K-Ar dating of dolerite dykes in the Kongsberg-Fiskum district, Norway, and their relationships with the silver and base metal veins

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Ihlen, P. M., Ineson, P. R., Mitchell, J. G. & Vokes, F. M.: K-Ar dating of dolerite dykes in the Kongsberg-Fiskum district, Norway, and their relationships with the silver and base metal veins. *Norsk Geologisk Tidsskrift,* Vol. 64, pp. 87–96. Oslo 1984. ISSN 0029-196X.

12 K-Ar isotopic ages are reported from 7 dolerite dykes from the Kongsberg-Fiskum district, Norway. Ages obtained from the unaltered central parts of the dykes fall in the range 270–276 m.a. The marginal parts of the dykes and those samples selected as being representative of hydrothermally altered dolerites give ages with a minimum of 237 m.a. The petrography and petrochemistry of the dolerites is discussed in relation to basaltic intrusions of Permian, Early Cambrian and Late Proterozoic age found in the south-western part of the Baltic Shield. A summary of the vein deposits of the area is given, together with new data on their spatial and temporal relationships to the dykes. The field relationships strongly suggest that the igneous activity is closely associated in time with vein formation. The ages of the dolerite dykes provide useful constraints on the age of the vein deposits, confirming ages previously obtained on wall-rock alteration related to the veins.

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This paper represents the continuation of a series of articles (Ineson et al. 1975, Ihlen et al. 1978, Ineson et al. 1978) dating thermal and metallogenic events in southern Norway. The work was carried out as part of the project 'Taphrogenic metallogeny in southern Norway' by the staff of the Department of Geology, University of Trondheim–NTH, Norway with the cooperation of colleagues in the United Kingdom. Results are presented from K-Ar-whole-rock dating of dolerite dykes in the Precambrian gneisses of the Kongsberg-Fiskum district, which is situated on the western margin of the Permian Oslo Rift (Dons & Larsen 1978) (Fig. 1).

K-Ar-dating of clay minerals which appeared to be the product of wall-rock alteration associated with ore mineral deposition was successful in distinguishing Permian and Precambrian thermal events (e.g. Ihlen et al. 1978) in the veins which occur in the Precambrian basement around the Oslo Paleorift (Ihlen & Vokes 1978, Vokes & Ihlen 1980).

K-Ar-age determinations on argillic alteration products spatially associated with native silver veins cutting the Precambrian gneisses of the Kongsberg area were previously reported by Ineson et al. (1975). As the silver mines in the Kongsberg area are currently inaccessible, the samples used in that study were collected on the old mine dumps.

Though Ineson et al. (1975) obtained Permian ages on the clay mineral fractions, it may be argued that these results do not represent the time of ore formation. In fact C. Bugge (1917) was of the opinion that the strongest and most abundant clay mineral alteration in the mines occurs associated with southerly inclined crush zones (***råtaganger*** or 'rotten veins') which are devoid of native silver. These 'rotten veins' cut across the more steeply dipping ore zones which constitute a dense system of thin silver-bearing calcite veins (C. Bugge 1917). If, therefore, the spoil heap samples used by Ineson et al. (1975) originated from among the 'rotten veins', the K-Ar ages could alternatively represent an imprint of a Permian hydrothermal activity on an earlier, possibly, Upper Proterozoic, metallogenic event (see Discussion).

In view of such arguments, the authors felt that an alternative, independent, approach was needed to determine the age of the mineralized veins in the Kongsberg-Fiskum district. C. Bugge (1917) had indicated that the emplacement of the Kongsberg diabase dyke swarm occurred at the same time as ore formation. Thus we have chosen an 'indirect' method of dating the mineraliza-

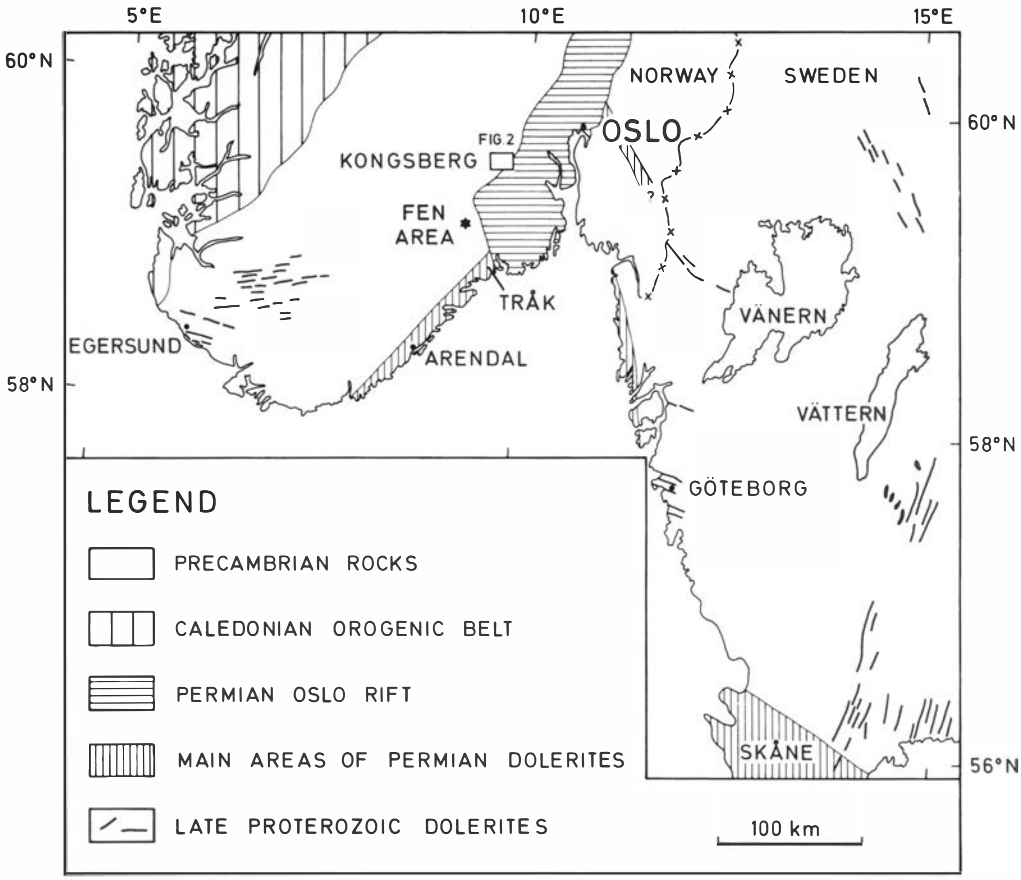

Fig. 1. Map of the southwestern part of the Baltic Shield showing the main areas with dyke emplacement during the Late Proterozoic to Permian. The locations of the Kongsberg-Fiskum district and the Fen carbonatite complex are shown by an open rectangle and black star, respectively.

tion, i.e. K-Ar whole-rock dating of the dolerite dykes. In order to interpret the K-Ar ages better, petrographical and chemical analyses on the dolerites have also been included in our survey (see Discussion).

Dolerite dykes

Field occurrence and petrography

The distribution of dolerite dykes in the Kongsberg-Fiskum district is shown in Fig. 2. Dyke emplacement has occurred in three major directions, namely N 0–35°E, N 50–80°E and N 90–120°E. The first-named is the dominant trend in the Fiskum area (east of Lågen river), while N 65–75°E is the dominant trend in the Kongsberg area to the west of the river (Fig. 2).

The dyke segments usually have a length of less than 1 km and a maximum width of 10 m, frequently forming a linear array which can be traced for 3–4 km (Fig. 2). C. Bugge (1917) found, however, that numerous dykes are irregular along both strike and dip. The dip varies between 45° and 90°.

Field work in the Fiskum area has revealed that individual dykes occurring outside the major NNE-SSW trending regional structures usually form lensoid bodies with a maximum length of 100 m.

Macroscopically the dolerite dykes can be subdivided into three types: a) massive, b) amygdaloidal and c) plagioclase porphyritic, types which

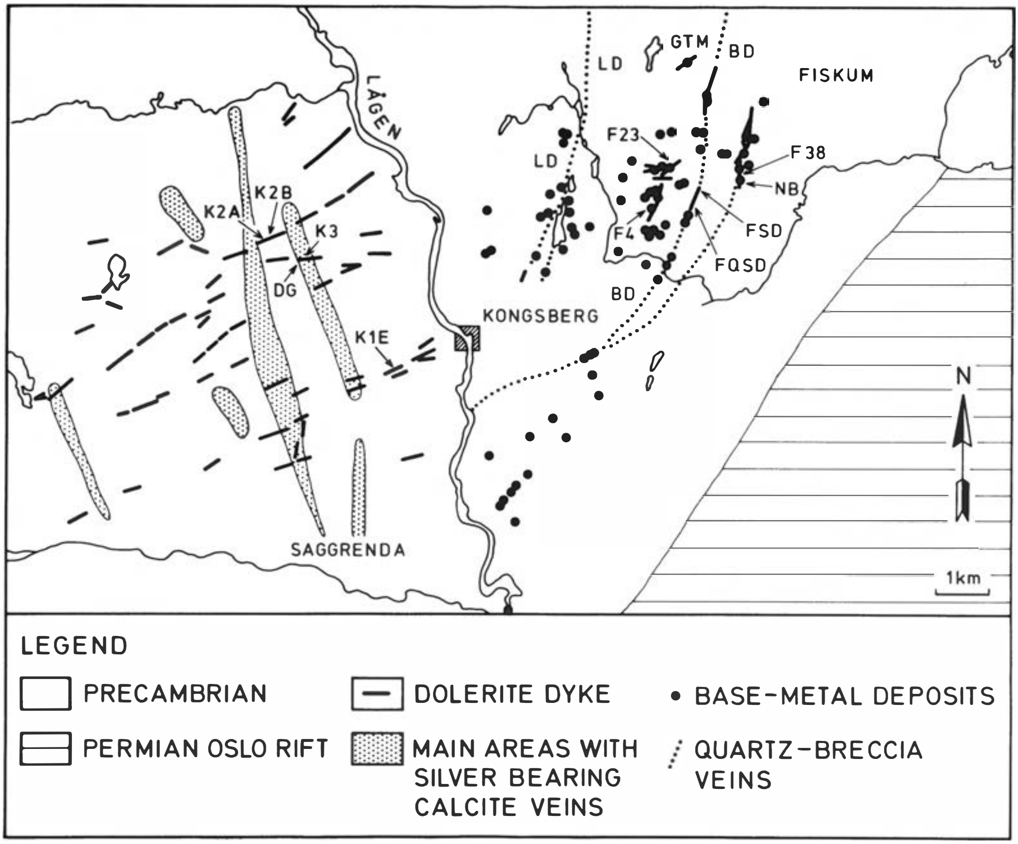

Fig. 2. Map of the Kongsberg-Fiskum district showing the distribution of dolerite dykes, vein deposits, and sample locations. BD = Brennåstjern-Disenplass, and LD = Lurdalen structures, DG = Der Gleichen mine, GTM = Grønntjernmyr prospect, and NB = Nordre Bråten prospect. K1E, K2A, K2B, K3, F4, F23, F38, FQSD and FSD are dated samples.

have a light to dark grey appearance. Type c) occurs less abundantly than the others, and usually comprises thin dykes or narrow zones in the other dykes (C. Bugge 1917). Though the different types mostly form individual bodies, they locally exhibit a zonal relationship within some of the thicker dykes. The amygdaloidal dolerite occurring along the core is then progressively rimmed by the porphyritic and the massive varieties (C. Bugge 1917, Fig. 7).

The dykes have a massive and unaltered macroscopic appearance, but microscopic examination shows their altered nature. These 'fresh' dolerites are composed of 0.3–1 mm long plagioclase laths carrying interstitial grains and aggregates of mafic minerals and Fe-oxides. The ophitic to sub-ophitic texture is often obliterated by later alteration.

The amygdaloidal dolerite has a characteristic red and white spotted appearance due to white amygdales filled with calcite, chlorite, epidote and/or quartz. The red halo invariably present around the amygdales may be caused by oxidation. Some of the red spots in the dolerite, however, are due to 1–2 mm tabular crystals of K-feldspar showing weak sericitic alteration. The plagioclase in the amygdaloidal type is turbid and shows different degrees of replacement by clinozoisite-epidote and 'sericite' (sericite, hydromica and clay minerals). Its composition falls in the range of oligoclase to andesine (An_{28-38}).

The original mafic constituents are altered to aggregates of chlorite, calcite and quartz. A few remnants indicate that brown pleochroic hornblende was one of the dominant mafic constituents. In dyke K 2B (Fig. 2) it is replaced by light green actinolite which is progressively altered to chlorite.

Table 1. Major and trace element analyses of the dolerites in the Kongsberg-Fiskum district. Sample locations noted in Fig. 2 and Table 3.

	K1D	K1F	K2B	F4	F29A	F38
SiO_2	51.51	52.20	44.59	51.49	46.64	46.28
TiO_2	2.17	2.09	3.84	1.93	2.79	2.93
Al_2O_3	15.,50	15.35	15.94	15.26	16.19	15.33
Fe_2O_3	4.89	6.69	5.51	1.35	4.38	0.00
FeO	5.87	4.46	7.60	8.28	7.01	10.93
MnO	0.15	0.18	0.15	0.18	0.17	0.22
MgO	3.06	3.13	5.48	2.67	3.57	4.11
CaO	4.44	4.68	6.52	5.90	6.94	6.69
Na_2O	4.61	4.49	3.21	3.92	3.97	2.30
K_2O	1.60	2.29	0.92	1.60	2.18	2.12
P_2O_5	0.55	0.57	0.36	0.58	0.52	0.54
CO_2	0.54	0.47	0.96	2.14	2.20	2.58
H_2O^+	2.56	1.80	3.01	3.40	2.53	4.01
H_2O^-	0.54	0.50	0.09	0.08	0.04	0.10
Σ	97.99	98.90	98.18	98.78	99.13	98.14
Rb	28	57	16	51	59	89
Sr	251	553	682	270	699	454
Y	43	47	22	32	27	37
Zr	210	350	168	352	261	277
Nb	46	43	26	20	34	38

The massive dolerites carry no epidote. The turbid plagioclase is altered to aggregates of 'sericite', calcite and chlorite, which in some cases (dyke F 29) take the form of pseudomorphous aggregates. The plagioclase is more basic, i.e. An_{38-60}, than that occurring in the amygdaloidal dykes. Some of the massive dolerites carry minor amounts of dark brown biotite. Chlorite alteration has destroyed the other mafic minerals (pyroxene, olivine and hornblende) which may have been present originally.

The dolerites with visible alteration have a light green colour and consist of a dense, fine-grained intergrowth of chlorite, 'sericite' and/or epidote. The original igneous mineral assemblages and textures have been completely obliterated during hydrothermal alteration taking place along late quartz-veins and breccias.

Chemistry

The chemical analyses (Table 1) show that the dykes have a general alkali-basaltic composition, according to the discriminant diagrams of Irvine & Baragar (1971). As this classification of basaltic rocks is based on the total alkali content, caution must be exercised when applying it to rocks which have been affected by metasomatic processes.

When the minor and trace element, Ti, P, Zr, Nb and Y (Table 1) are plotted on the discriminant diagrams of Winchester & Floyd (1976), most fall within the alkaline basalt field or at the field boundary. The only exception is sample F4 which plots in the area of overlap between the tholeiite and alkali-basalt fields (Floyd & Winchester 1975).

Therefore the major and trace element chemistry of the dolerites indicate that they were derived from an alkaline basalt magma.

Vein deposits

General

The epigenetic mineralizations in the Kongsberg district, and especially the silver-bearing veins, have been described by C. Bugge (1917) and A. Bugge (1937), while Lietz (1939) and Neumann (1944) dealt with the mineralogy of the silver ores. Ihlen & Vokes (1978) and Vokes & Ihlen (1980) have recently discussed the deposits in the framework of the tectono-magmatic evolution of the Oslo Paleorift (Ramberg & Larsen 1978).

The vein deposits can be separated into early quartz breccia veins carrying base metal sulphides, and late calcite veins containing native silver and Co-(Ni)-arsenides (Table 2). They were described by C. Bugge (1917) as first and second generation veins, respectively.

Quartz breccia veins

Veins of the first generation occur in the Fiskum area, east of the Lågen river (Fig. 2). The quartz-cemented breccias (reaching a width of 10 m) can be traced for several kilometres along the Lurdalen and Brennåstjern-Diseplass structures (Fig. 2). These breccias carry only minor sulphides, in most cases as accumulations along E-W offshoots from the main structures.

The major part of the base metal deposits is, however, situated at a distance from the regional structures and occurs as lodes which rarely exceed 20 m in length. These 0.1–1 m wide lodes consist of either milky quartz or a stockwork of thin quartz veins and veinlets. The latter often show the appearance of a quartz-cemented breccia. These mineralized zones may occur either individually, or arranged 'en echelon' with a general E-W, or N-S to NE-SW strike.

The quartz veins crosscut the foliation of the

Table 2. The age relationships between dolerite dyke emplacement and hydrothermal events in the Kongsberg-Fiskum district, based on C. Bugge (1917), Ineson et al. (1975) and the present study.

	Sequence of hydrothermal and magmatic events	Age
1.	Calcite veins carrying native silver and Ni-Co-Arsenides.	Permian
2.	Quartz breccia veins carrying base-metal sulphides.	Permian
3.	Dolerite emplacement.	Permian/Carboniferous
4.	Quartz breccia veins carrying base-metal sulphides and often enveloped by black carbonaceous gneisses.	Permian/Carboniferous and/or Upper Proterozoic

wallrock gneisses, which show a cataclastic fabric orientated parallel with the main lode direction. These zones of crushing or cataclasis rarely exceed 5 metres in width. The sheared gneisses often gradually become black in colour on approaching the quartz veins (Fig. 3) which contain coalblende as small globules interstitial to the quartz crystals. The coalblende may also occur as disseminations in fragments of the black gneisses which probably owe their colour to finely dispersed carbon. The black carbonaceous and schistose gneisses are often visually similar to the carbonaceous black shales of the Cambrian sequence inside the Oslo Rift. This observation is important, since C. Bugge (1917, p. 112 & 125) interpreted the black 'shales' included in the quartz breccia veins as representing fragments of the originally overlying Cambrian sequence. He therefore used this as evidence for the post-Cambrian, or probably Permian, age of the veins.

Apart from the carbon enrichment, the wall rock gneisses show local development of chlorite and sericite-clay mineral alteration due to the influx of hydrothermal solutions.

Ore minerals associated with the quartz veins are pyrite, sphalerite, chalcopyrite and galena. Minor amounts of calcite and/or fluorite may accompany some of the sulphides. Comb and cockade textures in the quartz veins indicate that repeated brecciation and fracturing occurred and led to the formation of several paragenetic sequences.

Calcite – native silver veins

The younger veins occur in the Kongsberg area (Fig. 2), where they were worked for native silver. Ore shoots along the veins were apparently controlled by their intersection with concordant sulphide-bearing zones, and so-called fahlbands (Gammon 1966), in the Precambrian country rocks. The silver-bearing veins which strike east-west have an average width of 5–10 cm, and rarely exceed 100 m along the strike and dip. The veins, steeply inclined to the south or north, often appear in sets which show a distribution resembling a 'fiederspalten' system or a fracture system related to the incipient development of a shear zone (Ihlen & Vokes 1978).

Some of the early quartz breccia veins in the fahlbands have been permeated by late silver-bearing solutions and contain silver-rich ores. In addition minor calcite veins, usually with a low ore content, are found along faults parallel with the strike of the gneisses (C. Bugge 1917).

The veins contain native silver, sphalerite, pyrrhotite, chalcopyrite, galena, argentite, Co-(Ni), arsenides and sulphominerals (Neumann 1944). Besides calcite, Neumann (1944) described the gangue minerals as quartz, fluorite, barite, zeolites, adularia, axinite, coalblende and other types of carbon.

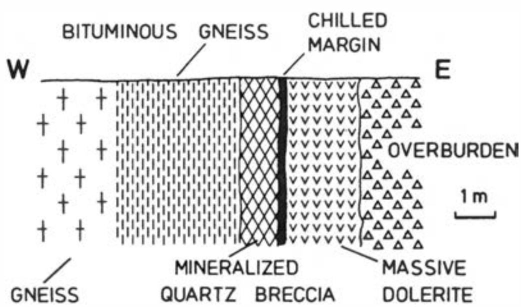

Fig. 3. Field sketch from the Nordre Bråten prospect showing the relationship between black carbonaceous gneisses, massive dolerite and a quartz breccia vein. Vertical section.

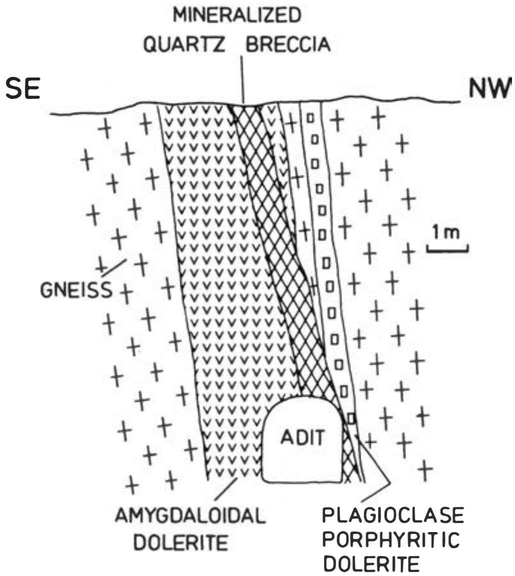

Fig. 4. Field sketch from the Grønntjernmyr prospect showing a quartz breccia vein cutting an amygdaloidal dolerite dyke. Vertical section.

Spatial and temporal relationships between the dolerite dykes and vein deposits

Field relationships

In the Kongsberg-Fiskum district both the dolerite dykes and the hydrothermal veins show the same trend. In addition they frequently occupy the same tectonic structures. C. Bugge (1917) also noted this spatial association, which he concluded was most probably due to a preexisting fracture system which controlled the location of both the dykes *and* the epigenetic veins.

The age relationships between the dolerite dykes and the ore bearing veins in the Kongsberg-Fiskum district were discussed by C. Bugge (1917). He found that the dykes occurring in the Kongsberg silver mines crosscut the quartz breccia veins but that they were older than the later Ag-bearing veins (Table 2). A similar age relationship between quartz breccia veins and dolerites had previously been recognized by Vogt (1907) during his study of the base metal veins in the Tråk area situated at the southern margin of the Oslo Rift (Fig. 1). C. Bugge's (1917) observations were later confirmed by Sæther (1964). C. Bugge (1917, p. 112) also mentioned that certain quartz breccia veins contain fragments of dolerite and that in the Fiskum area a vein of sphalerite, quartz and calcite was observed in the centre of a dyke.

While the dolerites in the Kongsberg area were emplaced after the formation of the quartz-base metal sulphide veins, the opposite relationship is usually observed in the Fiskum area. There the dolerites either carry quartz-cemented breccias along one of their contacts or occur as totally dismembered fragments in the larger quartz breccia veins. Quartz-base metal sulphide veins are only rarely found to crosscut the dolerites. An example of this is given in Fig. 4 from the Grøntjernmyr prospect. At another prospect (Nordre Bråten), a dolerite dyke shows sharp and chilled contacts against a metre wide quartz vein (Fig. 3). As this dyke is followed along the quartz breccia zone, thin veins of quartz are occasionally seen to cut the igneous contact. The quartz veins cutting the dolerites of the Fiskum area carry a greenish envelope due to the plagioclase in the dolerites being replaced by chlorite, calcite, sericite and clay minerals.

The general conclusion, that the dolerite dykes both pre- and postdate the early generation of quartz veins, agrees with the previous observations of Gammon (1966).

K-Ar dating of dolerite dykes

Sampling

The location of 7 different dolerite dyke samples investigated from the Kongsberg-Fiskum district is shown in Fig. 2 while UTM-coordinates on the Kongsberg 1:50,000 map are given in Table 3. This table also gives the widths of the dykes and the position of the dated samples relative to the nearest dyke contact.

Samples from the Kongsberg area comprise vesicular types, while those from the Fiskum area are of the massive variety. All were collected in situ, the only exception being sample K3 which was from old mine dumps outside Der Gleichen mine in the Kongsberg area. In the Fiskum area each of the dykes are represented by two samples, one being apparently unaltered, the other being altered and transected by quartz veins occasionally carrying base metal sulphides.

Analytical procedure

Conventional potassium-argon ages were determined on whole-rock samples using the tech-

Table 3. The location and K-Ar determination of dolerite samples from the Kongsberg-Fiskum district.

Sample no.	Location UTM Coord.	Dyke width*	Rock type	K_2O content %	Argon content (V^-/m. mm^3 .gm^{-1})	Atmospheric contamination (%)	Age (M.a.)
K1E	353140	4.0/2.0	Fresh dolerite	1.99 ± 0.01	(1.87 ± 0.03). 10^{-2}	6.3	270 ± 5
K2A	328164	3.0/0.2	Fresh dolerite	1.46 ± 0.02	(1.31 ± 0.02). 10^{-2}	14.6	254 ± 5
K2B	329165	3.0/1.0	Fresh dolerite	0.907 ± 0.009	(8.29 0.08). 10^{-3}	15.0	263 ± 4
K3	336161		Fresh dolerite	2.21 ± 0.02	(1.81 ± 0.03). 10^{-2}	20.0	237 ± 4
F4	403172	4.8/2.0	Fresh dolerite Q. Microveins	1.86 ± 0.01	(1.69 ± 0.02). 10^{-2}	4.1	262 ± 3
F4B	403172	4.8/0.9	Alt. dolerite Q.-Py. veined	2.27 ± 0.02	(2.08 ± 0.04). 10^{-2}	8.0	264 ± 6
F23C	406180	2.0/1.0	Fresh dolerite	0.918 ± 0.011	(8.73 ± 0.12). 10^{-3}	9.8	273 ± 5
F23A	406180	2.0/0.05	Alt. dolerite Py. veined	1.20 ± 0.01	(1.045 ± 0.012) 10^{-2}	6.8	251 ± 4
F38	420178	1.5/0.6	Fresh dolerite	3.13 ± 0.01	(3.01 ± 0.02). 10^{-2}	15.4	276 ± 5
F38B	420178	1.5/0.1	Alt. dolerite Q.-Sp. veined	1.50 ± 0.01	(1.34 ± 0.02). 10^{-2}	4.1	258 ± 4
FSD	412175	8.0/4.0	Fresh dolerite	2.59 ± 0.04	(2.44 ± 0.03). 10^{-2}	5.0	271 ± 5
FQSD	411173		Alt. dolerite fragments in Q-breccia	4.04 ± 0.03	(3.73 ± 0.05). 10^{-2}	2.5	266 ± 4

Abbreviations: Q: Quartz, Py: Pyrite and Sp: Sphalerite.
* Dyke width/Sample point in metres from nearest dyke contact.

niques described by Mitchell (1972). Decay constants used throughout this work are those recommended by Steiger & Jäger (1977). All ages are quoted with one standard deviation estimates of analytical uncertainties. Interlaboratory comparisons suggest that systematic errors are less than random analytical uncertainty.

Results

The results of the K-Ar isotopic age determinations are given in Table 3 and shown graphically in Fig. 5.

The minimum and maximum ages obtained were 237 ± 4 m.a. and 276 ± 5 m.a. In this range of ages, six of the eight apparently unaltered dykes yielded ages which are concordant at the 2 σ confidence limit, having a mean age of 270 ± 8 m.a.

The paired samples from the Fiskum area (Table 3) reveal a younger age in the altered part of each individual dyke. The alteration found in association with quartz veins is usually recognizable by its higher K_2O content. Also in the case of the unaltered dolerite (K2) of the Kongsberg area, a similar age relationship seems to occur, with an increase in age being found in the sample taken at greater distance from the dolerite-gneiss contact.

Discussion

The concordant K-Ar ages obtained here suggest at first sight that the dolerite dykes in the Kongsberg-Fiskum district were emplaced during the Late Paleozoic. In view of their evidently altered nature it might, however, be argued that the ages represent only thermal and/or hydrothermal imprint of the nearby Permian igneous complex of the Oslo Rift. It could be argued that the dykes were in fact appreciably older, and unrelated to the Permian tectono-magmatic activity.

The undeformed state of the dolerites clearly indicates that if an alternative, higher, age of emplacement is to be argued, then it has to be post-Sveconorwegian. In the southwestern part of the Baltic Shield (Fig. 1) isotopic age determinations have revealed the existence of two major periods of dyke emplacement prior to the Permian. The first period comprises dolerite and mica lamprophyre dykes having Rb/Sr ages from 995 m.a. to 871 m.a. (Patchett 1978) and K-Ar whole-rock ages within the range 950–650 m.a. (Versteeve

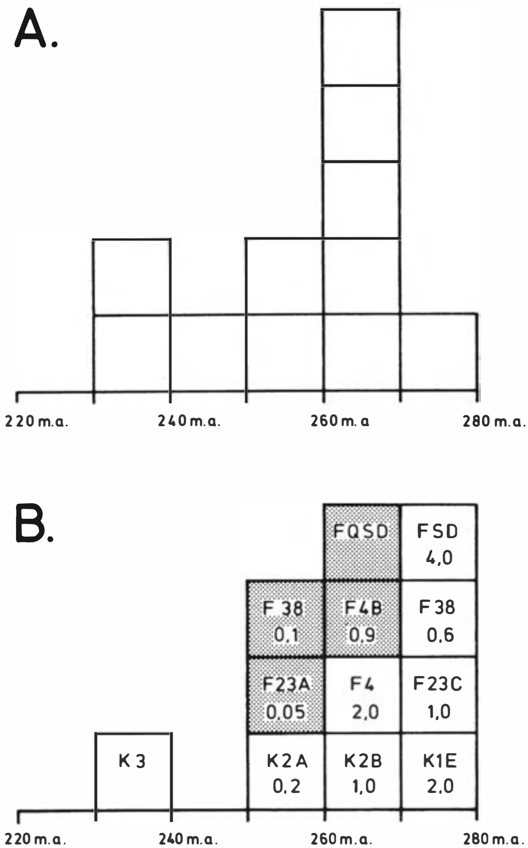

Fig. 5. Histograms of A: Previous results on wall-rock alteration spatially associated with the silver-calcite veins (Ineson et al., 1975). B: Present results. Dotted squares represent samples with visible alteration while numbers refer to distance in metres from nearest dyke contact.

1975, Klingspor 1976, Wahlgren & Kähr 1977). The second period of dyke emplacement occurred during the Early Cambrian 600–500 m.a. and comprises kimberlite (sensu lato) and tinguaite dykes. These are especially numerous in the areas surrounding the Fen carbonatite complex (Fig. 1) to which they appear to be related (Ramberg & Barth 1966).

The Late Proterozoic and Early Cambrian dykes which frequently show the same strike as those of the present area, are not, however, petrographically comparable. The Early Cambrian kimberlite dykes (damtjernites) carry biotite phenocrysts in a matrix of olivine, pyroxene, amphibole, biotite, feldspar and calcite, while the Late Proterozoic dolerites are characterized by the presence of olivine, orthopyroxene and uralite. The latter dykes are termed olivine-, olivine-hypersthene-, bronzite- and uralite-dolerite (Hermans et al. 1975, Klingspor 1976, Patchett 1978). The presence of brown hornblende in the amygdaloidal dolerites of the Kongsberg-Fiskum district sharply distinguishes them from Late Proterozoic dolerites (Hermans et al. 1975) in which the mineral is rarely found.

Petrographically the dolerites from the present area bear a strong resemblance to the descriptions of the Permian hornblende-bearing diabases (proterobases) and completely altered diabases from the Oslo Rift (Sæther 1945, 1947, 1962, Huseby 1971). In addition, dolerites with a similar mineralogical composition, occurring in southwestern Sweden, have given Late Carboniferous/Permian ages (Klingspor 1976). The scarcity of trace-element analyses on Late Proterozoic dolerites and Permian basaltic rocks does not permit chemical comparison to be made with the metasomatically affected dolerites of the present area. All, however, have a continental alkali basaltic affinity (Hermans et al. 1975, Weigand 1975).

The dolerite dykes of the Kongsberg-Fiskum districts therefore most probably belong to an igneous event related to the formation of the Oslo Rift. This essentially petrographical conclusion is supported by the fact that the K-Ar whole-rock ages reported here (by virtue of their concordancy) show no indication of partial isotopic resetting of an earlier igneous event. Partial Ar loss has, however, been noted in the weakly altered wall-rock gneisses associated with veins transecting the dolerites (publ. in prep.).

In view of the invariable presence and widespread occurrence of chlorite, epidote and sericite alteration within the so-called 'fresh' dolerites, it may be argued that the ages obtained can be explained by Ar mobility due to the circulation of hydrothermal fluids. This fluid interaction is clearly demonstrable by the lower age of the dolerites with visible alteration, compared with their 'fresh' counterparts within the same dyke. The lower age of the marginal zone of one of the dolerites (K2) relative to its central part may also support this conclusion.

Previous K-Ar dating of wall rock alteration spatially associated with silver-calcite veins in the Kongsberg area revealed ages in the range 231–272 m.a. (Fig. 5a, Ineson et al. 1975) which is comparable to the spread in ages (237–273 m.a.) of the 'fresh' dolerites (Fig. 5b). The results given by Ineson et al. (1975) also indicate that the hydrothermal/thermal activity in the Kongsberg area reached a maximum in the period 250–265 m.a. which is confirmed by the ages (251–266 m.a.) obtained from dolerites with visible alteration (Fig. 5b). In addition three out of eight samples of 'fresh' dolerites gave ages (254–262 m.a.) within the limits of the defined hydrothermal/thermal peak. The minimum age of 237 m.a. was obtained on a 'fresh' dolerite (K3) from Der Gleichen mine, where late stage silver mineralization with associated intense wall rock alteration is located along its margin (Bugge 1917).

The K-Ar ages of the altered dolerites also plot within the confidence limits of ages previously reported from ore deposits inside the Oslo Rift (Ineson et al. 1975, Ihlen et al. 1978). The arguments presented above therefore make it likely that the dolerites have suffered partial Ar losses, subsequent to their cooling, by fluids relatable to the formation of the vein deposits of Permian age.

Although no absolute age can be given for the emplacement of the dolerite dykes, the present results are in broad agreement with previous K-Ar whole-rock ages on petrographically similar dolerites from SW-Sweden which gave a K-Ar isochron of 294 ± 4 m.a., i.e. Late Carboniferous. It cannot, however, be ruled out that the K-Ar ages (270–275 m.a.) obtained on samples collected near to the centre of a dyke could be a consequence of Ar retention from the time of initial cooling of the dykes, i.e. Early Permian.

Neither fieldwork nor K-Ar dating has yet revealed any evidence of the dykes being of several generations. The dykes are therefore all probably of either Late Carboniferous or Early Permian age and were either formed contemporaneously with the plateau-lava eruptions inside the Oslo-rift or emplaced at a somewhat later stage, prior to the formation of the central volcanoes (Larsen & Sundvoll 1982).

Since field work has demonstrated the presence of fragments of both carbonaceous gneisses and dolerites in some of the quartz breccia veins as well as the absence of carbon deposited in any of the dykes, it is possible that the carbon deposition occurred prior to the dolerite emplacement. Therefore the possibility cannot be ruled out that the quartz breccia veins enveloped by carbonaceous gneisses are of Late Proterozoic age. A hydrothermal event having this age has been identified by Ihlen et al. (1978) in similar base metal-bearing quartz-breccia veins in the Precambrian basement adjacent to the northeastern part of the Oslo Rift.

Conclusion

K-Ar isotopic age determinations on unaltered and altered dolerite dykes in the Kongsberg-Fiskum district give ages which correlate with magmatic and hydrothermal activity inside the Permian Oslo Rift. Dolerite dykes least affected by later metasomatic processes give ages whose mean is 270 ± 8 m.a. The Early Permian or possibly Late Carboniferous age of the dolerites is also supported by their petrography which is comparable with that of amygdaloidal and massive proterobases and completely altered dolerites inside the Oslo Rift, and of some of the Late Carboniferous dykes in SW-Sweden.

The K-Ar ages obtained on the altered dykes and the marginal parts of some of the unaltered dykes give a wide spread of ages with a minimum of 237 m.a. These ages correlate with the dating of the clay mineral alteration assemblages which indicated a Permian metallogenetic event (Ineson et al. 1975, Ihlen et al. 1978, Ineson et al. 1978).

Acknowledgements. – The work was supported by NTNF grant 0801.08957 and a NATO Research grant No. 1774 for which the authors are grateful. Grateful thanks are also given to R. Ridley, Ivar Rømme, Karl Isachsen, Anne Irene Johannessen and Randi Skram for chemical analyses, rock sections, drafting and typing, respectively.

Manuscript received August 1983,
revised April 1984

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