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Lower Cretaceous Basalt and Sediments from the Kerguelen Plateau

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Abstract

Geological samples from the southern Kerguelen Plateau include Lower Cretaceous basalt and lava breccia, probable Lower Cretaceous conglomerate and shelf limestone, Upper Cretaceous chert with dolomite, Upper Cretaceous–Eocene ooze, and Tertiary conglomerate. Neogene sediments are only a few hundred m thick, and include foraminiferal and diatomaceous ooze, and ice-rafted debris. In conjunction with seismic reflection profiles, the samples indicate Early Cretaceous near-shore volcanism, followed by erosion, sedimentation, and subsidence through Cretaceous; arching of the plateau at the end of Cretaceous; subsidence through Paleogene; widespread emergence in mid-Tertiary; and slow subsidence through Neogene.

Introduction

The Kerguelen Plateau, in the southern Indian Ocean, is a major submarine feature, 2100 km long and up to 700 km across. It is thought to have originated during the breakup of Gondwanaland, and to have a basement of either thickened oceanic crust [1] or rifted continental crust (for example [2]). It was once contiguous with Broken Ridge, which now lies more than 1800 km to the northeast, the two having separated by spreading along the Southeast Indian Ridge, starting at Anomaly 18 or 19 time [3,4], 40-43 Ma ago [5].

The northern sector of the plateau, which includes Heard and the Kerguelen Islands, may overlie the hotspot whose former trace is preserved in the Ninety East Ridge [6,7]. This part of the plateau is high-standing, has a cover of 2–2.5 s (two-way time) of sediments much invaded by dykes or stocks, and has a record of volcanic activity from the late Middle Eocene to the present [8–10]. Oldest known sediments are Upper Cretaceous, probably Santonian, calcareous ooze (core 510, Table 1; Fig. 1) [9,10]. There is a major unconformity, lack of sediment record, and evidence of emergence, between the end of the Middle Eocene and the Late Oligocene or Early Miocene [9–11].

The southern sector may have a separate origin from the northern sector [1,4]. It has more subdued relief and, apart from widely-spaced dykes interpreted in seismic profiles, no obvious record of igneous activity [4,12]. Structurally, it is an elongated (NNW-SSE) broad upwarp, along part of which there is a north-south-trending axial graben (77°E Graben, Figs. 1,2) [1,13]. Sediment cover reaches a maximum thickness of about 4 km on the eastern flank of the upwarp, in the Raggatt Basin (Figs. 1,2) [4,12]. Processed multichannel seismic profiles across this basin reveal six seismic sequences overlying a basement that is partly stratified [14]. The boundaries between some of the seismic sequences are not distinguishable in our single-channel seismic profiles (Fig. 2A). Before our investigation, the oldest known sediment from the southern sector was Late Cenomanian chalk, cored on

Table 1. Summary of Dredge and Core Samples

A. Dredges

Site	Latitude (S)	Longitude (E)	Depth (m)	Tonnes	Partial description (Main rock type listed first)
1	51°58′	77°46′	2300–1600	0.2	Propylitically-altered basalt and a large block of phlogopite melagabbro; phlogopite K-Ar age 13.2 ± 0.1 Ma[a]
2	57°18′	77°36′	2400–1970	0.2	Saprolitic basalt; a large block and many sheared fragments of pink bioclastic limestone, absence of Cheilostome forms of bryozoa suggests pre-Cenomanian age;[b] minor chert; also includes ice-rafted granite and metamorphic rocks
3	57°18′	77°35′	2000	0.25	Chert, part phosphatic; ice-rafted erratics
4	57°17′	77°37′	2600–2000	0.4	Chert, with Late Cretaceous radiolaria; interbeds of dolomite; some basalt; minor erratics
5	58°06′	76°55′	2200–1620	1.5	Saprolitic basalt, some coarsely plagioclase-phyric, K-Ar age of plagioclase 114 ± 1 Ma;[c] lava breccia with Cretaceous bioclastic limestone matrix with *Hedbergella*; pebble conglomerate, some of which appears to be contemporaneous with the lava breccia, some younger with Tertiary globigerinidae
6	58°17′	76°55′	1550–1250	1.5	Saprolitic, microporphyritic basalt and lava breccia as in dredge 5
7	55°18′	77°28′	2265–1865	0.4	Conglomerate of saprolitic, coarsely-amygdaloidal basalt with Mn oxide as coating and as replacement of carbonate matrix; boulders of basalt of dredge 5 and dredge 6 types
8	50°19′	74°49′	2175	0.25	Saprolitic basalt; Miocene or younger conglomerate of basalt and limestone cobbles in tuffaeous matrix; planktonic foraminiferids in limestone cobbles are not older than Miocene;[d] most of the limestone has been replaced by clay minerals and silica; sub-angular and rounded boulders of unaltered olivine basalt
G	58°19′	77°01′	1750–1810	0.001	Two free-fall grabs collected 700 g of small pebbles; mostly saprolitic basalt, but including 20% granite and 10% metasediments[e]

B. Selected cores (Prefix 86-)

Core	Lat (S)	Long (E)	Depth (m)	Length (cm)	Partial description
697	57°23′	79°39′	1680	735	Pleistocene ooze, NN21
698	57°15′	80°10′	1980	627	Late Eocene calcareous ooze, NP19, under Pleistocene ooze, NN21
699	57°08′	80°57′	2625	375	Late Eocene calcareous ooze, NP19, under Pleistocene ooze, NN21
700	57°06′	81°11′	3130	134	Pleistocene ooze, NN21
701	57°04′	81°23′	3850	788	Mixed Maastrichtian[f] and Paleocene (NP6) calcareous ooze under Mid–Late Eocene (NP17-19) argillaceous calcareous ooze, under non-calcareous brown ooze with horizons of Mn oxide nodules
702	57°06′	81°13′	3115	605	Pleistocene ooze, NN21, and older (undated) ooze
703	57°04′	81°24′	3800	1203	Bottomed in undifferentiated Cretaceous,[d] partly recrystallized, calcareous ooze
704	57°17′	77°48′	1890	245	Bottomed in uppermost Eocene calcareous ooze, NP20/21
705	57°17′	77°31′	2272	790	Pleistocene siliceous ooze, NN21
510	50°20′	74°48′	1358	430	Four cores in 1259–1823 m of water bottomed in Upper Cretaceous ooze with some chert; oldest is core 510 which is probably Santonian.[g] Other cores are 503, 505, 506; all have prefix 83-
ELT	55°53′	81°07′	4021	483	Eltanian core 54-7 bottomed in Upper Cenomanian chalk[h]

Table 1. *Continued*

[a] From [25].
[b] From B. Walter, personal communication, 1987.
[c] From [17].
[d] From D. J. Belford, personal communication, 1986.
[e] From [4].
[f] From D. J. Belford and S. Shafik, personal communication, 1986.
[g] From [10].
[h] From [1,15].

the northeastern margin (ELT, Table 1; Fig. 1) [1,15].

The plateau will be drilled for the first time starting in late 1987, as part of the Ocean Drilling Program. Sites will be selected primarily on the basis of multichannel seismic data [4,8,12,14] (R. Schlich and M. Munschy, unpublished data). Cruise 48 of the R.V. *Marion Dufresne*, in March 1986, set out to supplement these data by sampling the different seismic horizons with a dredge and piston corer. Efforts were directed at the lesser-known southern sector of the plateau, south of 55°S. We collected eight dredge hauls and 16 piston cores (Table 1, Figs. 1,2), as well as geophysical data from 4000 km of line, including single-channel seismic reflection records for 2400 km [16]. In this article, we summarize the results of the geological sampling program, and relate these to the seismic stratigraphy of [14].

Correlation of Samples With Seismic Stratigraphic Units

Basement. We directed five dredges at basement, three on the flanks of the 77°E Graben (dredges 2,5 and 6; Figs. 1 and 2B), and two on the northeastern margin of the plateau (dredges 1 and 8). In each case we recovered altered and jointed basalt that, in dredges 5 and 6, was associated with submarine lava breccia (Figs. 1–3A; Table 1). Two of the three dredge hauls that were not directed at basement also recovered some basalt. The source of the basalt in dredge 8, in the northern sector of the plateau, was immediately downslope from Santonian sediments cored previously (core 510) [9,10]. The least altered basalt fragments in dredges 2,6 and 8 are tholeiitic and transitional basalts, chemically and isotopically of ocean island affinity, rather than ridge affinity (R. C. Price, F. A. Frey, M. T. McCulloch, S-S. Sun, personal communication, 1987).

Plagioclase in basalt from dredge 5 has a K-Ar age of 114 ± 1 Ma [17], equivalent to the Barremian stage in the Early Cretaceous [5]. The Cretaceous age is confirmed by the presence of the Cretaceous planktonic foraminiferid *Hedbergella* in bioclastic limestone that forms the matrix of the lava breccia (sample DR05.04) (F. Vieban and C. Darmedru-Ducreux, personal communication, 1987). The character of the bioclastic limestone suggests a littoral environment, as does the occurrence, in the same dredge haul, of

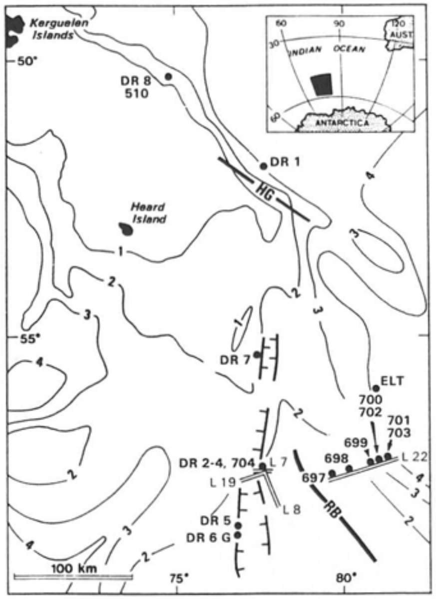

Figure 1. Locality map shows sample sites. Ticked lines mark 77°E Graben, while parallel lines indicate location of seismic profiles reproduced in Figure 2. RB, axis of Raggatt Basin; HG, horst-and-graben zone; DR, dredge; G, free-fall grab; 698, core; ELT, core. Isobaths are in km. Mercator projection, scale bar is correct for 57°S.

an apparently penecontemporaneous conglomerate, comprising basalt and lava breccia cobbles in a bioclastic limestone matrix.

In most samples of the conglomerate, the limestone matrix is partly exsolved and is locally replaced by opaline silica (Fig. 3B), Mn oxides, and, in some instances, by fluor-apatite; exsolution cavities are part-filled with later carbonate. Globigerinidae of Tertiary aspect are present in the matrix of one sample of conglomerate (DR05.05) (D. J. Beldford, personal communication, 1986), and it remains possible that some or all of the conglomerate is younger than Cretaceous.

Another Early(?) Cretaceous rock type recovered with the basalts is pink bioclastic limestone (samples DR02.04, DR02.05). This is a shelf limestone, which contains bryozoa that suggest an age older than Late Cretaceous (B. Walter, personal communication, 1987). The rock is moderately recrystallized, contains stylolites, and some is strongly sheared.

The dredging of Early Cretaceous basalt from presumed basement shows that the erosional unconformity on basement is probably Early Cretaceous, post-Barremian, rather than Late Cretaceous, as had been proposed (estimated age of reflector 'B' in [1]).

Lowermost Sediments (Unit F). The lowermost seismic sequence of the Raggatt Basin, unit F (Fig. 2), is nowhere exposed at the sea floor, and can only be sampled by drilling. Possible correlatives are the Late Cretaceous ooze and chalk that are known to be present on the northeastern margin of the plateau (cores 510 and ELT, Fig. 1; Table 1) [9,15], and the unit may include the bioclastic limestone and conglomerate mentioned above.

Unit E. Unit E (Fig. 2) is exposed on the eastern wall of the 77°E Graben, where we recovered mostly chert, some with interbedded dolomite (dredges 2,3, and 4). The chert includes Late Cretaceous radiolaria (J-P. Caulet, personal communication, 1987). Perhaps the chert forms the strong and continuous reflectors that are apparent within unit E [14]. By way of comparison, the main development of chert in the northern sector of the plateau is at the Paleocene-Eocene boundary, but patchy development of chert is known from different levels in the Upper Cretaceous [9,10]. The mounded upper surface of unit E may indicate reefs or volcanics [14].

The age of the unconformity at the top of unit E (reflector 'A', [1]) is of particular interest because seismic profiles [4,12] show this to have been a time of major faulting, including the development, or reactivation, of the 77°E Graben. Uplift of the central axis of the plateau at this time is suggested by the tilting of older strata and subsequent eastward shift of the basin depocentre (see, for example, Line 24, [4]). Probably the unconformity is at or near the end of the Cretaceous, given that chert within unit E is Late Cretaceous in age.

In the northern sector of the plateau there is independent evidence of shoaling at the end of the Cretaceous in (a) the selective phosphatization of Late Maastrichtian strata [11], and (b) the occurrence of Late Cretaceous macrofauna, including Inoceramus and brachiopods [9,10]. Another less conclusive line of evidence that the unconformity is at about the end of the Cretaceous is the relative thickness of sediment separating the unconformity from Barremian basement below, and from the Late Eocene unconformity above (top of unit C, Fig. 2A). It is most unlikely that the unconformity is Eocene, as had been proposed [1].

Unit C. Unit C (Fig. 2A) is, at least in part, calcareous ooze of Mid–Late Eocene, ranging to uppermost Eocene, as indicated by cores 698, 699 and 704 (NP19, NP20/21; Table 1; Figs. 1 and 2). Undated non-calcareous brown ooze with nodule horizons and mid-Eocene calc-argillaceous ooze in core 701 (Table 1; Figs. 1 and 2), may also be from unit C, although this is not clear from seismic profiles. We have no information on the composition of unit D.

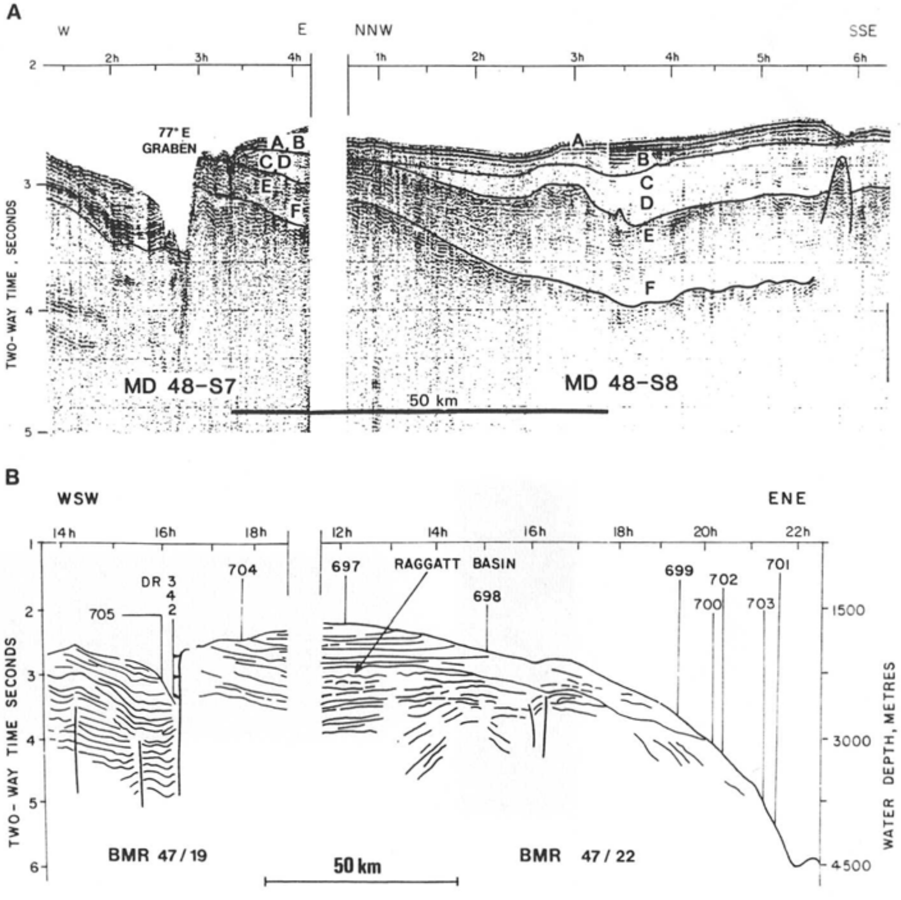

Figure 2. A Single channel seismic profiles show seismic sequences. Seismic sequences are modified from [14]. **B** Sample sites located on line drawings of seismic profiles. DR, dredge; 705, core. Line drawings are modified from [4].

The unconformity at the top of unit C probably is equivalent to, though slightly younger than, the major post-Middle Eocene unconformity in the northern sector of the plateau [8–11]. We suspect that, as with the northern sector, the southern sector was partially emergent at this time; seismic profiles show some contemporary faulting [4,12], and there is probably a major hiatus in the sediment record.

Units A and B. Units A and B (Fig. 2A), which represent the post-Eocene section in the southern plateau, have a maximum thickness of only a few hundred meters [14]. The thin and incomplete Neogene cover is almost certainly due to the effect of the Circum-Polar Current, which was active from Oligocene onwards [18]. Erosional effects apparent in seismic profiles include scour-and-fill (unit Z, [14]), and the bevelling

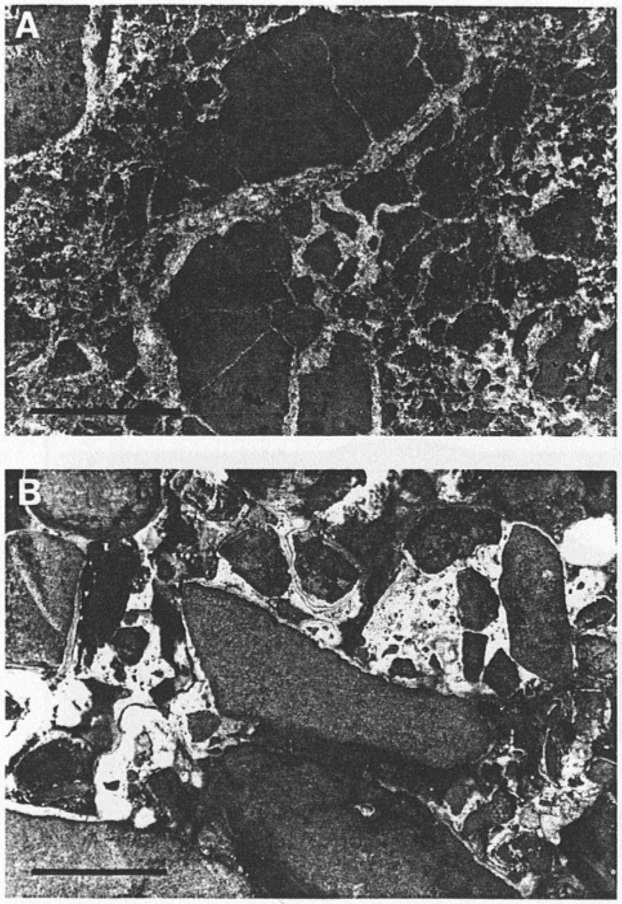

Figure 3. **A** Lava breccia from dredge 6 consists of saprolitic basalt clasts in a matrix of finely recrystallized calcite. The basalt is finely amygdaloidal and was vitrophyric, with altered fine phenocrysts of sodic labradorite and clinopyroxene, and fine opaques. Quartz occurs as fine veinlets and, with zeolite and calcite, in amygdules. Sample DR06.03. Scale bar is 1 cm. **B** Conglomerate from dredge 5 consists of clasts of saprolitic basalt, rare lava breccia and chert, in a matrix of bioclastic limestone. The limestone matrix is partly replaced by opaline silica and partly exsolved. Exosolution cavities are partly filled with soft carbonate. Sample DR05.07. Scale bar is 1 cm.

of units A and B towards the margins of the plateau [4,8]. The upper strata of unit A are Pleistocene ooze of foraminifera, radiolaria and diatoms, with ice-rafted debris (NN21; Table 1; Figs. 1 and 2). We did not knowingly sample unit B. The Miocene or younger conglomerate collected in dredge 8, on the margin of the northern sector of the plateau, might be from B or A.

Evolution of the Plateau

We propose the following scheme of evolution:

1. *Early Cretaceous, about 115 Ma (basement unconformity):* Construction of a volcanic island, or series of islands, on a basement of thickened oceanic crust or rifted (thinned) continental crust; sub-aerial erosion, littoral clastic sedimentation, coral, and bryozoa; probably contemporaneous with the initial separation of Australia and Antarctica [6,19].

2. *Early Cretaceous to end of Cretaceous, 115-65 Ma (units F,E):* Differential subsidence and sedimentation, initially fed by erosion of the Lower Cretaceous landmass (the peneplanation at reflector 'B' noted by [1] and the 'basement' angular unconformity and onlap recorded by [14]), followed by pelagic and neritic sedimentation; chalks and oozes with some bioclastic detritus and some chert.

3. *At about end of Cretaceous, 65 Ma (D/E unconformity):* Arching of the plateau and consequent development, or reactivation, of 77°E Graben and adjacent half-grabens; shoaling (at least in northern sector [9-11]). This may be the same event that caused the Santonian to Eocene angular unconformity and hiatus on Broken Ridge [19].

4. *Paleogene, 65-38 Ma (units C,D):* Subsidence through Paleocene and Early Eocene, then shoaling and emergence; emergence was before Late Eocene in the north [9–11] and after Late Eocene in the south. Onset of volcanism in the northern sector in the late Middle Eocene, NP16 [9,10], about 41-43 Ma [5]. Separation of Broken Ridge from Kerguelen Plateau at 40-43 Ma, concurrent with the onset of rapid spreading at the Southeast Indian spreading ridge [20]. The horst-and-graben zone on the NE margin of the plateau (Fig. 1) [1,8,13] is probably part of a rift system that developed immediately before or during the initiation of rapid spreading. It has an Early(?) Cretaceous basement overlain by Late Cretaceous ooze [9,10], and thus is clearly not an abandoned Eocene spreading ridge, as has been proposed [20,21].

5. *From about Late Oligocene onwards, 30 or 25 Ma to present (units A,B):* Slow subsidence, sedimentation limited by strong bottom currents. Continued faulting, as indicated in seismic profiles [4,13] and in outcrop on Heard and the Kerguelen Islands [22,23].

Discussion

Our dredge samples indicate that basement of at least part of the Kerguelen Plateau is Early Cretaceous basaltic lava and pyroclastics, erupted in a near-shore and possibly onshore environment. We speculate that, as in the case of the Voring Plateau [24], interbedded lava and volcaniclastic sediments may comprise the dipping reflectors that are apparent in seismic profiles [14]. However, the possibility remains that some of the basalt that we recovered was from dykes emplaced in the sedimentary cover, or from a volcanic veneer over (for example) continental crust.

Other questions that remain unresolved include the role, if any, of the Kerguelen hotspot in the development of the southern sector of the Plateau, and the cause of the arching of the plateau at or near the end of the Cretaceous.

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