A PRELIMINARY Rb/Sr GEOCHRONOLOGICAL STUDY OF THE HARDANGERVIDDA-RYFYLKE NAPPE SYSTEM IN THE RØLDAL AREA, SOUTH NORWAY*

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Different tectonostratigraphic units of the Hardangervidda–Ryfylke Nappe System have been dated by Rb/Sr methods. The three lowest units of the allochthon gave the following results, recorded from below: The Holmasjø Formation, 409 ± 15 m.y.; the Dyrskard Group, 1289 ± 80 m.y.; the Kvitenut Complex, 1643 ± 88 m.y. The highest part of the allochthon, the mica-gneisses of the Revsegg Formation, yielded a quite ambiguous result, 430 ± 250 m.y., indicating a Caledonian metamorphic influence on Paleozoic and/or Precambrian material.

An age of 943 ± 100 was obtained on the supracrustal series of the basement in Valldalen.

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The Hardangervidda–Ryfylke Nappe System in the Haukelisæter–Røldal area has recently been shown to consist of five tectonostratigraphic units, based on differences in lithology and the degree of deformation and metamorphism (Naterstad et al. 1973). Generally the different allochthonous units display an increasing degree of deformation and metamorphism in ascending order, a phenomenon well known and discussed in earlier literature (Brøgger 1893, Reusch et al. 1902, Reusch 1913).

The ages proposed for these non-fossiliferous rocks have varied from Precambrian to Devonian (see summary in Strand 1960, 1972). The first Rb/Sr dates available from rocks considered to be in a tectonic position similar to that of the present study were the granitic gneisses beneath Hardangerjøkulen, which yielded a whole-rock age of 1639 ± 100 m.y. (Priem 1967, 1968), and paragneisses in the Stavanger area which yielded an isochron age of 1160 ± 24 m.y. (Heier et al. 1972). The detailed tectonic position of the rocks giving these two dates has not been considered previously and we will now relate new radiometric determinations to positions in a known succession within a fairly restricted area.

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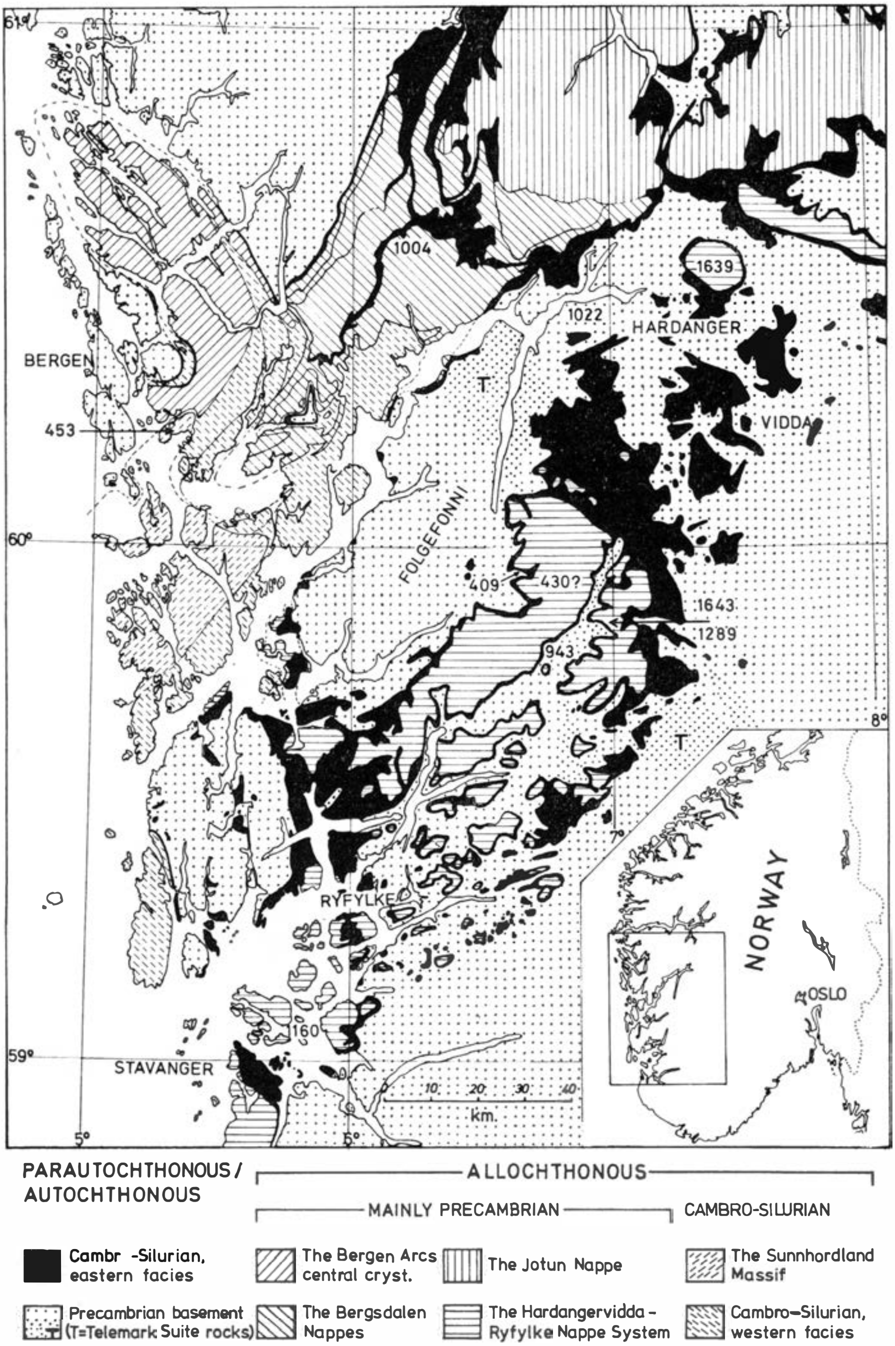

Fig. 1. Situation map showing the main tectonic units and relevant radiometric age determinations in southwest Norway.

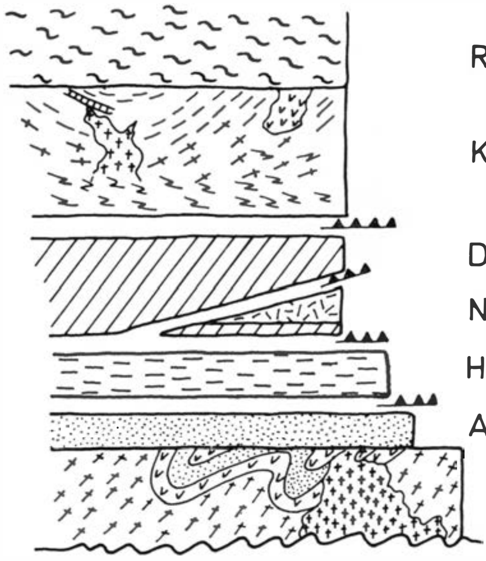

Fig. 2. Tectonostratigraphic succession in the Haukelisæter–Røldal area.

Geological setting

The geological structure of Hardangervidda has been considered a Precambrian basement overlain by an autochthonous Cambro-Silurian sequence with a crystalline nappe on top (Strand 1972). Naterstad et al. (1973) showed that both the Cambro-Silurian sequence and the crystalline nappe rocks could be divided into different tectonostratigraphic units, separated by more or less distinct thrust-zones. The tectonostratigraphic succession established by Naterstad et al., and used as a basis for the present geochronologic study, is summarized in Fig. 2.

The Precambrian basement is made up of foliated granodioritic gneisses metamorphosed in amphibolite facies, low-grade metamorphosed supracrustal rocks, and younger granites. The supracrustals are generally assumed to be the equivalents of the Telemark Suite, and are younger than the granodioritic gneisses (Naterstad et al. 1973). Both the gneisses and the supracrustals are intruded by granites and gabbros. The autochthonous Cambro-Silurian sequence described by Brøgger (1893) is here divided into an autochthonous Cambro-Ordovician sequence at the bottom with a supposed allochthonous unit, the Holmasjø Formation, on top.

The Holmasjø Formation is the lowermost thrust unit of the Hardangervidda–Ryfylke Nappe System, and consists mainly of strongly foliated metapelites with zones of quartzites and feldspathic quartzites. The major minerals are quartz, white mica, chlorite and sometimes albite, mainly as relict clastic grains. Chloritized garnets occur sporadically. Together with the saussuritized albite and chloritized biotite they indicate a previous history of higher-grade metamorphism.

The crystalline rocks of the higher part of the nappe system have been divided into four tectonostratigraphic units (Fig. 2). The Nupsfonn Complex at the bottom has a very restricted distribution and appears as a local wedge. It is characterized by cataclastically deformed gneisses, both orthogneisses and paragneisses, and shows a pre-cataclastic amphibolite facies metamorphism (Andresen 1972).

The Dyrskard Group is rather widespread. It is separated from the Holmasjø Formation and the Nupsfonn Complex by a thrust zone. The Dyrskard Group is largely made up of meta-supracrustals, of both volcanic and sedimentary origin. The Dyrskard Group has been subjected to metamorphism in upper greenschist/lower amphibolite facies (Andresen 1972).

Both the Nupsfonn Complex and the Dyrskard Group show signs of a post-cataclastic low greenschist facies metamorphism.

The Kvitenut Complex and the Revsegg Formation constitute the highest tectonic unit within the nappe system, and this unit is separated from the underlying Dyrskard Group by a thrust zone. The thrust zone is recrystallized in the amphibolite facies. The thrusting and subsequent metamorphism of the thrust zone must have taken place outside the present area, as the underlying autochthonous rocks are metamorphosed only in the lowest greenschist facies.

The Kvitenut Complex is heterogeneous, with orthogneisses, paragneisses, migmatites, calc-silicates and various basic and acid intrusives. Most of the complex is tectonized and metamorphosed in amphibolite facies. Locally rocks are found with mineral paragenesis characteristic of the transition hornblende-granulite/upper amphibolite facies (Andresen 1972). They are now mostly retrograded into amphibolite facies.

The Revsegg Formation is the highest tectonostratigraphic unit in this part of Hardangervidda. The formation has a tectonically disturbed sedimentary contact against the underlying Kvitenut Complex. Two-mica gneisses are the dominating rock type. Kyanite- and locally staurolite-bearing micagneisses are typical in distinct zones, indicating amphibolite facies metamorphism. Quartz-dioritic dykes and small bodies of garnet-amphibolites are common.

Analytical techniques

The Rb/Sr ratios were determined by a Philips Manual X-ray spectrograph, PW 1410 with 2.7 Kw-tube. This and the chemical separation of the Sr were carried out at Mineralogisk–Geologisk Museum, Oslo. The isotopic analyses of Sr were performed on the Oxford University 6″ mass spectrometer (a modified A.E.I.M.S.2) employing magnetic scanning of the spectra. Age calculations were made using a Rb^{87} decay constant of $1.39 \times 10^{-11} y^{-1}$ and in citing the literature all Rb–Sr dates have been recalculated using this decay constant. Regression lines were fitted using the method of McIntyre et al. (1966).

Geochronological results

Valldalen supracrustals

Although no direct connection exists in the field, the supracrustal series of the basement of Valldalen has been considered the equivalent of the Precambrian supracrustals in the central Telemark area.

Attempts at radiometric dating of the Telemark Suite east of the area studied here suggest ages of 1550–1600 m.y. (Versteeve 1970). Priem (1968) gives a Rb/Sr isochron age of 1227 ± 100 m.y. from the acid volcanics of the Telemark Suite. It is not apparent whether this is the age of extrusion or the metamorphic age of the 1550–1600 m.y. old rocks ($^{87}Sr/^{86}Sr_{initial}$ = 0.717 with a large uncertainty). Priem (1970) also reports ages of biotites separated from a meta-basalt intercalated between acid volcanics. The Rb/Sr age is 1040 ± 40 m.y. vs. the K/Ar age of 922 ± 25 m.y. K/Ar determinations on muscovite separated from the Eidsborg quartzschists, considered stratigraphically high in the Telemark Suite, indicate an age of 990 ± 36 m.y. (Dons pers. comm.). The younger granites intruding the Telemark Suite are between 850–1050 m.y. old (Priem 1968).

The samples analyzed for this study were collected in fresh roadcuts along the road to Valldalen, between Nyastøl Bridge and the damsite by Valldalsvatn. Exact localities are given in Table 1. Generally the rocks are only weakly metamorphosed in greenschist facies, but intense isoclinal folding, with the formation of an axial-plane cleavage, is apparent. Thin sections and sample descriptions are available on request from the authors.

The age 943 ± 100 m.y. indicated by the Valldalen supracrustals (Table 1, Fig. 3) most probably reflects the above-mentioned late period of extensive igneous activity and metamorphism which took place over vast areas in south Norway. The age of deposition of the Telemark sediments is still unknown.

The Holmasjø Formation

The depositional age of the Holmasjø Formation sediments is still unknown. On Hardangervidda they overlie the fossiliferous Cambro-Ordovician sediments described by Brøgger (1893), Reusch et al. (1902), and were considered to be of Middle Ordovician age. Recent work in the Haukelisæter–Røldal area has demonstrated that the lower border of the Holmasjø Formation is a thrust-plane (Naterstad et al. 1973). Sediments of the same type as the Holmasjø Formation have a wide distribution below and between the Caledonian nappes of southwest Norway (Kvale 1960). Nowhere have fossils been found in them.

The samples collected for analyses were taken in fresh cuts along the road from E 76 to Reinsnos. The sediments are in greenschist facies with at least two sets of intensely developed secondary cleavages. The analytical data are presented in Table 1 and plotted on an isochron diagram in Fig. 4.

The very good fit of the individual sample points to the regression line

Table 1.

Tectonic unit	Sample no.	Locality UTM military reference		Rock type	Sr^{87}/Sr^{86}	Rb^{87}/Sr^{86}	Isochron age and initial Sr^{87}/Sr^{86} ratio*
Revsegg Formation	C_1	7350	4535	Quartzdioritic two-mica gn.	0.7354	1.7645	
	C_2	7346	4522	Granitic two-mica gn.	0.7377	2.8273	
	C_5	7157	4550	Granodioritic two-mica gn.	0.7340	2.1850	
	C_7	7162	4545	Granodioritic two-mica gn.	0.7382	2.5575	430 ± 250 m.y.
	C_{10}	6972	4502	Quartzdioritic two-mica gn.	0.7334	1.5785	
	C_{11}	6972	4502	Two-mica gn.	0.7418	2.7007	
	C_{12}	7370	3472	Two-mica gn.	0.7297	1.3487	
Kvitenut Complex	B_2	8890	3795	Granitic gneiss	0.7984	4.2369	
	B_3	8890	3795	Granitic gneiss	0.8114	4.0288	
	B_4	8890	3795	Syenitic gneiss	0.9161	9.3532	1643 ± 88 m.y.
	B_5	8890	3795	Granitic gneiss	0.9491	9.9605	R_i = 0.7049 ±
	B_6	8890	3795	Amphibolite	0.7109	0.2577	0.0011
	B_8	8876	3758	Monzonitic gneiss	0.7251	0.8379	
	B_9	8880	3739	Quartzdioritic gneiss	0.7188	0.4897	
Dyrskard Group	A_2	9060	3668	Amphibolite	0.7108	0.1998	
	A_4	9028	3697	Quartz-schist	0.8268	7.8969	1289 ± 80 m.y.
	A_5	9006	3713	Biotite-amphibolite	0.7186	0.3941	R_i = 0.7075 ±
	A_6	8987	3713	Feldspathic quartz-schist	0.9621	13.838	0.0030
	A_7	8975	3722	Feldspathic quartz-schist	0.9198	11.474	
Holmasjø Formation	H_1	7077	4940	Phyllitic quartz-schist	0.7404	3.4117	
	H_2	7045	4914	Feldspathic quartz-schist	0.7265	0.9018	409 ± 15 m.y.
	H_4	7019	4867	Feldspathic quartz-schist	0.7240	0.6146	R_i = 0.7193 ±
	H_5	7013	4860	Feldspathic quartz-schist	0.7250	0.7161	0.0004
	H_6	7013	4860	Phyllitic quartz-schist	0.7460	4.4507	
Valldalen supracrustals	L_2	8215	4036	Calcareous meta-arkose	0.7544	2.3755	
	L_3	8215	4036	Feldspathic quartz-schist	0.7285	1.1659	
	L_4	8201	4008	Feldspathic quartz-schist	0.7290	0.7164	943 ± 100 m.y.
	L_7	8081	3870	Feldspathic quartz-schist	0.7595	3.3308	R_i = 0.7145 ±
	L_8	8074	3820	Quartzite	0.7901	5.9141	0.0017
	L_{10}	8047	3852	Meta-rhyolite	0.7810	5.0314	

* Computed initial ratios for the different rock units are corrected relative to the Sr^{87}/Sr^{86} = 0.7080 for the Eimer and Amend interlaboratory standard.

together with the high initial $^{87}Sr/^{86}Sr$ ratio (R_i = 0.7193 ± 0.0004) may be unexpected for low-grade sediments of such diverse type. If the main nappe thrusting is of Middle to Upper Ordovician age, as postulated by earlier authors (Kvale 1960, Strand 1960, Skjerlie 1969) on the basis of stratigraphical arguments, the age obtained here, 409 ± 15 m.y. (Model I age, McIntyre et al. 1966), most probably dates the post-thrusting deformation seen on Hardangervidda and described by Andresen (1972) and Naterstad et al. (1973). Data from Broch (1964), Bryhni et al. (1971) and Brueckner (1972) also indicate that an important episode in the late evolution of the Caledonides took place around 400 m.y. age (Ardennic phase).

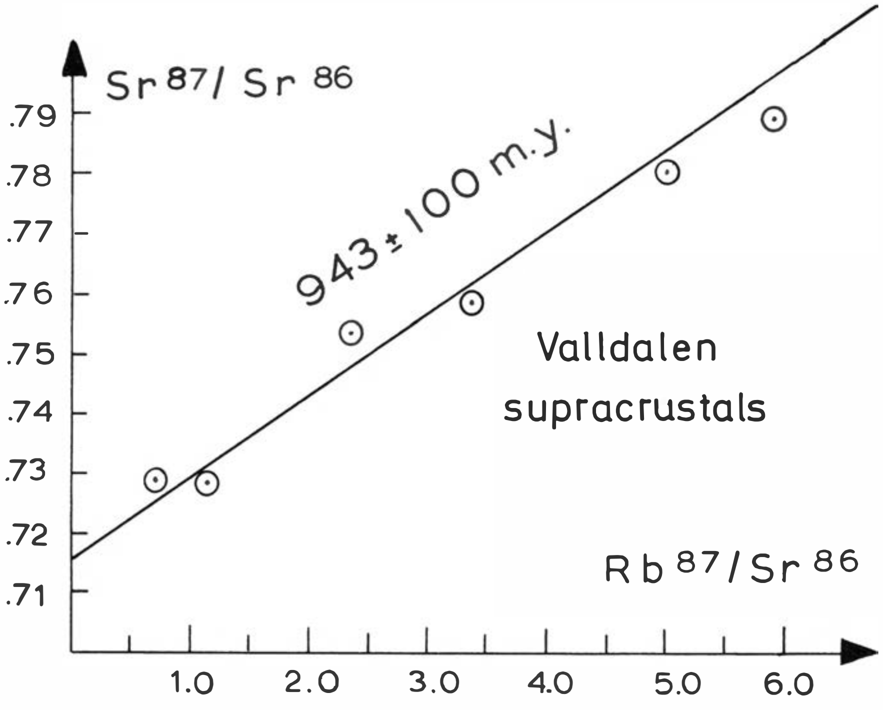

Fig. 3. Rb–Sr isochron plot of the Valldalen supracrustals whole-rock analyses.

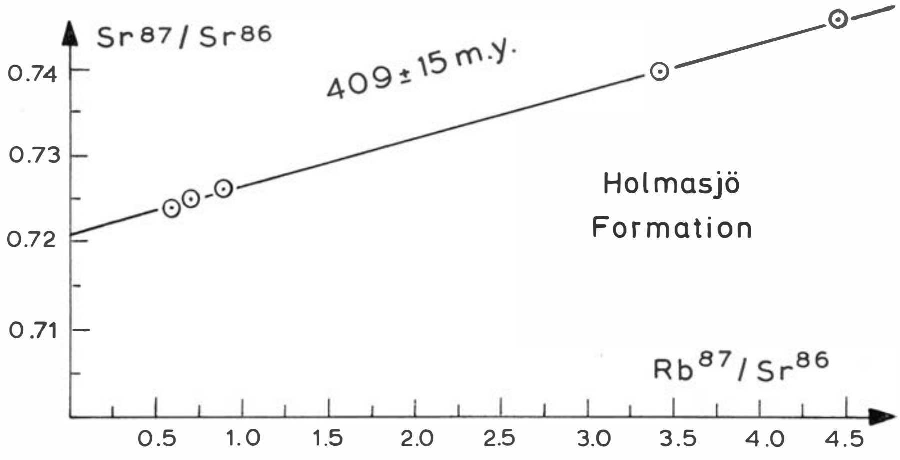

Fig. 4. Rb–Sr isochron plot of the Holmasjø Formation whole-rock analyses.

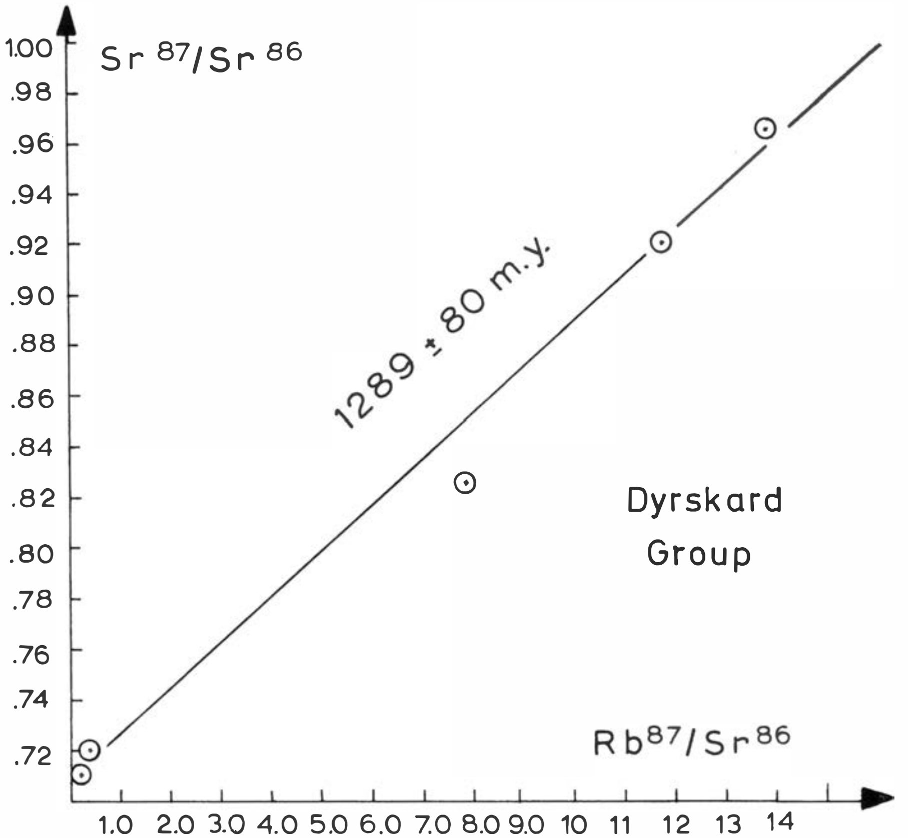

Fig. 5. Rb–Sr isochron plot of the Dyrskard Group whole-rock analyses.

The Dyrskard Group

All earlier descriptions report quartzites and hornblende rich rocks of supposed supracrustal origin low in the allochthonous sequence of the Hardangervidda.

Brøgger (1893) and Bjørlykke (1905) considered them to be of Cambro-Silurian to Devonian age and believed that their higher degree of metamorphism was caused by the younger intrusives above. However, based on lithological similarities, Reusch et al. (1902), Reusch (1913) and Kvale (1945) correlated them with rocks of the Precambrian Telemark Suite. This is also the view adopted by Naterstad et al. (1973).

The samples collected for this study were taken from representative rocks of the Dyrskard Group in the hillside north of Dyrskardnuten. The five point isochron obtained indicates an age of 1289 ± 80 m.y. (Table 1, Fig. 5). It should be kept in mind that the rocks are parts of a probably far-travelled nappe system with a complex geological history both in the Precambrian and during the Caledonian orogeny.

We interpret the age as the time of the amphibolite facies metamorphism.

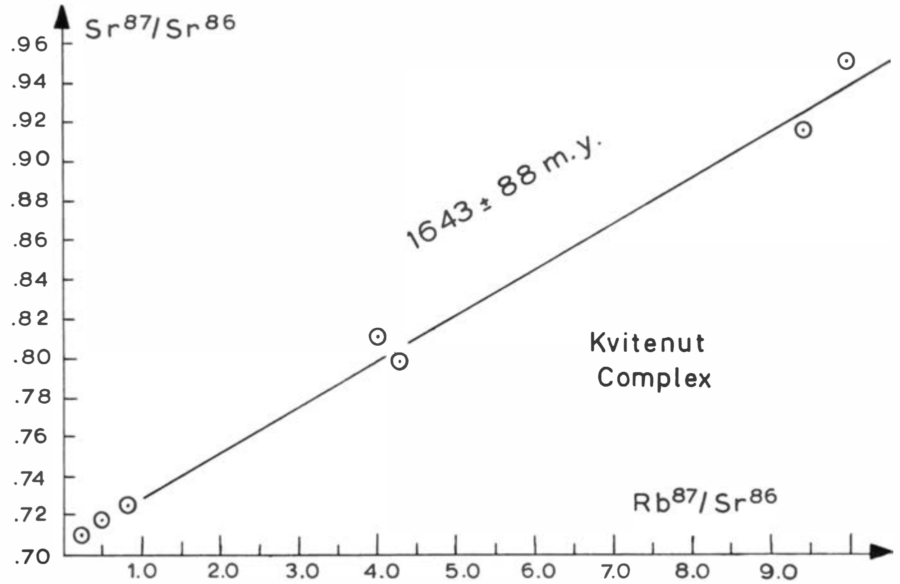

Fig. 6. Rb–Sr isochron plot of the Kvitenut Complex whole-rock analyses.

The overprinted greenschist facies mineralogy is associated with Caledonian structure and did not reset the whole rock radiometric age.

The only prior attempt to date rocks of comparable tectonic position and lithologic character is by Heier et al. (1972) on paragneisses from the Stavanger area. They gave an isochron age indicating a metamorphic event at 1160 ± 24 m.y.

The Kvitenut Complex

The granitoid rocks of this very heterogeneous complex were considered by Brøgger (1893) to be Caledonian intrusives responsible for the metamorphism seen in higher parts of the sections on Hardangervidda. Reusch et al. (1902), Reusch (1913) and others thought them to be allochthonous Precambrian rocks.

The samples analyzed in this paper were taken from the top area of Stavsnuten, 8–9 km west of Haukelisæter. Here the Kvitenut Complex is made up of meta-supracrustals and migmatites cut by younger granites, amphibolites, pegmatites, etc.

All the samples used are taken well away from the zone of mylonite-gneisses that separates the Kvitenut Complex from the underlying Dyrskard Group, and are thought to represent rocks with relict hornblende granulite/upper amphibolite facies mineralogy.

The age obtained, 1643 ± 88 m.y. (Table 1, Fig. 6) may reflect the upper amphibolite/hornblende granulite facies metamorphism, perhaps modified by the subsequent (retrograde?) amphibolite facies metamorphism. To separate these two periods of metamorphism, detailed mineral isochron studies are necessary. However, the low initial $^{87}Sr/^{86}Sr$ ratio indicates that the metamorphism could be close in time to the igneous activity and deposition of the rocks.

The only radiometric age obtained on rocks of similar tectonic position and petrographic character is by Priem (1967, 1968) on granitic gneiss in the Hardangerjøkul area. Recalculated to fit the decay constant used here it indicates an age of 1639 ± 100 m.y.

As a comment to the discussion on the possible root-zone for the nappes we want to point out the fact that so far no ages of the 1600–1800 m.y. group have been recorded from the basement in the near proximity of the 'Faltungsgraben'. However, when moving further northwest to the coastal area, a whole series of ages fall into this group (Broch 1964, McDougall & Green 1964, Bryhni et al. 1971, Brueckner 1972, Pidgeon & Råheim 1972).

The Revsegg Formation

The age of the highest part of the allochthon is completely unknown. Naterstad et al. (1973) concluded that the mica-gneisses of obviously metasedimentary origin have a tectonized depositional contact with the Kvitenut Complex and must be of younger age.

The Revsegg Formation shows great similarities to the lowest part of the Caledonian sequence in west central Norway (the Røros Group). The similarities include lithological and deformational types, the type of intrusives, as well as their relation to a gneissic basement partly showing relicts of higher grade metamorphic rocks (Hernes 1956a). Such relations are described from the western part of the Trondheim area, from Orkdalsfjorden via Surnadal to Tingvoll and Molde (Carstens 1919a, 1919b, Strand 1953, Hernes 1956a, 1956b). From the synclines along the coastal area of west Norway (Kolderup 1960) and from the Bergen Arcs (Kolderup, C. P. & Kolderup, N.-H. 1940). These similarities led Naterstad et al. (1973) to suggest an Ordovician age for the most prominent metamorphism now displayed by the Revsegg Formation.

Pidgeon & Råheim (1972) determined an age of 1700 m.y. for the gneisses underneath the Caledonian rocks of the Kristiansund area, and because no metamorphic unconformity was located in the region they concluded that the main metamorphism of all gneisses beneath the Støren Group, including the Røros Group of the Surnadal syncline, took place 1700 m.y. ago.

Field relations in the area give no indication of the age of deposition of the mica-gneisses of the Revsegg Formation. Petrographically identical meta-pelites of the Boknfjorden–Stavanger area in what we consider to be in an equivalent tectonic position, are followed upwards by a sequence of meta-volcanics and meta-sediments that most probably can be correlated with the zone of eugeosynclinal Cambro-Silurian sediments along Hardangerfjorden. If these relations are valid and no major breaks exist in the series, a Cambrian or older age for their deposition is indicated.

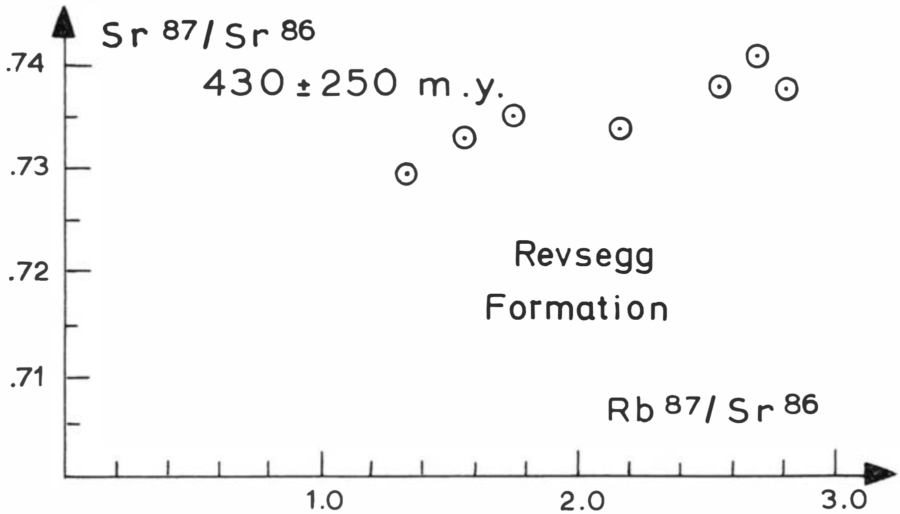

Fig. 7. Rb–Sr data from the whole-rock analyses of the Revsegg Formation.

The samples for this study were collected in the area of Søndre Krossfonnut. The analytical results (Table 1) show too much scatter to define a significant isochron age (Fig. 7). The best fit regression line of 430 ± 250 m.y. shows that the Revsegg Formation has been through a period of Caledonian metamorphism which was not recorded in the Dyrskard Group or the Kvitenut Complex whole rock ages. We tentatively suggest that this is related to the high mica content in the analyzed Revsegg samples compared to the 'dry rocks' of the Dyrskard Group and Kvitenut Complex. The implied lower grade of metamorphism would also require that the Revsegg rocks are younger than the underlying complexes.

Conclusions

Our interpretation of the available data is summarized below.

The 943 ± 100 m.y. isochron age for the Valldalen series assigns an age to these meta-supracrustals which is comparable to the youngest ages previously determined on meta-supracrustals from the Telemark area proper, and to the age of the younger granites penetrating them. The high initial $^{87}Sr/^{86}Sr$ ratio suggests that this may be the metamorphic age.

The crystalline part of the allochthonous rocks in the area are Precambrian, as postulated by Reusch et al. (1902).

Disregarding the Revsegg Formation it seems clear that the gradual upward increase in the degree of metamorphism, noted by earlier authors in this and neighbouring areas, reflects a tectonic arrangement of discrete nappe sheets of upward increasing age.

The relatively high age of the Kvitenut Complex matches a group of similar ages obtained on rocks along the west coast of Norway, a point that strengthens the suggestions that this is possibly the root area for this part of the allochthon.

The model I age of 409 ± 15 m.y. obtained for the Holmasjø Formation is interesting with regard to both the high initial $^{87}Sr/^{86}Sr$ ratio (R_i = 0.7193 ± 0.0004) and the very precisely determined regression line for these low grade metamorphosed sediments. We interpret the age as being the date of the late post-thrusting deformation and metamorphism of the Hardangervidda–Ryfylke Nappe System and the autochthonous sediments in the Ardennic phase of the Caledonian orogeny.

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