grained mass often recrystallised in fissures to a more coarse-grained clear zoisite in association with chlorite. On its turn, the zoisite is replaced by epidote forming a mesh texture (Plate I).

Epidote forms thick prisms or is fine-grained. It is developed in the interstices between zoisite prisms in the ophitic-like textures. Its chemical composition differs from that of the zoisite by a higher iron content (Table 3). It occurs also as alteration products on the zoisite and along with the latter replaces the relic garnets in the inclusions of garnet amphibolites.

Plagioclase also shows an irregular distribution as no less than two generations were established. In the first one the mineral developed mainly in medium to coarse-grained xenomorphic individuals with patchy extinction and unclear lamellar constitution. Some parts of the mineral are symplectites of plagioclases and quartz. The larger individuals often include poikiloblastically zoisite and epidote and also sheaf-like aggregates of tremolite and actinolite. The plagioclase is enriched in calcium and varies considerably even in a single grain from andesine-labradorite to anorthite An₉₅ (Table 3). Plagioclases of the second generation are localised in zones or veins formed during later impulse of pegmatite solutions penetration. They are fine- to coarse-grained, clear, with lamellar constitution. The composition is more acid ranging from oligoclase to andesine — An₂₂₋₄₀. Often it is associated with quartz.

Pyroxene. Sometimes it is found in badly preserved relics or pseudomorphs, and sometimes by relatively fresh grains similar to those found as veins in the serpentinites. Usually it is diopside and rarely enstatite. The replacement product is amphibole.

Amphibole. It is represented as relatively large (1-5 mm) prismatic or isometric individuals

Table 4

Representative microprobe chemical composition of amphiboles and plagioclases from metasomatic gabbroids - sample 40

	amph-1 core	amph-1 rim	amph-2 core	amph-2 rim	plag-1 core	plag-1 rim	plag-2 core	plag-2 rim
SiO ₂	52,028	47,153	51,898	51,269	57,068	53,706	57,857	47,492
TiO ₂	0,117	0,309	0,066	0,071	0,000	0,000	0,000	0,000
Al ₂ O ₃	6,227	11,659	4,897	6,028	26,854	28,924	26,320	32,650
FeO	10,150	11,283	9,506	10,437	0,117	0,080	0,131	0,023
MnO	0,209	0,232	0,168	0,098	0,000	0,000	0,000	0,000
MgO	15,872	13,056	16,379	15,685	0,000	0,000	0,000	0,000
CaO	11,994	12,225	13,005	13,109	9,588	12,351	8,088	17,128
Na ₂ O	0,923	1,308	0,707	0,668	5,787	4,594	6,539	1,919
K ₂ O	0,000	0,185	0,097	0,100	0,010	0,000	0,009	0,000
Zr ₂ O ₃	0,000	0,012	0,002	0,056	nd	nd	nd	nd
Cr ₂ O ₃	0,051	0,023	0,797	0,136	nd	nd	nd	nd
BaO	nd	nd	nd	nd	0,000	0,063	0,066	0,000
Total	97,570	97,445	97,522	97,657	99,424	99,716	99,010	99,212
basis	23(O)	23(O)	23(O)	23(O)	32(O)	32(O)	32(O)	32(O)
Si	7,415	6,821	7,428	7,348	10,282	9,747	10,437	8,788
Al ^{IV}	0,585	1,179	0,572	0,652	5,703	6,187	5,596	7,121
Al ^{VI}	0,461	0,809	0,254	0,366	-	-	-	-
Ti	0,013	0,034	0,007	0,008	0,000	0,000	0,000	0,000
Fe	1,210	1,365	1,138	1,251	0,018	0,080	0,020	0,004
Mn	0,025	0,028	0,020	0,012	0,000	0,000	0,000	0,000
Mg	3,372	2,815	3,495	3,351	0,000	0,000	0,000	0,000
Ca	1,832	1,895	1,994	2,013	1,851	2,402	1,563	3,396
Na	0,255	0,367	0,196	0,186	2,022	1,616	2,287	0,689
K	0,000	0,034	0,018	0,018	0,002	0,000	0,002	0,000
Zr	0,000	0,001	0,000	0,004	-	-	-	-
Cr	0,006	0,003	0,090	0,015	-	-	0	-
Ba	-	-	-	-	0,000	0,004	0,005	0,000
				Or	0,05	0,00	0,00	0,00
				Ab	52,18	40,18	40,18	16,87
				An	47,77	59,82	59,82	83,13

including or cutting through the early garnets or pyroxenes. The mineral contains brown-greenish spots in its central parts occupied by fine-grained rutile and magnetite that is evidence for assimilation of older pyroxene or amphibole. The shapes of the spots (angular with light rectangular domains) resemble the corona structure of amphibolitized gabbro norites, observed on other places in the Rhodope massif (Кожухарова, 1967; Приставова, 1996). Possibly it is amphibole pseudomorphs on basic magmatites. Single amphibole individuals has grown synchronous to the plagioclase. Sample 40 (Table 4) represents a typical, for the metasomatic gabbroids, paragenesis in advanced stage of homogenisation and mineral equilibrium. The amphibole in the central parts is transitional between actinolite and Mg-hornblende, in the periphery the alumina content increasing. The increasing anorthitic content in the accompanying plagioclase (Table 4) indicates for progressive trend in the temperature regime of crystallisation. Actinolite is common but not evenly distributed mineral. It can be found in the peripheral parts of the bodies in association with chlorite where replaces the serpe-

ntinite inclusions. Bundle like aggregates of needle actinolite are observed in quartz feldspatic segregations.

Chlorite which is developed within the serpentine is of talc-chlorite type and single individuals in quartz-feldspatic medium are enriched in Al sheridanite according to the classification of Hey (Хей, 1954).

Dolomite is sporadic. It builds up fine crystalline aggregates together with chlorite. The dolomitic component is 93,74%.

Accessories are rutile, titanite, magnetite, ilmenite, and in the pegmatoid segregations, also zircon.

The mineral association in which the epidote minerals predominate, the strong variations in the chemical composition and uneven development of the mineral species as well as the presence of replacement textures imply a typical metasomatic process that took place between the pegmatitic derivatives and the serpentines. Similar types of metasomatites are found in other areas of Rhodope massif where pegmatitic solutions had penetrated the rocks of the ophiolitic association (Кожухарова, 1998).

Table 5
Chemical composition of metasomatic gabbroids of Byala Reka dome, village Zhulti Chal

	1 892v	2 893	3 894	4 936v	5 2332	6 2333	7 2334	8 2337	9 5098a	10 5098g
SiO ₂	50,41	44,61	39,90	50,15	47,10	46,70	45,30	46,04	34,90	39,49
TiO ₂	0,41	0,13	0,61	0,42	0,01	0,01	0,16	0,01	0,04	0,02
Al ₂ O ₃	15,42	17,76	18,57	16,30	17,95	19,30	19,80	19,98	22,70	29,17
Fe ₂ O ₃	1,56	1,73	4,11	2,63	1,85	2,20	2,66	2,10	3,39	0,79
FeO	4,72	4,39	7,43	5,16	5,70	4,25	6,98	6,60	2,85	0,50
MnO	0,09	0,13	0,12	0,14	0,10	0,07	0,08	0,09	0,14	0,03
MgO	11,51	11,54	9,75	10,82	12,50	10,14	8,80	8,85	14,51	3,62
CaO	13,42	15,26	13,98	8,75	11,80	15,09	13,66	13,06	14,92	23,62
Na ₂ O	0,83	0,58	1,10	2,87	0,32	0,55	0,42	0,38	0,35	0,25
K ₂ O	0,05	0,06	0,10	0,13	0,04	0,02	0,04	0,04	0,00	0,00
P ₂ O ₅	0,01	0,01	0,01	0,05	0,01	0,01	0,01	0,02	0,02	0,01
H ₂ O	0,15	0,21	0,24	0,09	0,26	0,22	0,18	0,25	1,01	0,10
Loss	1,14	3,33	3,85	2,30	2,47	1,57	1,99	2,38	5,16	2,80
Total	99,75	99,74	99,86	99,81	100,1	100,1	100,1	99,78	99,99	99,95
ppm										
Ba	70	80	70	70	80	80	80	80	50	50
Sr	52	154	671	179	47	51	34	35	140	20
Rb	20	20	33	20	20	20	20	20	23	20
Zr	24	20	35	56	31	30	31	29	7	7
Ti	710	244	980	680	218	193	976	226	294	186
Mn	793	778	1325	1211	1120	719	907	998	1164	360
Cr	54	156	52	304	39	79	21	94	30	11
V	226	96	455	91	129	97	545	626	99	19
Co	31	31	34	28	33	28	42	34	29	3
Ni	139	252	127	171	114	164	53	82	103	4
Cu	15	108	20	16	34	33	174	39	54	17
Pb	9	3	23	5	1	10	1	1	4	3
Zn	24	36	44	45	47	36	61	54	20	4
Li	8	9	7,5	4,5	22,5	6	21	13,5	35	3
Sc	nd	32,77	nd	nd	nd	nd	nd	nd	nd	nd
Y	nd	nd	nd	nd	nd	nd	nd	nd	34	38

Petrochemistry of the metasomatic gabbroids

The metasomatic gabbroids have a chemical composition approaching that of the basic magmatic rocks of the gabbro group but, on the other hand, do not correspond exactly to any of the petrochemical species (Table 5). As the minerals themselves so the bulk chemical composition vary. The SiO₂ is between 34,9 and 50,41 % and the sum of alkalis from 0, 25 to 2,87 % as they fall in the field of ultrabasic and basic magmatic rocks (Fig. 4^a). The higher content of CaO (8,75-23,62 %) shifts the composition outside the gabbro field (Fig. 4^b). The same is the picture on the discrimination diagrams for FeO, MgO, CaO, TiO₂ (Fig. 5) where the large dissipation of the points out of the petrochemical fields is not characteristic for the magmatic rocks. The sharp changes in the petrochemical values were established even in the frame of one body of metasomatic gabbroids - samples 5098a and 5098b (Table 5; Figs 4, 5). The distribution of the trace elements is similar, especially that of the strontium content, which is controlled by that of the feldspars. The petrochemical discrepancy between the metasomatic gabbroids and magmatic rocks and

the significant variations in the chemical compositions (Fig. 6) confirm their metasomatic origin.

Metamorphosed basic dykes

They outcrop as several isolated bodies in the south-eastern limb of the syncline 1.5 km to the south of village Gougoutka (Fig. 7). The dykes cut the subvertical, dipping to the north-east 20-60° with angle 35-75° beds of Gnezdare Formation, presented by garnet-biotite tourmaline-bearing gneiss-schists. The strike of the dykes is north-east 25-30°. They have been deformed by later movements so their contacts are bended (Fig. 8). Inside the dykes, xenoliths of country rocks are observed as it is not clear whether they had been torn apart during the injection or somehow mechanically included during the later deformation. Their contacts are marked by quartz veins 3-4 cm thick. The gneisses are strongly compacted, fine-grained and silicified. The metamorphosed dyke rocks are fine-grained, grey-greenish garnet amphibolites with relic porphyritic texture (Fig. 8^a), expressed by rectangular white spots with length 0,5 to 1,5 cm and width 0,3 to 1 mm, resembling

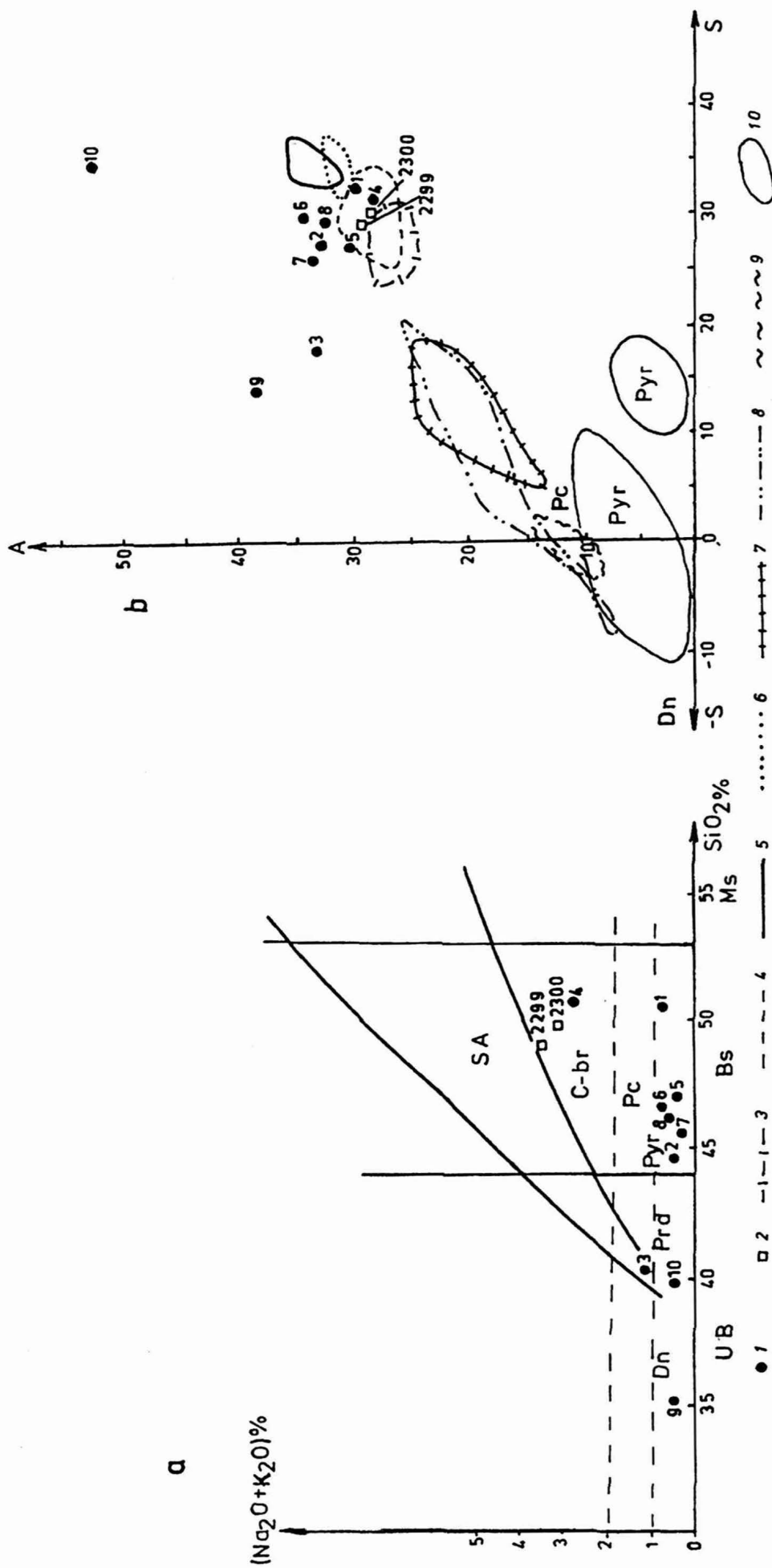


Fig. 4. Petrochemical diagram in coordinates: a. $\text{Na}_2\text{O} + \text{K}_2\text{O}$ vs. SiO_2 ; b. $A = (\text{Al}_2\text{O}_3 + \text{CaO} + \text{Na}_2\text{O} + \text{K}_2\text{O})$ vs. $S = [\text{SiO}_2 - (\text{FeO} + \text{MgO} + \text{MnO} + \text{TiO}_2)]$ after Magmatic rocks. Symbols: Du — dunite; Prd — peridotite; Pyr — pyroxenite; Pc — picrite; Gbr — gabbro; SA — subalkaline basic rock; UB — ultrabasic rock; Bs — basic rock; Ms — medium basic rock.

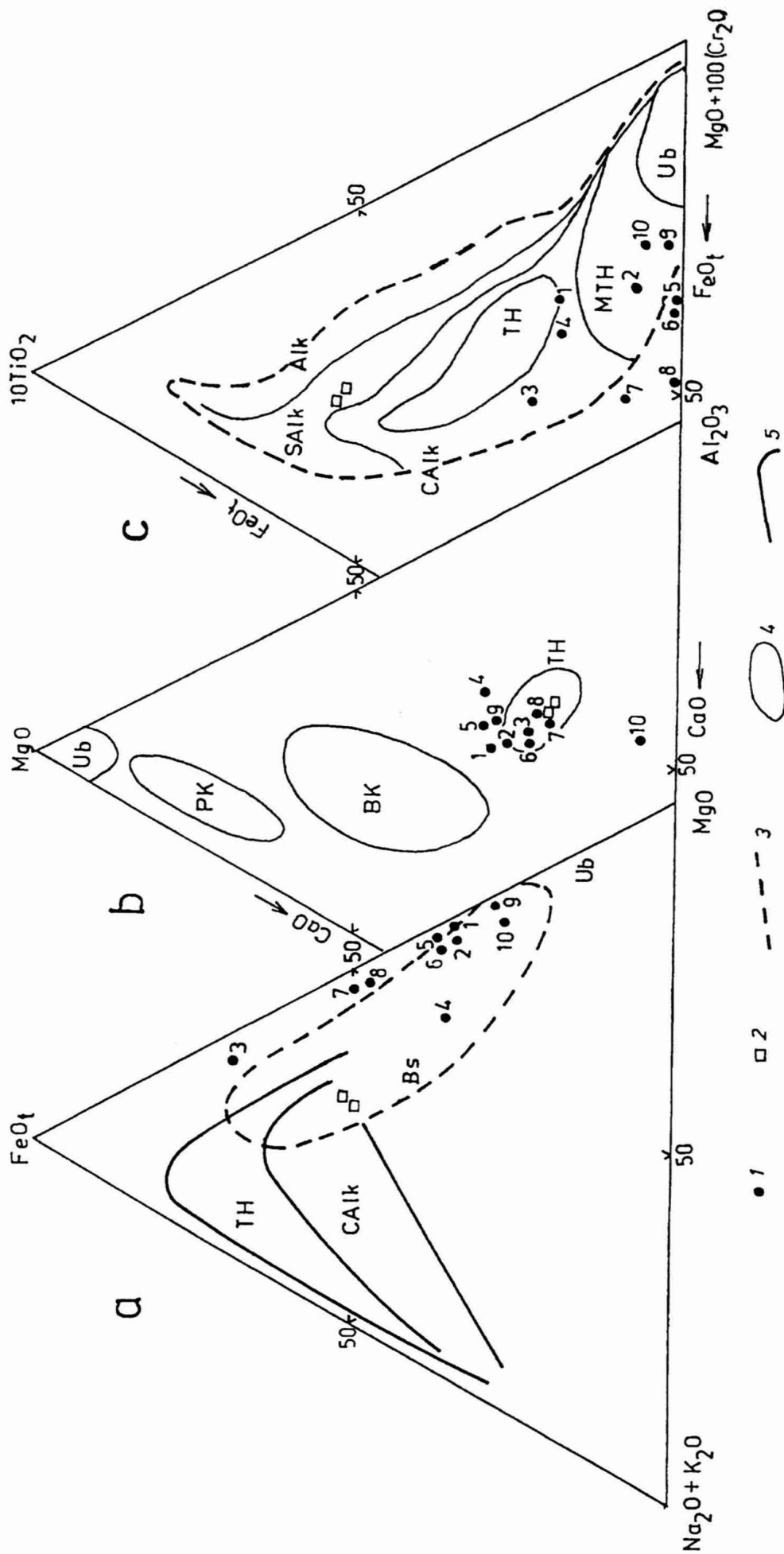


Fig. 5. Petrochemical diagrams in coordinates: a. ($\text{Na}_2\text{O} + \text{K}_2\text{O}$) — FeO_t — MgO , the field of basites — Bs after H. Л. Добрецов и др., 1985; b. CaO — MgO — Al_2O_3 , the petrochemical fields after К. Срикантанна и др., 1987; c. FeO_t — 10TiO_2 — $[\text{MgO} + 100(\text{Cr}_2\text{O}_3 + \text{NiO})]$, the petrochemical fields — Е. Kozhoukharova. Symbols: TH — tholeiites; Bs — basic magmatic rocks; CAIk — calc-alkaline basic rocks; BK — picrite komatiites; Ub — ultrabasic rocks; SAlk — subalkaline basic rocks; Alk — alkaline basic rocks; MTH — high magnesium tholeiites

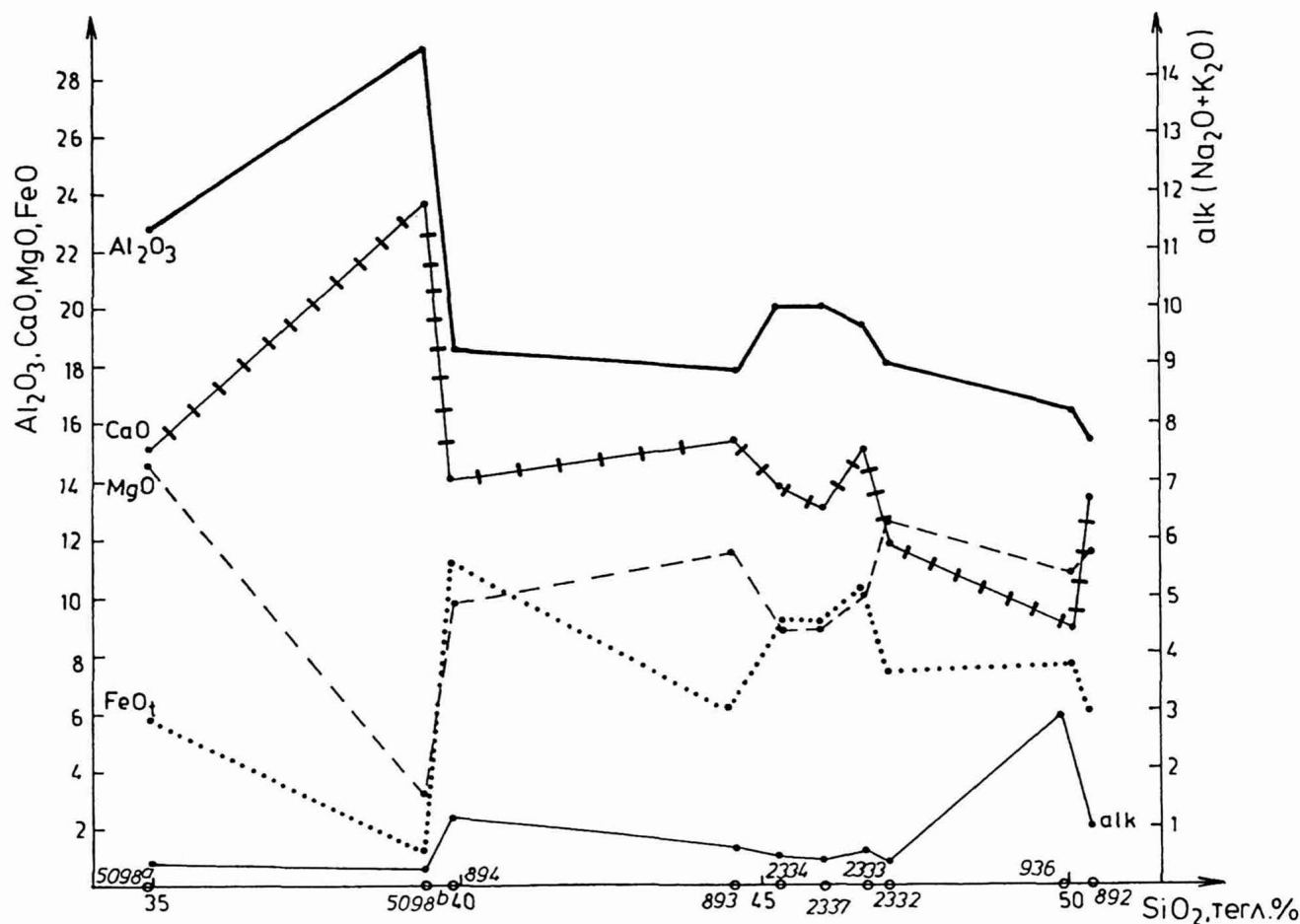


Fig. 6. Diagram for the chemical alterations of the metasomatic gabbroids

prismatic plagioclases. They are oriented in parallel to the outlines of the dyke like trachytoidal texture. The larger spots parallel to the contacts are concentrated in the peripheral parts of the dyke (6 to 7 for a cm^2), and at the central parts they are smaller and rarely distributed (Fig. 8a). In the chilled contacts porphyroid individuals disappear. The mentioned zonality features typical for the dykes are evidence for their subintrusive origin. It was established by microscopic work that white "porphyroids", are pseudomorphs after magmatic plagioclases filled with polymineral fine-grained aggregate of plagioclase, quartz, calcite and zoisite or with single plagioclase poikiloblast including amphibole.

The metamorphic process took place in two phases, marked by two mineral paragenesis. The first paragenesis includes - amphibole, garnet, zoisite, rutile, feldspar, quartz, ilmenite. It was observed mainly in the central parts (samples 2299, 2300). The minerals are fine-grained composing the matrix and the pseudomorphs. The ilmenite (4–6%) is probably a relic from the magmatic stage, with size 0.1–0.2 mm. Its form is irregular, sometimes torn. It is rimmed or replaced by rutile and titanite. The second mineral paragenesis is composed of plagioclase (oligoclase — An_{15-25}),

quartz, epidote, titanite, amphibole, biotite. It is developed in lenticular segregations commonly 2–3 mm wide. They are localised in the peripheral parts of the dykes. Minerals from the first paragenesis - amphibole and plagioclase recrystallised and increased in size or had been replaced by new minerals - zoisite by epidote, rutile by titanite, amphibole partly by biotite. At the exact contact assimilation processes related to the second metamorphic phase had been more intensive, and the garnet amphibolite is only partially preserved. Obviously the later metamorphism was accomplished at a greater activity of alkalines and silica. In addition to the described rocks in the studied area have been found small exposures of metagabbros with relic magmatic amphibole.

The chemical composition of basic dyke rocks determined by a sample from the centre of the dyke - No 2299 (Table 6, Fig. 4, 5) corresponds to high titanium tholeiite. The iron content is relatively low - Fe-10-11% and also Al_2O_3 - around 15%. Some increase over the average amount in alkalines was found for Na_2O - 3-3.4%. Considerable differences in composition from the periphery and the central parts of the dyke have not been found except a small increase in the amount of silica. On petrochemical diagrams the compo-

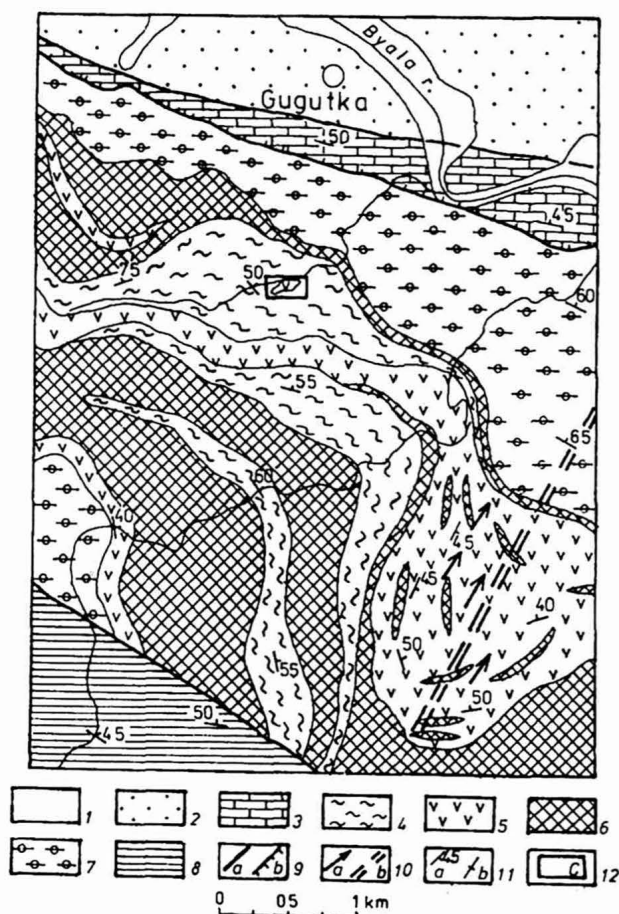


Fig. 7. Geological map of region Gougoutka. Symbols: 1 - alluvium; 2 - Pliocene; Precambrian; 3 - marbles; 4 - mica schists; 5 - amphibolites; 6 - serpentinites; 7 - porphyroblastic gneisses; 8 - leptynite gneisses; 9 - a. faults; b. thrust fault; 10 - a. axis of minor folds; b. axis of syncline; 11 - mode of occurrence of beds - a. inclined, b. vertical; 12 - detailed map from fig. 8

Table 6
Chemical analyses of metamorphosed basic dykes

weight %	2299	2300	ppm	2299	2300
SiO ₂	48,06	49,12	Ba	69	12
TiO ₂	2,07	2,05	Sr	178	179
Al ₂ O ₃	15,31	15,62	Rb	7	11
Fe ₂ O ₃	1,92	2,12	Zr	133	149
FeO	8,70	8,14	Ti	11484	10864
MnO	0,19	0,18	Mn	1311	1419
MgO	6,43	6,25	Cr	136	156
CaO	10,44	10,37	V	237	246
Na ₂ O	3,39	3,02	Co	30	30
K ₂ O	0,34	0,38	Ni	62	63
P ₂ O ₅	0,21	0,16	Cu	35	31
H ₂ O	1,10	1,05	Pb	93	66
H ₂ O ⁺	-	-	Zn	83	78
Loss	1,76	1,42	Li	25,5	30
Total	99,92	99,88	La	8,9	9,2
			Ce	17,0	16,4
			Sm	5,5	5,2
			Eu	1,36	1,44
			Tb	0,9	0,8
			Yb	3,6	3,3
			Lu	0,59	0,54

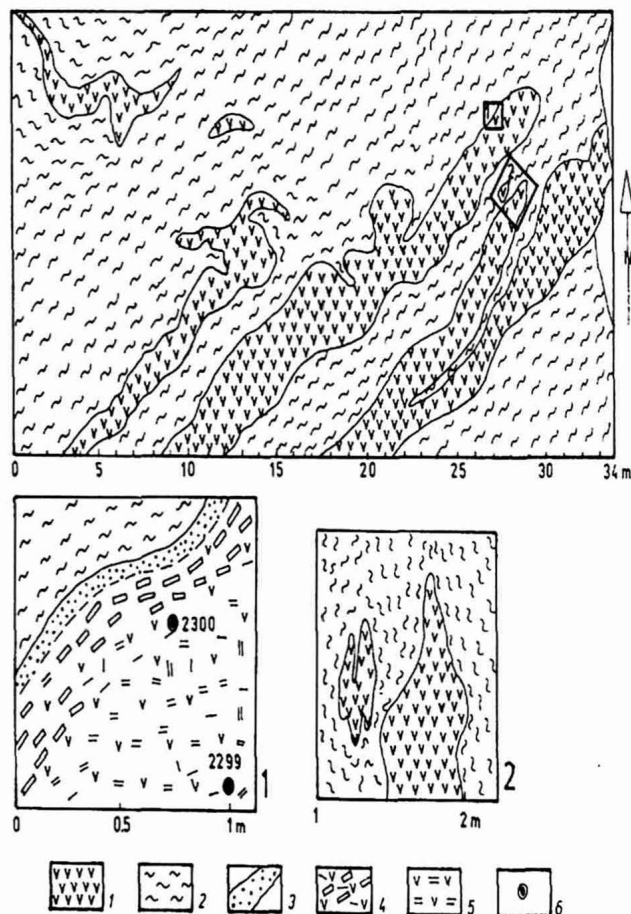


Fig. 8. Detailed geological map of a little region south of village Gougoutka - outcrop of deformed and metamorphosed dyke of basic rocks. 1, 2 - details of the map. Symbols: 1 - amphibolized basic rocks; 2 - biotite gneisso-schists; 3 - peripheral zone of dyke; 4 - transitional zone of dyke with relic porphyritoid structure; 5 - internal zone of equigranular amphibolites; 6 - location and number of sample

sitional points of dyke rocks fell in the field of tholeiites (Figs 4, 5), whereas these of the metasomatic gabbroids are outside this field.

Genesis of metasomatic gabbroids

Metasomatic gabbroids from the location Zhulti Chal are typical reaction products that do not belong to the primary components of the Ophiolitic Association. They differ from the metamorphosed basic dyke magmatites found near the village Gougoutka after their mineral, petrochemical and structural features. The similarity of the two types of rocks is only to the dyke - like shape of the bodies and some proximity of the mineral composition. But while the veins of metasomatic gabbroids are relatively linear and slightly deformed those of metamorphosed basites carry prints of ductile deformations. The relic trachitoid texture and zonal arrangement of a porphyritic pseudomorphosis is specific for the metabasic dyke

rocks, and the block, glomeroblastic or spotted texture, for the metasomatic ones. The metasomatic mineral association: zoisite, epidote, basic plagioclase (An₉₀) together with acid plagioclase (An₂₀₋₃₀), a variety of replacement textures, and visible assimilation of serpentinite from pegmatitic material undoubtedly speak for a metasomatic origin of the gabbroids. The odd and variable chemical composition compared with the clear tholeiitic ones of the dykes substitute the picture of a typical metasomatic process. The above reasoning affords us to accept the metabasites from the area of Gougoutka, as premetamorphic subintrusive rocks, eventually parts of an ophiolitic association, and the metasomatic gabbroids, for later metamorphic and post-tectonic products, related to penetration of pegmatite solutions into the rocks of the Ophiolite Association. An analogy exists in the geological relationships and mineral composition between the metasomatic gabbroids and decalcated pegmatites of the Rila mountain (Арнаудов, 1976; Арнаудов, Петрусенко, 1968). However, the desilicated pegmatites of Rila has zonality and contain emerald, chrysoberil, phenacite, orthite, fluorite, phlogopite, oxides of rutile, columbite-tantalite, augite, and euxenite group (Арнаудов, 1976) being evidence for their genetic link with granites. Metasomatic gabbroids have irregular spotted structure and simple mineral association that implies migmatic pegmatites poor of volatile and rare components.

The formation of metasomatic gabbroids at the expense of basic and ultrabasic ophiolites is not an isolated phenomenon and may be observed in other locations of the Rhodope massif being at different stages of development. Examples have been found in the valley of the river Arda in the neighbourhood of the villages Devesil (Krumovgrad district), Zherka (Zlatograd district), Vaklinovo (Gotse Delchev district), etc. (Кожухарова, 1998). An analogy in the origin may be inferred for pegmatized amphibolites which resemble magmatic gabbroids near the peak Damga in the Rila mountain. Same massive coarse-grained amphibole-plagioclase rocks of the contact aureole of the West-Rhodope batholith in the Velinograd district are similar in composition (Кожухарова, 1977). Metasomatic gabbroids are reaction products created by mingling of pegmatitic derivatives enriched in Si, Al and alkalis, and basic ophiolitic rocks enriched in Mg, Ca and Fe. The geochemical trend of the process is directed towards averaging of the composition of reacting substances. Gabbroization of serpentinites is one of the forms of assimilation of ophiolitic rocks taking place during the regional metamorphism. In the early stages of the process a nearly isochemical recrystallisation of serpentinites and transformation into talc-chlorite schists and metamorphic pyroxenites begins, passing into clear metasomatic alteration,

when an increased mobility of the components took place.

Structural end metamorphic evolution of the metamorphic complex

The several successive mineral associations and deformation phases are evidence for continuous polyphase metamorphic evolution (Table 8; Fig. 9). The earliest metamorphic events are related to the formation of porphyroblastic and leptynoid gneisses of the Strazhets Group from the Prarhodopian Supergroup, which is a sole for the Boturche Group. Wide lateral distribution of uniform quartzo-feldspatic gneisses, migmatic lenticular and porphyroblastic structure, abundance of pegmatite - aplite layered and intersecting segregations and granite bodies, witnesses for a deep level, and a continuous migmatic process, reaching high degree of selective melting. The most probable P-T conditions of crystallisation were T - 650-750°C and P - 4-8 kbars. The Strazhets Group corresponds to ancient Precambrian granite-gneissic infracrustal continental complexes.

A new stage in the geotectonic development of the region begins with formation of marginal sea basins over the shelf of the ancient continent and obduction of ophiolitic fragments (Kozhoukharova, 1984a, 1985), which together with carbonate pelitic sediments, covered the eroded granite-gneiss complex of the Prarhodopian Supergroup. A second regional metamorphic cycle begins with recrystallisation of the sediments and ophiolites of the Boturche Group. It is divided into two metamorphic events. The first one developed in the low temperature amphibolite facies (Table 7), restricted from the stability of serpentinite - 580°C (Murrell, 1985). Interrupted by deformation phases, the metamorphic recrystallisation took place in compressional setting marked by folding. Three episodes may be distinguished (Table 8), fixed by three paragenesis in the mica schists and amphibolites, recurrent zonation of garnets and amphibolization of eclogites. The temperature trend is progressive. Formation of glaucophane in the early phase of eclogite crystallization (Колчева, Цончева, 1993), shows onsetting temperature 360-450°C, reaching - 500-550°C at the culmination and in the zones of local migmatization of amphibolites during the third episode - 620°C. More complex variation marks a pressure reaching culmination at the second episode, when in the country mica schists abundant chloritoid and muscovite with high phengite content appear. The eclogitization probably developed during the second episode. A characteristic feature of the metamorphic process is the unsteady spatial distribution of the temperature and pressure. Eclogitization is not

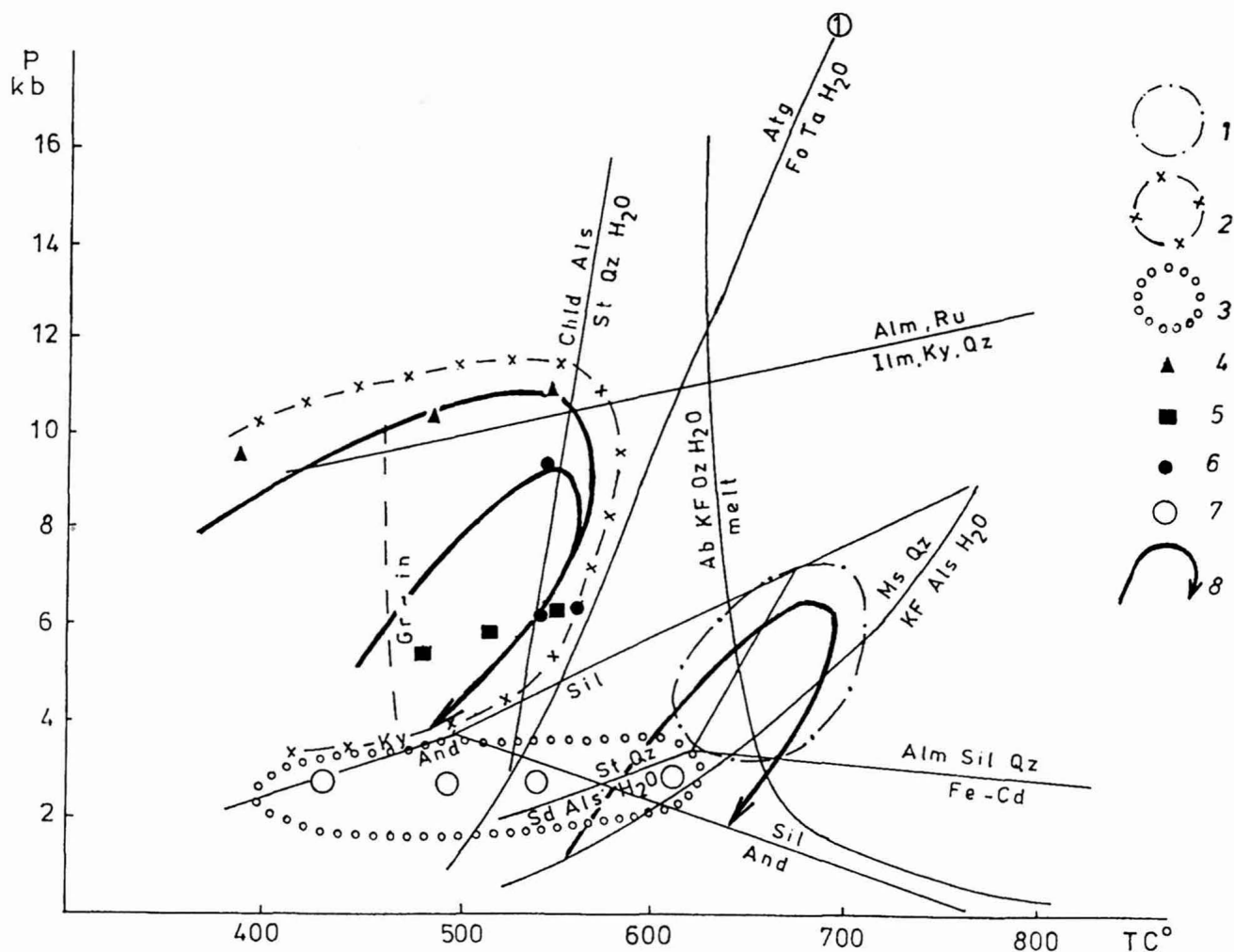


Fig. 9. Petrogenetic grid after B. W. D. Yardly, 1989, reaction 1 after K. Bucher and M. Frey, 1994 for the metamorphic rocks from north-eastern periphery of Byala Reka dome. Field of metamorphism: 1 — Prarhodopian Supergroup; 2 — Rhodopian Supergroup; 3 — metasomatic gabbroids; geothermobarometric estimations: 4 — eclogites; 5 — amphibolites; 6 — mica schists; 7 — metasomatic gabbroids; 8 — trend of P-T parameters

developed everywhere but in local zones of increased pressure which are located at the lithologic contacts between the competent gneisses of the Strazhets Group and varied materials of the Botu-

riche Group. Interformational friction in this zone produced relatively higher temperatures and pressure necessary to trigger eclogitic recrystallization. Similar processes have been established in the

Table 7
P - T conditions of crystallization of metasomatic gabbroids

Samples	Mineral association	Geothermometer	T - P
5098a - porcelain-like peripheral mass	Ab+Kfs+Q+Zo+Ta + +Chl+Ms+Grs	albite - K-feldspar	400°C 2 kbars
5098g - fine-grained gabbroid	Di+Gr+Zo+Ep+An+l +Chl	garnet-clinopyroxene Фонарев et al. 1989	411°C 2 kbars
5098j - fine-grained gabbroid	Amf+Ep+Zo+An ₍₈₆₋₈₈₎ (Table 2)	amphibole-plagioclase Blundy, Holland, 1990	498-501°C 2 kbars
2334 -medium-grained gabbroid	Amf+An ₉₅ +Zo+Ep+Gr +Chl	garnet-amphibole Graham, Powel, 1984	459°C 2 kbars
2334 -medium-grained gabbroid	the same minerals (Table 3)	amphibole-plagioclase Blundy, Holland, 1990	518-519°C 2 kbars
40 - coarse-grained gabbroid	Amf ₁ +An ₁₍₆₀₎ +Q+Zr (Table 4)	amphibole-plagioclase Blundy, Holland, 1990 Ферштатер, 1990	634-640°C 2 kbars 500-600°C 2 kbars 40 -
40 - coarse-grained gabbroid	Amf ₂ +An ₂₍₈₃₎ + Q+Zr (Table 4)	amphibole-plagioclase Blundy, Holland, 1990 Ферштатер, 1990	656°C 2 kbars 600-700°C 2 kbars

Table 8
Metamorphic evolution of the Byala Reka dome

Metamorphic complexes	First metamorph. cycle Archaean - lower Proterozoic	Transitional emersion period Riphean	Second metamorphic cycle			Second posttectonic metamorphicevent F4
			First syntectonic metamorphic event			
			First episode F1 D1	Second episode F2 D2	Third episode F3 D3	
Rhodopian Supergroup Boturche Group		Obduction of ophiolitic fragments covered by carbonate-pelitic sedimentational complex	schists Gr1 + St1 + Bi1 + Ms1	schists Gr2 + St2 + Ms2 + Chld + Pl1 + Q1 + Ru1	schists Bi2 + Ms3 + Q3 + Pl3 Chl + Pl2 + Q2 + Ru + Ky	Metasomatic gabbroids Amf + Tit + Q + Ep + Zs + Ta + Chl + Kf1 + Al + An
Zhulti Chal and Gnesdare Formations			amphibolites Amf ₁ + Pl ₁ + Gr ₁ + Ep ₁ + Ru ₁ + Ap serpentinites Ant + Ta + Chl + Cal + Mt + Trm T - 480-540°C P - 4-6 kbars	amphibolites Amf ₂ + Pl ₂ + Gr ₂ + Ep ₂ + Ru ₂ serpentinites Ant + Ta + Chl + Cal + Mt + Trm T - 480-550°C P - 4-8 kbars eclogites Omf + Gr1 + Rut1 T - 500-550°C P - 10-12 kbars	local slight migmatized amphibolites Amf ₃ + Bi + Pl ₃ + Q + Ep ₃ + Tit + Chl + Mt + Ba amphibolized serpentinites Amf + Ep + Zs + Tit + Mt T - 560-620°C P - 3-5 kbars amphibolized eclogites Amf + Pl ₂ + Gr ₂ + Zs	fine-coarse massif amphibole gneises Amf ₄ + Pl ₄ + Q ₂ + Tit ₂ + Bi + Zr
Prarhodopian Supergroup Strazhets Group	First migmatization Porphyroblastic, banded and leptytic gneises Pl + KF + Q + Bi T - 600-750°C P - 4-6 kbars	Uplift, erosion and weathering	Regressive metamorphic alterations Ms + Chl + Pl + Q + Bi + Gr T - 400-550°C P - 4-6 kbars			Second partial migmatization KF + Pl + Q + Bi + Zr

Avren syncline (Kozoukharova, 1996), where eclogitization was observed in narrow shear zones inside serpentinites. The anisotropic distribution of pressure was also expressed in variation of Si/Al ratio in muscovite that determines wide transitional field between typical muscovite and phengite. During the same metamorphic event diaphoritic alteration have been imposed over the porphyroblastic gneisses of the Punovo Formation at the contact with the Boturche Group. It is demonstrated by the appearance of muscovite-chlorite-garnet schists including feldspar tectonoclasts from porphyroblastic gneisses. A number of shear zones subparallel to bedding and particularly to the foliation of diaphoritic muscovite-garnet schists cuts the porphyroblastic gneisses. Its surfaces become more abundant with approaching the contact of the Boturche Group where similar deformation phenomena and wide development of muscovite and rarely of biotite have been present. The muscovite foliation is subparallel to NW-SE directed fold axial planes.

The second metamorphic event is weaker than the previous one, and with a less intensive recrystallization. Alteration was more intensive in zones of pegmatization where allochemical changes took place. Migmatized amphibolites have been transformed to amphibole gneisses with a massive structure. Replacement of low alumina amphibole and actinolite by high alumina ones, and of rutile by sphene, is an evidence for a decrease of the oxygen potential and a local temperature increase that implies a possible operation of deep crustal processes. Aplite-pegmatite fluids generated in deep levels penetrated along zones of increased permeability in relatively calm tectonic conditions.

Late folds elongated in north-east direction impose some deformation. In structural sense the most substantial effect is the formation of macroboudins (Fig. 1). Mineral transformations related to the second folding are represented by quartz veins striking NE-SW and appearance of second antigorite schistosity marked in the serpentinites (Fig. 2).

Discussion

Because of their temporal and spatial development, the metasomatic gabbroids of Byala Reka dome play important role as a marker in the tectono-metamorphic evolution of the basement. Their presence in a particular geological environment gives a chance for reexamining some traditional problems concerning the metamorphic basement.

1. Metamorphic complexes and metamorphic cycles. One of the first questions that arise, is whether the Strazhets and Boturche Groups belong to a single lithostratigraphic unit (Prarhodo-

pian Supergroup), with common metamorphic history or they are two different in age and lithology complexes? According to all researchers of the region (Боянов и др., 1963; Боянов, Русева 1984; Kozhoukharov et al., 1978; Кожухаров, 1987; Кожухарова и др. 1988) the metamorphites of the Strazhets Group are represented by relatively homogeneous quartz-feldspathic gneisses (granite participation is also possible) of deep-level origin. Macheva, Kolcheva (1992) also have already accepted the existence of two different rock complexes, although they groundlessly assumed the intrusion of the "Strazhets gneisses" in the varied rocks of the Boturche Group. A quite different lithology and metamorphism, transitional between greenschist and amphibolite facies, is typical for the rocks of the covering Boturche Group. Its original composition is represented by an alternation between quartzites and limestones, pelites and ophiolitic fragments. They are metamorphosed in P-T conditions typical for the upper crust level. Differences in lithology, metamorphic incompatibility (hyatus) and diaphoritic alteration superimposed over the porphyroblastic gneisses of the Strazhets Group witness for interruption of the primary stratification and the metamorphic process. The granite-gneissic complex of the Strazhets Group had been consolidated, completed its deep level metamorphic reworking, uplifted and eroded when a new ophiolite-sedimentary rock complex was deposited. The imposed later regional metamorphism was prograde for the pelites and ophiolites, and retrogressive for the Strazhets metagranites and migmatites. It is reliable to consider the rocks of the Strazhets and Boturche Groups belonging to different stratigraphic successions and metamorphosed in two metamorphic cycles. The lithology of the rocks of the Boturche Group are comparable with the lower stratigraphic levels of the Rhodopian Supergroup. Restricted participation of marbles in the Gnesdare and Zhulti Chal Formations, and abundance of ophiolitic bodies is due to lateral variation of the primary composition (Kozhoukharova, 1996a). It may be inferred that today's region of Byala Reka dome had been nearer to the edge of the ancient continent than the northern parts of Central and Western Rhodope. The boundary between the two complexes has been consolidated by later metamorphism, so in some exposures, a complete conformity can be observed. The primary transgressive position of the Boturche Group is established by the clear "geographic and angular unconformity" (Кожухаров, 1987). Thus, the new data, published in recent years, convincingly affirm the long ago uttered idea (Вергилов и др., 1963; Кожухаров, 1968) for existence of two complex (Кожухаров, 1984).

2. Age of the metamorphic rocks. The age of the protoliths of the Rhodopian Supergroup, to which

the Boturche Group is attributed, is determined by microfossils (Кожухаров, Тимофеев 1979, 1989; Tchoumatchenco, Sapunov, 1989; Кожухаров, Конзалова 1990) as Precambrian - Lower to Middle Riphean. Thus the age of the Rhodopian Supergroup is restricted to the Riphean. The question about the age of the metamorphic events that reworked the rocks of the Boturche Group is far more complex. Some new data for the rocks of the Biyala Reka dome obtained by U-Pb method for zircons from different levels of the Strazhets Group have shown 305 ± 19 to 319 ± 9 Ma and 1700 - 1800 Ma (Peycheva, Quadt, 1995). The first age is attributed to granite formation (also to the formation of porphyroblastic gneisses), and the second one, to some unspecified crust material included in the metagranite. The authors allow an incongruity considering all Strazhets gneisses as metagranites. Because of the lack of detailed petrographic map with sample location, it is not clear whether the authors (Peycheva, Quadt, 1995) have discriminated correctly the real metagranites, called Orlov vrh metagranites (Kozhoukharova et al., 1988), from the host gneisses. So far the reader is not acquainted with the petrologic character and the phase of formation of the analyzed samples.

It was emphasised (Пейчева и др., 1992; Peycheva, Quadt, 1995) that zircons from sample 1-47 (metagranites) showing an age of 310 ± 5.5 Ma possess an euhedral form. Similar habit have the late generation of zircons from pegmatite-aplite veins cutting locally migmatized amphibolites from the second metamorphic event (Table 8) as well as in pegmatoid central zones of the metasomatic gabbroids. These zircons differ in habit from deformed and clouded crystals from earlier metamorphic phases resembling those observed (Peycheva, Quadt, 1995) in the central parts of euhedral zircons from sample 1-46. It is reasonable to admit that crystallisation of euhedral zircons marks a later migmatization phase from the second metamorphic cycle that took place in the deep level of the Strazhets gneisses. The mentioned phase is manifested by pegmatite veins that generated the metasomatic gabbroids. The suggestion here for a possible correlation between the metasomatic gabbroids with the Biyala Reka gneiss-granites can be proven only after correct data about the age of the metasomatic gabbroids would be obtained. It would highlight also the problem about the existence of a possible third Palaeozoic metamorphic cycle, expression of which may be the second postdeformational metamorphic event and metasomatic gabbroids.

Pegmatites cutting the Lower Tectonic Unit in northern Greece (it is the analogy of the Strazhets Group) have yielded an age of 334 ± 3 Ma by Rb/Sr analysis on muscovites supposed to be relics from the magmatic stage of metagranites (Mposcos,

Wawrenitz, 1995). The mentioned authors do not recognise the full succession of metamorphic phases and the different generations of pegmatites; thus, it is not clear what is the position of the examined rock sample in the metamorphic evolution. It is important that the new isotopic data fix a great metamorphic event with Hercynian age. The discussed event has to be taken into account by the those who advocates only a Cretaceous metamorphism. Nevertheless, the cited data indicate a Hercynian rejuvenation of the Rhodope massif during which crustal granite magmas have been generated producing pegmatitic solutions and local migmatization in the East-Rhodope block. It is possible the small granite bodies from Orlov Vruh in Biyala Reka dome also to be of Hercynian age.

Conclusion

The metamorphic complex constituting the Biyala Reka anticline is composed of two sequential stratigraphic units differing in lithology and in the type of metamorphism. The lower one is represented of the rocks of the Strazhets and Tintyava Groups and represent an infracrustal metamorphic complex that includes a variety of migmatized gneisses and metagranites, penetrated by several generation of pegmatites. It has a deep-level character and is typical for the ancient continental Precambrian terrains. The lithology and metamorphism of the complex correspond to these of the Prarhodopian Supergroup. The upper unit includes the rocks of the Boturche Group. It was primarily composed of pelites, quartzites, marbles and obducted basic and ultrabasic ophiolitic fragments. Because it was transgressively deposited in Riphean times over an already metamorphosed, uplifted and eroded complex and taking into account its lower grade of metamorphism, we may refer to it as a supracrustal complex. It can be regarded as analogous to the Rhodopian Supergroup from the other parts of the Rhodope massif.

The metamorphic transformations of the entire rock complex have passed in two cycles. The first cycle is responsible for the transformation of the Prarhodopian Supergroup and had been completed before the Riphean. The second cycle is related to the progressive alteration and deformation of the Rhodopian Supergroup as well as to the retrogressive reworking of the Prarhodopian Supergroup.

Two metamorphic events have happened during the second cycle. The first, syndeformation event is marked by intensive ductile reworking in a compressional regime. At this time tight folds with axial planes striking NW-SE have been formed, the biggest of which is exposed as recumbent, closed syncline in the north-eastern periphery of the By-

1. Block fabric of metasomatic gabbroid (Sample 5098a) from marginal zone of dyke. Locality - valley of Kerezliyska Reka river: a. compact porcelaneous zoisite aggregate; 2. talc-chlorite aggregate from initial stage of assimilation of serpentinite xenolith.
2. Fine-grained aggregate with granoblastic texture (Sample 5098a): z - zoisite, ch - chlorite, ep - epidote. Magnification: x 50, XPL.
3. Metasomatic gabbroid with inequigranular pegmatoid structure, consisting of amphibole and plagioclase. (Sample 5098)
4. Metasomatic gabbroid with reaction texture (Sample 5098?). pl - plagioclase, amf - amphibole, ch - chlorite; ep - epidote. Magnification x 50, XPL.
5. Metasomatic gabbroid with coarse-grained pegmatoid structure from advanced stage of assimilation and recrystallization of ultrabasic substrate (Sample 42): amf - amphibole, amf-ch - amphibole-chlorite aggregate, q-f - quartz-feldspathic aggregate. Locality - valley of Kerezliyska Reka river.
6. Reaction zone in coarse-grained metasomatic gabbroid (Sample 42): pl - plagioclase, amf - amphibole, bi - biotite, ms - muscovite, ch - chlorite, ep - epidote. Magnification: x 50, XPL.

ala Reka dome. The metamorphic recrystallization was carried out in dynamic setting in the lower degree of the amphibolite facies, T - 450-580°C and P - 5-7 kbars. In narrow shear zones of interlaminar friction in conditions of higher pressure and temperature, a crustal type eclogitization has been imposed over the basic and ultrabasic components of the ophiolites. Zones of eclogitization are found in terrains of intense folding and most often at the lithologic contacts. Three metamorphic episodes have been established. The second postdeformational event passed in a relatively calm tectonic environment. It is marked by local migmatization and granite formation in the deeper levels of the gneiss complex of the Prarhodopian Supergroup. Its expression are the pegmatite-aplite derivatives penetrating the zones of increased permeability of the rocks of the Boturche Group. As a result of bimetasomatic reactions between pegmatite-aplitic fluids and serpentinites and amphibolites, dyke-like bodies of metasomatic gabbroids have arisen. They have skarnoid mineralisation: zoisite, epidote, diopside, anortite, titanite, grossular, amphibole, coexisting with albite-oligoclase, K-feldspar, quartz, talc, chlorite, actinolite.

Late folding deformed the axes of the earlier folds producing a new generation of north-eastern trending folds. The conjugate action of the two folding phases is responsible for the macroboudinage of the rocks of the Boturche Group. With the late folding local development of secondary schistosity in serpentinites appear.

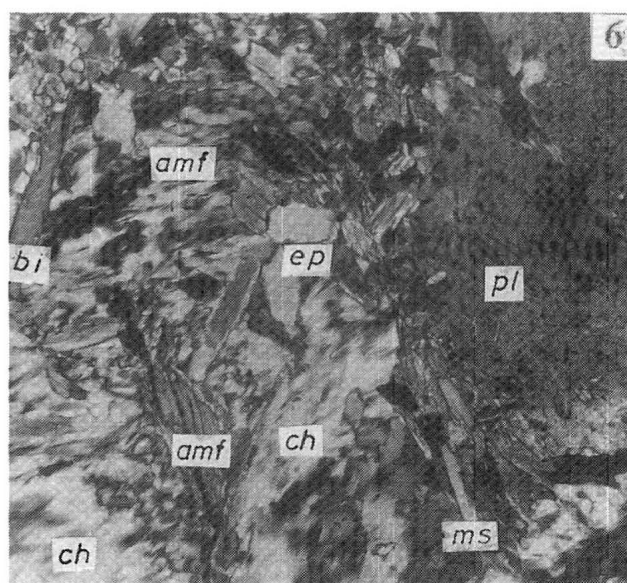
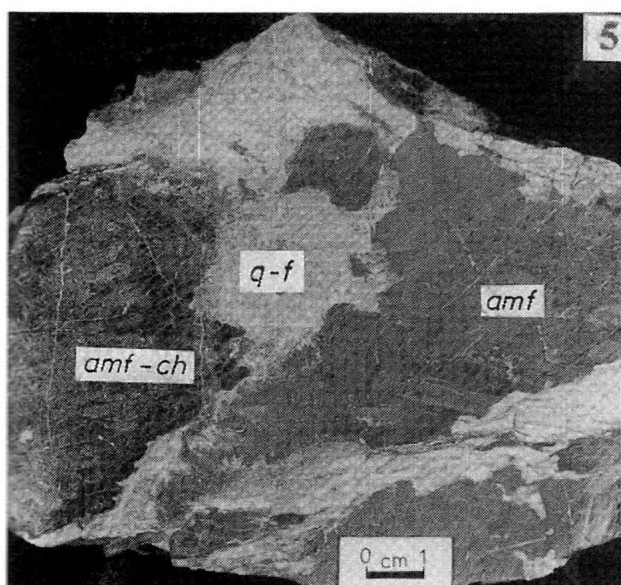
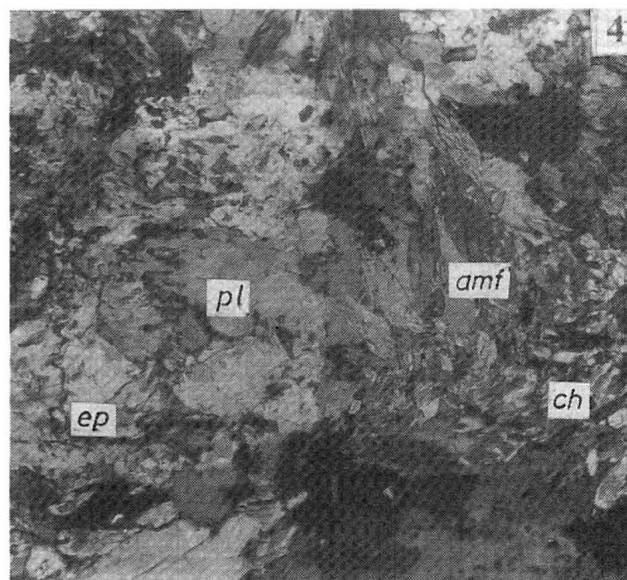
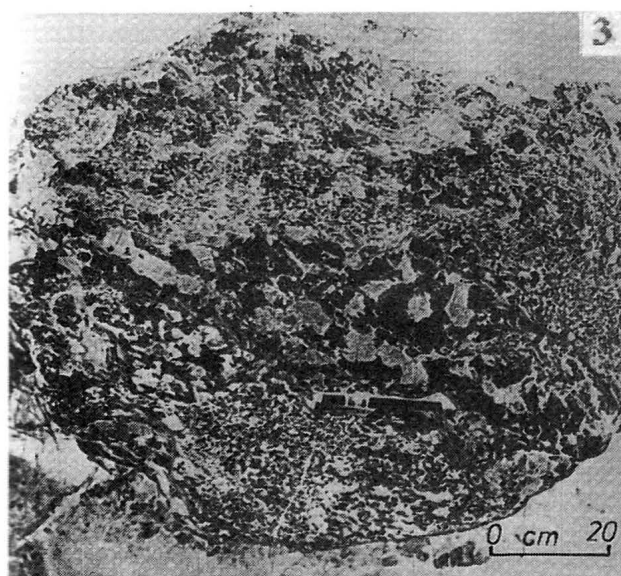
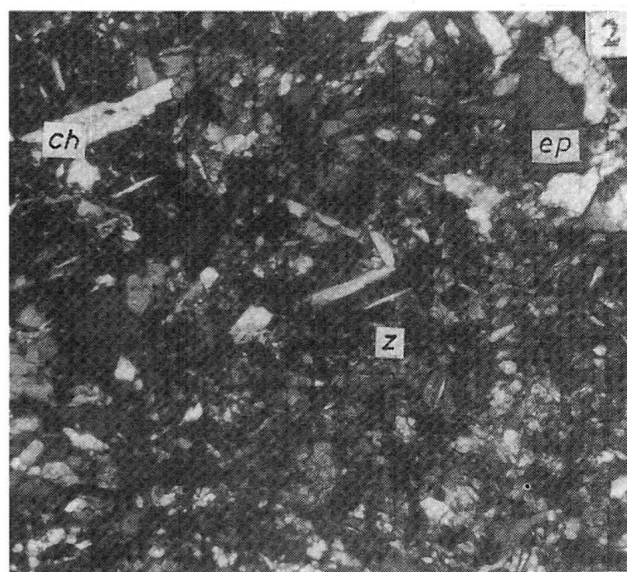
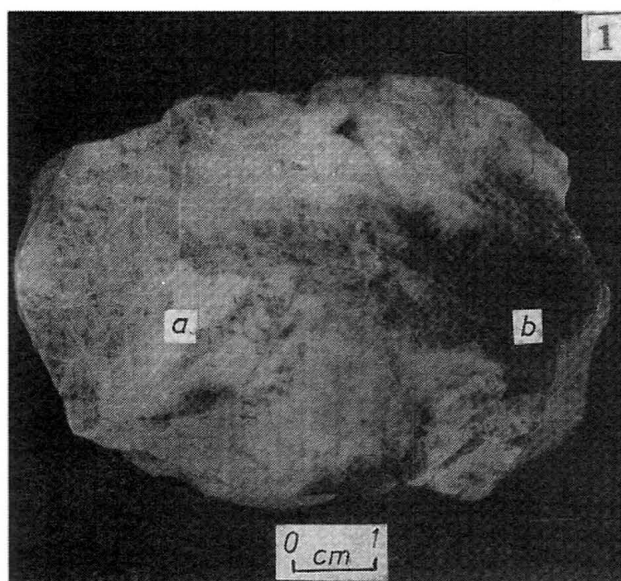
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References

Blundy, J. D., Holland, T. J. B. 1990. Calcic amphibole equilibrium and a new amphibole-plagioclase geothermometer. — *Contr. Miner., Petrol.*, 104; 208-224.
Burg, J. P., Ivanov, Z., Ricou, L. E., Dimov, D., Klain, L. 1990. Implications of shear-sense criteria for the tectonic evolution of the Central Rhodope massif, Southern Bulgaria.

— *Geology*, 18; 451-454.
Burg, J. P., Ricou, L. E., Ivanov, Z., Godfriaux, I., Dimov, D., Klain, L. 1996. Synmetamorphic nappe complex in the Rhodope massif. Structure and kinematics. — *Terra Nova*, 8; 6-15.
Dercourt, J., Ricou, L. E. 1987. Discussion sur la place de la Bulgarie au sein du système alpin. — *Cnuc. Bulg. geol.*, 48, 3; 1-14.
Dobretsov, N. I. 1991. Blueschists and eclogites: a possible plate tectonic mechanism for their emplacement from the upper mantle. — *Tectonophysics*, 186; 253-268.
Graham, C. M., Powell, R. 1984. A garnet-hornblende geothermometer calibration, testing and application to the Pelona schist, Southern California. — *Metam. Geol.*, 2; 13-33.
Hey, M. 1954. A new review of the chlorites. — *Miner. Mag.*, 30; 277-305.
Kozhoukharova, E. 1989. Evolution of metamorphism in the Rhodope Massif. — XIV Congress CBGA, Sofia, 1989, Extended Abstracts; 298-302.
Kozhoukharova, E. 1996a. New Data for the Geologic Position of the Precambrian Ophiolitic Association in the Rhodope Massif. — *C. R. Acad. bulg. Sci.*, 49, 1; 57-60.
Kozhoukharova, E. 1996b. Eclogitized layered serpentinites in the East Rhodope block. — *C. R. Acad. bulg. Sci.*, 49, 6; 69-71.
Kozhoukharova, E. 1997. Synmetamorphic metasomatic gabbroids in the ophiolites from East Rhodope block. — *C. R. Acad. bulg. Sci.*, 50, 6; 83-86.
Macheva, L., Kolcheva, K. 1992. Metagranitoids from East Rhodopes — occurrences and main features. — *C. R. Acad. bulg. Sci.*, 45, 6; 63-66.
Mposkos, E., Waerwinitz, N. 1995. Metapegmatites and pegmatites bracketing the time of metamorphism in polymetamorphic rocks of the E. Rhodope, N. Greece: petrological and geochronological constraints. — *Proceedings, XV Congress of the CBGA, Athens 1995*; 602-608.
Murrell, S. A. F. 1985. Aspects of Relationships between Deformation and prograde Metamorphism that Causes Evolution of Water. — In: A. B. Thompson, D. C. Rubie (Eds.). *Metamorphic Reactions. Kinetics, Textures, and Deformation*. Springer Verlag; 211-241.
Peytcheva, I., Quadt, A. V. 1995. U-Pb zircon dating of metagranites from Byala-reka region in the East Rhodopes, Bulgaria. — *Proceedings, XV Congress of the CBGA, Athens 1995*; 637-642.
Sokoutis, D., Brun, J. P., Driesche, J. Van Den, Pavlides, S. 1993. A major Oligo-Miocene detachment in Southern Rhodope controlling North Aegean extension. — *J. Geol. Soc. L.*, 150; 243-246.
Tchoumatchenco, P. V., Sapunov, I. G. 1989. Paleontological evidence of Precambrian age of the marbles at the Asenova Krepost Castle (Central Rhodopes, Bulgaria). — *Geologica Balcanica*, 19, 1; 33-36.

PLATE I



- Арнаутов, В. 1976. Десилицирани пегматити от Рила планина. — *Год. СУ, геология*, 1; 129-147.
- Арнаутов, В., Петрусенко, Св. 1968. Розов цоизит и клиноцоизит от Рила планина. — *Сп. Бълг. геол. д-во*, 29, 3; 317-321.
- Боянов, Ив., Русева, М. 1984. Структурные особенности Белоречкого поднятия. В: *Особенности становления земной коры в докембрий Южной Болгарии. Проблема IX многостороннего сотрудничества Акад. Наук соц. стран.*, Геол. инст. БАН; 118-135.
- Боянов, И., Маврудчиев, Б., Вапцаров, И. 1963. Върху структурно-формационните особености на част от Източните Родопи. — *Изв. Геол. инст.*, 12; 125-186.
- Боянов, И., Русева, М., Топракчиева, В., Димитрова, Е. 1990. Литостратиграфия мезозойских пород в Восточных Родобах. — *Geologica Balcanica*, 20, 5; 3-28.
- Вергилов, В., Кожухаров, Д., Боянов, И., Маврудчиев, Б., Кожухарова, Е. 1963. Бележи върху допалеозойските метаморфни комплекси в Родопския масив. — *Изв. Геол. инст.*, 12; 187-211.
- Добрецов, Н. Л., Конников, Э. Г., Медведев, В. Н., Складарев, Е. В. 1985. Офиолиты и олистростромы Восточного Саяна. — В: *Рифейско-нижнепалеозойские офиолиты Северной Евразии*. Новосибирск, „Наука“. 34-58.
- Иванов, Р. 1961. Стратиграфия и структура на кристаллина в Източните Родопи. — *Тр. геол. Бълг., сер. Геохим. и пол. изкоп.*, 2; 69-119.
- Кожухаров, Д. 1968. Докембрий. Протерозойски комплекс. — В: *Стратиграфия на България*, С., „Наука и изкуство“, 25-62.
- Кожухаров, Д. 1984. Литостратиграфия докембрийских метаморфических пород в Централных Родобах. — *Geologica Balcanica*, 14, 1; 43-88.
- Кожухаров, Д. 1987. Литостратиграфия и строение докембрия в ядре Белоречкого поднятия в Восточных Родобах. — *Geologica Balcanica*, 17, 2; 15-38.
- Кожухаров, Д., Тимофеев, Б. 1979. Первые находки микрофитофосилий в докембрий Родопского массива. *Докл. БАН*, 32, 12; 1691-1694.
- Кожухаров, Д., Тимофеев, Б. 1989. Микрофитофосильные данные о докембрийском возрасте Родопской супер-группы (Ситовская и Асеновградская группы) в Централных и Западных Родобах. — *Geologica Balcanica*, 19, 1; 13-31.
- Кожухаров, Д., Кожухарова, Е., Боянов, И. 1984. Стратиграфическое положение и состав Ботурченской группы Прародопской (Огражденской) надгруппы в ядре Белоречкой структуры в Восточных Родобах. — В: *Особенности становления земной коры в докембрий Южной Болгарии. Проблема IX многостороннего сотрудничества Акад. Наук соц. стран*, С. Геолог. Инст. БАН; 112-117.
- Кожухарова, Е. 1977. Образование двухфациальных минеральных парагенезисов при региональном метаморфизме докембрийских серпентинитов в Западных Родобах. — *Изв. Геол. инст., сер. Геохим., минер. и петр.*, 7; 47-62.
- Кожухарова, Е. 1984а. Происхождение и структурное положение ультрабазитов докембрийской офиолитовой ассоциации в Родопском массиве. ²Геологическое положение и состав офиолитовой ассоциации. — *Geologica Balcanica*, 14, 4; 9-36.
- Кожухарова, Е. 1984б. ²²Метаморфические изменения ультрабазитов. — *Geologica Balcanica*, 14, 6; 3-35.
- Кожухарова, Е. 1985. ²²²Этапы развития и возраст офиолитовой ассоциации. — *Geologica Balcanica*, 15, 5; 53-69.
- Кожухарова, Е., Кожухаров, Д., Загорчев, И., Боянов, И. 1988. Гнайсогранити в Източните Родопи. — *Сп. Бълг. геол. д-во*, 49, 2; 53-65.
- Колчева, К., Цончева, А. 1993. Глаукофанови склогити от Източните Родопи. — В: *Развитие на българската минералогия. Резюме на Научна сесия, София, 1993*; 31-32.
- Костов, И. 1993. Минералогия. — С., „Техника“, 734 с.
- Магматические горные породы. Классификация, номенклатура, петрография. 1983. — Отг. ред. О. А. Богатиков, т. 2. М., Наука; 366 с.
- Пейчева, И., Бибилова, Е., Макаров, В. 1992. U-Pb изотопное датирование цирконов двух типов гнейсов Юго-Восточных Родоп, Болгария. — *Докл. БАН*, 45, 8; 71-74.
- Приставова, С. 1996. Метаморфизирани базични магматити от източната периферия на Мадан-Давидковската структура. — *Сп. Бълг. геол. д-во*, 57, 1; 9-20.
- Срикантаппа, К., П. Херманн, К., М. Райт. 1987. Петрология и геохимия расслоенных ультраосновных-основных комплексов архейского кратона Карнатака, Южная Индия. — В: А. Кренер, Г. Н. Хенсон, А. М. Гудвин (ред.) *Геохимия архея*. М., Наука, 173-199.
- Ферштатер, Г. Б. 1990. Эмпирический плагиоклаз-роговообманковый барометр. — *Геохимия*, 3; 328-335.
- Фонарев, В. И., Графчиков, А. А., Конилов, А. Н. 1989. Система согласованных минералогических термометров для метаморфических комплексов. — В: В. А. Жариков (ред.) *Физико-химический анализ процессов минералообразования*. М., Наука; 96-126.