Age of the Krossnes Granite, West Norway

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Rb-Sr isotope whole-rock dating of the Krossnes Granite has yielded an isochron age of 430 ± 6 Ma with I.R. = 0.7066 ± 0.0005, interpreted as the age of intrusion. This age is close to that of the Håkre Granite of the Sunnhordland Batholith, to which the Krossnes Granite is probably related. The age indicates that the Krossnes Granite probably intruded during the period of deposition of the Ashgillian-Llandoverian sediments of the Ulven and Holdhus Groups, Major Bergen Arc. It also demonstrates that strong ductile deformation of rocks in the Major Bergen Arc occurred during the Ordovician or close to the transition from the Ordovician to the Silurian period.

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Introduction

The Krossnes Granite is located in the southeastern part of the Major Bergen Arc (Fig.1) in the Bergen Arc System (Kolderup & Kolderup 1940). The system contains several allochthonous units or terranes of different lithology and tectono-metamorphic development, which were juxtaposed during the main Caledonian (Scandian) orogeny. Rocks of Early Palaeozoic age are represented in the Minor and Major Bergen Arcs (Kolderup & Kolderup 1940).

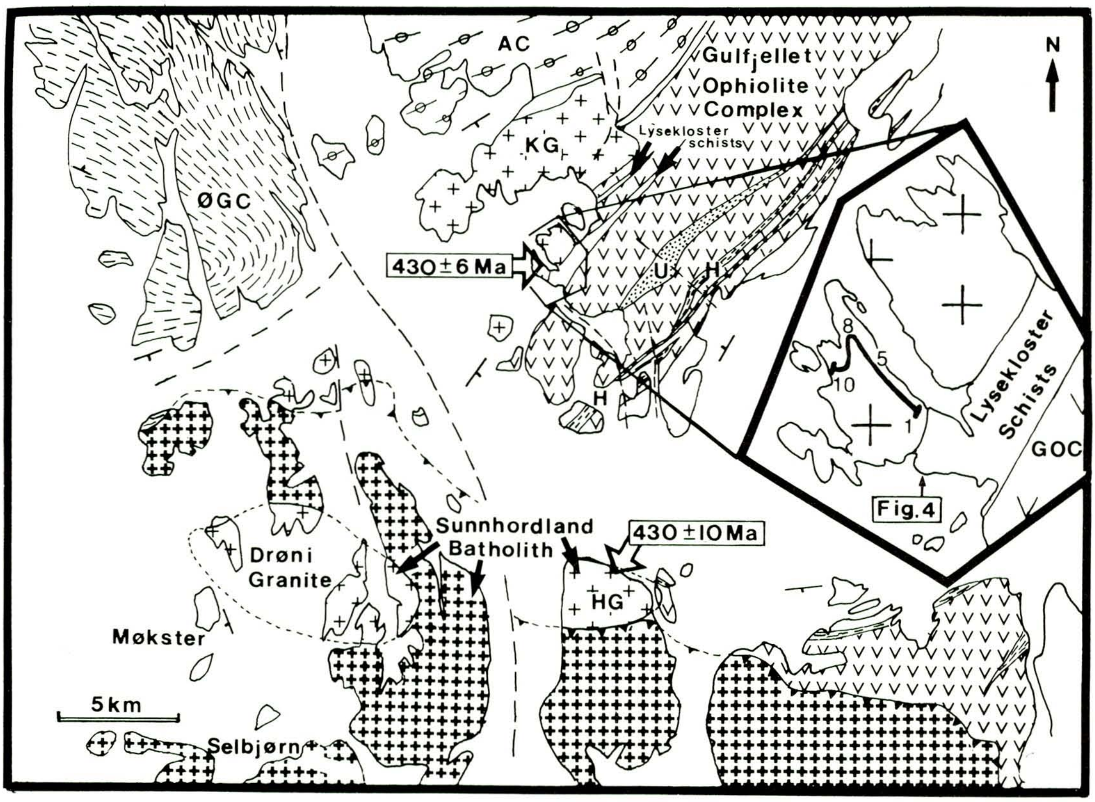

Fig. 1.Geological map of the area around the Krossnes Granite south of Bergen. ØGC = Øygarden Gneiss Complex, U = Ulven Group, H = Holdhus Group, HG = Håkre Granite, KG = Krossnes Granite. Mainly from Kolderup & Kolderup (1940), Andersen & Jansen (1987), Fossen & Ingdahl 1987 and Ingdahl (1985). Inset map shows sampling location for dating.

Geological setting

The Krossnes Granite preserves intrusive contacts with the Gulfjellet Ophiolite Complex (GOC) and the Lysekloster Schists of the Major Bergen Arc (Kolderup & Kolderup 1940, Fossen & Ingdahl 1987). The GOC (Thon 1985) is a dismembered suite of mafic to ultramafic plutonic, hypabyssal and volcanic rocks and is intruded and overlain by magmatic rocks of both island-arc and possible back-arc affinity (Ingdahl 1985). A plagiodifferentiate of the GOC is dated at 489 ± 3Ma, and an arc-related, intrusive tonalite at 482 ± 3Ma by Dunning & Pedersen (1988). The close relationship between the formation of the ophiolite and the arc-related magmatism indicates formation of the GOC in an arc-related intraoceanic basin (Pedersen et al. in prep.). The Lysekloster Schists (Kolderup & Kolderup 1940) are greywackes, marbles and schists of assumed Early Palaeozoic age. The Ulven and Holdhus Groups (Fig. 1) (Ryan & Skevington 1976, Færseth et al. 1977) are metasediments of Ashgillian - Early Llandoverian age, unconformably overlying the GOC but generally strongly deformed. To the southwest is the Sunnhordland Batholith (Andersen & Jansen 1987) which consists of magmatic rocks of gabbroic to granitic composition. One of the intrusions, the Håkre Granite (Fig.1) is dated at 430 ± 10 Ma with an I.R. of 0.70560 ± 0.00005 (Andersen & Jansen 1987).

Analytical techniques

The Rb-Sr ratios were determined by X-ray fluorescence spectrometry. Measurements of unspiked $^{87}Sr/^{86}Sr$ were carried out on a VG Micromass 30 at the Mineralogisk-Geologisk Museum, Oslo, and the methods used are the same as those described by Pankhurst & O'Nions (1973). Variable mass discrimination was corrected by normalisation of $^{88}Sr/^{86}$ to 8.3752. The ^{87}Rb decay constant used is 1.42 x 10^{-11} y^{-1} and the regression technique is that of York (1969). Ages and intercept errors are noted at the 2σ level.

Sampling and results

The samples were collected from localities within the undeformed part of the Krossnes Granite along road-cuts near Ytredrangsvågen (UTM 997784 to 968789) (Fig.1). Samples 1-9 are very similar, coarse-grained red granite, while sample 10 is from the aplitic phase

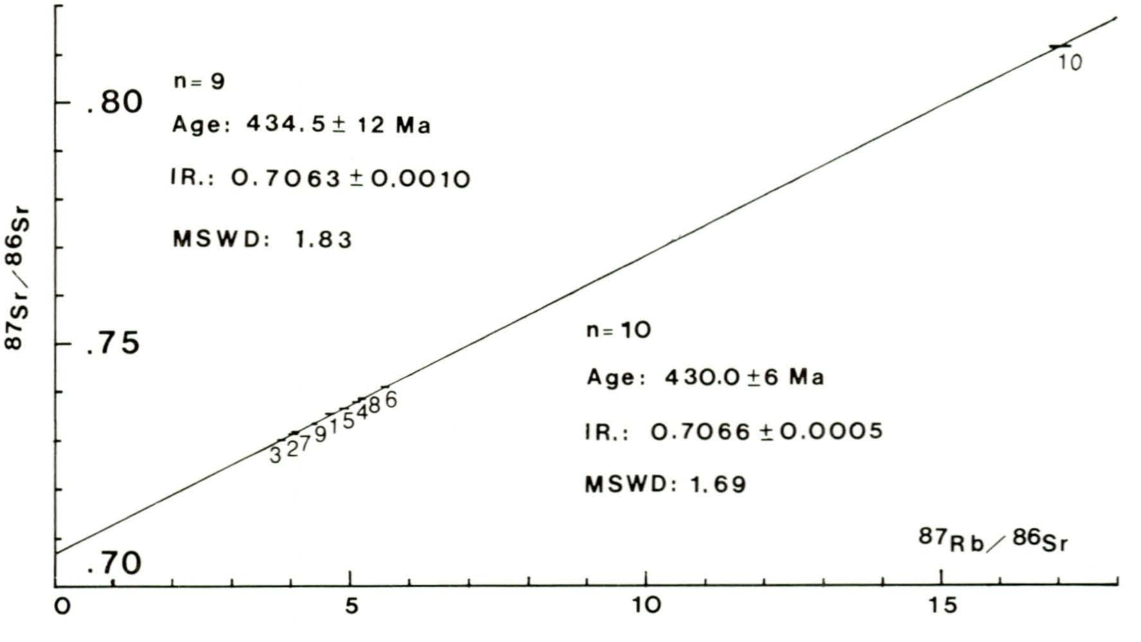

Fig. 2.Rb-Sr isochron diagram for the Krossnes Granite. n=10; all samples included, n=9; sample 10 (aplite) excluded.

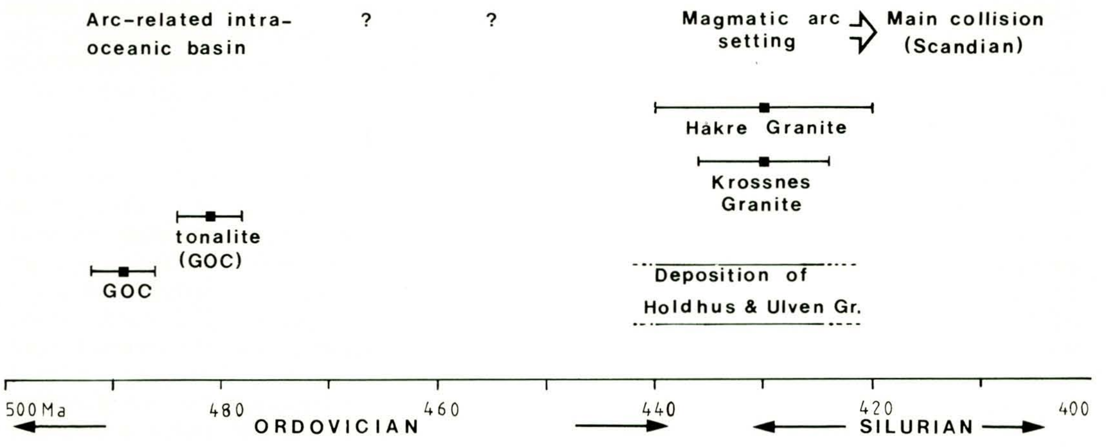

Fig. 3.Events in the area covered by Fig.1 that have been dated. GOC = Gulfjellet Ophiolite Complex.

which appears as dykes in the coarse-grained granite (Fossen & Ingdahl 1987). Joints are common in the area, but the samples collected were free of joints.

The regression analysis of the samples from the Krossnes Granite gives a date of 430.0 ± 6Ma and an initial $^{87}Sr/^{86}Sr$ ratio of 0.7066 ± 0.0005 with a MSWD of 1.69 (Fig.2). If sample 10, which has a Rb/Sr ratio considerably higher than the other samples, is excluded, a regression gives 435.5 ± 12Ma with an initial ratio of 0.7063 ± 0.0010 and a MSWD of 1.83 (Fig.2). The results show that the coarse-grained granite and the aplite are probably contemporaneous.

Discussion

The 430 ± 6Ma age is considered to be reliable, and, since it is the undeformed part of the Krossnes Granite which has been dated, apparently represents an intrusive age. The age is similar to that reported from the Håkre Granite (Andersen & Jansen 1987) (Fig.3). Their relatively low initial ratios indicate I-type intrusions in an immature magmatic arc setting. Their similar ages and initial ratios indicate that the Krossnes Granite is related to the granitoids of the Sunnhordland Batholith, which is interpreted as having intruded into a tectonic environment of ocean-continent convergence (Andersen & Jansen 1987). However, a much lower Sr content in the Krossnes Granite (Table 1) as well as a small difference in the initial ratios indicates that the two granites probably represent separate plutons.

The age of the Krossnes Granite provides a constraint on the timing of the deformation in the MaBA. Intense deformation and mylonitization at transitional greenschist-amphibolite

Table 1. Rb-Sr data.

Sample No.	Rb ppm	Sr ppm	Rb/Sr	$^{87}Rb/^{86}Sr$	±1σ	$^{87}Rb/^{86}Sr$	±1σ
1	274.9	172.2	1.5959	4.63	0.02	0.73519	0.00001
2	269.9	194.8	1.3853	4.02	0.02	0.73126	0.00001
3	255.2	195.3	1.3062	3.81	0.02	0.72985	0.00001
4	284.2	162.3	1.7502	5.08	0.03	0.73787	0.0001
5	285.5	170.2	1.6781	4.87	0.02	0.73629	0.00001
6	274.9	143.3	1.9179	5.57	0.03	0.74075	0.00001
7	240.7	172.5	1.3955	4.05	0.02	0.73163	0.00001
8	284.2	159.4	1.7826	5.18	0.03	0.73848	0.00001
9	276.6	183.4	1.5085	4.38	0.02	0.73315	0.00001
10	256.7	044.1	5.8184	17.02	0.09	0.81066	0.00001

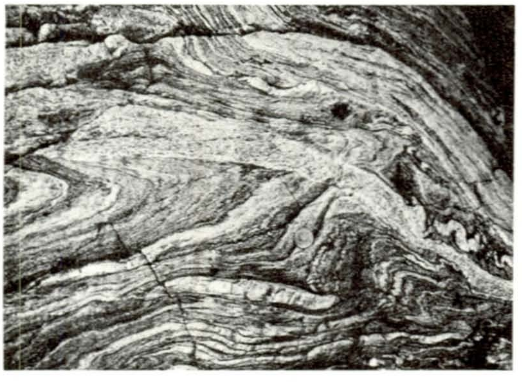

Fig. 4.Granitic dykes of the Krossnes Granite postdating a folded foliation in psammitic metasediments of the Lysekloster Schists. See Fig.1 for location.

facies in the northern and eastern part of the granite and adjacent rocks must be younger than c.430 Ma, and thereby probably Scandian. Where the intrusive contact between the Krossnes Granite and rocks of the MaBA is preserved from the strong Scandian shearing, dykes of the granite cross-cut foliated metasediments of the Lysekloster Schists. The foliation was already tightly folded prior to intrusion (Fig.4). Fossen & Ingdahl (1987) interpreted this deformation as due to pre-intrusion Scandian strain, but in the light of the radiometric dates of the GOC and of the Krossnes Granite, the deformation would now appear to be Ordovician or possibly very early Silurian. Pre-Scandian deformation and metamorphism have previously been interpreted from the MaBA (Kvale 1960, Sturt & Thon 1976, Færseth et al. 1977), although unambiguous evidence was not given (Ingdahl 1985, 1986).

The significance of the Ordovician deformation in the MaBA is not known, but it may be related to the strong, ductile deformation and metamorphism in the Selbjørn-Møkster area (Fig. 1) of the Sunnhordland Batholith which Rykkelid (1987) considered to be of Ordovician age, related to westward subduction below an active magmatic arc. Ordovician deformation and metamorphism are also recognized elsewhere in western Norway (Hall & Roberts 1988 and references therein, H. Gautneb in prep.) and may be equivalent to the Taconian orogeny in the Appalachians (Hall & Roberts 1988, Pedersen et al. in press).

The 430 ± 6Ma age of the Krossnes Granite indicates that the granite probably intruded during the time of deposition of the sediments of the Ulven and Holdhus Groups (Fig.3). The Ulven Group and the Krossnes Granite are separated by only 3 km of schists and ophiolitic rocks, which may indicate that the granite intruded the upper crust. Since the pre-intrusive ductile deformation of the Lysekloster Schist took place at depths of about 10-15 km, considerable uplift of the area occurred prior to deposition of the Holdhus and Ulven Groups (pre-Ashgill) and intrusion of the granite. However, it is possible that the Krossnes Granite intruded at a depth considerably more than 3 km during deposition of the Holdhus and Ulven Groups, and was subsequently uplifted by vertical crustal movements similar to those inferred from the Sunnhordland Batholite (Andersen & Jansen 1987).

Conclusions

1. Whole-rock Rb-Sr dating of the undeformed part of the Krossnes Granite has yielded a date of 430 ± 6Ma, interpreted as the age of intrusion.

2. The Rb-Sr age of the Krossnes Granite and its I.R. indicate that the granite is part of the Sunnhordland Batholith.

3. The age indicates that the Krossnes Granite probably intruded during the period of deposition of the Holdhus and Ulven Groups (Ashgill-Llandovery).

4. It is shown that strong ductile deformation occurred either at some stage during the Ordovician or close to the Ordovician-Silurian boundary in the Major Bergen Arc. The cause of this deformation is not known, but an arc-related event during the build-up of the Sunnhordland Batholith is a possible explanation.

Acknowledgements
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