ISOTOPE CONSTRAINTS ON THE AGE AND MAGMA EVOLUTION OF CHELOPECH VOLCANIC COMPLEX (BULGARIA)

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Introduction

High-sulphidation epithermal deposits are an important gold resource in Eastern Europe, notably in the Panagyurishte region (Central Srednogorie, Bulgarian). The genesis of the Chelopech mine (Fig. 1), the major ore producing epithermal deposit in this area, is related to intermediate Late Cretaceous volcanism, which extruded in the northern part of the Central Srednogorie magmatic zone. The ideas about the evolution of the magmatic complex changed through time, and one (Terziev, 1968; recently Jelev et al., 2003), or two (Mutafchiev, 1967; Popov and Mutafchiev, 1980) to four stages of magmatic activity (Popov and Kovachev, 1996) were supposed. Consequently the genetic models for the formation of the Chelopech deposit in relation to the volcanic products evolved. For the timing of the magmatic activity and the mineralisation/alteration products just K-Ar data are available (Lilov and Chipchakova, 1999), which range from 92 to 57 Ma. The magmatism in the Chelopech region was supposed to be prolonged, but mainly Senonian in age.

The aim of our investigation is to reconstruct the geological evolution of the Late Cretaceous Chelopech volcanic complex and to identify the temporal relationships between its magmatic products and the mineralised zones outside of the Chelopech mine. An important part of the present study is to trace the magmatic source and to reconstruct the magmatic processes that may contribute to the formation of the high-sulphidation epithermal Chelopech deposit. We have combined field observations with representative whole rock and mineral geochemical analyses. Conventional U-Pb single zircon dating has been utilized to determine the magmatic ages, as this method combines the relative resistance of zircons to hydrothermal overprint with the high precision of the ID-TIMS (isotope dilution – thermal ionisation mass spectrometry) techniques. Cathode-luminescence (CL) images and Laser Ablation (LA) ICP-MS analyses of zircons help the proper interpretation of the zircon data. Isotope Sm-Nd and Rb-Sr whole rock and Hf-zircon analyses provide additional information about the magma sources and their evolution.

Geological setting and petrology of Chelopech volcanic complex

The products of the Chelopech volcanic complex are located in the Central Srednogorie volcano-plutonic area, which forms part of the Srednogorie tectonic zone (Dabovski et al., 1991). The basement of the volcanic rocks consists of high-grade metamorphic rocks (two-mica migmatites with thin intercalations of amphibolites, amphibole-biotite and biotite gneisses), and low metamorphic phyllites and diabases of the Berkovitsa group (Early Paleozoic island-arc volcanic complex, Haydoutov, 2001; Peytcheva and von Quadt, 2004). These units are in tectonic contact with each other and to the north of Chelopech the phyllites of the Berkovitsa group are intruded by the Variscan granitoids (Kamenov et al., 2002) of the Vejen pluton. The base of the Chelopech volcanic rocks are partly exposed on the surface, although it has been intersected in the underground mine.

The Late Cretaceous succession in the Chelopech region starts with conglomerates and coarse-grain sandstones intercalated with coal-bearing interbeds (coal-bearing formation, Moev and Antonov, 1978) covered by polymictic, argilleous and arcose sandstones to siltstones (sandstone formation). Collectively, these units have a thickness of less than 500 m. Pollen data suggests that both formations are Turonian (Stoykov and Pavlishina, 2003). The sedimentary rocks are cut by volcanic bodies and overlain by sedimentary and volcanic rocks of the Chelopech Formation (Moev and Antonov, 1978). It comprises the products of the Chelopech volcanic complex, epiclastics, as well as the Vozdol sandstones. The latter are recently paleontologically dated as Turonian in age (Stoykov and Pavlishina, 2003). These formations have been eroded and transgressively covered by sedimentary rocks of the Upper Senonian-Campanian Mirkovo Formation (reddish limestones and marls), which is in turn overlain by flysch of the Chugovo Formation (Campanian-Maetrichtian in age, Moev and Antonov, 1978).

The first unit is composed of *dome-like volcanic bodies*, which extruded through the unconsolidated Turonian sediments (the sandstone and coal-bearing formation) and through the metamorphic basement. The dome-like bodies mainly have an andesitic and trachydacitic composition. They are highly porphyritic (phenocrysts >40 vol. %). The phenocrysts consist of plagioclase, zoned amphibole, minor biotite, titanite and rarely corroded quartz crystals, whereas the microlites consist only of plagioclase and amphibole. The accessory minerals are apatite, zircon, and Ti-magnetite. Lilov and Chipchakova (1999) obtained an age of 65-67 Ma for these bodies based on K-Ar dating.

The second unit is represented by *lava flows*, which grade upwards into agglomerate flows. Borehole data shows that the total thickness of these volcanic products is generally less than 1200 m, but exceeds 2000 m in the region of the Chelopech mine ("within their extrusive center", Popov et al., 2000). The composition of the lava flows varies from latitic-trachydacitic to dacitic. Subsidiary andesites are also present. These volcanic rocks consist of the same phenocrysts, microlites and accessory minerals as the first unit, with the exception of the corroded quartz crystals. The lava flows contain fine-grained, fully crystal-lized enclaves of basaltic andesites to shoshonites. The enclaves consist of the same minerals as the main mass of unit 2 (plagioclase, amphibole and minor biotite), but comprise phenocrysts of different (more basic) chemistry. A fine-grained quartz zone marks the margins of the enclaves. These features are typical for magma mingling and mixing processes and are mostly exhibited in the lava flows compared to the other volcanic units. Previous K-Ar dating of non-altered andesite yielded a Turonian age of 91 Ma (Lilov and Chipchakova, 1999).

The third unit is represented by *volcanic breccias and volcanites* that formed the so called Vozdol monovolcano of Popov et al. (2000). The volcanic breccias contain fragments within their lava matrix that vary in size between 20 and 80 cm. Brecciated fragments from the andesites of the first unit can be observed in outcrops in the Vozdol river valley. The matrix of the volcanic body in the eastern part hosts small lenses and layers of sedimentary material (sandstones to gravelites), which abundance increases towards the margins of the body. The Vozdol volcanic breccias additionally intercalate and are covered by the Vozdol sandstones, the latter palaeontologically dated as Turonian in age (Stoykov and Pavlishina, 2003). These features may suggest that the extrusion of the third unit volcanites occurred contemporaneously with sedimentation processes in Turonian. The composition of the Vozdol volcanites varies from basaltic andesites and andesites to latites. They show similar to the older units petrographic characteristics although their phenocrysts (plagioclase, amphibole, minor biotite, and titanite) are less abundant. The groundmass is composed of microlites of the same nature as the minerals of the second unit. K-feldspar is present as microlites only in the Vozdol andesitic rocks. A biotite $^{40}Ar/^{39}Ar$ dating yields a Turonian age of 89.95±0.90 Ma (Velichkova et al., 2001). Therefore, the K-Ar age of 65 Ma obtained by Lilov and Chipchakova (1999) from samples at the same locality reflects a low-temperature overprint.

Several dykes are exposed to the E and NE of the Chelopech deposit. They strike predominately in an E-W direction and intrude into the Pre-Upper Cretaceous metamorphic basement. They do not show crosscutting relationship with Chelopech volcanic complex.

The magma of the volcanic complex initially erupted more acid volcanic rocks. The earlier products (dome-like bodies and lava to agglomerate flows) contain 61- 64 wt% SiO_2 whereas the more basic Vozdol breccias and volcanites containe 55.5-58.0 wt% SiO_2. Bulk rock trace element compositions are typical for subduction-related magmatic sequences.

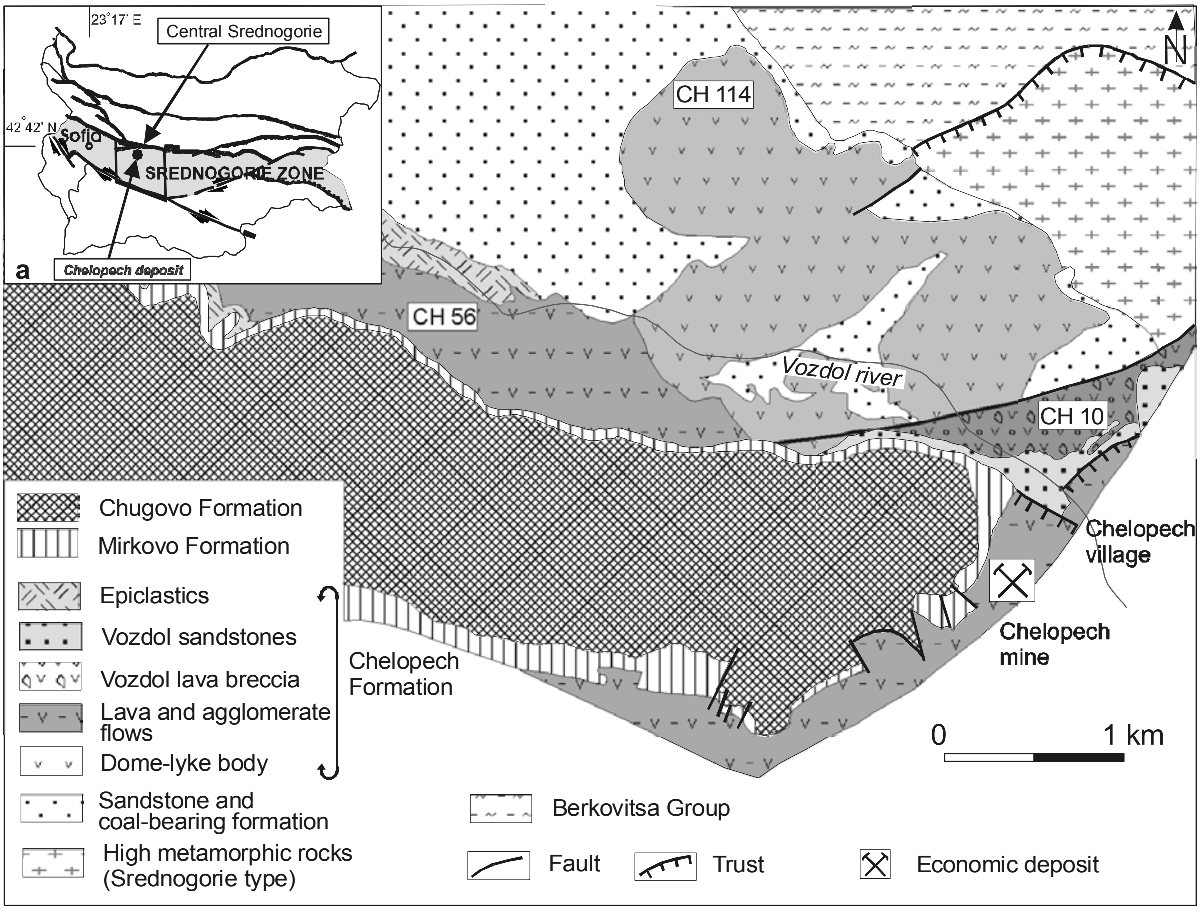

Fig.1. Geological map of the Chelopech region (modified after Popov et al., 2000) with sample localities. In the small window: the location of the Srednogorie zone and Chelopech deposit (shown on scheme of the major tectonic zones in Bulgaria after Ivanov, in press).

The cover of the Chelopech volcanic complex is composed of Vozdol sandstones (to the east), muddy limestones of the Mirkovo Formation (in the center) and sedimentary rocks of the sandstone and coal-bearing formation (to the west).

U-Pb zircon geochronology and Hf zircon isotope geochemistry

Zircons were separated from the three different units of the Chelopech volcanic complex. The zircon grains of an andesite sample from the Murgana dome-like body (CH-114) are plotting on the concordia within their uncertainties and define a mean $^{206}Pb/^{238}U$ age of 92.3 ± 0.5 Ma.

The U-Pb isotope systematic of the zircon fractions of a trachydacite from the second unit (CH-56) shows characteristics of lead inheritances and lead losses. Four data points are almost concordant and define a mean $^{206}Pb/^{238}U$ age of 91.3 ± 0.3 Ma. The e^{90}(Hf) values of the concordant zircons change in a narrow range of +1.06 to +1.38 indicating a mixed crustal and mantle origin of the magma, but more crustal influence, compared to the andesite of the first unit.

Five out of seven zircon analyses of an andesite from the Vozdol lava breccia neck (CH-10) are concordant and yield a mean $^{206}Pb/^{238}U$ age of 91.3 ± 0.3 Ma. It coincides within error limits with the age of the lava flow sample of the second unit. Some similar features of both samples are revealed by the e^{90}(Hf) values of the concordant zircons, changing in one and the same narrow range of +1.06 to +1.38. We interpret these similarities with close Hf-isotope characteristics of both type volcanites and with the error uncertainties of the dating.

Sr and Nd isotope geochemistry and magma sources

The initial Sr isotope ratios of the magmatic rocks from the Chelopech volcanic complex and the dykes show a small range between 0.70470 and 0.70554 at Cretaceous time (90 Ma correction). The $(^{87}Sr/^{86}Sr)_i$ and $(^{143}Nd/^{144}Nd)_i$ data plot close to the enriched mantle type 1 field. However using the variations of the initial Sr and Nd ratios vs. SiO_2 the evolution of the magma may be due to mingling/mixing processes, without isotope homogenisation in the whole volume of the magma chamber, and not due to a simple differentiation of one parental magma, combined or not with assimilation of upper crustal rocks.

Discussion and constraints on timing and magma sources

The high-precision U-Pb zircon data demonstrate that the magmatic activity of the Chelopech region started at the northern border with the intrusion of the dome like bodies at T 92.3 ± 0.5 Ma. The products of the second and the third units followed closely one after the other and they are undistinguishable within their uncertainties: U-Pb analyses of zircons of representative samples yield an intrusion age of 91.3 ± 0.3 Ma. The lava breccias of the third unit contain fragments of the first unit, hence the geological relationships in the field are in agreement with isotope geochronological data. The high-sulphidation epithermal Cu-Au mineralisation is hosted by the volcanites of the second unit. Assuming the error uncertainties we can calculate a maximum age of 91.6 Ma for the epithermal deposit, which coincides with the recently published data of Chambefort et al. (2003) and Moritz et al. (2003). The minimum age of the deposit is still not constrained. As it was mentioned in the above chapters, present investigations are focused on the special features of the volcanic products on the surface, so that we are still not able to link the strongly altered volcanic xenoliths in the volcanic breccias of the third unit to a distinct mineralising stage.

Chondrite-normalised patterns of REE and trace elements in the zircons (LA ICP-MS analyses) reveal a well-pronounced positive Ce-anomaly in the zircon grains of the second unit (trachydacite) and in the zircon cores of the third unit (andesite). The latter may be related to a higher oxidation state of the parental magma and show the potential of the second unit volcanites to be the fertile phase of the volcanic complex.

Present isotope-geochronological study support the model of a common magmatic chamber for Elatsite and Chelopech deposits with some pulses of intrusion/extrusion of magmatites. Unfortunately we did not observed and did not find published data about structures between Chelopech and Elatsite deposits, which could explain the horizontal distance of about 6 km and the vertical displacement of about 1 km. Therefore present isotope-geochronological data are not enough to favor the idea for one and the same magmatic-hydrothermal system for both deposits.

References

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