A note on Rb-Sr whole-rock ages in the Seve Nappe of the central Scandinavian Caledonides

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Rb-Sr whole-rock investigations in the Caledonian Seve Nappe indicate the presence of Sveconorwegian (Grenville) elements (ages about 1200–1000 Ma). The rocks underwent Caledonian metamorphism. As the thrust movement of the Seve Nappe was eastward, the crustal elements showing the imprint of the Sveconorwegian tectono-thermal event were originally located west of their present position in the Caledonian Belt. This confirms earlier indications that the Sveconorwegian 'front' turns north from the southern end of Trondheimsfjorden following the Norwegian coast on the Atlantic shelf.

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Geologic setting

The Seve Nappe belongs to the Seve-Köli Nappe Complex, one of the major nappe systems of the Scandinavian Caledonides (Strand & Kulling 1972). It extends about 800 km along the strike of the Caledonian Belt. During the last 10 years a detailed structural analysis has been made of the Complex by research teams of the Department of Structural Geology, Leiden University, which contributed to a better understanding of the structure and metamorphic evolution (Biermann 1979, Calon 1978, Trouw 1973, Williams & Zwart 1977, Zwart 1974). The present study is an offspring of these investigations.

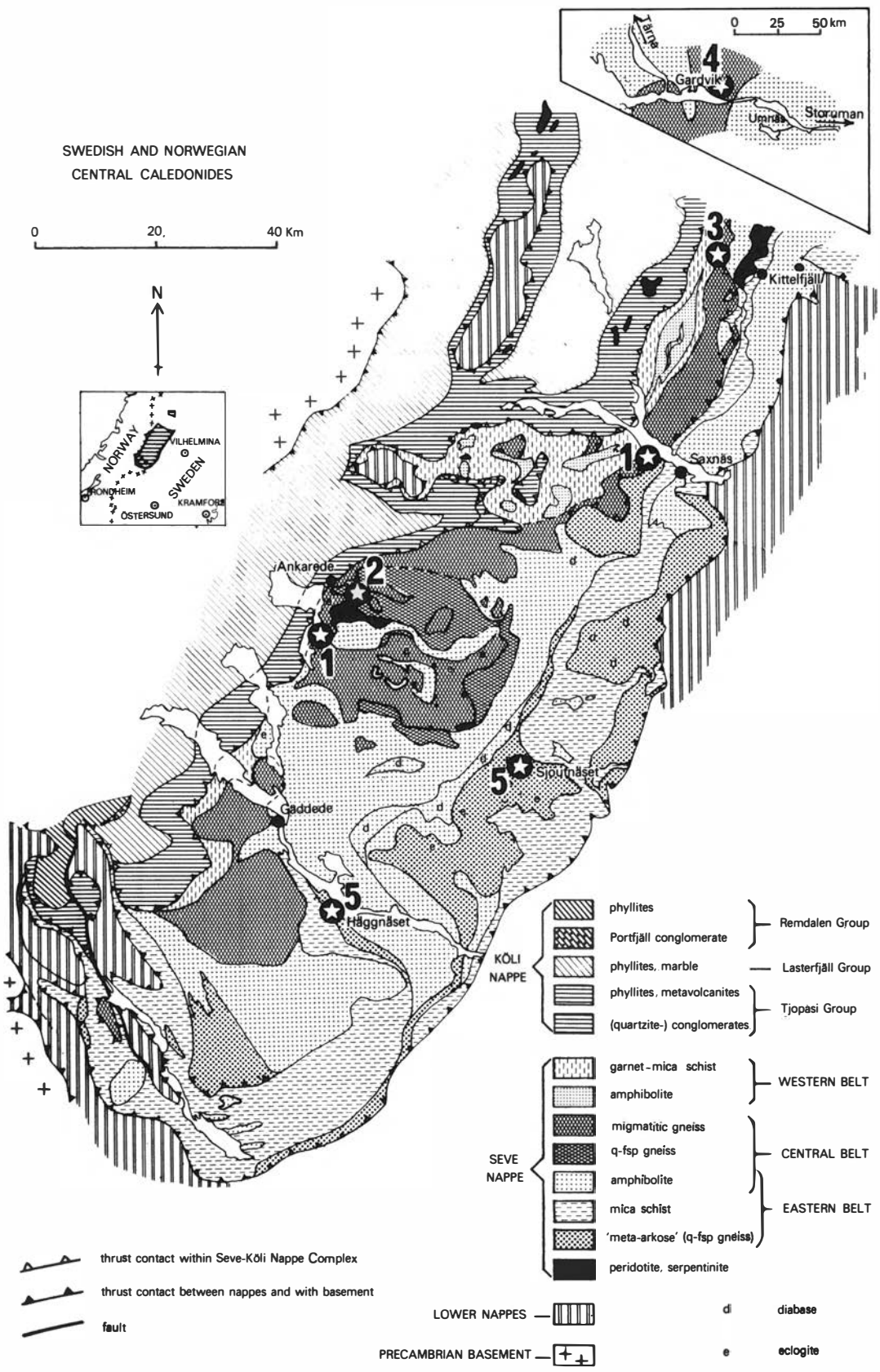
The Seve Nappe is underlain by lower nappes consisting of Cambro-Silurian metasediments and deformed Precambrian crystalline basement (Rb-Sr whole-rock model ages of up to 1950 Ma; Priem et al. 1967, Wilson & Nicholson 1973, this laboratory, unpublished data). Another thrust plane separated the Seve Nappe from the overlying Köli Nappe. All thrusting has been eastward and the rocks forming the Nappe Complex must have been derived from a zone to the west of the present coast of Norway (Gee 1974).

The Köli Nappe contains sequences of metasediments and metavolcanics generally metamorphosed under greenschist facies conditions. Scarce fossils indicate an Early Paleozoic age. The Seve Nappe, on the contrary, consists of high-grade metamorphic rocks devoid of fossils. Their age has therefore been a matter of dispute for a long time, but it was often assumed that they were derived from sedimentary-volcanic sequences of Eocambrian-Cambrian age. The rocks of the Seve Nappe were usually interpreted as the high-grade equivalent of the Köli Nappe, although it was already suggested by Törnebohm (1896) that the rocks of the Seve Nappe are of Precambrian age.

Three zones can be distinguished within the Seve Nappe (Fig. 1): the Western belt, the Central belt, and the Eastern belt (Strand & Kulling 1972). The Western belt consists mainly of garnet-mica schists and amphibolites. In the Central belt the predominant rocks are migmatitic gneisses, quartzo-feldspathic gneisses, and amphibolites locally containing eclogites and peridotites. In the Eastern belt the main rocks are amphibolites, quartzo-feldspathic gneisses (locally containing eclogitic lenses), and mica schists. The units distinguished on the map (Fig. 1) refer to tectono-lithologic, not to time-stratigraphic units. They wedge out and reappear along the strike of the belts.

Two phases of metamorphism can be recognized, an older high-grade phase under granulite and upper-amphibolite facies conditions and a younger one under lower-amphibolite facies conditions. The latter phase caused retrogression of the high-grade rocks.

This paper reports the results of Rb-Sr whole-rock investigations on suites of samples from


SWEDISH AND NORWEGIAN
CENTRAL CALEDONIDES
0 20 40 Km
N
NORWAY
SWEDEN
VILHELMINA
TRONDHEIM
KRAMFORS
ÖSTERSUND
0 25 50 km
Tärna
Gardvik
Umnäs
Storuman
Kittelfjäll
Saxnäs
Ankarede
Gaddede
Sjoutnäset
Häggnäset
KÖLI NAPPE
phyllites
Portfjäll conglomerate
Remdalen Group
phyllites, marble
Lasterfjäll Group
phyllites, metavolcanites
(quartzite-) conglomerates
Tjopasi Group
SEVE NAPPE
garnet-mica schist
amphibolite
WESTERN BELT
migmatitic gneiss
q-fsp gneiss
amphibolite
CENTRAL BELT
mica schist
'meta-arkose' (q-fsp gneiss)
EASTERN BELT
peridotite, serpentinite
thrust contact within Seve-Köli Nappe Complex
thrust contact between nappes and with basement
fault
LOWER NAPPES
PRECAMBRIAN BASEMENT
d diabase
e eclogite

different gneiss units in the Seve Nappe. The investigated rocks are migmatitic gneisses from the Central belt and quartzo-feldspathic gneisses from the Central and Eastern belts.

Experimental procedures, analytical errors, and constant

Of the 38 investigated samples, 26 have been analyzed in the Z. W. O. Laboratorium voor Isotopen-Geologie, Amsterdam (numbers with prefix LAP in Table 1). Splits of crushed and pulverized samples (total weight 7–15 kg) were analyzed for their Rb and Sr contents and the Rb/Sr ratios by X-ray fluorescence spectrometry, using a Philips PW 1450/AHP hardware programmed spectrometer (pressed-powder pellets; mass-absorption corrections for both sample and external standard based upon the Compston scattering of the MoKα primary beam; Verdurmen 1977). Of six samples the Sr content was also measured by isotope dilution, using a spike enriched in ^{84}Sr. The isotope measurements were made on a computer-controlled Varian CH-5 mass-spectrometer with Faraday cage collector and digital output (our value of $^{87}Sr/^{86}Sr$ in the NBS $SrCO_3$ standard: 0.71016 ± 0.00008). The accuracies are estimated at 1% for XRF Rb/Sr, 1% for isotope dilution Rb and Sr, and 0.05% for $^{87}Sr/^{86}Sr$.

The remaining 12 samples and one separated K-feldspar (numbers with prefix KAW in Table 1) have been analyzed in the Labor für Altersbestimmung, Mineralogisch-Petrographisches Institut der Universität Bern (Switzerland), during a stay of the first author (APSR). Essentially the same procedures were followed, except that Rb and Sr were exclusively analyzed by isotope dilution techniques and the $^{87}Sr/^{86}Sr$ ratios were calculated from the isotope dilution runs. The isotope measurements were made on a AVCO mass-spectrometer with Faraday cage collector and digital output.

A best-fit line was calculated through the Rb-Sr data-points of each suite of samples (York 1966, 1967). All errors are given at the 2σ level. For the age calculations the ^{87}Rb decay constant of $1.42 \times 10^{-11} a^{-1}$ is used. Where necessary, ages quoted from literature have been recalculated.

Investigated rocks and results

Five suites of samples from seven locations were investigated. The sampling sites are shown on the geological sketch map of Fig. 1. One suite of samples (suite 5) was taken from a unit in the Eastern belt; all others are from the Central belt. The analytical data are listed in Table 1 and plotted in the Rb-Sr diagrams of Fig. 2. Three suites, 1, 3, and 4, come from the same unit (migmatitic gneisses) which is exposed at several places along a N-S trending zone in the Central belt, in the direction of the overall strike. None of the suites displays a true isochron relationship between the Rb-Sr data-points. Nevertheless, most suites appear to exhibit a rough linear array.

Suite 1

This suite from the migmatitic gneisses comprises seven samples, four collected south of Ankarede and three near Saxnäs. The typical mineral assemblage is kyanite + sillimanite + K-feldspar + plagioclase + biotite + garnet + muscovite. Eclogite lenses are included within the gneisses.

The data-points cluster and do not show an obvious linear correlation. A regression analysis through six of the data-points yields an age of 1140 Ma and initial $^{87}Sr/^{86}Sr$ of 0.710, but with a very large error: $\pm$ 325 Ma. Sample KAW 1443 lies far above the regression line of the other six samples.

Suite 2

These samples come from a unit of homogeneous quartzo-feldspathic gneisses, tectonically underlying the gneisses of suite 1. Their mineralogical composition is characterized by the association quartz + K-feldspar + plagioclase + phengite + epidote. All of the nine investigated samples were collected near Ankarede. In one sample (KAW, 1438), the separated K-feldspar was also analyzed.

The lithologic homogeneity is reflected in the rather small spread of the Rb/Sr ratios. A regression line through eight of the data-points, including the K-feldspar, corresponds to an age of 930

Fig. 1. Geological sketch map of the Seve-Köli Nappe Complex in the central Scandinavian Caledonides (modified after Williams & Zwart 1977). The asterisks refer to the sampling sites of the suites of investigated samples (1–5).

Table 1. Rb-Sr whole-rock data of the Seve Nappe.

Sample No.+	Rb^{++} (ppm)	Sr^{++} (ppm)	Rb/Sr^{++} (m/m)	$^{87}Sr/^{86}Sr$	$^{87}Rb/^{86}Sr$
1. *Paragneisses Central Belt, Ankarede/Saxnäs*					
KAW 1437	159*	221*		0.7390	2.06
KAW 1443	94.5*	206*		0.7441	1.31
	92.5	206	0.4511		
KAW 1444	153	215		0.7423	2.03
KAW 1455	144	317		0.7300	1.30
KAW 1456	91.4	111		0.7523	2.35
KAW 1461	115	244		0.7377	1.34
KAW 1462	101	172		0.7355	1.67
2. *Quartzo-feldspathic gneisses, Central Belt, Ankarede*					
KAW 1436	123*	219*		0.7347	1.60
KAW 1438	133*	181*		0.7347	2.11
KAW 1447	140*	201*		0.7384	1.99
KAW 1459	134*	268*		0.7289	1.43
LAP 6	131	212	0.6213	0.7356	1.80
		211*			
LAP 12	128	176	0.7304	0.7390	2.12
LAP 13	117	215	0.5442	0.7355	1.58
LAP 14	114	204	0.5571	0.7341	1.62
LAP 15	131	182	0.7208	0.7388	2.09
KAW 1438 Kf	380*	494*		0.7408	2.19
3. *Paragneisses, Central Belt, Kittelfjäll*					
LAP 1	116	156	0.7444	0.7479	2.16
		157*			
LAP 2	98.2	328	0.2999	0.7256	0.87
		332*		0.7256	
		332*			
LAP 3	126	214	0.5874	0.7477	1.71
		213*			
		214*		0.7472	
LAP 16	83.9	244	0.3437	0.7333	1.00
LAP 18	114	417	0.2718	0.7239	0.79
LAP 19	124	220	0.5631	0.7396	1.63
LAP 20	177	374	0.4720	0.7289	1.37
LAP 21	145	223	0.6497	0.7431	1.89

Table 1. Continued.

Sample No.+	Rb++ (ppm)	Sr++ (ppm)	Rb/Sr++ (m/m)	$^{87}Sr/^{86}Sr$	$^{87}Rb/^{86}Sr$
4. Paragneisses, Central Belt, Gardvik					
LAP 41	140	151	0.9242	0.7461	2.68
LAP 42	218	34.1	6.3862	0.8525	18.7
LAP 43	105	154	0.6846	0.7476	1.99
LAP 44	95.5	143	0.6705	0.7419	1.95
LAP 45	71.1	162	0.4403	0.7408	1.28
LAP 46	177	111	1.6025	0.7651	4.66
5. Quartzo-feldspathic gneisses, Eastern Belt, Sjoutnäset/Häggnäset					
LAP 4	85.1	79.4	1.0721	0.7524	3.19
		80.0*			
LAP 5	93.4	153	0.6118	0.7346	1.77
		155*			
LAP 10	113	101	1.1228	0.7609	3.27
LAP 11	111	186	0.5999	0.7327	1.74
LAP 37	58	152	0.3813	0.7326	1.11
LAP 38	75	47.0	1.6047	0.7747	4.67
LAP 39	89	202	0.4394	0.7285	1.27
KAW 1442	88*	50.0*		0.7899	5.06
	87.8	50.0	1.7287		

+ Prefix LAP, analyzed in Amsterdam; prefix KAW, analyzed in Bern.

++ X-ray fluorescence spectrometry, except for the figures marked * which were obtained by isotope dilution.

Ma with initial $^{87}Sr/^{86}Sr$ of 0.712, although again with a rather large error: ± 110 Ma. Two samples (KAW 1438 and LAP 13) do not fit to the fairly good linear arrangement of the other eight data-points.

Suite 3

The rocks of this suite have the same mineral association as the gneisses of suite 1, except that no sillimanite has been found and that muscovite occurs exclusively as a secondary, retrograde mineral. The gneisses are underlain by amphibolites and a peridotite, both showing a polymetamorphic history (Biermann 1979, Calon 1978). The eight investigated samples were collected within a small area near Kittelfjäll. Examination of thin sections suggests that the samples suffered stronger deformation and associated retrogression during the second metamorphic episode than the other samples.

Of the eight analyzed samples, five data-points define a line of 1225 ± 30 Ma with initial $^{87}Sr/^{86}Sr$ of 0.710. Three points (LAP 3, 16 and 20) deviate from this line. A regression analysis through all samples would yield an age of 1300 ± 230 Ma.

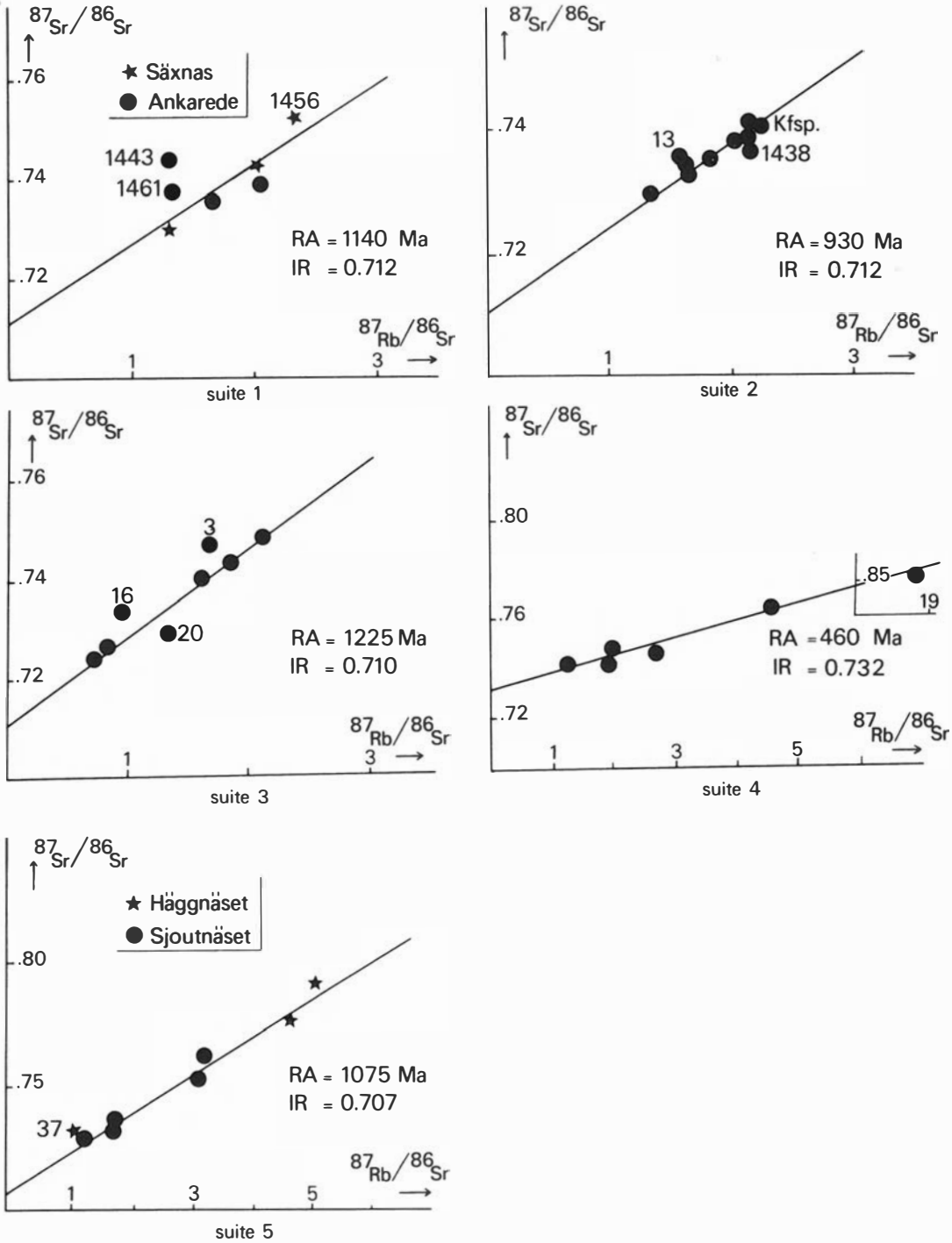


Fig. 2. Plots of Rb-Sr data of suites 1–5 (see text). ^{87}Rb decay constant of $1.42 \times 10^{-11} a^{-1}$. RA, reference age; IR, initial $^{87}Sr/^{86}Sr$ ratio. The figures refer to the sample numbers mentioned in the text.

Suite 4

This suite comes from strongly folded, migmatitic gneisses containing the same minerals as suite 3, except that biotite occurs in higher proportions. Sample LAP 42, the rock with the highest Rb/Sr ratio, is mainly made of biotite, quartz, and garnet. All samples were taken in a small area near Gardvik along road No. 361 to Tärnaby.

A regression line through all data-points corresponds to an age of 460 ± 35 Ma. The initial $^{87}Sr/^{86}Sr$ ratio is high, 0.732.

Suite 5

Of the eight investigated samples, five were collected near Sjoutnäset and three near Häggnäset. They come from a unit of quartzofeldspathic gneisses (interpreted as meta-arkoses on the map, Fig. 1) with approximately the same mineralogical composition as the gneisses of suite 2 (rocks of this type occur at several tectonic levels). The gneisses contain locally eclogites and are transected by diabase dikes at several places.

The data-points show a fairly good linear correlation. A regression line through seven samples, omitting LAP 37 which comes from a shear zone, corresponds to an age of 1075 ± 70 Ma with initial $^{87}Sr/^{86}Sr$ of 0.707. Sample LAP 37 also fits rather closely to this line.

Discussion

The regression analyses produce lines corresponding to an age of either about 1200–900 Ma (suites 1, 2, 3, and 5), or about 460 Ma (suite 4). Both ages correspond to well-known events in the geological history of Scandinavia, the older ages to the time-span of the Sveconorwegian tectono-thermal episode of SW Scandinavia (1200–850 Ma ago), and the younger age to that of the Caledonian Orogeny. It seems obvious to relate the two age groups recorded by the Rb-Sr systems to the two phases of metamorphism recognized in the Seve Nappe. This implies that the polymorphic history of the rocks in the Seve Nappe consists of an event of high-grade metamorphism in Sveconorwegian time, followed by a lower-grade event due to the Caledonian Orogeny.

During the Caledonian Orogeny, the gneisses of suite 4 became apparently open to their Rb-Sr systems on a scale exceeding the size of the investigated samples, without attaining complete Sr isotopic equilibration through the rocks. The samples of this suite differ from the other four investigated suites in displaying a much more intense Caledonian metamorphism and in containing large amounts of biotite. The process of Sr isotopic redistribution is also reflected in the high initial $^{87}Sr/^{86}Sr$ ratio (0.732), indicative of a prolonged pre-Caledonian Rb-Sr history. If we assume an average $^{87}Rb/^{86}Sr$ ratio of 2.5, the high initial ratio of this suite can be accounted for by an age of about 1050 Ma (assuming an initial $^{87}Sr/^{86}Sr$ ratio of 0.710). Such a Sveconorwegian age is quite feasible, as the samples come from the same unit as the suites 1 and 3 which also record Sveconorwegian ages.

Rb-Sr and K-Ar investigations on biotites, muscovites, and hornblendes separated from rocks of the Seve Nappe are currently in progress. Preliminary data likewise show widespread resetting during the Caledonian Orogeny, but Sveconorwegian and intermediate ages have also been preserved (this laboratory, unpublished data).

The K-feldspar KAW 1438 of suite 2 appears to have remained also closed to Rb-Sr since Sveconorwegian time, contrary to the corresponding whole-rock which lies below the 930 Ma alignment of the other data-points (Fig. 2). This suggests that the opening of the whole-rock Rb-Sr system involved a loss of Sr (including radiogenic Sr) and/or a gain of Rb during Caledonian metamorphism, rather than Sr isotopic redistribution within the rock.

Data-points lying above the linear array of the other samples of a suite (for example, 1443, 1456, and 1461 of suite 1; 3 and 16 of suite 3; 37 of suite 5) may likewise reflect disturbances of the Rb-Sr system by the Caledonian metamorphism. They could also be interpreted as relicts of a pre-Sveconorwegian Rb-Sr record, however, although the low initial $^{87}Sr/^{86}Sr$ ratios of the Sveconorwegian linear arrangements do not support a prolonged pre-Sveconorwegian history; such ratios rather suggest that the gneisses were derived during Sveconorwegian metamorphism from sedimentary sequences deposited shortly before the Sveconorwegian orogenic activities.

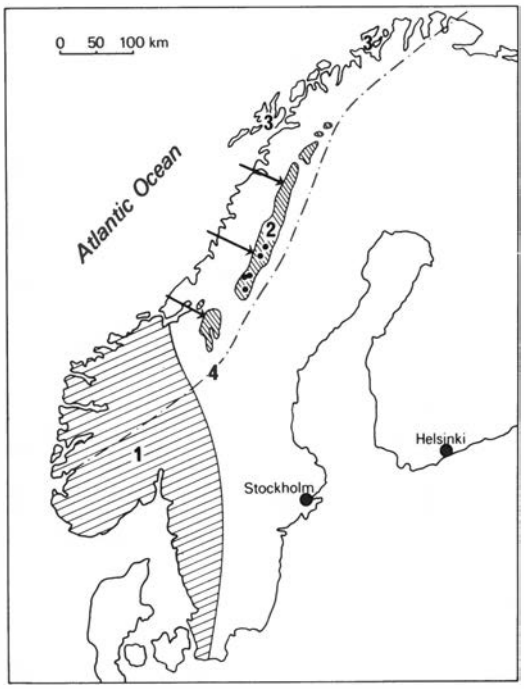


Fig. 3. The distribution of Sveconorwegian ages in Scandinavia. Legend: 1, Sveconorwegian province of S. W. Scandinavia; 2, Seve Nappe, displaying Sveconorwegian ages (shown as dots); 3, Sveconorwegian rocks of Lofoten (Griffin et al. 1978, Heier & Compston 1969) and Seiland province (Brueckner 1973); 4, Caledonian boundary. The arrows indicate the direction of Caledonian thrusting.

Northward extension of the Sveconorwegian province

The Sveconorwegian tectono-thermal event has affected the whole Precambrian basement of southern Norway and southwestern Sweden (Fig. 3). It is characterized by events of folding, high-grade metamorphism, and granitic plutonism between about 1200 Ma and 850 Ma ago (e.g. Kratz et al. 1968, O'Nions & Baadsgaard 1971, Priem et al. 1973b, Versteeve 1975) and can be correlated with the Grenville province of North America. Ages within the range of the Sveconorwegian event are also known from Greenland (Hansen et al. 1973) and Scotland (Brook et al. 1977). Geological correlations are difficult, however, because of differences in metamorphism, tectonics, and basement/cover relationships.

Sveconorwegian ages have also been measured at several places in the Precambrian basement within the Caledonian Belt of southwestern and western Norway (Andresen et al. 1974, Brueckner 1972, Priem et al. 1973a, 1976, Sturt et al. 1975), as far north as the southern part of Trondheimsfjorden (Råheim 1977). In northern Norway, Sveconorwegian ages have been reported from the Lofoten (Griffin et al. 1978, Heier & Compston 1969) and possibly even as far north as the Seiland area (Brueckner 1973) in northern Norway. From the Rb-Sr investigations reported in this study it is clear that Sveconorwegian elements also occur in the continental crust from where the Seve Nappe has been derived, i.e. west of its present situation in the Caledonian Belt (Fig. 3). On the basis of all evidence now available it may therefore be postulated that the Sveconorwegian 'front' actually turns north from the coastal area at the southern end of Trandheimsfjorden, following the Norwegian coast on the continental shelf. This supports Sturt's et al. (1975) suggestion that there is a connection between the Grenville Belts of Scandinavia and Greenland.

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