Geochemistry and Rb-Sr isochron age of trondhjemite dykes from the Gula Complex, near Snøan, Central Norway

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Trondhjemite dykes trending c.ENE-WSW and transecting early metamorphic fabrics in rocks of the Gula Complex, south-southwest of Støren, are themselves weakly metamorphosed and foliate. Geochemical data show that the dykes are characteristic of high-Al_2O_3 trondhjemites, and typical of those reported from continental margin environments worldwide.

Rb-Sr isotopic analysis of a series of samples from one particular dyke did not yield any isochron. However, samples lying farthest from the regression line are exclusively from the dyke margins; and if these samples are excluded, then a best-fit isochron defines an age of 465±11 Ma (MSWD 2.2, i.r. 0.70794±9). This is taken as the minimum age of intrusion, i.e. basal Llanvirn, and is interpreted as reflecting a post-emplacement thermal resetting age. Dyke margin samples are likely to have been affected by an influx of fluids containing abundant ions of radiogenic Sr, and concentrated along the dyke margins by the decay of ^{87}Rb during thermal resetting.

The isotopic age of the trondhjemite also provides a minimum age for the Early Ordovician deformation and metamorphism of the juxtaposed Støren ophiolite and Gula Complex succession. The gentle folding of the dykes and their weak foliate fabric are thus likely to be of Scandian (Late Silurian-Early Devonian) age.

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Introduction

Several, large, metamorphosed trondhjemite bodies, reaching up to 20 x 5 km in outcrop size, occur within the Gula Complex (formerly Gula Group) of the Trondheim Nappe Complex (TNC), in the Caledonides of Central Norway. These are depicted on the 1:250,000 map-sheets 'Trondheim' and 'Røros' (Wolff 1976, Nilsen & Wolff 1988), and some are also indicated on the 1:1 million bedrock map of Norway (Sigmond et al. 1984). In some areas, there are also swarms of finer-grained, variably foliate, trondhjemite dykes, many of which cut an earlier foliation. These dykes are therefore potentially valuable – if their ages can be determined, then they will provide useful temporal constraints on inferred early Caledonian deformation.

In this brief contribution we present the results of a study that was purposely concentrated on just 4 metatrondhjemite dykes in road-cuts, which were newly exposed in the early 1980's, along the minor road between Snøan and Budal, south of Støren (Fig.1). This local study began as part of a more regional investigation of greenstones and associated rocks in the Trondheim Region, but one specifically hatched by an inspiring excursion in the area, led by Odd Nilsen. More or less at the same time, Nilsen (1983) described a sedimentary mélange, or olistostrome, from this same general area.

The investigation encompasses an attempt at Rb-Sr dating of one of the more better exposed examples of these trondhjemite dykes, and a parallel geochemical investigation of this and three other comparable dykes. It was carried out over a period of several years through a step-by-step analysis of the data available to us at different times. Although the dykes have been affected by Scandian metamorphism, in this description we will, in general, omit the 'meta' prefix.

Local geology

A general introduction to the geology of this part of the Trondheim Nappe Complex is presented in two companion papers in this same volume (Dunning & Grenne 2000, Pannemans et al. 2000). Nilsen's (1983) map of the district (Fig.1) shows the area around Snøan to consist mainly of a grey and black phyllite member of the Undal Formation, part of the Gula Complex; and a unit of sedimentary mélange. Farther to the west, the Gula Complex (and Nappe) is structurally overlain by metabasalts, mafic dykes and associated rocks of the basal, ophiolitic part of the Støren Nappe (Gale & Roberts 1974, Nilsen 1983), a rock association that has traditionally been termed the Støren Group.

The *Undal Formation* consists largely of fine-grained, graphitic, grey to black, chlorite-sericite phyllites with a variable content of calcite. In places, there are thin intercalations of ribbon chert and chlorite-bearing amphibolitised greenstone. Ubiquitous sulphide mineralisations are seen as thin schlieren parallelling the pervasive schistosity (Nilsen 1978). Parts of the succession, including exposed sections near

Snøan, are also reminiscent of a tectonic mélange with a high content of deformed clast material in a schistose matrix. This particular mélange is comparable to that described by Horne (1979) from the Selbusjøen area c. 50 km northeast of Snøan, in what appears to be a strike extension of the Undal Formation.

The *sedimentary mélange*, as described by Nilsen (1983) and in that paper named the Soknedal mélange, is essentially an olistostrome formed as a debris flow with submarine sliding involved. The clast material, including one large block of greenstone covering 400 m^2, was considered by Nilsen to have been derived mainly from the Gula Complex, but also, in part, from the Støren ophiolite. He interpreted this mélange as a comparatively young deposit, of possible Late Silurian age, and *not* a part of the surrounding Undal Formation with its older, tectonic mélange (Fig. 1).

The trondhjemite dykes of this study cut through both the Gula Complex and the Støren Group rocks, but *not* the unconformably overlying, Ordovician Hovin Group which contains fossils as old as Late Arenig (Størmer 1932). In the Undal Formation they transect the earlier tectonic mélange. Accepting that there is just one broad age for the trondhjemite dyke swarm, then it is thus likely to be pre-Late Arenig. Although Nilsen (1983) reported "dykes of trondhjemitic type" cutting the Soknedal olistostrome, they have since been reinterpreted by him as elongate megaclasts of trondhjemite (O.Nilsen, pers. comm. 2000).

The trondhjemite dykes

Field relationships

Of the four trondhjemite dykes investigated, the one exposed in the road-cut at grid ref. 634858, 1:50,000 map-sheet Budal 1620-4, is the best exposed, and is from 80 cm to 1 m in thickness (Fig. 2). This is the one that was chosen for the Rb-Sr dating study; and is hereafter called the 'main dyke'. The other dykes vary in thickness from 50 cm to 2 m and strike at c.060°, dipping either to the southeast or to the northwest.

The main dyke strikes at 065° and also varies in dip, from 60° SSE to 55° NNW through vertical, in the road outcrop, defining a gentle, inclined fold (Fig. 2). The dyke, which is fine- to medium-grained and massive, appears to transect a prominent spaced cleavage in the country rocks that dips at 18° towards ESE. This cleavage may be broadly axial planar to the shallowly ESE-plunging fold, and is itself deforming an earlier schistosity. The country rock here consists of a matrix-supported, small-clast mélange where the matrix is mainly a grey to dark grey, silty phyllite. A few metres downhill, along the road, banded chert and phyllite are present. This unit carries small-scale folds with an axial planar crenulation cleavage which is parallel to that in the mélange. A lensoid structure of probable tectonic origin present in the mélange dips at up to 50° to the east and is older than both the dyke and the gently dipping cleavage.

The trondhjemites are comparatively fine-grained and show a weak foliate structure that is broadly parallel to the

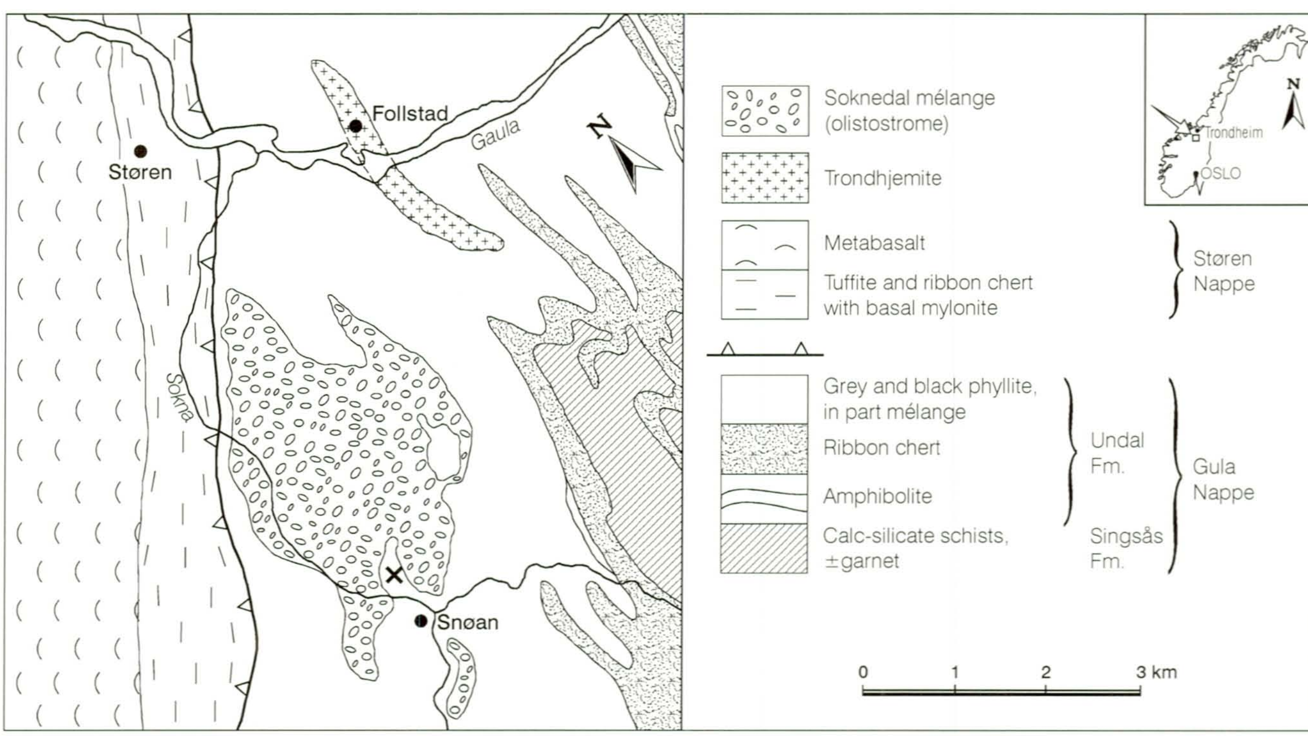

Fig. 1. Geological map of the Støren-Snøan-Soknedal area, Sør-Trøndelag; reproduced and modified from Nilsen (1983). Nilsen considered the Soknedal mélange (olistostrome) to be the very youngest metasedimentary unit in the area. This relationship is retained here, even though the present authors believe that parts or all of this mélange form an integral part of the Undal Formation. The road-section with dykes, forming the basis of this study, is marked by a cross (just NNW of Snøan).

Fig. 2. The 'main' trondhjemite dyke cutting a small-clast tectonic mélange of the Undal Formation, looking c. northeast. The dyke is very gently folded, with the prominent, shallowly dipping, late crenulation cleavage in the mélange lying roughly axial planar to the fold.

spaced cleavage seen in the mélange. The dykes thus predate the spaced cleavage noted above. In thin-section, the texture is allotriomorphic-granular, in places granoblastic. The principal minerals are quartz and plagioclase, with lesser and variable amounts of sericitic muscovite, chlorite, epidote and calcite, and accessory apatite, titanite, zircon and magnetite. This is a paragenesis which indicates that the dykes have been affected by a regional metamorphism of greenschist facies. Trondhjemite dykes of similar character and trend to those described here also occur widely in the Gauldalen district (Pannemans & Roberts 2000).

Geochemistry

Major and trace elements were analysed on rock powders using an automatic Philips 1450/20 XRF, at the Section for Analytical Chemistry, NGU, Trondheim. Calibration curves were made with international standards. For the determination of major elements the rock samples were melted with lithium tetraborate 1:7. Trace elements were determined on pressed rock powders. Ferrous iron, H_2O^+, H_2O^- and CO_2 were determined by wet chemical methods. Rare earth elements (REE), Th, Ta, Hf and Sc were analysed by INAA and Nb by mass spectrometry.

Major elements

Major element concentrations and ratios of the Snøan trondhjemite dykes (Tables 1 & 2) fall largely within those specified under Barker's (1979) definition of trondhjemites, except that the SiO_2 content of the Snøan dykes is slightly low, and lower than the mean value from the Follstad quarry trondhjemite (Size 1979, Pannemans & Roberts, this volume). This is compensated, however, by a higher content of Al_2O_3, which is not abnormal for trondhemites worldwide and is, in fact, a measure of palaeotectonic setting (see below). The Snøan trondhjemites are, by definition, high-Al_2O_3 trondhjemites. By comparison with the Follstad trondhjemite, the Snøan dykes show a lower Na_2O/K_2O ratio (2.3, as against 3.8), and the FeO_{tot}/MgO ratio is also a good deal lower (1.4 vs 2.8). On an AFM plot they are, not unexpectedly, calc-alkaline, at the low-T end of the gabbro-trondhjemite trend (Fig.3), but they are slightly more Fe- and Mg-rich than the Follstad trondhjemite.

Trace elements

Rb and Sr abundances and the Rb:Sr ratio are known to be particularly sensitive indicators in discriminating between trondhjemites and related plagiogranites generated in widely different tectonic settings. In the case of the Snøan trondhjemite dykes, mean values of 388 ppm for Sr and 70 ppm for Rb far exceed those typifying oceanic trondhjemites (c.100 and <5 ppm, respectively) (Fig.4). The Rb:Sr ratio of 0.18 for Snøan is also substantially higher than that (0.015) for oceanic trondhjemites (Coleman & Donato 1979). On the Rb-Sr plot (Fig.4) the Snøan dykes mostly fall within the field for continental trondhjemites.

The high Al_2O_3 content of trondhjemites is also known to provide an indication of their continental affinity, and notably when seen in relation to depletion in heavy rare-earth elements. Contents of Yb are low, and on a Yb vs. Al_2O_3 plot (not shown here) (Arth 1979) the Snøan dykes cluster well within the continental field (see Fig. 11 in Pannemans & Roberts 2000).

Chondrite-normalised rare-earth element (REE) plots, as well as REE abundances and ratios, provide reliable pointers with regard to trondhjemite tectonic setting and genesis. Two samples were chosen from Snøan for REE analysis, from different dykes. Their REE contents (Table 3) and patterns are extremely similar (Fig.5), with fairly low abundances, a fractionated pattern for the LREE with La c.20 x chondrites and the HREE down to 1 x chondrites. The La_N/Lu_N ratio is just under 20, and there is just a hint of a small positive Eu anomaly. These data are similar to those presented by Barker & Millard (1979) from the Støren district, but differ slightly from the REE data in Size (1979) where the La to Sm patterns are flat.

The REE patterns and contents from the Snøan dykes are almost identical to those reported from continental margin environments (Arth 1979). Trondhjemites from continental interiors show a more pronounced LREE enrichment, with La about 70 x chondrites. Oceanic or island-arc trondhemites, on the other hand, have fairly flat REE, or even LREE-depleted patterns, negative Eu anomalies and HREE contents <10 x chondrites (Fig.5).

Table 1. Major and trace element composition of the Snøan trondhjemite dykes. Major elements in wt.%, trace elements in ppm.

Sample	1	2	3	4	5	6	7	8	9	10
SiO_2	66.04	66.50	64.16	64.08	68.30	67.95	66.30	66.77	67.41	66.40
TiO_2	0.23	0.24	0.24	0.24	0.17	0.18	0.24	0.24	0.22	0.20
Al_2O_3	16.98	17.12	17.11	16.92	16.87	17.28	17.05	17.11	16.64	17.24
Fe_2O_3	0.12	0.33	0.60	0.61	0.48	0.60	0.60	0.33	0.29	0.20
FeO	1.26	1.25	1.12	1.19	0.75	0.71	1.16	1.17	1.14	1.17
MnO	0.05	0.05	0.03	0.03	0.02	0.03	0.02	0.03	0.03	0.03
MgO	1.01	0.98	1.37	1.40	0.76	0.77	1.08	1.09	1.10	1.19
CaO	2.23	2.17	3.47	3.74	3.60	3.25	3.34	3.22	3.17	3.51
Na_2O	4.50	5.10	5.00	4.80	5.20	5.00	5.33	5.30	5.60	4.80
K_2O	2.86	2.51	2.08	2.07	0.97	1.49	1.54	1.50	1.44	1.68
P_2O_5	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.07	0.08	0.06
H_2O^+	1.95	2.02	1.88	1.91	1.15	1.56	1.89	1.67	1.65	1.85
H_2O^-	0.06	--	0.03	0.04	--	0.03	0.03	0.04	0.05	--
CO_2	1.61	1.50	1.44	1.60	0.40	0.52	1.52	1.47	1.31	1.37
Total	98.97	99.84	98.60	98.69	98.73	99.43	100.16	100.01	100.13	99.70
Zr	80	80	73	71	74	80	75	72	71	65
Y	<5	<5	5	<5	<5	<5	<5	<5	<5	<5
Sr	210	241	284	299	548	498	521	522	533	568
Rb	92	80	80	80	34	54	49	50	46	61
Zn	28	28	23	24	26	26	33	34	36	32
Cu	<5	<5	6	<5	<5	<5	7	<5	<5	12
Ni	7	6	11	11	<5	<5	7	8	6	8
Cr	15	15	26	27	6	7	18	18	13	11
Ba	454	394	380	367	278	302	345	297	292	282
Nb	<5	<5	<5	<5	<5	6	<5	<5	<5	5
V	26	27	40	37	13	14	30	25	26	18

Sample	11	12	13	14	15	16	17	18	19	20
SiO_2	66.53	65.14	65.34	66.35	65.97	65.80	66.24	65.30	65.89	64.91
TiO_2	0.21	0.24	0.24	0.25	0.24	0.23	0.23	0.24	0.24	0.25
Al_2O_3	17.51	17.18	17.25	17.10	16.56	16.24	16.30	16.57	16.59	18.34
Fe_2O_3	0.29	0.42	0.48	0.49	0.54	0.56	0.55	0.56	0.55	0.50
FeO	1.13	1.07	1.15	1.05	1.00	1.09	0.98	0.96	1.01	1.04
MnO	0.02	0.05	0.04	0.03	0.03	0.07	0.05	0.04	0.04	0.04
MgO	1.28	0.98	0.96	1.00	0.96	0.93	0.96	1.04	0.98	0.96
CaO	3.19	2.84	2.50	2.48	3.19	2.75	3.11	3.32	2.96	2.15
Na_2O	5.10	5.60	4.50	4.60	4.30	3.80	4.30	4.40	4.50	4.60
K_2O	1.76	2.13	2.49	2.26	2.41	3.01	2.46	2.53	2.43	2.62
P_2O_5	0.07	0.05	0.03	0.05	0.04	0.05	0.05	0.05	0.05	0.04
H_2O^+	1.76	2.15	1.80	1.67	1.93	2.04	2.03	2.06	2.09	1.82
H_2O^-	0.05	0.06	0.05	0.04	--	0.05	0.06	0.05	0.03	0.05
CO_2	1.18	1.78	1.42	1.22	1.74	1.96	2.04	2.12	2.00	1.41
Total	100.08	99.69	98.25	98.59	98.91	98.58	99.36	99.24	99.36	98.69
Zr	67	89	89	92	83	82	89	87	91	99
Y	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Sr	543	358	335	357	324	223	310	355	366	358
Rb	63	69	80	69	73	94	79	81	81	88
Zn	30	28	28	27	30	25	28	33	32	28
Cu	<5	<5	<5	<5	<5	<5	<5	<5	6	<5
Ni	10	6	<5	<5	<5	<5	<5	7	7	6
Cr	17	17	17	16	17	15	15	20	16	18
Ba	380	306	373	357	347	439	337	321	353	400
Nb	<5	<5	<5	<5	<5	<5	<5	<5	<5	5
V	24	24	25	27	29	27	24	26	26	31

Rb-Sr geochronology

Thirteen samples from the main Snøan dyke were subjected to Rb-Sr isotopic analysis. The results are reported in Table 4. As can be seen from Fig.6a, the complete data do not yield any isochron. It was realised, however, that the five samples lying farthest from the regression line in this figure were exclusively from the *marginal* parts of the dyke. If these dyke margin samples are excluded, then the remainder (nos.1, 2, 12, 17, 96a, 96c and 96e; Table 4) yield a reasonably acceptable fit (MSWD = 2.2), with an age of 465 ± 11 Ma and an initial $^{87}Sr/^{86}Sr$ ratio of 0.70794 ± 9 (Fig.6b).

A reason for excluding the samples taken from the very

	Snøan	Follstad
SiO_2	66.07	71.47
Al_2O_3	16.99	16.20
TiO_2	.23	.23
FeO	1.07	.78
Fe_2O_3	.45	.58
MgO	1.04	.48
CaO	3.01	2.72
Na_2O	4.82	5.33
K_2O	2.11	1.39
MnO	.03	.02
P_2O_5	.06	.08
(n)	*20*	*15*
Zr	80	81
Nb	<5	<5
Y	<5	<5
Ba	350	407
Sr	388	606
Rb	70	29
Cr	16	3
V	26	12
Rb/Sr	.18	.05
(n)	*20*	*4*

Table 2. Mean major element and selected trace element contents for the Snøan trondhjemite dykes and the Follstad trondhjemite pluton. The Follstad major element data are taken from Size (1979), and the trace element means from Pannemans & Roberts (2000).

marginal parts of the dyke is not immediately evident if one considers just the major and trace element data (Tables 1 & 2). These do not show any significant variation between samples taken from the dyke margins and those from the central parts of the intrusion, i.e. a bulk assimilation of wall-rock does not appear to have occurred. However, transport of fluids into, and admixture of fluids from the wall-rock are likely to have taken place along the margins of the intrusion. Such fluids may have contained abundant ions of radiogenic Sr, which are commonly expelled from the minerals wherein they were formed and concentrated by the decay of ^{87}Rb. This mechanism may provide an explanation for samples with excess radiogenic Sr (e.g., sample no.16). Experience from Rb-Sr dating of dykes and sills in other areas of Norway strongly suggests that such a mechanism has been operative (Sundvoll et al. 1992, Sundvoll & Larsen 1993), notably in contact zones that display other evidence of fluids having been present during both intrusion and subsequent regional metamorphism.

Samples showing a deficiency in radiogenic Sr generally reflect: (a) a variable degree of some post-intrusive alteration process, or (b) reheating, which may have disturbed the isotopic equilibration. Both mechanisms are governed by the general fact that radiogenic Sr is unstable in the lattices of minerals containing Rb and thereby easily removable. If mechanism (a) can be dismissed, then the dyke may have suffered a post-emplacement thermal resetting event, which may have resulted in varying degrees of reequilibration of the Rb-Sr system in different parts of the intrusion which had disparate physical properties, i.e. the marginal versus the central parts.

Thus, the Rb-Sr isochron age derived from the central part of the main Snøan dyke may be taken, at best, as *a minimum age* for the intrusion. As noted earlier, the fossil record in the adjacent, overlying, Lower Hovin metasedimentary succession which is not cut by the dyke swarm, extends down into the Upper Arenig. The geological evidence thus allows for the possibility that the dyke intrusion itself may be at least 10 million years older than indicated by the Rb-Sr isochron age, i.e. more or less equivalent to the upper error limit. Accordingly, the Rb-Sr isochron age can most probably be interpreted as reflecting a post-intrusive thermal resetting age.

Discussion

Geological and structural relationships in this part of the southwestern Trondheim Region involved an obduction of Iapetus ocean-floor volcanites (dismembered Støren ophiolite) upon part of what has been termed the Gula Complex, coeval with a common early Caledonian deformation and metamorphism. The complexes were then uplifted and eroded, prior to deposition of the Lower Hovin Group above a surface of major unconformity. As the oldest fossils in the Lower Hovin are of Late Arenig age, then this places a minimum age on the early Caledonian deformation. Since the Gula contains Tremadoc graptolites in one area farther to the east, then an Early to Mid Arenig age has been assumed for this tectonothermal event (Sturt & Roberts 1991).

The trondhjemite dyke swarm in the Snøan-Støren-Gauldalen district cuts both the Gula sequence and the Støren metabasalts, and their *early* deformation/metamorphic fabrics, but *not* the low-grade Hovin metasedimentary rocks. Our attempt at Rb-Sr dating of the 'main' trondhjemite dyke at Snøan has produced a best-fit isochron of c.465 ± 11 Ma, interpreted as a minimum age for the dyke swarm and

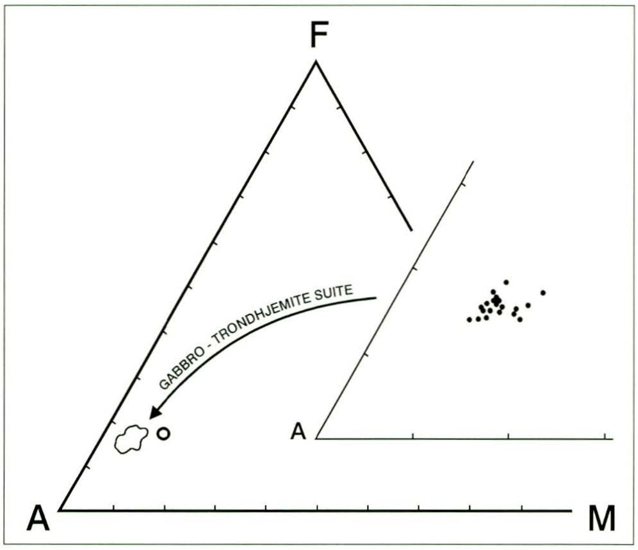

Fig. 3. AFM diagram showing the mean value (circle) for the Snøan trondhjemite dyke samples, the field for the Follstad trondhjemite (shaded), and the trend line for the 'gabbro-trondhjemite' suite (Size 1979). The enlargement of the alkalies corner of the diagram shows a plot of all 20 samples of the Snøan dykes.

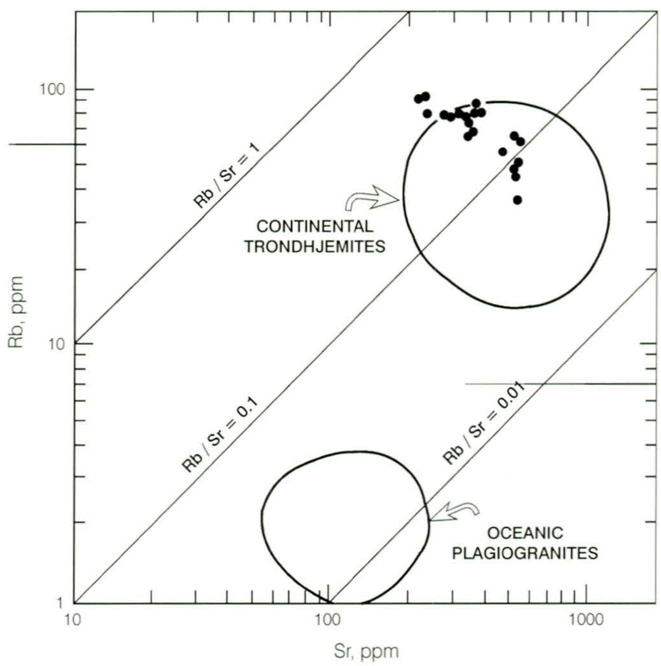

Fig. 4. Rb-Sr log/log variation diagram with the 20 Snøan dyke analyses plotted. The fields of continental trondhjemites and oceanic plagiogranite/trondhjemites are indicated (after Coleman & Peterman 1975).

one probably reflecting a measure of post-emplacement thermal resetting. This age is the age of the base of the Llanvirn on the latest time scale for the Ordovician (McKerrow & van Staal 2000) – but taking account of the error bar, this would bring us close to Mid Arenig. Thus, the Rb-Sr dating does appear to verify the palaeontological evidence from the Lower Hovin Group, i.e. signify a likely pre-Late Arenig age for this particular swarm of trondhjemite dykes.

The geochemical data on the Snøan dykes add a further detail to our understanding of the geological development of this region. The data show convincingly that the trondhjemite dykes were emplaced in a continental margin environment, through a crust which had presumably thickened following inferred Early Arenig continent/arc collision with coeval ophiolite obduction. There is no trace in the REE data, however, of an inherited arc component.

While there are evident similarities in chemistry between the Snøan trondhjemite dykes and the medium-grained trondhjemite from the type locality at Follstad, some small differences are apparent (cf. Table 2; also; Pannemans & Roberts 2000). Three or possibly four phases or pulses of trondhjemite emplacement have been reported from this southwestern Trondheim Region, seen in relation to fold-structural episodes. The U-Pb zircon and titanite age of the Follstad trondhjemite, 432±3 Ma, is reported in another paper in this volume (Dunning & Grenne 2000). Rb-Sr and U-Pb dating of trondhjemites of Early to Mid Ordovician age have previously been reported from Trøndelag, though only in an abstract (Klingspor & Gee 1981). A small, high-Al_2O_3 trondhjemite pluton from near Jonsvatnet, southeast of Trondheim, has provided the youngest U-Pb zircon age so far – Late Silurian (Roberts, Solli & Walker, unpublished data). These diverse ages thus support the suggestion (Size 1979) that trondhjemite magma, generated by an early partial melting of basalt, ultimately intruded through the continental margin crust at various stages throughout the Ordovician, and even well into Silurian time.

Plagiogranite or trondhjemite dykes also occur in association with the Løkken (493 ± 10 and 487 ± 5 Ma) and Vassfjellet (480 ± 4 Ma) Ophiolites (Dunning 1987 and pers. comm.1990), the U-Pb zircon dates pointing to a latest Cambrian to very Early Arenig age (Landing et al. 1997, Davidek et al. 1998). These particular trondhjemites developed in an oceanic/arc setting and are therefore chemically different and unrelated to the continental-margin trondhjemite dykes reported here. At Løkken, however, there are also younger trondhjemitic dykes that cut the basal greenstone conglomerate above the obducted ophiolite, and one such dyke has yielded a Late Arenig zircon age (T. Grenne & G. Dunning, unpublished data; in prep.).

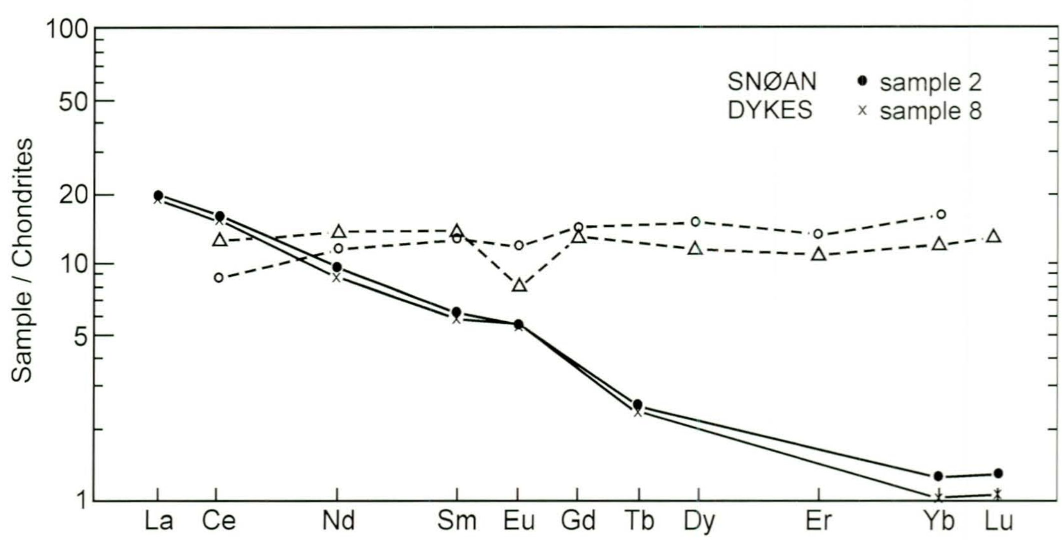

Fig. 5. Chondrite-normalised REE plots for representative samples (nos. 2 and 8) from two of the trondhjemite dykes; road-section near Snøan. For comparative purposes, the profiles for a typical ophiolite-related trondhjemite/plagiogranite (circles) and an island-arc trondhjemite (triangles) are also shown (after Arth 1979).

Table 3. Rare-earth element and Th, Ta, Hf, U and Sc analyses for the trondhjemite dyke samples nos. 2 and 8 (see Fig. 5).

Sample	*La*	*Ce*	*Nd*	*Sm*	*Eu*	*Tb*	*Yb*	*Lu*	*Hf*	*Ta*	*Th*	*U*	*Sc*
2	6.7	13.6	6.1	1.25	.42	.12	.24	.04	2.07	.087	1.41	.68	3.11
8	6.2	12.3	5.3	1.18	.42	.11	.22	<.04	1.95	.077	1.21	.71	3.05

Table 4. Snøan trondhjemite dykes, Rb-Sr isotopic data. Rb and Sr in ppm.

Sample	Rb	Sr	^{87}Rb/^{86}Sr	^{87}Sr/^{86}Sr	SE
1	81.18	195.10	1.2048	.71596	±13
2	74.30	233.26	.9222	.71411	±8
12	63.81	323.09	.5717	.71189	±10
13	73.43	314.67	.6754	.71124	±10
14	65.63	337.79	.5623	.71113	±10
15	71.90	328.86	.6328	.71125	±10
16	87.11	211.44	1.1931	.71780	±10
17	72.93	289.74	.7286	.71271	±6
96a	31.32	388.17	.2335	.70953	±3
96b	76.36	319.70	.6941	.71179	±3
96c	61.81	389.35	.4594	.71088	±3
96d	50.69	409.32	.3584	.71052	±3
96e	84.30	246.85	.9870	.71452	±3

Conclusions

Trondhjemite dykes, locally of swarm proportions and trending c.ENE-WSW, transect early metamorphic fabrics in rocks of the Gula Complex, near Snøan, southwest of Støren. The Snøan dykes are only weakly metamorphosed, in greenschist facies, and poorly foliate. Geochemical data show the dykes to be fairly homogeneous and quite characteristic of high-Al_2O_3 trondhjemites. Trace element abundances and ratios, including REE data and chondrite-normalised patterns (with La c. 20 x chondrites and a La_N/Lu_N ratio of just under 20), indicate that the dykes are typical of those reported from continental margin environments.

Rb-Sr isotopic analysis of thirteen samples from one particular dyke showed that the complete data set does not yield any definitive isochron. However, the samples lying farthest from the regression line are those taken from the

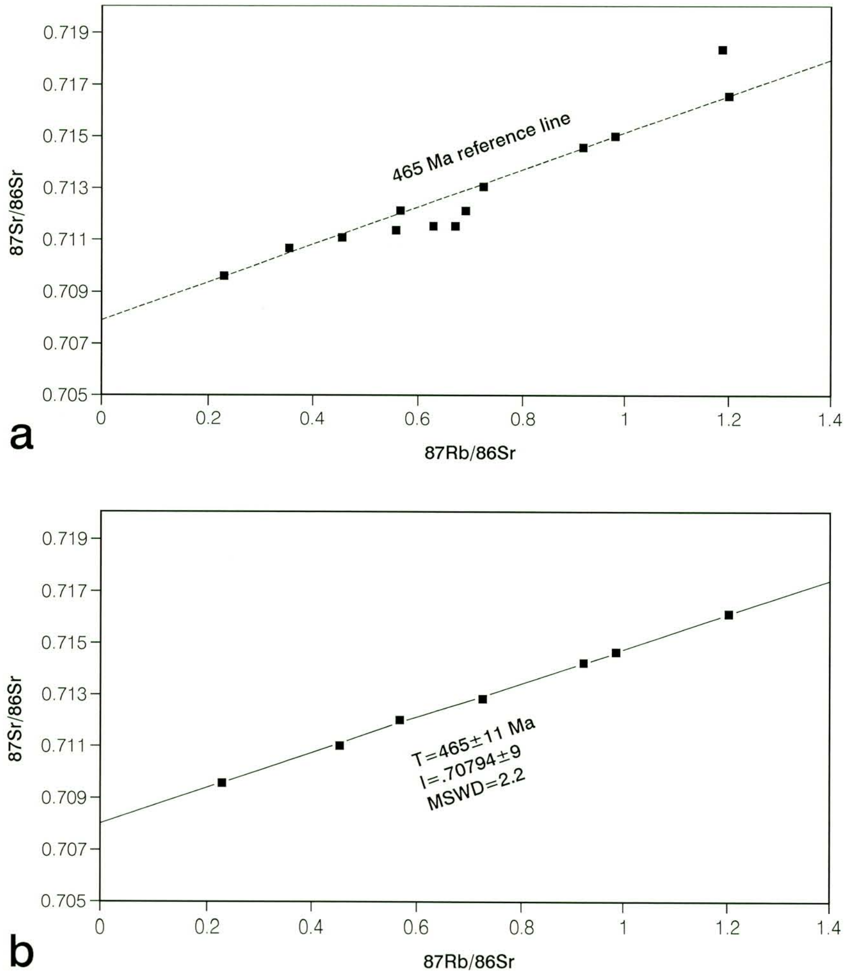

Fig. 6. (a) Rb-Sr scatterchron diagram showing the complete analytical data for 13 samples taken from the main trondhjemite dyke, Snøan. The 465 Ma reference line (cf. Fig. 6b) is also shown. (b) Rb-Sr isochron diagram excluding the five samples taken from the very marginal parts of the dyke. See text for explanation and discussion.

marginal parts of the dyke. If these samples are excluded, then a reasonable best-fit isochron defines an age of 465 ± 11 Ma, with a MSWD of 2.2 and an initial $^{87}Sr/^{86}Sr$ ratio of 0.70794 ± 9. This isochron age is taken to be a *minimum* age for the dyke intrusion, and is provisionally interpreted as reflecting a post-emplacement, thermal resetting age. Samples taken from the dyke margins are likely to have been affected by an introduction of fluids, and admixture of fluids from the wall rock; and such fluids may have contained abundant ions of radiogenic Sr, expelled from diverse minerals and concentrated by the decay of ^{87}Rb during thermal resetting.

The isochron age for this set of trondhjemite dykes thus provides a minimum age for the Early Ordovician deformation and metamorphism of the juxtaposed Støren ophiolite and Gula succession, and of the Selbusjøen tectonic mélange. It also supports an earlier postulate (Size 1979) that trondhjemite magma derived from partial melting of basalt may have intruded through the continental margin crust, and the Gula Nappe in particular, throughout Ordovician time and well into the Silurian. The gentle folding of the dykes and their weak foliate fabric are likely to be of Scandian (Late Silurian-Early Devonian) age.

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