A RB, SR STUDY OF THE ROCKS OF THE SURNADAL SYNCLINE

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A nine point Rb-Sr total-rock isochron of gneisses from the Tingvoll Group, close to the contact with schists of supposedly Paleozoic age in the Surnadal district of central Norway, defines an age of 1707 ± 63 m. y. and an initial $^{87}Sr/^{86}Sr$ of 0.7026 ± 0.0007. This age is the same as that obtained earlier from the Kristiansund and Frei Groups in the Kristiansund area. Rb, Sr total-rock samples from the Røros Group do not define a unique isochron age, but suggest that the rocks were originally older (1700 m. y.) and were subsequently partially reequilibrated during a younger metamorphism (the Sveconorwegian and/or the Caledonian). This possible old initial age for the Røros Group agrees with field studies where no structural and/or metamorphic beaks between the gneisses and the metasediments of the Surnadal syncline have been observed.

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A major problem of the Surnadal area (in the region of Nordmøre and Sør-Trøndelag) is the relationship between the 'basal gneisses' and the overlying metasediments and metavolcanics of the Surnadal syncline. These metasedimentary and metavolcanics, which comprise the Røros Group and the Støren Group (mainly basic metavolcanics) were regarded to be of Caledonian age (Strand 1953, Hernes 1956). This assumption led Strand (1953) to suggest that at least the upper part of the underlying 'basal gneisses' must also be of Caledonian (Eocambrian) age because of the concordant relationship between the gneisses and the metasupracrustals of the Surnadal syncline. Hernes, in several papers (1956, 1967), divided the rocks of the basal gneiss region into the Frei, the Raudsand (Kristiansund), and the Tingvoll (Sandvik) Groups (Fig. 1). The so-called Trondheim Suite of the Surnadal syncline include two groups, the lower Røros Group (mainly metasediments) and the higher Støren Group (mainly metavolcanics). The Røros Group is also commonly called the Gula Group. The name Røros Group is used in this paper, consistent with most relevant literature (Hernes 1956). Hernes (1956, 1967) also found no discordant relationship between the groups of the basal gneiss region and the metasediments of the Surnadal syncline. He suggested that not only the upper part of the basal gneiss region (Strand 1953), but the entire gneiss region of the western central

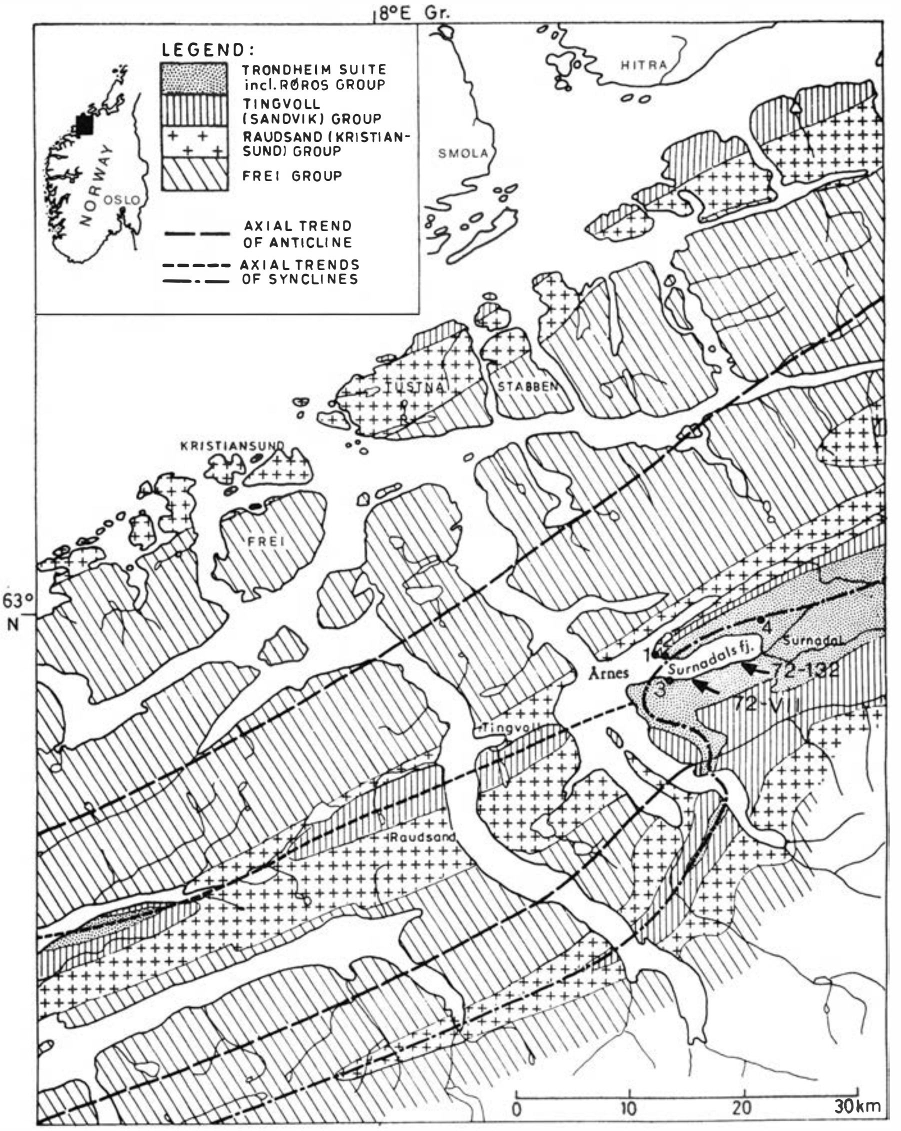

Fig. 1. Map showing the distribution of the different rock groups (Hernes 1965). Numbers 1–4, 72-VII and 72–132 give the sampling localities, see also Table 1.

Norway is of Eocambrian age and was metamorphosed during the Caledonian orogeny. Oftedahl (1964) found that the concordant contact relationship between the gneisses and the 'Cambro-Silurian rocks' appeare to be valid on a regional scale throughout the Trondheim district.

The author is in broad agreement with Hernes' division of the rocks into groups and his conclusion about the concordant relationship between them (Råheim 1972). The groups appear to have been through the same metamorphic and structural events. These observations suggest that there is no major age difference between the groups. However, detailed mapping between the Kristiansund area and the Surnadal area shows that the stratigraphic-tectonic situation is more complex than previously thought. It is now thought that each group contains several rock units that are repeated due to a complex system of isoclinal syn- and antiforms rather than that each individual rock unit represents one 'layer' in the original supracrustal sequence (Råheim 1972). The Frei Group has, until now, been regarded as the stratigraphically oldest group in the region (Hernes 1967, Råheim 1972). However, there is lithological (repetition of characteristic rock types) and structural evidence (drag folds) to suggest that the Tingvoll-Raudsand Groups may structurally underlay the Frei Group.

In a geochronological investigation of gneisses and minor intrusive rocks from the Kristiansund area (Pidgeon & Råheim 1972) it was concluded that the high grade metamorphism of the Kristiansund Group and the Frei Group took place 1700 m.y. ago. This is based on a total-rock Rb-Sr isochron giving an age of 1708 ± 60 m.y. and on 'upper U-Pb intersection age' (zircons) of approximately 1660 m.y. The lack of any type of discordance between the Røros Group and the groups of the Kristiansund area indicates that the metamorphism of the Røros Group also may have occurred about 1700 m.y. ago (Pidgeon & Råheim 1972, Råheim 1972). The only possible tectonic and metamorphic break in the area is between the Røros Group and the Støren Group (greenschists) within rather than beneath the Surnadal syncline.

The possibility that the Røros Group was metamorphosed 1700 m.y. ago contradicts the current opinion of many geologists that it has a Caledonian age. It is therefore very important to clarify the age relationship between the gneiss region and the Røros Group of the Surnadal syncline. The general nature of this contact is of regional importance, not only for the entire basal contact of the Trondheim Region (Oftedahl 1964), but possibly also for the medium to high grade metamorphic rocks that occur within the Trondheim Region (Gula Group).

Samples

Samples were collected from the Tingvoll Group and the Røros Group. The sample localities are shown in Fig. 1. After examination of the samples, it was decided to concentrate the work mainly on three localities. Two suites were collected from the gneisses and schists, respectively, close to the 'critical border' near Årnes (Fig. 1, locality 1 and 2). Another suite of schists was collected at a locality on the southern side of Surnadalsfjorden (Fig. 1, locality 3). All samples (similar rock types) were collected within less than 4 m of each other perpendicular to the strike of the rocks. The samples from the Tingvoll Group represent the gneisses immediately below the Røros Group of the Surnadal syncline (loc. 1). The gneisses are very similar to those of the Kristiansund Group and the Sandvik Group described from the Kristiansund area (Råheim 1972). The main minerals are quartz, potash feldspar, plagioclase, with biotite as the most important mafic mineral. Accessory minerals are epidote minerals, apatite, zircon, and iron oxides. Chloritization has sometimes affected the biotite within the rocks to varying degrees. The main rock type of the Røros Group is a micaschist which is usually garnet-bearing. The most important minerals are quartz, plagioclase (oligoclase), and biotite. Sometimes calcite is present in considerable amounts. Amphibole is also important in some rocks which grade into garnet amphibolite. The important accessories are epidote minerals, apatite, zircon, sphene, and iron ores.

The garnet amphibolites of the Røros Group occur interlayered with the mica-schists. In the field these are clearly different from the greenschists of the Støren Group, as they are garnet-bearing, more massive, and darker than the greenschists. The main minerals are amphibole (pleochroic in light green-blue green to olive green colours), plagioclase (oligoclase), garnet, and, in some cases, quartz. The accessory minerals are biotite, epidote minerals, sphene, and iron ores. Chlorite is the main secondary mineral (possibly together with secondary biotite) and is present in variable amounts in different rocks.

There are numerous small 'trondhjemitic' intrusions in the Røros Group. These intrusions are most frequently seen on the southern side of Surnadalsfjorden. Compositionally these intrusions range from granitic to quartz dioritic, and are fine-grained, medium-grained, or pegmatitic. The most important minerals are plagioclase and quartz together with varying amounts of perthitic potash feldspar. Muscovite is common and some rocks contain amphibole and garnet. Chlorite is also the main secondary mineral of the trondhjemites which are weakly folded together with the metasediments.

Analytical procedure

The rocks were crushed in a steel jaw-crusher and finely ground in a tungsten carbide Sieb mill. Rb and Sr were determined by X-ray fluorescence spectrography on all the total-rock samples except one of the trondhjemites (72-VII). Bias in the ratio $^{87}Rb/^{86}Sr$ was monitored by comparison with simultaneous isotopic dilution analysis. Rb-Sr of the minerals and of the total rock (72-VII) were determined by isotope dilution using mixed $^{87}Rb/^{84}Sr$ and $^{85}Rb/^{84}Sr$ spikes. Unspiked measurements of $^{87}Sr/^{86}Sr$ were made for all total rock samples except for total rock sample 72-VII. Variable mass discrimination in $^{87}Sr/^{86}Sr$ was corrected by normalizing $^{88}Sr/^{86}Sr$ to 8.3752. Mass spectrometry was performed on a Nuclide 12-60-SU mass spectrometer. The ^{87}Rb decay constant used was 1.39×10^{-11} yr^{-1}. The regression technique of McIntyre et al. (1966) was used and tests of significance associated with the isochron interpretation were made at the 95 percent level of confidence. In assigning errors to the regression points, the coefficient of variation for $^{87}Rb/^{86}Sr$ was taken as 0.5 percent and the standard deviation for $^{87}Sr/^{86}Sr$ as 1×10^{-4}.

Rb-Sr isotopic results

The results of Rb-Sr isotopic analyses of total-rock samples and minerals from gneisses of the Tingvoll Group, mica-schists of the Røros Group, and trondhjemitic intrusions of the Røros Group, are recorded in Table 1.

The age of the Tingvoll Group

The age and initial ratio of the gneisses from the Tingvoll Group (Fig. 1, loc. 1) as defined by McIntyre et al. (1966) model 4 isochron are 1707 ± 63 m.y. and 0.7026 ± 0.0007, respectively. The mean square of weighted deviates (MSWD) is 18.35. The scatter about the isochron (Fig. 2) can therefore not be assigned only to experimental error, but also to geological variation. The samples are clearly genetically related and are considered to be mainly of volcanic origin. Variation in the initial $^{87}Sr/^{86}Sr$ is therefore not thought to be the main reason for the geological scatter in this case. It was most probably caused by a partial reequilibration of the Rb-Sr isotopic system during the Caledonian or a younger Precambrian event. The determined age is the same as the Rb, Sr total-rock isochron age of 1708 ± 60 m.y. obtained from the gneisses of the Kristiansund Group (Pidgeon & Råheim 1972). In accordance with Pidgeon & Råheim (1972) this age is interpreted as the age of the high-grade metamorphism of the region. Evidence for a 1700 m.y. metamorphism is based on an Rb, Sr study of migmatites from the Raudsand (Kristiansund) Group and the Frei Group west of Tingvoll, where both neosomes (in situ melts during metamorphism) and paleosomes together with the corresponding total rock plot on the 1700 m.y. isochron (work in progress). The results of the Rb, Sr total-rock analyses of the pelitic migmatic (high grade equivalent of a mica-schist, Råheim 1972) from the Frei Group support the conclusion that the age of the main metamorphism and associated deformations is approximately 1700 m. y. It is difficult to envisage how a pelitic rock could have remained a closed Rb, Sr system during the rather extreme metamorphic conditions, associated with intense deformation, if this happened during Caledonian time. It is particularly difficult to accept a main Caledonian metamorphism and deformation as deformational effects even at low metamorphic conditions have been shown to be important factors when Rb-Sr of total rock systems are disturbed or reset (Råheim & Compston 1977, Berg 1977). Therefore, since mapping between the Kristiansund area and the Surnadal area has not revealed any metamorphic or tectonic breaks, it is concluded that all the high-grade metamorphic rocks between the contact with the Røros Group in Surnadal and the coast are of the same age. This 1700 m.y. metamorphic age is probably of general significance for most of the Møre region as individual rock types and groups can be followed for

Table 1. Rb-Sr results from total-rock and mineral samples from the Surnadal area. Samples from the same locality are grouped together.

	Sample		Rb ppm	Sr ppm	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
Locality 1	Tingvoll Group gneisses					
	72-100		107,9	133.0	2.3375	.75915
	72-101		138.0	114.5	3.5054	.78524
	72-102		119.3	138.8	2.4725	.76356
	72-103		105.4	661.0	.4614	.71325
	72-104		91.7	734.5	.3607	.71166
	72-104	Biotite	549.9	17.3	80.9054	1.15804
	72-105A		152.3	308.7	1.4280	.73589
	72-105B		111.3	487.1	.6606	.71916
	72-106		98.7	759.9	3752	.71136
	72-107		89.1	796.6	.3229	.71029
Locality 2	Røros Group schists					
	72-82		134.9	652.7	.5974	.72110
	72-83		97.9	95.5	2.9734	.75502
	72-83	Biotite	493.7	7.7	189.6774	1.76057
	72-83	Muscovite	276.1	81.1	9.8248	.79506
	72-84		84.4	177.6	1.3760	.73584
	72-85		111.5	376.1	.8577	.72600
	72-86		87.1	247.9	1.0152	.71751
	72-86	Biotite	337.4	16.5	60.9142	1.03770
	72-86	Muscovite	283.1	185.6	4.4166	.73492
	72-87		61.0	143.9	1.2261	.72110
	72-88	(garnet amphibolite)	8.9	245.0	.10531	.70709
Locality 3						
	72-122		108.5	162.1	1.9559	.72695
	72-122	Biotite	415.4	6.4	206.8733	1.83480
	72-124A		35.9	131.5	.7898	.72001
	72-124B		35.9	144.4	.7191	.71991
	72-124C		37.3	146.1	.7373	.72001
	72-124D		33.5	129.8	.7611	.71988
	72-124E		28.5	127.8	.6436	.71922
	72-125		96.8	216.9	1.2905	.72200
	72-126A		94.7	164.8	1.6615	.72177
	72-126B		92.5	140.9	1.8979	.72374
	72-126C		102.2	201.1	1.4694	.72101
	72-126D		92.5	145.2	1.8420	.72335
	72-127A		63.4	68.9	2.3891	.72918
	72-127B		89.9	90.6	2.8732	.73193
	72-127L		59.2	54.7	3.1354	.73375
	72-127D		101.2	102.7	2.8539	.73152
	72-127TR		72.5	76.6	2.7378	.73198
	72-128		37.0	79.7	1.3400	.72174
Locality 4						
	72-118		72.2	308.0	.6767	.71197
	72-118	Biotite	319.0	6.3	147.1735	1.50815
	Trondhjemites					
	72-132		132.2	414.5	.9983	.71192
	72-132	Muscovite	417.5	45.5	26.4935	.86279
	72-132	Potash feldspar	321.3	587.3	1.5785	.71542
	72-VII		7.0	450.6	.0446	.70699
	72-VII	Muscovite	590.3	41.1	45.5320	.96107

Samples from the same locality are grouped together.

distances of the order of at least 150 kms along strike (Hernes 1967, Råheim 1972). In agreement with this are Rb-Sr total rock isochron ages of 1682 ± 70 m.y. reported by Mysen & Heier (1972) from Hareidland and 1775 ± 114 m.y. from the Tafjord area (Brueckner pers. com. 1977).

The Caledonian influence on the Tingvoll Group is clearly seen in the total rock + biotite age of sample 72-104 (398 ± 4 m.y.).

The age of the metasedimentary and minor intrusive rocks of the Røros Group

Mineral analyses. – Total rock + biotite ages of schists from the Røros Group range from 384 m.y. to 390 m.y. (Table 2). These numbers are well within the range of Rb-Sr and K-Ar ages of biotites reported from other parts of the Caledonian orogenic belt, with the majority between 420 and 380 m.y. (Wilson et al. (1973), Brueckner et al. (1968), Strand (1969), Brueckner (1972), Wilson (1972) and Wilson & Nicholson (1973)). These ages are most commonly interpreted as related to cooling during post metamorphic uplift.

Neither of the muscovites of samples 72-83 or 72-86 (Fig. 1, loc. 2), when regressed together with biotite and total rocks, give model I isochrons (MSWD's are 72.73 and 14.3 respectively). This lack of linearite clearly indicates that the minerals (muscovite and biotite) are not isotopically homogenized. The older muscovite age 419 ± 7 m. y. is clearly older than the biotite ages (384–390 m. y.). This is consistent with the normal relationship of biotites and muscovites dates in slowly cooled areas (Wilson & Nicholson 1973). The other muscovite gives a younger age (367 m. y.) than the biotites; the significance of this young age is not understood. It is possible, however, that this muscovite responded to a later deformational event at the end or after the Caledonian orogeny while the older muscovite (419 m. y.) survived. A similar situation is reported from western Tasmania, where phengitic muscovites responded differently to superimposed metamorphic events (Råheim & Compston 1977).

Table 2. Mineral + total rock ages.

Sample no.	Mineral	Rock type	Age m.y. 2 σ
72-83	biotite	garnet biotite schist	386 ± 4 m.y.
72-83	muscovite	garnet biotite schist	419 ± 7 m.y.
72-86	biotite	garnet biotite schist	384 ± 4 m.y.
72-86	muscovite	garnet biotite schist	367 ± 8 m.y.
72-118	biotite	garnet biotite schist	390 ± 4 m.y.
72-122	biotite	garnet biotite schist	388 ± 4 m.y.
72-104	biotite	quartz dioritic gneiss	398 ± 4 m.y.
72-132	mineral isochron, (total rock + muscovite +feldspar; MSWD 0.19)	trondhjemite	425 ±29 m.y.
72-IIV	muscovite	trondhjemite	429 ± 4 m.y.

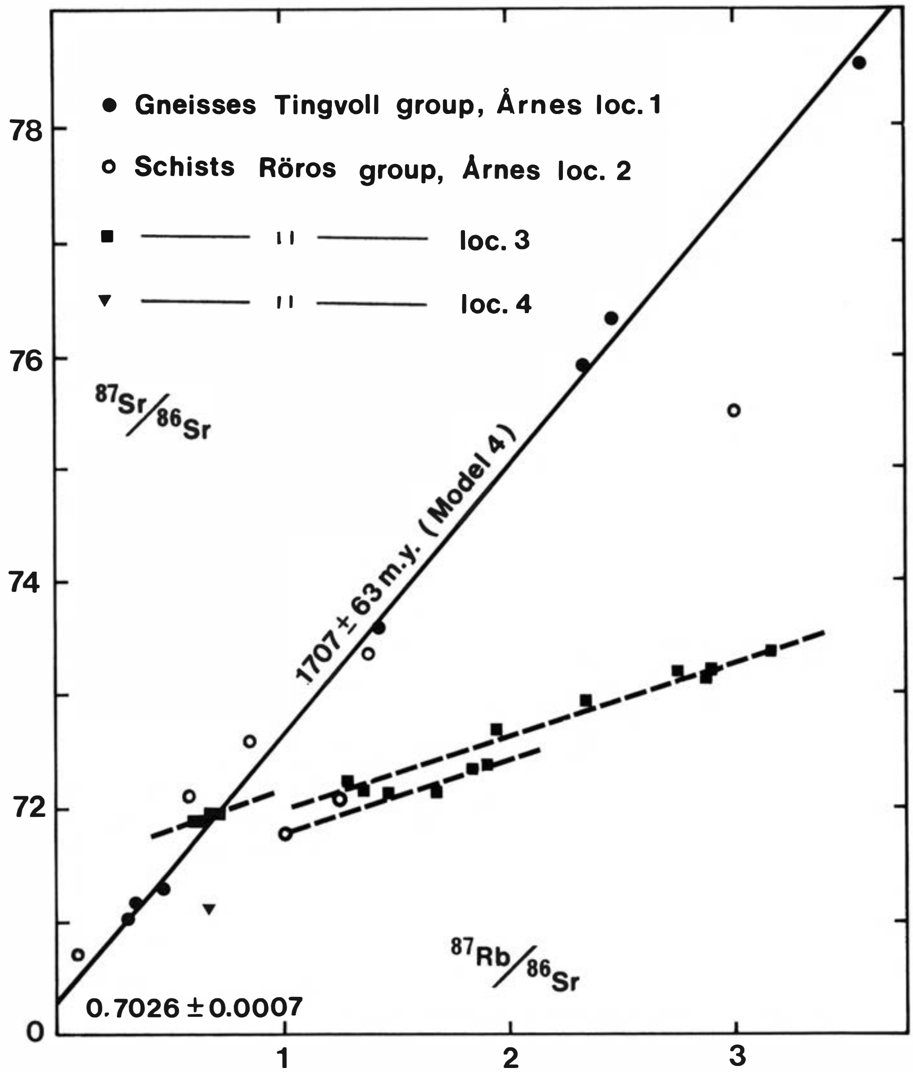

Fig. 2. Isochron diagram of gneisses (Tingvoll Group) and schists (Røros Group) from the Surnadal area. Broken lines indicate possible secondary total rock alignments.

The trondhjemites. – No attempt was made to get total rock isochron ages of trondhjemite intrusions from this area. However, in other parts of the Trondheim Region, trondhjemites intrude rocks of undoubted Cambrian-Ordovician age. A mineral isochron (model 1: total rock + potash feldspar + muscovite) give an age of 425 ± 29 m.y. and a muscovite + total rock age of 429 ± 5 m.y. These ages are clearly older than the total-rock biotite ages of the mica-schists, but not significantly different from the highest total rock + muscovite age of the schists (419 ± 7 m.y.). The main reason for the higher mineral ages of the trondhjemites is probably that the igneous rocks survived Caledonian deformations better than the schists. In addition the Rb, Sr systematics of potash feldspar and muscovite may have been less affected by later deformations than that of the biotites. However, since the trondhjemite dykes are observed to be gently folded together with the schists, the mineral ages reported above must be regarded as minimum ages for the crystallization of the trondhjemitic intrusions, and probably at the same time represent the minimum age for the Caledonian metamorphism of the area (425 m.y.).

Total-rocks analyses of the Røros Group

The work was initially concentrated on total-rock samples of Røros Group rocks next to the border with the gneisses at Årnes (72–82 to 72–88). When the data are plotted in an isochron plot (Fig. 2) it is apparent that either more than one age is present in the Røros Group or that large differences in the initial $^{87}Sr/^{86}Sr$ abundance of the source materials were preserved through medium/high grade metamorphism. To get a better understanding of the situation, six samples (72-129 to 72-128) from a locality south of Surnadalsfjorden (Fig. 1, loc. 3) were selected for further analyses. Three of these samples, each weighing 1–2 kg, were split up into smaller samples (72-124 into 5 parts, 72-126 into 4 parts, and 72-127 into 5 parts) making a total of 17 samples from a restricted locality of about 4 metres. When plotted in an isochron plot the splits of the 72-127 sample and the samples 72-128, 72-125, and 72-122 give an apparent alignment which indicates an age of 462 ± 51 m. y. (model 3. MSWD = 19.7). An alignment of similar slope, but with a different initial ratio, is seen for the splits of sample 72-126 and possibly also for the splits of sample 72-124. These total rock alignments indicate an age which is older than the biotite ages of the Røros schists (390 ± 10 m.y.), but not different from the mineral ages of the trondhjemites (425 ± 29 m.y.) which are thought to represent the minimum age of the Caledonian metamorphism of the area. It is therefore suggested that the peak of the Caledonian metamorphism of the region did occur between 425–465 m.y. ago. However, even if the total-rock age of the Røros Group schists clearly shows that the Caledonian metamorphism has affected total rock systems, it is apparent from Fig. 2 that complete homogenization of Sr isotopes did not take place even on a local scale (Årnes loc., 3 m) within rocks with the same or similar mineralogy. This inhomogeneity of the Sr isotopes is surprising if the Røros schists represent mainly Cambrian clays which went through only one major metamorphism. On the other hand, if the medium/high-grade metamorphism was older, and the total rock alignments were due to a partial reequilibration of the Rb-Sr isotopes during the Caledonian metamorphism, then it is hardly surprising that good 'secondary' total rock isochrons are absent (Råheim & Compston 1977). Similarly, the absence of an isochron from the Årnes locality can also be explained by a partial resetting of older total rock samples during a superimposed metamorphism of Caledonian or younger Precambrian age. Note that two of the samples

(72-84, 72-85) plot close to the 1700 m.y. total rock Tingvoll gneiss isochron. These two, together with two other samples from this locality (72–82 and 72-88) and sample 72-124 from the locality south of Surnadalsfjorden, give a 'total-rock trend' of 1656 m.y. based on the best fitted line through the data points. This apparent 'age' is in rough agreement with the 1700 m.y. age obtained by the total-rock gneiss isochron. Sample 72-83 also indicates an age older than Cambrian unless the initial ratio $^{87}Sr/^{86}Sr$ of this rock was unusually high (> 0.735) compared to other samples from this locality.

It is therefore suggested that the schists of the Røros Group may have been metamorphosed to medium/high-grade metamorphic conditions about 1700 m. y. ago and were partially isotopically reequilibrated during the subsequent Caledonian orogeny which probably occurred between 425 and 465 m.y. ago. The possible original 1700 m.y. age of the Røros Group is also in agreement with the observed concordant contact relationships and absence of a metamorphic beak between the Tingvoll gneisses and the schists of the Røros Group. However, as the evidence for a 1700 m.y. isotopic age of the Røros Group is not conclusive, the problem requires more work to be done before any firm conclusion can be made.

In this discussion it should be noted that 4 (out of 6) schist samples from the Årnes locality (72-82 to 72-85) have another 'total-rock trend' indicating an 'age' of about 1000 m.y. The other two schist samples which contain considerable amounts of amphibole give together with sample 72–88 (garnet amphibolite) a similar 'total-rock trend'. It is at present not known whether this '1000 m.y. age' is significant or not, but it is interesting as it agrees with reports from the southern part of the gneiss region (Brueckner et al. 1967, Brueckner 1972, pers. com. 1977, Priem et al. 1973). The age of the Hestbrepiggan granite (975 ± 35 m.y. Priem et al.) is of particular interest as the emplacement of this granite is accompanied or followed by a second folding phase F_2, which implies that F_1 and possibly F_2 folds are Precambrian structures, and that the main metamorphism (accompanied by F_1) cannot be younger 975 m.y. but very probably older, possibly 1700 m.y. old.

Conclusions

The total rock isochron age of 1707 ± 63 m.y. from gneisses of the Tingvoll Group near the contact with the Surnadal syncline is the same as that obtained earlier from gneisses near Kristiansund (Pidgeon & Råheim 1972). Since no metamorphic or/and tectonic breaks occur between these areas, the 1700 m. y. age, interpreted as the age of the high/ medium grade metamorphism of the region, is probably valid for all the rocks between the contact with the Røros Group in Surnadal and the coast (Kristiansund).

The age of the Røros Group cannot be conclusively determined. The data suggest, however, that the rocks originally were old and were partially reequilibrated during a subsequent Caledonian metamorphism. A total rock 'trend' indicates an apparent 'age' of 1660 m.y., which is in good agreement with the 1700 m.y. age of the gneisses. This possible old 'age' of the Røros Group agrees with the observed absence of metamorphic and/or tectonic breaks between the gneisses and the Røros Group.

Caledonian effects are observed as total-rock alignments (interpreted as secondary) on an isochron plot (Fig. 2) giving an age of about 460 m.y. This age agrees with mineral isochron ages of about 425 m.y. for trondhjemite intrusions and is interpreted as the minimum age for the main episode of folding and metamorphism of the Caledonian orogeny. Possible later deformations, or the final cooling during post metamorphic 'uplift', are seen in biotite ages, which range from 384–398 m.y.

The possible Precambrian age of the Røros Group has, according to correlations by Oftedahl (1964), a regional significance. The contact between gneisses and schists of the Trondheim Region may not reflect a true geochronological beak. If the Cambrian age of the Røros Group can be questioned, then the supposedly Cambrian age of the stratigraphically lowest and highest metamorphic grade rocks of the Gula Group (Wolff 1967) may also be questioned.

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