16. K/AR AGES OF THE BASALTS OF THE NORWEGIAN-GREENLAND SEA DSDP LEG 38

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INTRODUCTION

K/Ar age determinations on basalt specimens at nine sites of Leg 38 were carried out by two groups:

(1) USSR group, (abbreviation, RG): Age determinations are presented for basalts of potassium and argon from Sites 336, 337, 342, 343, 344, and 345. The low basalt content from Sites 348 and 350 prevented an age determination.

German group (abbreviation, GG): K/Ar ages were obtained for basalts from Sites 336, 337, 338, 342, 344, 348, and 350. Because of the high degree of alteration of the specimens made available to this laboratory, no age determinations were performed for basalts from Sites 343 and 345.

Characteristics of the samples used for age determination are listed in Table 1. The results of both groups are presented in Tables 2 and 3.

ANALYTICAL PROCEDURE

RG

Analyses of three specimens (2, 4, 6, Table 2) were carried out at the Institute of Geology of Ore Deposits, Mineralogy, Petrography, Geochemistry (IGEM) by means of IGEM argon setting and mass-spectrometer M1-1301. Three other specimens (1, 3, 5, Table 2) were analyzed in the Central Laboratory of the West Siberian Geological Survey in Novokuznetsk by means of WSEGEI argon setting and mass spectrometer MI-1309. Radiogenic argon was determined by the method of isotope dilution with ^{38}Ar standard. Potassium was determined by flame photometry. The whole rocks taken for analyses weighted from 1 to 3 up to 10 g. The samples were prepared by crushing and sieving (0.5-3 mm). The results are given in Table 2.

GG

The same analytical methods were applied as by the RG. Potassium was analyzed by a digitalized EEL-two-channel flame photometer with internal Li-standard and addition of cesiumchloride/aluminiumnitrate as a buffer. For the determination of radiogenic argon a mass spectrometer MAT-CH4 was used. All analyses were carried out in duplicate, and additionally, partly on different sieve fractions. In general, the 95% confidence interval for the potassium analyses is 1.2% relative. Some replicates of the argon determinations differ by several percent. This may be explained partly by low contents of radiogenic argon. However, inhomogenities in the distribution of argon have to be assumed. The results are given in Table 3. The errors represent the interval of 95% of analytical confidence, calculated from the scatter of the individual results. Additionally, the ignition losses given in Table 3 provide a rough measure of the freshness of the basalts.

Constants

Different constants were used by the two groups for age calculation. The RG adopted the constants which were established by the Age Determination Commission of Geologic Formations (1964): $\lambda K = 0.557 \times 10^{-10}\ yr^{-1}$, $\lambda\beta = 4.72 \times 10^{-10}\ yr^{-1}$; $^{40}K/K = 0.00122$ wt %. The GG used the constants of the Phanerozoic Time scale (1964): $\lambda K = 0.584 \times 10^{-10}\ yr^{-1}$, $\lambda\beta = 4.72 \times 10^{-10}\ yr^{-1}$; $^{40}K/K = 0.00119$ atom %. From the different constants a systematic deviation is introduced of -4.3% from RG to GG apparent ages. For better comparison in Table 2, age values calculated by PTS constants are added. In the discussion, only these values are cited.

General Remarks

The specimens for K/Ar age determination were, if possible, chosen from lower sections of magmatic units. If full cores were not available, only minicores of a few grams weight were used for the analyses. Great care was taken to find samples free of brecciated zones, slickensides, glass rims or glassy groundmass, and/or higher degrees of all kinds of alteration. A brief mineralogic and petrographic description is given in Table 1.

It is well known that submarine basalts which suffered rapid cooling under increased pressure might have captured excess argon (Dalrymple and Moore, 1968). These basalts yield K/Ar model ages which might exceed the geological age. Suspicious, in this respect, are specimens with chilled margins and rich in glass. On the other hand, if the potential potassium-bearing matrix or glass phase are weathered or altered under submarine conditions, losses of argon and a reduction of the K/Ar apparent ages have to be assumed. Thus, the geological significance of K/Ar data of basalts from deep-sea drill holes is entirely obscured by these opposing influences. In the discussion to follow,

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TABLE 1
Characteristics of Rock Samples Used for Age Determinations by K/Ar Method

Sample	Sample (Interval in cm)	Petrographic Sample Description (Composition in Volume %)
1	336-44-2, 78-100	Fine-grained holocrystalline porous fresh basalt with augite (45%), plagioclase (45%), titanomagnetite (5%), biotite (2%), smectite (3%)
2	337-15-2, 110-117	Olivine hyalobasalt with calcite and smectite amygdules; plagioclase (23%), groundmass (70%), amygdules (7%)
3	342-8-4, 78-99	Fine-grained plagioclase-pyroxene phyric basalt with augite (42%), plagioclase (43%), titanomagnetite (10 %), smectite (5%)
4	343-13-2, 60-80	Fine-grained brecciated hyalobasalt with calcite amygdules; plagioclase (19%), groundmass with glass (60%), amygdules (17%), ore mineral (4%)
5	344-37-3, 19-52	Medium-grained holocrystalline gabbro-diabase with augite (44%), plagioclase (50%), magnetite (5%), pyrite (1%), biotite and smectite
6	345-36-1, 85-90	Fine-grained phyric hyalobasalt with zonal plagioclase phenocrysts; glass replaced by smectite; plagioclase (13%), groundmass with glass (70%), amygdules (17%)
GG		
1000	336-41-1, 36-37	Porphyric basalt with small phenocrysts of plagioclase, augite, and olivine; the latter is always altered to smectite; groundmass consists of subparallel oriented lath-shaped plagioclase, idiomorphic augites, and ore; interstices (and rarely present amygdules) are filled with light brown smectite
1018	337-15-2, 128-130	Microlithic porphyric basalt with olivine, phenocrysts, always altered to smectite; groundmass consists of mostly needle-like plagioclase, skeletal augite (mostly altered), ore, and devitrified glass
1027	338-43-4, 54-57	Fine-grained porphyric and amygdaloidal basalt with clusters of plagioclase phenocrysts, phenocrysts of altered mafics (olivine or pyroxene), and some small phenocrysts of augite; groundmass: lath-shaped plagioclase, augite, and ore; interstices and amygdules are filled with smectite
1064 1071 1072 1073	342-7-2, 137-140 342-8-4, 127-130 342-8 3, 110-118 342-8-3, 89-110	Medium-grained porphyric basalt with macrophenocrysts with all transitions in size to the plagioclase of the groundmass; hypidiomorphic microphenocrysts of augite and idiomorphic augite in the groundmass with little alteration to smectite (and calcite), skeletal grains of ore, and olivine (always altered to brown smectite); interstices are filled with brown smectite
1050	344-37-3, 85-113	Coarse-grained ophitic basalt with plagioclase, mostly lath-shaped and less tabular developed, partly altered to smectite. Augite generally hypidiomorphic and partly strong altered to smectite; interstices are filled with smectite (and calcite), single crystals of alkalifeldspar, and traces of chlorite and biotite; ore: small idiomorphic or large skeletal crystals rimmed by traces of biotite or hydrobiotite
1059	348-33-1, 56-59	Medium-grained subophitic basalt with lath-shaped plagioclase and hypidiomorphic augite, olivine (always altered to smectite), and ore; interstices are filled with green smectite, pigeonite in subordinate amounts, little calcite and single grains of quartz
1061	348-34-2, 91-105	Amygdaloidal ophitic basalt-plagioclase, augite, and olivine like above sample; interstices and amygdules are filled with brown smectite
1081	350-16-2, 30-33	Medium-grained porphyric basalt with strongly zoned plagioclase phenocrysts of, and hypidiomorphic augite; groundmass: lath-shaped plagioclase and idiomorphic augite; the latter is partly altered to smectite; olivine, generally altered to smectite, and ore; interstices are filled with smectite which represents partly devitrified glass
1082	350-16-3, 73-76	Medium-grained porphyric basalt like the above sample, but augite and olivine are less altered, and partly there is fresh glass in the interstices
1083	350-16-3, 120-140	Medium-grained porphyric basalt like Sample 16-2, 30-33, but less smectite and devitrified glass in the interstices and instead more augite

the petrographic properties of the basalts have to be considered and the analytical results have to be compared carefully with the assumptions deduced from overlying sediments, or from the geographic position.

Only specimens from Site 337 were taken from rapidly cooled flow basalts with glass rims. Therefore, generally, losses of argon are more probable than excess argon. We tentatively regard the K/Ar data as minimum ages.

The basalts from Sites 342 and 350 (Table 3, GG) are represented by four and three samples, respectively; some of them were dated in different size fractions. Petrographic and geochemical similarity of the basalts indicates a similar origin and age within each site. Consequently, similar K/Ar ages were expected for samples from the same site. However, a significant spread of the dates in both sites was obtained, which indicates a disturbance of the K/Ar system.

DISCUSSION OF RADIOMETRIC AGES

Site 336, Iceland-Faeroe Ridge

The K/Ar ages of different specimens are in good agreement with paleontological evidence; RG: 40.4

TABLE 2
Whole-Rock K-Ar Dating of Leg 38 Basalts (RG)

Sample	Site	K (%)	$Ar^{40}rad$ (ngm/g)	$Ar^{40}rad$ / $Ar^{40}total$	Apparent Age (m.y.) with $\lambda_K = 0.557 \times 10^{-10}yr^{-1}$	Apparent Age (m.y.) with $\lambda_K = 0.584 \times 10^{-10}yr^{-1}$
1	336	0.365	1.1, 1.02	15.6, 10.8	43.4, 41.2	40.4 ±3.2
2	337	0.32 ±0.02	0.40 ±0.03	4, 5	18 ±1.5	17.5 ±1.5
3	342	0.307	0.974	20.5	46.6	44.1
4	343	1.03 ±0.03	2.10 ±0.15	20, 32	30 ±2	28.5 ±2
5	344	0.398	1.23, 1.22	18.4, 5.4	45.4, 45.1	42.8
6	345	1.45 ±0.03	2.8 ±0.3	23, 43	28 ±3	27 ±3

TABLE 3
K/Ar Data of Basalts of Leg 38 (G.G.)

Sample	Loss of Ignition (%)	Sieve Fraction (μm), and Treatment[a]	Radiogenic ^{40}Ar (%)	Radiogenic ^{40}Ar (ccSTP/g)×10^9	K (wt %)	Apparent Age (m.y.)	Sedimentary Cover and Minimum Age of Basalt[b]
Site 336							
1000	1.6	1000-200 HF	25.0	1.77 ±7.5	0.1015	43.4 ±3.3	Middle or late Eocene; 49-38 m.y.
Site 337							
1018	5!	1000-200 HF	14.5	2.61 ±9.4	0.255	25.5 ±2.4	Early or middle Oligocene; 38-32 m.y.
Site 338							
1027	2.9	1000-400 US	12.0	1.73 ±5.2	0.0938	46.6 ±2.5	Early Eocene; 54-49 m.y.
Site 342							
1064	1.5	1000-400 US	41.4	6.95 ±2.0	0.374	46.1 ±2.5	
1073	0.98	800-63	60.3	6.78 ±1.8	0.282	59.4 ±1.3	
		800-250	73.9	9.11 ±2.2	0.300	73.9 ±1.9	
		800-250 HF	78.0	9.13 ±2.7	0.281	79.9 ±2.4	
		250-63			0.264		Early Miocene; 22-16 m.y.
1072	1.1	800-63	50.4	4.78 ±3.0	0.262 ±2.1%	45.3 ±1.7	
		800-250	52.9	5.04 ±1.6	0.280	44.6 ±0.9	
		250-63			0.245		
1071	0.82	1000-200 HF	58.1	4.99 ±2.0	0.300	41.3 ±1.0	
Site 344							
1050	2.8	800-63	4.8	0.562 ±14	0.430	3.3 ±0.5	Miocene or younger; 7-3 m.y.
		800-250	4.6	0.528 ±14	0.475	2.8 ±0.4	
		250-63			0.389		
Site 348							
1059	0.83	1000-400 US	8.9	0.369 ±12	0.051 ±5.0%	18.2 ±2.4	Oligocene-early Miocene; 35-15 m.y.
1061	2.5	1000-200 HF	3.8	5.23 ±11	0.0673	19.4 ±2.2	
Site 350							
1081	0.60	1000-400 US	56.2	4.56 ±2	0.271±3.0%	41.8±1.6	
1082	0.77	1000-400 US	50.6	3.43 ±2.8	0.255 ±7.7%	33.5 ±2.8	
1083	0.37	800-63	45.0	4.77±11	0.237 ±3.6%	50 ±5.5	Late Eocene; 43-38 m.y.
		800-250	41.3	3.77±4.0	0.227	41.2 ±1.7	
		250-63			0.231		
		800-250 HF	51	3.70 ±4.2	0.226	40.6 ±1.8	

[a]US = soaking over night in 0.01 N $Na_4P_2O_7$ followed by strong ultrasonic treatment;
HF = 15 min 15% HF at 50°C followed by "US".

[b]Ages according to Berggren (1972).

±3.2 m.y.; GG: 43.4 ±3.3 m.y. Because of the lack of glassy matrix, no excess argon has to be expected. However, the secondary formation of smectite minerals will have diminished the apparent age of the basement. So 43 m.y. or a late Eocene age may be regarded as a minimum age of the basaltic basement. This is younger than the youngest basalts of Faeroe Islands (around 50 m.y.), but the basalts of Site 336 are surely older than the probable beginning of the Iceland hot-mantle plume activity. This occurred during the time of possible shifting of the rift axis at 30 m.y. from the Norway Basin to the Iceland Jan-Mayen Ridge.

Site 337, Extinct Axis in the Norway Basin

The minimum age of the basaltic basement expected from the oldest sediments at Site 337 (near the extinct axis in the southern Norway Basin) was early or middle Oligocene (about 34 m.y.). The ages obtained in both groups (RG: 17.5 ±1.5 m.y.; GG: 25.5 ±2.4 m.y.) are significantly younger than the sediment cover. However, all petrographic features indicate a presedimentary formation of these oceanic basalts, which extruded and cooled under submarine conditions. An intrusive character can be excluded.

Because of the high degree of alteration of the former glass matrix and of most minerals, as well as the frequency of amygdules filled with smectite and calcite, a change of potassium content and an argon loss by diffusion must be assumed. These features are probably the reason for the diminution of the age of basaltic basement.

Sites 338, 342, and 343, Outer Vøring Plateau

At these three sites, the basalts show features of alteration either subaerial or submarine, but close to sea level. The oldest sediments above the basement are predominantly terrigenous in origin. Although there are some contradicting statements in the shipboard report between sedimentologists and petrographers, the prevailing opinion seems to favor a sedimentary origin of the contact of the basalts and the overlying sediments (Hole Summaries, Leg 38). The top basalt layer of Site 343, which is underlain by a sand, is probably a sill with a variolitic margin, and with thermal metamorphism in the sediments near the contacts.

Based on magnetic anomalies 23 and 24 in the Vøring Plateau region, the ages of the basaltic basement at Sites 338 and 342 were expected to be near 60 m.y., and at Site 343 near 53 m.y. The overlying sediments suggest ages not younger than around 50 m.y. for Site 338. The early Miocene sediments on top of the basement at Site 342 gave a minimum age of only 22 m.y. However, from geological evidence, it must be assumed that until Miocene time at Site 342, the crest of a basaltic basement ridge remained close to sea level and inhibited sedimentation, or led to erosion of older sediments, and probably parts of the basalt flows.

The radiometric age of the Site 338 basalts (GG:46.6 ±2.5 m.y.) is so far in agreement with the Eocene age for the oldest sediments, thus suggesting that there was no major gap between the extrusion of the basalt flows and the beginning of sedimentation.

For Site 342, four samples yielded apparent ages close to 44 m.y.: Core 7-2 (46.1 ±2.5); Core 8-3 (44.9 ±0.9); Core 8-4 (44.1 [RG] and 41.3 ±1.0 m.y.). One sample gave abnormally high values (Sample 1073, Sample 8-3, 89-110 cm, Table 3). The cause of this is not clear. From petrographic and geochemical evidence, there are no hints for glassy matrix and excess argon.

Basaltic rocks from Site 343 gave an age of only 28.5 ±2 m.y. (RG), which does not agree with the early Eocene age for the basal sediments. Either the basalts are intrusive, which is indicated by thermal metamorphism of the sediments and/or the very high degree of alteration of these rocks has changed the K/Ar data. In both cases, the K/Ar ages do not indicate the formation of basaltic basement during initial rifting.

If the ages have not considerably changed by alteration, the basement rocks at Sites 338 and 342 are of a similar age. Upon the normal ocean floor tholeiites at Site 338 a generally complete sequence of Tertiary sediments was deposited, whereas on the presumably contemporaneously extruded basalts at Site 342, only Miocene muds and oozes were deposited or preserved.

We have to assume for the time of initial rifting and/or during the mid-Tertiary a strong morphology existed, as we know from other regions where new rifts come into existence. For example, the differences in height in the Afar region lie between 120 meters below and more than 2000 meters above sea level within short horizontal distance. We find there also a close basalt association with different degress of alkalinity. The more transitional character of the basalts from Site 342 could better be explained by a rise in a central volcano, or a seamount, rather than by a normal sea-floor-spreading origin.

Site 344, Knipovich Ridge

Without any doubt the coarse-grained diabase and gabbro at Site 344 near the Knipovich Ridge is a sill or a dike within Miocene or younger sediments. Therefore, the K/Ar ages found by GG of around 3 m.y. are reasonable. The datum 42.8 m.y. determined by RG on specimens from the same core are at present controlled by the authors. High amounts of excess argon were not assumed to be present in these coarse- to medium-grained hypabyssal rocks.

Site 345, Lofoten Basin

The K/Ar age of 27 ±3 m.y. (RG) of the basaltic basement is younger than the late Eocene (?) sediments at the base of the sedimentary section. Considerable deficiency of the radiometric age is to be assumed, because of the devitrification of the glass matrix and secondary filling of the numerous amygdules observed in the extrusive rock. The thin interbedding of sediments with radiolarians in the upper part of the basaltic unit is an argument for a similar age of basalt and sediments.

Site 348, Eastern Icelandic Plateau

The tentative age determinations of the terrigenous sediments in the shipboard report, based on arenaceous foraminifera, gave an age of early Miocene to Oligocene for basaltic basement, whose sea-floor-spreading origin is no longer questioned. The absence of typical pillow lavas and glassy rims is not necessarily to be interpreted as an indicator of the intrusive character of the basalts.

K/Ar ages of rather fresh and glass-free basalt specimens provide a maximum age of only early Miocene for the oldest sediments above the basement

(18.8 ±1.7 m.y., GG). This slightly younger age seems more probable for the basal sediments at this site. This date would not conflict with a sea-floor-spreading axis, which was active in the eastern Icelandic Plateau from 30 m.y. to 15 m.y.

Site 350, Southern Extension of Jan-Mayen Ridge

According to the shipboard report, the very fresh basalts from Site 350 on the southernmost Jan-Mayen Ridge are possible intrusive into highly altered tuff breccias, and overlain by sediments of tentative late Eocene age. The radiometric ages of the different specimens are varying significantly between 33.5 m.y. and 50 m.y. (GG). From thin-section examination, Sample 1082 seems to be the least altered. It contains glass with only minor devitrification. In spite of this, Sample 1082 yielded the lowest K/Ar datum. At present, no safe explanation of the pattern of K/Ar ages can be given. An age of 41.2 ±1.0 m.y. as determined on three of the five basalt fractions would be in agreement with an extrusion or intrusion of the basalt in the youngermost Eocene before the extinction of the axis in the Norwegian Sea, when the Jan-Mayen Ridge and its morphological extension to the south was part of the Greenland continent or its shelf area (Talwani and Eldholm, in press).

SUMMARY

K/Ar data of basalts from drill sites in the Norwegian-Greenland Sea are compared with the age of overlying sediments and the overall geologic position. Data falsified by excess argon were not recognized. However, a diminution of radiometric ages by argon loss, because of alteration processes, must be assumed to a general extent for all basalt samples, especially those from Sites 337, 343, and 345.

According to the K/Ar data basaltic basement of the Iceland-Faeroe-Ridge (Site 336), the Vøring Plateau (Sites 338 and 342), and the southern extension of the Jan-Mayen Ridge (Site 350) are, at a minimum, of middle (338) to late (336, 342, 350) Eocene age. The late Oligocene date of the basalts from the Lofoten Basin (Sites 343 and 345), and the extinct axis in the Norway Basin (Site 337) do not correspond to the Eocene (343, 337) respectively to middle Oligocene (345) ages for the covering sediments and have probably been diminished by alteration processes. The basement in the eastern Icelandic Plateau at Site 348 is probably early Miocene. The intrusive sill near the Knipovich Ridge at Site 344 is of Pliocene age.

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