$(MgFe^{2+}Ca)SiO_3$-Al_2O_3. In order to elucidate the stability of high aluminous orthopyroxene, therefore, it is necessary to determine the pressure and temperature dependence of the substitution MgSi = Fe^{3+}Al and its influence on the substitution MgSi = AlAl.

In this paper, the stability of enstatite in the system $MgSiO_3$-Al_2O_3-Fe_2O_3 and the solubility of Al_2O_3 and Fe_2O_3 in enstatite are determined experimentally in the pressure and temperature range 8 – 16 Kb and 800 – 1300°C. The geological significances of Al_2O_3 and Fe_2O_3 contents of orthopyroxenes are discussed.

Previous works

The join $MgSiO_3$-$MgAl_2SiO_6$ at 1 atm.

The join $MgSiO_3$(En)-$MgAl_2SiO_6$(MgATs) was studied by Onuma and

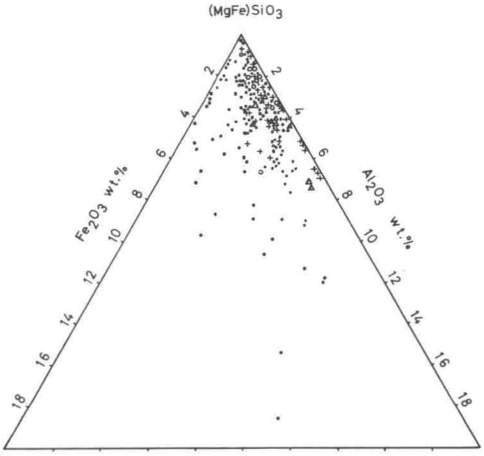

Fig. 1 Al_2O_3 and Fe_2O_3 contents of natural orthopyroxenes. Sources of data. *Plutonic differentiated rocks and volcanic rocks* (open circle) Hess (1952), Brown (1957), Kuno (1954, 1964), Atkins (1969). *Intrusive peridotite* (triangle) Green (1964), Onuki (1965), Challis (1965), Takeda and Onuki (1973), Niida (unpublished). *Inclusion of volcanic rock* (cross mark) Ross (1954), Banno (1964), Lovering (1964, 1969), Onuki (1965), Meyer (1976), Le Maitre (1965). *Metamorphic rock* (solid circle) Eskola (1952), Howie and Subramaniam (1957), O'hara (1960, 1961), Kranck (1961), Binns (1962, 1965), Dodd (1963), McKie (1963), Barker (1964), Engel et al. (1964), Green (1964), Howie (1963, 1964), Sen and Rege (1965), Klein (1966), Philpotts (1966), Leelanandam (1967), Chinner and Sweatman (1968), Davidson (1968), Bhattacharyya (1970), Bondarenko (1972), Lutts and Kopanava (1972), Nixon et al. (1973), Clifford (1975), Jayawardene and Carswell (1976), Murthy (1976), Wilson (1976), Woodford and Wilson (1976), Arita (unpublished).

Arima (1975) at atmospheric pressure with special reference to the solubility of Al_2O_3 in protoenstatite above 1300°C. The phase equilibrium diagram is given in Fig. 2. MgATs is incorporated in protoenstatite as much as 3.5 wt.% (1.75 wt.% Al_2O_3), in an agreement with the observation of Bigger and Clark (1973). At subsolidus temperature the phase assemblage protoenstatite+forsterite was confirmed in the compositional range from En(96.5)MgATs(3.5) to En(94.5)MgATs(5.5). The presence of this field indicates that the composition of protoenstatite$_{ss}$ extends over an area on both sides of the join En-MgATs on the ternary plane of MgO-Al_2O_3-SiO_2 as shown in Fig. 3 (probably protoenstatite$_{ss}$ is nonstoichiometric). In the more aluminous region the subsolidus phase assemblages are protoenstatite$_{ss}$+forsterite+cordierite$_{ss}$ and forsterite$_{ss}$+cordierite$_{ss}$+spinel. The unit cell parameters a, b and V of protoenstatite$_{ss}$ decrease with increasing Al_2O_3 content in it. In their discussion Onuma and Arima (1975) showed that the Al_2O_3 content of protoenstatite can be used as an indicator of temperature only above 1400°C, and that when the Al_2O_3 content is less than 2 wt.% it can not be used either as a pressure or temperature indicator.

The join $MgSiO_3$-$MgAl_2SiO_6$ at high pressures.

The join $MgSiO_3$-$MgAl_2SiO_6$ was studied by Arima and Onuma (1977) in the pressure and temperature range 10 – 25 Kb and 1100 – 1500°C, with special reference to the solubility of Al_2O_3 in enstatite. The T-X sections at 10, 15, 20, and 25 Kb are shown in Fig. 4. At subsolidus temperatures, the solubility of Al_2O_3 increases with increasing temperature. At 1450°C and 15 Kb MgATs is incorporated in enstatite as much as 33 wt.% (16.5 wt.% Al_2O_3). The P-T diagrams of the both compositions En(80)MgATs(20) and En(70)MgATs(30) are given in Fig. 5. The two univariant reactions, enstatite(En)+sillimanite(Sill) = sapphirine(Sa)+quartz(Qtz) and pyrope(Py) = En+Sill+Sa were determined experimentally. The temperature and pressure values of these univariant lines are in a good agreement with those determined by previous workers (Boyd 1959, Chatterjee and Schreyer 1972, Newton 1972). As shown in Fig. 6, these univariant lines do not intersect each other, indicating the metastable invariant point where En, Sa, Sill, Py, and Qtz coexist. The P-X sections of the join En-MgATs at various temperatures are given in Fig. 7. The pressure dependence of the solubility of Al_2O_3 is variable with respect to the coexisting minerals. The solubility decreases with increasing pressure when enstatite coexists with pyrope or with sillimanite+sapphirine, but increases with increasing pressure when enstatite coexists with sapphirine+quartz. From these experimental results, the Al_2O_3 content of orthopyroxene