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Timing of polymetallic Pb-Zn mineralisation in the Laki district, southern Bulgaria – constraints from $^{40}Ar/^{39}Ar$ dates

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The Central Rhodopean Dome (CRD), in southern Bulgaria and northern Greece, is composed of high-T, low-P gneisses and marbles which were exhumed along detachment faults during post-collisional extension, resulting in widespread migmatisation and local anatexis. Peak metamorphic temperatures are recorded at 35.9 ± 0.2 Ma (Ovtcharova et al., 2003), whereas cooling below ~ 300ºC occurred between 36 and 34 Ma (Kaiser-Rohrmeier et al., 2013). Regional acid magmatism (~ 33 – 30 Ma; Ovtcharova et al. 2001), occurring throughout the CRD as dykes and sub-volcanic bodies, cross-cuts detachment faults and sedimentary basins, and is commonly spatially associated with polymetallic Pb-Zn veins and metasomatic replacement bodies.

The CRD hosts six Oligocene Pb-Zn mining districts: Laki, Davidkovo, Ardino, Enyovche, Madan and Thermes (from north to south), all of which display similar mineralisation styles (polymetallic veins and metasomatic replacement bodies) and are all located proximal to the Middle Rhodopean detachment fault. Fluid inclusion studies from the Madan (Kostova et al., 2004; Kotzeva et al., 2011) and Laki (Buret, 2012) districts reveal similar temperatures and salinities of the mineralising fluids (~ 300 – 350°C; ~ 1 – 10 wt % NaCl eq) for both districts. However, previous studies, based on ^{40}Ar-^{39}Ar dating of sericite indicate a significant age difference between the Laki (~ 29.5 Ma) and the Madan (~ 30 – 30.5 Ma) districts, which suggests an overall younging of mineralisation towards the north (Kaiser-Rohrmeier et al., 2004).

This study applies high-precision $^{40}Ar/^{39}Ar$ thermochronology to hydrothermal and metamorphic K-feldspar from the Laki mining district. In order to better constrain the timing of mineralisation, K-feldspar separates were dated from vein selvages and a mineralised polymictic volcanic breccia containing intergrown hydrothermal K-feldspar and sulfides. Hydrothermal K-feldspar from non-mineralised sub-volcanic bodies were also dated to establish the extent of the hydrothermal activity in the Laki district, while metamorphic K-feldspar from gneiss spatially unrelated to mineralisation was dated to constrain the upper age limit of metamorphic K-feldspar in the vein selvages.

Our data obtained from hydrothermal and metamorphic K-feldspar reveal three stages: (1) ~ 33 – 33.5 Ma, pre-mineralisation metamorphic K-feldspar; (2) ~ 32 – 30 Ma, K-feldspar from vein selvages and mineralised polymictic breccia; and (3) ~ 27 – 29.5 Ma, post-mineralisation hydrothermal K-feldspar from non-mineralised sub-volcanic bodies.
$^{40}Ar/^{39}Ar$ dates from stage (1) closely match U-Pb zircon dates from sub-volcanic bodies in the Laki district, which form part of the Borovitsa volcanic zone (~33 Ma; Ovtcharova et al., 2001), and therefore can be interpreted as being thermally reset by magmatism.
The range of $^{40}Ar/^{39}Ar$ dates displayed during stage (2) is indicative of partial to complete resetting of metamorphic K-feldspar by the hydrothermal, mineralising fluid. Consistent minimum dates of ~ 30 Ma from the vein selvages and corresponding hydrothermal K-feldspar dates obtained from a mineralised polymictic breccia from the Chetroka mine, as well as fluid temperatures of 300-350°C recorded during the main stage of mineralisation in the Djurkovo mine, suggest that mineralisation in the Laki district ceased at ~ 30 Ma, and was coeval with hydrothermal activity in the Madan district to the south.
Post-mineralisation hydrothermal fluid circulation (at temperatures <200°C) during stage (3) resulted in the precipitation of hydrothermal K-feldspar within the previously altered sub-volcanic bodies from 27 – 29.5 Ma, possibly corresponding to previously published $^{40}Ar/^{39}Ar$ sericite dates from the Laki district.

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A magmatic origin of ore-forming fluids in Carlin-type deposits? Fluid inclusion studies on Carlin-type deposits and a Au-Cu porphyry deposit on the Carlin and Battle Mountain-Eureka trends, Nevada

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Eocene ore deposits of the Great Basin in north-central Nevada are collectively the US' largest producer of gold. They resulted from an ideal combination of early tectonics making the determining structures for later events, and several phases of metamorphism and magmatism, causing fertile fluids and melts to rise in the crust into a stratigraphy of reactive, carbonate rocks covered by non-reactive, siliceous cap rock (e.g. Dickinson, 2006). The majority of deposits are aligned in three main trends: the Carlin, Getchell and Battle Mountain-Eureka trends. While many studies have identified similarities between the individual structurally-controlled, sediment-hosted deposits, the source and evolution of the mineralizing fluid remain debated. Recent studies favour a conceptual model including a deep magmatic fluid source (e.g. Muntean et al., 2011) rather than a sedimentary or metamorphic fluid source. This magmatic-hydrothermal hypothesis implies that Carlin-type Au-deposits are distal products of gold transported in fluids derived from a large, deep-seated intrusive body. On the Carlin trend itself, there is only indirect evidence for the existence of Eocene plutons at depth. However, in the Battle Mountain-Eureka trend, gold mineralization that formed at relatively higher P-T is found in proximity to Eocene granodioritic intrusions. Under the conditions prevailing in the Carlin area, transport of gold via similar magmatically-derived fluids over large distances would be feasible (Heinrich, 2005). Two joint fluid inclusion studies on both of these sub-parallel trends were performed aiming to determine the major- and trace-element composition of the ore forming fluids.

Here, we present results from petrographic observations, fluid inclusion microthermometry and laser ablation ICP-MS analyses on fluid inclusions from the Copper Canyon Cu-Au porphyry, located at the northwest end of the Battle Mountain-Eureka trend and from the Gold Quarry and Chukar Underground Carlin type deposits located on the central Carlin-trend. An Eocene granodioritic porphyry is central to the deposits at Copper Canyon and is thought to be the cupola of a larger intrusion that acted as the source of fluids and metals (Cu, Au, Ag, Mo, Pb, Zn) for the deposits. It is hypothesized that the granodiorite cupola and its associated ore fluids could represent the highest P-T part of gold-producing hydrothermal systems, which formed the proximal skarn-hosted Au-Cu mineralization at Copper Canyon, whereas Carlin-type Au mineralisation may have been formed as more distal products of similar systems, at lower temperature and preserved in areas that were eroded less deeply.

Copper Canyon contains abundant fluid inclusion assemblages of vapour, intermediate-density, aqueous and hypersaline fluids in quartz veins and garnets. We present evidence for phase separation of a moderately saline intermediate density supercritical fluid splitting into a vapour and a brine under relatively high pressures. Subsequent small variations in pressure upon cooling of the vapour, caused parts of the vapour to contract to a liquid. Fluid inclusions in quartz and barite from the Carlin trend deposits have a very similar appearance to the contracted vapour liquid. Similarities in the chemical composition of fluid inclusions of the different sources indicate chemically similar source.

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