OSUMILITE, AN APPROXIMATELY 970 Ma OLD HIGH-TEMPERATURE INDEX MINERAL OF THE GRANULITE-FACIES METAMORPHISM IN ROGALAND, SW NORWAY[1]

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ABSTRACT

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In SW Norway mineral assemblages in metapelites indicate three stages of Precambrian high-grade metamorphism, M-1, M-2 and M-3. An osumilite-in isograd is recognized in the higher-grade part of the M-2 high-temperature granulite-facies aureole surrounding the Bjerkreim-Sokndal lopolith. Osumilite separated from a metapelite yields K-Ar and Rb-Sr cooling ages of 987 ± 30 Ma and 952 ± 25 Ma, respectively, indicating that it may be a suitable mineral for isotopic dating with a closure temperature to Rb-Sr and K-Ar similar to or slightly higher than that of hornblende to K-Ar.

INTRODUCTION

The Rogaland anorthositic igneous complex comprises several anorthosite masses and the layered anorthosite-leuconorite to quartz-monzonite lopolith of Bjerkreim-Sokndal (Fig. 1). These plutons occur in a high-grade metamorphic Precambrian basement mainly consisting of charnockitic migmatites with intercalations of garnetiferous migmatites (HERMANS ET AL., 1975). The grade of metamorphism gradually increases from the upper amphibolite facies in the northeastern part of the map area of figure 1 to the high-temperature granulite facies near the plutons. The transition between both facies is marked by the hypersthene-in isograd, defined by the first occurrence of hypersthene in rocks of leucogranitic composition.

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PETROLOGY

The garnetiferous migmatites are essentially metapelites. They are composed of various assemblages of almandine-rich garnet, biotite, sillimanite, cordierite, green spinel and orthopyroxene, along with quartz, feldspars and locally sapphirine (HERMANS ET AL., 1976). Textures and mineral compositions in the metapelitic rocks reveal at least three successive Precambrian stages of high-grade metamorphism, M-1, M-2 and M-3, each characterized by different mineral assemblages.

The relictic assemblage M-1 comprises garnet I, biotite I, sillimanite I, quartz, plagioclase and perthite, indicative of the upper amphibolite facies. This stage probably affected the Precambrian basement all over south-western Norway.

In a 15-45 km wide zone along the anorthositic igneous complex the M-1 assemblages have partially been replaced by assemblages of orthopyroxene, cordierite, green spinel/magnetite, quartz, plagioclase (often antiperthitic) and perthite or mesoperthite; they define the high-temperature granulite-facies stage M-2. Preliminary geothermometric calculations on element distribution between several mineral pairs in pelitic and basic rocks in this zone yield temperatures in the range 750-1000 °C (HERMANS ET AL., 1976; JACQUES DE

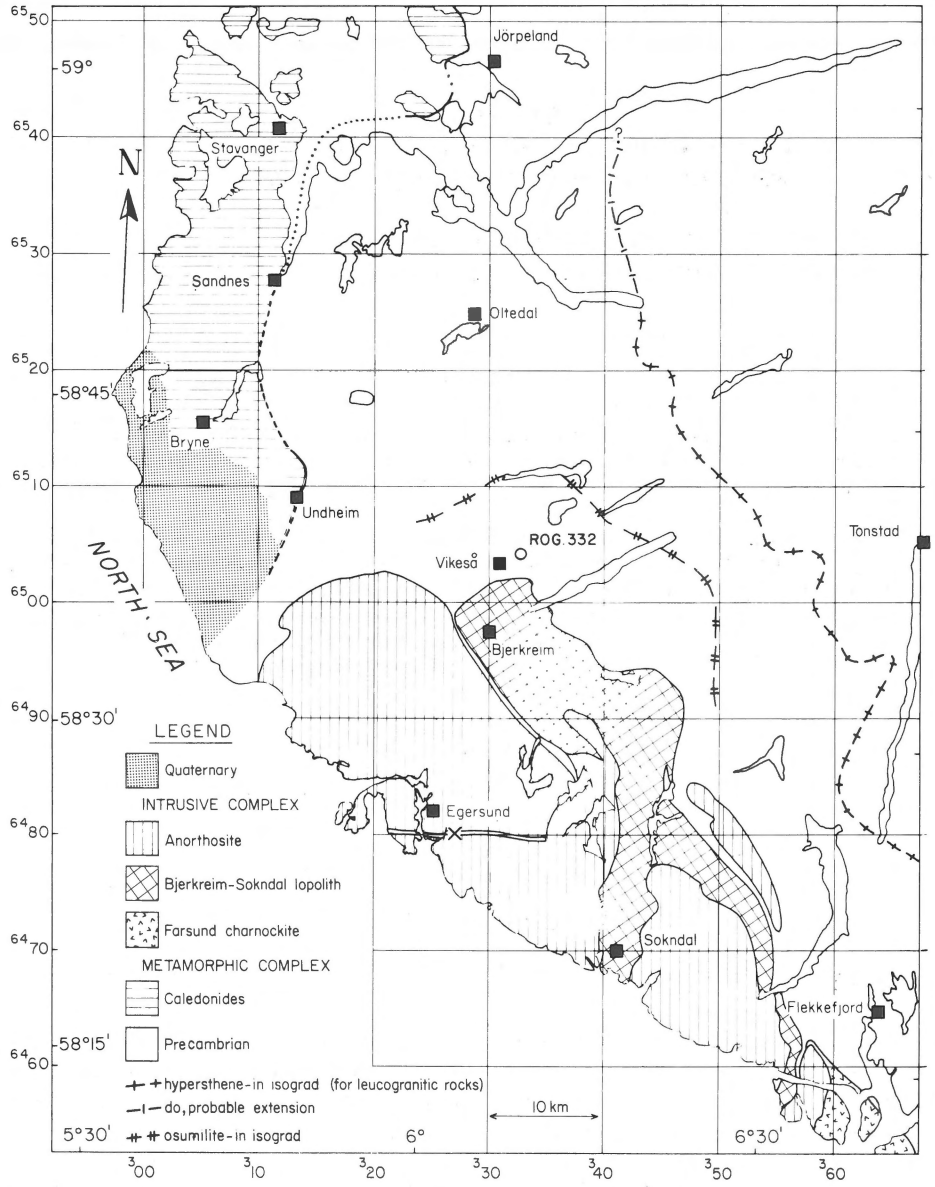

Fig. 1
Simplified geological map of SW Norway, showing the location of the investigated osumilite sample.

DIXMUDE, 1978). The distribution of the temperature data and the gradual change in colour of hornblendes from green to brown towards the intrusive complex (DEKKER, 1978) indicate a gradual increase in metamorphic grade. In the higher-grade parts of the high-temperature granulite facies zone, osumilite participates in the M-2 assemblages. From experimental work it is concluded that the low-temperature stability limit of osumilite is about 800 °C (HENSEN, 1977), confirming that it is a typical high-temperature mineral.

Stage M-3 is recognized locally by various assemblages composed of minor amounts of biotite II, orthopyroxene II, garnet II, sillimanite II, quartz, plagioclase and orthoclase. Cordierite I from relict M-2 textures has locally re-equilibrated chemically with green spinel II during this stage (KARS ET AL., 1980). The metamorphic conditions during M-3 were those of the low granulite to upper amphibolite facies.

OSUMILITE

$(K_{0.80}Na_{0.19})\ (Mg_{1.46}Fe^{2+}{}_{0.55}Mn_{0.02})\ (Al_{2.67}Ti_{0.03}Mg_{030})\ (Si_{10.13}Al_{1.87})0_{30}$

In the area around Vikeså (Fig. 1) osumilite appears in the M-2 assemblages of the metapelitic rocks. The best exposure is a new road-cut in vaguely banded migmatites, 1.8 km ENE

of Vikeså (MAIJER ET AL., 1977). Thin quartz- and feldspar-rich bands alternate with pinkish-violet layers in which osumilite is a major rock-forming mineral, comprising up to one third of the rock volume. This occurrence of osumilite, the sixth known on Earth, is situated at a horizontal distance of approximately 2 km of the anorthositic base of the folded lopolith (Fig. 1). Microscopically, the osumilite is always associated with green spinel/magnetite intergrowths and often also with orthopyroxene (Fig. 2). Occasionally, the osumilite encloses numerous quartz blebs, biotite flakes or relictic garnet crystals. An osumilite-in isograd could be established in the Vikeså area on the basis of field observations and the examination of over 500 thin sections of metapelitic rocks. The regular occurrence of armoured relicts of garnet or biotite in osumilite-orthopyroxene-spinel-magnetite aggregates points to a replacement of the assemblage garnet-biotite-quartz by these aggregates. In rocks of similar bulk composition garnet, biotite and quartz are frequently observed in mutual contact beyond the osumilite-in isograd, while this is only rarely found on the high-temperature side of the isograd; this phenomenon supported the mapping of the isograd.

At many localities the osumilite has partially or completely been decomposed into fine symplectitic cordierite-quartz-orthoclase intergrowths, occasionally along with dendritic orthopyroxene (Fig. 3). The decomposition of osumilite into cordierite II-quartz-orthoclase-(hypersthene) symplectites is attributed to the M-3 stage of metamorphism. Identical symplectitic intergrowths in a narrow zone of metamorphic rocks between two anorthosite masses ca 25 km SSW of Vikeså (X on Fig. 1) have been interpreted as breakdown products of osumilite by SCHREYER & SEIFERT (1967). Similar symplectites have also been described from Antarctica (GREW, 1978).

The osumilite-in isograd roughly parallels the outline of the lopolith, as is the case with a large part of the hypersthene-in isograd at a lower metamorphic grade (Fig. 1). This suggests a direct genetic relationship between the high-temperature granulite facies stage M-2 and the intrusion of the Bjerkreim-Sokndal lopolith. A crystallization temperature of about 1050-900 °C has been calculated for the younger quartz-monzonitic phase of the lopolith on the basis of proxene thermometry (RIETMEIJER, 1979), so the intrusion temperature of the older anorthositic-(leuco)noritic phase was probably higher.

ISOTOPIC DATING

Isotopic dating in the Precambrian basement of SW Norway revealed a few ages of about 1500 Ma and 1200 Ma (zircon

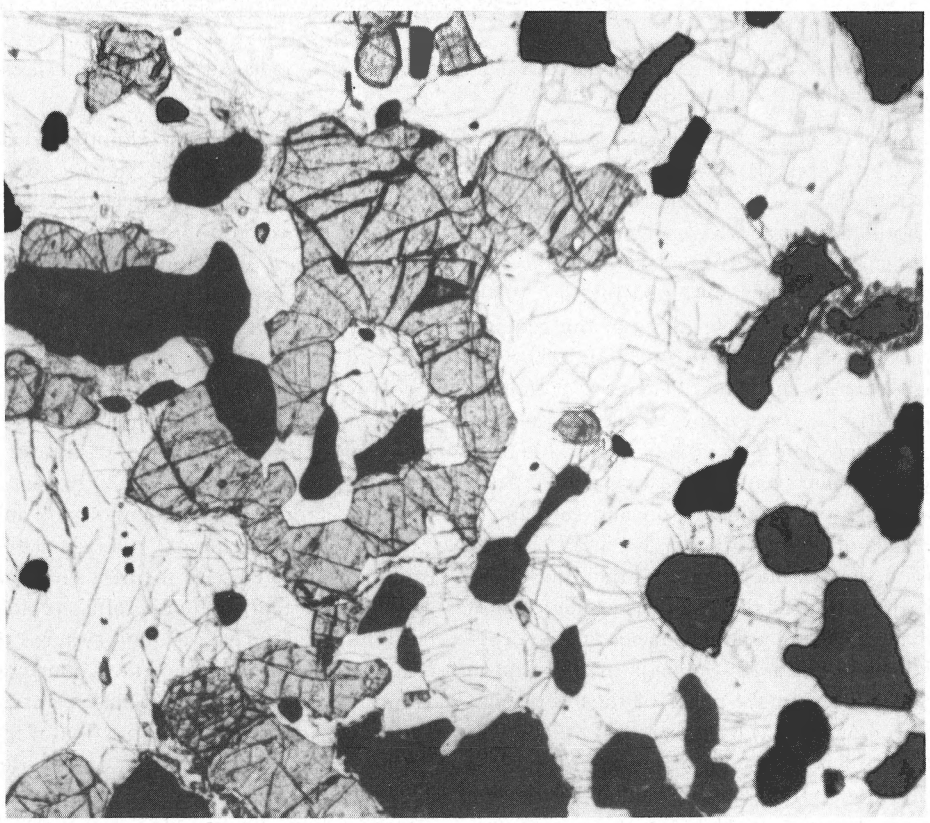

Fig. 2
M-2 aggregate of osumilite (white), green spinel-magnetite (dark) and orthopyroxene (grey). Garnet II rims of stage M-3 surrounding spinel are seen at the right-hand side. Sample MA 490, x 24.

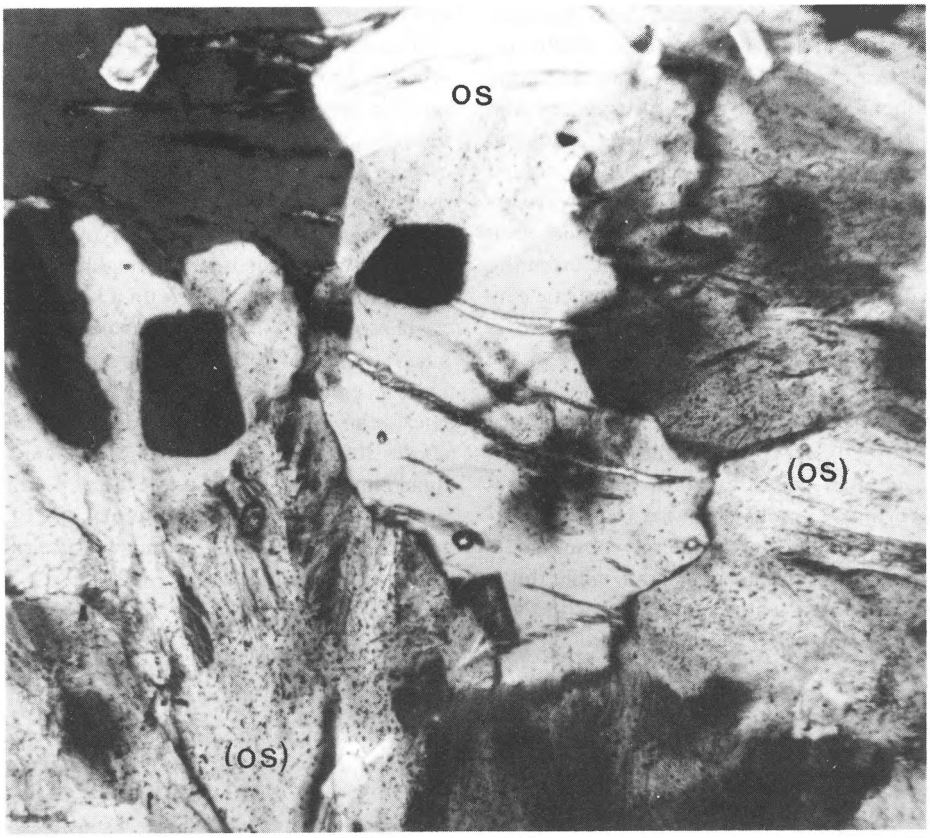

Fig. 3
Fine symplectitic intergrowth of cordierite II-quarz-orthoclase (OS), radially developed at the expense of osumilite OS. Sample BE 040, x 90 (X nicols).

U-Pb and whole-rock Rb-Sr), but most ages are about 1050 Ma (zircon U-Pb, whole-rock Rb-Sr), about 950 Ma (hornblende K-Ar, zircon U-Pb, whole-rock Rb-Sr) and about 870 Ma (biotite Rb-Sr and K-Ar) (VERSTEEVE, 1975; DEKKER, 1978; PASTEELS ET AL., 1979; WIELENS, 1979; WIELENS ET AL., 1980; PRIEM, 1980; VERSCHURE ET AL., 1980). These ages have been interpreted in terms of the geologic evolution as follows (WIELENS ET AL., 1979; PRIEM, 1980). The ages of about 1500 Ma may signal an old stage of metamorphism and/or magmatism, although any petrological evidence for this event is lacking. A few ages of about 1200 Ma from granulitic gneisses and some syenitic intrusions may be attributed to the M-1 stage of metamorphism and subsequent magmatism. The ages of about 1050 Ma are interpreted as dating the intrusion of the older phase of the Bjerkreim-Sokndal lopolith, which induced the M-2 phase of high-temperature/intermediate-pressure granulite-facies metamorphism. Zircon U-Pb ages and a Rb-Sr whole-rock isochron date the intrusion of the younger phase of the Bjerkreim-Sokndal lopolith at about 950 Ma. Similar ages are also registered by whole-rock Rb-Sr systems of country rocks close to the contact with the lopolith, and are related to the M-3 stage of low granulite to upper amphibolite-facies metamorphism. The regional cooling is registered by the hornblende and biotite ages of about 950 Ma and 870 Ma, respectively.

In an attempt to obtain additional evidence for the age of the high-temperature M-2 stage, osumilite was separated from one metapelitic sample (Rog 332). The mineral is virtually free from retrogradation products and contains no biotite or quartz inclusions. A heavy-liquid pre-concentrate of osumilite was purified to about 99% by handpicking and used for K-Ar and Rb-Sr age determinations, following the standard procedures in the Z.W.O. Laboratory of Isotope Geology, Amsterdam (e.g., WIELENS ET AL., 1980). In table I the analytical data and calculated ages are presented. The K-Ar and Rb-Sr ages are 987 ± 30 Ma and 952 ± 25 Ma, respectively. Both ages are nearly concordant and suggest that excess radiogenic Ar cannot play an important role.

Petrologically, osumilite is a typical M-2 mineral, but the isotopic ages lie close to the M-3 ages of about 950 Ma. This may indicate that the temperature regime of the M-3 stage has influenced the M-2 isotopic systems, if the M-3 stage was related to the intrusion of the younger phase of the Bjerkreim-Sokndal lopolith (WIELENS ET AL., 1980; PRIEM, 1980) and/or the folding and deformation of the lopolith.

However, an interpretation of the osumilite, hornblende and biotite ages as stages of a prolonged, more or less continuous cooling after the climax of the M-2 stage is also possible. The volume of the younger phase of the lopolith is much smaller than that of the older phase (RIETMEIJER, 1979),

Table I
K-Ar and Rb-Sr data and calculated ages of osumilite (sample Rog 332, UTM coord. 3325-64042).

K (% Wt)	rad. ^{40}Ar (ppm)	Atm. ^{40}Ar (% total ^{40}Ar)	Rb (ppm)	Sr (ppm)	$^{87}Sr/^{86}Sr$	calculated ages (Ma)[1] K-Ar	Rb-Sr[2]
3.33	0.301	13	228	5.77	2.55420		
3.35	0.311	11	228	5.79	2.51942	987 ± 30	952 ± 25
	0.302	16					

[1] Calculated with the IUGS recommended constants: $\lambda\beta(^{40}K) = 4.962.10^{-10}a^{-1}$, $\lambda_e(^{40}K) = 0.581.10^{-10}a^{-1}$, abundance $^{40}K = 0.01167$ atom % total K, $\lambda(^{87}Rb) = 1.42.10^{-11}a^{-1}$.

[2] Initial $^{87}Sr/^{86}Sr = 0.705$.

so the thermal imprint of the younger phase on the country rocks may be expected to be much less. It seems therefore rather improbable that the M-3 stage represents a renewed stage of metamorphism affecting the whole map area. Only in restricted areas adjacent to the lopolith some formation of new minerals of M-3 assemblages has taken place, accompanied by resetting of some whole-rock Rb-Sr and zircon U-Pb systems, while away from the lopolith the effects of the M-3 stages become less pronounced. Farther away the influence of the M-3 event may have resulted in a period of more or less stagnant cooling, while at a still greater distance from the lopolith the crustal cooling after M-2 has hardly been disturbed by the M-3 event.

It should be noted, however, that both the magmatic hornblendes in the younger, upper phase of the Bjerkreim-Sokndal lopolith and the metamorphic hornblendes in the country rocks all over the map area are concordant at about 950 Ma. It is as yet unclear how this hornblende age pattern should be related to the M-3 metamorphism and the intrusion of the youngest phase of the lopolith.

Anyhow, osumilite appears to be a suitable mineral for isotopic dating of high-temperature metamorphic events, with a closure temperature to Rb-Sr and K-Ar similar to or slightly higher than that of hornblende to K-Ar, 550-500 °C (HART ET AL., 1968; ANDRIESSEN, 1978).

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