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NOTE ON "LARGE-SCALE HYDROTHERMAL ZONING REFLECTED IN THE TETRAHEDRITE–FREIBERGITE SOLID SOLUTION, KENO HILL Ag–Pb–Zn DISTRICT, YUKON" BY J.V. GREGORY LYNCH

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INTRODUCTION

In his paper on "large-scale hydrothermal zoning reflected in the tetrahedrite–freibergite solid solution, Keno Hill Ag–Pb–Zn district, Yukon", Lynch (1989) documented east-to-west trends of increasing Ag/(Ag + Cu) and decreasing Zn/(Zn + Fe) in the solid-solution series $(Cu,Ag)_{10}(Zn,Fe)_2Sb_4S_{13}$ – $(Ag,Cu)_{10}(Fe,Zn)_2Sb_4S_{13}$, occurring over a scale of 25 km. This tetrahedrite solid-solution occurs in "epithermal" polymetallic fissure–vein deposits in graphitic quartzite and constitute the distal portion of a laterally zoned, fossil hydrothermal system extending over 40 km from the Mayo Lake Pluton to the east (Lynch *et al.* 1990). Mineralogical zoning in these deposits includes the outward (westward) appearance of "pyrargyrite, polybasite, stephanite, acanthite and native silver wire, as well as a quartz-dominated gangue with clay alteration". Lynch (1989) used the term "epithermal" to describe such occurrences. Tetrahedrite coexists with sphalerite and galena in a siderite gangue and records its highest average Ag values in samples from western mines and from the pyrargyrite-bearing Lucky Queen mine and adjacent Shamrock and Porcupine mines to the east (Fig. 1; Lynch 1989, Figs. 8, 9). Fluid-inclusion studies have established that the primary tetrahedrite-bearing ores were deposited at temperatures between 250 and 310°C (Lynch *et al.* 1990).

DISCUSSION

The most striking feature of the Ag/(Ag + Cu) and Zn/(Zn + Fe) values of the Ag-rich Keno Hill suite of tetrahedrite – freibergite is that the averages for all but the Calumet and Husky mines plot within about 10° of the 300°C isotherm on Figure 1. The isotherms on this figure define the maximum Ag content that tetrahedrite solid-solution may have at 170, 200, and 300°C (Sack *et al.* 2002). The vast majority of the Ag-rich tetrahedrite compositions have Ag/(Ag + Cu) and Zn/(Zn + Fe) values consistent with the fluid-inclusion-established temperatures. In addition, tetrahedrite from several of the mines defines linear arrays of decreasing Ag/(Ag + Cu) and Zn/(Zn + Fe) that cross-cut the 300°C isotherm (Fig. 1); these arrays may well represent retrograde Ag-depletion paths with decreasing Zn/(Zn + Fe) due to increasing Fe–Zn partitioning between tetrahedrite and sphalerite with cooling (*e.g.,* Sack & Loucks 1985, O'Leary & Sack 1987). Finally, tetrahedrite compositions from the Husky mine appear to reflect a lower temperature of compositional equilibration, about 170°C.

The fact that virtually all of the Keno Hill tetrahedrite compositions coexisting with sphalerite and pyrargyrite have Ag/(Ag + Cu) values effectively limited by the isotherm for the maximum fluid-inclusion-derived temperature (310°C) on Figure 1 would seem to offer strong evidence for the correctness and utility of the thermodynamic database for sulfides and sulfosalts on which the isotherms are based (*e.g.,* Sack 2000, Balabin & Sack 2000). The case made in this comparison is even more forceful than that presented by Sack *et al.* (2002, Fig. 5), because Lynch's temperature–composition dataset includes both Zn- and Fe-rich tetrahedrite. The fact that the majority of the Keno Hill tetrahedrite – freibergite appear to retain "primary" Ag/(Ag + Cu) and Zn/(Zn + Fe) values (*i.e.,* fall between the 250 and 310°C isotherms) stands in sharp contrast with compositions of tetrahedrite that typically coexists with Ag-bearing sulfosalts in other Ag–Pb–Zn mining districts, such as those in Coeur d'Alene, Idaho (Fryklund 1964) and Julcani, Peru (Goodell & Petersen 1974). In both of these districts, the Ag/(Ag + Cu) values of high-Ag tetrahedrite have been altered by secondary reactions associated with cooling. These alterations result in Ag/(Ag + Cu) values appropriate to roughly 175 and 220°C at Coeur d'Alene and Julcani (Sack *et al.* 2002, Sack & Goodell 2002), and must be corrected for

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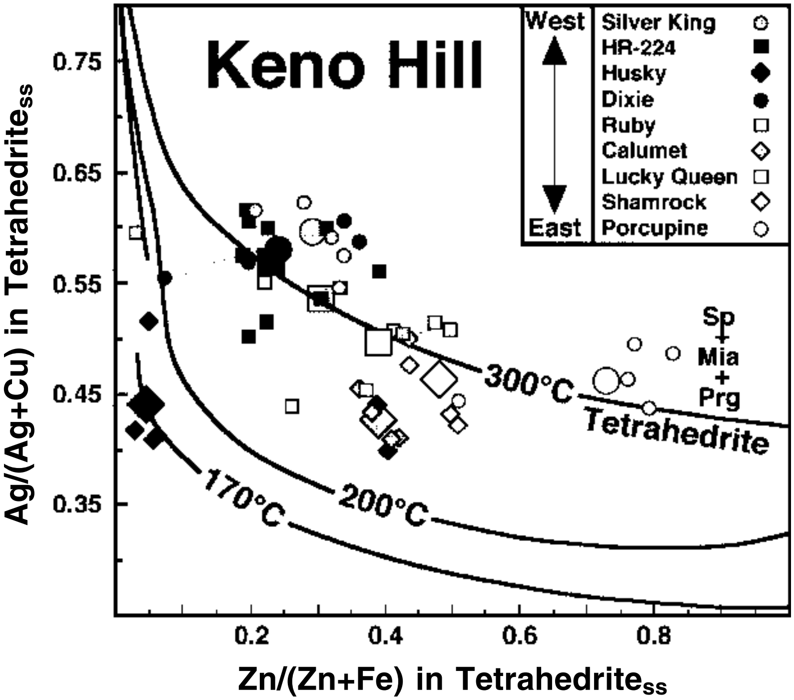

Fig. 1. Molar Ag/(Ag + Cu) and Zn/(Zn + Fe) values of high-Ag tetrahedrite – freibergite solid-solution series from the Keno Hill Suite (Lynch 1989, Table 1) compared with the calibration of Sack *et al.* (2002, Fig. 5) for the maximum solubility of Ag in tetrahedrite in the system Ag_2S–Cu_2S–ZnS–FeS–Sb_2S_3 at 170, 200, and 300°C (tetrahedrite in equilibrium with pyrargyrite, sphalerite, and miargyrite). Samples displayed are from the pyrargyrite-bearing ores of the western mines (filled symbols) and from the pyrargyrite-bearing Lucky Queen mine and the adjacent Shamrock and Porcupine mines to the east (open symbols). Larger symbols of a given type represent sample averages and exclude four out of fifty electron-microprobe datasets because they contain anomalously high values of Zn, considered to represent contamination by sphalerite (Dixie 2, Lucky-Q 2, H–R224–A 1, Calumet–A 2). Shaded lines with arrows at the end represent possible retrograde paths for tetrahedrite from the Dixie and Lucky Queen mines. Mineral abbreviations: Sp: sphalerite, Prg: pyrargyrite, Mia: miargyrite.

before the original parameters of these fossil hydrothermal systems may be defined. Notwithstanding evidence for some retrograde modifications of Ag/(Ag + Cu) and Zn/(Zn + Fe) values of tetrahedrite at Keno Hill (particularly that from the Husky mine), the largely "primary" character of these values makes the Keno Hill hydrothermal system ideal for a characterization of parameters of the fluid phase during the deposition of a bonanza Ag deposit (*e.g.,* Hackbarth & Petersen 1984, Sack 1992) and the development of modern methods of mineral exploration based on realistic thermochemical models for solid solutions of sulfides and sulfosalts.

It is easy to rationalize a higher effective temperature of blocking, or "freezing-in", for retrograde Ag–Cu diffusion in tetrahedrite from Julcani, which crystallized at high levels in the Andean crust (*e.g.,* Deen *et al.* 1994) relative to tetrahedrite re-equilibrated during the slow cooling of the deep-seated veins in the Coeur d'Alene district. However, it is difficult to understand the preservation of such a large "primary" component at Keno Hill, unless the quenching of the veins was virtually instantaneous, geologically speaking. Such quenching could readily be achieved by boiling in an "epithermal" environment. Indeed, Lynch *et al.* (1990) recorded evidence for boiling in the fluid inclusions and stable isotopes in the quartz and siderite intimately associated with tetrahedrite, sphalerite, pyrargyrite, and galena mineralization. According to the calculations of Lynch *et al.* (1990), the primary ore fluid began boiling at 310°C and cooled to about 250°C as boiling proceeded. Further cooling was accomplished with the aid of mixing with meteoric water (Lynch *et al.* 1990). On the basis of experimental constraints on the reaction kinetics of tetrahedrite (Ebel & Sack 1994), the ore veins must have cooled to less than 150°C within several years of tetrahedrite crystallization.

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