Age and tectonic setting of the Tysfjord gneiss granite, Efjord, North Norway

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The Tysfjord gneiss granite, forming an easterly salient from the Lofoten-Tysfjord-Vesterålen Basement Region, is dated at 1742 ± 46 Ma by the Rb-Sr whole-rock method. Its $^{87}Sr/^{86}Sr$ initial ratio of 0.71151 ± 0.00247 is distinctly higher than the initial ratios of the plutons of the Rombak Window as well as the mangeritic rocks of the Hamarøy and Lofoten areas, suggesting that no simple comagmatic relationships exist between these plutons. A tentative model assumes the Tysfjord granite to be derived by partial melting in the lower to middle crust associated with the emplacement of the slightly older mantle(?)-derived mangerites. Much of the foliation and lineation in the Tysfjord granite are considered to be Caledonian fabric elements formed early in the orogenic cycle, most probably associated with an early phase of nappe emplacement. The Caledonian structures are not restricted to the uppermost part of the basement, but occur at least 2500 metres structurally below the basement/cover contact. Evidence from outside the Tysfjord area suggests that the nappe emplacement, and thus the fabric elements, cannot be older than 410 Ma. Two biotite-whole rock isochron ages from the Tysfjord gneiss granite, of 367 ± 8 Ma and 347 ± 7 Ma respectively, are interpreted as late Caledonian cooling ages associated with uplift of the Tysfjord basement above the blocking temperature (350°C) for diffusion of Sr in biotite.

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The age and tectonic setting of the Tysfjord gneiss granite as well as the nature of the basement/cover relationships in the Tysfjord area (Fig. 1) have been discussed in several papers during the last four decades (Foslie 1941, 1942, 1949, Gustavson 1966, 1969, 1972, Kautsky 1946, 1953, Tull 1977, Griffin et al. 1978, Tull et al. 1985, Vogt 1942, Hodges 1982, Hodges et al. 1982, Oftedahl 1966). Two opposing views have been presented regarding the basement/cover relationships and the Caledonian structures in this region. Foslie (1941, 1942) considered the foliated Tysfjord gneiss granite to be a Caledonian intrusive, because the granite on a regional scale had discordant boundaries with the overlying Caledonian schists. Vogt (1942), on the other hand, interpreted the granite as a Precambrian granite 'remobilized' during the Caledonian orogeny. A Precambrian age was also favoured by Gustavson (1972) after observing a depositional contact between gneissic granite and conglomerate on Hinnøy. The proposed Precambrian age for the gneisses and granites on Hinnøy as well as for the Lofoten-Vesterålen areas has been verified by various isotopic age dating methods (Heier & Compston 1969, Griffin et al. 1974, 1978, Jacobsen & Wasserburg 1978, Bartley 1981, Andresen & Tull 1983). Although correlations between the Tysfjord gneiss granite and the magmatic rocks of the Precambrian basement east (Kulling 1960, 1964, Gunner 1981) and west (Griffin et al. 1978), Hodges 1982, Hodges et al. 1982, Malm & Ormassen, 1978) of Tysfjord have been presented, no absolute age dates have been presented from the former rocks.

In 1979 detailed geological investigations were started in the area between Ofotfjorden and Efjord (Figs. 1 and 2). The project was undertaken with three objectives; (1) to clarify the absolute age of the Tysfjord gneiss granite and its post-magmatic structures (folds, lineations, foliations, etc.), (2) to investigate the stratigraphic and structural relationship between the Tysfjord basement and its Caledonian cover, and (3) to carry out a detailed structural and stratigraphic analysis of the cover rocks, especially to study the relationship between the Salangen Group and the Narvik Group. This paper is a report dealing with the two first objectives.

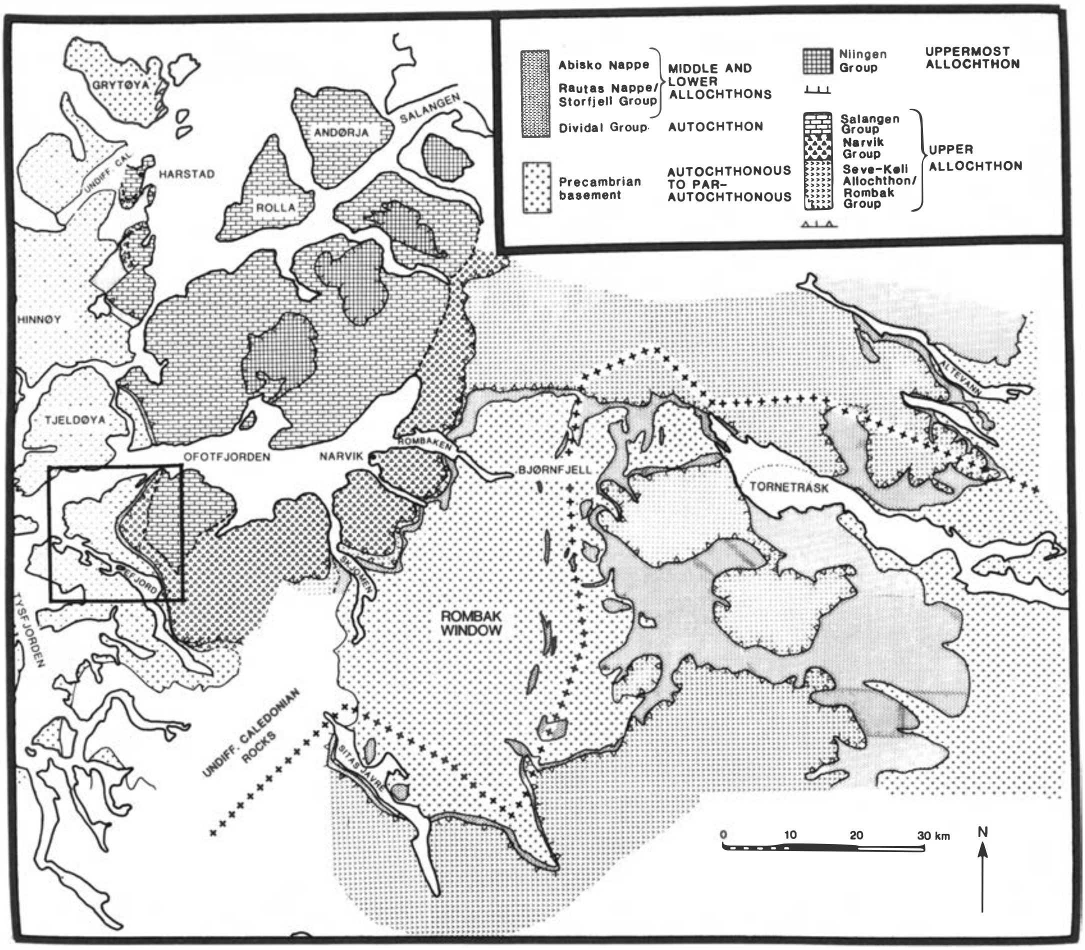

Fig. 1. Simplified geologic map of the Ofoten-Tysfjord-Torneträsk area showing the study area (box).

General geological setting

The Tysfjord area forms a salient of the Precambrian Lofoten-Vesterålen-Tysfjord Basement Province (Fig. 1), which is overlain to the east by the Caledonian geosynclinal rocks, most of which are considered allochthonous (Kautsky 1946, 1953, Kulling 1964, Oftedahl 1966, Gustavson 1972, 1974). The degree of continuity of the foliated granites of the Tysfjord area beneath the Caledonian cover rocks to the east is debated. Some workers consider that these rocks are structurally continuous eastward underneath the Caledonian cover and connect up with the weakly foliated to unfoliated Precambrian rocks of the Rombak Window and with the non-caledonized Precambrian rocks of the Baltic Craton in Sweden, east of the Caledonian front (Fig. 1) (Gustavson 1972). Others believe that tectonic breaks occur between these basement terranes (Tull 1973, 1977, Hodges 1982, Hodges et al. 1982, Tull et al. 1985). The Precambrian basement rocks of the Rombak Window include both supracrustal and gabbroic rocks, but are dominated by the Rombak-Hundal and Sildvik granites/gneiss granites (Vogt 1942, Kulling 1960, Gustavson 1966, 1974, Birkeland 1976). The supracrustal sequences, consisting of metasedimentary and metavolcanic rocks, are intruded by the Sildvik granite. Heier & Compston (1969) reported a combined four point Rb-Sr whole rock isochron age of 1715 ± 90 Ma from the two granites. This age has recently been confirmed by Gunner (1981) who obtained an age of 1780 ± 85 Ma.

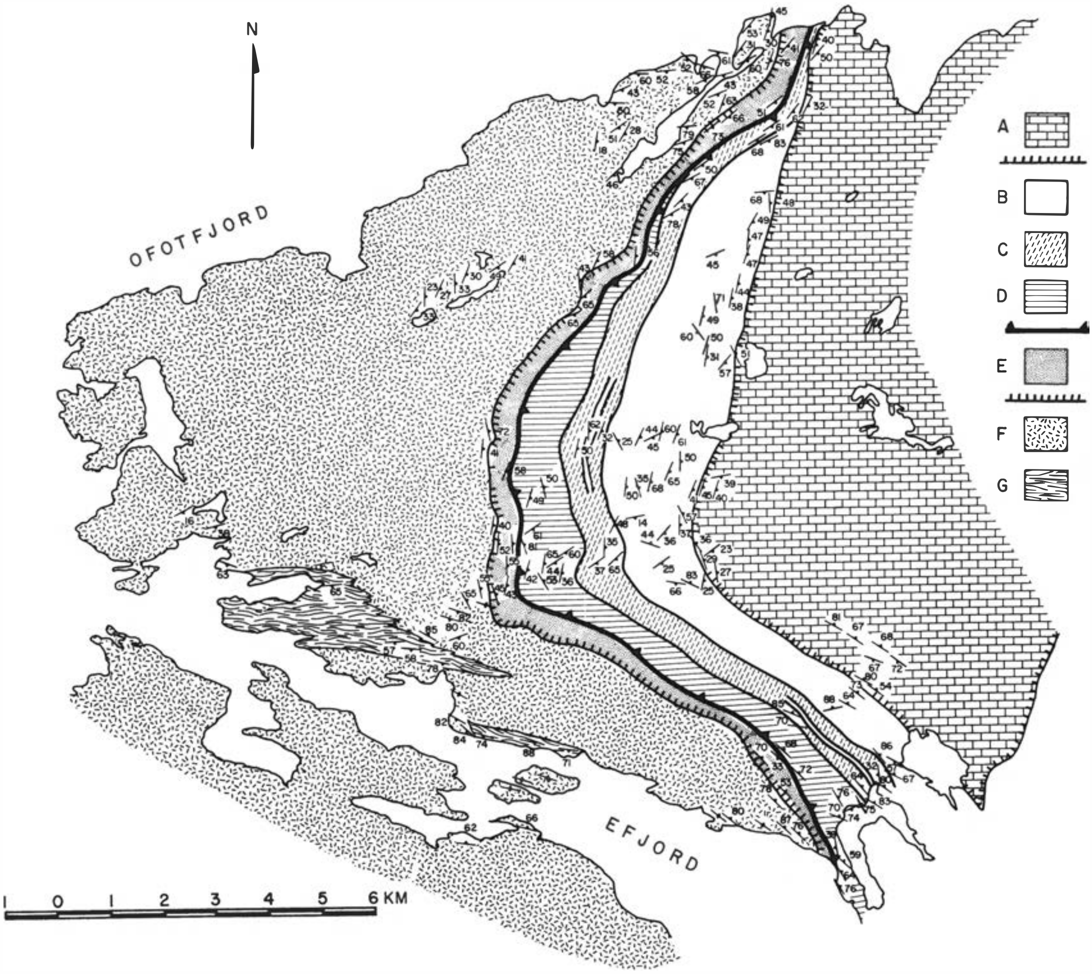

Fig. 2. Geologic map of the Ofotfjord-Efjord peninsula. A: Marbles and mica schist of the Salangen Group; overlying unconformity. – B: Garnetiferous biotite schist with extensive pegmatites and trondhjemites; minor graphite schist and quartzite; amphibolite in upper part. – C: Kyanite-bearing two mica schist, locally graphitic. Marble units occur near central portions. – D: Two mica garnet schist and amphibolite; pegmatites and trondhjemite dikes; underlain by pre-metamorphic thrust fault. – E: Quartzite, quartzofeldspathic gneiss, biotite schist, minor amphibolite; overlying tectonically disturbed unconformity. – F: Tysfjord gneiss granite. – G: Partly retrogressed mafic to intermediate hornblende gneiss. – Structural symbols represent strike and dip of principal metamorphic foliation.

The Caledonian cover sequence is dominated by rather flat-lying thrust sheets overlying a discontinuous Vendian to Cambrian autochthonous to parautochthonous sequence (Dividal Group) of variable thickness (up to 200 m). The lowermost allochthonous sheets surrounding the Rombak window are composed of (?) Precambrian granites and syenites with minor quartzite, schist and dolomite (Rautas Nappe Complex and Abisko Nappe, Kulling 1964). These allochthonous sheets display an upward as well as westward increase in metamorphic grade. The westward extension of many of the nappes is disputed. Gustavson (1972) and Bjørklund (1981, 1984), following Foslie (1941), have suggested that the various allochthonous units can be traced westwards to Hinnøy around and beneath the keel of the Ofoten synform. Bartley (1980), Hodges (1982) and Hodges et al. (1982) on the other hand denied the existence of allochthonous Precambrian sheets west of Ofotfjorden, and Tull (1973, 1977) and Hodges et al. (1982) have recently proposed that these nappes root in the basement somewhere between Tysfjord-Ofoten and the basement exposures in the Rombak window (Fig. 1).

The lower granite-dominated thrust sheets within the Rombak Window are tectonically overlain by garnet-mica schist and carbonate dominated allochthons, but these allochthons also include quartzite and conglomerate, and are intruded by plutonic rocks varying in composition from silicic to ultramafic. This upper part of the nappe pile is referred to as the Seve-Køli Nappe Complex in Sweden (Kulling 1964), but has been sub-divided into the Rombak, Narvik, Salangen and Niingen Groups respectively in Norway (Gustavson 1978).

Field relationships

The Precambrian basement

The basement rocks of the Efjord area can be grouped into three, (1) mafic gneisses, (2) coarse-grained biotite-gneiss granite (Tysfjord gneiss granite) and (3) biotite-poor fine-grained aplitic granite. The basic rocks occur as small lenses and layers in the Tysfjord gneiss granite and the boundary between the two is almost everywhere conformable. Locally, however, contact relationships interpreted as intrusive contacts have been observed. In such cases the gneiss granite appears to be the younger. Most of the mafic gneisses are now biotite schists and/or gneisses, but relict amphiboles suggest they were amphibolites prior to the (?) Caledonian deformation or at an early stage of the Caledonian evolution. The biotite gneisses are intensely foliated and display a distinct lineation coaxial with the lineation in the surrounding gneiss granite.

The major volume of the basement around Efjord consists of coarse-grained Tysfjord gneiss granite. A variably developed gneissic foliation is typical. The foliation is most pronounced near the contact with the overlying Caledonian cover rocks and becomes less distinct tectonically downward into the granite. Near the contact, up to several hundred metres below it, the Tysfjord granite is transformed into a medium grained completely recrystallized mylonite gneiss/blastomylonite (Higgins 1971) with a well-developed LS fabric. Farther away from the contact, a weak mylonitic to protomylonitic LS fabric, often with augen of large K-feldspar porphyroclasts, dominates. Locally zones of more highly strained granite occur. An excellent section showing the variation in strain from the basement/cover contact down into the core of the east-west trending Efjord basement culmination is seen in the road cuts along highway E-6 (Fig. 5). Nowhere has a completely non-foliated granite been observed, indicating that the basement rocks around Efjord were plastically deformed even to deep structural levels during Caledonian orogenesis. The fine-grained biotite-poor granite has only been observed along the northern limb of the Efjord antiform. It is foliated and lineated like the coarser grained Tysfjord granite, but the foliation is less obvious due to the lower biotite content and smaller grain size in the former.

The basement-cover contact strikes E–W and dips steeply toward N north of Efjord, but changes to an almost N–S strike and easterly dip between Efjord and Ofotfjorden (Figs. 3 and 4). Early (synmetamorphic) mineral lineations are coaxial in basement-, parautochthonous-, and allochthonous cover rocks (Figs. 3 and 5). The linear fabric elements display a great circle distribution with a pole that coincides with the axis of the later synformal cross folds. The structural data thus suggest that the planar and linear fabrics in the granite were formed prior to the development of the Efjord Antiform but during or after the early assembly of the lowest Caledonian allochthon (Narvik Group) in this region. An early development for the LS mylonitic fabric in the Efjord basement rocks is in agreement with structural data from farther to the east. There Hodges et al. (1982) consider the E–W and N–S trending basement culiminations and depressions as F_4 and F_6 structures respectively.

Basement/cover relationships

In the preceding description the structural upper part of the autochthonous/parautochthonous Tysfjord basement north of Efjord and west of highway E-6 is believed to be at the base of a quartzitic gneiss and mica schist sequence. This interpretation is clearly different from the interpretation given by Gustavson (1972, 1974), who considered the uppermost 1000 m or so of the basement to be allochthonous with respect to the granites in the core of the Efjord antiform. Our field work does not support this interpretation. Except for a somewhat more penetrative blastomylonitic fabric than that within the underlying rocks, the 'allochthonous' granite sheet of Gustavson (1974) is indistinguishable from the underlying autochthonous basement granites. We interpret these relationships to indicate that, while

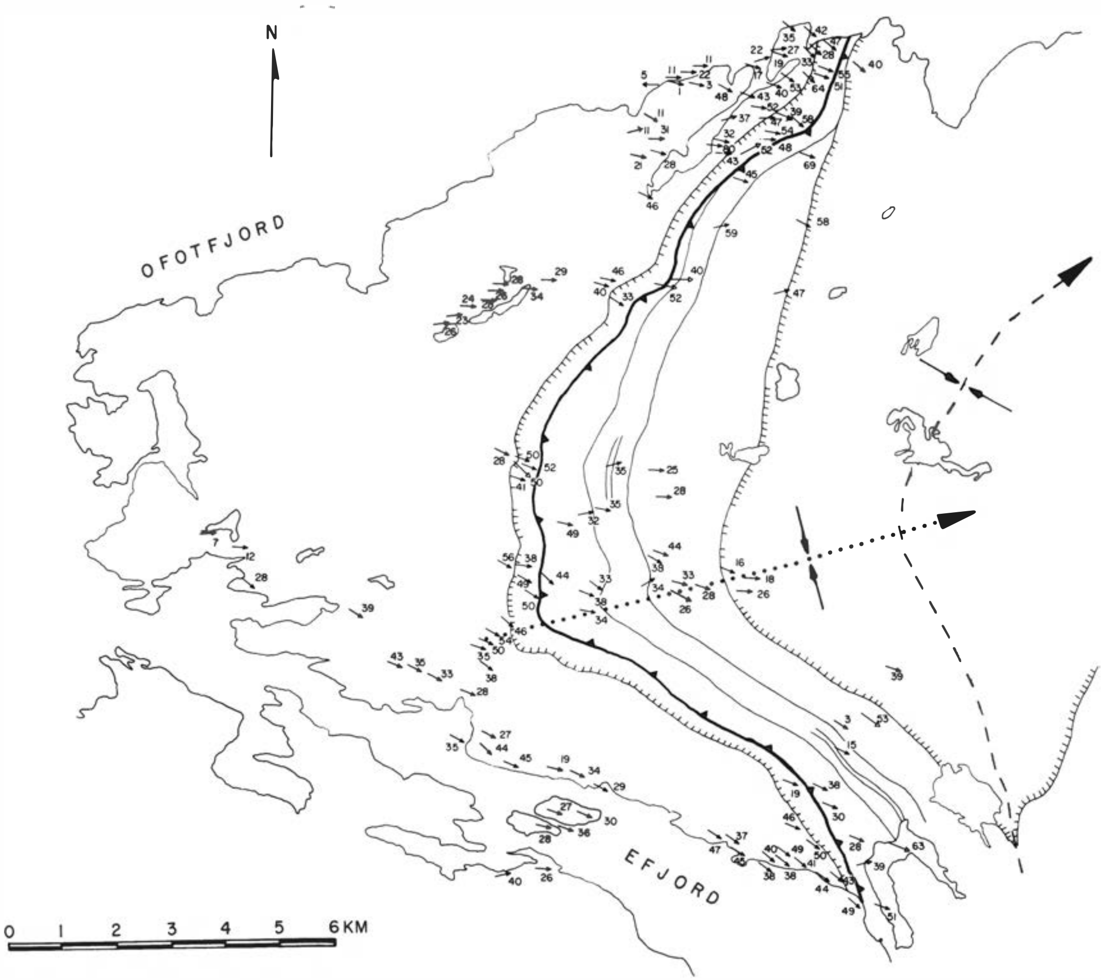

Fig. 3. Map showing spatial relationships of linear structures. Closed small arrows – bearing and plunge of mineral lineations and compositional layering/metamorphic foliation intersection lineations. Open small arrows – bearing and plunge of synmetamorphic fold axis. Dotted line with arrow – axial trace of synformal cross fold paired with Efjord antiformal basement culmination. Dashed line with arrow – axial trace of refolded Håfjell synform.

basement strain was variable within this region and tends to be more intense structurally upward in the basement, it was broadly distributed and not marked by abrupt discontinuities or dislocations down to the basement depths which we have examined. These conclusions are supported by the mesoscopic fabric data. It thus appeared that the extensive sheets of allochthonous Precambrian granites found further east (Kulling 1964, Hodges 1982, Hodges et al. 1982, Tull et al. 1985) are missing from Forså and westwards around the Håfjell Synform to Ofotfjorden. However, sheets of allochthonous Precambrian granites reappear on Hinnøy (Gustavson 1972, Bjørklund 1981, 1984).

The contact between the Precambrian Tysfjord gneiss granite and the overlying Caledonian lithotectonic units is concordant on outcrop scale but discordant on a regional scale. On a regional scale various Caledonian lithotectonic units are found in contact with the Tysfjord gneiss granite. A zone of quartzite gneisses, meta-arkoses and graphitic schists occurs next to the gneiss granite from Ofotfjorden and around the Håfjell Synform to Forså (Fig. 3). These metasediments are considered to be autochthonous to parautochthonous with respect to the basement rocks. From Forså and eastwards, kyanite-bearing garnet mica schist of the overlying Narvik Group nappe complex is found in tectonic contact with the

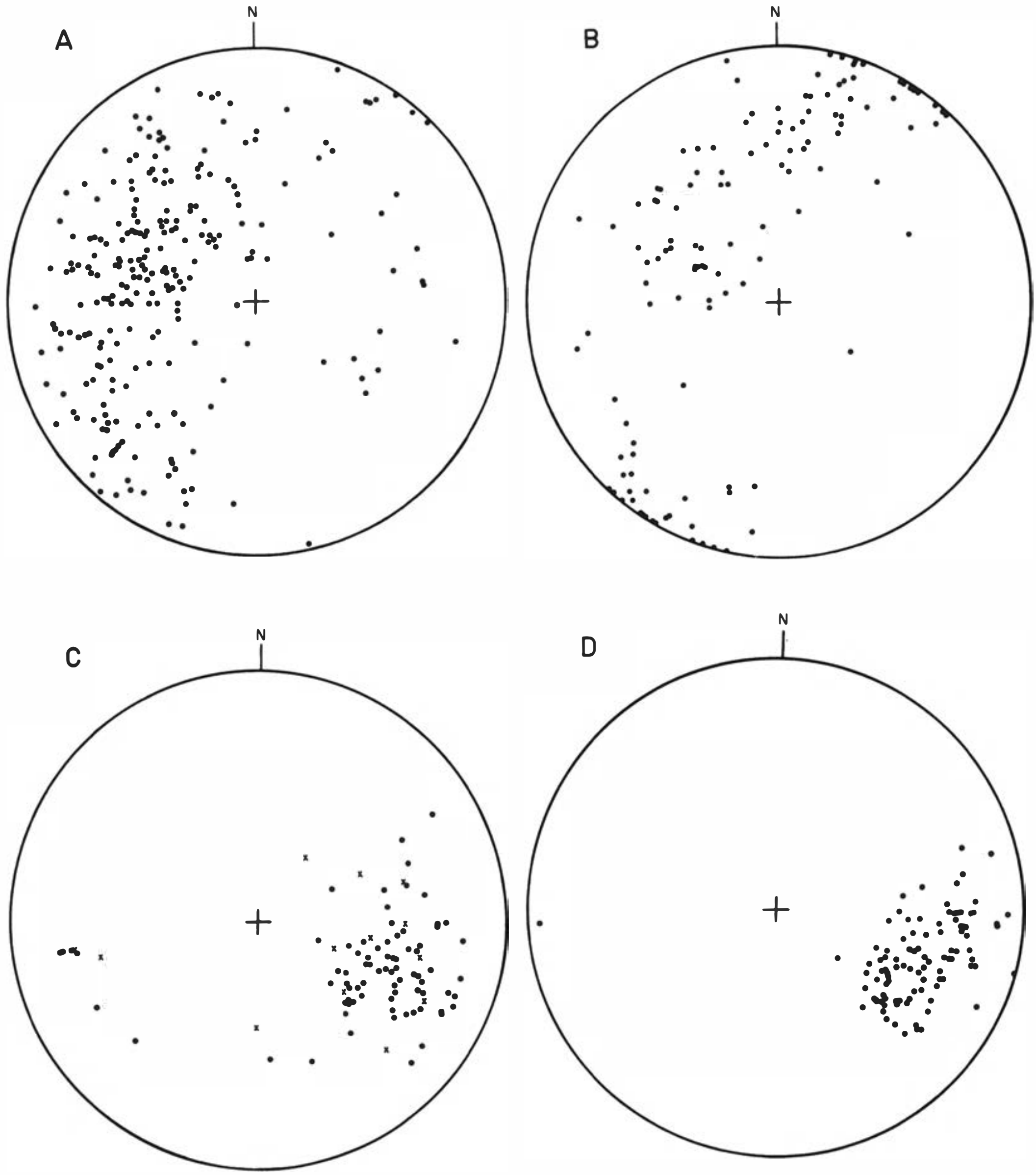

Fig. 4. Lower hemispheric equal area projection of mesoscopic fabric data. A) 240 poles to metamorphic foliation in cover units B-E of Figure 2. B) 124 poles to metamorphic foliation in basement lithologies F-G of Figure 2. C) 79 mineral lineations and compositional layering/ metamorphic foliation intersection lineations (dots) and 13 synmetamorphic fold axes (x's) in cover units B-E of Figure 2. D) 97 mineral lineations in basement lithologies F-G of Figure 2.

basement granites (Hodges 1982). Towards the inner parts Efjord, Hodges (1982) describes yet another tectonic unit next to the granite. Similar relationships are also described on Hinnøy (Bartley 1980). Both the parautochthonous metasediments and the schist and gneisses of the overlying Narvik Group display a distinct synmetamorphic (?) mineral and stretching lineation (Fig. 4). The lineations vary somewhat across the Håfjell Synform, but appear in any given area to be co-axial with the lineation in the underlying Tysfjord gneiss granite, indicating that the lin-

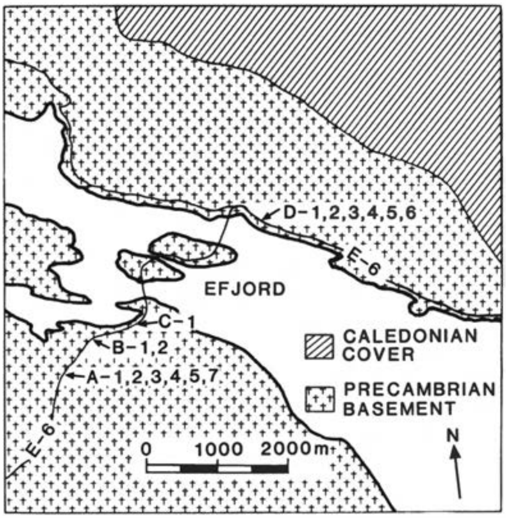

Fig. 5. Location map of samples used for age calculations.

eations in the two lithologies were formed contemporaneously and synchronously with or following the tectonic emplacement of the Narvik Group above the basement and parautochthonous metasediments.

Geochronology

Sampling and sample petrography

A total of seventeen samples were collected from 4 localities along E-6 across Efjord. The sample localities are given in Fig. 5. All samples from each of the four localities were collected within a distance of twenty metres or so from each other. Each sample weighted 5 kg or more. Samples from localities A, B and C are all taken from the coarse-grained biotite granite. A distinct foliation is seen in all the samples, as is a weak biotite mineral lineation. The modal composition of the granite is about 20% quartz, 40–45% K-feldspar, 25–30% plagioclase, 10–12% biotite with minor chlorite, epidote, sphene and zircon.

Sample series D is taken from a fine-grained biotite-poor granite body, interpreted as a late stage differentiate (aplite), within the coarse-grained biotite-granite. The sampled fine-grained granite has an intrusive contact relationship with the coarse grained granite but shares the same foliation as the country rock. The modal composition of the granite aplite samples is on the average 15–20% quartz, 45–50% K-feldspar, 30–35% plagioclase and 3–5% biotite. Chlorite, sphene apatite and zircon occur in accessory amounts.

Analytical methods

The rocks were crushed in a steel jaw-chrusher. A small representative portion of the resulting gravels was ground into fine powder in a tungsten carbide swingmill. The Rb and Sr contents in the finely ground whole rock samples were determined by duplicate X-ray fluorescence spectrography on all the seventeen samples following the methods described by Norrish & Chappell (1967). Unspiked measurements of $^{87}Sr/^{86}Sr$ were made for fifteen whole-rock samples (Table 1) using the V 6 Micromass 30″ mass spectrometer at Mineralogisk-Geologisk Museum, University of Oslo, using procedures similar to those described by Pankhurst & O'Nions (1973). Variable mass-discrimination in $^{87}Sr/^{86}Sr$ was corrected by normalizing $^{88}Sr/^{86}Sr$ to 8.3752 (Faure & Hurley 1963). Rb, Sr and $^{87}Sr/^{86}Sr$ ratios on biotite separated from samples A-2 and C-1 were determined on spiked samples. The ^{87}Rb decay constant used in age calculations is 1.42×10^{-11} yr^{-1} (Steiger & Jäger 1977). Regression lines were calculated using the technique of York (1969). Following Brooks et al. (1972) a quality of fit number (MSWD) of 2.5 has been used as a cut off level for a straight line, where the scattering of data points about the best fit line is due to experimental error. In assigning errors to the regression points, the coefficient of variance for Rb/Sr is taken as 1%. The standard errors for $^{87}Sr/^{86}Sr$ for each sample are listed in Table 1. All errors quoted in this paper are two sigma errors.

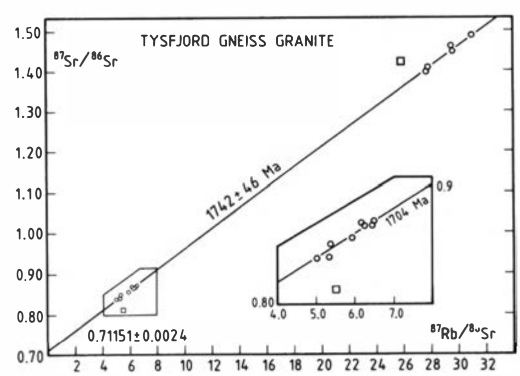

Fig. 6 Rb-Sr isochron plot of the analysed whole-rock samples from the Tysfjord gneiss granite. Squares represent data point not included in the regression calculations.

Table 1. Rb-Sr data, Tysfjord Granite, Efjord

Sample no.	UTM coord.	Rock type	Rb (ppm)	Sr (ppm)	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr \pm 1 \cdot 10^{-5}$
A-1	598749	Med. grained gneiss	180.1	98.2	5.36935	0.85212±9
A-2	598749	Med. grained gneiss	198.4	89.8	6.46496	0.86818±5
A-3	598749	Med. grained gneiss	193.8	95.2	5.95861	0.85637±7
A-4	598749	Med. grained gneiss	189.4	90.2	6.17214	0.86993±5
A-5	598749	Med. grained gneiss	198.0	93.2	6.25945	0.86851±9
A-7	598749	Med. grained gneiss	189.1	85.6	6.49743	0.87270±22
B-1	602754	Med. grained gneiss	200.7	110.3	5.33438	0.84119±9
B-2	602754	Med. grained gneiss	200.9	106.8	5.49523	0.81375±4
C-1	608756	Med. grained gneiss	205.8	120.2	5.01109	0.83937±9
D-1	625771	Fine grained gneiss	317.9	35.5	27.67168	1.39723±8
D-2	625771	Fine grained gneiss	300.0	33.4	27.79298	1.40849±4
D-3	625771	Fine grained gneiss	349.0	35.1	30.97774	1.48849±4
D-4	625771	Fine grained gneiss	324.1	34.1	29.50553	1.44748±21
D-5	625771	Fine grained gneiss	320.7	33.8	29.45053	1.46167±11
D-6	625771	Fine grained gneiss	297.8	35.8	25.78521	1.42322±8
A-2_{Bi}		Biotite	1049.6	15.6	218.82295	1.97672±13
C-1_{Bi}		Biotite	1206.1	18.9	204.28845	1.82187±34

Analytical results

Fig. 6 and Table 1 show the Rb and Sr data from the 15 whole rock samples analyzed on the mass spectrometer. Also shown are the isotope data on the two biotite concentrates. The whole-rock isotope data group into two regions in the isochron diagram. The coarse to medium-grained granite (Tysfjord gneiss granite) is characterized by a low Rb content, as well as low $^{87}Rb/^{86}Sr$ and $^{87}Sr/^{86}Sr$ ratios relative to the biotite-poor aplite facies. Thirteen of the analyzed samples align fairly well along an isochron line. Two samples, B-2 and D-6, plot clearly off the best fit line and are excluded from the age calculations. A detailed petrographic comparison of these two samples with the rest of the samples gave no indication as to why they plot off the best fit line drawn in Fig. 6. The best fit line yields an age of 1742 ± 46 Ma with an initial $^{87}Sr/^{86}Sr$ ratio of 0.71151 ± 0.00247. The MSWD value is 5.8. This relatively high MSWD value indicated that the scatter of data points cannot be attributed to routine analytical errors only, but is most likely caused by some disturbance of the isotope system.

To see if the two petrographically different granites give ages significantly different from the composite age obtained above, two separate age calculations have been carried out. Sample series A, B and C yield an age of 1704 ± 207 Ma, an initial ratio of 0.71482 ± 0.0175 and MSWD of 9.9. The five samples from the fine-grained granite give an age of 1912 ± 206 Ma and an initial ratio of 0.69399 ± 0.087 and MSWD = 1.14. The large errors in calculated ages, due to the limited variation in Rb/Sr ratios within each sample series, make it impossible to conclude anything about an age difference or difference in initial ratio between the two different facies of the Tysfjord gneiss granite. Calculations of whole-rock biotite ages for the two samples of the coarse-grained granite A-2 and C-1 gave ages of 367 ± 8 Ma and 346 ± 7 Ma respectively (Fig. 7).

Interpretation of analytical results

Isotope Rb-Sr whole rock studies on metamorphosed and plastically deformed igneous rocks have documented that the igneous crystallization age is normally retained (Jacobsen & Heier 1978, Schärer 1981, Jäger 1970, 1977, 1979, Krill & Griffin 1981). This is especially true if the sampling area covers a large portion of the isotopically homogeneous igneous rock body. In certain situations secondary isochron ages recording post-magmatic metamorphic events have been reported (Råheim 1977, Field & Råheim 1979, Hunziker 1970). We interpret the isochron age of 1742 ± 46 Ma obtained for the Tysfjord gneiss granite to represent the magmatic crystallization age. This age is comparable within two standard deviations with the 4 point whole rock isochron age of 1691 ± 90 Ma obtained by Heier & Compston (1969) on the Rombak and Sildvik granites and the age of 1780 ± 85 Ma obtained by Gunner (1981) from the southern part of the Rombak Window. There is, however, a distinct difference in calculated $^{87}Sr/^{86}Sr$ initial ratios for the three areas. The initial $^{87}Sr/^{86}Sr$ ratio for the Rombak – Sildvik granites is 0.706 ± 0.002 (computed from data in Heier & Compston 1969, Table 11), while the data for the best-fit line in Gunner's (1981) study gave an initial $^{87}Sr/^{86}Sr$ ratio of 0.700 ± 0.006. This low initial ratio and the relatively high Rb/Sr ratios led Gunner (1981) to suggest that the parental material for the granite did not reside in the sialic crust for any significant time but had been derived from the mantle shortly before the crystallization age of 1780 Ma. The relatively high $^{87}Sr/^{86}Sr$ initial ratio obtained for the Tysfjord gneiss granite on the other hand strongly suggests that its parent material was of crustal origin and different from the portion of the Rombak granite dated by Gunner (1981). Thus the existing Sr isotope data do not support the idea that the Tysfjord gneiss granite and the granites of the Rombak Window were derived from the same magma or magma source, as suggested by previous petrographic observations (Vogt 1942). However, it should be kept in mind when evaluating the variation in $^{87}Sr/^{86}Sr$ initial ratios that the analyzed samples in the study by Gunner were collected from a relatively large area of the Rombak Window, probably representing more than one plutonic body. In addition to this the data points in the isochron diagram show considerable scatter about the best-fit line.

The apparent difference in available initial ratios between the Tysfjord and Rombak granites supports the recent structural models that the Rombak and Tysfjord areas are unrelated, separated by a major low-angle imbrication zone of Caledonian age (Tull 1977, Hodges et al. 1982).

Before too much emphasis is placed on the difference in initial ratios, however, a more detailed isotope study of the individual plutons within the Rombak Window must be carried out.

The relationship between the Tysfjord gneiss granite and the igneous rocks of the Hamarøy-Lofoten-Vesterålen area is unclear. Griffin et al. (1978) suggested that the Tysfjord gneiss granite might be a retrograded mangerite, whereas Andresen & Tull (1983) favoured a genetic link between the Tysfjord gneiss granite and the Lødin-

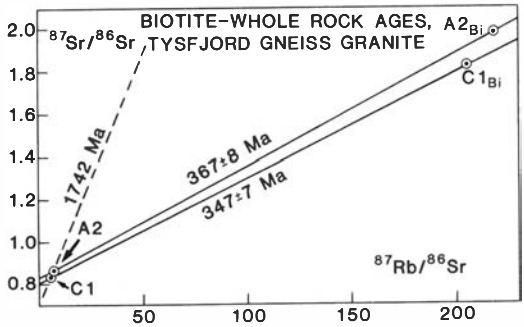

Fig. 7. Whole-rock-biotite Rb-Sr isochron plot of samples A-2 and C-1.

gen granite, a composite plutonic complex intruding the mangerites. The obtained age on the Tysfjord gneiss granite clearly favours a link with the Hamarøy mangerites with ages of (1770 ± 70 Ma, 1710 ± 60 Ma and 1695 ± 15 Ma) respectively, whereas the associated initial ratios of 0.70463 ± 0.00078, 0.70462 ± 0.00048 and 0.70434 ± 0.00028 (Griffin et al. 1978), are lower than in the Tysfjord gneiss granite. Comparison of ages and initial ratios for the Tysfjord gneiss granite and the Lødingen plutonic complex show that the Løding granite is slightly younger (1644 ± 36) but has an initial ratio which is comparable.

The whole rock – biotite ages of 367 ± 8 Ma and 347 ± 7 Ma are interpreted as cooling ages, most probably dating the late- to post-Caledonian erosion and subsequent basement uplift above the 350°C isothermal surface (Fig. 7). This interpretation is in agreement with an internally concordant $^{40}Ar/^{39}Ar$ age spectra on biotite (Dallmeyer & Andresen 1984) from the same area. In this latter study a total gas age of 371 ± 8 Ma and a plateau age of 373 ± 7 Ma were obtained.

Similar mineral ages have also been reported by Bartley (1981) from Hinnøy. A study of Svekofennian granites in Nordland gave Rb-Sr whole-rock biotite ages ranging in age from 358 Ma to 388 Ma (Wilson & Nicholson 1973). Although only three sets of biotite – whole rock ages were given, they appear to show a decrease in age from the relatively undeformed granites of the Nasafjell Window (388 Ma) to the plastically deformed basal gneisses of the Glomfjord area (358 Ma). This may indicate that uplift and cooling below biotite blocking temperatures of the basement took place earlier to the east than to the west, providing that the samples were located at the same stratigraphic level below the basement-cover contact prior to uplift.

Structural development of the Tysfjord gneiss granite

The isotope data presented here give little exact information as to the absolute timing of the foliation- and lineation-forming events in the Tysfjord gneiss granite. The whole rock isochron age represents the magmatic crystallization age of the Tysfjord granite, whereas the biotite – whole rock ages are cooling ages, clearly post-dating the syn-metamorphic lineation- and foliation-forming event(s), which took place under amphibolite facies conditions (Hodges et al. 1982). The observed relatively gradual increase in strain as one approaches the basement-cover contact from the core of the Efjord Antiform, and the coplanar and coaxial nature of the observed foliations and lineations in the basement as well as in the cover, strongly favour a Caledonian development, although it does not exclude the possibility that some of the foliations seen elsewhere in the Tysfjord – Hamarøy area can be of pre-Caledonian age (Griffin et al. 1978, Griffin & Taylor 1978). Structural observations from the basement rocks within the northern part of the Rombak Window (Tull et al. 1985) indicate that the earliest Caledonian fabric here, including a NW – SE trending mineral and stretching lineation, is most probably related to the emplacement of the nappes early in the orogenic cycle. A similar mode of formation is invoked for the foliations and lineations around Efjord. The geometric relationships along the western limb of the Håfjell synform and on Hinnøy suggest that the basement took part in fairly large scale isoclinal folding (Bartley 1980). We have no evidence to conclude that an episode of basement doming took place prior to thrusting, as suggested by Gustavson (1972).

Hodges et al. (1980) and Hodges et al. (1982) have proposed that the eugeosynclinal allochthonous rocks (Narvik Group and higher tectonic units), were emplaced above the Tysfjord – Lofoten basement area as early as 450 Ma ago, based on K-Ar dating of minirals from the Narvik Group. Such an early emplacement age for the nappes is in apparent conflict with data from several of the dated plutons located in the allochthonous rocks, which are believed to have crystallization ages of about 410 Ma (Roddick 1977, Wilson 1981, Andresen in prep.). Because there is no evidence that these plutons have penetrated the underlying Lofoten – Tysfjord basement, nappe emplacement and formation of the mylonitic fabric in the basement must post-date the crystallization age of these intrusions. However, the mylonite forming event can be no younger than 350 Ma based on the biotite cooling ages.

The rotation of the basement-cover contact around the Håfjell Synform and Efjord Antiform and adjacent synform to the north is the result of a late structural feature clearly post-dating the mylonite-forming event in the basement. From structural and metamorphic studies in the Salta Region, Cooper & Bradshaw (1978) suggested that the basement doming took place during both the D_2 and D_3 deformational events. Hodges (1982) considered the Håfjell Synform and the Efjord Antiform to be F_4 and F_6 fold structures respectively. More interesting than the exact chronology of folding are the processes whereby these basement involved structures were formed. Two principally different modes of formation are envisioned; (1) either that the basement antiforms and synforms are the result of subhorizontal compressive stresses or (2) that they are formed by diapiric processes caused by density inversion (Ramberg 1966, 1973, 1980). The latter model is favoured by Cooper & Bradshaw (1978) for the Salta Region. Our own data from Bjørnfjell (Andresen in prep.) suggest that basement shortening and reverse faulting associated with subhorizontal compressive stresses dominate the late basement structures.

Conclusions

The Tysfjord gneiss granite is a 1742 ± 46 Ma old pluton. It has an initial $^{87}Sr/^{86}Sr$ ratio of 0.71151 ± 0.00247 which suggests that the parental material was the continental crust itself or included a considerable portion of continental material. The initial ratio is distinctly higher than the initial $^{87}Sr/^{86}Sr$ ratio (0.700 ± 0.006) from the granites of similar age in the Rombak Window (0.700 ± 0.006) as well as the initial ratios obtained from the mangeritic plutons in Lofoten – Hamarøy. A common source for the Tysfjord gneiss granite and the igneous rocks to the east and to the west of it seems unlikely. The model favoured here is one in which the Tysfjord granite is derived by ultrametamorphism in the lower to middle crust as a result of emplacement of the mangerites in the lower crust (Andresen & Tull 1983). There is no petrographic evidence that the Tysfjord granite represents a retrograded mangerite. The foliation and lineation seen in the Tysfjord gneiss granite are interpreted as Caledonian fabric elements, developed at an early stage during Caledonian orogenesis; probably associated with the initial emplacement of the eugeosynclinal Caledonian allochthons. Intrusives dated at 410–420 Ma within these allochthons indicate that nappe emplacement and thus the formation of the synmetamorphic foliation has to post-date these ages. The foliation in the Tysfjord gneiss granite is not restricted to the uppermost part of the basement. It is recognized at least 2500 metres structurally below the basement/cover contact. The exact P-T conditions under which the foliation was formed is not known, but the temperature was probably well above the blocking temperature of about 350°C for diffusion of Sr, as indicated by the biotite-whole rock ages. Temperature estimates from the Narvik Group indicated that the temperature in the allochthonous units once were as high as 600°C (Hodges 1982). It is, however, unclear what the temperature was when the Narvik Group was emplaced onto the Tysfjord gneiss granite. The biotite-whole rock isochron ages around 350–360 Ma are interpreted to record the time of uplift of the region above the 350°C isotherm.

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