Temperatures from triple-junction angles in sulfides

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ABSTRACT

Experiments carried out between 280 and 980 °C demonstrate that dihedral angles for galena, $\theta_{gn}$, sphalerite-galena-sphalerite triple-junctions increase with increasing temperature, and that the rate of change increases in the same direction. Similar behavior is evident for sphalerite, $\theta_{sp}$, in sphalerite-galena-sphalerite triple-junctions, and also for pyrrhotite, $\theta_{po}$, in sphalerite-pyrrhotite-sphalerite triple-junctions. Triple-junction thermometry (TJT) is therefore most sensitive at high to very high temperatures where isotope thermometers are least sensitive. The method relies on the temperature-dependence of competitive surface tensions between shared surfaces of intergrown minerals. Because chemical interaction is not a prerequisite, the TJT method is potentially applicable to a variety of mineral pairs found in regional metamorphic situations. The method requires a slightly modified microscope equipped with a precision X-Y stage.

The application of $\theta_{sp}$-T (temperature) and $\theta_{po}$-T calibrations to regionally metamorphosed sulfide ores yields temperatures that compare reasonably with temperatures obtained from sulfur isotopes and other geothermometers. Maximum regional metamorphic temperatures of ~470–480, ~590, and ~700 °C were obtained for the Bathurst (New Brunswick = greenschist facies), Ruttan (Manitoba = amphibolite facies) and Broken Hill (N.S.W. = granulite facies) deposits, respectively. The $\theta_{sp}$ and $\theta_{po}$ thermometers also reveal recrystallization effects in microfabrics.

INTRODUCTION

Some of the world’s largest Pb-Zn sulfide deposits have been regionally metamorphosed at temperatures between 300 and 800 °C and at pressures up to 8 kbars. An improved understanding of the effects of metamorphism on sulfide deposits is advantageous because the maximum temperature of metamorphism determines mean grain size and the grain shapes of minerals. These factors are of significance because they affect the efficiency of mineral separation in sulfide ores. A thorough knowledge of sulfide ore microfabrics is valuable to sulfide petrologists seeking a better understanding of metamorphic temperatures ($T$) and pressures ($P$), as well as metamorphic histories.

Chemically based mineralogical thermometers have long been applied to regionally metamorphosed sulfide deposits and their enclosing rocks. These thermometers have led to broad agreement on respective $T$-$P$ conditions for the various grades of regional metamorphism. Among the thermometers used, sulfur (Ohmoto 1986) and oxygen (Valley 1986) isotope thermometers have been extremely important due to their pressure-independence and their application over wide temperature ranges. For sulfide ores, the sphalerite-galena sulfur isotope thermometer has been applied extensively (Ohmoto 1986). Fluid inclusion thermometry is commonly useful at lower grades of metamorphism where aqueous fluids are typically present (Roedder 1986). Very precise temperatures can be obtained directly in situations where fluid boiling is evident, but pressure corrections must be applied to homogenization temperatures obtained from other situations (Roedder 1986). The arsenopyrite thermometer has received limited attention, but has been applied successfully to some sulfide deposits (e.g., Sharp et al. 1985).

The world’s Pb and Zn are obtained from the common sulfides galena (PbS) and sphalerite (ZnS) that occur together in multi-million ton deposits in the crust of continents. Predominant among these are sedimentary sulfide deposits of widely variable age that have been buried and heated in the crust for millions of years. Stanton (1964) has demonstrated that sulfide microfabrics in regionally metamorphosed sulfide deposits have resulted from surface tension-induced grain growth in response to increases in temperature. Depending on local geothermal gradients, extreme depths of burial to around 25–30 km equate with maximum regional metamorphic temperatures of between ~600 and ~800 °C. The highest metamorphic temperatures promote the highest diffusion rates and generate the coarsest mean grain sizes. Stresses in the Earth’s crust cause a variety of deformation effects that can be large scale, such as in folding, or localized within microfabrics. Sulfide deposits are characteristically affected to varying degrees during long periods of slow cooling from maximum metamorphic temperatures. Localized deformation generates lattice strain within minerals, and temperature simultaneously relieves strain through annealing and recrystallization at prevailing temperatures. Consequently, ongoing or multiple deformation events during cooling can yield a range of recrystallization temperatures within a given deposit (Lusk and Krouse 1997).

In the absence of fluid-filled cavities, solid grains share contact surfaces with adjacent grains. Where the grains are of