Economic Geology
Vol. 98, 2003, pp. 535–556

Geochemical and Oxygen Isotope Signature of Sea-Floor Alteration Associated with a Polydeformed and Highly Metamorphosed Massive Sulfide Deposit, Ruostesuo, Central Finland

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Abstract

Massive sulfide deposits in the Vihanti-Pyhäsalmi district, central Finland, are hosted by a highly deformed and metamorphosed bimodal volcanic sequence. Alteration zones that envelop these deposits are composed of cordierite + orthoamphibole ± garnet-bearing rocks (referred to as COR rocks) belonging to upper amphibolite to granulite facies. Outcrops of mafic and felsic COR rocks (M_{COR} and F_{COR}) in the vicinity of the Ruostesuo Zn-Cu deposit define mappable layers with distinctive metamorphic mineral assemblages: orthoamphibole + cordierite ± plagioclase ± quartz (M^1_{COR}); garnet + orthoamphibole + cordierite ± plagioclase ± quartz (M^2_{COR}); quartz + cordierite + biotite ± orthoamphibole ± cummingtonite ± garnet ± plagioclase (F^1_{COR}); and quartz + cordierite + garnet + sillimanite (F^2_{COR}). These rocks are interlayered with, or grade into, typical amphibolites (i.e., hornblende + plagioclase) and quartz + plagioclase-bearing rocks that are interpreted as least altered mafic and felsic metavolcanic rocks, respectively.

Whole-rock geochemical data for least altered metavolcanic rocks and COR rocks at Ruostesuo define three mafic suites (primitive basalts, basaltic andesites, and ferrobasalts) and two felsic suites (R1 and R2 rhyolites). Using a combination of high field strength element ratios and rare earth element profiles, COR rocks can be assigned to all five volcanic suites.

Calculated mass changes for the majority of exposed COR rocks at Ruostesuo are similar to those reported for chlorite + quartz assemblages found within the inner core of alteration pipes located below some sea-floor massive sulfide deposits. Relative to least altered precursors, mafic COR rocks have gained Fe, Mg ± S and lost variable amounts of Si, Ca, Na, K, Rb, Ba, Sr, and Eu, which resulted in an average net mass loss of about 10 percent. The bulk composition of most altered mafic COR rocks (near total loss of Ca, Na, K) reflects the proportion of chlorite to quartz within the premetamorphic alteration assemblages and the composition of the chlorite. Mass-change results for altered mafic rocks indicate that basalts at Ruostesuo were altered by an evolved, Fe-rich hydrothermal fluid at high water/rock ratios.

Mass changes for COR rocks of the R2 felsic volcanic suite are similar to those of the mafic rocks (enriched in Fe ± Mg and depleted in Ca, Na, K, Rb, Ba, Sr, and Eu) except for significant additions of Si that resulted in net mass gains of 20 to 30 percent. Felsic COR rocks of the R1 volcanic suite show gains in K, Rb, and Ba that are attributed to the formation of premetamorphic sericite during an alteration stage dominated by hydrothermal seawater.

In comparison to least altered metavolcanic rocks, mafic and felsic COR rocks are depleted in ^{18}O, with $\delta^{18}O$ values 2 to 5 per mil lower than precursor rocks. Estimated temperatures of alteration were 270° to 350°C. These data indicate that the signature of a high-temperature (~300°C) sea-floor hydrothermal upflow zone is preserved within upper amphibolite to granulite facies rocks at Ruostesuo.

The stratigraphic boundary between strongly chloritized mafic volcanic rocks and silicified felsic volcanic rocks marks a transition from net mass losses associated with hydrothermal fluid-dominated alteration to net mass gains associated with seawater-dominated alteration. Silicification at or near the boundary between mafic and felsic volcanic rocks may have been the result of conductive cooling or mixing with seawater from above. In the absence of textural or crosscutting relationships indicative of a younging direction, a stratigraphic model is proposed on the basis of the above geochemical constraints. Altered basalts at Ruostesuo represent the exposed base of a chloritic stockwork zone that passes upsection into altered felsic volcanic rocks that host massive Zn-Cu sulfides.

This stratigraphic model has significance for the interpretation of other massive sulfide deposits in the Vihanti-Pyhäsalmi district and exploration strategies that couple chemostratigraphy with mass-change results. More significantly, the preservation of premetamorphic oxygen isotope values for strongly metamorphosed and locally migmatitic COR rocks indicate that oxygen isotope mapping is a viable exploration tool in the district and in other mineralized upper amphibolite to granulite facies terranes worldwide.

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0361-0128/01/3339/535-22 $6.00