observed in close association with the sodium-zippeite on several specimens and are probably derived from the action of salt water on primary sulphides. Botallackite was also recorded within the mine, but not in association with sodium-zippeite.

Gypsum, johannite and andersonite have been found associated with sodium-zippeite at other localities (Frondel *et al.*, 1976). Synthesis and stability studies show that andersonite is only stable when the activity of Na is very high and that of Ca and Mg very low (Alwan and Williams, 1983). It is likely that such conditions within Geevor mine would favour the formation of sodium-zippeite rather than zippeite.

Samples of sodium-zippeite have been lodged with The Natural History Museum, London.

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Tregears, Little Treviscoe, St Austell, Cornwall PL26 7QL N. J. ELTON

48 St. Julitta, Luxulyan, Bodmin, Cornwall PL30 5ED J. J. HOOPER

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Cordierite–K-feldspar–quartz–orthopyroxene symplectite from southern Algeria: new evidence for osumilite in high-grade metamorphic rocks

IN recent years, osumilite, $(K,Na)(Mg,Fe,Mn)_2(Al,Mg,Fe^{3+})_3(Si,Al)_{12}O_{30}$, has been reported from a number of high-temperature granulite facies terranes (for example, Berg and Wheeler, 1976; Ellis *et al.*, 1980; Grew, 1982*a*; Arima and Gower, 1991). In addition, there are a few localities where osumilite is thought to have been stable as evidenced by its characteristic breakdown products (Ellis *et al.*, 1980; Grew, 1982*b*; Nicollet, 1988). In this paper, a new occurrence of this type is reported in granulite facies rocks from the In Ouzzal block, southern Algeria. The stability of the primary mineral association involving osumilite is then discussed in the light of preliminary experimental results in the KFMAS system.

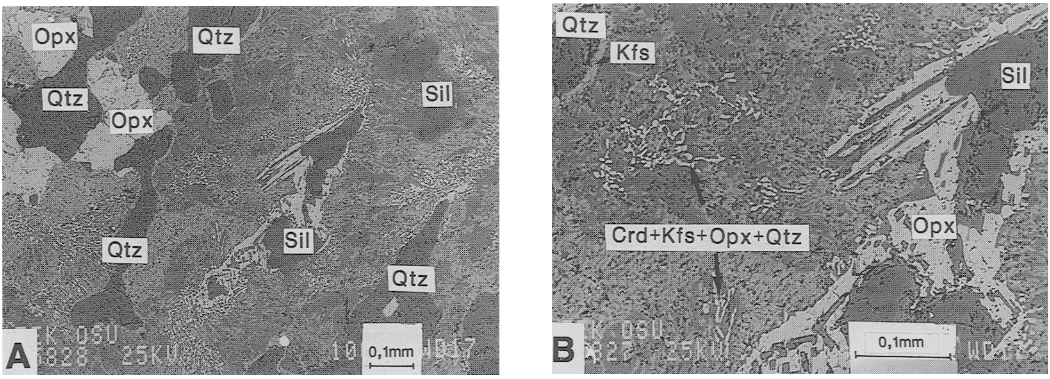

FIG. 1. (*a*) Back scattered electron photomicrograph of the quartzite with osumilite pseudomorphs. The cordierite–K-feldspar–orthopyroxene–quartz symplectites form fine grained intergrowths between the coarser grained primary minerals. Grey–white mineral = orthopyroxene; medium grey = K-feldspar; dark grey = cordierite, quartz and sillimanite. (*b*) Back-scattered electron photomicrograph, detail of (*a*) showing the fingerprint-like intergrowth of cordierite, K-feldspar, orthopyroxene and quartz. Sillimanite and quartz have coronas of secondary orthopyroxene and K-feldspar, respectively.

Osumilite breakdown products

The In Ouzzal complex is a Precambrian inlier (450 km long) within a Late Proterozoic, Panafrican belt (Bertrand and Lasserre, 1976). This complex, which was metamorphosed around 2 Ga ago under granulite facies conditions, comprises a wide variety of metasedimentary rocks, including pelites, banded iron formations, marbles, quartzites which are associated with norite and lherzolite lenses, and charnockitic gneisses (Ouzegane, 1987; Kienast and Ouzegane, 1987). On the basis of reaction textures observed in the metapelites, Bertrand *et al.* (1992) have shown that this terrane experienced a near isobaric heating up to about 970 °C at pressures around 10 kbar, during which coarse mineral assemblages developed. After this prograde stage, the terrane underwent decompression and cooling, down to about 700 °C and 6 kbar, during which finer grained mineral assemblages formed.

The sample containing symplectites after osumilite is a fine grained quartzite (0.1–0.5 mm) which occurs in a lens, 1000 metres long and 200 metres wide, of metasedimentary rocks enclosed in charnockitic gneiss. Pelites associated with the quartzite show coarse grained orthopyroxene–sillimanite–quartz (± garnet) assemblages and also the rare mineral association sapphirine–quartz (Rahmani *et al.*, 1991; Bertrand *et al.*, 1992). The quartzite contains equigranular quartz (Qtz), orthopyroxene (Opx), sillimanite (Sil), and minor F-Ti-rich phlogopite, zircon and rutile. In addition to these phases, very fine grained symplectites of K-feldspar (Kfs), cordierite (Crd), quartz and orthopyroxene have been found (Fig. 1). We interpret the fine grained symplectite as the breakdown product of osumilite (Os) according to the reaction Os = Crd + Opx + Kfs + Qtz (Berg and Wheeler, 1976). Very similar textures have been described in granulite facies rocks from Antarctica where they demonstrably formed by the breakdown of osumilite (Ellis *et al.*, 1980; Grew, 1982*a*) and also from southern India (Grew, 1982*b*) and Madagascar (Nicollet, 1988). Wide scan electron microprobe analyses of the symplectites all plot within the Opx–Crd–Kfs–Qtz tetrahedron, but do not generally correspond to the osumilite composition. The symplectites are modally heterogeneous which may have resulted from local control of nucleation. Secondary K-feldspar forms preferentially around primary quartz, whereas sillimanite seems to provide a nucleation site for orthopyroxene (Fig. 1).

Assuming that the Crd–Opx–Kfs–Qtz symplectite is a breakdown product of osumilite, the assemblage Os–Opx–Sil–Qtz (± phlogopite) must have been stable at some earlier stage in the metamorphic history of this rock. To our knowledge, this assemblage has only been reported in a granulite from Reference Peak, Antarctica (Grew, 1982*a*). The In Ouzzal quartzite is relatively rich in Al_2O_3 and MgO and is very similar in composition to the Antarctic sample, although CaO and Na_2O in the quartzite is lower, in agreement with the absence of plagioclase (Table 1). Secondary orthopyroxenes which form in the symplectites and in coronas around sillimanite included in symplectites, have the same Mg-number [$100Mg/(Mg + Fe^{2+}) = 78$] but have lower Al_2O_3 contents than primary orthopyroxene (4.9 *vs.* 6.5%). In Opx–Sil–Qtz-bearing pelites associated with the quartzite, centimetre-sized orthopyroxene contains up to 11 wt.% Al_2O_3. Both secondary pyroxenes and cordierites are magnesian (Mg-number of 78 and 94, respectively).

Experimental study of the primary mineral assemblages

To further constrain the *P–T* peak conditions experienced by the In Ouzzal quartzite, the primary mineral assemblage Os–Opx–Sil–Qtz has been duplicated experimentally. Three synthetic starting materials with compositions close to the natural sample and variable Mg/(Mg + Fe) ratio were seeded with natural garnet (Gt) and osumilite (Table 1). Runs were carried out in a piston cylinder apparatus following the experimental procedure of Hensen and Green (1971). To promote reaction rates, starting materials were slightly moistened by breathing. In all of the runs a small amount of liquid is present together with both quartz and K-feldspar.

Table 1: Whole rock chemistry (recalculated volatile-free analysis)

	1	2	3
SiO_2	76.17	75.46	70.45
Al_2O_3	13.66	13.94	15.73
FeO^a	1.63	0.75	1.58
MnO	0.01	0.01	-
MgO	6.01	3.35	7.70
CaO	0.11	1.79	-
Na_2O	0.33	3.02	-
K_2O	1.74	1.12	4.54
TiO_2	0.30	0.53	-
P_2O_5	0.04	0.03	-
Total	100.00	100.00	100.00
100 Mg/(Mg+Fe)	86.8	88.9	89.7

[a] Total iron as FeO

1) Quartzite with pseudomorphs after osumilite from In Ouzzal (sample Inz 94)

2) quartz - orthopyroxene - sillimanite - osumilite- plagioclase - rutile -bearing gneiss from Reference peak, Tula Mountains, Antarctica , (sample 2306B; Grew, 1982a)

3) Composition of the Mg-rich starting material used in the experiments. The other two starting materials differ only in their Mg-number (respectively 73.5 and 81.6)

In the more Fe-rich bulk composition (Mg-number = 73.5), osumilite reacted out at 1000 and 1050 °C at 11.1 kbar and the stable assemblage is Opx–Sil–Gt–Kfs–Qtz (Fig. 2). In the intermediate composition (Mg-number = 81.6), garnet is not stable at 1050 °C and 11·1 kbar and the assemblage Opx–Sil–Os–Kfs–Qtz occurs. At 1000 °C and the same pressure, the six-phase univariant assemblage Opx–Sil–Gt–Os–Kfs–Qtz is found (note that both garnet and osumilite grew). For clarity, the Gt–Os tie-line is not shown in Fig. 2. In the Mg-rich composition (Mg-number = 89.7), which was run only at 1000 °C, the garnet seeds disappeared completely and the trivariant assemblage Opx–Os–Kfs–Qtz occurs. The parageneses observed at 11.1 kbar (Fig. 2) indicate that osumilite is more magnesian than coexisting orthopyroxene as reported from natural rocks (Grew, 1982*a*). At 12 kbar and 1000 and 1050 °C, osumilite is no longer stable in any of the compositions studied.

Discussion

The close similarity of the textures of the rock sample described in this paper with those of Antarctic osumilite-bearing granulites suggests that the symplectites involving K-feldspar, cordierite, quartz and orthopyroxene correspond to the breakdown product of osumilite. This implies that the mineral assemblage Os–Opx–Sil–Kfs–Qtz may been stable early in the metamorphic history of the In Ouzzal terrane. In our experiments we have duplicated this mineral assemblage at 1000 and 1050 °C at 11.1 kbar. Moreover, our data suggest that the upper pressure stability limit of osumilite at 1000 and 1050 °C is close to 12 kbar, since osumilite is not stable even in the Mg-rich composition at this pressure. Recent experimental work in the Mg end-member system (Motoyoshi *et al.*, 1993) supports this conclusion. According to Grew (1982*a*), the tie-line Opx–Sil is replaced at lower pressure by the tie-line Os–Gt (Fig. 2). This corresponds to the univariant reaction Os + Gt = Opx + Sil + Kfs + Qtz. The occurrence of reactants and products of this reaction in the intermediate Mg/(Mg + Fe) composition at 1000 °C and 11.1 kbar, suggests that the univariant boundary is close to these *P–T* conditions. Therefore, the assemblage Os–Opx–Sil–Kfs–Qtz appears to be stable over a narrow

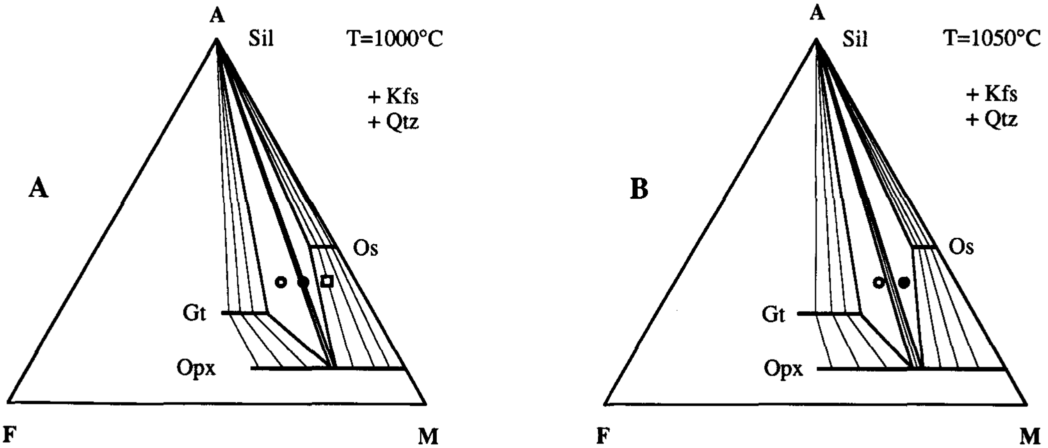

FIG. 2. AFM diagram showing phase relations at 11.1 kbar and 1000 °C (A), 1050 °C (B). The open circles, solid circles and square stand for starting materials having Mg-numbers of 73.5, 81.6 and 89.7 respectively. For clarity, the crossed tie-lines observed at 1000 °C with the intermediate composition are not shown.

pressure range and restricted to very magnesian bulk compositions. Further work on the univariant reaction Os + Gt = Opx + Sil + Kfs + Qtz is in progress. Our data indicate that the In Ouzzal granulites have experienced a maximum pressure of less than 12 kbar. Such pressure conditions are consistent with those estimated by Bertrand *et al.* (1992) for the peak metamorphic conditions experienced by these rocks. The exact position of the symplectite-producing reaction Os = Crd + Opx + Kfs + Qtz remains to be determined. However, the lower Al_2O_3 contents of orthopyroxene in the symplectites compared with that of primary coarse orthopyroxene and the fine-grained texture of the symplectites indicate that this reaction takes place at lower temperature, probably during uplift and cooling of the terrane.

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Pétrologie Physique, Sciences de la Terre, Univ. Paris-7075251, Paris Cedex 05, France N. AUDIBERT

Pétrologie Physique, Sciences de la Terre, Univ. Paris-7075251, Paris Cedex 05, France P. BERTRAND

Dept. of Applied Geology, Univ. of NSW, PO Box 1, 2033 NSW, Australia B. J. HENSEN

Pétrologie Métamorphique, Sciences de la Terre, Univ. Paris-7075251, Paris Cedex 05, France J.-R. KIENAST

Institut Sciences de la Terre, U.S.T.H.B., Alger, Algeria KH. OUZEGANE