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Metasomatic families in Bulgaria – a review

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А. Кунов – Метасоматические фамилии в Болгарии – обзор. Работа является сокращенным обобщением данных по метасоматическим семействам в Болгарии. Обобщение сделано на основании номенклатуры метасоматизма и метасоматических процессов, предложенной Подъкомиссией по систематике метаморфических пород.

В Болгарии представлены следующие семейства: скарновое, кварц-полевошпатовое, грейзеновое, березитовое, пропилитовое, вторичных кварцитов, эйситовое, аргиллизитовое, кварц-серицитовое, кварц-адуляр-серицитовое. Приведены данные об их широком распространении.

При характеристике семейств описаны признаки их индивидуальности, геологические и физикохимические условия образования, особенности минерального состава, поведение элементов, метасоматическая зональность и металлогеническое значение. Показана необходимость более широких исследований физикохимических условий, при которых происходит образование метасоматитов, а также – взаимоотношений разных семейств, их геохимической характеристики и металлогенической оценки. Автор считает, что обстоятельственный анализ метасоматических процессов и пород может способствовать выявлению новых семейств и может внести поправки и дополнения к характеристике уже известных, в том числе – и семейств, которые не обозначены на обобщенной диаграмме.

Abstract. The paper is a short summary of the metasomatic families in Bulgaria and is based on the nomenclature of metasomatism and metasomatic processes proposed by the Subcommission on systematic of metamorphic rocks.

The following families are represented: skarn, quartz-feldspar, greisen, beresite, propylite, secondary quartzite, aceite, argillisite, quartz-sericite, quartz-adularia-sericite ones. Their wide spread distribution in Bulgaria is described.

The characterization of these families includes indications for: individuality, geological and physical and chemical conditions of formation, peculiarities of the mineral composition and behavior of the elements, metasomatic zoning, and metallogenic importance.

It is outlined that there is need of larger scale studies of the physical and chemical conditions of formation, the interrelations between the families, the geochemical characteristics, and the metallogenic evaluation. A detailed analysis in future of the metsomatic processes and rocks may introduce some corrections and additions in the known families as well as to give opportunity for establishment of new families including those not registered already on the given diagram.

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Key words: metasomatic family, Bulgaria, a review.

Introduction

The metasomatic rocks in Bulgaria are widely spread. Their summarized representation is complicated due to problems that accompany their systemizing (Каназирски, 2006). In the Bulgarian geological literature among the known classifications of the wall-rock alterations that are used to different extent are those of Meyer and Hemley (1967), Жариков and Омельяненко (1978), Piranjo (1992), Русинов (В: Метасоматизм и ..., 1998), Corbett and Leach (1998), as well as the classifications of the epithermal deposits based on types of wall-rock alterations and ore mineralizations (Hayba et al, 1985; Heald et al, 1987, Hedenquist and Lowenstern, 1994; White and Hedenquist, 1995; Hedenquist et al, 1996). A good opportunity for proper determination of the appurtenance of metasomatites is given by the systematic of the metasomatic families incorporated in the proposed already nomenclature of metasomatism and metasomatic processes (Zharikov et al., 2007). The scheme of the metasomatic systematics is constructed on the basis of the main elements – metasomatic facies and family.

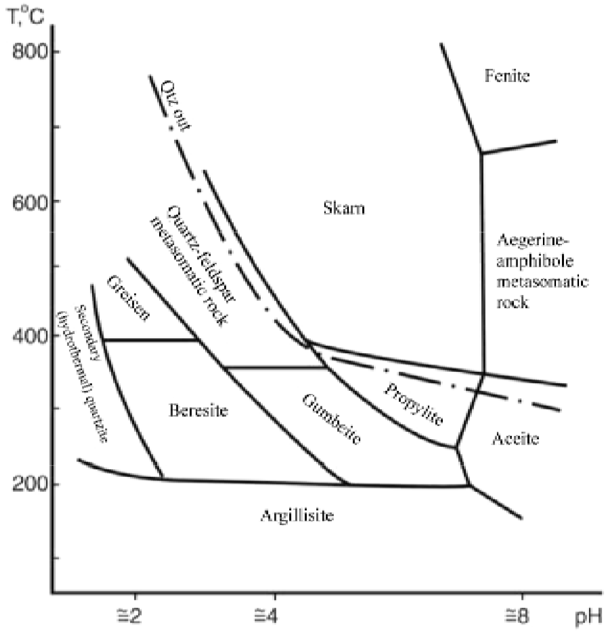

Fig. 1. Diagram, illustrating the general T-quantitative pH fields of the metasomatic families. The dot-dash line separates acidic and neutral-alkaline families (with and without quartz) (Zharikov et al., 2007)

The diagram on Figure 1 shows the most widely spread metasomatic families. The authors propose that when describing other metasomatic families these must be typical and widely spread. The Subcomission on systematic of metamorphic rocks additionally recommends that in such cases the rocks have to be named acounting for the mineral composition.

From the metasomatic families shown on the diagram characteristic for Bulgaria (Fig. 2) are the following ones: skarn, quartz-feldspar metasomatites, greisen, beresites, propylites, secondary quartzites, aceites, and argillisites. The author of this paper includes in addition the quartz-sericite and quartz-adularia families (Table 1) proposed by Zharikov and Omelyanenko (Жариков and Омельяненко (1978). Reason for this is their distribution (Каназирски et al., 2000; Kanazirski et al, 2002, Кунов et al., 2003) and metallogenic importance in Bulgaria. Taken into acount are also the products of potassium feldspatization and granitization (Вергилов, 1960; Борисов, 1960; Маринов, 1991). The data for rodingites (Желязкова, 1974; Колчева, Йорданов, 1984) are still not enough for specifying a separate family. Zharikov et al. (2007) have described a new family of alkaline metasomatites, connected with regional fault structures and having concrete representatives of al-

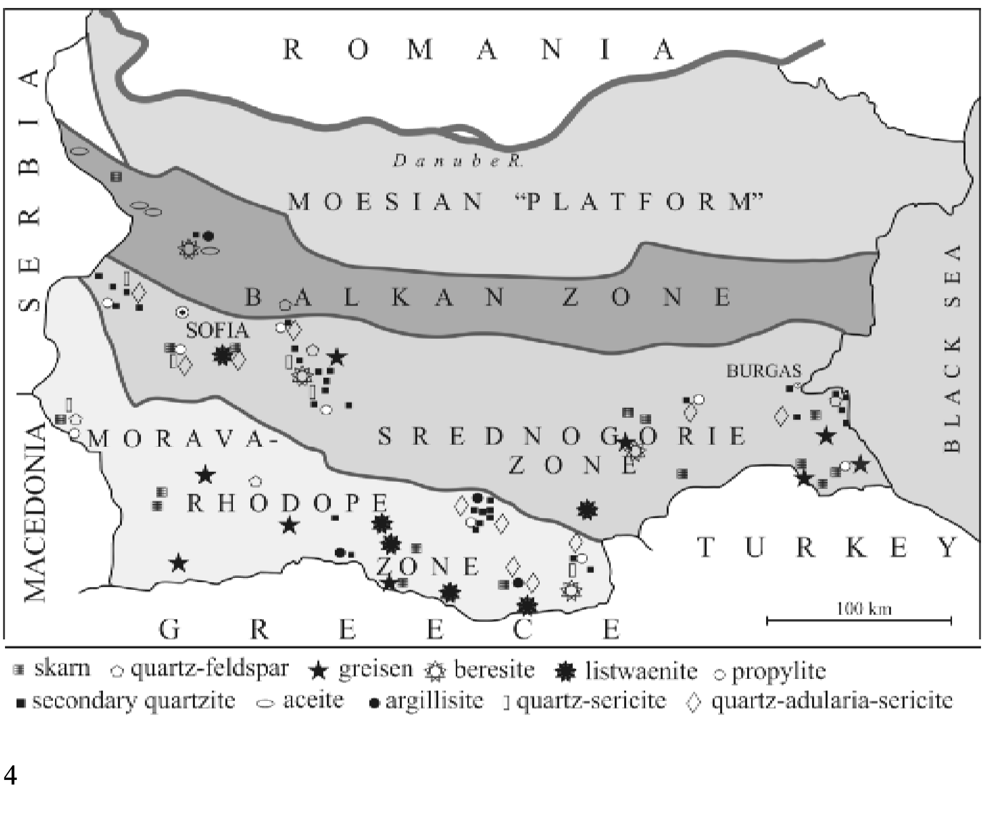

Fig. 2. Distribution of the more important metasomatic families in Bulgaria (tectonic scheme after Dabovski et al., 2002)

Table 1
Distribution of the metasomatic families in Bulgaria

Metasomatic family	Region, deposit, occurrences	References
Skarn	Western Stara planina Mts. (Martinovo); Western Srednogorie (Ostra Mogila, Chupetlovo); Eastern Srednogorie (Krumovo, Boydzhik, Iglika, Fakiya, Zvezdets, Gramatikovo, Malko Tarnovo); Osogovo (Svlachishteto, Lagera); Rila (Beliyat uluk, Orlovets, Petlite); Rhodopes Mts. (Osikovo, Mogilata, Petrovitsa, En'ovche, Erma Reka and others)	Бонев, 1968; Желязкова et al., 1972; Иванова-Панайотова, 1973; 1974; Гаджева, 1978; Мънков, 1984; Кольковски, Манев, 1988; Йорданов, 1988; Цветанов et al., 1988; Тарасова, 1984; Иванова-Панайотова, Каназирски, 1995; Петрусенко, 2002; Tzvetanova, 2002
Quartz-feldspar metasomatic rocks	Botevgrad Stara planina Mts.; Central Srednogorie Elatsite, Medet and others.); Osogovo (Ruen Ore Field); Eastern Srednogorie (South of the Sozopol); Westren Rhodopes (Grancharitsa)	Андреева, 1977; Цветанов, Славилов, 1979; Димитров, 1981; Арнаудова et al., 1991; Стоянова, 1992; Strashimirov et al, 2002; Kanazirski et al, 2002
Greisen	Central Srednogorie; Rila (Babyak) South Pirin (Petrovo); Western Rhodopes (Srebren); Central Rhodopes (Chereshkite); Strandzha (Bardtse, Dolno Panicharevo, Brodilovo); Sakar (Polski gradets)	Делчев, Димитров, 1965; Стайков et al., 1968; Михова et al., 1981; Стайков, Ангелков, 1986; Йорданов, 1988; Скендеров et al., 1994; Мънков – unpublished data ; Ангелова – unpublished data, and others
Beresite	Western Stara planina Mts. (Cherveni dol); Ihtiman Sredna Gora (Yamkite); Central Srednogorie (Panagyurishte Ore Region), Eastern Rhodopes (Laki Ore Field, Madan Ore Field, Lozen Ore Field, Popsko Ore Field, Dobroselets, Golyamo Kamenyane, Dobromirtsi)	Желязкова-Панайотова, 1960; 1963; Цветанов, 1976; Цветанов et al., 1984; Цветанов, Бресковска, 1984; Михова, Стайкова, 1985; Кольковски, Манев, 1988; Бресковска, Гергелчев, 1988; Velinov and Nokov, 1992; Петрова, 1995: Плющев et al., 1995; Христова et al., 1997; Каназирски et al., 2000, Zheliazkova-Panaiotova et al, 2000; Желязкова-Панайотова et al., 2000; Паздеров et al., 2005
Propyllite	Westren, Central and Eastern Srednogorie, Rhodopes	Радонова, 1962, 1969, 1970, 1973; Велинов, 1974; Радонова, Велинов, 1974; Чипчакова, 1974; Цветанов, 1979; Цветанов, Славилов, 1981; Кунов 1986; Попов et al., 1994, Popov et al, 2000, a, b
Secondary (hydrothermally) quartzite	Western Stara planina Mts. (Ignatitsa); Western Srednogorie (Krusha, Pishtene, Breznik, Gurgulyat, Klisura); Central Srednogorie (Chelopech, Asarel, Radka, Petelovo, Pesovets, Elshitsa, Tsar Asen); Wetern Srednogorie (Bakadzhik, Zidarovo, Alefo Tumba, Kavatsite, Dyuni, Ropotamo); Central Rhodopes (Stomanovo); Eastern Rhodopes (Spahievo and Madzharovo Ore Field)	Velinov et al, 2007
Aceite	Western Stara planina Mts. Kotenovtsi, Chuprene, Stakevtsi, Kostentsi, Pesochnitsa, in the river valley Proboinitsa, Gabrovnitsa, Elenov Dol)	Вълчев, Бедринов (1981); Маринов (1991)
Argillisite	Western Stara planina Mts. (Ignatitsa); Central Rhodopes (Perelik); Eastern Rhodopes (Zvezdel and Bryastovo Ore Field)	Бахнева, 1977; Цветанов, 1980; Плющев, 1994; Кунов et al., 1996
Quartz-sericite	Western Srednogorie (Chupetlovo, Radulovtsi); Central Srednogorie (Elatsite, Karlievo, Asarel, Radka, Krasen, Vlaikov Vrah, Elshitsa, Tsar Asen); Osogovo (Ruen Ore Field); Rhodopes (Madzharovo)	Велинов, 1974, Радонова, Велинов, 1974; Андреева, 1977; Velinov, Nokov, 1991; Popov et al., 2000; Popov et al., 2000a; Kanazirski et al, 2002
Quartz-adularia-sericite	Western Srednogorie (Zlatusha); Central Srednogorie (Chelopech); Eastern Srednogorie (Bakadzhik, Zidarovo and others.); Eastern Rhodopes (Chala, Bryastovo, Gaberovo, Sarnak, Han Krum, Rozino and others)	Kunov, Nakov, 2002; Кунов et al., 2003; Желев, 2007, and others

bitized granites and that family mignt be expected to be included in the nomenclature.

Characteristics of the metasomatic families in Bulgaria

A definition according to the nomenclature (Zarikov et al., 2007) is given for each family at the beginning of the description.

Skarn family

Skarn family is a metasomatic rock formed on the contact between a silicate rock (or magmatic melt) and a carbonate rock. It consists mainly of Ca-Mg-Fe-Mn- silicates, which are free or poor in water.

Magnesian skarn is a high-temperature skarn rock containing forsterite, diopside, spinel, periclase, clinohumite, phlogopite, pargasite and is formed at the contacts of magmatic and calc-magnesian or magnesian carbonate rocks. Typically magnesian skarns may host ores of iron, base metals, Cu, Au, Fe-Mg- borates, and phlogopite.

Calc-skarn is a high (to medium) temperature skarn consisting mainly of granditic garnet, salite (to ferrosalite or/and johannsenite-rich pyroxene), wollastonite or Mn-rich pyroxenoids and is formed at the contacts of magmatic (or other silicate rocks) with calcium carbonate rocks. It can replace former magnesian skarns (in hypabyssal or subvolcanic conditions). Typically calc-skarns may host ores of Fe, base metals, Cu, W, Mo, Be, B, U, REE.

Geological and physical-chemical conditions of formation. Correlations with other metasomatites

Important feature during development of skarns is the existence of a contact between intrusive and carbonate rocks. Except specifying them in sub-families of magnesium and calcium skarns additional characteristic feature is that they can form both in the magmatic and postmagmatic (only magnesium skarns) stages. In Bulgaria there exist two principle opinions about skarns as a family (Иванова-Панайотова, 1974; Каназирски, 2007) and as rocks and products of scarning (Бонев, 1968).

The individuality of the skarn family in Bulgaria is determined by the development of both the calcium and magnesium skarns. A fully mobile state of MgO has been established for the magnesium skarns when they form after marbles (Иванова-Панайотова, 1973). The rarely found mono-mineral garnet skarns have also been described (Бонев, 1958).

The magnesian skarns of the magmatic stage had formed before the post-magmatic magnesian and calc skarns. One important contribution is the proved relation of the magnesian skarns to more basic components of the intrusives that react upon more weakly dolomitized marbles (Иванова-Панайотова, 1973).

Analysis of formation of the monticellite magnesian skarns in Iglika deposit (Иванова-Панайотова, Каназирски, 1995) showed;

– inert behavior and slow mobility of Al_2O_3 accompanied by piling in the at the rear magnesian zone; MgO is a fully mobile component; SiO_2 being also a very mobile component has been easily migrated from the rear zone towards the zone of the monticellite skarns;

– Al_2O_3 and SiO_2 are inert in the zone of the monticellite skarns, while MgO is fully mobile;

– SiO_2 is the only inert component in the monticellite-calciferous zone;

– in all zones the CaO component is fully mobile.

Typical features are the post-magmatic alterations, which took place accompanied by changes in the mineral composition (for example spinel-forsterite skarns transfrom to clinohumite ones), but without the formation of new metasomatic columns.

The magnesian skarns of the post-magmatic stage come just after these of the magmatic stage and before the calc-skarns and are most often diffusion bimetasomatic and more rarely – contact-infiltrational.

Ivanova-Panayotova (unpublished data, 1995) proposed that many of the skarn deposits have been formed during replacement of magnesian skarns. Based on the analysis of the geological environment and the peculiarities of the mineral composition this researcher has proposed the specifying of a separate apomagnesian calc formation.

Imposed greisen mineralizations in skarns have been observed (Йорданов, 1988) as well as small skarn bodies situated among propylitized monzonites (Tzvetanova, 2002).

Tzvetanov et al. (Цветанов et al., 1979) consider the skarns in Madan ore field being composed of time divided own skarn and overprinted mineral associations. They relate the imposed low- to medium temperature paragenesis to beresite type hydrothermal alteration of gneisses.

Mincheva-Stefanova and Gorova (Минчева-Стефанова, Горова, 1965) have separated a skarn stage in Gradishte deposit and noted that skarn mineralizations are in the form of lenses with various dimensions. The above authors consider that the formation of the metasomatic ore bodies are not only a result of replacement of skarns caused by the hydrothermal solutions but are result also of replacement of the host marbles.

In the region of river Erma the metasomatic alterations that include skarn stage are found on the contact of marbles and gneisses (Гаджева, 1978).

Peculiarities of the mineral alterations and behavior of elements

An calc-skarn mineralization is overprinted upon the monticellite skarns in Iglika deposit that is represented by vesuvian, grossular, diopside, calcite, chlorite.

It is proved that the mineral composition of calc-skarns from the different Bulgarian deposits is composed of: hedenbergite, Mn-hedenbergite, diopside, andradite, grossular, pyroxene, johannsenite, ilvaite, Mn-ilvaite, rhodonite, bustamite, epidote, vesuvian, zoisite, wollastonite, scapolite, titanite, apatite, pyrite, chalcopyrite, hematite, calcite, quartz, etc. (Минчева-Стефанова, Горова, 1965; Иванова-Панайотова, 1974; Гаджева, 1978; Кольковски, Манев, 1988; Цветанов et al., 1988; Цветанов, Цветанова, 1993).

In the case of magnesian skarns the main minerals characterizing the magmatic stage are spinel, pyroxene (fasaite?), forsterite, periclase. The minerals of the post-magmatic stage are represented by clinohumite, monticellite, phologopite, chrysotite, antogorite, and serpophite.

The chemical analyses determined the varieties of vesuvian from the calc-skarns in Rila as low Fe-containing ones (Петрусенко, 2002; Желязкова-Панайотова et al., 1972) have reported on the mineralogical features of REE-containing skarns.

Metasomatic zonning

Best examples for such zoning are shown by Ivanova-Panayotova (Иванова-Панайотова, 1974); unaltered intrusive rock (sienodiorites, gabrodioritic porphirites, pyroxenites) → plagioclase-pyroxene rocks → spinel-pyroxene skarns → forsterite skarns → forsterite calcifires? → host dolomites and marbles. In such a way two types of metasomatoc columns are formed: first type with full development of the column – spinel-pyroxene skarns → forsterite skarns → forsterite calcifires and a second type, in which the forsterite calcifires are missing. The following mobility raw has been determined – H_2O, CO_2, K_2O, Na_2O, CaO II MgO, SiO_2, Al_2O_3.

Metallogenic specialization and importance

The calc skarns in Martinovo (Тарасова, 1988) are host medium for magnetite-pyrhotite ore formation. Also, significant ore formations are related to the magnesian skarn deposits in Southeast Bulgaria mainly, magnetite ones with boron-containing minerals in the forsterite zone and boron-containing minerals both in the forsterite zone and the zone of forsterite calcifires. In the region of Svlachishte and Lagera (Osogovo Mt; Мънков, 1984) there have been found self-detached bismuth mineral paragenesis. In the region of river Erma (Гаджева, 1978) the skarns are hosts of polymetal ore formations.

Family of quartz-feldspar metasomatites

It is difficult to define and describe exactly this family because it is included in the diagram as quartz-feldspar metasomatic rocks but is missing in the paper of Zharikov et al (2007). The above, together with other problems give us reason to accept currently this family as being a result of potassium and sodium metasomatism, which corresponds to the opinion of the respective Bulgarian authors and the specification of this family in Bulgaria was given by Kanazirski et al. (2002).

Geological and physicochemical conditions of formation. Relations to other metasomatites

An expressed relation to granitoid magmatism is established characterized by clear structural control. The metasomatic bodies in Western Stara planina Mt are with linear elongated form and are well developed in depth. Two tectonic ruptures are observed in Ruen ore field, which form sub-parallel halos.

The constant presence of potassium feldspar and plagioclase with varying ration is a main feature, which defines the individuality of the formation.

Strashimirov et al. (2002) stated that the K-feldspar – biotite metasomatites described by Arnaudova et al. (Арнаудова et al., 1991) in some places of the propylitic granodiorite porphyrites show, in fact, early potassium-silicate and potassium-silicate-propylitic alteration. The epithermal sericitization and intensive argillization in the lithocaps are overprinted on propylite and potassium-silicate alterations.

According to Vergilov (Вергилов, 1960) the crystalline schists in the Central and Western Rhodopes are deeply metasomatically reworked. The manifestations of potassium feldpatization (and granitization) had proceeded depending on the potassium content (in the host rocks or intruded) and the quantity of Mg and Fe in the host rocks.

Tzvetanov and Slavilov (Цветанов, Славилов, 1979) sate that the quartz-feldspar metasomatites into south of Sozopol town transfrom into sericitic metasomatites when the content of sericite increases. Secondary quartzites and quartz-sericite metasomatites overprint the former rocks.

Peculiarities in the mineral transformations and behavior of the elements

Except potassium feldspar and plagioclase (albite, albite-oligoclase) the altered rocks contain in addition quartz, biotite, sericite, chlorite, and magnetite. Almost full pseudomorphism of potassium feldspar and plagioclase is reached in the host rocks. Strashimirov et al. (2002) have noted for Elatsite deposit that during the potassium-feldspar type of alteration (namely potassium-silicate one) a replacement is taking place – the primary potassium feldspar, biotite, plagioclase, and amphibole are later replaced by potassium feldspar, biotite and quartz. More rarely, the magmatic biotite is replaced by chlorite while plagioclase is transformed into calcite and illite.

In Ruen ore field the differential mobility of the components is the following: H_2O, SiO_2, CaO, FeO, MgO, Na_2O, K_2O, Al_2O_3.

Metasomatic zoning

The zoning in Ruen ore field is discussed in detail. One characteristic feature there is its unilateral development with halos with repeating mineral composition. Five zones foram after the fine-porphiritic deleniteporphyrs:

– sericite, plagioclase, chlorite, magnetite, quartz, orthoclase;
– sericite, plagioclase, chlorite, quartz, orthoclase;
– sericite, albite-oligoclase, quartz, orthoclase;
– albite, quartz, orthoclase (relics);
– albite, quartz.

Metallogenic specialization and importance

The quartz-feldspar formation in Ruen ore field is connected with the tingsten-molibdenum one, while Grantcharitsa deposit it is in relation with the tungsten mineralization.

Greisen family

Greisen: This is a medium-temperature metasomatic rock characterised by the presence of quartz and white mica, commonly with topaz, fluorite, tourmaline and locally with amazonite, orthoclase, andalusite and diaspore. Typically greisens may host Be, W, Mo, Sn, and Ta mineralization. They are associated with high-level late-orogenic leucogranites and form as replacements either in the granite body and/or in a wide range of country rocks. Zoning may be present.

Greisenization is a metasomatic process leading to the formation of greisen.

Geological and physicochemical conditions of forming. Relations to other metasomatites

In the majority of cases typical greisens have not been described. The reports have introduced terms like "greisenoids", "pseudogreisens", "not typical quartz-muscovite greisenization" or "greisen-like rocks" (Делчев, Димитров, 1965; Стайков et al., 1968; Михова et al., 1981; Йорданов, 1988 et al.). Angelova et al. (unpublished results) have observed quartz-muscovite greisens in Srebren deposit. However, it is quite possible that the family is fully developed and thus, the observable zones are only the outermost ones. Most convincing, although small in volume are the data of Zidarov et al. (2007) for the region of Klyuch village (Belassitsa mountain). The post-magmatic processes had developed in a tectonic zone with length of 1800 m and width between 30 and 120 m in granitoids. The above authors have specified processes of greisenization and sericitization. The greisens are composed of muscovite (radial aggregates), coarse-grained xenomorphic quartz and random fluorite, tourmaline, beryl, cassiterite, molybdenite, and scheelite. These materials are of no economic significance.

Usually gresenization develops on granitoids and gneisses and has area or fissure-related character. Important for the gresenization in Babyak deposit (Делчев, Димитров, 1965) is the role of the ore-bearing meridional faults. The metasomatic rocks had formed at hifg-temperature conditions when the solutions had reached maximal acidity. In some cases the alterations overprint scans and quartz-feldspar metasomatites (Bardtseto deposit).

Peculiarities of the mineral alterations and behavior of elements

Main minerals are quartz and muscovite but there are also present albite, cassiterite, molibdenite, fluorite, barite, etc. Plagioclase minerals are entirely replaced by muscovite and when the alterations are upon quartz-feldspar or scarn metasomatites the mineral composition of the later does not change substantially but quartz content in quartz-feldspar metasomatites increases while the content of amphiboles is increased in the scarn metasomatites. A tendency is observed towards single mineral phase content during formation of rear quartz zones.

Metasomatic zoning

Such zoning is not well expressed and therefore it is not well studied. Angelova et al. (unpublished results) describe the following zones for Srebren deposit: non-altered granite, chlorite-sericite, quartz-sericite, quartz-muscovite ones.

Metallogenic specialization and importance

The ore mineralizations are mostly of the molibdenum-tungsten type.

Beresite family

Beresite is a low-temperature metasomatic rock characterised by quartz, sericite, carbonate (ankerite) and pyrite assemblages resulting from the replacement of both igneous and sedimentary protoliths. It may be associated with a variety of Au, Au-Ag, Ag-Pb, U ore mineralizations.

Beresitization: This is a metasomatic process resulting in the formation of beresite or listwaenite.

Geological and physicochemical conditions of formation. Relations to other metasomatites

The formation of beresites or listwaenite results from the action of beresite-forming hydrothermal solutions in magmatic and sedimentary or ultrabasic rocks. The rocks from the beresite family in Bulgaria are formations at the earth surface. Their forming and defining is strongly related to the role of the original rocks and the conducting fault structures. The beresite and listwaenite bodies are elongated in form and their fault attachment is well expressed. Their dimensions reach sevetal tens of meters. Sometimes the closeness of the bodies along the lateral metasomatic zoning creates the impression for a wider area alteration.

The presence of ankerite is an indication for the individuallity of this family. Listwaenite type on marbles in Madan ore field has been described (Кольковски, Манев, 1988) characterized with formation of manganocalcite, quartz, troilite, hematite, and talk.

Mihova and Staikova (Михова and Стайкова 1985) have described this family following the alteration sequence (type integral metasomatic column). Later, Kanazirski (Каназирски, 2007) commenting the family has added and idealized metasomatic column giving background for affirmingof this family.

The analysis of the physicochemical conditions of formatinn of beresites in Cherveni dol ore manifestation (Каназирски et al., 2000) has shown that these products are moderately acidic metasomatites (pH 3–5,5). The stability of the paragenesis quartz+sericite+ankerite+pyrite needs sufficiently high concentration of Ca, Mg and CO_2. The limits of the temperature conditions of the noted paragenesis are 400–350 to 250–200° C and pressure of 0,5–3 kbar.

In the region of Svetulka village (Ardino region) the hydrothermal activity in serpentinites with antigorite and chrysotile composition has lead to formation of listwaenites. They form a body in the form of halo to north of the cropping out ultrabasites (Паздеров et al., 2003).

From the other metasomatic families the argillizites are the ones that can be observed together with beresites (Плющев, 1994) as well as rocks with propylite type of alteration (Плющев, 1994), whereas listwaenites are relatively independent. There are cases when alterations of quartz-adularia type overprint the listwaenites (Velinov and Nokov, 1992).

Peculiarities of the mineral transformations and behavior of the elements

The beresitization in Cherveni dol ore manifestation (Каназирски et al., 2000) is characterized by complete pseudometamorphis of biotite and partial one of plagioclase to sericite, acccompanied by rich development of potassium feldspar in the main mass as well as by significant quartz formation.

The sequence of differntial mobility of components in the same ore manifestation is as follows: Ca $\rightarrow$ Na $\rightarrow$ Mg. The same sequence was proved for Vozdol (Каназирски, 2007)

The beresite family in Madan ore field has been related to processes that had taken place on granite-gneisses and gneisses before the ore alteration processes (Кольковски, Манев, 1988).

Metasomatic zoning

Three zones are specified in Cherveni dol ore manifestation formed after the original rocks (dacites, andesites, and diorite porphyrites) and the propylitized andesites (with epidote, chlorite, albite, and calcite), namely:

– weakly beresitized rocks – chlorite, albite, calcite, illite/muscovite, quar, pyrite;

– beresitized rocks – albite, ankerite, calcite, illite/muscovite, quartz, pyrite;

– intensively beresitized rocks – ankerite, illite/muscovite, quartz, pyrite; illite/muscovite, quartz, pyrite.

Basing on the data of Mihova and Staikova (Михова, Стайкова, 1985) Kanazirski (Каназирски, 2007) has constructed an idealized metasomatic column for the zoning in Vosdol separating a beresite facies of the beresite formation.

The zoning in Madan ore field is also well expressed (Кольковски, Манев, 1988): quartz-sericite-carbonate-pyrite $\rightarrow$ chlorite-carbonate ($\pm$ albite, rarely epidote, very rarely adularia) zone.

For the chromite deposit Golyamo Kamenyane Zhelyazkova-Panayotova (Желязкова-Панайотова, 1962) has described listwanites that have developed on ultrabasic rocks where this author has found outer and inner zoning.

The zoning proved for Sveta Marina deposit in Lozen ore field (Цветанов, Бресковска, 1984) outlines the following zones: ultrabasites $\rightarrow$ quartz-sericite-carbonates (calcite, dolomite, ankerite, rarely siderite) $\rightarrow$ central part (dolomite, quartz, chlorite, brannerite, and small amount of ankerite).

Pazderov et al. (Паздеров et al., 2005) have described the listwaenites from ore manifestation Svetulka, which are characterized with variable composition – from above 90% silicon dioxide to above 90% carbonate minerals. Probably these are signs for a not well expressed zoning. Just after listwaenites there are marbles that are disposed and calcite mineralization is impregnated in these carbonate rocks.

The intensive alteration in Yamkite ore manifestation is marked by silification, quartz-mariposite and overprinted sulfide mineralization. The following tendency is outlined for alteration from intensive to relatively pure hydrothermal metamorphites: silification $\rightarrow$ quartz-mariposite quartz-sericite $\rightarrow$ altered rock of propylitic type (Velinov and Nokov, 1992).

Metallogenic specialization and importance

The importance of beresites and listwaenites as an alteration in lead-zinc and some gold containing deposits in Bulgaria is out of doubt. However, the ore potential of listwaenites still remains not clear, although they are gold bearing in many ore manifestations.

Propylite family

Propylite: is a low to medium temperature metasomatic granofels formed by the alteration of basic volcanic rocks; low temperature varieties are principally composed of albite, calcite and chlorite; high-temperature varieties are composed of epidote, actinolite and biotite. They form at the postmagmatic stage.

Propylitization: is a metasomatic process leading to the formation of propylites.

Geological and physicochemical conditions of formation. Relation to other metasomatites

Propylitization is directly connected with intrusive and volcanic activity as well as with fault disturbances. This process influences predominantly rocks with basic and medium composition and is manifested also in granitoids but is not typical for volcanic rocks with acidic composition.

Propylites form at small depth as a result of action of slightly acid solution. The temperatures are low to medium high. In the majority of cases there is registered an increase in the activity of K_2O at the end of the process accompanied by respective lowering of the activity of Na_2O.

The metasomatites related to the family of propylites are developed mainly on rocks with basic to medium composition. One characteristic feature is the presence of associations being in more or less equilibrium, namely: amphibole-epidote, epidote-chlorite, chlorite-carbonate, sericite-carbonate, quartz-sericite. One interesting point is the different relation of adularia to propylites. The same is the problem with the zeolitization in Srednogorie and Rhodopes.

From another side the question concerning acceptance of the propylite type altered rocks either as a family or as a peripheral zone of the family of secondary quartzites is not enough clarified (Velinov, Kanazirski, 1990; Velinov et al, 1990).

Kanazirski (unpublished results) has noted that the process of propylitisation and the propylite type rocks are widely distributed in Bulgaria, but columns with inner zones, which are typical for the propylite family are rarely found (Velinov, Kanazirski, 1990).

The propylite family has a formational independence but dieplays also clear relations with argillizites, secondary quartzites, and quartz-sericite metasomatites.

Peculiarities of the mineral transformations and behavior of elements

Main minerals are albite, chlorite, carbonate, sericite, actinolite, quartz, pyrite, but some authors add adularia and zeolites as well. Typical are the pseudomorphs of the primary rock-forming minerals and replacement of the main mass of the volcanic rocks. Al they are partial up to complete.

Velinov (2002) has noted two interesting features of the propylites from Western Srednogorie: mutual development of actinolite and prehnite and of uralite in association with basic plagioclase (An – 60–80%).

The petrogenetic components display various differential mobility. SiO_2, Al_2O_3, and TiO_2 remain inert up to the end of the process. MgO, FeO, Fe_2O_3, Na_2O, K_2O, and CaO are inert and during separate stages they transform into an entirely mobile state.

The behavior of the chemical elements in the case of propylites is an expression of the peculiarities of the ore formation in the separate deposit and ore manifestations.

Metasomatic zoning

A specific character of the zoning is typical also for the Bulgarian deposits and is caused by the incomplete equilibrium of the process (Русинов, 1972). The development of the zoning is related to the geological and physicochemical conditions. The result that is found is diversity in the lateral and vertical zoning, from one side, and, from another side, in the mineral composition of the separate zones in the different deposits.

One main feature of the zoning that must be noted is the presence of actinolite or uralite and epidote in the relatively higher temperature facies, connected with intrusive source, frequent participation of chlorite-carbonate-albite facies, the presence of impregnated pyrite, etc.

Metallogenic speciallization and importance

The surface sin-volcanic propylitisation is characterized only by pyritization and thus it is with restricted potential. The examples from a row of copper and lead-zinc Bulgarian deposits (Radka, Elshitsa, Varli Bryag, Zvesdel, etc.) demosnstrate the ore importance and potential of the propylitization in Bulgaria.

Secondary (or hydrothermal) quartzite family

'Secondary quartzite': is a medium- to low- temperature metasomatic rock mainly composed of quartz with subsidiary high-alumina minerals, such as pyrophylite, diaspore, alunite and kaolinite. Common accessories include fluorite, dumortierite and lazulite. Secondary quartzites are associated with volcanic and subvolcanic rocks of rhyolitic to andesitic composition. Normally they form as replacements of acid igneous rocks and more rarely of sedimentary rocks. They may host mineral deposits of alunite, pyrophyllite, Au, Ag, Sb, Hg.

Geological and physicochemical conditions of formation. Relations to other metasomatites

The secondary quartzites are characteristic for surface conditions. There are cases of volcanic necks that have been described (Попов et al., 1993; Кунов et al., 1996) as well as cross-sections of faults with constant participation of the system 120–140° (Батанджиев, 1987). The metasomatic alterations have developed in rocks with medium basic to medium composition and there is only one case (Stomanovo) where the composition is more acidic.

They have formed at low temperatures. The formation of separate facies is related to temperature, pH of the medium and the chemical activity of K^+ and SO_4^{2-}. According to Kanazirski et al (2002) the hydrothermal system in the porphyry copper deposits Asarel, Petelovo, and Tsar Asen is with a predominant meteoric character. According to the data of Lerouge et al (2006) the alunites from nine Bulgarian deposits including the discussed porphires have been formed in a predominating magmatic hydrothermal system.

Among the peculiarities, which characterize the individuality of the family of secondary quartzite the most important are:

– development acidic-chlorid and acidic-sulfate type (Каназирски, 1996).

– almost constant and widespread presence of APS minerals in the alunite facies (Kunov et al, 2006).

Typical accompanying metasomatic families are the propylite, quartz-sericite, and argilizite ones. The secondary quartzites in Asarel deposit together with quartz-sericite metasomatites, which are epithermal products are developed in the upper levels of the porphiritic system (Каназирски, 1996; Каназирски et al., 2000).

Peculiarities of the mineral transformations and behavior of the elements

The family under discussion is characterized with a great number of typomorphic minerals: quartz, (cristobalite, opal, chalcedony), sericite, hydromica, kaolinite, dickite, alunite, diaspore, pyrophillite, andalusite, corundum, dumortierite, rutile, APS, etc.

The mobility of K_2O in definite parts of the integral column and the inert behavior of Al_2O_3, TiO_2 SiO_2 including as well the rear zones are specificities in the geochemical behavior of the elements. Among the elements most impressive are Sr and Ba.

The rare earth elements display the behavior of elements with medium mobility (Yordanov, Kunov, 1987). The propylitized latites and the dickite and alunite quartzites are enriched in rare earth elements and the over concentration of REE is respectively k_k = 1.4, 1.9 and 1.12. Marked change in the REE distribution in the case of quartz-sericite and diaspore rocks compared to the initial latites is not observed. The considerable depletion in REE in the monoquartzites (k_k = 0.06) shows direct dependence on the degree of acid extraction.

Metasomatic zoning

The family is a classical representative of the dependence on the metasmatic zoning on the geological and physicochemical conditions of formation with expressed tendency to monomineral composition towards the rear zones.

The investigation of the metasomatic zoning in the secondary quartzites (Velinov et al, 2007) has revealed the following peculiarities:

– the outer zones of the transition to unaltered rocks are built by propylitized rocks (exceptions are Stomanovo and to a great extent Susam and Svetlina);

– the establishment of opalized rocks on the transition to unaltered rock (for example Susam locality) determines the zoning to be of the types “degradation of the outer zones” and “development of metastable opal instead of quartz, which is typical for conditions in greater depth” (Русинов, 1972);

– quartz-alunite facies participates in almost all deposits;

– the presence of fluorine, chlorine, and boron and the minerals that contain these elements (zunyite, topaz, dumortietrite) is an indication for existence of halogen-acid solutions that cause specific mineralizations;

– the absence of some zones, which could have formed, is explained basing on the thesis of Rusinov (Русинов, 1984) for extremely nonequilibrium conditions of mineral formation and drastic change in the acidity;

– in case of fault disturbances, influence of subvolcanic and ontrusive bodies, and relatively higher temperature solutions there can be obtained some complications in the vertical zoning (Madjarovo, Bryastovo, Dyuni, etc.)

– characteristic feature of the zoning in secondary quartzites is the development of various bi-mineral paragenesesin the metasomatic columns of several object (for example the Spahievo ore field).

Kanazirski (Каназирски, 1996) has performed an experimental modeling of upper parts of the copper-porphyry deposit Asarel and the obtained metasomatic columns reflect the sequence of distribution of the zones and the mineral composition.

The isotopic analysis of vein alunite from Madjarovo (Marchev et al., 1997) and Spahievo ore field (Marchev and Singer, 1999) gave data for a more exact determination of the age of alterations and the range of mineralizations.

Metallogenic specialization and importance

The questionable role secondary quartzites as ore-hosting rock must be elucidated only on the basisof proved data. In this sense, for Bulgaria it can be accepted that the rocks of this family are hosting medium for gold and gold-beraing ores in Chelopech and Petelovo. Another alternative is to use these ores as a complex nonmetallic raw material.

Aceite family

Aceite: is a low temperature alkaline metasomatic rock, mainly composed of albite with subsidiary carbonate and haematite. U-bearing apatite is a common accessory. Aceites are closely associated with U-mineralisation.

Geological and physicochemical conditions of formation. Relations to other metasomatites

The metasomatic rocks are attached to fault structures and regions with high permeability for the hydrothermal solutions. Witness for this is their arrangement or orientation as main fault structures (Маринов, 1978, 1991).

The indications that characterize the individuality of the family are as follows:

– predominantly the rocks of the diabase-philitoid formation are charged by alteration;

– raised radioactivity of the metasomatic rocks.

Peculiarities of the mineral transformations and behavior of the elements

The minerals, which participate in the composition of the altered rocks are as follows: albite, quartz, sericite, chlorite, calcite, ferrous dolomite, and hematite. Metasomatic apatite is also formed and is connected with the process of albitization (Маринов, 1991).

In the case of petrogenic components there is found introduction of Na_2O, CaO, FeO, and MnO and export of K_2O and SiO_2. The sodium metasomatites compared to the initial rocks display repeated increase of U, Mo, Th, Ta, La, Sm, Ba, Nd. Smaller but noticeable contents are registered for Lu and Tb. The contents of Ce, Yb, and Eu are high as well.

It is accepted that during the low temperature metasomatic process Na is mobilized mainly from the diabases and dibase tuffs in the complex.

Metasomatic zoning

According to Marinov (Маринов, 1991) studies in depth showed zoning only in the volume of the separate metasomatic bodies and absence of common vertical zoning. The presence of quartz zones, which "crown" the metasomatic bodies is looked upon as a specific feature. Most probably these are the rear quartz zones.

Metallogenic specialization and importance

The sodium metasomatites are potential saurce for rare earth element and uranium.

Argillised rock (argillisites) family

Argillisite: is a low temperature metasomatic rock that is mainly composed of clay minerals, also present may be silica minerals, carbonates and iron sulphides. The rock forms from the hydrothermal alteration of both igneous and sedimentary rocks.

Argillization: is a metasomatic process leading to the formation of argillisites.

Geological and Physicochemical conditions of formation. Relations with other metasomatites

The individuality of this family in Bulgaria is defined by the prevailing development of clayey and minerals and hydromica during endogeneous (solfataric and hydrothermal) and supergene argillization. A variety of other minerals are present also – like sulfides, silicates, carbonates, etc. as well as veins of carbonates, zeolites, fluorite, and adularia.

The hydrothrmal argillisites in Bryastovo ore field (Кунов et al., 1996) have formed at surface conditions and low temperatures. The host rocks are predomnantly volcanic. The sub-paralel fault systems have played an important role. The hydrothermal argillizites in the region of Perelik (Бахнева, 1977) have a restricted distribution compared to the solfataric ones and display an expressed structural control. The infringements are with northeastern, subequatorial or northwestern directions. The alterations are most expressed in the sediments and less manifested in the effusives and clastolavas.

Main accompanying metasomatic families are those of secondary quartzites, propylites, and, in some cases, beresites. Characteristic feature of the hydrothermal argillizites is their formational independence.

The metasomatic halos in the case of solfataric argillisites are attached to around-neck zones of volcanic apparatuses and mark the transition between the extrusive and flow-type subfacies

The theoretical and experimental studies of the argillization localize this process in the range low- to medium temperature conditions (100–250°C) and pH range of 2 to 6. The mineral composition of the argillisites in Bulgaria reveals lowering of the acidity towards the post-ore metasomatic products and transition from acidic to alkaline conditions of deposition.

Peculiarities of the mineral transformations and behavior of the elements

The family of argillizites is characterized by varied mineral composition: illite, smectite, chlorite, kaolinite, montmorillonite, zeolites, pyrite, marcasite, quartz, chalcedony, opal, calcite, dolomite, ankerite, alunite, etc.

During formation of hydrothermal argillisites from the primary rock-forming minerals the most quick and entire process is that of replacement of pyroxenes and amphiboles; biotite from the outer zones is fresh, while potassium feldspar is most stable and often, although partially, is preserved in the most intensive alteration zones.

The inertness of SiO_2 and Al_2O_3 is well expressed in the geochemical behavior of the petrogenetic components (except the rear monoquartzite zone for the Al_2O_3 component) as well as the varying state of K_2O

(from inert to fully mobile during the different transitions) and the active participation of water and P_2O_5. More interesting is the specific behavior of F.

The mineral composition of the solfataric argillisites is as follows: kaolinite, quartz, chlorite, carbonates, albite, montmorilinite, admixtures of pyrite, rutile, apatite, sulfur. One apecific feature of the petrogenetic elements is the extraction of the alkali and alkaline earth elements (with the exception of MgO).

Metasomatic zoning

Lateral and vertical zonings are both established, which in the case of Bryastovo deposit (Кунов et al., 1996) are characterized by increase of the alteration magnitude from outer to inner zones, inconstancy of the intermediate zones, and formation of ore bodies in the inner zones at the stage of complete development of the zoning:

– outer zone – relatively preserved biotite, widspread dvelopment of carbonates (predominantly calcite), and clayey-hydromica alteration, while in the main mass this alteration is of the type clayey-chlorite one.

– intermediate zone – with elements from both the outer and inner zones, relics of biotite, and the quantity of carbonate is drastically lowered;

– inner zones – the clayey and hydromica components prevail but with varying predomination. The hydromica minerals increase in content towards the inner zones. Rear monoqaurtzite zones have formed as a result of intense acid extraction.

The sequence of mineral decomposition reflects the differential row of component mobility. The activity of potassium is very continuous.

A clear lateral and vertical metasomatic zoning is observed in hydrothermal argillisites in the region of Perelik, while in the case of kaolinite argillisites the zoning is simple (synchronous) with the following zone sequence: unaltered rocks → albite-montmorillonite → chlorite-carbonate → karbonate-kaolinite → quartz-kaolinite, monoquartz, or monokaolinite ones. In the case of montmorillonite-kaolinite argillizites the zoning is complex (tropochronic): unaltered rocks → montmorilonite-chlorite-sericite quartz-kaolinite → quartz-hydromica ones. The vertical zoning includes an increased number of zones compared to the double-zoned lateral zoning.

In the case of solfataric argillizites the pseudomorfs of albite-montmorillonite-carbonate and chlorite are probably metastable and are quickly replaced by quartz-kaolinite aggregates.

Metallogenic specialization and importance

The argillisites in Rhoddopes (Bulgaria) usually include urarnium epithermal and polymetal ores.

Also, it is possible to use the argillisites as a nonmetallic raw material for proving of reserves of kaolinite and other industrially important clay minerals.

Quartz-sericite family

This family has been described by Zharikov and Omelyanenko (Жариков и Омельяненко (1978) as a metasomatic formation, which is typical for smaller depths and for the acid stage of the process. Kanazirski et al. (Каназирски et al., 2000) have been the first to prove and name it for Bulgaria.

Geological and physicochemical conditions of formation. Relations to other metasomatites

The metasomatic alterations take place in diverse geological environment and on different rocks. The connection with magmatic activity, fault disturbances, and ore formation is out of doubt.

The features that determine the individuality of this family are the following:

– main minerals are quartz and sericite (in same case pyrophillite and illite);

– at the upper levels of Elatsite deposit the sericite type alteration replaces the potassium-silicate one and in Asarel deposit it is developed as a representative of epythermal style in the upper levels of the porphyry copper system (Kanazirski et al, 2002).

This family demonstrates apparent independence but it has relations with propyllites, argillisites, and secondary quartzites, upon which it is overprinted.

The epythermal sericite type of alterations in Elatsite, Vlaikov Vrah, Kominsko Chukarche, and Karlievo are connected with magmatic-meteoritic type of syste, whereas in Asarel and Tsar Asen deposit – with a prevailing meteoritic type (Kanazirski et al, 2002).

Peculiarities of the mineral transformations and behavior of elements

Main minerals are: sericite (iilite), quartz, and to a lesser degree albite, chlorite, carbonate, and pyrite. The replacement of the porphire minerals and the main mass is from partial to complete.

The SiO_2 and TiO_2 petrogenetic components are inert up to the end of the process when monoquartz zones may form. However, K_2O is also inert (during the sericitic facies, Каназирски, 2007). The components MgO, FeO, Fe_2O_3, Na_2O and CaO transfrom into a fully mobile state relatively early.

Metasomatic zoning

In the majority of cases the vertical and horizontal zoning is simple similar to each other.

Integral metasomatic columns (sequence of the mineral parageneses) for the porphyry deposits Medet and Elatsite have been given by Kanazirski (Strashimirov et al, 2002).

Metalogenic specialization and importance

The role of these rocks as sin-ore ones in the ore-formation process determines their importance as criterions for ore prospecting

Quartz-adularia-sericite family

The rocks of this family have formed on smaller depths and the early stage of the acid extraction (Жариков, Омельяненко, 1978).

The indications that determine the individuallity of the family are the following;

– constant presence of adularia, quartz, sericite, sometimes barite and almost always gold;

– the short erosional rupture (cutting), not completely expressed tendency in the metasoamtic zoning towards monomineral rear zone, mineralogical diversity in the oxidation zones, etc.

Geological and physicochemical conditions of formatiom. Relation to other metasomatites

The host medium is built by various rocks: altered volcanic rocks and intrusives (andesite-basalts, andesites, latite-andesites, latites, rhyolites, rhyodacites, monzonites, granites, etc.), metamorphic rocks (marbles, gneisses, schists of DFC), sedimentary rocks (breccia-conglomerates. epiclastites, sandstones).

No data is available for the role of the character and type of the structure on origination of the adularia-sericite altertaion. Almost in all cases there are indications to propose direct relations to fault structures with different orientations. In many cases the contemporary morphology of the relief as well as the neotectonic processes are a secondary factor for the localization of the mineralized zones and metasomatites and their erosional cutting.

The facts about the fluid systems are also not enough but, however, the available data determine the epithermal character of the studied deposits. Hristova et al. (Христова et al., 1996) have reported the following results:

– 270–240°C; 1.7–4% NaCl eq; composition of the system → $NaCl–KCl–FeCl_2–H_2O$ (for Madjarovo, Chala, Popsko, Obichnik);

– 270–220°C; 4.9% NaCl eq; composition of the system → $NaCl–KCl–FeCl_2–H_2O$ (for Sedefche);

– 270–190°C; 0.9–1.2% NaCl eq; composition of the system → $NaCl–KCl–(NaHCO_3)–H_2O$ (for Rosino, Sarnak).

The adularia-sericite are one of the latest manifestations of the ore formation and they overprint the earlier metasomatic and metamorfic alterations, which makes it difficult to follow the zoning.

Peculiarities of the mineral formation and behavior of the elements

The main minerals are adularia, quartz, sericite (illite), carbonate, rarely kaolinite.

The low-sulfidized type of alterations is characterized by anomalously high content of Au, Ag, As, Sb, Hg, Zn, Pb, Se, K, Ag/Au and anomalously low content of Cu, Se/Te (White and Hedenquist, 1995). Additional features, which can be noted for this type in Bulgaria are higher values for Ba, tlow values for Se, inconstant presence of As, Hg, and Sb, and varying content of Cu. Some of these manifestations display individual specificity. For example contents of Mo have been proved only for Madjarovo ore field.

Metasomatic zoning

Quartz-adularia-sulfide veins are usually formed in the central parts of the zones, followed by quartz-sericite (illite)-adularia metasomatites but in the outer zone they are followed by alterations of propyllitic type (sericite, chlorite, carbonates, ± adularia. etc.). Althorg the tendency is towards formation of monomineral bodies in the central part monoquartz zones are rarely observed. Gold usually concentrates in the inner zones where the quantities of quartz and adularia are higher.

Metallogenic specialization and importance

The perspectives for survey and exploration of gold can be improved through finding of new areas with adularia-sericite type of host rock alterations. This is valid both for regions with known manifestations of this type as well as for places where such are still not found (Osogovo, Pirin, Stara Planina Mts., etc.). The same is true for regions with metamoephic and sedimentary rocks, which are interesting as hosting medium for epithermal manifestations. From another point of view re-evaluation and purposeful prospecting may increase the perspective areas of some deposits and ore manifestations. The confirmation of ore conducting and ore hosting structures is also very important.

Conclusion

This summarized review on the metasomatic families in Bulgaria gives one possibility for a general idea about their peculiarities. At the same time it demonstrates the necessity of more systematic studies on the physicochemical conditions of formation, the relations between the different families, the geochemical characteristics, and metallogenic evaluation. One detailed analysis of the metasomatic processes and rocks in Bulgaria can allow the introduction of corrections and additions in the known alreday families as well as give a possibility for proving of new families, which are already not registered on the diagram.

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Резюме. А. Кунов — Метасоматични семейства в България — обзор. Статията е кратко обобщение на метасоматичните семейства в България, основана на предложената от Подкомисията за систематика на метаморфните скали номенклатура на метасоматизма и метасоматичните процеси.

Представени са следните семейства: скарново, кварц-фелдшпатово, грайзеново, березитово, пропилитово, вторично кварцитово, ейситово, аргилизитово, кварц-серицитово, кварц-адулар-серицитово. Показано е широкото им разпространение в България.

Характеристиката на семействата съдържа признаците за индивидуалност, геоложките и физикохимичните условия на образуване, особеностите на минералния състав и поведението на елементите, метасоматичната зоналност и металогеннното значение.

Подчертава се необходимостта от по-широки изследвания на физикохимичните условия на образуване, на взаимоотношенията на различните семейства, на геохимичната характеристика и металогенната оценка. Един обстоен анализ на метасоматичните процеси и скали в бъдеще може да внесе корекции и допълнения в известните семейства, както и да даде възможност за установяване на нови семейства, в това число и останалите нерегистрирани от диаграмата.