$^{40}Ar/^{39}Ar$ DATES FROM RECYCLED PRECAMBRIAN ROCKS IN THE GNEISS REGION OF THE NORWEGIAN CALEDONIDES*

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Rocks from Nordfjord have been dated by conventional K-Ar and $^{40}Ar/^{39}Ar$ methods. Both the lower complex of relatively homogeneous gneisses (Jostedal Complex) and the tectonically overlying supracrustals with inliers of Anorthosite Kindred rocks and gneisses (lower part of the Fjordane Complex) contain original Precambrian rocks. The region apparently has ancient (> 1550 m.y.) elements which were rejuvenated by both the Sveconorwegian and the various Caledonian orogenies, thus confirming McDougall & Green's (1964) results based on radiometric evidence from eclogite minerals.

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Introduction

The Gneiss region of western Norway is generally regarded as an area with Precambrian, Eocambrian and Cambro-Silurian rocks which were strongly influenced by Caledonian orogeny (Holtedahl 1944, Strand 1960). It is, however, still a matter of speculation which rocks are 'Caledonized' original Precambrian elements and which are metamorphosed Late Precambrian to Cambro-Silurian supracrustals, and much remains to be learned about the chronology of the various Precambrian and Caledonian events.

Modern radiometric dating would add greatly to the understanding of this complex and polymetamorphic region and important contributions have already been published (Broch 1964, McDougall & Green 1964, Brueckner et al. 1968, Priem 1967, 1968 and Priem et al. 1970). We add new conventional K-Ar and $^{40}Ar/^{39}Ar$ age determinations from the Nordfjord area, currently being mapped by one of the present writers (I. B.).

The $^{40}Ar/^{39}Ar$ method of age determination depends upon conversion of a known proportion of the natural isotope ^{39}K to the radioisotope ^{39}Ar by neutron activation and subsequent degassing and measurement of the ratio between this ^{39}Ar and radiogenic ^{40}Ar in a mass spectrometer (Mitchell

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1968, Dunham et al. 1968). The isotopic composition of the argon in the irradiated sample can be studied over a series of heating steps towards complete fusion. In this way a $^{40}Ar/^{39}Ar$ 'age spectrum' can be obtained (Fitch et al. 1969, Fitch & Miller 1970). For a historical review of the research which led up to the development of this method, see Kent et al. 1969, pp. 301–302. In a sample originally devoid of argon which has quantitatively retained naturally accumulating radiogenic argon since its formation, the two isotopes will be released in proportionate amounts during the heating and a multipoint $^{40}Ar/^{39}Ar$ isochron is obtained. Samples affected by geological age discrepancy – for example, samples which have suffered gain or loss of radiogenic argon since they were formed – produce $^{40}Ar/^{39}Ar$ ratios which vary from step to step. Samples containing extraneous argon have $^{40}Ar/^{39}Ar$ age spectra which can be distinguished from those affected by other forms of discrepancy. Many samples from complex terrains produce low $^{40}Ar/^{39}Ar$ ratios at early heating steps (which can be related to geologically late phases of argon degassing) and higher $^{40}Ar/^{39}Ar$ ratios at later heating steps (which come closer to indications of the 'true' age of the sample). Such a method may be a powerful geochronological tool in polymetamorphic rocks like those of the Gneiss region of Norway, although – like other K-Ar dating methods – interpretation is sometimes equivocal. Additional information may be obtained by considering the argon isotope ratio plot obtained during age spectrum analysis (see Fitch & Miller 1971, Miller 1971, Fitch et al. 1971). The argon isotope ratio plot is particularly valuable in the elucidation of initial argon error, in the evaluation of suspected introduced argon or argon loss errors and in improving the precision of certain age estimations. For a full discussion of discrepancy in K-Ar dating see Fitch 1971.

Regional geology

True Pre-Eocambrian rocks which unconformably underlie Eocambrian to Cambro-Silurian supracrustals and Precambrian Jotun thrust masses in Central Norway are hard to distinguish with certainty from younger or overthrusted rocks nearer to the coast where all contacts are conformable. But a distinction can be made between rather monotoneous gneisses below the glacier Jostedalsbreen and the heterogeneous rocks nearer to the coast (Bryhni 1966, Skjerlie 1969, Strand 1969, Kildal 1970). The two units have previously been termed the 'Jostedal' and the 'Fjordane' complexes respectively (Fig. 1). Recent authors have agreed that the rocks within the Jostedal Complex are Precambrian while opinions on the rocks of the Fjordane Complex differ. Greenschist facies supracrustals in the westernmost part of the area are indisputably Cambro-Silurian but the amphibolite facies gneisses and supracrustals with anorthosites, eclogites and ultrabasites in the eastern part of the Fjordane Complex have as yet an uncertain age. It has been speculated that they were: (1) granitized Eocambrian and Cambro-Silurian rocks –

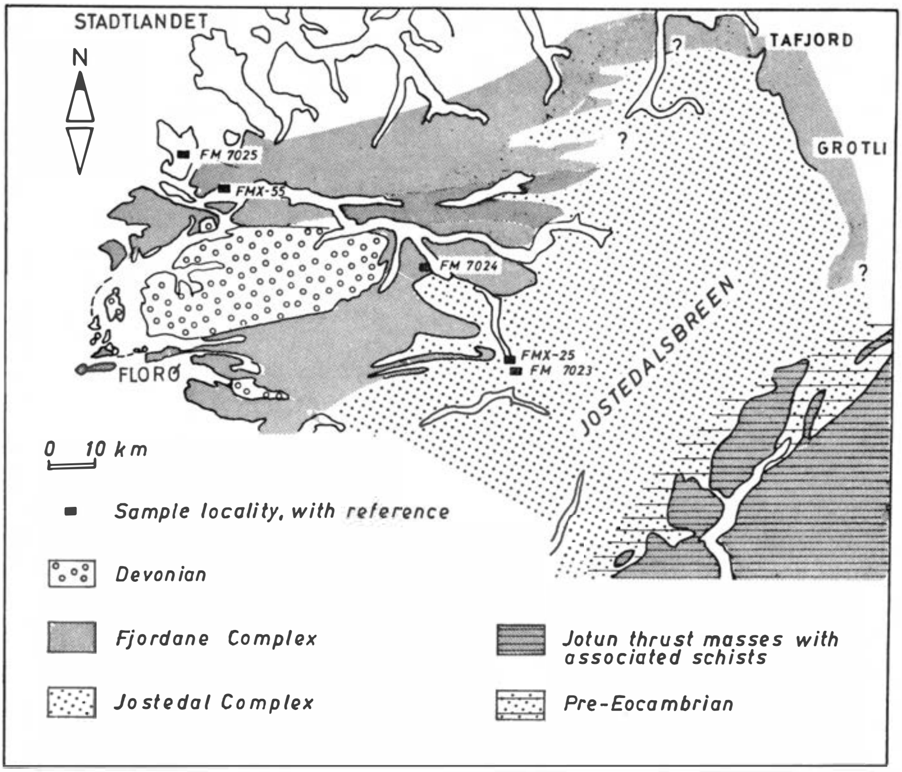

Fig. 1. Simplified and largely tentative geological map of western Norway between Jostedalsbreen and Stadtlandet with sample localities.

although it could not be denied that also older Precambrian rocks were present (Kolderup 1960, p. 15), (2) Precambrian gneisses reworked in the Caledonian orogeny (McDougall & Green 1964, pp. 193–194) or that they represent either (3) a stratigraphic sequence of essentially parautochtonous supracrustals of Late Precambrian to Cambrian age (Holsen and Askvoll groups of Skjerlie 1969, pp. 330–338), or (4) a tectonic succession of Precambrian to Eocambrian rocks and nappes similar to those east of the Jostedal culmination (Bryhni 1966, p. 11, Bryhni & Grimstad 1970, p. 137). Hernes (1967, 1968) has claimed that the anorthosites and related rocks of Nordfjord belong to the upper part of his 'late Precambrian-Eocambrian eugeosynclinal stratigraphic sequence' (Upper Tingvoll group), where the main part of the anorthosites are assumed to be Eocambrian volcanics.

Results

Sample localities are given in Fig. 1, the results of conventional K-Ar and $^{40}Ar/^{39}Ar$ total degassing age determinations are presented in Table 1 and $^{40}Ar/^{39}Ar$ age spectrum analyses in Table 2 and Figs. 2, 3 & 4. Petrographic descriptions on the dated rocks can be found in the Appendix.

Table 1. Conventional K-Ar and $^{40}Ar/^{39}Ar$ total degassing age determinations.

Sample	Method	K_2O %	Atmospheric contamination %	Vol. radiogenic ^{40}Ar in mm^3 NTP/gm	$^{40}Ar/^{39}Ar$	Apparent age (m.y.) and error
Biotite						
FMX-25	$^{40}Ar/^{39}Ar$		3.3		12.20	398± 2
Amphibole		1.25	8.4	0.0253		531±21
FM 7023	K-Ar	1.25	14.2	0.0270		561±22 } 552±22
Amphibole		1.25	10.7	0.0272		565±23
FM 7023	$^{40}Ar/^{39}Ar$		12.7		12.78	566±14
Pyroxene					26.38	1051±26
FM 7024	$^{40}Ar/^{39}Ar$		4.0			
Muscovite		10.3	16.3	0.1735		451±10
FMX-55	K-Ar	10.3	14.9	0.1691		441± 9 } 446± 9
Biotite		10.3	14.1	0.1710		445± 9
FM 7025	$^{40}Ar/^{39}Ar$		5.2		10.61	495±12

Ages calculated on the basis of $\lambda\beta = 4.72 \times 10^{-10}$ years^{-1} and λ_e 0.584×10^{-10} years^{-1}. J (constant of proportionality derived from the ^{39}Ar yield in standard muscovite USGS. P.270 and biotite N.388 irradiated by the same neutron dose) is 1.925×10^{-2} for FMX-25; 2.74×10^{-2} for FM 7023; 2.84×10^{-2} for FM 7024 and 2.83×10^{-2} for FM 7025. References to methodology can be found in Mitchell (1968) and Fitch et al. (1969).

JOSTEDAL COMPLEX

Samples FMX-25 and *FM 7023* are respectively biotite and amphibole concentrated from gneiss-granite and amphibolite. The gneiss is a rather coarse-grained variety of a unit which is sheared and partially recrystallized into an augen gneiss where it disappears below basal schists of the Fjordane Complex in large westwards plunging folds. The amphibolite occurs as a lenticular body in the gneiss. The total degassing $^{40}Ar/^{39}Ar$ age of biotite FMX-25 at 398 ± 2 m.y. is in agreement with the 'plateau' at 402 ± 1 m.y. recorded by stepwise degassing from step 7 onwards. Only a minor fractional loss of radiogenic argon (1%) has occurred since this time. A really excellent linear argon isotope ratio plot was obtained with a slope age of 405 ± 2 m.y. and an intercept on the $^{40}Ar/^{36}Ar$ axis of 25 ± 73 m.y. These results indicate that biotite in this ancient gneiss was completely outgassed by an important geological event which *ceased* at 405 ± 2 m.y., and that since that time, as only very minute losses and/or gains of argon isotopes have occurred from the lowest energy locales, it has not been involved in any further overprinting events. The low intercept value is compatible with overprinting at 405 ± 2 m.y. being due to reheating in a metamorphic environment and explains the small difference between the accepted age of 405 ± 2 m.y. for this event obtained from the slope of the argon isotope ratio plot and the ages obtained by $^{40}Ar/^{39}Ar$ total degassing and $^{40}Ar/^{39}Ar$ age spectrum age determination, both of which were calculated using conventional atmospheric argon procedures (see Fitch & Miller 1971 for a more detailed explanation of this matter).

Table 2. $^{40}Ar/^{39}Ar$ age spectrum analyses.

(a) *Argon release patterns*

	Heating step	Atmospheric contamination	$^{39}Ar/^{36}Ar$	$^{40}Ar/^{39}Ar$	Apparent age (m.y.)
Biotite FMX-25	3	75	27.6	3.57	125± 18
J=1.925×10^{-2}	4	47.1	50.6	6.55	224± 7
	5	18.8	144.5	8.81	295± 4
	6	6.0	387	11.94	390± 2
	7	2.4	950	12.26	399± 2
	8	1.8	2720	12.32	402± 2
	9	1.0	2340	12.30	400± 2
	10	0.9	1910	12.32	402± 2
	11	0.9	1540	12.33	402± 2
	12	1.0	1790	12.31	400± 2
	13	1.0	1900	12.38	403± 2
	14	0.9	2050	12.30	400± 2
	15	1.1	1840	12.39	403± 3
	16	1.2	1630	12.34	402± 2
Amphibole FM 7023	1	57.8	2.7	81.2	2105±126
J=2.53×10^{-2}	3	54.8	3.6	62.6	1790± 89
	5	39.3	13.0	35.0	1200± 48
	7	25.6	44.1	19.56	758± 30
	9	13.8	120	15.44	621± 19
	11	13.6	124	15.05	609± 18
	13	11.6	164	13.76	563± 17
	15	8.4	248	12.94	535± 16
	17	9.6	214	13.00	536± 16
	18	13.9	140	13.00	536± 16
Pyroxene FM 7024	1	95.1	7.8	2.61	130± 26
J=2.74×10^{-2}	2	46.3	34.4	9.94	454± 36
	3	37.8	44.1	11.06	500± 25
	4	7.5	136	26.85	1039± 21
	5	4.9	251	22.61	908± 18
	6	4.1	324	21.73	880± 18
	7	2.6	465	23.78	946± 19
	8	1.3	852	25.90	1011± 20
	9	1.4	662	29.11	1105± 22
	10	6.4	91.5	47.00	1560± 39
	11	28.9	18.0	40.51	1410± 70
Biotite FM 7025	1	98.0	2.9	2.27	120± 24
J=2.90×10^{-2}	2	73.4	21.6	4.97	254± 25
	3	51.9	37.2	6.68	334± 27
	4	19.6	127	9.58	463± 28
	5	3.8	725	10.25	491± 15
	6	1.1	2658	10.15	486± 10
	7	2.0	1412	10.21	489± 10
	8	2.0	1301	10.20	489± 10
	9	2.0	1465	10.10	484± 10
	10	2.3	1715	10.10	484± 10
	11	2.4	1186	10.05	483± 10
	12	2.1	1362	10.24	491± 10
	13	2.0	1425	10.24	491± 10
	14	2.2	1107	10.25	491± 10
	15	2.4	734	10.26	492± 10

Each step heating of 10 minutes duration

Table 2 (cont.)

(b) *Argon isotope ratio data*

Sample	Intercept on $^{40}Ar/^{36}Ar$ axis	Apparent age derived from slope of plot (m.y.)
FMX-25	25± 73	405± 2 (all points)
FM 7023	525± 31	524± 6 (all points)
FM 7024	398±272	1022±18 (RF 1–8 only)
FM 7025	228± 43	488± 2 (all points)

Another Caledonian date is recorded in the conventional K-Ar apparent ages for amphibole around 552 ± 22 m.y., which are in agreement with the total degassing $^{40}Ar/^{39}Ar$ apparent age of 566 ± 14 m.y. obtained from the same concentrate. Individual divergences in the runs, other than that due to the inherent experimental error, may be caused by excess argon and to effects of impurity and age inhomogeneity within the sample.

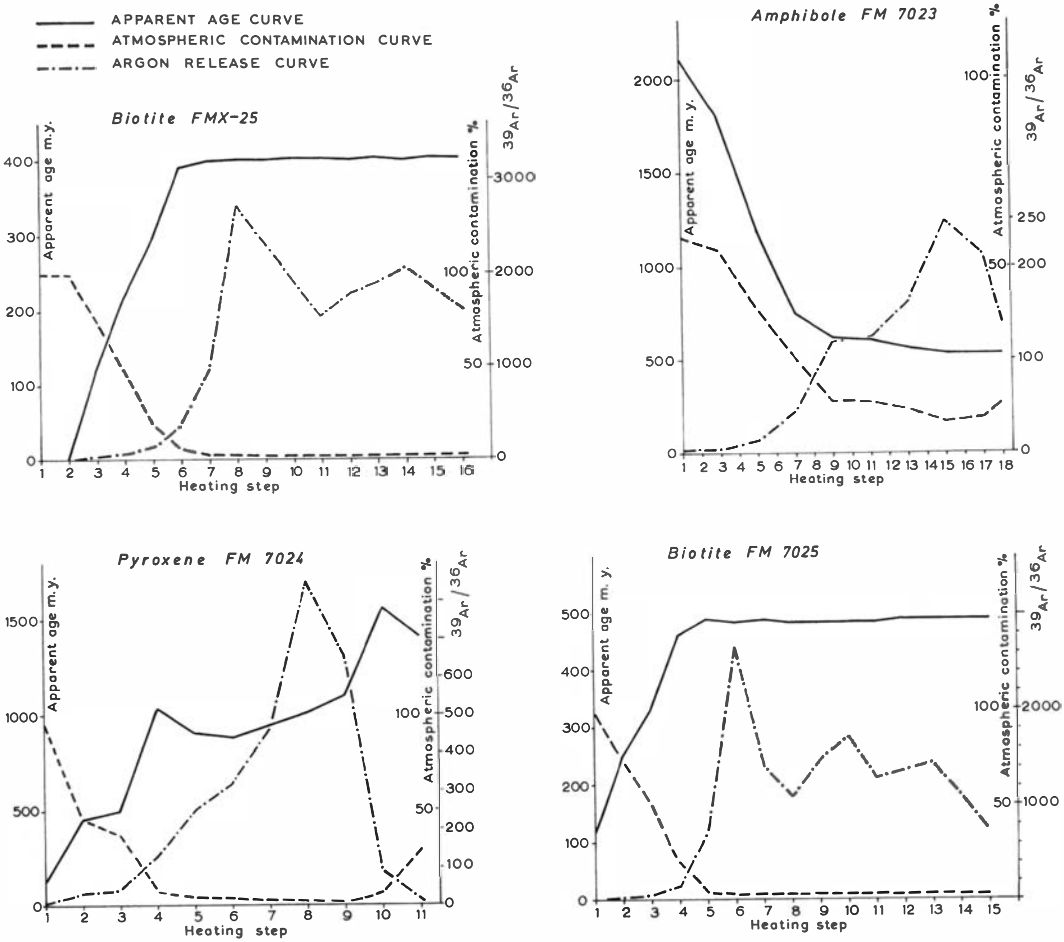

Fig. 2. $^{40}Ar/^{39}Ar$ release patterns ('age spectra') of the investigated samples.

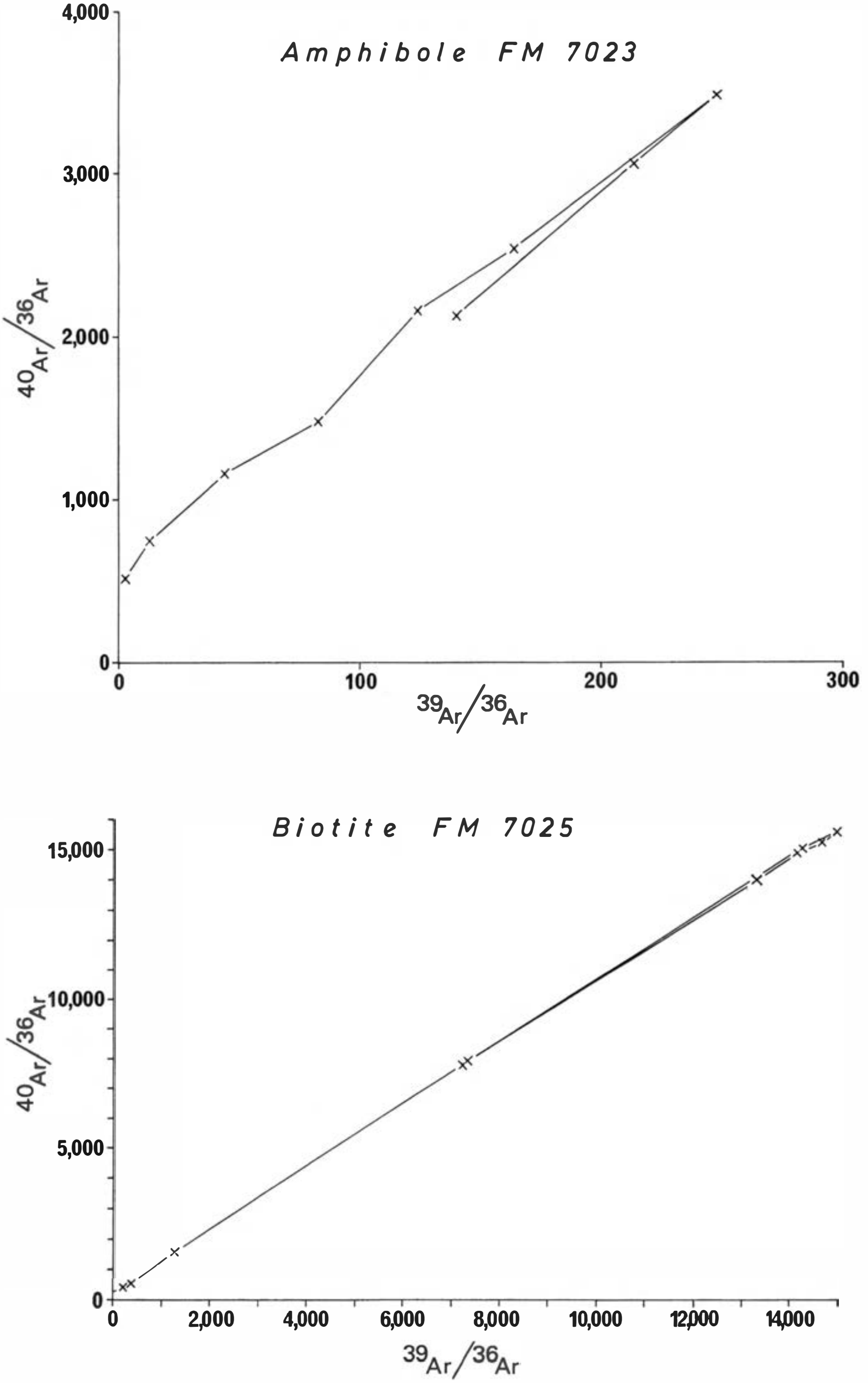

Fig. 3. Argon isotope ratio plots.

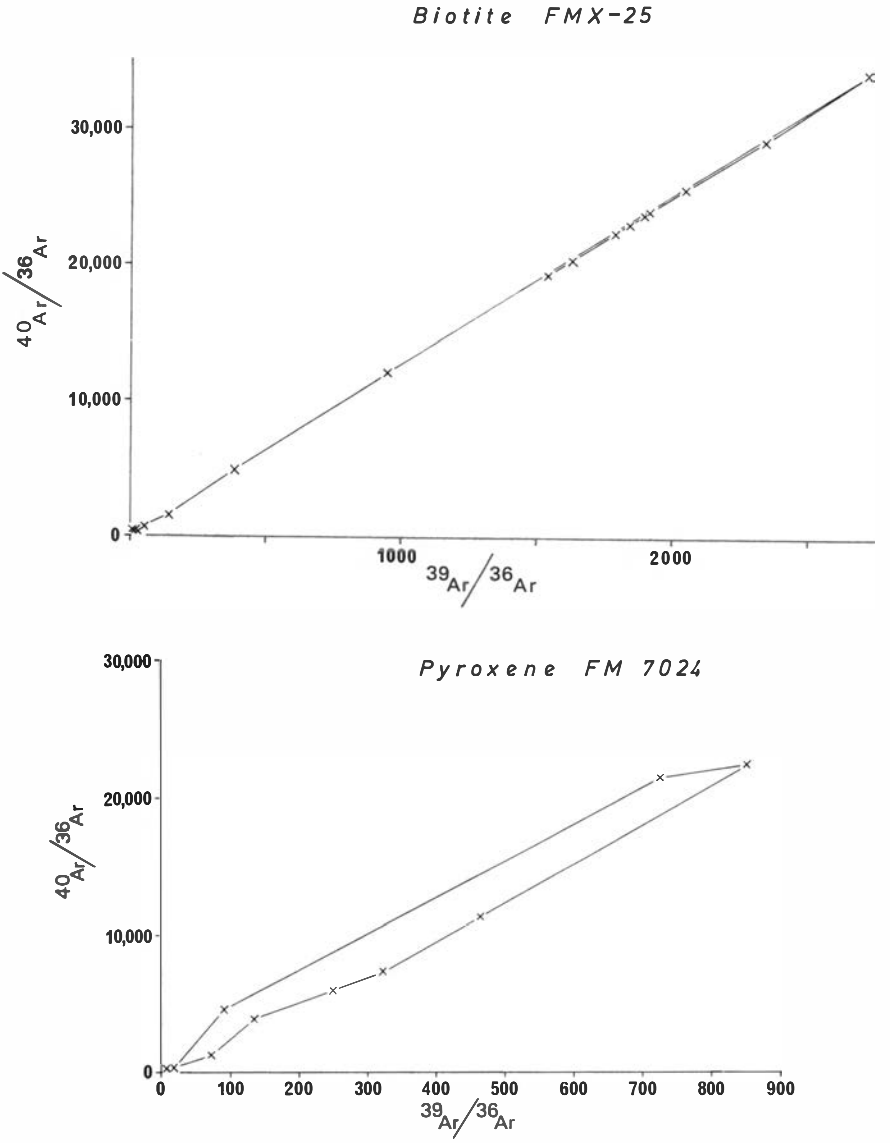

Fig. 4. Argon isotope ratio plots.

One interpretation of these total degassing ages from amphibole, against the background knowledge that adjacent gneisses of the Jostedal Complex have previously yielded Rb/Sr whole rock ages around 1,000–1,100 m.y. (Brueckner et al. 1968, Priem et al. 1970), whilst K-Ar and $^{40}Ar/^{39}Ar$ ages from biotite have been completely overprinted around 400 m.y., would be to suggest that they were 'mixed' ages representing incomplete overprinting of amphibole ages originally considerably in excess of 560 m.y.

Consideration of the $^{40}Ar/^{39}Ar$ age spectrum of this same concentrate indicates that the amphibole contains very small quantities of extraneous radiogenic argon which is present in non-lattice sites not related to those originally occupied by its parent potassium atoms. The spuriously ancient apparent ages obtained from steps 1, 3 and 5 are due very largely to this effect. The shape of the atmospheric correction curve, however, reveals that an additional 'initial argon' error is present throughout. The shapes of the argon release curve and the age spectrum from step 7 onwards may suggest that fractions with slightly different argon release patterns are present in the sample, possibly related to the texturally different and zoned varieties of amphibole seen in thin section. The major component responsible for the main argon release peak at step 15 has an apparent age of around 536 ± 16 m.y., for during the very flat three-point plateau at that age a large part of the argon is released. The argon isotope ratio plot is seen to be undoubtedly that of a mineral that has suffered almost completely metamorphic overprint under conditions of high argon partial pressure. The intercept on the $^{40}Ar/^{36}Ar$ axis is 525 ± 31 m.y. indicating the presence of a considerable amount of excess initial argon of high $^{40}Ar/^{36}Ar$ ratio. The slope age of 524 ± 6 m.y. is more precise than that obtained from the uncorrected spectrum or from the total degassing analyses.

FJORDANE COMPLEX

Sample FM 7024 is a pyroxene concentrate from an unusually massive body of augen gneiss in 'Anorthosite Kindred' rocks at Sande, Gloppen. The gneiss can be considered to be an original igneous granulite facies relict which is only partially affected by the amphibolite facies metamorphism – a close analogue to the 'mangeritic rock' of outer Nordfjord (Bryhni 1966, pp. 33–43). The surrounding rocks are dark grey banded gneisses with meta-anorthosite, amphibolite and serpentinite which together form a unit of wide regional extent, continuous with the 'Storeskarseggen banded gneiss and meta-anorthosite' of Bryhni & Grimstad (1970). The unit occurs above gneiss and meta-psammites (quartz schists) and other supracrustals of the lower part of the Fjordane Complex and is overlain by a 'stack' of new gneiss and Anorthosite Kindred units sandwiched between meta-psammites and other supracrustals. The succession is laid in open EW folds (F_2) which probably formed subsequent to a period of recumbent folding (F_1) where the sheet or inlier tectonics become established.

The apparent age of 1051 ± 26 m.y. obtained from a total degassing $^{40}Ar/^{39}Ar$ analysis of the pyroxene concentrate indicates that ancient radiogenic argon is undoubtedly present in this mineral. In this case the actual 'age' obtained can be regarded with some confidence as a 'mixed' age, i.e. it represents a date intermediate between the age of crystallization and the age of the last major overprinting event. This prediction is confirmed by the

$^{40}Ar/^{39}Ar$ age spectrum which has the shape typical of spectra from repeatedly overprinted rocks. No evidence of any significant error due to excess initial or introduced argon is present. Argon released from the most retentive sites suggests that the initial crystallization of the oldest generation of pyroxene occurred at least 1550 m.y. ago. The great bulk of the argon locales within the pyroxene crystals present, however, has an apparent age within the range 880–1105 m.y. Thus it is clear that this rock may have been involved in a major overprinting event (or series of events) during the period around 1000 m.y. There are also indications in the spectrum of another date of overprinting close to 500 m.y. ago, although this is represented by only a very small volume of argon.

The shape of the argon isotope ratio plot confirms the interpretation that at least two and possibly three main events in the history of the rock are contained within the spectrum results from this pyroxene concentrate. It is not possible to obtain satisfactory estimates for the ages of the earlier and later of these events from the plot, but the slope of the least mean squares best fit for the results from heating steps 1–8 suggests an age of 1022 ± 18 m.y. for the major intermediate event.

Sample FMX-55 is a muscovite which occurs in a pod secondarily within a body of eclogite in outer Nordfjord. Adjacent gneiss has previously yielded a K-Ar whole rock age of 372 m.y. while eclogites which occur further to the north and northwest have been shown to be Precambrian rocks in which phlogopite gives Caledonian dates at 415 m.y. (K-Ar) or 382 and 401 m.y. (Rb-Sr) (McDougall & Green 1964).

Conventional total degassing K-Ar age determinations on sample FMX-55 gave apparent ages around 446 ± 9 m.y. Again, the background knowledge that adjacent rocks show evidence of Caledonian overprinting dates around 400 m.y. could be taken to suggest that the recorded K-Ar dates were 'mixed' ages, representing incomplete overprinting of muscovite ages originally in excess of 446 ± 9 m.y. In the absence of age spectrum confirmation of this view, another possible interpretation could be that the more retentive muscovite has recorded a higher cooling age than adjacent phlogopite and gneiss. In either case, the true age of crystallization of the muscovite must be accepted Ordovician or older.

Sample FM 7025 is a biotite concentrate from an augen gneiss in a retrograded part of a 'mangeritic' rock body near Måløy (Bryhni 1966, pp. 33–43) which displays granulite-facies mineral assemblages preserved as relicts within almandine-amphibolite facies gneiss.

Biotite of the 'mangeritic' bodies of this area occur as two varieties, (?) primary and secondary, and sample FM 7025 is a biotite of the secondary variety. The total degassing $^{40}Ar/^{39}Ar$ date at 495 ± 12 m.y. is in agreement with the 'plateau' at 488 ± 10 m.y. recorded by stepwise degassing from step 5 onwards. Consideration of the argon isotope ratio plot allows this apparent age to be determined with greater precision at 488 ± 2 m.y. and indicates that it represents either complete thermal or metamorphic overprinting or recrystallization of biotite already existing in an older rock at that date. It might be related to the age of the almandine-amphibolite facies regional metamorphism or to an even younger thermal event.

Discussion

It is always difficult to tell whether conventional K-Ar dates are incorrect because of excess argon or argon loss errors, or, if correct, whether they relate to specific orogenic-thermal events or rather are related to the cooling interval when the regional temperature passed threshold values below which radiogenic elements ceased to diffuse out of the mineral systems. This uncertainty can be resolved by $^{40}Ar/^{39}Ar$ age spectrum geochronometry (see Fitch et al. 1969, Fitch & Miller 1971 and the discussion on pp. 298–304 in Kent et al. 1969). With due allowance for possible errors, the chronology of apparent ages recorded in the present study can be summarized as follows:

∼ 405 m.y.	(Biotite FMX-25):	apparently an overprinting 'event'.
> 446 m.y.	(Muscovite FMX-55):	apparently a 'mixed' age.
∼ 488 m.y.	(Biotite FM 7025, possibly also Pyroxene FM 7024):	apparently an overprinting 'event', possibly when secondary biotite crystallized.
∼ 524 m.y.	(Amphibole FM 7023):	apparently an overprinting 'event'.
∼1022 m.y.	(Pyroxene FM 7024):	apparently an overprinting 'event'.
>1550 m.y.	(Pyroxene FM 7024):	apparently an early metamorphic event.

CALEDONIAN AGES

There is ample evidence from the Norwegian Caledonides that metamorphic events were followed by uplift and erosion before subsequent deposition. Vogt (1928) based his chronology of Caledonian orogenies on conglomerate horizons on regional extent.

Our 405 m.y. apparent age (Early Devonian) falls within the range 372–427 which has been recorded previously from the Gneiss region as conventional K-Ar whole rock, conventional K-Ar biotite and Rb-Sr biotite apparent ages (Broch 1964, McDougall & Green 1964, Brueckner et al. 1968, Strand 1969, Priem et al. 1970), e.g. through Silurian into Middle Devonian. Is this Ardennian date to be regarded as an orogeny more penetrative than any of the previous orogenies in the Caledonides (Vogt 1928, p. 109) or should it rather be considered as a cooling date (Moorbath 1967, p. 125)? Our radiometric data cannot by itself decide this problem, but it does suggest *very strongly* that an important thermal/orogenic overprinting event did occur around 400 m.y. In this respect, it should be kept in mind that Middle Devonian and older Old Red clastics rest in western Norway with profound angular unconformity on folded rocks where the youngest elements are Upper Ordovician or Lower Silurian. The rock body in this part of the Caledonides must have been folded, uplifted, eroded and cooled during the Silurian period. The very thick accumulations of Old Red sediments in fault-bordered basins, their folding, slight metamorphism, thrusting and locally even volcanic accumulations indicate that there have been orogenic movements also through the Silurian/Devonian boundary and into the Devonian period – albeit scattered and local in their distribution. Upper Silurian rocks have been folded along EW axes in south-eastern Norway, and it is tempting to relate some of the EW folding in western Norway also to movements near the Silurian/Devonian time boundary, possibly at our recorded date of 405 m.y. ago.

The higher apparent ages recorded by muscovite FMX-55, biotite FM 7025 and amphibole FM 7023 can be related with results by Strand (1969, p. 357) that the almandine-amphibolite facies metamorphism at Grotli occurred before 463 ± 6 m.y. ago, and by Sturt et al. (1967) that the last major plutonic event at Sørøy in northern Norway was completed before 490 m.y. ago. Of particular interest in western Norway is Kvale's observation (1960, pp. 14–15, 41) that Middle Ordovician supracrustals with trondhjemite intrusions were metamorphosed, and exposed to erosion before deposition of the now folded (?)Upper Ordovician Moberg conglomerate. A corresponding break in deposition probably occurs below the (?)Upper Ordovician Upper Herland Group (Skjerlie 1969, p. 340) not far from our area. Taken in all, geochronological and stratigraphical evidence suggest that the main and most widespread Caledonian orogenic events in western Norway occurred within the Early Ordovician or before. Sturt et al. (1967, p. 267) have already suggested that this early (Trondhjem orogeny according to Vogt 1928, pp. 101–104) phase of the Caledonian orogeny took place over wide areas of the European Caledonides. Our results suggest that two important maxima of these orogenic/metamorphic events occurred 524 and 488 m.y. ago.

PRECAMBRIAN AGES

The Anorthosite Kindred rocks and various related lithologies in the Fjordane Complex in our area may correspond to the overthrust masses of central Norway where a Rb-Sr whole rock date at 1550 (± 100) m.y. has been recorded (Priem 1967, 1968). The structural geology of our rocks is not yet perfectly understood, but inlier tectonics like the Moine/Lewisian interrelation in the Scottish Caledonides is strongly suggested. Rocks similar to the Anorthosite Kindred of western Norway occur, in fact, in the Lewisian basement of the outer Hebrides (Dearnley 1963, Watson 1969). The $>$1550 m.y. date recorded in pyroxene FM 7024 may be correlated with the Laxfordian (1900–1550 m.y.) of the Lewisian basement in Scotland (where a few apparent ages of uncertain interpretation have been recorded in some areas (Fitch 1965, Moorbath et al. 1967)). The date of around 1022 m.y. from our pyroxene, however, can only be interpreted as representing important overprinting in the Fjordane Complex around that time.

The regional extent of Precambrian dates in the Gneiss region of Norway is indicated by Rb/Sr whole rock ages in the 1600–1800 m.y. range from Trollheimen (Priem 1967), and in the 1057–1078 m.y. range from western Jotunheimen (Priem et al. 1970) and a Rb/Sr whole rock isochron age of 1000 ($\pm$ 150) m.y. from Tafjord (Brueckner et al. 1968). McDougall & Green's results on eclogites (1964) which gave conventional K-Ar apparent ages at 1740–1850 m.y. and 950–1170 m.y. have indeed been confirmed by later data. They are also in agreement with recent results from northern Norway where Heier & Compston (1969) found a very penetrative 1800 m.y. event to have affected most of the basal gneisses of Vesterålen. They found local rejuvenations at 1550 m.y. and possibly also at 1160 m.y. The presently available information suggests that the Gneiss region contains elements with radiometric ages comparable with the oldest rocks of the Precambrian foreland in southern Norway ($\sim$ 1478 m.y. in Rogaland, 1550–1600 m.y. in Telemark according to Versteeve 1970). These elements were recycled during the Sveconorwegian (Grenville, Dalslandian) orogeny about 1000 m.y. ago as in the southern part of the Baltic Shield and later partially affected or completely rewaked during various Caledonian orogenies or by thermal and/or their associated cooling events. On a global scale the Gneiss region might contain the eastern continuations of the Ketilidian-Sanerutian fold belt of East Greenland, be comparable with the Laxfordian of Scotland and confirm the former presence of a Grenville chelozone overlain by the Caledonian mobile belt as suggested by Fitch (1965).

The age and tectonic position of the psammitic supracrustals within the Gneiss region is still unsettled, and it is an important task for current field and radiometric research in the region to see to what extent, if any, Eocambrian to Silurian geosynclinal rocks are present.

Appendix

LOCALITIES AND DESCRIPTION OF ANALYSED SPECIMENS

FMX-25. Biotite from a gneiss-granite, sampled at Førde, Nordfjord (LP 660 340) near the southern end of Breimsvatn. The rock contains 24% quartz, 33% plagioclase, 32% perthitic alkali feldspar, 7% biotite and 2% sphene. Accessory and secondary minerals include apatite, calcite, chlorite, epidote, orthite, magnetite, sericitic muscovite, limonitized pyrite and idiomorphic zircon. Biotite (X: pale yellow, Y, Z: dark olive green) occurs as clusters of books 0.5–1.0 mm thick and as trains of somewhat smaller grains in sheared zones.

The rock was found to have a too low Rb/Sr ratio (0.04) for Rb/Sr whole rock age determination.

FM 7023. Amphibole from a quartz-biotite amphibolite in gneiss, sampled at the Grungen crossroads (LP 678 316) where the road to Førde, Nordfjord, takes off from the main road north of Jølster. The rock contains more than 75% amphibole (X: greenish yellow, Y: blue-green, Z: grass-green) of which the major portion is pigmented. Unpigmented amphiboles occur as rims, as porphyroblasts and as part of fine-grained granular aggregates of amphibole, biotite and sodic plagioclase. Biotite (X: colourless, Y, Z: olive-brown) occurs inside amphibole grains or intergrown with sodic plagioclase and amphibole. Apatite, magnetite with sphene rims, pyrite and rounded zircon occur as accessories.

FM 7024. Clinopyroxene from a coarse quartz-garnet-clinopyroxene-plagioclase-microperthite gneiss with plagioclase-mantled microperthite augen more than 5 cm wide at places. The rock was sampled at a creek about 1.5 km NW of Sande, Gloppen (LP 473 554) where a large block has been split during recent road construction work. The rock body is exposed about 300 m above in the steep hillside.

The augen gneiss is mesoscopically rather homogeneous and massive, but tectonic transitions into a foliated, fine-grained banded gneiss and anorthositic rocks are obvious. Thin sections of the investigated massive variety indicate much granulation of feldspar and some secondary formation (~ 5%) of amphibole and biotite. Microperthite (~ 50%) is a mesoperthite at places but usually contains the rather *refrigent* plagioclase-component as tiny lenticles or irregular bodies within a potash feldspar host. Plagioclase (~ 35%) has abundant inclusions of mica – sometimes as grains big enough to be identified as biotite and white mica – and zoisite. Clinopyroxene is pale-green with negligible pleochroism, contains inclusions of biotite and is often enclosed in deep-green amphibole. Hypersthene only occurs in dark domains within the gneiss body. Garnet is present as homogeneous grains or as irregular grains with abundant inclusions. Where the two varieties occur together, the homogeneous type is always rimmed by the inhomogeneous type. Apatite, black iron minerals, pyrite and much idiomorphic zircon occur as accessories.

The rock was found to have a too low Rb/Sr ratio (0.17) for Rb/Sr whole rock age determination.

FM 7025. Biotite from a biotite-quartz-plagioclase-microperthite augen gneiss at a roadside cutting south of Refsvikvatn near Måløy (KP 960 790). Apatite, black iron minerals, epidote minerals, muscovite, sphene and zircon occur as accessories.

The rock is mesoscopically foliated and microscopically granulated with about 50% microcline-twinned microperthite. The plagioclase-component of microperthite is present as rather *refrigent* tiny rods and lenticular bodies. Plagioclase grains (~ 35% of composition An 25) have abundant inclusions of mica and zoisite. Biotite (~ 5%) is pleochroitic with X: pale yellow, Y, Z: black-green and occurs as clusters of books with black iron minerals, epidote, muscovite and sphene.

The Rb/Sr ratio (0.78) was found unfavourable for Rb/Sr whole rock age determination.

FMX-55. Muscovite from a small eclogite body at Halvneset, east of Almenningen, outer Nordfjord. The mineral occurs as aggregates of books in amphibolized parts of the eclogite (Bryhni 1966).

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