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STABILITY OF OSUMILITE IN GRANULITE FACIES METAMORPHISM: KMAS SYSTEM AND NATURAL OCCURRENCES

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Abstract: The stability relation of osumilite in granulite facies rocks is evaluated in the light of the recent study of osumilite-bearing granulites in the Paradise River area, Laborador, Canada (M. ARIMA and C. F. GOWER: Geol./Mineral. Assoc. Canada, Program with Abst., **10**, 1987; to be publ. in J. Petrol., 1990) The mineral parageneses in the Paradise River granulites indicate that osumilite is stable at temperatures lower than those required for sapphirine-quartz stability. The *P-T* grid deduced from the Paradise River occurrence is in accordance with that proposed by E.S. GREW (Am. Mineral., **67**, 762, 1982) for osumilite-sapphirine-quartz granulites in the Napier terrane, Antarctica. This conclusion is supported by high pressure experimental results in the KMAS system which suggest that osumilite is stable at temperatures lower than the univariant reaction En+Sil=Sa +Q.

1. Introduction

Osumilite [$K(Mg, Fe)_2(Al, Fe, Mg)_3(Sil, Al)_{12}O_{30}$], first described by MIYASHIRO (1956) from volcanic rocks in Sakkabira, Osumi Peninsula, Japan, is a rare K-bearing ferromagnesian alumina silicate occurring in both igneous and metamorphic rocks. Since metamorphic osumilite was described by BERG and WHEELER (1976) from granulite facies metamorphic rocks in Nain, Labrador, Canada, osumilite-bearing granulites have been reported from four other localities worldwide such as: Napier, Antarctica (ELLIS, 1980; ELLIS *et al.*, 1980; GREW, 1982; SHERATON *et al.*, 1987), Vahugdzhur, Aldan Shield, Eastern Siberia (BOGDANOVA *et al.*, 1981), Rogaland, Norway (MAIJER *et al.*, 1977; JANSEN *et al.*, 1985; TOBI *et al.*, 1985), and Paradise River, Eastern Labrador, Canada (ARIMA and GOWER, 1987, 1990). Of these occurrences, Napier is the only regional granulite terrane where osumilites has been reported. Other four localities are granulite facies contact aureoles of anorthositic complexes. Osumilite, however, is probably a common and important mineral in regional granulite facies metamorphism, as its stable existence is suggested in numbers of granulite terranes by the presence of symplectic intergrowths diagnostic of osumilite breakdown products. These terranes are Wilson Lake, Canada (GREW, 1982), Labwor, Uganda (SANDIFORD *et al.*, 1987), Chogar, Aldan Shield, USSR (PERCHUK *et al.*, 1985), and Eastern Ghats, India (GREW, 1982; LAL *et al.*, 1987). It is noteworthy that a high temperature mineral assemblage of sapphirine-quartz occurs in all of the terranes.

In this paper the stability of osumilite in granulite facies pelitic rocks is examined in the light of the recent study of the mineral and chemographic relationships in osumilite-bearing granulites in the Paradise River area, Labrador, Canada (ARIMA and GOWER, 1987, 1990). We also report preliminary results of experimental works on the stability of osumilite at high temperatures and pressures in the K_2O-MgO-Al_2O_3-SiO_2 (KMAS) system.

2. Previous Experimental Studies on the Stability of Osumilite

SCHREYER and SEIFERT (1967) synthesized osumilite at 1 kbar between 500–900°C and suggested that osumilite may be a metastable phase. The experiments by HENSEN (1977), however, showed that osumilite is probably stable with cordierite, orthopyroxene, feldspar and liquid at 1000–1100°C at 3.8–7.2 kbar. OLESCH and SEIFERT (1981) investigated the stability of osumilite in the KMAS-H_2O, suggesting that in the hydrous system the stability field of osumilite is limited to water pressure below 800 bar. These experimental studies collectively suggest that osumilite can be stable at *P-T* conditions comparable to those of granulite metamorphism under relatively low water fugacities, but no systematic experimental study has been done to establish the *P-T* stability relation of osumilite under the granulite facies metamorphic conditions.

3. Phase Relationships Involving Osumilite in Napier

The osumilite-bearing primary assemblages in the Napier terrane can be summarized as: Os+Sap+Q$\pm$Opx$\pm$Gt$\pm$Sp, Os+Opx+Sil+Q$\pm$Gt, Os+Sap+Sil+Q $\pm$Gt, Os+Sap+Opx+Sil+Q, Os+Sap+Opx+Cd+Q, and Os+Opx+Cd+Q (ELLIS *et al.*, 1980; GREW, 1982, SHERATON *et al.*, 1987). ELLIS (1980) estimated peak metamorphism in the Tula Mountains at 8–10 kbar and 900–980°C. GREW (1980) estimated 900°+30°C and 7+1 kbar for the same area. In the western part of the Napier terrane, HARLEY (1983, 1985) estimated 900–950°C and 7–10 kbar. Such conditions would approximate the *P-T* stability of osumilite in pelitic compositions. GREW (1982) estimated the stability of osumilite with quartz in granulite facies pelitic rocks to be at temperatures above 750°C, lithostatic pressure not exceeding 8–9 kbar, and at water pressure not exceeding 1 kbar.

Based on the mineral and chemographic relationships in granulites in Napier, ELLIS *et al.* (1980) and GREW (1982) independently constructed *P-T* grids for the osumilite and sapphirine-quartz. In the grids formulated by GREW (1982), which involves osumilite, sapphirine, orthopyroxene, cordierite, garnet, phlogopite, K-feldspar, sillimanite, and quartz, an assemblage osumilite-quartz is stable at temperatures lower than those for sapphirine-quartz, unlike the grids proposed by ELLIS *et al.* (1980). A progressive *P-T* path has not been well defined in the Napier terrane (*cf.* SHERATON *et al.*, 1987). Without knowing the independently estimated temperature and pressure gradients for the area where osumilite- and sapphirine-quartz occur, it seems difficult to define the stability relationships between osumilite-bearing and sapphirine-quartz assemblages.

4. Osumilite in the Paradise River Area, Labrador

A progressive *P-T* path has been delineated for osumilite-bearing granulite facies metasedimentary gneisses in the Paradise River area, eastern Grenville Province, Labrador, Canada (ARIMA and GOWER, 1987, 1990). The osumilite-bearing gneiss occurs in the contact aureole of the Proterozoic gabbronorite complex. The critical mineral assemblage in the pelitic gneiss varies, toward the intrusive contact, from assemblages containing muscovite+phologopite+quartz, through those with phlogopite+sillimanite+quartz, to those with cordierite+K-feldspar+quartz, and finally to those with osumilite and sapphrine. An osumilite-in isograd is delineated at a distance of 1–3 km from the intrusive contact. The osumilite occurs in association with cordierite, orthopyroxene, sillimanite, sapphirine, spinel, K-feldspar, plagioclase, phlogopite, hematite, magnetite, corundum, and quartz. The stable osumilite-bearing assemblages deduced from petrographic features and from the phase relations in the KMAS system are Os+Sa+Cd, Os+Sil+Cd+Q, Os+Cd+Kf+Q, Os+Cd+Opx+Q, Qs+Opx+Kf+Q. Symplectic intergrowth of cordierite-orthopyroxene-K-feldspar-quartz is ubiquitously present which partly or completely replaced osumilite. The sapphirine-bearing assemblages are restricted to silica-deficient (quartz-absent) zones of the gneiss. This suggests that the assemblage Sa-Q is not stable under the peak metamorphic conditions in the Paradise River granulites.

5. *P-T* Grid for Osumilite-Bearing Assemblages in the KMAS System

A *P-T* grid involving sapphirine, enstatite, cordierite, sillimanite, spinel, corundum, and quartz in the MgO-Al_2O_3-SiO_2 (MAS) system is depicted in Fig. 1. The grid is constructed on the basis of the experimental data by SCHREYER and SEIFERT (1969), ACKERMAND (1970), CHATTERJEE and SCHREYER (1972), NEWTON (1972), NEWTON *et al.* (1974), and ARIMA and ONUMA (1977). An assemblage with sapphirine+quartz is constrained to fields of higher temperatures than univariant reactions En+Sil=Sa+Q and Cd+Sil=Sa+Q. The *P-T* position of the invariant point I(1) is a subject of debate. NEWTON *et al.* (1974) located the invariant point I(1) at 950°C and 7.5 kbar for the synthetic system and at 825°C and 6.7 kbar for the natural system. HENSEN (1987), however, estimated the *P-T* position of the invariant point I(1) at 950°+50°C and 10+1 kbar, based on the experimental data by ACKERMAND (1970), NEWTON (1972), and SEIFERT (1974). Recent experimental data by BERTRAND *et al.* (1989) suggest that Mg-cordierite can be stable as high as 13 kbar at 1000°C, supporting the *P-T* estimation of I(1) at 1000°C and 10 kbar by HENSEN (1987).

In the Paradise River area, sapphirine does not coexist with quartz in the osumilite-bearing gneiss, suggesting that the equilibrium conditions of the Paradise osumilite-bearing assemblages were located at temperatures lower than those required for sapphirine+quartz stability. This is in accordance with the *P-T* grid in the KMAS system proposed by GREW (1982) but not consistent with that of ELLIS *et al.* (1980). Based on the mineral assemblages in the Paradise River area, ARIMA and GOWER (1990) extended the grid proposed by GREW (1982) to quartz-absent assemblages (Fig. 2). In the quartz-absent system, the univariant reaction En+Sil+Kf=Os+Sa

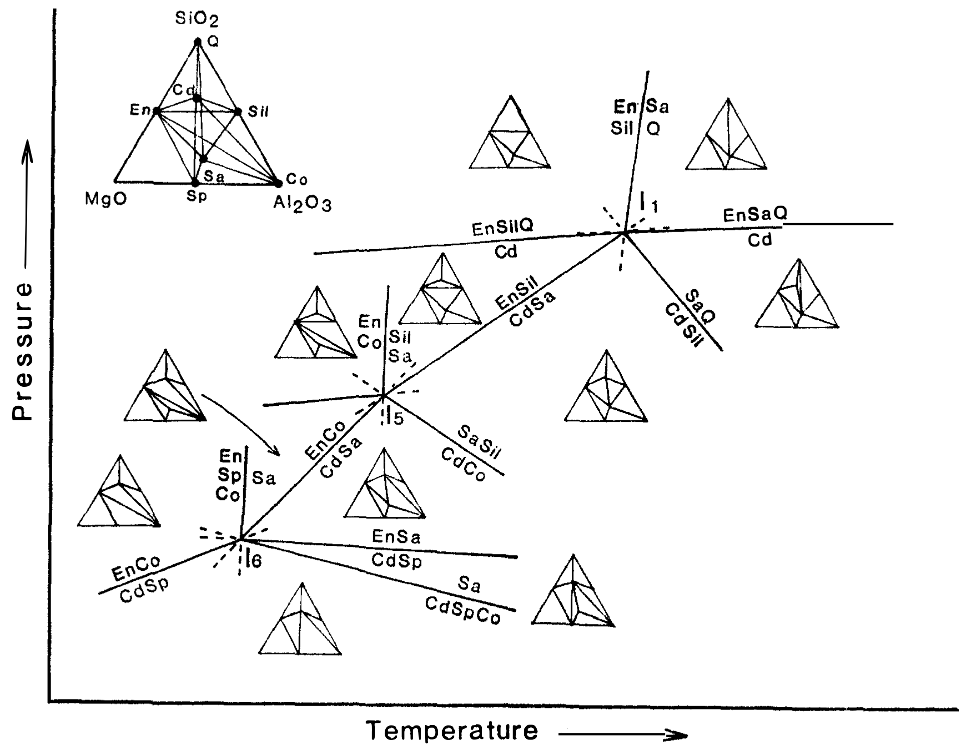

Fig. 1. P-T grid showing phase relations in MAS system. The univariant reactions En + Sil=Sa+Q and Cd+Sil=Sa+Q define the lower temperature stability limit of the assemblage sapphirine+quartz. HENSEN (1987) estimated P-T position of the invariant point I(1) at about 900-1000°C and 9-10 kbar.

intersects the univariant reaction En+Sil=Sa+Cd at the invariant point I(4) (Fig. 2). This suggests that osumilite can coexist with sapphirine in quartz absent compositions at higher temperatures than univariant lines En+Sil+Kf=Os+Sa and/or En+Cd +Kf=Os+Sa.

A series of high temperature and pressure experiments have been done with a piston cylinder apparatus at Yokohama National University to define *P-T* positions of the univariant reaction Os=En+Sil+Kf+Q in the KMAS system. A crystal mixture (Os+En+Kf+Sil+Q) was used as a starting material. Run products were examined by XRD, and intensities of X-ray reflections of osumilite and other phases in the run products were compared with those of the starting mixture. The results suggest that osumilite is stable at 1100°C and 12 kbar, 900°C and 11 kbar, but breaks down to the assemblage En+Sil+Kf+Q at 1100°C 13 kbar, 900°C and 12 kbar. The univariant reaction En+Sil=Sa+Q (Figs. 1 and 2) is located at 1000°C and 10 kbar and 1100°C and 14 kbar (CHATTERJEE and SCHREYER, 1972: ARIMA and ONUMA, 1977). The present results suggest that osumilite is probably stable at temperatures lower than the univariant reaction En+Sil=Sa+Q, being in accordance with the *P-T* grid depicted in Fig. 2.

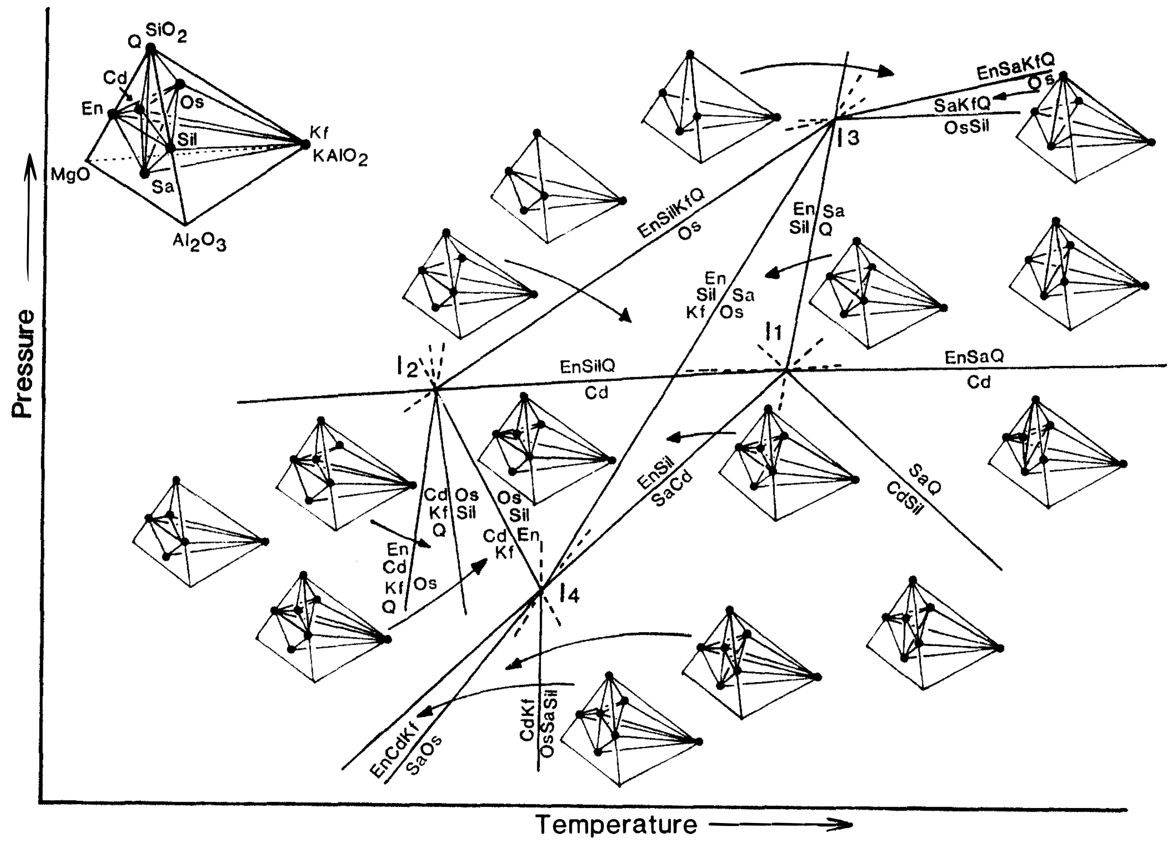

Fig. 2. P-T grid in KMAS system depicting the stability relations of osumilite in both quartz-present and quartz-absent compositions under granulite facies metamorphic conditions. The invariant point I(2) is located at temperatures lower than those for the invariant point I(1), and osumilite-bearing assemblages can be stable at temperatures lower than those for sapphirine-quartz stability.

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