Thermodynamics of the amphiboles: Ca-Mg-Fe^{2+} quadrilateral

MARK S. GHIORSO* AND BERNARD W. EVANS

Department of Geological Sciences, Box 351310, University of Washington, Seattle, Washington 98195-1310, U.S.A.

ABSTRACT

A thermodynamic model has been developed and calibrated for monoclinic and orthorhombic amphiboles compositionally contained within the Ca-Mg-Fe^{2+} amphibole quadrilateral. The model incorporates the energetic consequences of cation ordering of Fe^{2+} and Mg over nonequivalent sites in the crystal structure, and accounts for the temperature, pressure, and compositional dependence of the orthorhombic-monoclinic phase transition. Calibration is based on previously published work on the thermodynamic properties of Fe^{2+}-Mg amphiboles and tremolite, and experimental cation-ordering data, along with solvus width and tieline orientations of natural coexisting amphiboles in the quadrilateral.

Among derived parameters is the enthalpy of formation of end-member ferroactinolite (–10534.966 kJ/mol). A calculated FeMg$_{-1}$ isopotential solvus at mid-composition in the quadrangle agrees well with a revised calibration of experimental data from Cameron (1975). The solvus is not strongly asymmetric and narrows with increasing Fe/Mg ratio and temperature. Phase relations along the Mg and Fe sides of the quadrilateral are compared and contrasted. Cummingtonite-anthophyllite phase relations are shown in the T-X_{Fe} plane, with and without coexisting calcic amphibole. The breakdown reactions of quadrilateral amphiboles to assemblages of two pyroxenes, olivine, quartz, and H$_2$O are depicted as functions of temperature, pressure, composition, H$_2$O activity, and oxygen fugacity. Some highlights of their relevance to metamorphic and igneous systems are discussed.