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Geochemistry and Rb-Sr dating of trondhjemite dykes from the Gula Group, near Snøan. Sør-Trøndelag

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REPORT

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Geochemistry and Rb-Sr dating of trondhjemite dykes from the Gula Group, near Snøan. Sør-Trøndelag

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Summary:

Trondhjemite dykes forming part of a swarm cutting the Gula Group metasediments and tectonically overlying Støren Group metabasalts in the district south of Støren, Sør-Trøndelag, have been investigated in road-cuts in the Snøan area. Geochemically, the fine-grained dykes are high-Al_2O_3 trondhjemites which show clear trace and rare-earth element signatures indicative of a continental margin setting. An attempt at Rb-Sr radiometric dating produced a best-fit isochron of 465 $\pm$ 11 Ma, interpreted as a minimum age for the dyke swarm. The dyke has also probably been affected by thermal resetting.

The dykes do not penetrate the Lower Hovin Group succession which unconformably overlies the Støren Group volcanites, and contains fossils of Late Arenig age. The Rb-Sr minimum age is thus in reasonable accord with the faunal evidence. The trondhjemite dyke swarm was evidently emplaced into a thickened continental margin crust following obduction of the Støren ocean-floor basalts upon the Gula, with coeval deformation, metamorphism and subsequent uplift, probably in earliest Ordovician time.

(Keywords: Trondhjemite dykes, geochemistry, Rb-Sr dating, Caledonides, Lower Palaeozoic, Trøndelag)

Keywords: Geokjemi	Paleozoikum	Datering
Trondhjemitt	Gangbergart	

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1. INTRODUCTION

Trondhjemites constitute one of the more common varieties of plutonic or hypabyssal rock in lower parts of the Trondheim Nappe Complex (TNC) of Central Norway. The type locality of trondhjemite as first described by Goldschmidt (1916) is at the Follstad quarry, just east of Støren, situated within the Undal Formation of the Gula Nappe (Nilsen 1978, 1983). The petrology and geochemistry of the Follstad trondhjemite has been described in some detail by Size (1979). There, the steeply WNW-dipping type trondhjemite body is some 375 m thick and can be followed over a strike distance of 3 km.

Many, even larger, trondhjemite bodies occur within the Gula unit, as can be seen from the 1:250,000 map-sheets 'Trondheim' and 'Røros' (Wolff 1976, Nilsen & Wolff 1988). In several districts there are also swarms of finer-grained trondhjemite dykes, and in the region around and to the south of Follstad many of these dykes also penetrate the structurally overlying, mainly ocean-floor basaltic Støren Group. However, these particular dykes do not continue into the unconformably overlying, low-grade, Hovin Group metasediments. This lack of dykes in the Hovin Group does not deny the existence of tonalitic, trondhjemitic and dioritic intrusions elsewhere in the Trondheim Region in non-fossiliferous metasediments which have been considered as Hovin Group correlatives (e.g., Rohr-Torp 1974, Nilsen & Wolff 1988).

In this brief report we present the results of a study which was purposely concentrated on just 4 trondhjemite dykes in road-cuts, which were new in the early 1980's, along the minor road between Snøan and Budal (Fig.1). This local study began as part of a more regional investigation of greenstones and associated rocks (e.g. Gale & Roberts 1974), 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 from this same area, a rock-type which is clearly transected by the trondhjemite dykes.

The study 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, without haste, over a period of several years through a step-by-step analysis of the data available to us at different times.

2. LOCAL GEOLOGY AND DYKE FIELD RELATIONSHIPS

Nilsen's map of the district (Fig.1) shows the area around Snøan to consist of two main units: (1) a grey and black phyllite member of the Undal Formation; (2) a unit of mélange. Further to the west the Gula Group (and Nappe) is structurally overlain by the volcanites of the Støren Group (Gale & Roberts 1974).

The *Undal Formation* is part of what has tradionally been called the Gula Group. This 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 1983).

The *mélange*, as described by Nilsen (1983) and named the Soknedal mélange, is essentially an olistostrome formed as a debris flow with submarine sliding involved. The clast material, including one large block covering 400 m^2, was considered by Nilsen to have been derived mainly from the Gula Group, but also from the Støren. He interpreted the mélange as a very young, post Støren-upon-Gula thrusting deposit, of possible Late Silurian age.

Critical to this interpretation is the age of the trondhjemite dykes. As noted above, the dykes cut through both the Gula and Støren Group rocks *and* the mélange, but not the Hovin Group which contains fossils as old as Late Arenig (Størmer 1932). Accepting that there is just one broad age for the dyke swarm then it is likely to be pre-Late Arenig. This, by itself, questions the validity of the suggested Silurian age for the mélange.

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 Rb-Sr dating; 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 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. The dyke, which is fine- to medium-grained and massive, clearly transects a prominent spaced cleavage in the country rocks dipping at 18° towards ESE. This cleavage appears to be broadly axial planar to the shallowly ESE-plunging fold. 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 detected in the mélange dips at up to 50° to the east and is older than the shallower dipping cleavage.

The trondhjemite is very fine-grained and shows a weak foliate structure that is broadly parallel to the cleavage seen in the mélange. In thin-section it is allotriomorphic-granular and clearly metamorphosed. The principal minerals are quartz and plagioclase, with lesser amounts of sericitic muscovite, chlorite, epidote and calcite, and accessory apatite, sphene, zircon and magnetite.

3. 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 pooled value from the Follstad quarry trondhjemite (Size 1979). 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. On a Yb vs. Al_2O_3 plot (not shown here) (Arth 1979) the Snøan dykes cluster well within the continental field.

Chondrite-normalised rare-earth element (REE) plots, as well as REE abundances and ratios, provide reliable pointers as 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).

4. 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.6, the complete data do not yield any isochron. However, it was found that if the samples from the marginal parts of the dyke are excluded, then the remainder (nos.1,2,12,17,96a,96c and 96e) yield a fairly acceptable fit (MSWD = 2.2) with an age of 465 $\pm$ 11 Ma and an initial $^{87}Sr/^{86}Sr$ ratio of .70794 $\pm$ 9 (Fig.7).

A reason for excluding the marginal samples is not 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 contain 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 strongly suggests that such a mechanism has been operative (Sundvoll et al. 1992, Sundvoll & Larsen 1993).

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 metasediments which are not affected by the dyke swarm, extends down into the Upper Arenig. The geological evidence thus indicates that the dyke intrusion itself may be at least 10-15 million years older than indicated by the Rb-Sr isochron age, i.e. just outside the upper error limit. Accordingly, the Rb-Sr isochron age can most probably be interpreted as reflecting a post-intrusive thermal resetting age.

5. DISCUSSION

Geological and structural relationships in this part of the southwestern Trondheim Region involved an 'obduction' of Iapetus ocean-floor volcanites (Støren Group) upon part of what has been termed the Gula Group, and a common early deformation and uplift of these complexes, 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 further east, then an Early to Mid Arenig age has been assumed for this tectonothermal event (Sturt & Roberts 1991).

The fact that the trondhjemite dyke swarm in this district cuts both the Gula sequence and the Støren metabasalts, and their early deformation/metamorphic fabrics, but *not* the Hovin sediments, has made it important to try to date these dykes radiometrically. Our attempt at Rb-Sr dating of the 'main' trondhjemite dyke at Snøan has produced a best-fit isochron of c.465 $\pm$ 11 Ma, interpreted as a minimum age for the dyke swarm and one probably reflecting a measure of post-emplacement thermal resetting. This age is Llanvirn on the latest time scale for the Ordovician (Tucker & McKerrow 1995).

Although this does little more than verify the palaeontological evidence from the Lower Hovin Group, i.e. signify a pre-Late Arenig age for the trondhjemite dykes, it refutes the suggestion made by Nilsen (1983) that the mélange unit in the Gula may be of Late Silurian age.

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 intruded in a continental margin environment, through a crust which had presumably thickened following probable Early Arenig continent/arc collision with coeval ophiolite obduction; though there is no trace of an inherited arc component from the REE data.

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. Three or possibly four phases of trondhjemite emplacement have been reported from this southwestern Trondheim Region, seen in relation to fold-structural episodes. The Follstad trondhjemite has itself been investigated applying the U-Pb zircon method; the result has so far been reported only in a lecture (EUG, Strasbourg 1987), and is not definitive (c.432 Ma, F.Dunning & T.Grenne, pers. comm. 1987). Should this be verified, then it would confirm the postulate (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 into Early Silurian time.

Plagiogranite or trondhjemite dykes also occur in association with the Løkken (493 $\pm$ 10 and 487 $\pm$ 5 Ma) and Vassfjellet (480 $\pm$ 4 Ma) Ophiolites (Dunning 1987 and pers. comm.1990); Tremadoc to Early Arenig. These particular trondhjemites developed in an oceanic/arc setting and are therefore unrelated to the continental trondhjemite dykes reported here.

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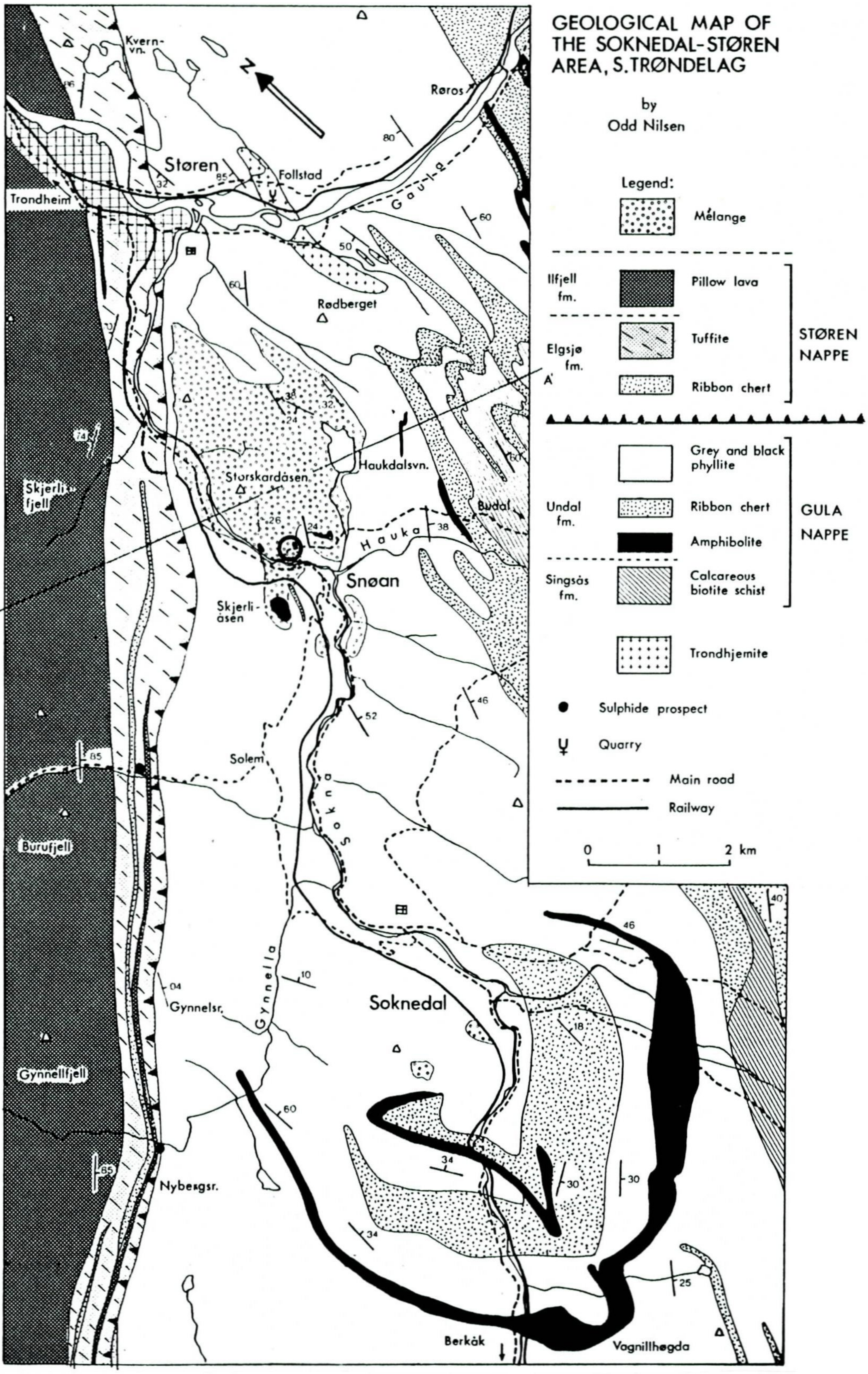

Fig.1. Geological map of the Støren-Snøan-Soknedal area, Sør-Trøndelag, reproduced from Nilsen (1983). Nilsen considered the mélange to be the very youngest sedimentary unit in the area. The road section with dykes, forming the basis of this study, is marked by a circle (just NNW of Snøan, in the central part of the map).

Fig.2. The 'main' trondhjemite dyke cutting the Sokndal mélange, looking approximately northeast. The dyke is very gently folded, with the prominent, shallowly dipping, crenulation cleavage in the mélange lying roughly axial planar to the fold.

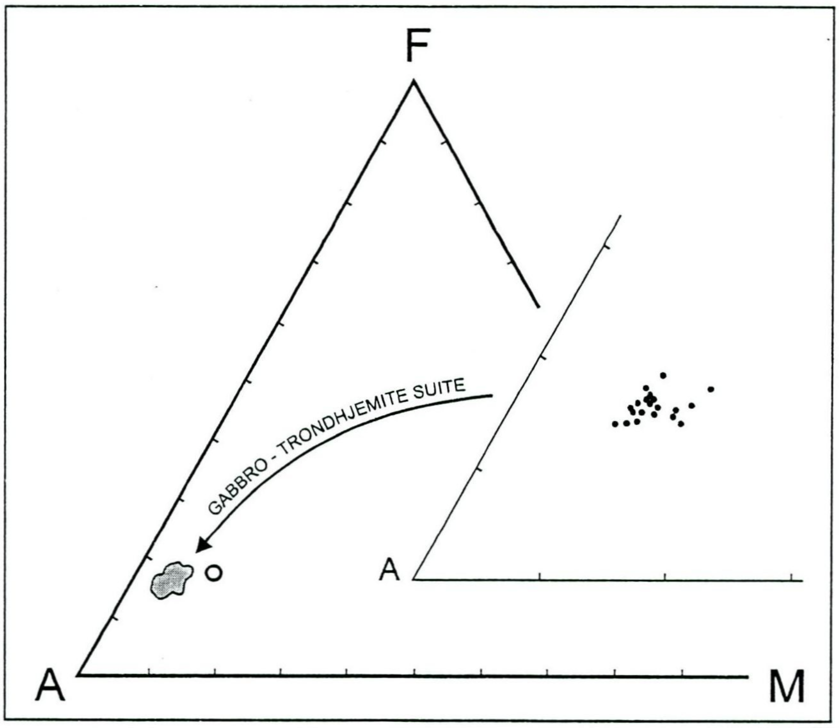

Fig.3. AFM diagram showing the mean value (circle) for the Snøan trondhjemite dyke samples, the field for Follstad trondhjemite (shaded), and the trend line for the 'gabbro-trondhjemite suite' (Size 1979). The enlargement of the alkalies corner of the diagram shows a plot of all 20 samples of the Snøan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

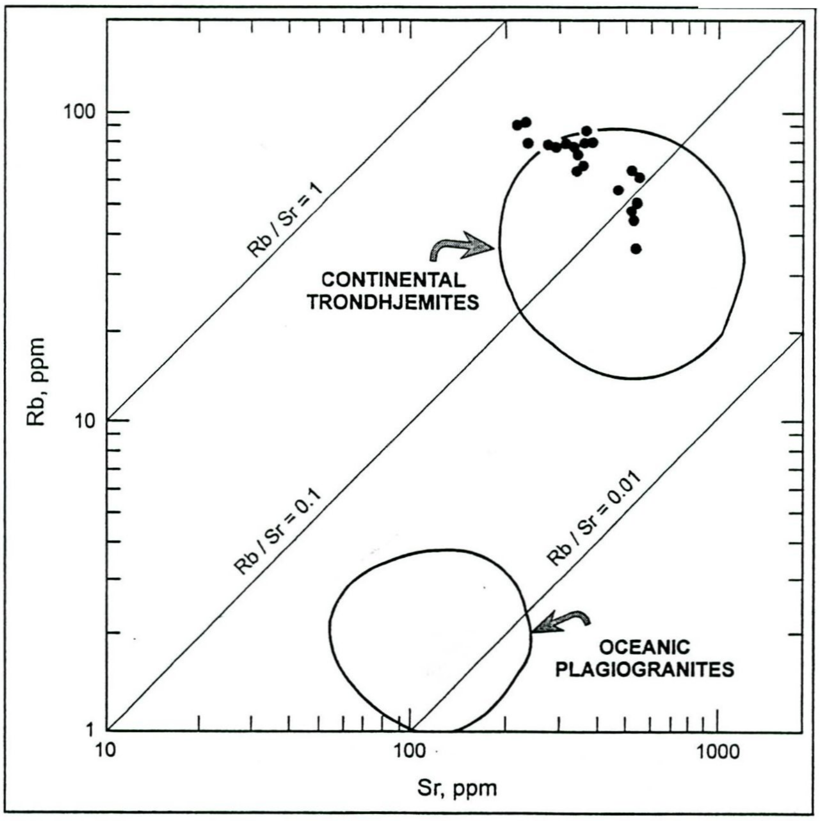

Fig.4. Rb-Sr log/log variation diagram with the 20 Snøan dyke analyses plotted. The fields of continental trondhjemites and oceanic plagiogranite/trondhjemites are indicated (after Coleman & Peterman 1975).

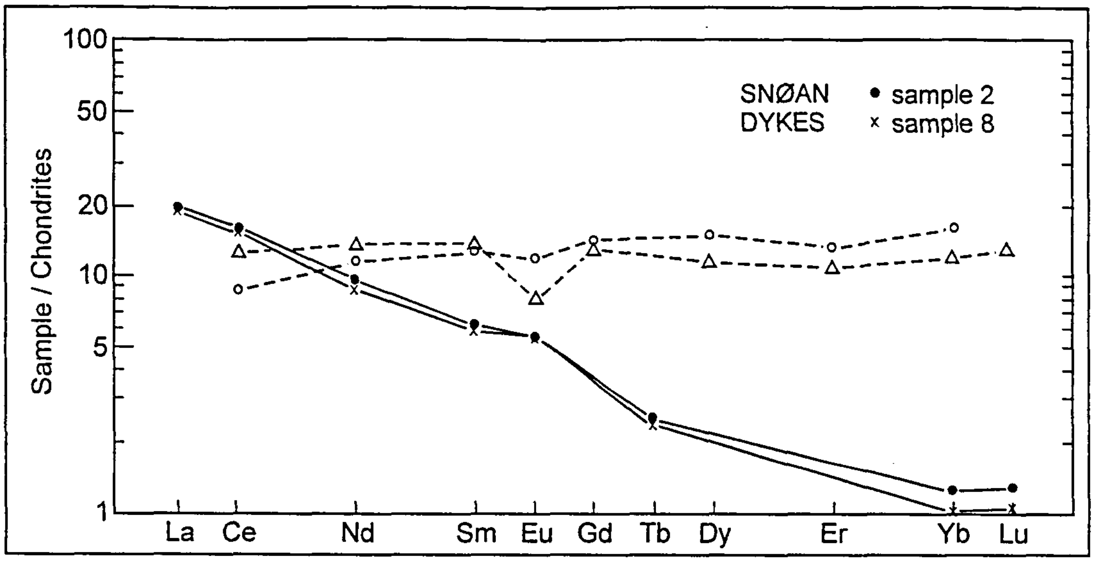

Fig.5. Chondrite-normalised REE plots for representative samples (nos. 2 and 8) from two of the trondhjemite dykes, road section near Snøan. For comparative purposes, the profiles for a typical ophiolite-related trondhjemite/plagiogranite (circles) and an island arc trondhjemite (triangles) are also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

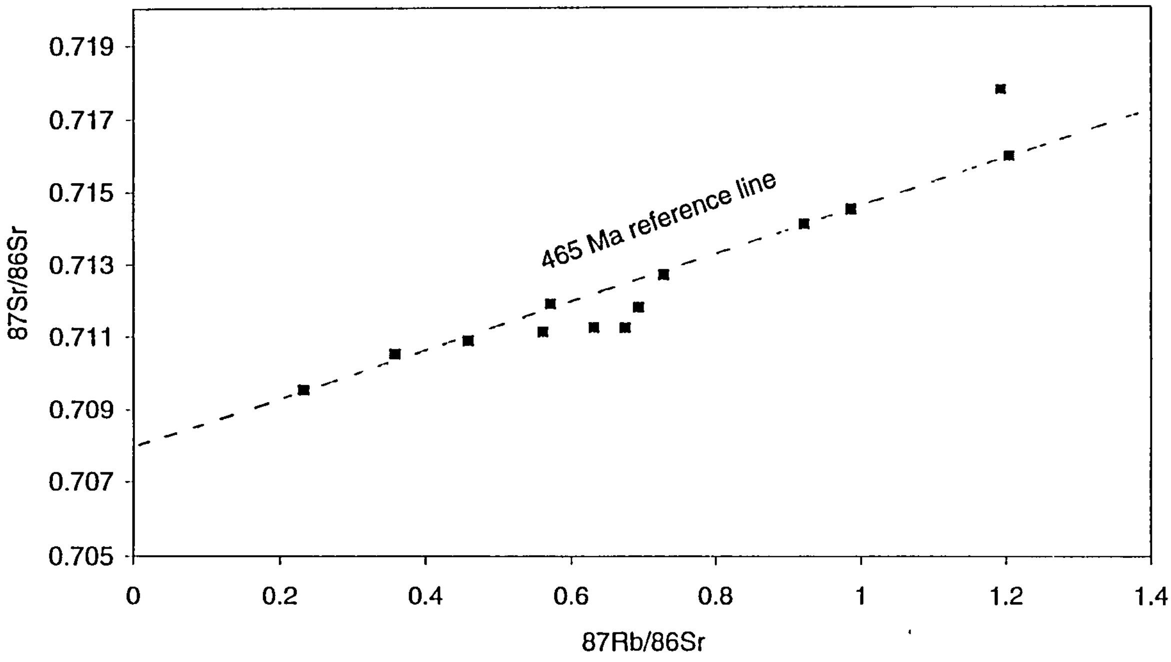

Fig.6. Rb-Sr scatterchron diagram showing the complete analytical data for 13 samples taken from the main trondhjemite dyke, Snøan. The 465 Ma reference line (cf. Fig.7) is also shown.

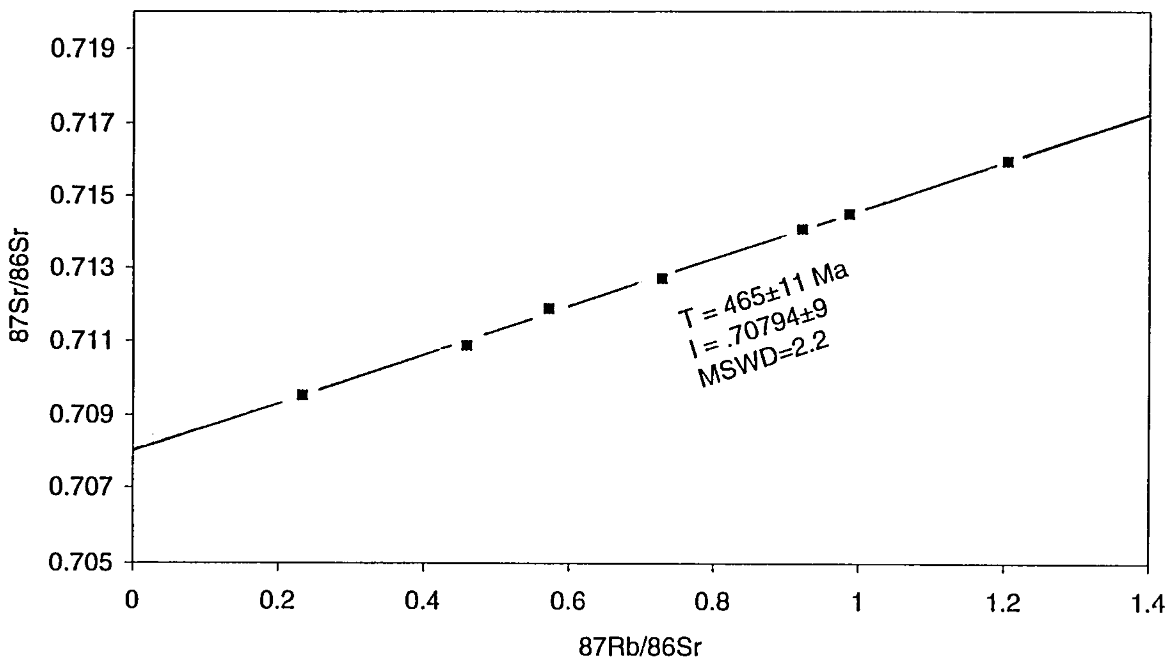

Fig.7. Rb-Sr isochron diagram for samples taken *only* from the *central parts* of the main dyke.

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

Sample no.	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
Al_2O_3	16.98	17.12	17.11	16.92	16.87	17.28	17.05	17.11	16.64	17.24
FeO	1.26	1.25	1.12	1.19	.75	.71	1.16	1.17	1.14	1.17
Fe_2O_3	.12	.33	.60	.61	.48	.60	.60	.33	.29	.20
TiO_2	.23	.24	.24	.24	.17	.18	.24	.24	.22	.20
MgO	1.01	.98	1.37	1.40	.76	.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	.97	1.49	1.54	1.50	1.44	1.68
MnO	.05	.05	.03	.03	.02	.03	.02	.03	.03	.03
P_2O_5	.07	.07	.07	.06	.06	.06	.06	.07	.08	.06
LOI	2.78	2.59	2.47	2.65	1.34	1.63	2.58	2.48	2.44	2.70
Sum	98.26	99.04	97.83	97.91	98.59	99.02	99.39	99.43	99.67	99.30
Nb	<5	<5	<5	<5	<5	6	<5	<5	<5	5
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
V	26	27	40	37	13	14	30	25	26	18
Ba	454	394	380	367	278	302	345	297	292	282

Sample no.	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
Al_2O_3	17.51	17.18	17.25	17.10	16.56	16.24	16.30	16.57	16.59	18.34
FeO	1.13	1.07	1.15	1.05	1.00	1.09	.98	.96	1.01	1.04
Fe_2O_3	.29	.42	.48	.49	.54	.56	.55	.56	.55	.50
TiO_2	.21	.24	.24	.25	.24	.23	.23	.24	.24	.25
MgO	1.28	.98	.96	1.00	.96	.93	.96	1.04	.98	.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
MnO	.02	.05	.04	.03	.03	.07	.05	.04	.04	.04
P_2O_5	.07	.05	.03	.05	.04	.05	.05	.05	.05	.04
LOI	2.56	2.77	2.20	2.09	2.91	3.21	3.08	3.08	2.88	2.29
Sum	99.76	98.58	97.30	97.86	98.25	97.85	98.41	98.19	98.22	97.84
Nb	<5	<5	<5	<5	<5	<5	<5	<5	<5	5
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
V	24	24	25	27	29	27	24	26	26	31
Ba	380	306	373	357	347	439	337	321	353	400

Table 2. Mean major element and selected trace element contents for the Snøan and Follstad trondhjemites. The Follstad data are taken from Size (1979).

	Snøan	**Follstad**
SiO2	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	-
Nb	<5	-
Y	<5	-
Ba	350	290
Sr	388	-
Rb	70	32
Cr	16	-
V	26	-
(n)	*20*	*4*

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 no.	*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, Rb-Sr isotopic data.

Sample	Rb(ppm)	Sr(ppm)	87Rb/86Sr	87Sr/86Sr	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