EXCESS RADIOGENIC ARGON IN PYROXENES AND ISOTOPIC AGES ON MINERALS FROM NORWEGIAN ECLOGITES

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Abstract. Potassium-argon measurements on eclogites enclosed in gneisses of the Nordfiord area, Norway, show that the pyroxenes contain excess radiogenic argon, indicating the presence of a high partial pressure of argon at one or more periods during the history of these rocks. Potassium-argon determinations on secondary hornblende suggest that the eclogites are as old as 1800 m.y.; dates on phlogopite and hornblende in the range 950 to 1600 m.y. may be interpreted as indicating a metamorphism during this period. Micas from an altered eclogite and a country rock gneiss yield K-Ar ages of about 400 m.y., and Rb-Sr ages on two micas from altered eclogites also give dates of about 400 m.y., showing that the area was affected by the Caledonian orogeny.

Introduction

Improved techniques allow the use of pyroxenes for potassium-argon age determinations (HART, 1961; McDOUGALL, 1961). Recently HART and DODD (1962) showed the presence of excess radiogenic argon in pyroxenes from a skarn within amphibolite and from a pyroxene gneiss, and they suggested that this occurred during metamorphism by introduction of argon into the pyroxene lattice. Such behaviour introduces an unpredictable element into K—Ar 'ages' of pyroxenes, which is in contrast with the apparent reliability of igneous clinopyroxenes for dating, particularly from dolerites (McDOUGALL, 1961, 1963).

In this paper we report the potassium and argon contents of pyroxenes and associated minerals from some of the Norwegian eclogites described by ESKOLA (1921). In addition Rb—Sr ages were measured on two micas. The study was undertaken to examine further the apparent ages of pyroxenes that have been affected by metamorphism. The age results from hornblende and mica show that the area probably was affected by at least two metamorphic episodes prior to the Caledonian orogeny.

Analytical methods

Argon was determined by isotope dilution by the method previously described (MCDOUGALL, 1963). The argon extractions were made in a bakeable, high-vacuum, glass system, using about 1 gram of sample for each run. The isotopic composition of the argon was measured on a Reynolds mass spectrometer. Replicate argon measurements agree to better than 2 per cent and the accuracy is thought to be better than $\pm$ 2 per cent.

For those minerals in which the potassium concentration was greater than 0.1 per cent, measurements were made in duplicate using a Perkin—Elmer flame photometer, after the method described by COOPER (1963). Except for GA 760 amphibole, duplicate potassium determinations disagree by less than 1 per cent, and from previous comparisons with isotope dilution measurements the accuracy probably is better than $\pm$ 2 per cent (MCDOUGALL, 1963; COOPER, 1963). In the case of GA 760 amphibole, the poor reproducibility of the potassium results appears to be due to sample inhomogeneity.

Determination of potassium in the pyroxenes was made by isotope dilution. About 1 gram of sample was digested in HF and $HClO_4$ and after addition of K^{41} tracer the K was concentrated by ion exchange. The K concentrate was loaded as chloride on the side filament of a triple filament bead, and the K^{39}/K^{41} ratio measured on a Metropolitan Vickers type MS2 mass spectrometer. Diopside GA 756 was determined in triplicate; the spread in the measured K contents was 2 per cent. Only a single analysis was made on each of the other pyroxenes. The K blank for this method is about 5 μg and as the K concentrations are as low as 20 μg/g the blank correction is very significant. At this low level the accuracy is probably about $\pm$ 5 per cent. However, because of the exponential nature of the radioactive decay and the high radiogenic argon content of the pyroxenes, the calculated ages are relatively insensitive to quite large errors in the measured K concentrations. Thus in the case of GA 759 diopside, for which the measured K content was 0.0018 per cent, increasing the K concentration by 100 per cent decreases the calculated age by only 15 per cent. If in error the calculated ages are more likely to be too low owing to undetected contamination giving higher apparent K contents.

Rubidium and strontium were determined by isotope dilution as described by McDOUGALL, COMPSTON and HAWKES (1963). The ages on the two phlogopites determined by this method were calculated by assuming an initial Sr^{87}/Sr^{86} ratio of 0.71, but because of the degree of enrichment in radiogenic strontium in these micas a higher initial ratio would have a relatively small effect on the calculated age and would decrease the age.

Description of Eclogite Occurrences

The eclogites used in this study are among those described by ESKOLA (1921). They are from two distinct localities and of two distinct types. The first is an eclogite pegmatite at Grytingvaag near Selje [eclogite of 'Gryting' type (ESKOLA, 1921, p. 49 and fig. 4)] and occurs as a lens about 20 m long and 10 m wide within biotite- and garnet-bearing gneiss. The body is composite, consisting in part of medium grained eclogite (GA 757) of red pyrope-almandine garnet, deep green omphacite and accessory pyrite, and in part of pegmatitic enstatite eclogite (GA 761) with pyrope-rich garnet, enstatite (Mg_{86}) and diopside with accessory rutile. ESKOLA (p. 49) regarded the lens as being part of a larger eclogite body intersected by a primary enstatite eclogite pegmatite dyke.

Secondary alteration is extensive, particularly at the edges of the lens. The eclogite pegmatite locally contains little or no enstatite, but contains coarse flakes of phlogopite intergrown with secondary amphibole. This type of eclogite (GA 756) appears to be transitional to completely altered eclogite consisting of hornblende pseudomorphs and aggregates, containing well-crystallized phlogopite (GA 758).

The second eclogite body is of the type called 'Rødhaugen type' by Eskola and occurs as a small lens (1—2 m thick) in peridotite, in part garnet peridotite, between Lien and Helgehornsvand, Almklovdalen. Both the eclogite (GA 760) and the nearby garnet peridotite (GA 759) show very little low-temperature, retrogressive alteration. In the garnet peridotite (GA 759) this is confined to incipient serpentinization of olivine and kelyphitization of garnet. However the peridotite shows strong deformation of olivine, with garnet, chrome-diopside and enstatite tending to remain as larger augen during recrystallization of olivine.

In addition to the two eclogite occurrences, one example of biotite gneiss (GA 755) from near Totland, Nordfiord, was used to obtain a K—Ar age of a typical country-rock gneiss. This biotite gneiss contains eclogite lenses but is not the immediate host rock to either of the investigated eclogites.

Interpretation of Results

The K—Ar results are listed in Table 1, and the Rb—Sr results in Table 2.

Accepting current estimates of the age of the earth as about 4.5×10^9 yrs. then the diopside from the eclogite in peridotite (GA 760) and the chrome-diopside from the garnet peridotite (GA 759) both give impossible ages for the pyroxenes. Similarly the ages of pyroxenes from the composite eclogite lens in gneiss are all 'impossible' ages. All pyroxenes examined [one chrome-diopside (GA 759), three diopsides with low but significant jadeite contents (GA 760, GA 761, GA 756), one true omphacite (GA 757) and one enstatite (GA 761)] must be interpreted as either containing excess radiogenic argon or else as having lost K but not Ar in some event recent in comparison with their true age. Of these two possibilities, the first is the more probable. It is concluded that high partial pressure of radiogenic argon existed at some unknown time and that, under these conditions, the pyroxenes accepted argon into their structure.

In Table 3 the excess argon contents of the pyroxenes are examined for any significant pattern. We have calculated the amount of excess radiogenic argon present in each of the pyroxenes for ages of 1850, 1000 and 400 m.y.; these figures being chosen because they are the ages given by minerals occurring with the pyroxenes. If 1850 m.y. is taken as the real age of the eclogites then the calculations show that only 26 per cent (GA 761, enstatite) to 2 per cent (GA 759, diop-

Table 1. Potassium-Argon Results from the Nordfiord Region, Norway.

Sample Number	Field Number	Mineral	K analyses (wt. per cent)	$\frac{^{40}Ar^*}{^{40}K}$	Air Correction (per cent)	Calculated Age (m.y.)	Rock Type and Locality
GA 755	2523	Biotite . . .	7.88 7.90 } 7.89	0.0240	1.7	372	Gneiss, Totland
GA 756	2540	Diopside . .	0.0056 0.0057 0.0056 } 0.0056	1.268	37.7	4760	
		Amphibole	0.422 0.425 } 0.424	0.0752	7.5	980	Pegmatitic Eclogite (Grytingvaag)
		Phlogopite	7.82 7.84 } 7.83	0.0723	1.3	950	
GA 757	2544	Omphacite	0.0046	1.068	14.9	4470	Eclogite (Grytingvaag)
GA 758	2545	Amphibole	0.419 0.420 } 0.419	0.0940	4.3	1170	Phlogopite
				0.0924	3.9	1150	Hornblendite (Grytingvaag)
		Phlogopite	7.20 7.21 } 7.205	0.0272	1.9	415	
GA 761	2539	Enstatite .	0.0031	0.7175	52.8	3800	Enstatite
		Diopside . .	0.0038	1.493	12.2	5050	Eclogite
		Amphibole	0.0966 0.0979 } 0.0973	0.1691	7.8	1750	Pegmatite (Grytingvaag)
				0.1670	13.9	1740	
GA 759	2501	Diopside .	0.0018	8.092	4.4	8100	Garnet Peridotite (Rødhaugen)
GA 760	2507	Diopside . .	0.0032	5.319	15.7	7350	Eclogite (Rødhaugen)
		Amphibole	0.216 0.228 0.213 } 0.219	1.836	6.1	1850	

$^{40}Ar^*$ — radiogenic argon $\lambda_\beta = 4.72 \times 10^{-10}\ yr^{-1}$ $\lambda_k = 0.584 \times 10^{-10}\ yr^{-1}$ $K^{40} = 1.19 \times 10^{-4}$ mole/mole K

Table 2. Rubidium-Strontium Analytical Data.

Sample Number	Mineral	Rb p.p.m.	Sr p.p.m.	$\frac{^{87}Rb}{^{86}Sr}$	$\frac{^{87}Sr}{^{86}Sr}$	Calculated Age (m.y.)
GA 756	Phlogopite ...	466	25.94	51.65	0.9998	401
GA 758	Phlogopite ...	314.7	8.01	113.0	1.3129	382

$\lambda_\beta = 1.39 \times 10^{-11}$ yr^{-1}

Table 3. Argon Content of Pyroxenes and Calculated Excess Radiogenic Argon Content for Various Ages.

Sample Number	Mineral	K content (wt. pr. cent)	Ar content (10^{-11} mol/g)	Excess radiogenic argon content (10^{-11} moles/g) for 400 m.y. age	1000 m.y. age	1850 m.y. age
	Grytingvaag — eclogite pegmatite lens in gneiss					
GA 756	Diopside ..	0.0056	21.60	21.16	20.29	18.47
GA 761	Diopside ..	0.0038	17.08	16.78	16.20	14.98
GA 757	Omphacite	0.0046	14.95	14.59	13.87	12.38
GA 761	Enstatite..	0.0032	6.88	6.63	6.14	5.12
	Rødhaugen — eclogite lens in peridotite					
GA 760	Diopside ..	0.0032	52.44	52.18	51.68	50.63
GA 759	Diopside ..	0.0018	45.31	45.16	44.88	44.28

side) of the radiogenic argon could have formed by decay of K^{40} present in the lattice of the pyroxenes during this time.

Table 3 shows that, whatever the real age of the clinopyroxenes, the excess argon contents are similar for all the clinopyroxenes from any one locality, i.e., the three Grytingvaag clinopyroxenes have similar excess argon contents and these differ from the two much higher values for the Rødhaugen locality. Such a relationship is suggestive that the partial pressure of argon could be a controlling factor in determining excess argon content, and that this partial pressure was higher in the Rødhaugen than the Grytingvaag locality. The lower excess argon of the enstatite (GA 761) co-existing with the diopside indicates that under the same conditions the orthopyroxene structure has accepted less excess radiogenic argon than the clinopyroxene. HART and DODD (1962) suggested that the excess argon is held in crystal imperfections such as dislocations and low-angle grain boundaries.

Detection of excess radiogenic argon in pyroxenes is possible because of their extremely low K contents. Such behaviour may be expected in any mineral with a low K content that has been exposed to a high partial pressure of argon. Conversely, minerals with a high K content, such as micas and K-feldspar, would not be expected to possess excess argon, because the production of a high argon partial pressure is most likely the result of loss of argon from these minerals by diffusion.

The presence of excess radiogenic argon in the pyroxenes makes it difficult to interpret K—Ar ages from these rocks or their secondary alteration products. Thus the dates on amphiboles GA 761 and GA 760 may be true ages, ages that are too old due to excess argon produced by the same high argon partial pressure that affected the pyroxenes, or ages that are too low due to partial argon loss. There are no 'impossible' ages given by the amphiboles and it is considered that the ages of 1850 and 1750 m.y. given by amphiboles GA 760 and GA 761 respectively are close to a meaningful age. As evidence favouring this interpretation it should be noted that although there is over twice the K content in GA 760 than in GA 761, yet the amphiboles give similar ages. In contrast the three pyroxenes from GA 760 and GA 761 give very different apparent 'ages' due to varying excess argon content.

It is clear that there can be no unique interpretation of results on amphiboles and micas but in the absence of evidence to the contrary, it is assumed that these minerals do not contain excess radiogenic argon and give evidence on the ages and sequence of events in the area.

The two oldest amphibole ages, 1850 and 1750 m.y., are from hornblendes in the enstatite eclogite pegmatite (GA 761) and the eclogite in peridotite (GA 760). In both cases the hornblende occurs as subhedral crystals, much smaller in grain-size than the garnet and pyroxenes, usually along grain boundaries but rarely cutting across the pyroxene grains. The hornblende does not show a pseudomorphic relation to the pyroxenes and is clear and well-crystallized. The growth of hornblende probably represents the first stage of the retrogressive alteration of the eclogite to amphibolite. As such it could represent the waning of the P—T environment responsible for the eclogite assemblage or a separate, later metamorphic event producing amphibolite facies rocks.

The amphibole of the phlogopite-bearing eclogite (GA 756) can be seen in many places to be in replacement relationship to pyroxene and particularly garnet. On the other hand it is of coeval crystallization with phlogopite. The rock contains much relict pyroxene and garnet and is not as strongly altered as the end product of retrogressive metamorphism, the phlogopite amphibolite (GA 758). Phlogopite and hornblende from GA 756 yield K—Ar ages of 950 and 980 m.y. respectively (Table 1), whereas the phlogopite has a measured Rb—Sr age of 400 m.y. (Table 2). The hornblende from GA 758 gives a K—Ar age of 1160 m.y. and the phlogopite from this rock has a 'Caledonian' age of 415 m.y. by K—Ar and 380 m.y. by Rb—Sr.

Notwithstanding the fact that these rocks have had a complex metamorphic history it is possible to draw some tentative conclusions as to the probable meaning of the apparent ages. The relatively good agreement between the K—Ar ages of hornblende and phlogopite from GA 756 suggests that the apparent age of 965 ± 15 m.y. is significant, particularly as the potassium contents of the two minerals differ by a factor of more than 18. However, the much lower Rb—Sr age of 400 m.y. on the phlogopite requires explanation. Such a large difference in apparent age by the K—Ar and Rb—Sr methods in some metamorphic rocks contrasts markedly with the reasonable agreement generally found between both methods on minerals from igneous rocks, in which any difference usually is reflected in a lower K—Ar age. However, in complex metamorphic areas older apparent K—Ar ages than Rb—Sr ages have been reported previously by RICHARDS and PIDGEON (1963) from Broken Hill, Australia. The older K—Ar age of GA 756 phlogopite compared with the Rb—Sr age may be the result of a high partial pressure of argon, developed during the metamorphism in Caledonian times, inhibiting leakage of radiogenic argon from the mica, although radiogenic strontium has migrated out of the mica. This explanation is similar to that advanced by RICHARDS and PIDGEON (1963) to account for their Broken Hill results. Our study strengthens this hypothesis as the presence of excess argon has been demonstrated in the pyroxenes, indicating that a high, but unknown, partial pressure of argon existed at one or more periods during the history of these rocks.

It is worth stressing that the operation of a high argon partial pressure, caused by argon diffusion from minerals with a high K content, in a rock undergoing metamorphism, is to give grossly excess ages for low K-pyroxenes but to preserve the Ar content of the high K-phlogopite, and thus to give a minimum age for the earlier crystallization.

Both Rb—Sr and K—Ar ages on phlogopite from GA 758 are typically Caledonian. In this rock the K—Ar age of the hornblende is much older at 1160 m.y. Similar large differences in measured K—Ar ages on co-existing hornblende and mica have been found in metamorphic rocks of the Front Range, Colorado (HART, 1964), and may be the result of the higher retentivity of radiogenic argon in hornblende compared with mica. Another factor contributing to the age discrepancy in this Norwegian phlogopite amphibolite may be the relatively high partial pressure of argon produced during metamorphism in Caledonian times. However, the argon partial pressure necessarily would be lower than in the region of GA 756, because the phlogopite from GA 758 has lost much of its radiogenic argon during the Caledonian metamorphism.

In the absence of excess radiogenic argon in these minerals then the ages given are either the true ages of their crystallization or ages between the true age and the age of the last metamorphic event affecting the area. The following sequence of events is compatible with both petrography and age determinations:

1. Crystallization of eclogite in a high-pressure environment.

2. Growth of subhedral hornblende on grain boundaries in the eclogite. This was possibly a late effect in the waning of the eclogite facies conditions and implies the access of water into the eclogite and very probably the access of K since the hornblendes contain higher K (.219 and .097 per cent) than either clinopyroxene (.0032 and .0037 per cent) or garnet ($<$.01 per cent).

This event occurred at least 1800 m.y. ago (isotopic ages of 1850 and 1750 m.y.) and gives a minimum age for the eclogite crystallization.

3. Detachment of the eclogite and peridotite bodies and incorporation into deforming acid and mixed gneiss (cf. ESKOLA, 1921;

KOLDERUP, 1960), or alternatively, fragmentation of larger eclogite and peridotite bodies into lenticular, often extremely large "boudins" in the more rapidly deforming gneiss. This event is marked by marginal retrogressive alteration of eclogite to amphibolite. The gneisses enclosing the eclogite and peridotite are generally of amphibolite or lower metamorphic facies, although there are granulite facies rocks from Stadt, i.e., in the region of the eclogite localities, and from further north (ESKOLA, 1921; ROSENQVIST, 1956).

This event is characterized in the eclogite pegmatite by the extensive introduction of K with crystallization of phlogopite and by the complete replacement of the eclogite by a phlogopite hornblendite. The K—Ar ages on minerals of this generation are 980 m.y. (hornblende, GA 756), 950 m.y. (phlogopite, GA 756), 1160 m.y. (hornblende, GA 758) and 420 m.y. (phlogopite, GA 758). There is no unique interpretation of these results — the event may have occurred about 1800 m.y. ago and the lower ages may be the result of varying argon loss during the Caledonian orogeny. The fair agreement of phlogopite and hornblende K—Ar ages for GA 756 may indicate that all these minerals date an event of 950 to 1160 m.y. age, with argon loss in the Caledonian orogeny in phlogopite GA 758.

4. The Caledonian orogeny clearly affected this area as shown by the K—Ar and Rb—Sr ages on micas in the range 370 to 420 m.y. However, the much older ages recorded for hornblende and one mica by the K—Ar method show that the metamorphism during the Caledonian orogeny did not cause loss of all the pre-existing radiogenic argon from these minerals.

Comparison with Other Age Measurements on Norwegian Rocks

The compilation of ages on Norwegian rocks by NEUMANN (1960) suggests that two main orogenies affected the region in pre-Permian times. In the north and west of Norway ages range from 350 to 600 m.y., clearly reflecting the Caledonide folding and metamorphism. In the south and northeast ages are reported which, in general, range from about 750 to 1100 m.y., and Neumann suggested that the two most important geological events occurred in the Precambrian at about 900 to 950 m.y. and 1100 m.y. Neumann draws attention to the apparent lack of evidence for events between 1400 and 1800 m.y., corresponding to events which are well recorded in rocks in Sweden and Finland. The oldest amphibole ages here reported provide some evidence for an 1800 m.y. orogenic event in Norway. This may be compared directly with the extensive Svecofennian and Karelian terrains in Sweden and Finland, cut across by the Caledonian belt, and giving ages commonly in the range 1750—1850 m.y. (MAGNUSSON, 1960).

The gneisses enclosing the eclogite and peridotite lenses are part of the Basal Gneiss of Norway. There appear to be three possibilities as to age and correlation of this Basal Gneiss:

i) The Basal Gneiss can be correlated with the Precambrian gneiss of southern Norway, folded but not greatly modified in the Caledonian orogeny.

ii) The Basal Gneiss may represent an original basement to the Eo-cambrian and Lower Palaeozoic sediments, but if so has been infolded and re-metamorphosed in the Caledonian orogeny so that the rocks as we now see them reflect Caledonian structures and Caledonian grades of metamorphism.

iii) The Basal Gneiss is intensely metamorphosed and deformed Lower Palaeozoic and Eo-cambrian sediments.

Following the second or third concepts Kolderup (1960), writing on the origin of the eclogites in gneisses from Bergen to Nordfiord, suggested that the eclogites are Caledonian igneous rocks, related to Caledonian gabbros in the Cambro-Silurian south of Bergen, but in the northern areas metamorphosed to eclogites and eclogitic amphibolites. GJELSVIK (1952, pp. 123—4) suggested that some of the eclogites of the region discussed herein may be altered dolerites of the type occurring as lenses in the gneiss area to the northeast and east. The age of these dolerites and the enclosing gneiss cannot be clearly established but Gjelsvik presents some arguments for a Caledonian age.

The concept that the eclogites which we have examined are products of the Caledonian orogeny is not consistent with our interpretation of the K—Ar ages here presented. These show that the eclogite and peridotite of the Selje and Almklovdalen districts were partly affected by the Caledonian orogeny, but owe their original crystallization to a much earlier period, and their main secondary alteration also to an earlier Precambrian event, possibly in the range 950 to 1150 m.y. These dates suggest that metamorphic events which affected rocks of southwest Norway also affected the Nordfiord region. Other age determinations reported (NEUMANN, 1960) from the gneiss area of this region of Norway include two Caledonian ages of 385 and 405 m.y. (K—Ar) on biotites in gneiss from the Romsdal area, and older ages of 582 m.y. (K—Ar) on muscovite in gneiss from Loen, Nordfiord and of 590 m.y. (K—Ar) on mica in pegmatite from Ortnevik, Sogn.

The Vesterålen region of northern Norway described by Heier (1960) has a geographically similar location with respect to the Caledonian orogenic belt as the region discussed here. In Vesteralen an age pattern can be discerned which may be interpreted as being the result of partial argon loss from Precambrian metamorphics involved in the Caledonian orogeny. Molybdenites from the adjacent area of Lofoten, in the same province, give Re—Os ages of approximately 2000 m.y., whereas K—Ar ages on micas and feldspars from the Vesterålen area range from 650 to 420 m.y. (NEUMANN, 1960).

Conclusions

The presence of excess radiogenic argon is demonstrated in clinopyroxenes and enstatite from eclogites. Extreme caution is necessary in the use of such minerals for K—Ar age determination (c.f. MILLER *et al.*, 1963), since flame photometric methods of potassium determination at levels <0.1 per cent are extremely difficult (COOPER, 1963), and the environment of some eclogites as lenses within acid gneiss affected by several metamorphic episodes is one favourable for incorporation of excess radiogenic argon into the pyroxenes.

The radiogenic argon and potassium contents of secondary amphiboles and micas in the eclogites examined can be interpreted without postulating excess radiogenic argon in the minerals. These minerals provide evidence for a Precambrian (Svecofennian) age for the eclogite and peridotite, and a Precambrian age for their main secondary alteration. Rb—Sr and K—Ar ages on micas show that the area also suffered metamorphism during the Caledonian orogeny.

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REFERENCES

COOPER, J. A., 1963: The flame photometric determination of potassium in geological materials used for potassium-argon dating. Geochim. et Cosmochim. Acta, V. 27, pp. 525—546.

ESKOLA, P., 1921: On the eclogites of Norway. Videnskapsselsk. Skr. I. Mat.-naturv. Kl. No. 8. pp. 1—118.

GJELSVIK, T., 1952. Metamorphosed dolerites in the gneiss area of Sunnmøre on the west coast of Southern Norway. Norsk Geol. Tidsskr., V.40, pp. 33—134.

HART, S. R., 1961: The use of hornblendes and pyroxenes for K-Ar dating. Journ. Geophys. Res., V.66, pp. 2995—3001.

— , 1964: The petrology and isotopic mineral age relations of a contact zone in the Front Range, Colorado. Journ. Geol. (in the press).

— and DODD, R. T., 1962: Excess radiogenic argon in pyroxenes. Journ. Geophys. Res., V.67, pp. 2998—2999.

HEIER, K. S., 1960: Petrology and geochemistry of high-grade metamorphic and igneous rocks on Langøy, Northern Norway. Norges Geol. Unders., V. 207, pp. 1—246.

KOLDERUP, N.-H., 1960: Origin of Norwegian eclogites in gneisses. Norsk Geol. Tidsskr., V.60, pp. 73—76.

McDOUGALL, I., 1961: Determination of the age of a basic igneous intrusion by the potassium-argon method. Nature, V.190, pp. 1184—1186.

— , 1963: Potassium-argon age measurements on dolerites from Antarctica and South Africa. Journ. Geophys. Res., V.68, pp. 1535—1545.

— , COMPSTON, W. and HAWKES, D. D., 1963: Leakage of radiogenic argon and strontium from minerals in Proterozoic dolerites from British Guiana. Nature, V. 198, pp. 564—567.

MAGNUSSON, N. H., 1960: Age determinations of Swedish Precambrian rocks. Geol. Fören. Förh., V.82, pp. 407—432.

MILLER, J. A., BARKER, A. J. and KEMPTON, N. H., 1963: A potassium-argon age determination from a Lewisian inlier. Nature, V.197, pp. 1095—1096.

NEUMANN, H., 1960: Apparent ages of Norwegian minerals and rocks. Norsk Geol. Tidsskr., V.40, pp. 173—192.

RICHARDS, J. R. and PIDGEON, R. T., 1963: Some age measurements on micas from Broken Hill, Australia. Journ. Geol. Soc. Australia, V.10, pp. 243—260.

ROSENQVIST, I. TH., 1956: Granulitt-mangeritt-eclogitt. Norsk Geol. Tidsskr., V.36, pp. 41—48.

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