The relationship between late-orogenic extension and hydrothermal ore formation – New age constraints from the Central Rhodopes, south Bulgaria

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The Madan Dome, Central Rhodopes, south Bulgaria, is considered to be a large metamorphic core complex of late Alpine age (Ivanov et al., 2000, Field guide, *ABCD-GEODE workshop, Borovets*). It is an ideal setting to study the relationship between late-orogenic geodynamics and magmatism, hydrothermal fluid flow and ore formation. This study utilizes high-precision Rb-Sr, U-Pb and Ar-Ar geochronology to constrain the timing of extension, exhumation, acid magmatism and lead-zinc mineralization in the Madan Dome.

Since the Late Cretaceous, compression led to nappe thrusting, followed by amphibolite facies metamorphism peaking in the Oligocene. In the subsequent extensional phase, a detachment system developed, followed by the exhumation of the highly metamorphosed footwall of the Madan Dome. The detachment is crosscut by undeformed silicic dykes, which are locally cut by large vein- and carbonate-replacement lead-zinc deposits and altered to carbonate and sericite-bearing assemblages. Most economic deposits are hosted in high-grade gneisses and interbedded marbles.

Rb-Sr (biotite-feldspar) and Ar-Ar (biotite) isochrons from footwall gneisses reveal ~300° cooling ages of ~33-36Ma in the center of the dome and significantly younger ages at its western rim. These latter ages are likely affected by late fluid disturbance. Older ages of ~40Ma and ~50Ma are dominant in the northwestern footwall of the dome, whereas the northern hanging wall gneisses record an age of ~31Ma. U-Pb zircon ages from the silicic dykes range from ~32-30Ma. Ar-Ar dating on white micas grown in the ore veins and their alteration haloes show ages around 30.5Ma in the southern and around 29.5Ma in the northernmost of several ore fields.

Rb-Sr and Ar-Ar ages from hanging and footwall gneisses reveal a rapid but complex cooling history during updoming. There is no significant change in foot and hanging wall thermal history, therefore the interpretation of this dome as a core complex could not be confirmed until now. Post-doming silicic magmatism and hydrothermal vein formation overlap within the dome as a whole, but vein mineralization is distinctly younger in individual ore fields where both are precisely dated.

Establishment of the phosphorous cycle in early Archean oceans

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The geochemical cycle of phosphorous in early oceans is an important problem for the origin and early evolution of life. However, the phosphorous chemistry in early oceans is poorly understood. Seawater/rock interactions were common phenomena on the Archean ocean floor, producing chemically altered hyaloclastite and pillow lavas. Chemistry of Archean oceans can be constrained by examining these pillow lavas and hyaloclastite. The petrography, chemical analyses and elemental mapping using the X-ray analytical microscope were performed on pillow lava samples collected from the 3.8 Ga Isua, 3.5 Ga Pilbara and 2.7 Ga Abitibi regions. 3.5Ga and 2.7 Ga pillow lavas are less metamorphosed and still containing primary volcanic glasses (palagonite). Margins of pillow lavas from both regions are intensively carbonatized, due to the seawater/rock interaction under high P_{CO2} conditions. Abundant apatite crystals are found in carbonatized pillow margins. These apatite crystals were most likely precipitated during the Archean seawater/rock interaction using oceanic phosphates. The similar texture, chemistry and mineralogy were found in the Isua pillow lavas, although it is questionable if occurrence of apatite in Isua pillow lavas represents the primary feature. The results of this study suggest that phosphate were probably accumulated in the early Archean oceans at least since 3.5 Ga. There exists a large possibility that the continental weathering already controlled the phosphate cycle, thus biological productivity, at the early Archean stage.