

SOLID SOLUBILITY OF  $\text{Al}_2\text{O}_3$  in Enstatite at High Temperatures  
and 1-5 kb Water Pressure

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P. Anastasiou and F. Seifert

Institut für Mineralogie der Ruhr-Universität, Bochum, Germany

*Abstract.* Solid solubility of  $\text{Al}_2\text{O}_3$  in orthorhombic enstatite by the substitution  $\text{AlAl} = \text{MgSi}$  is, in the range studied, mainly a function of temperature and not strongly pressure-dependent. Even at 1 kb up to 9 wt.-%  $\text{Al}_2\text{O}_3$  can be substituted at  $1200^\circ\text{C}$ . The thermal stability of the orthorhombic pyroxene phase is strongly increased by the incorporation of Al.

In crustal rocks the alumina content of orthopyroxene might be used as a geothermometer but not, as sometimes suggested, as a barometer.

**Introduction, Previous Studies**

The stability and miscibility relations of the orthopyroxene phases have received special attention by petrologists due to their common occurrence in magmatic and high-grade metamorphic rocks as well as in ultramafic nodules in volcanic rocks.

The stability of the most important end member enstatite,  $\text{MgSiO}_3$ , was investigated up to 50 kb by Boyd, England, and Davis (1964) under dry conditions, whereas Kushiro, Yoder, and Nishikawa (1968) studied its melting behaviour in the presence of water up to 30 kb.

Many substitutions are known to occur in enstatite but the substitution  $\text{AlAl} = \text{MgSi}$  proved to be especially sensitive to pressure and temperature variations under high confining pressures and thus useful for petrologic interpretations of orthopyroxene-bearing rocks of supposed mantle origin. Boyd and England (1964) showed that, in the range 20–50 kb,  $1100\text{--}1600^\circ\text{C}$ , solid solubility of  $\text{Al}_2\text{O}_3$  in enstatite decreases markedly with increasing pressure and increases with rising temperature, though this increase with temperature becomes less pronounced with increasing pressure. Boyd and England, therefore, suggested the use of these solid solutions as a geobarometer. The general relationships mentioned also hold for iron-bearing orthopyroxenes as demonstrated by MacGregor and Ringwood (1964).

The high solid solubility of alumina in enstatite around 20 kb and its very restricted solubility in the high-temperature polymorph protoenstatite at 1 atm has led Boyd and England (1960)—in accordance with an earlier hypothesis by Hess (1952)—as well as some later investigators (e.g. Green, 1964; Jamieson, 1966) to the conclusion that  $\text{Al}_2\text{O}_3$ -rich orthopyroxenes must have formed at high pressures on the order of 10 kb or more, i.e. within the earth's upper mantle. This theory was highly speculative, however, because sufficient experimental data in the pressure range 1 bar to 20 kb were lacking. Thermodynamic calculations of the miscibility of enstatite on the pseudobinary join  $\text{MgSiO}_3\text{--Al}_2\text{O}_3$  by Dobretsov (1968) indicate a rather high solid solubility of the orthopyroxene phase also at relatively low pressures. However, these data cannot be very precise be-