A Precambrian age for the Ofredal granodiorite intrusion, Central Jotun Nappe, Sogn, Norway

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New Rb–Sr whole rock investigations of the granodioritic Ofredal intrusion in Sogn give a Sveconorwegian intrusion age of 887 ± 101 Ma. with an initial $^{87}Sr/^{86}Sr$ of 0.70320 ± 0.00016 suggesting a mantle or deep crustal origin.

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In Indre Sogn, where the east end of Sognefjord cuts the central part of the Jotun Nappe, the gabbroic high grade gneisses are intruded by numerous leucocratic dykes of granodioritic composition. Kjerulf (1879) correlated these dykes with others of similar composition from the Trondheim region. Goldschmidt (1916) called the leucocratic intrusions from both localities trondhjemites, defined by their low content of mafic minerals, by the general absence of K-feldspar and by a Na_2O/K_2O ratio of about 2–4. Oxaal (1913) suggested a Caledonian age of intrusion. The first attempt at dating these intrusions in Sognefjord by Rb–Sr methods was made by Berthomier et al. (1972). By measuring three whole rock samples they obtained a badly defined isochron of about 690 Ma. Data on separated K-feldspar and biotite show alignments interpreted as reflecting Caledonian intrusion ages. They interpreted these data as reflecting some disturbance of the Rb–Sr system by the older surrounding rocks. Schärer (1980a) gave some U–Pb data on concordant sphene, showing an early Caledonian age, and slightly discordant zircons. In connection with Caledonian Rb–Sr mineral data he concluded that this age represents the time of intrusion.

This note presents new Rb–Sr whole rock data on the Ofredal granodiorite intrusion.

Geological and structural setting of the Ofredal granodiorite

The greatest concentration of leucocratic dykes is found along Årdalsfjorden (most eastern part of Sognefjord), around the valley Ofredal. Therefore, I will call this intrusive complex the 'Ofredal intrusion'. The complex consists of a large body and numerous veins, varying in size and with a general decrease in abundance towards the border, which lies at Kaupanger in the west, at the Hurrungane mountain range in the north and at the Lærdal-Gjende fault zone in the southeast (Fig. 1).

The country rock in the northern part is a pyroxene granulite. Observations of cumulates of K-feldspar, primary layering and magmatic breccias show that this granulite crystallized from a magma under granulite facies conditions as was suggested by Battey & McRicthie (1975). Rb–Sr whole rock data (Koestler, unpubl.) indicate an intrusion age of about 1700 Ma. The granulite body shows a mineral aggregate lineation which is thought to have originated during cooling under an oriented stress field. The retrogression in amphibolite facies metamorphism in Sveconorwegian time produced a metamorphic banding and a foliation, mostly defined by oriented hornblendes and biotites. The country rocks of the southern part along Sognefjord are anorthosites and anorthositic gabbros (Goldschmidt 1916). The structural relations have not been studied in detail there.

Between Kaupanger and Ofredal the granodiorite intrusion is a more or less homogeneous body with some large xenoliths of country rock. The xenoliths show effects of the Sveconorwegian amphibolite facies metamorphism. From this centre, dykes spread out over the large area described above. Usually, the leucocratic dykes cut the amphibolite facies banding and foliation of the country rocks, but may also, as in the steep wall along Årdalsvatn (Fig. 2), lie parallel with them. At many localities, the dykes are folded with an axial plane parallel to the country rock foliation. The scarcity of mafic minerals in

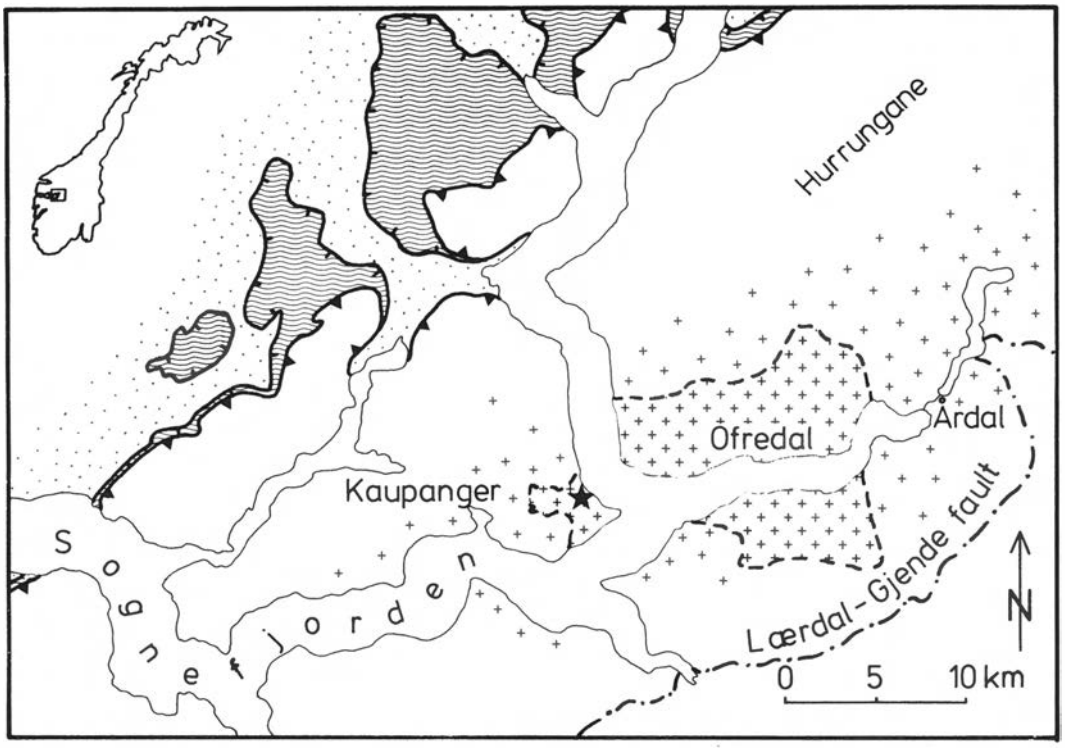

Fig. 1. Sketch map of eastern Sognefjord, showing the Western Gneiss Region (dotted), the parautochthonous phyllite sequence (undulated) and the Caledonian Jotun Nappe (blank) with the Ofredal granodiorite intrusion (crosses). The sample locality is marked by a star.

the dykes makes it difficult to trace the foliation in the dykes. Almost all the dykes show a distinct lineation defined by elongation of mineral aggregates. In the Årdal area, this lineation is parallel to fold axes of the folds described above. Parts of the dykes lying parallel with the foliation of the surrounding rocks are mostly deformed by boudinage. It is possible to distinguish different generations of intrusions, because of the crosscutting relations of the dykes. However, an attempt to work out an intrusive sequence for the whole area has not been successful. It appears that all the veins have intruded more or less simultaneously, during and/or shortly after the amphibolite facies metamorphism.

It is obvious that a post-intrusion metamorphism and deformation has overprinted the intrusive relations. The country rocks, as well as some biotites of the dykes, are chloritized. Quartz in the dykes is often recrystallized and forms ribbons. Small shear zones with mylonitic textures cut the dykes. Some normally zoned plagioclase shows rims of albite and centres converted to sericite.

Samples and analytical techniques

Samples for whole rock investigations were taken 9 km E of Kaupanger along a forest-road section (Amblegårdsskog). The average weight of the samples was 9 kilos. All the samples are from the same intrusive body, which can be continuously followed along the road. The distance between sample KAU 1 and KAU 6 is about 1 1/2 kilometers. There are some large xenoliths in the granodiorite, but samples have been taken as far as possible from such inclusions.

The analytical procedures and isotopic measurements were carried out at Mineralogisk-geologisk museum in Oslo. Rb and Sr concentrations were determined by X-ray fluorescence spectrography on all samples. Unspiked measurements of $^{87}Sr/^{86}Sr$ were made for all whole rock samples on a computer controlled VG Aldermaston Micromass 30 masspectrometer. Variable mass discrimination in $^{87}Sr/^{86}Sr$ was corrected by normalizing $^{88}Sr/^{86}$ to 8.3752. The Rb decay constant used was 1.42×10^{-11} yr^{-1}. Errors quoted in Table 1 are 2 σ standard errors.

Fig. 2. The steep rock wall on the W-side of Årdalsvatn shows the leucocratic dykes, intruding concordantly and discordantly to the foliation and banding of the mafic country rock. Some discordant dykes are folded and sheared; some concordant ones are deformed by boudinage. (Samples not taken from this area.)

Results

Figure 3 shows 6 data points. Five of these define an isochron age of 887 ± 101 Ma (MSWD = 1.1) and an initial $^{87}Sr/^{86}Sr$ of 0.70320 ± 0.00016. The sample KAU 3 is not included in this regression. If a regression line is calculated through all six data points it gives an age of 769 ± 260 Ma (MSWD = 8.0).

Discussion and conclusions

The small spread in Rb/Sr ratio results in a relatively large uncertainty for the isochron. Five of the six data points lie within analytical error 2 σ of the isochron (Fig. 3). One point (KAU 3) is excluded from the defined isochron. This sample was taken 1.5 m away from an anorthositic xenolith. It is not possible to see any petrographic change around the xenolith for more than 20 cm; nevertheless it seems that the Rb–Sr system of the granodiorite is disturbed.

Berthomier et al. (1972) get such a poorly defined age (about 690 Ma) from their whole rock data that they do not discuss the meaning of this age at all. They got a regression line through the K-feldspar of two different samples showing an age of 448 ± 30 Ma. An 'isochron' defined by biotite of two samples from Kaupanger and three samples from a locality in the Trondheim region gives an age of 446 Ma. It is not valid to use mineral data from different samples, and espe-

Table 1. Rb–Sr analytical results

Sample no.	Rb (ppm)[a]	Sr (ppm)[a]	$^{87}Rb/^{86}Sr$	$(^{87}Sr/^{86}Sr)$ norm[b]
KAU 1	37.3	1947	0.0550	0.70392 ± 0.00010
KAU 2	40.7	1453	0.0810	0.70417 ± 0.00010
KAU 3	41.2	852	0.1388	0.70467 ± 0.00008
KAU 4	47.6	1243	0.1099	0.70455 ± 0.00010
KAU 5	48.1	1187	0.1157	0.70470 ± 0.00006
KAU 6	52.8	1062	0.1446	0.70501 ± 0.00010

a) by x-ray fluorescence, precision ± 1 %
b) precision is quoted as 2 σ standard error of mean normalized to $^{86}Sr/^{88}Sr = 0.1194$

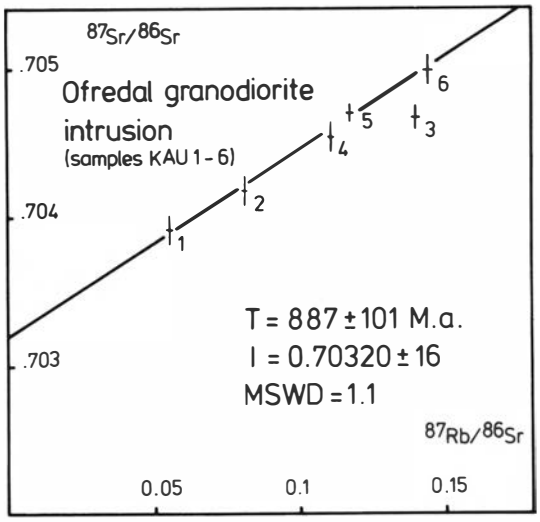

Fig. 3. Rb–Sr isochron plot for the Kaupanger samples (KAU 1–6) of the Ofredal intrusion (KAU 3 not included in regression).

cially not from such widely separated localities, to calculate a regression line. Such a line cannot be used as an isochron because there is no reason to believe that the different samples have had the same initial $^{87}Sr/^{86}Sr$ ratio, which is a fundamental prerequisite for the use of the Rb–Sr system. Recalculated data for biotite/whole rock and K-feldspar/whole rock pairs in the Kaupanger samples give ages between 600 and 390 Ma and show that the Rb–Sr system was not in equilibrium during Caledonian time. Despite this, Berthomier et al. interpreted the Caledonian age as the time of intrusion.

The Sveconorwegian age presented here fits well with the structural setting of the granodiorite dykes. The syn- or slightly post-metamorphic intrusive age is indicated by concordant dykes parallel to the amphibolite facies foliation and metamorphic banding, by discordant relationships between foliation and dykes and by folds with axial planes parallel to the foliation. Recalculated U-Pb data of sphene and zircon from Schärer (1980a) give an upper intercept on the discordia of 1145 ± 120 Ma. Schärer reported two concordant sphene fractions with an age of 430 ± 5 Ma. This age was interpreted as the time of intrusion. The discordance of the zircons was assumed to be caused by the gain of lead from the surrounding country rocks or by the presence of anatectic zircons. The Sveconorwegian age of the upper intercept for these discordant zircons is slightly older than the present Rb–Sr whole rock age. The U–Pb upper intercept age shows that the zircons originally crystallized in Sveconorwegian time, perhaps with some older components. The Caledonian sphene age probably reflects a metamorphic event, with new crystallization of sphene. This retrograde metamorphism may represent the event of nappe transport, and is reflected by the disturbance of the Rb–Sr system, and the loss of Pb from zircons.

The whole rock isochron age of 887 ± 101 Ma is interpreted as the age of intrusion of the Ofredal complex into the central part of the Jotun Nappe. Although there are several generations of dykes, all of them seem to belong to the same intrusion event. The low initial $^{87}Sr/^{86}Sr$ of 0.70320 supports a mantle or deep crustal origin. The geological evidence for the syn- or slightly post-tectonic intrusion of the dykes, together with the Rb–Sr data given here, confirm the Sveconorwegian age for the amphibolite facies metamorphism of the Jotun complex. It is important to note that the intrusion of the granodiorite into the central Jotun Nappe at Sognefjord does not show any connection to the Caledonian orogeny.

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