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5. K-Ar AND $^{40}Ar/^{39}Ar$ AGES OF CENTRAL KERGUELEN PLATEAU BASALTS[1]

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ABSTRACT

Conventional K-Ar and $^{40}Ar/^{39}Ar$ analyses on whole-rock samples are reported for basaltic samples retrieved on the Central and Southern Kerguelen plateaus during Ocean Drilling Program Leg 120. Sites 747, 749, and 750 recovered basalts from the plateau basement, whereas Site 748 drilled a lava flow interbedded with sediments of probable Albian age.

The freshest core basalts from the basement yielded dates falling in the 110–100 m.y. interval. Sample 120-749C-15R-3 (26–31 cm) gave conventional K-Ar, total fusion, and plateau $^{40}Ar/^{39}Ar$ ages that are closely concordant: 111.5 ± 3.2 m.y., 109.9 ± 1.2 m.y., and 109.6 ± 0.7 m.y., respectively. Sample 120-750B-15R-5 (54–60 cm), when taking into account the analytical uncertainties, yields conventional K-Ar and $^{40}Ar/^{39}Ar$ plateau ages that can be considered similar: 101.2 ± 7.5 and 118.2 ± 5 m.y., respectively. Inspection of the $^{39}Ar/^{40}Ar$ vs. $^{36}Ar/^{40}Ar$ diagram does not reveal the occurrence of an initial argon component of radiogenic composition in the two samples. Accordingly, our results suggest that the formation of the basement of the Central Kerguelen Plateau was closed at 110 m.y.. Furthermore, these results are in agreement with a K-Ar age of 114 ± 1 m.y. mentioned in the literature for a basalt dredged in the 77°E Graben.

The still scant amount of data indicates that the outpourings of the Central Kerguelen Plateau correspond rather well with widespread continental magmatism in Gondwanaland that is believed to mark the incipient opening of the eastern Indian Ocean. This implies a huge head for the mantle plume at the source of these liquids. Nevertheless, on land and at sea the exact duration of magmatism remains unknown. Therefore, a catastrophic pattern similar to that currently invoked for the Deccan Traps at the end of the Cretaceous, though possible, is not yet required by present geochronologic data.

INTRODUCTION

The Kerguelen Plateau is a topographic broad high located in the southern Indian Ocean on the Antarctic Plate between 46° and 63°S (Fig. 1). This plateau is one of the largest intraplate physiographic features in the oceans. It stretches over 2300 km in a northwest-trending direction and 600 km in an east-trending direction. The thickness of its crust varies between 15 and 23 km (Recq and Charvis, 1986; Houtz et al., 1977). Originally contiguous with Broken Ridge, seafloor spreading isolated it 40 m.y. ago (Houtz et al., 1977; Munschy and Schlich, 1987). The Kerguelen Plateau itself exhibits a volume of 26×10^6 km^3. If Broken Ridge is taken into account, the total volume of the plateau before 40 m.y. was on the order of 57×10^6 km^3, more than the volume of any of the largest plateaus in the Pacific. The plateau is overlain by alkaline magmatic rocks cropping out in the Kerguelen and Heard islands. The latter magmatism started at 39 m.y. and is still active (Giret, 1983).

Magnetic Anomalies Around the Kerguelen Plateau

The northern and central parts of the Kerguelen Plateau are bordered on the east by the oceanic crust formed at the Southeast Indian Ridge (Fig. 1). Magnetic anomaly 18 (43 m.y.; Berggren et al., 1985) at the margin of the plateau precisely dates the separation between the Kerguelen Plateau and Broken Ridge (Houtz et al., 1977).

The southern part of the plateau is bordered on the east by the Labuan Basin, which is characterized by the absence of magnetic anomalies. This basin, juxtaposed to the plateau, might represent a piece of the plateau itself offset by a normal fault or, more likely, by a piece of oceanic crust formed during the magnetic quiet period (84–118 m.y.; Rotstein et al., 1991).

To the west, the oldest anomaly identified by Schlich (1982) in the Crozet Basin is magnetic anomaly 34 (84 m.y.; Kent and Gradstein, 1985). A revision of the magnetic profiles in the Enderby Basin, which borders the southwestern margin of the plateau, suggests the existence of east-trending Mesozoic magnetic anomalies from at least M1–M7 (122–128 m.y.; time scale of Kent and Gradstein, 1985; Li, 1988). Although these magnetic anomalies have to be confirmed, their presence would suggest that the plateau was built beside or upon an oceanic crust of Early to Late Cretaceous age.

Origin of the Kerguelen Plateau

The origin of the Kerguelen Plateau is extensively discussed in two papers of this volume (Salters et al., this volume; Storey et al., this volume). In short, the reliable hypothesis, supported by trace element and isotope geochemistry, is that the plateau resulted from excess volcanism linked to a mantle plume in an extensional or spreading zone, as suggested by Storey et al. (1989) and Weis et al. (1989). The idea that the Kerguelen Plateau is a fragment of a rifted, subsided continental lithosphere (Dietz and Holden, 1970; Schlich et al., 1971; Ramsay et al., 1986) is neither supported by plate reconstructions, which provide a reasonable pre-drift fit of the continents without the need to incorporate the plateau (Powell et al., 1988; Norton and Sclater, 1979), nor by isotope geochemistry (Dosso et al., 1979). The geophysical

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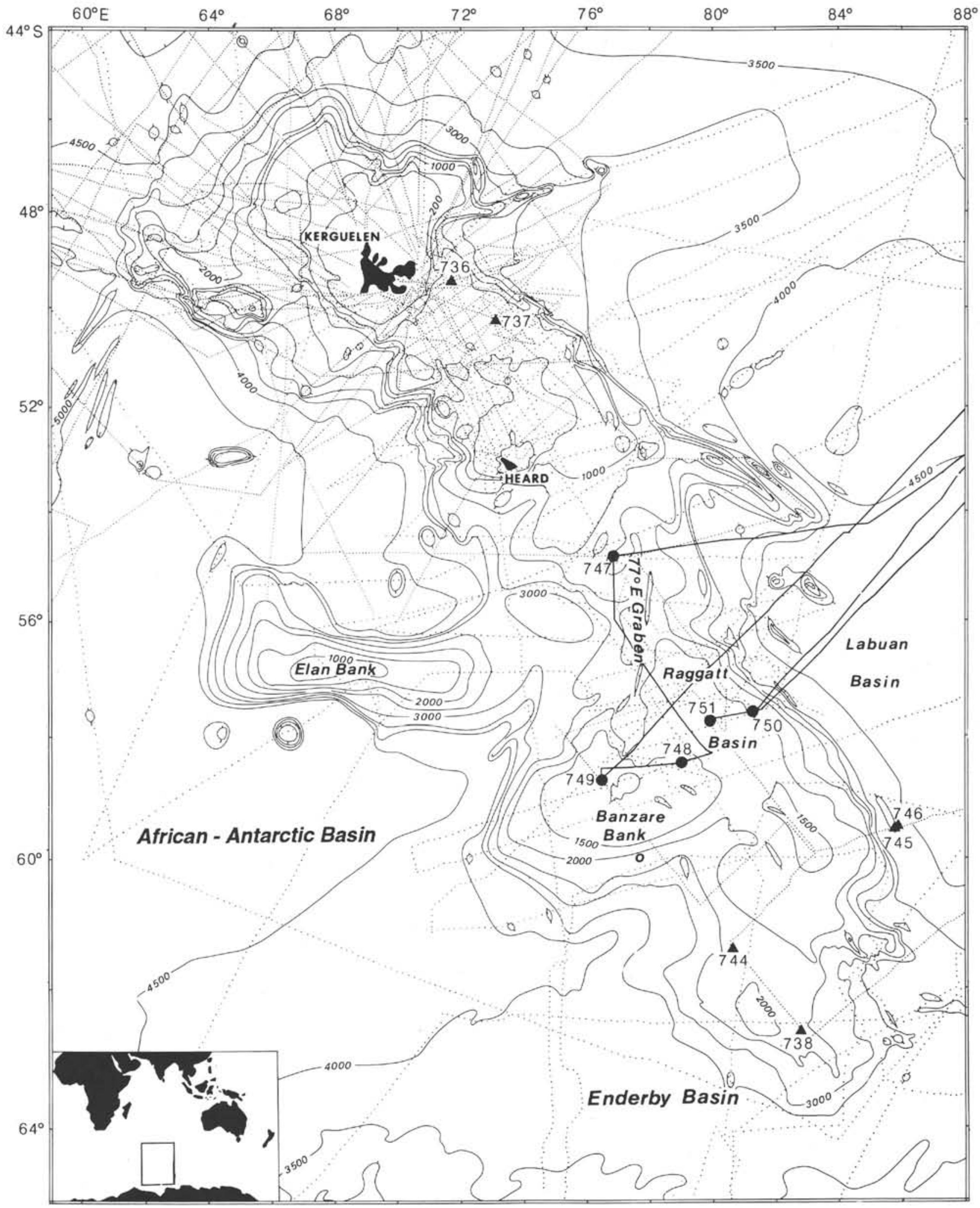

Figure 1. Bathymetric map of the Kerguelen plateau giving the position of the sites drilled during Legs 119 (738, 744, 745, and 746) and 120 (747, 748, 749, 750, and 751). Contour are in meters.

data are entirely compatible with an oceanic origin for the Kerguelen Plateau. The seismic velocity values vs. the depth distribution is similar to that of typical oceanic islands (Recq et al., 1983; Recq and Charvis, 1986).

Age of the Kerguelen Plateau

The problem now is one of assigning an age to the formation of this huge oceanic structure. The isotopic ages must be constrained by stratigraphic data. These ages can yield additional constraints on the timing of the breakup of eastern Gondwanaland, which initiated the drifting between the Indian and Antarctic-Australian plates.

Basalts from the Kerguelen Plateau were dredged during the NASKA MD 48 cruise (Bassias et al., 1987). Those retrieved in the axial graben of 77°E Graben are transitional, characterized by the common occurrence of labradorite and bytownite crystals. Bassias et al. (1987) and Leclaire et al. (1987) mention a K-Ar age of 114 ± 1 m.y. obtained on plagioclase extracted from a lava breccia. The latter group stresses that the Early Cretaceous age is confirmed by the presence of the Cretaceous foraminifer, *Hedbergella,* in a bioclastic limestone that formed the matrix of the lava breccia.

Leg 120 of the Ocean Drilling Program (ODP) retrieved basement basalts in the central part of the Kerguelen Plateau at Site 747 and in the southern part at Sites 749 and 750. In addition, a lava flow interbedded with siltstones was drilled 200 m above the basement at Site 748. Such samples provide, therefore, an opportunity to determine the nature and age of the upper part of the basement of the Kerguelen Plateau and, hence, to test the idea that the opening of the Southern Indian Ocean was caused by a short but catastrophic event.

This paper presents the results of K-Ar and $^{40}Ar/^{39}Ar$ studies of the aforementioned basalts. Because these rocks contain evidence of hydrothermal circulation, in the condition of the zeolite facies (Sevigny et al., this volume), the use of the two methods was expected to provide a better geological appraisal of the apparent ages.

STRATIGRAPHIC SETTINGS AND NATURE OF THE BASALTIC BASEMENT

The basaltic basement at Site 747 was reached at 296.6 m below the seafloor (mbsf). It is overlain by cherty nannofossil chalk of lower Santonian age (Schlich, Wise, et al., 1989). The basalts at Site 749 lie beneath an early Eocene nannofossil ooze, a typical drift deposit at 202 mbsf. At Site 750, dark silty claystones with charcoal and conglomerates of probable Albian age overlie the basaltic basement. The highly altered lava flow at Site 748 is overlain by an undated basaltic conglomerate and then by upper Albian–Turonian sandstones.

Detailed descriptions of the cores recovered are given in Schlich, Wise, et al. (1989). In addition, major and trace element and isotope geochemistry studies (Salters et al., this volume; Storey et al., this volume) complete the characterization of these basalts. All these basalts are more or less horizontal flows that have been emplaced in a subaerial environment, as evidenced by the oxidized and highly vesicular flow tops. This is corroborated by the presence at Site 750 of continental sediments overlying the basaltic basement. Seismic stratigraphic constraints (Munschy et al., this volume) and pressure determinations for the zeolite metamorphic facies of the basalts (Sevigny et al., this volume) suggest an erosion of the basement during the Cretaceous of about a few hundred meters.

Most of the basalts drilled from Sites 747, 749, and 750 are silica-saturated, olivine normative tholeiites containing plagioclase and clinopyroxene phenocrysts in a matrix composed of the same minerals together with ilmenite and magnetite. They are enriched in light rare earth elements (LREE) and in large ion lithophile elements (LILE) up to 50 times the chondritic values. In contrast, the basalts of Site 748 are undersaturated and enriched in LREE-LILE up to 100 times the chondritic values. They exhibit an alkaline signature. Their isotopic compositions (Sr, Nd, and Pb) are very scattered, indicating complex mixing between different mantle sources beneath the plateau (at least enriched, depleted, and metasomatized mantle sources).

These basalts suffered pervasive hydrothermal circulation, which deposited minerals of the zeolite facies (zeolite-smectite assemblages) essentially in the veinlets and vesicles and locally in the groundmass. The zeolite assemblage suggests a high temperature for Site 749 ($T \leq 225°C$) and a lower one for Sites 747 and 750 ($T \leq 115°C$) (Sevigny et al., this volume).

PETROGRAPHICAL DESCRIPTIONS OF THE ANALYZED BASALTS

Thin sections were made on drill cores selected for K-Ar dating. The following brief descriptions are useful in interpreting the geochronological data:

Sample 120-747C-13R-1, 51–58 cm

The basalt is aphyric to sparsely phyric with an intergranular texture. Rare plagioclase (An_{60}) phenocrysts (2–3 mm) are associated with clinopyroxene (2 mm). Phenocrysts constitute 2% of the rock. The matrix is made of plagioclase laths (<2 mm), which constitute a framework inside of which clinopyroxene (<1 mm), oxides, and altered glass can be observed. Cavities 3–4 mm in size are filled with smectite. The degree of alteration is low (about 5%).

Sample 120-747C-16R-5, 33–40 cm

The basalt exhibits an ophitic texture. Plagioclase (An_{50}) laths 0.5–1 mm in size are cemented by clinopyroxene (1 mm). Oxides are absent. The degree of alteration is moderate; part of the clinopyroxene is transformed into brown-green smectites. Green clays are also present. The alteration is estimated at 20% of the rock.

Sample 120-748C-79R-6, 34–40 cm

The basalt is sparsely phyric with only rare oxide phenocrysts. The groundmass is composed of plagioclase microlites (<1 mm) within a glass replaced by clays. Cavities (4 mm) are filled by smectite. The degree of alteration is estimated to be 25%.

Sample 120-749C-15R-3 (26–31 cm)

The basalt is of medium grain size with an intersertal texture. Rare phenocrysts that reach up to 3 mm are uniquely plagioclase. The groundmass minerals are plagioclase laths (0.5–1 mm), which form a network containing clinopyroxene (0.5 mm) and oxides. The degree of alteration is low (2%).

Sample 120-749C-16R-6, 42–50 cm

The basalt is porphyritic. The plagioclase phenocrysts are mostly euhedral and form glomerocrysts. They can reach up to 4–6 mm in size. They are enclosed by a groundmass composed of plagioclase laths (0.2 mm) and intergranular clinopyroxene. The degree of alteration is estimated at 10%.

Sample 120-750B-15R-5 (54–60 cm)

The basalt is ophitic in texture. Rare plagioclase in laths and clinopyroxene phenocrysts vary between 2 and 3 mm. The groundmass is composed of a network of plagioclase crystals ranging in size from 0.2 to 1 mm that enclose poikilitic clinopyroxenes. Oxides in laths (ilmenite) or cubes (magnetite) occur in intergranular form. The degree of alteration is very low (1%).

Sample 120-750B-17R-2, 94–100 cm

It is a fine-grain basalt, pseudotrachytic in texture. The rare plagioclase phenocrysts (2 mm) in laths are enclosed by small laths of clinopyroxene (<2 mm) associated with euhedral clinopyroxene and oxides. The magnitude of the alteration is low (3%).

ANALYTICAL TECHNIQUES

Minerals suitable for K-Ar dating, such as plagioclase, could not be extracted because of the fine grain size and the small samples available. The K-Ar and $^{40}Ar/^{39}Ar$ investigation, therefore, was restricted to whole-rock samples. Two sieve fractions were used, 100–160 μm and 160–250 μm. The analytical procedure, described more extensively elsewhere (Westphal et al., 1979) is as follows. Potassium was measured by flame photometry with a lithium internal standard. Argon was extracted in a heat-resistant glass vacuum apparatus and determined by isotope dilution (^{38}Ar as a tracer) using an AEI MS-10S mass spectrometer. The set of constants recommended by Steiger and Jäger (1977) was used for age calculation. Quoted uncertainties represent estimates of analytical precision at 1 standard deviation (1ρ). They were calculated using the procedure given by Cox and Dalrymple (1967).

The $^{40}Ar/^{39}Ar$ experimental techniques were described earlier (Montigny et al., 1988). The samples, which were sealed in quartz vials, were irradiated for 30 hr in the Osiris reactor at Saclay under continuous rotation. The integrated flux was about 5.3×10^{18} neutrons/cm^2. The samples were positioned within irradiations cans at two levels along with one or two monitors at each level. The variation in the $^{40}Ar^*/^{39}Ar$ ratio for monitors on a given level is less than ±1%, but a flux gradient of 3%–5% may occur between the two levels of an irradiation can.

To determine correction factors for interfering isotopes produced by nuclear reactions during irradiation, CaF_2, KF, and K_2SO_4 salts were included in the irradiation package. Measurements of the irradiated samples yielded the following correction factors: $(^{40}Ar/^{39}Ar)_K = 2.22 \times 10^{-2}$, $(^{36}Ar/^{37}Ar)_{Ca} = 2.25 \times 10^{-4}$, and $(^{39}Ar/^{37}Ar)_{Ca} = 8.42 \times 10^{-4}$. Intralaboratory standard LP-6 biotite (129 m.y.) was used as the flux monitor. The errors are quoted at 1ρ and were calculated after the procedure given by Albarède (1976). The formula corresponding to ρ is that of Berger and York (1970), which takes into account the error in the $^{40}Ar^*/^{39}Ar$ ratio of the monitor but not the error in its age. The criteria we used to define a plateau are those of Féraud et al. (1986): (1) the plateau region of the age spectrum should include about 70% of the ^{39}Ar released; (2) there should be at least three steps in the plateau; and (3) the individual fraction ages should agree, within 2ρ limits, with the integrated age. Furthermore, possible occurrences of trapped argon of high $^{40}Ar/^{36}Ar$ were systematically checked with the use of isochron plots: $^{39}Ar/^{36}Ar$ vs. $^{40}Ar/^{36}Ar$ and $^{36}Ar/^{40}Ar$ vs. $^{39}Ar/^{40}Ar$ (Roddick et al., 1980).

RESULTS AND DISCUSSION

Conventional K-Ar and $^{40}Ar/^{39}Ar$ results are presented in Tables 1 through 4, respectively. Conventional K-Ar dates exhibit two salient features. On the one hand, we observed a cluster of ages in the 100–110 m.y. interval for Sites 747, 749, and 750, all of which recovered basalts from the basement. Site 748 basalts yielded a younger age of 80 ± 4 m.y. On the other hand, age discrepancies within Sites 747 and 750 display the following pattern: the deeper the sample, the younger the age. The latter characteristic can be attributed to water-rock interaction, which probably caused variable potassium additions and argon losses. Indeed, a microscopic examination reveals that the samples corresponding to the younger age figures are the more altered. Because metamorphism of zeolite facies is pervasive in the basaltic pile, a question arises about the significance of the ages that fall in the 100–110 m.y. range for the upper part of the basement.

We may enlist the stratigraphical constraints provided by the sedimentary cover. In this respect, basalts from Site 747 must be at least as old as 91 m.y. (early Turonian–late Cenomanian), whereas the basalts from Sites 748 and 750 should exhibit minimum ages of 97 (late Cenomanian) and 105 m.y. (early Albian), respectively, when taking the geological time scale proposed by Kent and Gradstein (1985). Notice that Site 749 is stratigraphically loosely constrained with a sedimentary cover starting at the lower Eocene. Therefore, it has to be kept in mind that the stratigraphic ages of the overlying sediments are only minimum estimated ages of the basaltic basement. The nature of the sedimentary cover, however, may shed light on the environment, where the basalts erupted and cooled. At Site 750 the Albian sediments, which rest immedi-

Table 1. K-Ar results, Leg 120.

Core, section, interval (cm)	K_2O (wt%)	$100 \times {}^{40}Ar^*$ / Total ^{40}Ar	$^{40}Ar^*$ (10^{-11} mol/g)	Age (1σ) (m.y.)
120-747C-				
13R-1, 51–58	0.309	70	4.6172	100.9 ± 3.7
	0.296	63	4.8212	109.7 ± 5.3
16R-5, 33–40	0.471	87	5.3307	77.0 ± 2.3
120-748C-				
79R-6, 34–40	0.458	55	5.4177	80.4 ± 2.5
120-749C-				
15R-3, 26–31	0.651	89	10.0780	111.5 ± 3.2
16R-6, 42–50	0.070	41	1.0362	100.0 ± 12.0
120-750B-				
15R-5, 54–60	0.098	61	1.4690	101.2 ± 7.5
17R-2, 94–100	0.101	31	1.1271	75.9 ± 5.9

Notes: $\lambda_\epsilon = (0.581 \times 10^{-10})a^{-1}$; $\lambda_\beta = (4.962 \times 10^{-10})a^{-1}$; ^{40}K/total K = 1.167×10^{-4} mM^{-1}. The ± figures represent estimations of the analytical precision at the 68% confidence level. $^{40}Ar^*$ = radiogenic ^{40}Ar.

Table 2. $^{40}Ar/^{39}Ar$ total fusion ages, Leg 120.

Core, section, interval (cm)	$100 \times {}^{40}Ar^*$ / Total ^{40}Ar	$^{37}Ar_{Ca}$[a] / ^{39}Ar	$^{40}Ar^*$ / $^{39}Ar_K$	Age (m.y.)	SD (± 1σ)
120-747C-					
13R-1, 51–58 (J = 0.013199)	60.7	23.266	7.230	164.4	4.9
16R-5, 33–40 (J = 0.012303)	76.9	10.592	4.219	97.8	2.3
120-748C-					
79R-6, 34–40 (J = 0.012303)	57.7	7.188	4.536	98.0	2.0
120-749C-					
15R-3, 26–31 (J = 0.012303)	76.0	5.841	5.579	109.2	1.2
16R-5, 42–50 (J = 0.013199)	19.09	6.373	4.045	80.3	18.0
120-750B-					
15R-5, 54–60 (J = 0.013199)	26.8	60.633	3.556	82.8	13.3

Notes: Total fusion temperature = 1500°C. $^{40}Ar^*$ = radiogenic ^{40}Ar. SD = standard deviation.
[a]Corrected for decay of ^{37}Ar.

Table 3. $^{40}Ar/^{39}Ar$ results on Sample 120-749C-15R-3, 26–31 cm, by incremental heating.

Step T(°C)	$100 \times {}^{40}Ar^*$ / Total ^{40}Ar	^{39}Ar (%)	$^{37}Ar_{Ca}$[a] / ^{39}Ar	$^{40}Ar^*$ / $^{39}Ar_K$	Age (m.y.)	SD ($\pm 1\sigma$)
J = 0.010755						
450	4.5	1.63	1.1780	2.742	54.8	26.2
600	49.7	8.72	0.6336	5.457	107.5	2.2
670	76.4	7.34	0.8528	6.064	119.1	2.1
750	72.0	16.55	2.8560	5.257	103.7	2.0
820	67.7	8.37	4.1190	5.943	116.8	3.2
900	75.1	18.99	3.2100	5.646	111.1	1.0
990	76.7	25.92	1.6150	5.468	107.7	1.1
1050	53.2	7.42	3.8170	4.944	97.7	1.9
1150	33.5	3.26	40.9400	3.968	78.8	10.2
1500	6.3	1.80	72.3800	13.772	260.0	26.6

Notes: T = temperature. $^{40}Ar^*$ = radiogenic ^{40}Ar. SD = standard deviation.
[a]Corrected for decay of ^{37}Ar.

Table 4. $^{40}Ar/^{39}Ar$ results on Sample 120-750C-15R-5, 54–60 cm, by incremental heating.

Step T(°C)	$100 \times {}^{40}Ar^*$ / Total ^{40}Ar	^{39}Ar (%)	$^{37}Ar_{Ca}$[a] / ^{39}Ar	$^{40}Ar^*$ / $^{39}Ar_K$	Age (m.y.)	SD ($\pm 1\sigma$)
J = 0.0095548						
650	22.5	16.2	35.93	7.382	128.5	12.8
850	53.1	33.5	39.81	6.638	115.9	7.1
1020	54.5	25.4	34.40	6.953	121.3	6.4
1150	52.0	17.6	89.84	6.202	108.5	16.3
1250	12.0	2.3	303.60	3.055	54.3	79.0
1500	14.0	5.0	443.90	12.716	215.9	87.7

Notes: T = temperature. $^{40}Ar^*$ = radiogenic ^{40}Ar. SD = standard deviation.
[a]Corrected for decay of ^{37}Ar.

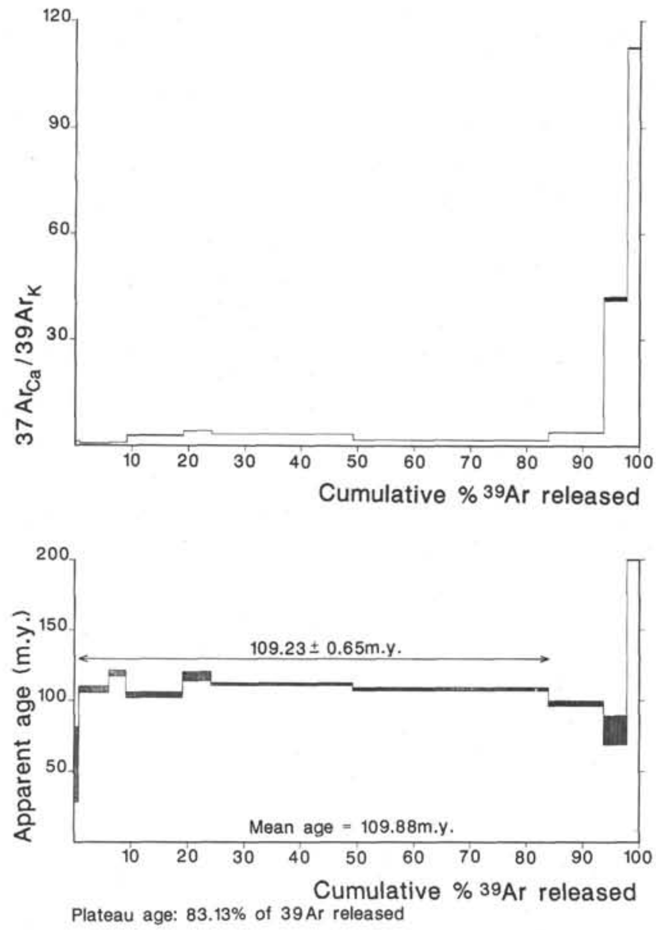

Figure 2. $^{40}Ar/^{39}Ar$ age spectrum and ($^{39}Ar_K/^{37}Ar_{Ca}$) ratios of Sample 120-749C-15R-3 (26–31 cm).

ately on the lavas, are typical of nonmarine deposits. By late Turonian times (87 m.y.), the basement was subsiding. Similar conclusions can be drawn for Sites 747 and 748. At Site 749, the first "drift"-type sediment is early Eocene in age, suggesting that the basement was maintained in near-subsurface conditions up to this date. Therefore, we conclude that the lava flows were emplaced generally in a rather subaerial environment, which might have protracted, at least locally, up to the end of the Late Cretaceous. Furthermore, one must stress that, unlike the lava flows, the sedimentary piles are unaffected by zeolite metamorphism. Hence, the water-rock interaction was contemporaneous with the eruption. In summing up, an examination of the sedimentary record indicates that the cooling of the basalts can be considered geologically short. Thus, in the case of fresh samples, the calculated ages should mirror the crystallization ages.

Because of the petrographic evidence for seawater alteration and variable K-Ar ages, we performed $^{40}Ar/^{39}Ar$ determinations on six of the samples. Dalrymple and Clague (1976) showed that marine seawater-altered basalts from the Emperor Seamounts systematically yielded $^{40}Ar/^{39}Ar$ ages far higher than conventional K-Ar ages. Preferential loss of ^{39}Ar from K-rich clay minerals during irradiation was invoked to explain such a feature. Moreover, the samples deemed most suitable for K-Ar dating (120-749C-15R-3, 26–31 cm, and 120-750B-15R-5, 54–60 cm) were also investigated with the $^{40}Ar/^{39}Ar$ stepwise-heating technique.

An important result of the $^{40}Ar/^{39}Ar$ analyses is the good agreement for Sample 120-749C-15R-3, 26–31 cm, between the K-Ar age (111.5 ± 3.2 m.y.) and $^{40}Ar/^{39}Ar$ ages, either by total fusion (109.2 ± 1.2 m.y.) or by the incremental technique, in which Steps 2–7 define a plateau with an age of 109.2 ± 0.7 m.y. (Fig. 2). The corresponding total gas (recombined) age is 109.9 ± 1.0 m.y. The coherence of the results along with inspection of isochron plots permits us to draw the following conclusions:

1. No ^{39}Ar loss occurred during irradiation from the ^{39}Ar recoil effect.
2. The isochron plots ($^{36}Ar/^{40}Ar$ vs. $^{39}Ar/^{40}Ar$ and $^{39}Ar/^{36}Ar$ vs. $^{40}Ar/^{36}Ar$) yield $^{40}Ar/^{36}Ar$ intercepts that are indistinguishable from the atmospheric value. The corresponding ages are 107.5 ± 2.5 and 105.8 ± 3 m.y.
3. The plateau age is defined with steps yielding similar $^{37}Ar_{Ca}/^{39}Ar_K$ (Fig. 2), which implies that the argon degassing is controlled by one mineral phase, probably plagioclase.
4. The calculated ages are likely close to the sample crystallization age. Therefore, for Site 749, the end of the volcanism that gave rise to the Kerguelen Plateau cannot be younger than 109–110 m.y.

In contrast, Sample 120-750B-15R-5, 54–60 cm, apparently yields discordant results with a K-Ar age of 101.2 ± 7.5 m.y., an $^{40}Ar/^{39}Ar$ total fusion age of 828 ± 13.3 m.y., and a plateau age of 118.2 ± 5 m.y. (Fig. 3). The discrepancies are attributable to a low content in potassium, which led large analytical uncertainties and might be responsible of significant sample heterogeneities. Nevertheless, the stepwise-heating technique indicated a plateau age fairly similar to that of Sample 120-749C-15R-3, 26–31 cm, and the isochron plots do not reveal the existence of trapped argon of radiogenic composition. Furthermore, three steps out of 4 that compose the plateau have similar $^{37}Ar_{Ca}/^{39}Ar_K$

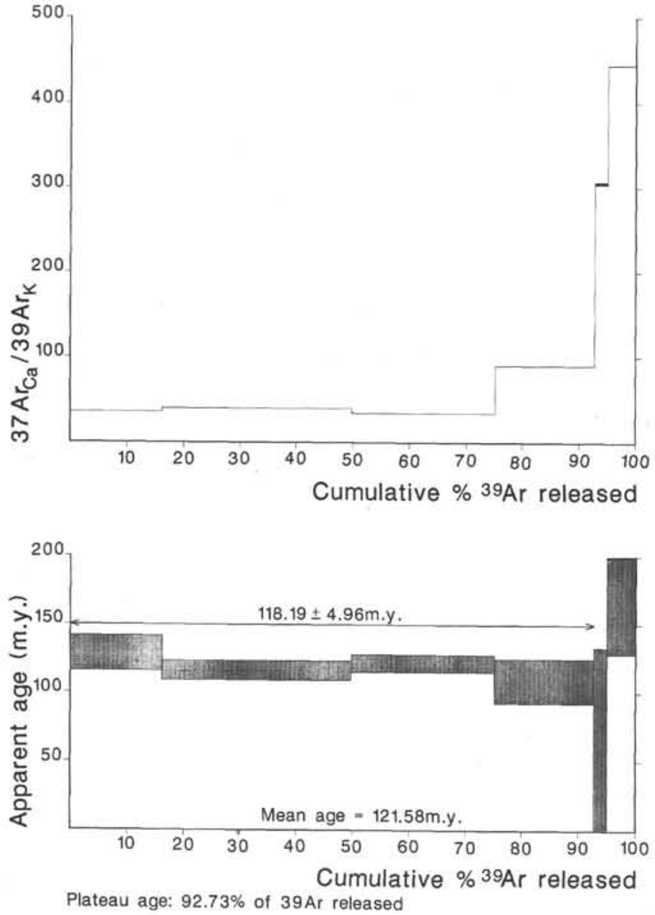

Figure 3. $^{40}Ar/^{39}Ar$ age spectrum and ($^{39}Ar_K/^{37}Ar_{Ca}$) ratios of Sample 120-750B-15R-5 (54–60 cm).

ratios (Fig. 3). We think, then, that a crude estimate of the crystallization age, which would be comprised between 110 and 120 m.y., can be proposed from the $^{40}Ar/^{39}Ar$ stepwise-degassing pattern for this sample. The other samples show discrepancies between conventional ages and $^{40}Ar/^{39}Ar$ total fusion ages. The differences exhibited by Samples 120-748C-79R-6, 34–40 cm, and 120-747C-16R-5, 33–40 cm, are beyond error margins and may be attributed to ^{39}Ar loss during irradiation. Petrographical inspection of these samples reveals occurrences of clay minerals caused by water-rock interaction. The ^{39}Ar recoil effect must also be invoked to explain the age discrepancy observed for whole-rock Sample 120-747C-13R-1, 51–58 cm, even though the sample displays only a low degree of alteration. The $^{40}Ar/^{39}Ar$ total fusion age of 164.4 ± 5 m.y. appears geologically untenable whereas the K-Ar date, besides an acceptable concordance between duplicates (100.9 ± 3.7 m.y. and 109.7 ± 5.4 m.y.) fits the geological record rather well since the breakup of the Gondwanaland should not be older than 130 m.y. (Powell et al., 1988).

In summing up, we conclude that the top of the Kerguelen Plateau basement is at least as old as 100 m.y. Convincing results, however, obtained on Sample 120-749C-15R-3, 33–40 cm, lead us to propose that the magmatism of the Kerguelen Plateau ceased, on the whole, by 110 m.y.

IMPLICATIONS FOR PLATEAU FORMATION

The K-Ar and $^{40}Ar/^{39}Ar$ results indicate a best estimate of 110 m.y. for the end of the flood basalt eruptions composing the central portion of the Kerguelen Plateau. At that time in the plate tectonic reconstructions, an oceanic basin about 500 km wide separated the Indian Plate from the Antarctic-Australian Plates (Powell et al., 1988). Thus, the Kerguelen Plateau could result from an excess magmatism linked to a mantle plume on or near an accretion zone (like in Iceland). The geochemical results are not in contradiction with this hypothesis (Salters et al., this volume).

The question, then, arises whether the continental flood basalts outcropping in the adjacent continents, which were formerly forming Gondwanaland, are contemporaneous or preceded the magmatic activity of the plateau. K-Ar investigations on the Rajmahal-Bengal-Sylhet Traps in India [which are considered, together with the Ninetyeast Ridge, by Duncan (1978, 1981), Morgan (1981), and Mahoney et al. (1983) to be the trace of the Kerguelen hotspot] indicate a best age of 117 m.y. (Baksi et al., 1987). Lack of stratigraphic control and pervasive water-rock interaction (McDougall and McElhinny, 1970), however, preclude further refinement of these estimations. A few age determinations of 108–110 m.y. have been obtained on lamprophyres from Prince Charles Mountains, Antarctica (Sheraton, 1983). Likewise, the Bunbury basalts in southwest Australia are reported to have ages between 136 and 105 m.y. (Playford et al., 1976). Again, a lack of stratigraphic control and water-rock interactions preclude definitive conclusions on those ages. Nevertheless, the ages yielded by the continental flood basalts are on the same order of magnitude as those determined for the Kerguelen Plateau. The close age agreement, around 117–110 m.y., between marine and continental flood basalts would support the contention that early in the opening of the eastern Indian Ocean a huge mantle plume with a head of several hundred kilometers burst into activity (Richards et al., 1989).

At the moment, it is difficult to constrain the duration of this intense magmatic activity. There is no definitive argument to claim that the beginning of the plateau formation was contemporaneous, preceded, or postdated the pieces of Mesozoic oceanic crust observed in the Enderby Basin, for example, which was formed immediately after the breakup of the Gondwanaland 130 m.y.. Accordingly, we cannot conclude that the buildup of the Kerguelen Plateau resulted from a catastrophic process, such as that proposed by Courtillot et al. (1986) for the Deccan Traps, at the Cretaceous/Tertiary boundary, where enormous amounts of basaltic material were emitted probably in <1 m.y.

CONCLUSION

A good concordance between the maximum K-Ar ages obtained and the $^{40}Ar/^{39}Ar$ stepwise-heating method on the freshest sample, yielded an age of 110 m.y. for the upper part of the basement, drilled at three different sites in the central and southern part of the Kerguelen Plateau. A comparison of this age with those yielded by flood basalts from adjacent Gondwanaland areas lends some credence to the idea that the drifting between the continents bordering the eastern Indian Ocean was accompanied, at least around 110 m.y., by huge hotspot activity, giving rise to vast outpourings of lavas. K-Ar results at the moment fail to constrain the duration of magmatism, precluding definitive discussion based on geochronological data about the timing and extent of initial mantle plume activity in the eastern Indian Ocean.

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