# Ages of lamprophyre dykes from Ytterøy and Lerkehaug, near Steinkjer, Central Norwegian Caledonides

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$^{40}Ar/^{39}Ar$ stepwise degassing age spectra have been obtained from phlogopite phenocrysts from two lamprophyre dykes in the Trondheimsfjord district. Phenocrysts of phlogopite from a previously investigated, unmetamorphosed, post-Scandian lamprophyre on Ytterøy have yielded a complex age spectrum with no clear plateau; however, the calculated 'total fusion' age is 370 Ma, supporting earlier indications of a probable late-Caledonian (Devonian) age for this dyke. The 'saddle-shaped' release curve for phlogopite from a weakly metamorphosed lamprophyre from the Leksdalsvatn Nappe near Steinkjer suggests that the rock is younger than c.688 Ma and probably Late Precambrian, although a Cambrian age cannot be excluded. An upper constraint is set by the initial regional metamorphism in this nappe which, based on data from elsewhere in the orogen, may be of Early Ordovician age.

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The island of Ytterøy in Trondheimsfjord (Fig. 1), Central Norway, is known to geologists largely through the occurrence, in Lower Palaeozoic metasediments, of a solitary lamprophyre dyke (Carstens 1961). The paleomagnetic properties of the dyke formed the basis of an initial attempt to determine its probable age, and led to the conclusion (Storetvedt 1967) that a Late Caledonian emplacement age was more likely than the suggestion of a Permian age proposed by Carstens. An isotopic age study of biotite phenocrysts from the dyke yielded discordant Rb-Sr and K-Ar ages (Priem et al. 1968): 256 Ma by the Rb-Sr method (recalculated according to the decay constants of Steiger & Jäger 1977), and 370 Ma by K-Ar (recalculated after Dalrymple 1979). Priem et al. (1968) argued that 'there can be little doubt, however, that the K-Ar age sets a reliable date for the intrusion of the dyke', and thus concurred with Storetvedt's conclusions.

In a study of hypabyssal rocks from the district east of Steinkjer (Fig. 1), Andreasson et al. (1979) described a set of alkaline-ultrabasic dykes from their Leksdal Nappe. Some of these contain phenocrystic phlogopite and as a consequence may be designated as lamprophyres. From preliminary paleomagnetic studies on two sets of these thin dykes (Zellman et al. 1978), two separate phases of emplacement have been suggested, one Late Precambrian and the other possibly Late Devonian. In more recent years, blasting operations at a road-aggregate quarry at Lerkehaug, just south of Steinkjer, have revealed several further examples of these mica-lamprophyric dykes, which have been incorporated in an ongoing petrochemical study. In this note we present the results of $^{40}Ar/^{39}Ar$ stepwise degassing analyses on large (several mm) flakes of mica separated from the best preserved dyke at Steinkjer and also on micas of similar grain size from the Ytterøy dyke.

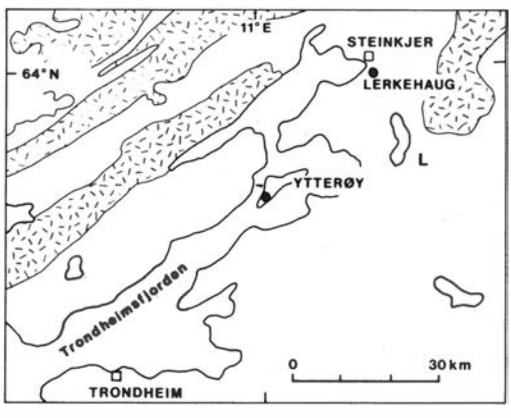


*Fig. 1.* Outline map showing the locations of the lamprophyre dykes sampled in this study. Ornament – areas of Proterozoic crystalline rocks. Blank – mostly metasedimentary and metavolcanic rocks of the Caledonian nappes. L – Leksdalsvatn.

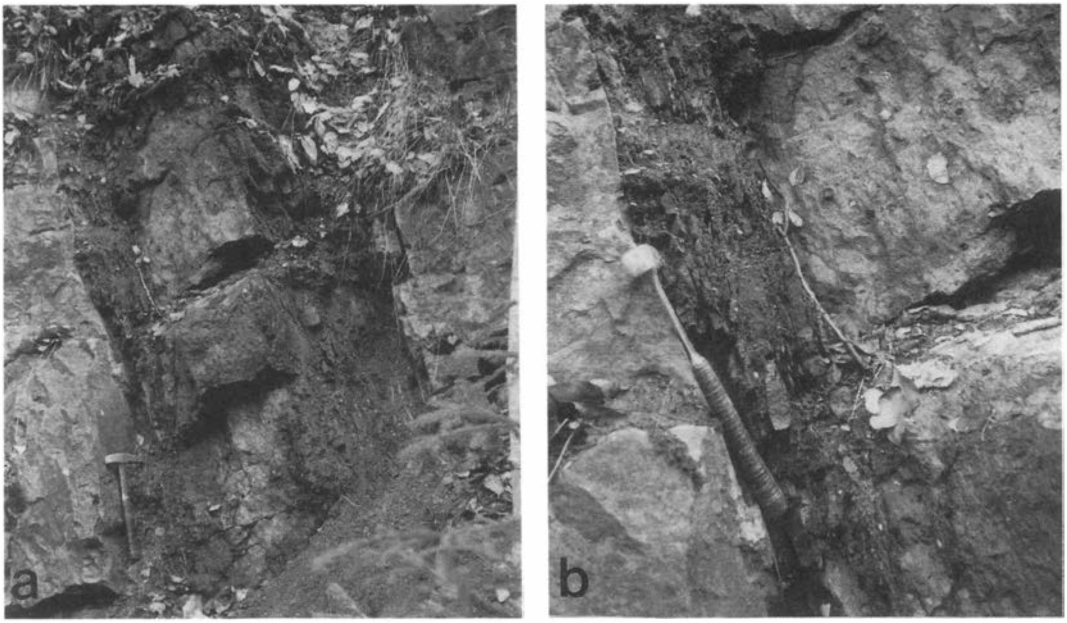


*Fig. 2.* The lamprophyre dyke on Ytterøy, looking northeast. (a) General view. (b) Closer view of the marginal zone to show the contact-parallel shearing. Phlogopite phenocrysts can be seen in the massive part of the dyke, to the right.

# Field relationships and petrography

As a detailed description of the Ytterøy lamprophyre has been given by Carstens (1961), only the main features will be noted here together with some additional new observations. Many of the features described by Andreasson et al. (1979) from their alkaline-ultrabasic dykes are also recognisable in the dyke from the Lerkehaug quarry. Here we outline only the main aspects of the field occurrence and petrography.

## *The Ytterøy lamprophyre*

The geology of Ytterøy consists mainly of strongly deformed schistose greenstones, with a 20–25 m thick metalimestone in the southwestern part of the island. Based on detailed mapping and lithostratigraphic correlation within the Trondheimsfjord region the rocks are considered to be of Ordovician age (Carstens 1961, Wolff 1979), and form part of the Støren Nappe. The 80 cm–1 m thick dyke occurs in the eastern part of a disused limestone quarry (grid-ref. 999 723, 1:50 000 map-sheet Verran), striking c.053° with a dip of c.65° to the southeast (Fig. 2). Contacts with the limestone are sharp and chilled marginal zones are observed (Carstens 1961). The massive central parts of the dyke pass outwards into 20–25 cm thick zones of friable, sheared material (Fig. 2) containing thin, weathered carbonate veinlets a few mm in width.

The rock consists of large flakes (up to 4 cm across) of phlogopitic biotite and smaller carbonate-chlorite pseudomorphs after olivine set in a dark, fine-grained groundmass of biotite, clinopyroxene, calcite, analcite and magnesite, with K-feldspar, pyrite and apatite as accessory minerals (Fig. 3a). Most of the mica phenocrysts show a narrow, darker border colour-zoning, which is characteristic of lamprophyre biotites generally, and some show kink-type deformation structures. Chemical analysis has shown that the mica is close to phlogopite in composition with over 20 wt % MgO (Carstens 1961). Ocelli of analcite are common particularly in the central parts of the dyke. Fresh flakes of the phlogopite were handpicked for the present $^{40}Ar/^{39}Ar$ dating study.

Some 20 m from the dyke locality, along the track entering the main quarry, the limestone displays mesoscopic recumbent folds and is transected by abundant carbonate-filled joints. These joints have approximately the same strike and dip as the lamprophyre dyke.

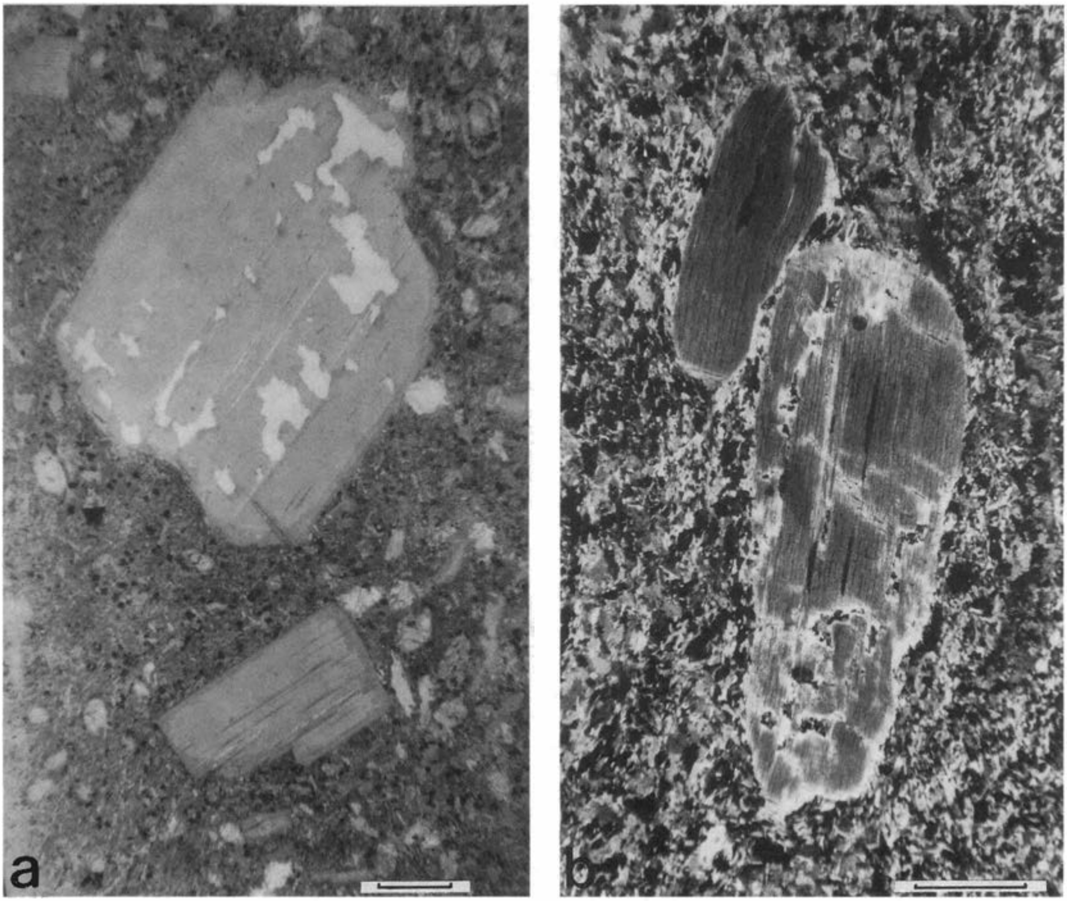


*Fig. 3.* Photomicrographs of phlogopite-biotite phenocrysts in the (a) Ytterøy and (b) Lerkehaug lamprophyres. In (a) the phlogopite flakes show 0.1–0.2 mm wide, darker marginal zones. The matrix is devoid of any secondary schistose facric. In (b) the matrix shows a pronounced schistosity, into which the phlogopite phenocrysts have been rotated, subrounded, and recrystallised along their margins. (a) Plane-polarised light. (b) Cross-polarised light. Bar scale = 1 mm.

## *The lamprophyres at Lerkehaug Quarry, Steinkjer*

Several thin, dark grey to green-grey, mafic dykes cut the westerly dipping cross-bedded meta-arkoses of the Leksdal (Wolff 1979) or Leksdalsvatn Nappe (Roberts & Wolff 1981) at the Lerkehaug roadstone quarry near Steinkjer (grid-ref. 227 982, 1:50,000 map-sheet Stiklestad). Because of quarrying operations, dyke outcrop is never permanent, and some of the thinner dykes have unfortunately disappeared since first being recorded, sampled and photographed. Thicknesses vary from dyke to dyke between 5 cm and 50 cm. Within-dyke variations in thickness have also been noted, the thinner portions being more prominently sheared and schistose. Mica phenocrysts are clearly visible in many of the dykes.

The host meta-arkoses are medium- to thick-bedded with thin muscovite-chlorite pelite partings which define a weak regional foliation. This part of the Leksdalsvatn Nappe has experienced only lowest greenschist facies metamorphism, according to Tietzsch-Tyler (1983) only of chlorite grade, although green biotite has been recorded further south (Andreasson 1980). In contrast to the Leksdalsvatn Nappe, rocks of the overlying Skjøtingen Nappe were metamorphosed in almandine-amphibolite facies before their thrust emplacement upon the Leksdalsvatn arkoses. Isotopic dating work from rocks in Sweden which are equivalent to those of the Skjøtingen (the Seve Nappe) has shown that this high-grade metamorphism occurred in Early Ordovician time (Dallmeyer et al. 1985).

Based on strike trend, the lamprophyre dykes are divisible into two groups, the principal set striking c.215° with a 60–70° dip to the north-west and a secondary grouping at c.260° with c.60° northerly dip. Some dykes are slightly curviplanar with corresponding changes of dip and strike.

The micas selected for isotopic age analyses were hand-picked from the less sheared central portion of one of the c. E.-W dykes. Unlike the Ytterøy dyke, this rock has a distinct schistosity into which most of the mica phenocrysts have been rotated and abraded (Fig. 3b). Thin-section examination shows that the 1–2 cm micas are pale yellow-brown phlogopite or phlogopitic biotite packed with a 'dust' of an unidentified opaque mineral; and the phenocrysts have clearly been broken down and recrystallised along their margins into new 0.1–0.2 mm phlogopitic micas.

*Table 1.* $^{40}Ar/^{39}Ar$ data for the Ytterøy and Lerkehaug samples.

a) Ytterøy phlogopitic biotite

| Step | $^{40}Ar/^{39}Ar$ | $^{37}Ar/^{39}Ar$ | $^{36}Ar/^{39}Ar$ | Temperature (°C) | $^{40}Ar^*/^{39}Ar$ | % $^{39}Ar$ Cumulative release | % Atmospheric contamination | Age (Ma) |
|---|---|---|---|---|---|---|---|---|
| 1 | 1011 | 0.294 | 2.41 | 200 | 322 | 0.05 | 68.2 | 2679± 76 |
| 2 | 230 | 0.776 | 0.437 | 300 | 105 | 0.21 | 54.2 | 1356± 34 |
| 3 | 32.6 | 2.97 | 0.0410 | 400 | 21.2 | 1.02 | 35.2 | 367± 10 |
| 4 | 24.7 | 0.145 | 0.0117 | 500 | 21.4 | 11.72 | 13.5 | 369± 3 |
| 5 | 22.5 | 0.00526 | 0.00775 | 600 | 20.3 | 25.33 | 9.8 | 352± 2 |
| 6 | 24.0 | 0.00558 | 0.00626 | 700 | 22.2 | 37.08 | 7.4 | 382± 3 |
| 7 | 21.3 | 0.00541 | 0.00335 | 800 | 20.4 | 48.30 | 4.5 | 354± 3 |
| 8 | 19.2 | 0.00552 | 0.00207 | 850 | 18.6 | 62.22 | 3.1 | 323± 2 |
| 9 | 21.5 | 0.00514 | 0.00199 | 900 | 20.9 | 74.51 | 2.6 | 362± 3 |
| 10 | 23.5 | 0.000 | 0.00187 | 950 | 23.0 | 76.63 | 2.3 | 394± 4 |
| 11 | 23.0 | 0.000 | 0.00208 | 1000 | 22.4 | 80.78 | 2.6 | 384± 3 |
| 12 | 22.7 | 0.00830 | 0.00138 | 1100 | 22.3 | 88.08 | 1.7 | 383± 3 |
| 13 | 24.8 | 0.0153 | 0.00312 | 1200 | 23.9 | 93.21 | 3.6 | 407± 4 |
| 14 | 26.3 | 0.0116 | 0.00283 | 1300 | 25.4 | 99.87 | 3.1 | 432± 3 |
| 15 | 75.0 | 1.10 | 0.187 | 1400 | 21.8 | 99.95 | 71.0 | 375±120 |
| 16 | 147 | 4.73 | 0.488 | 1500 | 8.41 | 100.00 | 94.3 | 154± 53 |

b) Lerkehaug phlogopitic biotite

| Step | $^{40}Ar/^{39}Ar$ | $^{37}Ar/^{39}Ar$ | $^{36}Ar/^{39}Ar$ | Temperature (°C) | $^{40}Ar^*/^{39}Ar$ | % $^{39}Ar$ Cumulative release | % Atmospheric contamination | Age (Ma) |
|---|---|---|---|---|---|---|---|---|
| 1 | 122 | 0.312 | 0.256 | 275 | 48.6 | 0.17 | 60.0 | 690± 36 |
| 2 | 79.3 | 2.20 | 0.107 | 350 | 49.1 | 0.30 | 38.1 | 696± 47 |
| 3 | 66.4 | 0.0972 | 0.0314 | 450 | 57.4 | 2.21 | 13.5 | 791± 6 |
| 4 | 62.6 | 0.0313 | 0.0168 | 550 | 57.8 | 4.60 | 7.6 | 796± 6 |
| 5 | 64.3 | 0.0166 | 0.00686 | 650 | 62.3 | 9.01 | 3.0 | 846± 6 |
| 6 | 58.0 | 0.00912 | 0.00247 | 700 | 57.2 | 11.80 | 1.2 | 790± 5 |
| 7 | 55.8 | 0.0135 | 0.00132 | 750 | 55.4 | 15.97 | 0.7 | 769± 5 |
| 8 | 53.2 | 0.0258 | 0.00199 | 800 | 52.7 | 21.67 | 1.1 | 737± 5 |
| 9 | 50.6 | 0.0261 | 0.00106 | 850 | 50.3 | 36.15 | 0.6 | 710± 5 |
| 10 | 48.7 | 0.0190 | 0.000825 | 900 | 48.5 | 47.20 | 0.5 | 688± 4 |
| 11 | 49.5 | 0.0203 | 0.000722 | 950 | 49.3 | 58.87 | 0.4 | 698± 4 |
| 12 | 50.6 | 0.0167 | 0.000859 | 1000 | 50.4 | 67.48 | 0.5 | 710± 5 |
| 13 | 56.9 | 0.0223 | 0.00139 | 1050 | 56.5 | 79.84 | 0.7 | 781± 5 |
| 14 | 58.9 | 0.00964 | 0.000532 | 1100 | 58.7 | 85.02 | 0.3 | 806± 5 |
| 15 | 57.6 | 0.0218 | 0.00105 | 1150 | 57.3 | 91.59 | 0.5 | 791± 5 |
| 15 | 50.3 | 0.0343 | 0.00104 | 1200 | 50.0 | 97.52 | 0.6 | 706± 4 |
| 17 | 45.9 | 0.373 | 0.00368 | 1300 | 44.8 | 99.95 | 2.2 | 645± 5 |
| 18 | 89.7 | 0.000 | 0.121 | 1400 | 55.1 | 99.98 | 38.6 | 765±190 |
| 19 | 113 | 0.000 | 0.232 | 1500 | 46.3 | 100.00 | 58.8 | 663±250 |

* = Radiogenic
$\lambda_e = 0.581 \times 10^{-10} a^{-1}$
$\lambda_\beta = 4.962 \times 10^{-10} a^{-1}$

$^{40}K/K = 1.67 \times 10^{-4}$ atom/atom

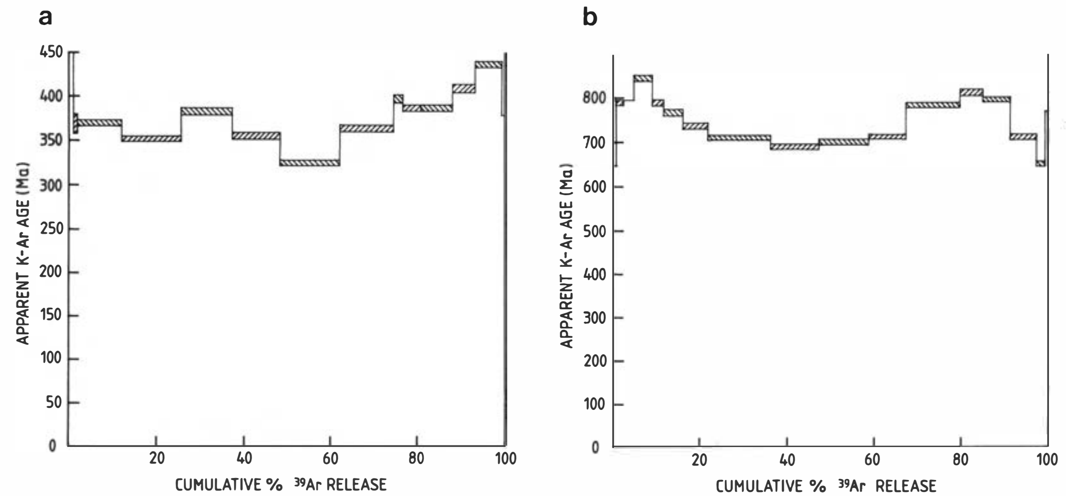


*Fig. 4.* $^{40}Ar/^{39}Ar$ stepwise degassing curves for phlogopites from (a) Ytterøy and (b) Lerkehaug, Steinkjer.

Many of the phenocrysts have also been flexed and kinked during a later, post-schistosity deformation. The fine-grained schistose groundmass consists of the new phlogopitic biotites, tremolite-actinolite, calcite and magnetite, with accessory sphene, K-feldspar, chlorite and epidote.

## Age determinations

$^{40}Ar/^{39}Ar$ ages were determined using the techniques described by Halliday (1978). Approximately 0.2 gm of each mica was irradiated with fast neutrons in the 'Herald' (A.W.R.E., Aldermaston) reactor, using Biotite 133 as the calibration standard (for details, see Halliday 1978). Argon analyses were performed on a modified MS10 mass spectrometer, and ages calculated using the decay constants of Steiger & Jäger (1977). Analytical data are presented in Table 1 and Fig. 4.

## Discussion

In attempting to deduce the geological age of these micas from the stepwise degassing curves, we are unable to satisfy the criteria proposed by Fleck et al. (1977) for distinguishing an age 'plateau', namely that it must comprise 'contiguous gas fractions that together represent more than 50% of the total $^{39}Ar$ released from the sample, and for which no detectable difference in age can be detected between any two fractions at the 95% level of confidence'. The spectra do, however, allow certain constraints to be imposed on the ages of the micas when the independent evidence from the field relationships is taken into account.

A 'saddle shape' such as is evident in the release curve of the sample from Lerkehaug (Fig. 4b) has been demonstrated (Lanphere & Dalrymple 1971, Brereton 1972, Dalrymple et al. 1975) to be a feature of rocks which contain excess argon, and for which the central portion of the plateau provides an age (possibly significantly) greater than the age of crystallisation. According to this interpretation the Lerkehaug dyke would be *younger* than 688 Ma. An upper limit for its age can be set by the fact that this lamprophyre displays a distinct metamorphic fabric, and like the schistosity in the host greenschist facies meta-arkoses, this is undoubtedly Caledonian, and may well be earliest Ordovician (Finnmarkian). This is based on correlations of the arkose-dominated nappes of the Baltoscandian miogeocline across the Trøndelag-Jämtland region and further north, and Rb-Sr dating of mylonites at the base of one of these units (Claesson 1980). It is therefore probable that this dyke belongs to the latest Precambrian group of dyke rocks discussed by Andreasson et al. (1979) and is perhaps related in a wider context, though not chemically, to the Swedish Ottfjället dolerite dyke swarm, the approximate age of which is 665 Ma (Claesson & Roddick 1983). The paleomagnetic data also lend support to this suggestion. Our evidence, however, does not exclude the possibility that the Lerkehaug lamprophyre may be associated in some way with the 590–565 Ma rifting and alkaline-intrusive event recognised throughout northwestern Europe and Greenland (Doig 1970, Vertiainen & Woolley 1974, Andreasson et al. 1979, Verschure et al. 1983).

An interesting aspect of this result is that, as biotite has a blocking temperature of < 300°C, it is curious that this particular age spectrum has survived the low greenschist facies metamorphism recorded in this part of the Leksdalsvatn Nappe. The phenocrysts have been mechanically rotated into the schistosity, and recrystallised only along their margins. This may mean that temperatures barely exceeded the blocking temperature. Another possibility is that phlogopitic biotite or phlogopite may be more stable than ordinary biotite, and that the age spectrum has thus not been affected in any way. Precambrian K-Ar and Rb-Sr ages have previously been obtained from coarse-grained (10 cm) muscovite (though not biotite) micas from 'Moine' pegmatites which were subjected to partial 'Caledonian' metamorphism up to kyanite grade (Long & Lambert 1963, Fitch et al. 1969).

The age spectrum obtained from the Ytterøy biotite is more complex than that of the Lerkehaug sample. It is irregular and shows no clear 'plateau' of any true statistical significance (Fig. 4a). As a consequence we are able only to calculate a 'total fusion' age, namely 370 Ma (Frasnian). The $^{40}Ar/^{39}Ar$ study substantiates the biotite K-Ar age of Priem et al. (1968) as well as Storetvedt's (1967) suggestion of a Late Caledonian (Devonian) age which was based on paleomagnetic data.

The Ytterøy lamprophyre was clearly intruded later than the polyphase folding and greenschist facies metamorphism that affected the host volcano-sedimentary succession, and which was part of the widespread and pervasive Mid- to Late Silurian Scandian orogenic event (Roberts & Wolff 1981). The dyke itself has somewhat sheared margins and the fresh phlogopite phenocrysts show evidence of kink-style brittle deformation. Priem et al. (1968) attributed their low Rb-Sr age of 256 Ma for the phlogopite to a possible episodic loss of radiogenic strontium at this time, perhaps as a consequence of hydrothermal activity related to Permian rift faulting. It may be significant in this respect that, on Ytterøy, a feature of the geology is the presence of orange- to red-brown-coloured hydrothermal alteration zones along quartz-carbonate-filled or brecciated fracture surfaces. These zones trend mainly between 040°C and 060°C and have been shown by Grønlie & Hembre (1985) to be enriched in elements such as Th, U, F, K, Rb and Sr. It is possible, therefore, that this fracture-related hydrothermal activity may be of Permian age. In southern Norway as a whole there is now substantial evidence for Late Carboniferous to Permain igneous and hydrothermal activity related to rifting (Råheim 1974, Ineson et al. 1975, Færseth et al. 1976, Sundvoll 1978, Furnes et al. 1982). Further afield, it is of interest to note that paleomagnetic studies on Upper Devonian sediments and lavas from Hoy in the Orkney Islands, Scotland, have revealed a secondary magnetisation of Permian age ascribed to hydrothermal overprinting (Storetvedt & Meland 1985). This overprint, which may also be expressed in camptonite dykes occurring on Orkney (Flett-Brown 1975), has been linked to reactivation of the adjacent extension of the Great Glen Fault; one of several subparallel megafractures which may have extended into the Trøndelag region (Oftedahl 1975) in Mid- to Late Palaeozoic time.

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