GEOCHEMISTRY OF STRONTIUM IN ADVANCED ARGILLIC ALTERATION SYSTEMS – POSSIBLE GUIDE TO EXPLORATION

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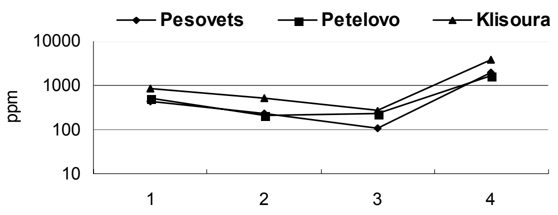
Introduction

Advanced argillic alteration (AAA) systems have a good potential for exploration because of the close relationships with the ore deposits. Over 30 occurrences of AAA are known in Bulgaria (Velinov et al, 2003), some of them associated with porphyry copper and epithermal deposits. They are located in the Srednogorie tectonic zone, where host rocks are Upper Cretaceous intermediate volcanics (andesites and andesite-latites), and in the Eastern Rhodopes – related to Paleogene andesites and latites. The Stomanovo occurrence in the Central Rhodopes, which is hosted in Paleogene rhyolites, is an exception. The advanced argillic alteration systems are characterized by a well-developed alunite zone, combined in most cases with kaolinite and/or dickite zones, and less commonly with pyrophyllite and diaspore zones. The transition toward fresh unaltered volcanic rocks is marked by zones of sericitization, intermediate argillic alteration (not in all deposits) and propylitization. Geochemical studies have been carried out in five occurrences with the aiming in the study of the distribution of some trace elements in different types of altered rocks. Such studies include ore deposits and occurrences in the Panagyurishte ore region of the Central Srednogorie (Assarel porphyry copper deposit, Petelovo gold porphyry deposit, Pesovets epithermal occurrence), in the Western Srednogorie (Klisoura epithermal occurrence) and in the Rhodopes (Spahievo ore field).

Strontium geochemistry

All studied deposits are characterized by similar strontium distribution in zones of hydrothermal alteration. As a rule, strontium contents decrease in propylitic, intermediate argillic and sericitic outer zones of hydrothermal alteration and rapidly increase in the most intensely altered internal zones of advanced argillic alteration (Fig. 1). Its concentration (2000 to 5000 ppm) is 2 to 5 times higher as compared to fresh volcanic rocks and exceeds tens of times the amounts in the external alteration zones. Strontium contents are steadily high in all zones of advanced argillic alteration that are identified in the studied deposits – alunite, pyrophyllite, diaspore, dickite, kaolinite, though there are other geochemical differences between them. In most deposits, the highest values are detected in alunite rocks. Only in zones of pervasive silicification, Sr values are low.

(a)



(b)

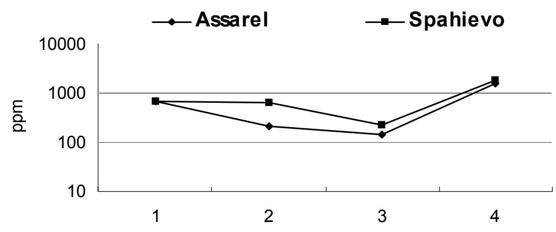


Fig. 1. Distribution of strontium in the zones of hydrothermal alteration in: (a) – Pesovets, Petelovo and Klisoura; (b) – Assarel and Spahievo; 1 – initial rocks; 2 – propilitic; 3 – sericitic; 4 – advanced argillic.

The geochemistry of strontium does not depend on the behavior of other elements. In magmatic rocks Sr is an isomorphic admixture in Ca-minerals, first of all plagioclase, but here calcium is leached from all zones of hydrothermal alteration. Phosphorus is the only element with higher contents in zones of advanced argillic alteration.

Three forms of strontium occurrence in AAA zones have been established. First, in the main minerals bearers of Sr – svanbergite, svanbergite-woodhouseite solid solutions and woodhouseite. They are registered in all studied deposits. Most commonly, these minerals are found in the cores of alunite crystals but they may also occur independently in rocks without alunite.The strontium content in the studied svanbergite from Petelovo deposit varies from 12 to 14%, in the mixed phases – from 5.5 to 9% and in woodhouseite – from 2,7 to 5,2%. The origin of aluminium phosphate-sulphate (APS) minerals has been explained by Stoffregen and Alpers (1987) as a product of apatite destruction. Primary apatite occurs in volcanic, propylitized and partially in sericitized rocks. Apatite is absent from the advanced argillic zones. At the same time, Sr is extracted from the outer, less altered zones and concentrates in the inner zones of advanced argillic alteration. There, strontium and phosphorus, along with small amounts of calcium (in acid-sulphate environment), form the minerals svanbergite, woodhouseite and mixed APS phases.

Another form of occurrence of strontium is as admixture in alunite. It is commonly observed in amounts up to 0,5%, less commonly 1 to 2%. Cases of solid solution between alunite and svanbergite-woodhouseite have been established in which strontium may reach 5%. The participation of Sr as admixture in alunite may dominate in cases when the content of alunite is very high. In Pesovets occurrence, there are areas rich in alunite that contains admixtures of strontium in which no APS minerals have been established. The third form of occurrence of strontium is as admixture in barite from Petelovo deposit (about 2,5%), but this form is not characteristic of advanced argillic alteration zones due to the irregular distribution of barite mineralization.

Rb/Sr ratios

Rb/Sr ratio (Fig. 2) is common used for various genetic interpretations. Neverthenless some differeces between the single deposits (because of the different concentrations of the both elements in magmatic rocks) Rb/Sr ratio has characteristic trend between the alteration zones. In propilitic and intermediate argillic altered rocks Rb/Sr values are close to that of the unaltered volcanics. Rb/Sr increase 3 to 8 times in the zones of sericitic alteration. The highest values (1,52) are in sericitic zones of Spahievo ore field, where Rb/Sr in volcanic rocks is the highest (0,44). In advanced argillic alteration zones Rb/Sr values are anomalously low between 0,01 and 0,001. The large variation in Rb/Sr is due to changes in the concentrations of both elements which have different distribution in the alteration zones.

(a) (b)

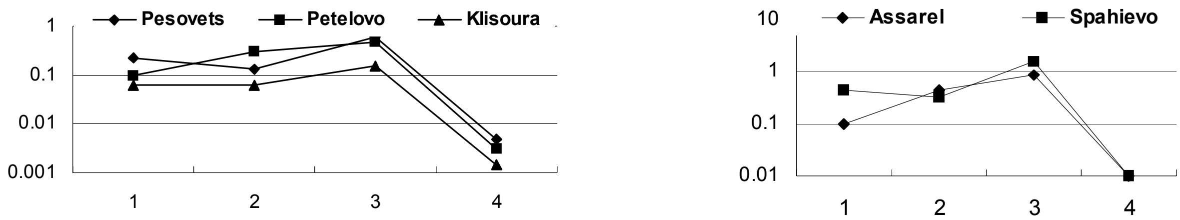


Fig. 2. Rb/Sr ratios in the zones of hydrothermal alteration in: (a) – Pesovets, Petelovo and Klisoura; (b) – Assarel and Spahievo; 1 – Initial rocks; 2 – propilitic; 3 – sericitic; 4 – advanced argillic.

Discussion and conclusion

No influx of strontium and phosphorus by deep solutions has been established. Their amounts (and of APS minerals respectively) are limited by the primary composition of the volcanic rocks and probably by the volume of the altered zones. In rocks with lower strontium content, as for instance the rhyolites from Stomanovo (216 ppm), the same regular pattern of strontium accumulation in advanced argillic rocks has been established but in smaller concentrations (441 ppm). No APS minerals have been described there. Strontium content in alunites from Stomanovo is up to 0,12%. It may be assumed that the most of the element is present as admixture in alunite.

All geochemical data suggest that there is mobilization and re-distribution of strontium during hydrothermal alteration. If we take into account that the volume of the strontium-leached external zones exceeds several times the volume of the enriched zones, than the amount of this element in advanced argillic alteration rocks should be no higher than the amount extracted from the external zones.

The concentrations of strontium in zones of advanced argillic alteration in the studied deposits and occurrences in the Srednogorie and Rhodopes regions is probably a widespread phenomenon. A number of data confirm this assumption. Kashkai (1970) provided numerous data on the strontium content in alunite from many deposits. Schwartz (1981) described influx of this element into the advanced argillic zone of La Granja porphyry copper deposit (Peru). Arribas et al. (1995) noted high strontium concentrations in advanced argillic alteration zones in the Rodalquilar epithermal gold deposit (Spain) and explained it by formation of svansbergite. Higher strontium content has been detected in other deposits as well (Pirajno, 1995; Huston & Kamprad, 2000; Karakaya & Karakaya, 2001). APS minerals (including svanbergite and svanbergite-woodhouseite solid solution series) were found in a number of zones of advanced argillic alteration related to high sulphidation epithermal and porphyry copper deposits such as Summitville, Pueblo Viejo, Lepanto, El Salvador, Chelopech and others.

The data obtained in the frame of this study combined with those of other deposits mentioned above allowed the author to hypothesise that "the accumulation of strontium is a characteristic feature of the process of advanced argillic alteration in volcanic rocks" (Hikov, 2002). High concentrations of strontium should be expected everywhere where advanced argillic alteration occurs because it leads to strontium re-distribution and accumulation. This may be an additional tool in geochemical mapping of advanced argillic alteration zones.

Arribas et al. (1995) noted similar distribution of Rb/Sr ratios in the altered rocks of Rodalquilar epithermal gold deposit. There are high Rb/Sr values in intermediate argillic and sericitic altered rocks. Rb/Sr are anomalously low in advanced argillic altered rocks and in vuggy silica and chalcedonic ore. Authors considered Rb/Sr ratio to has the best potential for identifying promising exploration zones in Rodalquilar deposit. On the other hand, Olade and Fletcher (1975) and Armbrust et al. (1977) studied the distribution of Rb/Sr ratio in the alteration zones around some porphyry copper deposits in Canada and Chile (where alterations are without AAA). They finded out that the highest Rb/Sr values are in sericitic rocks and proposed this as a guide to exploration for porphyry copper deposits.

So, Rb/Sr ratio may be recommended for geochemical prospecting in volcanic terrains with intensive hydrothermal alteration. Anomalously low Rb/Sr values are characteritic of advanced argillic alteration zones and may be perspective for high sulphidation epithermal Cu-Au mineralizations. The high Rb/Sr values are tipical for sericitic alteration which may be perspective for porphyry copper or low sulphidation epithermal gold or base metal deposits. Rb/Sr ratio shoud be used for geochemical prospecting only together with the whole complex of geological, petrological, structural and geophysical data which are available.

All studied alunite occurrences are of magmatic-hydrothermal origin (Lerouge et al., 2003). This means that the results from strontium geochemistry studies in advanced argillic rocks are related to magmatic-hydrothermal systems. So far, alteration zones of "steam-heated" type alunite have not been detected in Bulgaria. It would be interesting to test if there are some differences in the strontium geochemistry between the two environments of alunite formation. This may turn out to be a good criterion for their identification. The presence of APS minerals in the core of alunite is more typical of magmatic-hydrothermal environments. These minerals are the main bearers of Sr in the altered rocks. It may be suggested that the higher concentrations of strontium in advanced argillic zones might be characteristic of magmatic-hydrothermal environments.

Acknowledgements

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