

# Applied Modeling of Metamorphic Phase Equilibria for Alteration Vectors in Volcanogenic Massive Sulfide Systems

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Discordant zones of alteration associated with the development of the volcanogenic massive sulfides (VMS) have well defined alteration facies that range from fresh volcanic strata to monomineralic chloritite cores. Commonly these alteration zones are characterized as a series of chemical reactions that result in bulk rock elemental gains and losses. Using Noranda VMS deposits as an example, these reactions can be separated into three stages: 1) glass-plagioclase transformed into sericite-quartz, 2) sericite-quartz transformed into magnesium rich chlorite and quartz, and 3) magnesium rich chlorite transformed into iron rich chlorite and quartz is removed. These stages represent alteration vectors that chemically express the compositional changes of the rock: a sericitic alteration vector (SAV) for the first stage of alteration, and a chloritic alteration vector (CAV) for the second and third stages of alteration. In metamorphosed terrains these common alteration facies experience phase transformations that obscure their mineralogy, resulting in problematic identification of alteration.

Cordierite-orthoamphibole bearing assemblages are commonly interpreted to represent metamorphosed hydrothermal alteration. However, discrimination of metamorphosed hydrothermal alteration is severely hindered by their resemblance to pelitic metasedimentary assemblages. This problem is further enhanced by the use of simple chemical systems (FeO-MgO-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub>-H<sub>2</sub>O) to model the phase equilibria, which are not appropriate for bulk rock compositions that characterize VMS alteration systems. In contrast the Na<sub>2</sub>O-CaO-K<sub>2</sub>O-FeO-MgO-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub>-H<sub>2</sub>O chemical system allows the role of calcium, sodium and potassium, which are important constituents in the early stages of alteration, to be monitored during the evolution of alteration mineral assemblages.

Until recently, thermodynamic modeling has not allowed the expansion to larger and more complex chemical systems, and this study represents one of the first to appraise the phase equilibria for VMS alteration systems using such a complex system. A series of chemical

vectors that track compositional changes across a spectrum of alteration have been developed, which incorporates the known gains and losses in VMS alteration systems. These vectors are then applied to an average rock composition for volcanic strata, and then integrated into a temperature-composition diagram that models the metamorphic phase equilibria as a function of metamorphic temperatures. The system was fixed to a pressure of three kilobars, in order to compare the models to conditions in Noranda. This work presents the predicted metamorphic phase equilibria and modal abundances of phases that can be directly correlated to precursor alteration compositions.

Generalized results from modeling of rhyolitic glass demonstrate that the presence or absence of cordierite is not indicative of alteration intensity within the CAV, as cordierite exists throughout at temperatures equivalent to amphibolite conditions. It's not until higher temperatures (greater than 630°C) are achieved that cordierite is a stable phase in the SAV, although at these temperatures the cordierite stability field extends from the core of the alteration to the unaltered rhyolitic glass. With increased alteration the cordierite abundance increases until the most extremely altered compositions are reached, where quartz is not a stable phase. The loss of quartz in the metamorphic assemblages then results in the consumption of cordierite.

The topology of the orthoamphibole stability field mimics that of cordierite. However, there is a strong compositional control on the location of this field, in that orthoamphibole is only present after approximately 35% of CAV has reacted with the SAV; supporting the interpretation that the occurrence of orthoamphibole is indicative of alteration intensity. These results will be compared to VMS deposits in Noranda to further understand the evaluation of metamorphosed alteration, and define facies within these zones.