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Effects of frictional–viscous oscillations and fluid flow events on the structural evolution and Re–Os pyrite–chalcopyrite systematics of Cu-rich carbonate veins in northern Norway

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ABSTRACT

Mesothermal chalcopyrite + pyrite + magnetite-bearing calcite-dominated vein deposits in the Repparfjord Tectonic Window, northern Norway, have been studied to constrain the mechanics of their emplacement and the timing of initial vein formation and reactivation. The veins cut across Paleoproterozoic tholeiitic metabasalts and present textural contrast between their hydrofractured, coarse-grained margins, and the fine-grained mylonitic cores. They formed under overall viscous conditions, although cyclically increased fluid pressures caused transient embrittlement. As mineral precipitation sealed the fractures, deformation was accommodated again viscously leading to mylonitization of the vein's core. Local brecciation of the calc-mylonite demonstrates the cyclicity of this process. Re–Os chalcopyrite–pyrite and K–Ar fault gouge dates define an almost continuous age range from ~2540 Ma to ~460 Ma. Regression of three Re–Os analyses yields a 2069 ± 14 Ma age ($^{187}Os/^{188}Os = 0.18 \pm 0.04$), interpreted as the age of vein emplacement, sulfide precipitation, and initial frictional–viscous deformation. K–Ar ages are mixed ages that constrain a maximum age of faulting in association with the veins at approximately 460 Ma, hence indicating structural reactivation connected with Silurian Caledonian orogenic compression. The spread in Re–Os model ages reflects this reactivation, wherein renewed strain accommodation and circulating oxidizing fluids caused fracturing, dynamic recrystallization, and isotopic disturbance of the sulfides. The study provides evidence for fluid flow during viscous deformation and demonstrates that strain, and flow of oxidizing fluids, can have a significant yet localized control on the integrity of the Re–Os systematic in pyrite and chalcopyrite.

1. Introduction

Mesothermal vein deposits are epigenetic, structurally controlled vein systems that are enriched in base and/or noble metals and are hosted in metamorphic terranes (Kerrich, 1993). Most of them are dominated by quartz and carbonate and are emplaced under greenschist facies metamorphic conditions during deformation along brittle–ductile shear zones and faults (Groves, 1993; Sibson et al., 1988). Critical to the formation of the veins is the opening and successive sealing of fractures, a process mostly governed by the regional stress state and its interplay with local conditions, in particular, fluid pressure (Cox, 1995). Overpressured fluids can cause brittle failure even under overall viscous conditions (Fischer and Paterson, 1989; Mancktelow, 2006). Indeed, the presence of mutually cross-cutting brittle and ductile structures in mesothermal vein deposits is commonly attributed to cyclic fluctuations of the fluid pressure (Cox, 2010; Micklethwaite et al., 2010; Sibson, 1990; Sibson et al., 1988), whereby repeated transient fracturing in addition to vein and possibly ore precipitation (Phillips, 1972; Sibson et al., 1975) reflect the cyclic increase of hydrostatic pressure toward lithostatic values before fluid venting eventually leads the system back to overall viscous conditions.

Although fracturing remains a key mechanism to explain fluid migration and mineral precipitation within fault-vein systems, recent studies have suggested that substantial fluid flow may also take place during viscous deformation by creep cavitation, that is, without the need of fracture-sustained permeability (Fusseis et al., 2009; Menegon et al., 2015). This observation is of great importance for the understanding of mineralization associated with mesothermal veins, where there exists an intimate temporal relationship between both frictional and viscous deformation, fluid migration, and the precipitation of the ore.

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The precipitation of sulfide minerals offers the possibility to isotopically date, by Re–Os geochronology (Shirey and Walker, 1998; Stein, 2014), the event(s) of vein formation and, indirectly, fluid flow and the associated regional tectonic stress fields. The advantage of the Re–Os sulfide chronometer compared to most other chronometers is that both Re and Os are chalcophile–siderophile elements that are not soluble in silicates, carbonates, or reducing aqueous fluids and consequently fractionate strongly into the sulfide phases (Burton et al., 1999; Stein, 2014). Hence, as long as oxidizing, sulfide-corrosive fluids are not present, sulfides hosted in silicate- or carbonate-rich rocks are unlikely to lose or gain Re and Os during tectonometamorphic episodes (Stein et al., 2003).

We present the results of a combined structural, petrographic, and Re–Os and K–Ar geochronological study of selected mesothermal Cu-rich carbonate veins situated within the Repparfjord Tectonic Window (RTW) in northern Norway (Fig. 1). The vein systems outcrop within

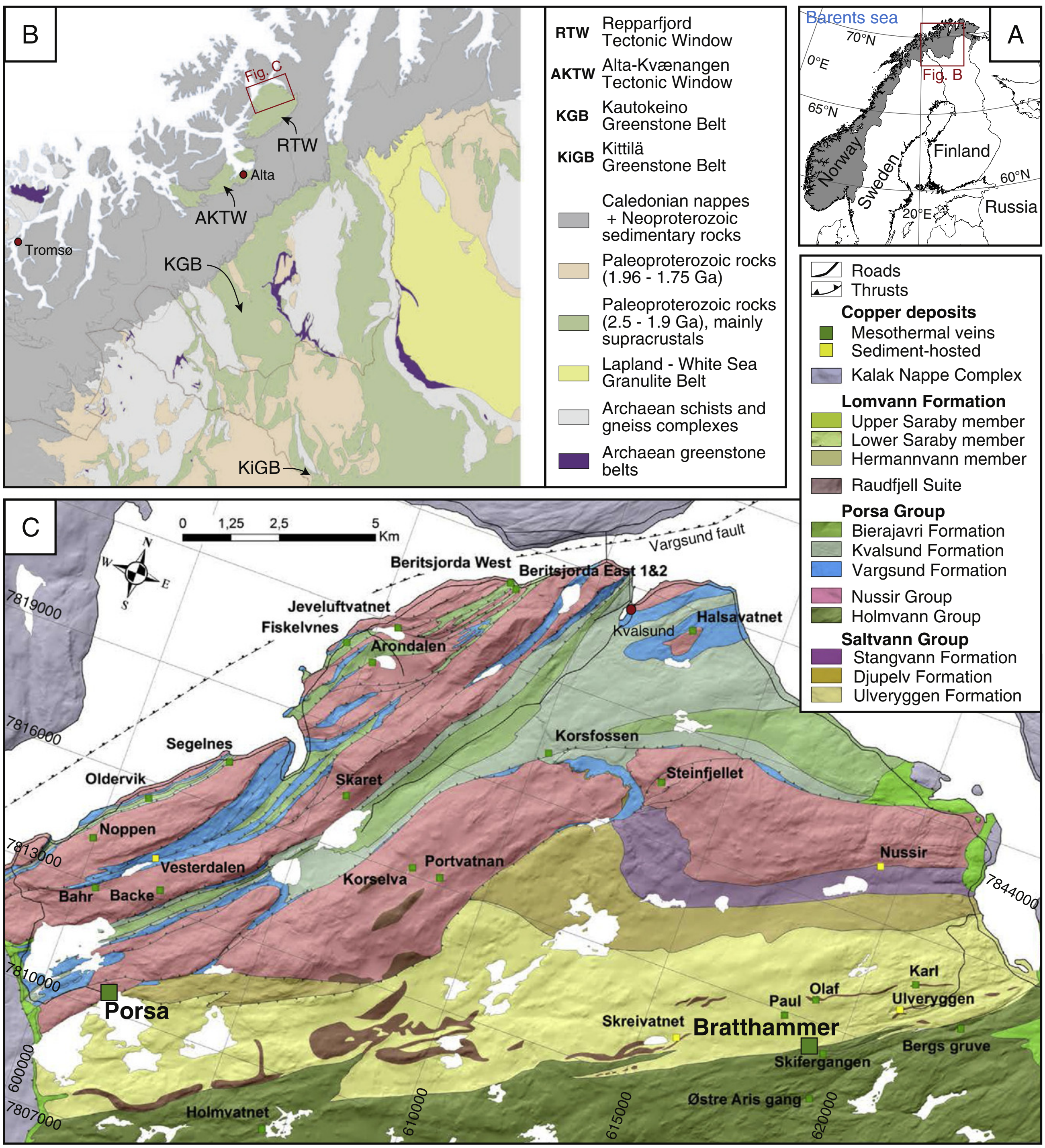

Fig. 1. (A) Location of the study area. (B) Simplified geological map of northern-most Fennoscandia (modified from Koistinen et al., 2001), showing the location of the Repparfjord (RTW) and Alta-Kvænangen (AKTW) tectonic windows within the Caledonian nappes, as well as the Kautokeino and Kittilä greenstone belts (KGB and KiGB, respectively) to the south of the two windows. (C) Bedrock map of the northwestern part of the Repparfjord Tectonic Window, including the location of known Cu-mineralization, prospects, and mines. The two sampling sites for geochronology, the Porsa and the Bratthammer veins, are highlighted. Map is based on new mapping and preexisting maps (Nilsen and Nilsson, 1996; Pharaoh et al., 1983; Reitan, 1963). Coordinates in WGS84/UTM zone 34 N.