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Low-rhenium molybdenite by metamorphism in northern Sweden: Recognition, genesis, and global implications

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Abstract

Re–Os dating of molybdenite is an accurate means to date intrusions and intrusion-related ore deposits using the model age or isochron approach. But, molybdenite has a new niche in the greenschist- to granulite-facies metamorphic environment. Re–Os ages for metamorphic molybdenite may be used to construct regional metamorphic histories. Age significance and accuracy are established by analyzing multiple molybdenite separates extracted from single, petrographically-characterized molybdenite occurrences. In this study, twelve geologically distinct molybdenite-bearing samples from two small Mo districts in northern Sweden trace a 150 m.y. Paleoproterozoic Svecofennian metamorphic history from ~1900 to 1750 Ma. These data reveal a little-known, widespread and protracted, Late Svecofennian anatexis in northern Sweden.

The Kåtaberget Mo–(Cu, F) deposit is located in the Moskosel granite batholith north of the economically-renown Skellefte district. Four different molybdenite samples from outcrop at Kåtaberget indicate an intrusion age of 1895 ± 6 Ma with the formation of later pegmatite–aplite at 1875 ± 6 Ma. The Allebuoda (Björntjärn) and Munka Mo–(W) deposits in the Rappen district are represented by three outcrop and five drill core samples of molybdenite-bearing aplite–pegmatite–granite. These two deposits were previously described as intrusion-related Climax-type Mo mineralization. Re–Os ages for molybdenites from these deposits range from 1865 to 1750 Ma and, significantly, Re concentrations are markedly low, extending to the sub-ppm level. Age agreement within the deposits is conspicuously lacking, whereas, with one exception, age agreement within any single sample (geologic occurrence), as established by analysis of additional molybdenite separates, is very good. These data, together with fundamental geologic observations discussed in this paper, suggest that Mo–(W) mineralization in northern Sweden is not intrusion-related, but the local product of episodic melting of Archean–Paleoproterozoic supracrustal gneisses related to the Svecofennian orogeny. Petrographic traverses across the boundary between widespread, foliation-parallel units of aplitic to pegmatitic pink granite and hosting biotite gneiss directly capture the process of ore formation. Dehydration breakdown of zircon-rich biotite aligned with the foliation in the gneiss is accompanied by formation of new pristine, post-deformational biotite plus sulfides, oxides, hydrothermal zircon and fluorite, all associated with microcline-dominant leucosomes.

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This process has profound implication for the traditional leucogranite, intrusion-related genesis attributed to the broad classification of Mo–W–Sn–base and precious metal mineralization (e.g., South Mountain Batholith, Nova Scotia; Okiep, Namaqualand, South Africa; Mactung, Yukon; Pogo–Liese, Tintina, Alaska; Carajás and Goiás–Rio Tocantins, Brazil; New England Batholith, NSW, Australia; Bergslagen, Sweden; Nevoria, Western Australia; Alpeinerscharte, Austria; Erzgebirge, Germany; Sardinia–Corsica Batholith). In addition to biotite, metallogenic contributions (e.g., Mo, W, Sn, U, Bi, Cu, Pb, Zn, Fe, Ni, Co, Au, Ag, Te, As, Sb, REE) in various combinations may also be controlled by breakdown of amphibole. In effect, the trace element composition of dehydrating or recrystallizing components in a gneissic rock essentially defines the local and district metallogenic suite. In the absence of focusing structures (e.g., shear zones, sheeted vein development), this process will generally form small and disconnected subeconomic deposits with erratic and unpredictable grades. Low Re content in associated molybdenite is a key indicator for a subeconomic origin by *local* melting of biotite gneiss (Mo–W) or muscovite schist (Sn–W).

Keywords: Molybdenite; Biotite; Re–Os; Metamorphism; Anatexis; Svecofennian; Mo–W–Sn–base and precious metal deposits

1. Introduction

Re–Os dating of molybdenite has proven to be a powerful chronometer with a nearly perfect memory for the event during which it formed (Stein et al., 2001). Its successful debut was in the realm of economic geology where for the first time reproducible age results, in agreement with U–Pb ages, were acquired for ore formation in the magmatic–hydrothermal environment (e.g., Stein et al., 1997, 1998a; Selby and Creaser, 2001). The utility of molybdenite and other sulfides for dating mineralized quartz veins of metamorphic origin has also been established (Stein et al., 2000; Bingen et al., this volume). The Re–Os chronometer in molybdenite subsequently subjected to high-grade thermal metamorphism has been shown to be robust (Bingen and Stein, 2003). The Re–Os chronometer has also been successfully used to date ductile and brittle episodes of deformation (Stein and Bingen, 2002; Stein et al., 2004; Bingen et al., this volume). In summary, the Re–Os chronometer in molybdenite exhibits enormous potential for defining pulses of metamorphism and documenting deformation within orogenic cycles.

In this paper, the formation of molybdenite during protracted anatexis of orogenic magnitude is documented. Molybdenite and other minor sulfides are formed locally during dehydration melting of gneisses at the upper amphibolite facies, where melt generation dominates over hydrothermal processes. This environment goes beyond the formation of hydrothermally-dominated metamorphic quartz veins, but stops short of full-scale plutonism where large volumes of melt are able to coalesce and migrate upward. The results are important to future studies utilizing Re–Os dating of molybdenite in the metamorphic environment, a far more common occurrence than previously recognized. The classic greisen or microcline ± biotite ± garnet alteration attributed to an intrusion-related origin for many Mo–W–Sn-base and precious metal deposits may in fact be little more than the dehydration, contact-metamorphic record for flat-lying, rootless, nearly in situ leucosomatic melt fronts marking the instability of metal-rich biotite and/or hornblende. Low Re in molybdenite is a hallmark of its crustal derivation.

The Fennoscandian shield is host to a wide range of base and precious metal ore deposits (e.g., Weihed, 2003a). The Svecofennian terrane in northern Sweden north of the actively mined Skellefte district and south of the Luleå–Jokkmokk shear zone (LJSZ, Fig. 1) has been described both as a U and a Mo–(W) province (Adamek and Wilson, 1979; Walser and Einarsson, 1982; Öhlander, 1983). Present mining activity includes the Cu–Au–Ag deposit at Aitik (Wanhainen et al., 2003) and the classic Fe oxide ores at Kiruna (e.g., Cliff et al., 1990; Romer et al., 1994) north of the Mo–W–U province. In the Skellefte district south of the Mo–W–U province (Fig. 1), Au deposits such as Björkdal (Billström and Weihed, 1996; Weihed et al., 2003), VMS Zn–Cu–Au–Ag deposits such as Boliden and Kristineberg (Weihed et al., 1992; Bergman Weihed et al., 1996; Allen et al., 1997), and the recently discovered high-grade Storliden deposit (Imaña et al., 2004) are recently or actively mined.