Geophysical Research Abstracts, Vol. 8, 04013, 2006
SRef-ID: 1607-7962/gra/EGU06-A-04013

Paired Re-Os molybdenite and U-Pb zircon ages resolve Mo ore-forming events in magmatic-metamorphic environment, Knaben district, S Norway

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New Re-Os molybdenite ages by ID-NTIMS and U-Pb zircon ages by SIMS and ID-TIMS establish the temporal relations between magmatic, metamorphic, hydrothermal and ore-forming events in the Knaben Mo district, Rogaland-Vest Agder, S Norway. In Rogaland-Vest Agder, the Sveconorwegian orogeny is associated with protracted 1.03-0.97 Ga intermediate-P amphibolite- to granulite-facies metamorphism, 0.93-0.92 Ga high-T metamorphism associated with intrusion of the Rogaland anorthosite complex, and several pulses of granitic magmatism, with dominantly crustal sources, at 1.05-1.03, 0.96-0.95 and 0.93-0.92 Ga. Molybdenum deposits, associated with migmatites, pegmatites, quartz veins or small granite bodies, are common in S Norway and are generally hosted in sulphide-biotite-bearing gneisses. The largest district, at Knaben, includes the main Knaben II deposit (ca. 16500 tonnes molybdenite mined between 1918 and 1973), two smaller deposits, Knaben I and Kvina, and a number of prospects. The Knaben district is spatially related to a composite gneiss unit, the Knaben gneiss, which includes sulphide-biotite-bearing banded gneiss together with a 1.25 Ga augen gneiss and amphibolite. This gneiss is structurally underlain by a uniform 1.04-1.03 Ga felsic granitic gneiss. The first molybdenite formation is recorded at 1021 +/-2 Ma (6 Re-Os analyses) at Knaben I & II and two associated prospects. This event is coeval with crystallization of the 1021 +/-13 Ma granite (gneiss) body forming the hanging wall at Knaben II (SIMS zircon age of the "red granite") and to crystallization of a U-rich metamorphic-hydrothermal zircon rim recorded at the Knaben I & II mines (frequency maximum of SIMS $^{206}Pb/^{207}Pb$ ages at 1022 and 1016 Ma). A second event of molybdenite formation at 996 +/-3 Ma (8 Re-Os analyses) at Knaben I & II

and one prospect is also recorded in a U-rich zircon rim (1001 Ma). Younger molybdenite ages between 983 +/-3 and 950 +/-3 Ma are reported from several different ore-bearing facies (massive quartz, pegmatites, aplite, gneiss), mainly from the Kvina mine. This molybdenite is distinctly younger than metamorphic zircon from the same locality.

Molybdenite Re-Os ages in the six main Mo districts of Rogaland-Vest Agder, including Knaben, range between 1.02 and 0.92 Ga, and link Mo enrichment to Sveconorwegian orogenic processes. We argue that Mo, originally dissolved as a trace element in biotite, magnetite and ilmenite in the biotite gneiss, was released by melt- or fluid-producing reactions and was concentrated in simultaneously-forming molybdenite, either in situ or at short distance from the source. This process occurred repeatedly during peak and post-peak metamorphism. At Knaben II, there is field and geochronological evidence for at least one event of Mo transport in a granite magma (the 1.02 Ga "red granite") and deposition of molybdenite from a hydrothermal fluid released during granite crystallization. Knaben II possesses a number of characteristics in common with Climax-type Mo porphyry deposits (e.g. stockwork veining).