shown in Fig. 16 on the basis of the experimental results in the other compositional region. In this field Eqs. 2 and 4 should be taking place.

In most aluminous region, the three phase field of En_{SS}+Sa_{SS}+Qtz is present as shown in Fig. 16. In this field there are two reaction of Eqs. 5a and 5b. Eq. 5b is an invariant reaction in the system MgO-Al_2O_3-SiO_2 and Eq. 5a is an univariant reaction in the system MgO-Al_2O_3-Fe_2O_3-SiO_2. The composition of $enstatite_{SS}$ is determined by these two reactions in this field. With increasing Fe_2O_3 content of $enstatite_{SS}$ coexisting with Sa_{SS}+Qtz, the solubility of Al_2O_3 in it strongly increases at constant pressure and temperature as shown in Fig. 16. This result indicates that the solubility of Al_2O_3 in enstatite depends on the Fe_2O_3 content of it as well as temperature and pressure variations. Therefore, the Al_2O_3 content of orthopyroxene can not be used as an indicator of temperature and/or pressure without taking the Fe_2O_3 content of it into account. On the other hand, the solubility of $MgAl_2SiO_6$ in enstatite is constant at constant temperature and pressure when it coexists with Sa_{SS}+Qtz as shown in Fig. 16. The increase of Al_2O_3 content of $enstatite_{SS}$ with increasing Fe_2O_3 content of it is attributed to the solubility of $MgFe^{3+}AlSiO_6$ in it. This results makes it possible to use the $MgAl_2SiO_6$ content as an indicator of temperature and/or pressure.

Present experimental results indicate that sapphirine breaks down to the assemblage of Sp_{SS}+Qtz in the part of high Fe_2O_3 content in the system

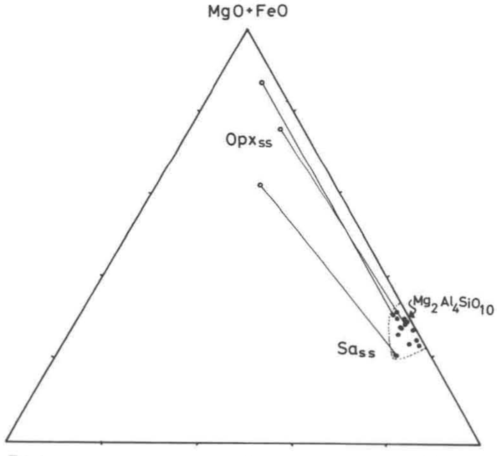

Fig. 25 The compositional relationships between natural orthopyroxenes and sapphirines in the system MgO-Al_2O_3-Fe_2O_3. A tie line indicates a coexisting relation. Sources of data, Segnit (1957), McKie (1963), Barker (1964), Lutts and Kopaneva (1967), Moore (1969), Haapala et al. (1971), Monchoux (1972), Merlino (1973), Woodford and Wilson (1976).

MgO-Al_2O_3-Fe_2O_3-SiO_2. This breaking down reaction is expressed by the Eqs. 6a and 6b. In fig. 25, Fe_2O_3/Al_2O_3 ratio of several natural sapphirines are plotted, implying the narrow field of sapphirine$_{SS}$ between $Mg_2Al_4SiO_{10}$ and $Mg_2Fe^{3+}_4SiO_{10}$. Though there is no experimental study on the relation between them, the presence of solvus is assumed and a tie line between Sa$_{SS}$ and En$_{SS}$ is presented as shown in Fig. 16.

The temperature and pressure dependence of the solubility of Al_2O_3 and Fe_2O_3 in enstatite

In Fig. 22, the single phase field of enstatite$_{SS}$ at various temperatures and 8 Kb are given. Independently of coexisting phases, the solubility of Al_2O_3 and Fe_2O_3 in enstatite increases with increasing temperature. Fig. 24 shows the single phase field of enstatite$_{SS}$ at 1100°C in the pressure range 8 – 16 Kb. The solubility of MgFATs slightly decreases with increasing pressure when enstatite coexists with hematite (Fig. 12). The pressure dependence of the solubility of MgATs in enstatite coexists with spinel$_{SS}$+quartz is estimated to be slight. From these data, the pressure dependence of the solubility of MgFATs in enstatite (maximum solubility) coexisting with sapphirine$_{SS}$+quartz is determined as shown in Fig. 24.

Geological applications

Al_2O_3 content of orthopyroxene has been given an attention by many investigators as a geobarometer and a geothermometer. The experimental studies have been made on the incorporation of Al_2O_3 in enstatite by the substitution MgSi = AlAl, and these experimental results have been used to estimate the pressure and/or temperature conditions of natural rocks (Boyd 1973, Hermans et al. 1976).

In general, natural orthopyroxenes show small amount of silica deficiency in these chemical formulas. These silica deficiencies are explained by the replacement of Si by Al in tetrahedral site and the corresponding replacement of Mg by Al in octahedral site(M1). This substitution of MgSi = AlAl leads to the hypothetical pyroxene molecule $MgAl_2SiO_6$ (MgATs). In chemical formulas of natural orthopyroxenes, Al in M1 site is generally less than Al in T site, and Cr, Ti, and Fe^{3+} are regarded to enter in M1 site, filling up the vacancy. These assumption lead to the hypothetical pyroxene molecules such as $MgCrAlSiO_6$, $MgTiAl_2O_6$. As shown in Fig. 1, some natural orthopyroxenes show both high contents of Al_2O_3 and Fe_2O_3 (exceed 2 – 3 wt.%), indicating the substitution MgSi = Fe^{3+}Al as well as MgSi = AlAl. While Cr_2O_3 and TiO_2 contents are