Carboniferous dolerite dykes on Magerøy: new age determination and tectonic significance

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Lippard, S. J. & Prestvik, T.: Carboniferous dolerite dykes on Magerøy: new age determination and tectonic significance. *Norsk Geologisk Tidsskrift*, Vol. 77, pp. 159–163. Oslo 1997. ISSN 0029-196X.

New, high-precision, $^{40}Ar/^{39}Ar$ age determination on a plagioclase separate and whole rock samples from a post-Caledonian dolerite dyke from southern Magerøy gives ages of 337.3 ± 0.4 Ma and 340 ± 4 Ma respectively. A conventional K/Ar whole rock analysis of the same sample gives 301 ± 8 Ma. The $^{40}Ar/^{39}Ar$ ages are Early Carboniferous (Visean) and indicate an age older than previously published K/Ar results from a comparable dyke. The dykes were intruded parallel to a set of NW–SE trending normal faults associated with the Late Palaeozoic rifting in the Barents Sea area. The new age determination on the dykes places constraints on the timing of Late Palaeozoic rifting in the southern part of the Barents Sea.

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Introduction

The presence of a 3.5-km-long, NW–SE trending dolerite dyke on the island of Magerøy in northernmost Norway was first reported by Andersen (1981) who noted that the dyke post-dated the Caledonian (Scandian) D2 deformation in the area. In a later article, Roberts et al. (1991) presented both geochemical data on the dyke, which indicated a continental tholeiite composition, and three K/Ar age determinations on pyroxene separates which suggested a Permo-Carboniferous age. Here, following up from an initial report (Lippard & Prestvik 1995) of the discovery of several more dolerite dykes in the area, we present new geochronological results. The tectonic significance of the dykes is further discussed in relation to the Late Palaeozoic rifting of the Barents Sea region.

Field relations and occurrence

At least five separate, post-Caledonian mafic dykes have been found on the southern part of Magerøy (Fig. 1). In addition to the dyke first described by Andersen (1981), three subparallel en echelon dykes occur inland in the Sarnes–Baklia area and one further east along the cliffs at Næringen (Fig. 2). Two NE–SW trending basic dykes had previously been mapped by Geul (unpublished map later reproduced in Krill et al. (1988)) at Næringen. Andersen (1981) also showed these two dykes on his map, but with a more E–W trend. Although these maps showed more than one dyke at Næringen, detailed mapping has shown that only a single dyke is present. The dyke is seen as a prominent feature on the cliff section west of Honningsvåg.

Figs. 1 and 2 show that the dykes occur along the same general NW–SE (120°) trend over a distance of about 14 km. This narrow system of parallel to subparallel, rectilinear and closely related dykes is best termed a dyke 'set'. The individual dykes can be traced more or less continuously on the ground over distances ranging from 1 to 4 km (Fig. 2). The dykes have vertical to near vertical contacts and widths ranging from 5 to 15 m. They commonly display a subhorizontal joint set perpendicular to the walls (in places showing well-developed columnar structure) and several vertical joint sets.

In general, the dykes are more easily eroded than the surrounding country rocks and form linear depressions in the landscape. Good exposures are mostly limited to stream sections. Outcrops and loose blocks of the dykes are easily distinguished by their brown spheroidal weathering from the grey-coloured quartz-mica schist country rocks. The dykes are dark green to black coloured when fresh.

The contacts with the country rocks are sharp with narrow, up to 5 cm wide, chilled margins. The country rocks are largely unaffected by the intrusions except for a few centimetres thick hornfels at the contact. Roberts et al. (1991) report that the dyke studied by them locally forms an intrusion network in fractured country rocks along a fault zone. Andersen (1981) also notes that the dyke post-dated the movements along the fault. The dykes studied by us show no evidence of either intrusion into fault zones or fractured country rocks.

Petrography

All of the dykes are petrographically similar. The primary mineralogy consists, in order of decreasing abundance, of plagioclase, clinopyroxene, opaque oxides and olivine. The plagioclase ranges from fresh to strongly sericitized while the clinopyroxene is generally unaltered. The opaque oxides are magnetites with thin lamellae of ilmenite or separate ilmenite grains. The olivine is com-

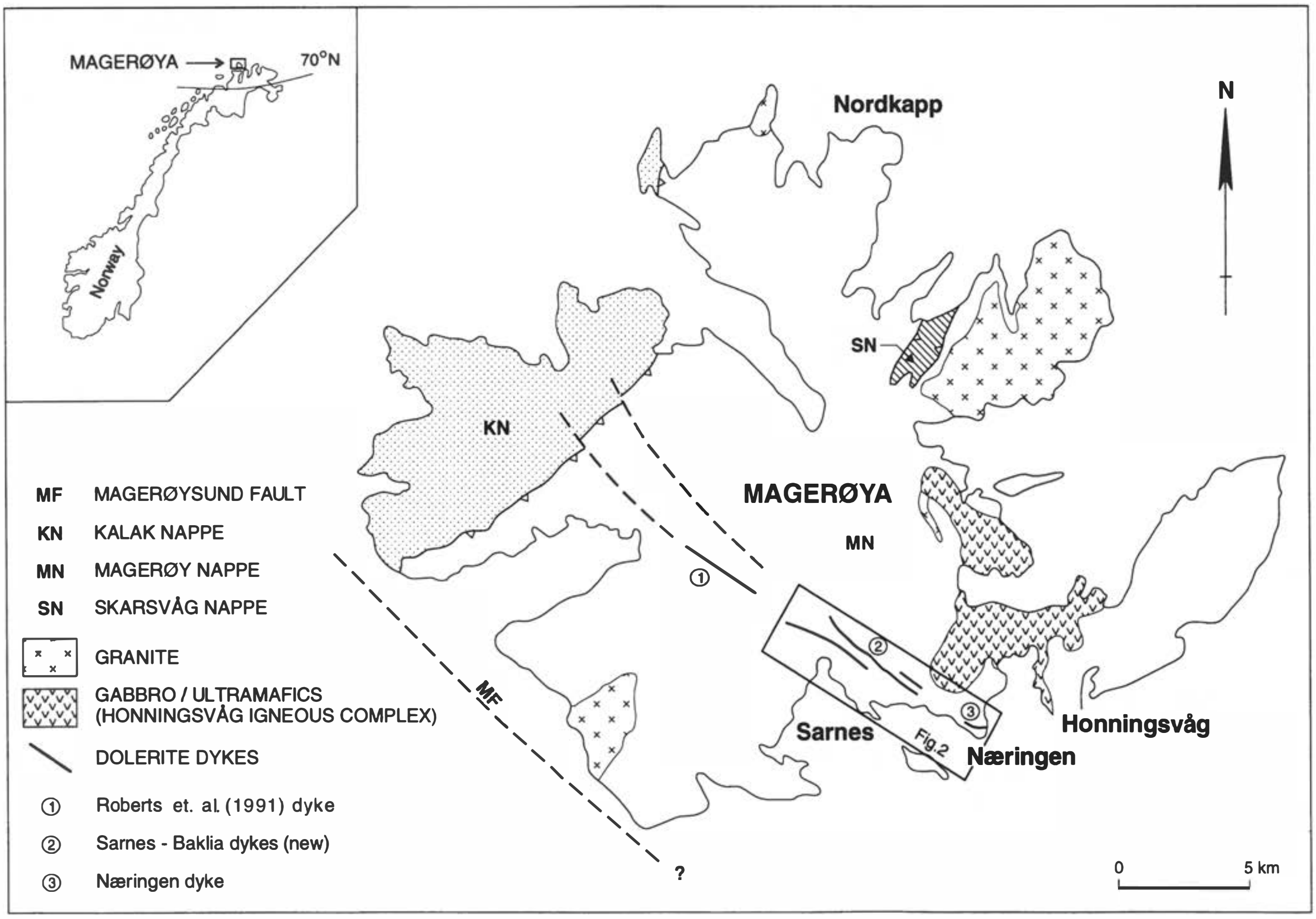

Fig. 1. Simplified geological map of Magerøy showing the locations of the dolerite dykes.

pletely pseudomorphed to a brown fine-grained mixture of smectite, serpentine and secondary iron oxide and hydroxide minerals.

The interiors of the dykes have fine-grained (0.1–0.5 mm) intergranular textures. The chilled margins are finer-grained but holocrystalline (grain size <0.2 mm) and consist of altered plagioclase, clinopyroxene and abundant iron oxides. One sample was found to contain a small (0.5 mm) rounded inclusion of strained quartz surrounded by a zoned reaction rim of finely granular pyroxene.

Geochemistry

Fresh samples from the interiors of all the dykes were analysed for major and trace elements and found to be very similar in composition (Table 1), thus establishing their consanguinity. The analyses lie on the boundary between basalt and basaltic andesite according to the IUGS TAS (total alkali-silica) classification scheme (Fig. 3). They are quartz and hypersthene normative (q 1–3%, hy 17–20%; with Fe_2O_3/FeO recalculated to 0.15) and are relatively rich in TiO_2 (>3 wt%). Our analyses (Table 1), including one sample from the Roberts et al. (1991) dyke, are similar to those reported by Roberts et al. (1991) (Table 1). Roberts et al. (1991) characterized the dykes, on the basis of trace element compositions, as 'within-plate' tholeiites.

New age determinations

A plagioclase concentrate (80–200 mesh fraction), separated from the least altered dolerite (sample MA 6 from the Næringen dyke) and probably more than 98% pure, was analysed by incremental $^{40}Ar/^{39}Ar$ step-heating (Table 2). This gave an excellent plateau using five steps (89.8% of ^{39}Ar), giving an age of 337.3 ± 0.4 Ma (Fig. 4). The total gas age of this experiment is 336.1 ± 1.7 Ma. A $^{40}Ar/^{39}Ar$ age of 340 ± 4 Ma was obtained on the whole rock, whereas conventional K/Ar dating gave 301 ± 8 Ma on the same material (Table 2). Furthermore, an 'inverse isochron' (isotope correlation plot) gave an age of 337.1 ± 1.0 Ma with an intercept on the $^{40}Ar/^{36}Ar$ axis at 274.4 ± 23.5 (MSWD = 5.0). We interpret the plagioclase separate plateau age (337.3 ± 0.4 Ma) as the best estimate of the emplacement age of the dyke. This is within the Visean Epoch on the time-scale of Harland et al. (1990) and corresponds to the Arundian Stage in the lower part of the Visean according to a more recent time-scale for the Carboniferous published by the Australian Geological Survey Organization (Jones 1995).

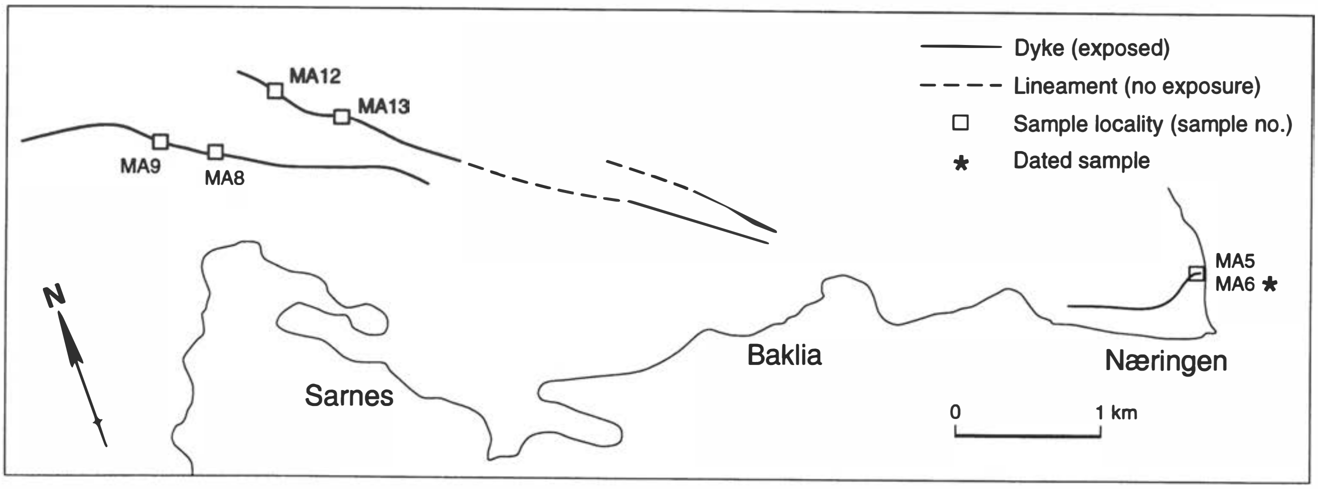

Fig. 2. Map of the Sarnes–Næringen area, southern Magerøy, showing the dykes and sampling localities.

Comparison with earlier dating

The whole rock K/Ar age (301 ± 8 Ma) of the dyke at Næringen analysed here is very similar to one (302 ± 11 Ma) of the three K/Ar ages obtained on pyroxene separates by Roberts et al. (1991, their sample #2) and close to another (312 ± 14 Ma, their sample #5). However, their third sample (#1) gave a considerably younger age (ca. 266 ± 8 Ma). There are several studies on dating of mafic rocks which have emphasized the unreliability of K/Ar ages. Turner et al. (1994), referring to the Early Cretaceous Paraná-Etendeka continental flood basalts, stated that the Ar/Ar technique has clear advantages over the K/Ar technique and showed that the K/Ar ages are systematically lower than the $^{40}Ar/^{39}Ar$ ages. Heinmann et al. (1994) reported K/Ar ages younger than $^{40}Ar/^{39}Ar$ ages on the Jurassic Kirkpatrick basalt and the Ferrar Group from Antarctica, and interpreted this as being due to argon loss from 'poorly retentive matrix material'. Similarly, Baker et al. (1996) stated that much of the K/Ar age data of the Oligocene continental flood basalts in Yemen '... are misleading, due to the disturbed Ar age systematics of whole rock samples'. The new $^{40}Ar/^{39}Ar$ and K/Ar ages reported here support these observations and strongly suggest that the earlier K/Ar ages on pyroxene separates obtained by Roberts et al. (1991) are also too young.

Table 1. Major and selected trace element composition of dolerite dykes on Magerøya.

	MA 3[1]	MA 5	MA 6	MA 8	MA 9	MA 12	MA 13	Roberts et al. (1991) mean of 5 analyses
SiO_2	51.03	50.95	50.30	50.49	50.91	49.26	48.91	48.55
TiO_2	3.17	3.18	3.19	3.16	3.06	3.28	3.30	3.09
Al_2O_3	13.62	13.67	13.41	13.45	13.49	13.38	13.36	12.82
FeO*	12.51	12.30	13.16	12.60	12.45	13.00	13.19	12.77**
MnO	0.22	0.24	0.24	0.24	0.23	0.22	0.24	0.22
MgO	4.38	4.35	4.35	4.34	4.17	4.73	4.82	4.17
CaO	8.13	8.02	8.03	8.01	7.57	8.10	8.19	7.59
Na_2O	3.05	3.14	3.12	3.04	3.20	2.66	2.84	3.26
K_2O	1.43	1.44	1.42	1.46	1.52	1.34	1.37	1.57
P_2O_5	0.63	0.64	0.64	0.63	0.66	0.67	0.64	0.56
L.O.I.	1.67	1.94	1.77	1.99	2.72	2.44	2.33	3.30***
Total	99.84	99.87	99.63	99.41	99.98	99.08	99.19	97.90
Nb	26.9	27.2	27.2	25.8	27.6	25.2	24.5	22.4
Zr	237	234	239	237	247	226	227	259.2
Y	42	42	42	41	42	40	40	44.8
Sr	315	305	311	316	296	295	299	305.8
Rb	31	33	35	35	40	34	34	41.0
Cr	6	5	6	3	5	18	17	5.2
V	358	382	367	364	340	389	397	336.0
Ba	660	646	646	656	704	638	644	746.4

* Fe_{total} analysed as FeO.
** FeO_{total} calculated from $FeO + 0.9\ Fe_2O_3$ (which reduces the total by 0.76 wt%).
*** $H_2O^+ + H_2O^- + CO_2$.
[1] Sample MA 3 is from the 'Roberts et al. (1991) dyke'. For sample locations, see map, Fig. 2.
Analytical methods: Both major and trace elements were analysed by XRF at the Geoanalytical Laboratory, Washington State University, Pullman, USA.

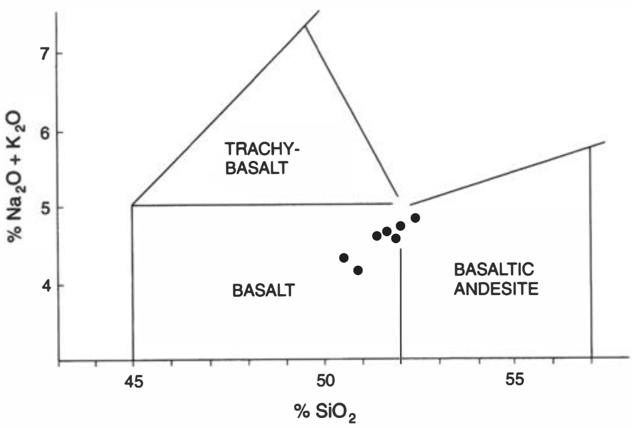

Fig. 3. Total alkalis versus silica (TAS), diagram for the Magerøy dykes.

Tectonic significance of the Magerøy dykes

Andersen (1981) and Roberts et al. (1991) showed that the dyke studied by them is intruded into a NW–SE trending fault zone which they could trace further to the northwest, where it displaces the contact between the Magerøy Nappe and the underlying Kalak Nappe Complex (Fig. 1). They interpret the fault as one of a series of post-Caledonian normal faults parallel to the Magerøysundet Fault that downthrow mainly to the northeast. Aerial photographs of south–central Magerøy reveal two dominant sets of lineaments that are clearly related to fractures: one trending WNW–ESE to NW–SE (110–140°), parallel to the dyke and fault trends, and the other ENE–WSW (060–080°).

Other 'late' dolerite dykes have been reported from northern Finnmark. A NE–SW trending dyke from the eastern Varanger Peninsula (Komagnes) was dated by K/Ar at 360 ± 10 Ma (Beckinsale et al. 1975, recalculated by D. Roberts), but recent palaeomagnetic work points to a possible Late Precambrian age (Torsvik et al. 1995). Furthermore, Gjelsvik & Gabrielsen (1995) describe several generations of, as yet, undated dykes from the Varanger area with both N–S and NW–SE trends.

Magerøy is apparently bounded by NW–SE trending faults: by the Magerøysund Fault (Fig. 1) to the southwest, and what appears to be an offshore continuation of the Trollfjorden–Komagelva Fault Zone (TKFZ) to the northeast (Gabrielsen & Færseth 1989). These and other NW–SE trending faults, which occur both onshore and offshore (Lippard & Roberts 1987; Gabrielsen & Færseth 1989), were probably active during Late Palaeozoic extension following the Caledonian orogeny. In the offshore area, several fault trends can be identified, but NW–SE and NE–SW trends appear to predominate (Lippard & Roberts 1987). The NE–SW trend of the western part of the Nordkapp Basin represents a major Late Palaeozoic rift zone (Gabrielsen et al. 1990), complicated by later halokinesis (Gabrielsen et al. 1992). The southwestern end of the basin is limited by an important NW–SE fault that forms a prominent spur of the Finnmark Platform and seems to continue the line of the TKFZ offshore. On the eastern part of the Finnmark Platform both NE–SW and NW–SE trends occur, giving rise to a recticulate pattern of faulting (Lippard & Roberts 1987).

Although the age of the earliest sediments in the Nordkapp Basin is unknown, regional interpretations

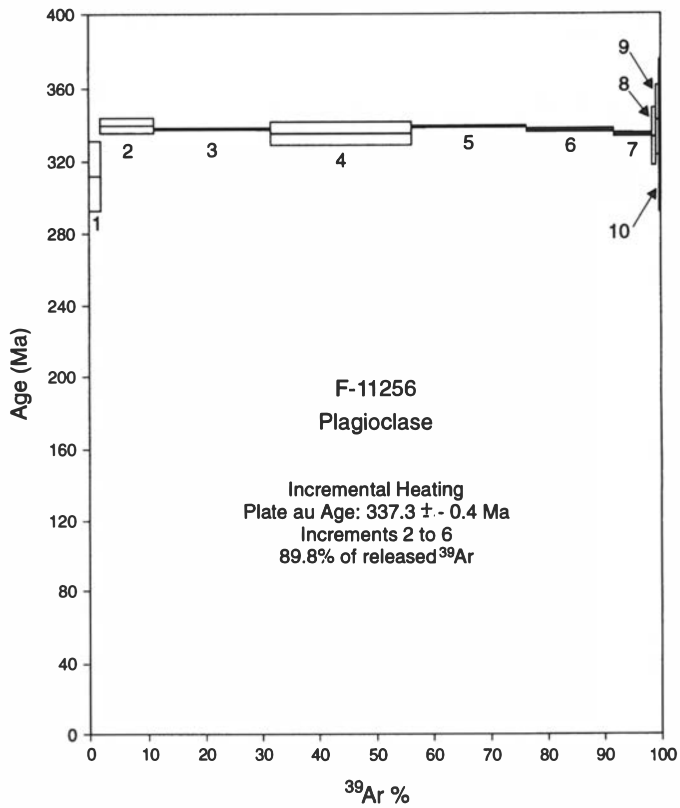

Fig. 4. Incremental step-heating Ar-Ar analysis on the plagioclase concentrate.

Table 2. $^{40}Ar/^{39}Ar$, $^{40}Ar/^{36}Ar$ and K/Ar age data of dolerite sample MA 6.

Material	Method	Age ± 2σ	K%	Rad ^{40}Ar (ppm)
Plagioclase separate	$^{40}Ar/^{39}Ar$	337.3 ± 0.4 Ma (plateau) 336.1 ± 1.7 Ma (total gas)		
Whole rock (53–200 mesh fraction)	$^{40}Ar/^{39}Ar$	340 ± 4 Ma		
Whole rock (53–200 mesh fraction)	K/Ar	301 ± 8 Ma	1.359	0.03091
Plagioclase separate	'inverse isochron'	337.1 ± 1.0 Ma		

Constants used: $\lambda_\beta = 4.962 \times 10^{-10}$ a^{-1}; $\lambda_\varepsilon = 0.581 \times 10^{-4}$ a^{-1}; $^{40}K/K = 1.193 \times 10^{-4}$ g/g (0.01167 atom%).

Analyst: Dr R. Reesman, Geochron Laboratories and the Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, Massachusetts, USA.

suggest that by the Late Carboniferous (Moscovian) rifting activity had ceased and an extensive shallow-marine carbonate platform had developed in the southern Barents Sea (Dengo & Røssland 1992; Nøttvedt et al. 1993). Nøttvedt et al. (1993) suggest that the main syn-rift sedimentary package in the Nordkapp Basin, including the thick salt deposits, is of Early- to Mid-Carboniferous age. This is supported by the results of shallow drillings on the eastern part of the Finnmark Platform which show Visean sediments as the oldest post-Caledonian sediments resting directly on Caledonian basement (Bugge et al. 1995).

The new, Early Carboniferous, $^{40}Ar/^{39}Ar$ age determination for the dolerite dykes of southern Magerøy provide a marker for the timing of post-Caledonian rifting in the southern Barents Sea. The dykes are partly emplaced into NW–SE trending extensional faults. The dykes themselves show no evidence of being affected by the faulting; however, they were probably emplaced during the same extensional tectonic phase. It seems likely, therefore, that the rifting events in the area started before or during Early Carboniferous (Visean) time. It is most probable that the dykes were emplaced during an early stage of the rifting process and represent mantle-derived magmas emplaced into near-vertical fractures, analogous to the Permian and early Mesozoic dykes described from western Norway by Færseth et al. (1976).

Acknowledgements. – We thank Dr David Roberts for discussion, for his comments and suggested improvements to an early version of the article and for providing up-to-date information on the Carboniferous time-scale. Anne I. Johannessen is thanked for helping to draft the figures.

Manuscript received June 1996

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