

26. BASALTS FROM THE EASTERN INDIAN OCEAN, DSDP LEG 27

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ABSTRACT

During Leg 27 basalt was recovered from three sites in the eastern Indian Ocean on the Perth, Argo, and Gascoyne abyssal plains. Basaltic basement of Upper Jurassic to Lower Cretaceous age was encountered at Sites 259 and 261. The upper part of the basement consists of highly altered basaltic breccia which grades downward into more compact and generally fresher rock. Relatively fresh specimens are quartz-normative tholeiites and olivine tholeiites, chemically similar to ocean ridge basalts; altered specimens are enriched in K_2O and somewhat depleted in SiO_2 and Na_2O . These are the oldest basalts known from the Indian Ocean, and they are believed to represent ancient oceanic crust formed during early rifting off Western Australia. Basalt sills were encountered at Site 260 and at the top of the basalt sequence at Site 261. At Site 260 the sill intrudes middle to lower Albian sediments and is probably much younger than basalt basement at adjacent sites. At Site 261 the sill has intruded at the base of the sedimentary sequence and its relative age is unknown. Both sills consist of relatively fresh quartz-normative tholeiite characterized by very low K_2O ($<0.01\%$ - 0.14%). One specimen with 0.65% K_2O is probably altered. The sills are chemically similar to the basement; however, the sill at Site 260 has a relatively unfractionated rare earth element (REE) pattern compared to typical abyssal tholeiites. At Site 261 a thin sill or flow of fine-grained, compact basalt lies between the basement and the uppermost sill. This basalt is considerably more alkaline than others from Leg 27 and is characterized by high TiO_2 (3.40%) and total iron ($>12\%$) and by strong enrichment in REE relative to chondrites. This basalt probably represents intraplate activity at some time after formation of the basement.

INTRODUCTION

During Leg 27 basalt was recovered from Sites 259, 260, and 261 in the eastern Indian Ocean (Figure 1). At Site 259, on the Perth Abyssal Plain, basaltic basement was encountered at a depth of 307.5 meters below the sea floor and drilled to a depth of 346 meters. The overlying claystones of Upper Jurassic age are indurated but show no signs of baking or alteration. The upper part of the basalt consists of greenish-gray, altered breccia, which grades downward into dark gray, fine-grained basalt at about 25 meters below the sediment-basalt contact. Because of the brecciated and altered nature of the basalt and the lack of an intrusive contact, this sequence is believed to represent oceanic basement of Upper Jurassic age.

Most of the basalt encountered at Site 261, in the Argo Abyssal Plain, is also interpreted as oceanic basement. Here basalt was encountered at a depth of 532.5 meters and was drilled to a depth of 579.5 meters. The uppermost basalt is fresh, relatively coarse grained, and in steep intrusive contact with the overlying

sediments (see frontispiece, this volume). At a depth of approximately 10 meters below the contact, the coarse-grained basalt passes sharply into dark gray, fine-grained, highly fractured basalt. The fine-grained basalt is about 3 meters thick and is separated from a lower fine-grained sequence by about 2 meters of soupy breccia composed of fragments of basalt and mudstone. The mudstone fragments contain fossils from most of the younger units at this site, strongly suggesting that this sequence is a drilling breccia rather than a sedimentary interbed in the basalt. Below the breccia the fine-grained basalt passes downward into a breccia sequence typical of oceanic basement (see frontispiece, this volume). Based on these relationships, the basalt at Site 261 is divided into three units; a basalt-breccia complex interpreted as oceanic basement (Unit C), an overlying fine-grained, highly fractured flow or sill (Unit B), and a 10-meter-thick sill which was intruded at the base of the sedimentary section (Unit A).

At Site 260 in the Gascoyne Abyssal Plain basalt was encountered at a depth of 323 meters and drilled to 332 meters. The contact between the basalt and the

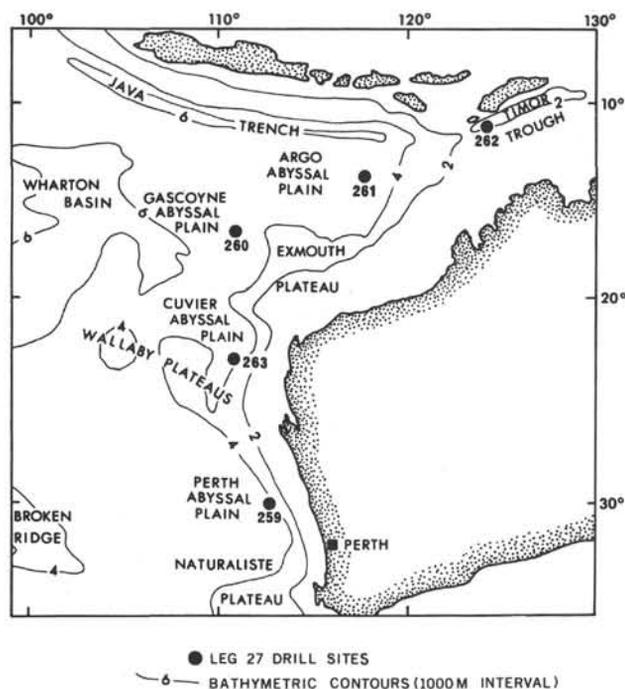


Figure 1. Locations of sites drilled during Leg 27.

overlying sediments was disturbed by drilling, and there is no direct evidence of an intrusive contact. However, several lines of evidence suggest that this basalt is probably a sill: (1) the sediments immediately overlying the basalt are middle to lower Albian in age, significantly younger than the basement rocks at Sites 259 and 261, suggesting that a considerable thickness of sediment may underlie the basalt; (2) the basalt is medium-grained, unbrecciated, and relatively fresh, quite unlike the basement complexes at adjacent sites; and (3) the claystones immediately above the contact are red in sharp contrast to the predominantly green color of the higher sediments, suggesting some baking and discoloration.

Based on the foregoing relationships, basalt basement is recognized at Sites 259 and 261. Basalt sills are inferred at Sites 260 and 261, and a fine-grained basalt lying between the basement and the topmost sill at Site 261 may be either a flow or a sill.

PETROGRAPHY

Site 259

The upper part of the basement at Site 259 consists of light gray to greenish-gray, intensely altered basaltic breccia. The degree of brecciation and alteration decreases with depth and at about 25 meters below the sediment-basalt contact, the breccia passes into dark gray, fine-grained, compact basalt. The breccia consists of angular to subangular fragments of altered basalt up to 50 cm across. The fragments grade from light gray at the center to light green on the margins and are typically separated by zones of black to dark green smectite, probably representing altered glass (see frontispiece, this

volume). Veinlets and small masses of calcite are common throughout the breccia, and a few geodes of quartz are also present.

The compact basalt is typically dark greenish-gray but is dull red along fractures. It is fine to medium grained and sparsely porphyritic with an intergranular to intersertal groundmass. The average grain size ranges from 0.3 to 0.5 mm, and most specimens have a few plagioclase phenocrysts up to 5 mm long. Sparse vesicles up to 0.5 mm in diameter are filled with calcite and smectite.

Typical specimens consist of small ragged laths of labradorite set in a matrix of poorly crystallized clinopyroxene, magnetite, and smectite. Clinopyroxene sometimes occurs in plumose or sheaf-like aggregates and sometimes as small, isolated grains. The plagioclase phenocrysts are euhedral and weakly zoned, ranging in composition from approximately An_{55} to An_{60} . Rare microphenocrysts of clinopyroxene are augite ($2V_z = 45^\circ-50^\circ$) and the groundmass crystals are probably the same. Small corroded crystals of olivine, completely replaced by smectite and iron oxides, make up 2%-3% of some specimens.

All of the basalts at Site 259 have been altered, but the degree of alteration decreases markedly with depth. In the most altered specimens green to yellowish-green smectite makes up 30%-40% and replaces olivine, glass, clinopyroxene, and, occasionally, plagioclase. In fresher specimens, clay makes up 5%-10% by volume and occurs chiefly as vesicle and fracture fillings and as pseudomorphs after olivine.

Site 260

The basalt at Site 260 is light gray, medium-grained, and sparsely porphyritic. It is cut by a few narrow fractures filled with calcite and smectite, but it is unbrecciated and contains no glassy zones. Most specimens contain a few small vesicles, 0.25-0.5 mm in diameter, filled with calcite, chlorophaeite, and smectite.

Typical specimens have sparsely porphyritic, intergranular textures and consist chiefly of plagioclase, clinopyroxene, and magnetite. Plagioclase occurs in subhedral laths, from 0.5 to 1 mm long, with a few microphenocrysts up to 2 mm in length. Most of the plagioclase is zoned, often with a sharp compositional break between core and rim. The average composition is sodic labradorite, but some crystals have cores as calcic as bytownite. Clinopyroxene forms small, colorless, anhedral crystals ranging from 0.1 to 0.3 mm across. Rare microphenocrysts are up to 1 mm in diameter and are typically subhedral. All of the clinopyroxene is augite ($2V_z = 40^\circ-45^\circ$), but some of the larger crystals are noticeably zoned. Magnetite occurs as tiny octahedra often arranged in clusters and linear groups. Smectite is usually present in small quantities, and it occurs as interstitial patches, as vesicle fillings, and as marginal replacements of augite crystals. Some of the vesicles have cores of brownish-green, isotropic chlorophaeite. Olivine was not definitely identified in these basalts; a few smectite patches have shapes suggestive of olivine crystals but obvious pseudomorphs are lacking.

Site 261

Unit A—This unit consists of relatively fresh, dark greenish-gray, fine- to medium-grained basalt. The rock is irregularly fractured and cut by numerous veinlets and irregular patches of calcite but is unbrecciated. Small vesicles filled with smectite and calcite are present in most specimens.

This basalt varies considerably in grain size and texture. It is typically slightly glomeroporphyritic with clusters of plagioclase, augite, and olivine crystals in a fine-grained variolitic groundmass. However, in some specimens the groundmass is a well-crystallized mixture of plagioclase and clinopyroxene with an intergranular to subophitic texture. Plagioclase makes up 50%-60% of the well-crystallized specimens with the remainder consisting of augite, olivine (altered to clay), and magnetite with small quantities of interstitial smectite and calcite. Clinopyroxene predominates in the variolitic specimens. The plagioclase occurs as subhedral laths, some of which are up to 1.5 mm long. It is chiefly labradorite (An_{50-55}) and only the largest crystals are optically zoned. Augite ($2V_z = 35^\circ-45^\circ$) occurs as pale brown crystals with a wide range of grain size. In fine-grained specimens it forms laths or rods arranged in variolitic clusters; in coarser-grained specimens it occurs as interstitial granules, which with increasing grain size, grade into subophitic plates up to 1 mm across. Olivine occurs only in the glomeroporphyritic clusters where it forms crystals up to 0.5 mm across completely replaced by yellowish-brown smectite. Small, irregular patches of smectite in the groundmass are probably after glass. The magnetite forms tiny laths and octahedra associated with the variolitic intergrowths of clinopyroxene and plagioclase.

Unit B—This unit consists of approximately 3 meters of dark greenish-gray, fine-grained basalt lying between basaltic basement and the uppermost sill. The rock is closely fractured and cut by numerous veinlets of calcite, but is generally not brecciated. Unlike the overlying unit, this basalt is extensively altered and discolored particularly along fractures. The intensity of alteration decreases somewhat away from the fractures, but none of the rock is unaffected.

This basalt is nonporphyritic and consists of a fine-grained mixture of plagioclase, augite, ilmenite, and olivine. Textures range from intergranular to intersertal; no variolitic zones are present. Olivine comprises 3%-5% by volume and occurs in subhedral to euhedral crystals up to 0.5 mm long, completely replaced by yellowish-brown smectite. The other minerals generally form subhedral laths with an average grain size of 0.3 mm. Most of the pyroxene crystals and the cores of many plagioclase laths have been replaced by smectite. Sparse vesicles up to 0.5 mm in diameter are partly filled with green smectite and minor chalcedony.

Unit C—The basement at Site 261 consists of alternating layers of dark brownish-gray, compact basalt and brown to green, highly altered basalt breccia, suggesting the presence of several flows. In general, the brecciation becomes more intense and more continuous with increasing depth (see frontispiece, this volume).

The compact basalt is very fine grained, nonporphyritic, and poorly crystallized. Veinlets and small,

irregular masses of calcite are common, and sparse vesicles up to 1 mm in diameter are also filled with calcite. Along cracks and fractures the rock is discolored to yellowish-brown or reddish-brown. Typical specimens consist of small plagioclase laths (average 0.1 mm long), poorly crystallized clinopyroxene, and minute crystals of magnetite in a cryptocrystalline matrix. Yellowish-orange smectite forms irregular patches in the matrix and also occurs as vesicle linings. Small, irregular and lath-like masses of hematite up to 0.5 mm across make up 10%-15% by volume. The lath-like shape of these masses suggest that they formed after ilmenite.

The breccia consists of fragments of light brown, altered basalt in a matrix of bright green, waxy smectite and white calcite (see frontispiece, this volume). The basalt fragments range from 5 mm to 25 cm across, and many of the larger fragments have rounded outlines suggestive of pillow fragments. The fragments themselves consist chiefly of cryptocrystalline material and hematite, with a few incipiently developed plagioclase laths.

PETROCHEMISTRY

Introduction

From petrographic examination it is apparent that all of the Leg 27 basalts have undergone some degree of low-temperature alteration after emplacement. Alteration of this type complicates the interpretation of chemical data obtained from ocean floor basalts. In general, alteration of the basalts results in increases in H_2O , K_2O , and ferric iron and losses in CaO , MgO , and SiO_2 . Certain other elements, notably Na, Rb, Ba, Cs, Sr, Pb, U, and Th, tend to become remobilized and are either enriched, depleted, or simply redistributed during alteration, whereas elements such as Al, Mn, Ti, Fe, Ga, V, Ni, Zr, Nb, Hf, P, REE, and Y remain essentially immobile (Frey et al., 1968; Philpotts and Schnetzler, 1969; Hart, 1969; Cann, 1970; Pearce and Cann, 1971; Thompson, 1973).

Analytical Techniques

Most major elements were determined by P. T. Robinson using X-ray fluorescence following a modified version of the technique of Norrish and Chappell (1967). Precision, in percent of amount present, is SiO_2 , 0.5; TiO_2 , 0.5; Al_2O_3 , 0.9; Fe_2O_3 (total iron), 1.0; CaO , 0.8; and K_2O , 1.0. Na_2O , MnO , MgO , and P_2O_5 were determined by T. Spittler using atomic absorption techniques. These analyses have a precision of 4% of the amount present, except for P_2O_5 which has a precision of 10%. Trace-element analyses were performed by D. J. Whitford using an AEI MS7 spark source mass spectrograph following the method of Taylor (1965, 1971). Photographic plates were read on a Jarrell-Ash microdensitometer, and the data processed following the method of Taylor (1971). From analysis of standard rocks and well-analyzed lunar samples, the precision of the technique expressed as a relative deviation is approximately $\pm 10\%$ for most elements.

Results

Major element analyses and CIPW norms are given in Table 1, and trace-element data are presented in Table 2.

TABLE 1
Chemical Analyses and CIPW Norms of Basalts from the Eastern Indian Ocean and Western Australian Margin

	Sample											
					260-20 Pc. 5	Unit A		Unit B		Unit C		Bunbury Basalt
	259-37-2, 32-38 cm	259-38-2, 116-129 cm	259-39-1, 85-92 cm	259-40-1, 140-150 cm		261-33, CC Pc. 2	261-34-2, 142-150 cm	261-35-3, 13-20 cm	261-35-4, 87-97 cm	261-37-1, 126-133 cm	261-38-5, 110-120 cm	
SiO ₂	50.69	51.65	51.62	51.23	51.86	50.22	49.84	48.95	49.69	48.49	49.94	51.42
TiO ₂	1.61	1.27	1.27	1.37	1.75	1.39	1.32	3.46	3.34	0.94	1.00	1.69
Al ₂ O ₃	16.67	15.61	16.49	16.58	13.84	14.82	14.40	15.75	15.60	15.96	15.28	15.86
Fe ₂ O ₃	11.64	11.14	9.89	10.42	13.61	11.75	11.69	12.74	11.65	9.92	10.50	11.48
MnO	0.13	0.19	0.16	0.18	0.20	0.21	0.22	0.43	0.15	0.22	0.25	0.18
MgO	7.70	7.19	7.91	8.38	5.84	7.15	7.41	7.74	6.91	7.08	7.60	5.53
CaO	7.82	10.04	9.52	8.42	10.25	11.33	12.03	6.34	7.09	13.09	11.84	10.37
Na ₂ O	1.89	2.34	3.12	2.70	2.72	2.16	2.16	3.32	3.64	3.16	2.19	3.15
K ₂ O	0.65	0.31	0.13	0.27	0.14	0.64	0.01	0.92	0.83	0.67	0.61	0.18
P ₂ O ₅	0.22	0.13	0.09	0.15	0.13	0.07	0.19	0.33	0.29	0.17	0.08	n.d.
Total	99.02	99.87	100.20	99.70	100.34	99.74	99.27	99.98	99.19	99.70	99.29	99.86
LOI	2.65	1.59	2.41	2.91	1.15	1.70	0.27	3.10	2.25	3.05	1.68	0.60
CIPW Norms												
Q	4.58	3.18	—	0.90	3.42	0.18	1.02	—	—	—	—	—
or	3.89	1.67	0.56	1.67	0.56	3.89	0.05	5.56	5.00	3.89	3.89	—
ab	16.25	19.91	26.72	23.06	23.06	18.34	18.34	28.30	31.44	17.82	18.86	—
an	35.86	31.69	29.47	32.80	25.58	29.19	30.30	25.58	24.19	27.52	30.30	—
ne	—	—	—	—	—	—	—	—	—	5.11	—	—
di	1.36	14.31	13.97	6.99	20.53	22.10	24.12	3.37	9.91	30.38	23.34	—
hy	32.17	23.86	23.65	29.36	20.89	21.01	20.88	19.76	16.70	—	15.70	—
ol	—	—	0.15	—	—	—	—	7.60	5.26	10.71	3.39	—
mt	2.32	2.32	2.09	2.32	2.09	2.32	2.32	2.32	2.32	2.32	2.32	—
il	3.19	2.43	2.43	2.58	3.34	2.74	2.58	6.69	6.54	1.82	1.98	—
ap	0.67	0.34	0.34	0.34	1.01	0.34	0.34	0.67	0.67	0.34	0.34	—

Note: Abbreviations used are as follows: Q, = quartz; or, orthoclase; ab, albite; an, anorthite; ne, nepheline; di, diopside; hy, hypersthene; ol, olivine; mt, magnetite; il, ilmenite; ap, apatite; n.d., not determined.

TABLE 2
Averaged Trace Element Analyses (in ppm)

	(1) Site 259	(2) Site 260	(3) Site 261 Unit A	(4) Site 261 Unit B	(5) Site 261 Unit C	(6) ^a Midocean Ridge Av	(7) ^b Av Chondrite
Ba	6.1-9.3	45	3.4	35	9.2-35		
Eu	0.76	0.98	0.79	1.8	0.61		
Pb	1.7	1.5	0.61	1.4	0.46		
Th	0.10	0.12	0.08	0.42	n.d.		
U	0.07	n.d.	n.d.	0.86	n.d.		
Zr	58	85	62	150	40		
Hf	1.8	2.6	1.8	4.7	1.4		
Sn	0.60	0.98	1.0	2.3	0.55		
Nb	1.1	4.2	0.84	7.1	0.80		
Mo	0.36	5.3	0.80	0.70	0.36		
Th/U	1.4			0.49			
Zr/Hf	32	33	35	32	29		
Zr/Nb	53	20	74	21	50		
La	1.8	4.3	1.6	6.0	1.3	2.67	0.300
Ce	6.7	12	5.5	18	4.2	9.99	0.840
Pr	1.1	1.8	1.0	3.0	0.69	1.58	0.120
Nd	5.3	8.3	5.0	15	3.6	8.79	0.580
Sm	2.0	2.8	2.1	5.3	1.6	3.09	0.210
Eu	0.76	0.98	0.79	1.8	0.61	1.15	0.074
Gd	3.0	4.1	3.1	7.0	2.3		0.300
Tb	0.53	0.70	0.55	1.1	0.42	0.793	0.049
Dy	3.5	4.5	3.6	7.5	2.6		0.310
Ho	0.95	1.2	0.99	1.8	0.67	1.03	0.073
Er	2.7	3.5	3.0	5.2	2.0		0.210
Tm ^c	0.46	0.61	0.46	0.84	0.33	0.425	0.030
Yb	2.8	3.7	2.8	5.1	2.0	2.94	0.200
Lu ^c	0.43	0.57	0.43	0.79	0.31	0.517	0.034
ΣREE	32	49	31	78	23		3.330
Y	22	26	26	42	17	29.2	2.00
ΣREE+Y	54	75	57	120	40		5.33
La/Yb	0.64	1.16	0.57	1.18	0.65	0.91	1.50

Note: See Table 1 for Samples analyzed.

n.d. = not determined.

^aAverage REE+Y composition of midocean ridge tholeiites (Schilling, 1971).

^bREE abundances for chondrites used for normalization.

^cEstimated indirectly.

In order to eliminate oxidation effects, the norms were calculated after setting Fe₂O₃ equal to 1.5% (Kay et al., 1970). Most of the basalts are quartz normative; four contain both normative olivine and hypersthene, and one is nepheline normative (Table 1). In general, Leg 27 basalts lie within the range of variation previously established for Indian Ocean basalts, but on the average they are somewhat lower in normative quartz (Figure 2). Based on the alkali-silica ratios, three specimens, all from Site 261, are slightly alkalic (Figure 3). When plotted on an AFM diagram, Leg 27 basalts are seen to vary primarily parallel to the iron-magnesium join, as do others from the Indian Ocean (Figure 4).

Figure 5 shows the REE distribution pattern of the basalts normalized to average chondrite abundances. All of the rocks analyzed have relatively primitive trace-element distribution patterns, and except for the middle unit at Site 261 (Unit B) they lie within the limit of observed variation in abyssal tholeiites (Frey and Haskins, 1964; Engel et al., 1965; Kay et al., 1970). The REE are enriched relative to chondrites, but their distribution patterns are either flat or slightly depleted in the lighter elements (La-Nd). No Eu anomalies were

detected in any of the samples.

Site 259—At Site 259 the upper part of the basement consists of highly altered breccia which grades downward into less-altered, fine-grained, compact basalt. All of the analyzed specimens are from the lower compact basalt. Three of the four analyzed specimens are quartz normative, the other is only slightly olivine normative (Table 1). The three uppermost specimens, taken over an interval of 8 meters, exhibit nearly linear chemical variations with depth. K₂O, P₂O₅, total iron, and normative quartz decrease whereas Na₂O increases. These variations, particularly the decrease in K₂O from 0.65% to 0.13%, are probably due to decreasing alteration with depth. Normative quartz usually increases in basalts with increasing alteration because of oxidation of the iron. Here, however, oxidation effects have been eliminated by calculation of the norms on a fixed percent of Fe₂O₃. Hence, the upward increase in normative quartz in this sequence must be due to other variations. Even the lowest potassium specimen in this sequence is somewhat altered as indicated by petrographic examination and by the relatively large weight loss on ignition.

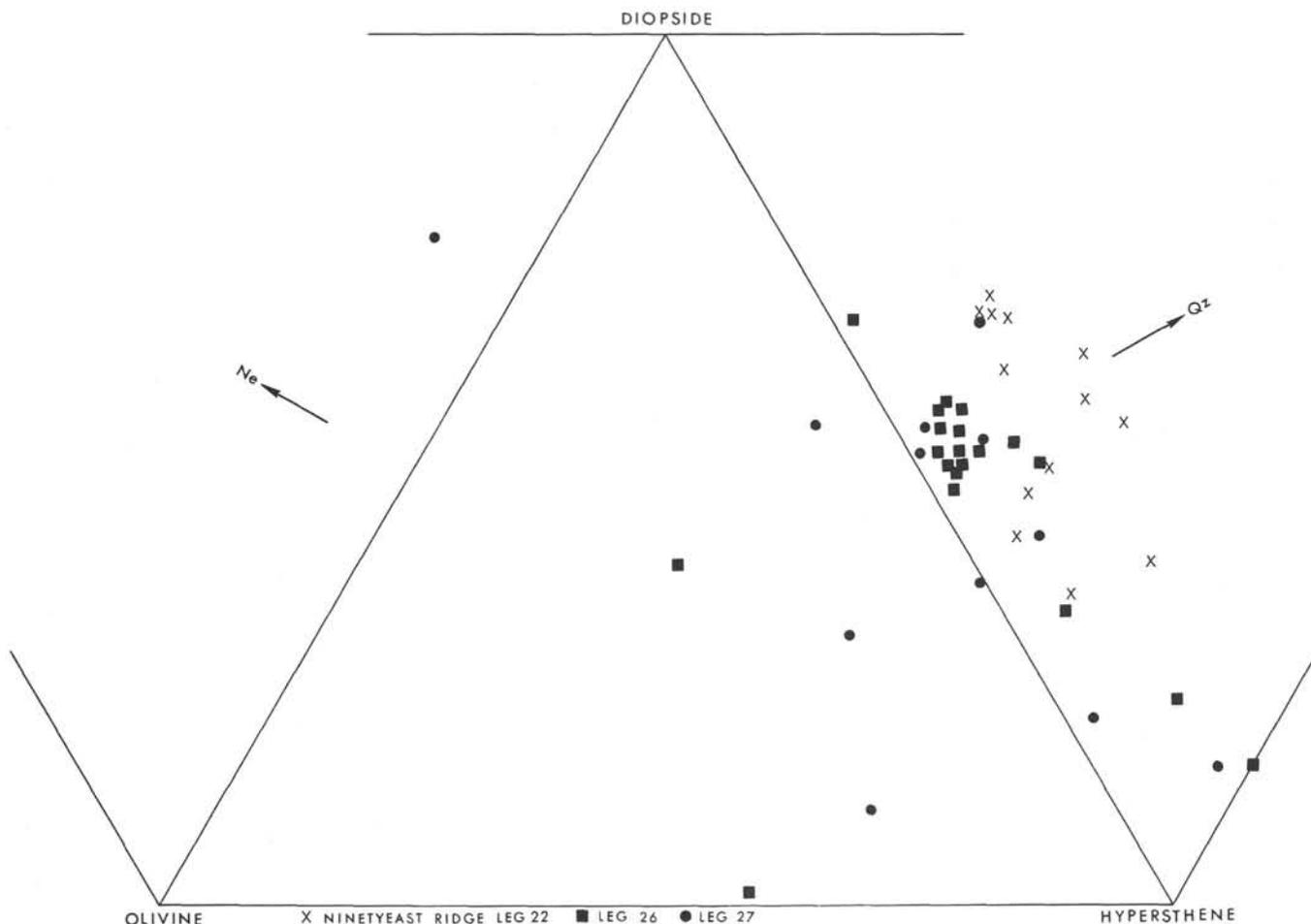


Figure 2. Triangular diagram of weight percents of normative diopside, olivine, and hypersthene in basalts of the Indian Ocean. Data for Leg 26 from Kempe (1973) and for Leg 22 from Hekinian (1974).

Site 260—The basalt sill at Site 260 is the freshest basalt encountered during Leg 27. It consists of low potassium, quartz-normative tholeiite similar to the freshest rock at Site 259. However, compared to the basalts at Site 259, this rock has distinctly higher CaO and total iron and lower Al_2O_3 and MgO (Table 1). Both of the samples from this site analyzed for trace elements have similar compositions with respect to the immobile elements, but the mobile elements show appreciable variations (Table 2). The trace-element geochemistry of these specimens is similar to that of the basalts from Site 259, although there is an overall relative enrichment in almost all elements (Table 2). The chondrite-normalized REE pattern is essentially flat, with no depletion in the lighter elements (Figure 5).

Site 261—All of the basalts at Site 261 are slightly more alkalic than those from Sites 259 and 260. However, each of the three units at Site 261 recognized on lithologic criteria have distinct chemical characteristics.

Only the uppermost unit is quartz normative; the others have normative olivine or nepheline, or both. Two analyzed specimens from Unit A are very similar in composition, except for percent K_2O ; the uppermost specimen has 0.64% K_2O whereas the lower has <0.01%. There is also a marked difference in weight loss between

these two specimens suggesting that the K_2O difference is due primarily to alteration, although there are no petrographic differences between these two specimens. If the lower specimen with <0.01% K_2O represents the unaltered composition, this is an extremely depleted basalt. However, as seen from Table 2, the REE composition of this basalt is almost indistinguishable from the basalt at Site 259.

Unit B consists of relatively alkalic, olivine-normative basalt. Total alkalis average over 4%, total iron over 12%, and TiO_2 nearly 3.5% (Table 1). P_2O_5 is also enriched relative to most tholeiites and CaO is depleted. Specimens from this unit are also relatively enriched in both the Zr group of trace elements and especially in the REE which lie at or above the limit of observed variation in abyssal tholeiites (Figure 5). Like that of the basalt at Site 260, the REE pattern of this unit is almost flat and shows only a minor depletion of the lighter elements.

The basalt of Unit C is also relatively alkalic with one specimen containing over 5% normative nepheline. However, these basalts are all hydrated (as indicated by high weight loss on fusion) suggesting that their alkalic character may be due primarily to alteration. For example, the nepheline-normative specimen has over 13% CaO which is very high for such an alkalic basalt.

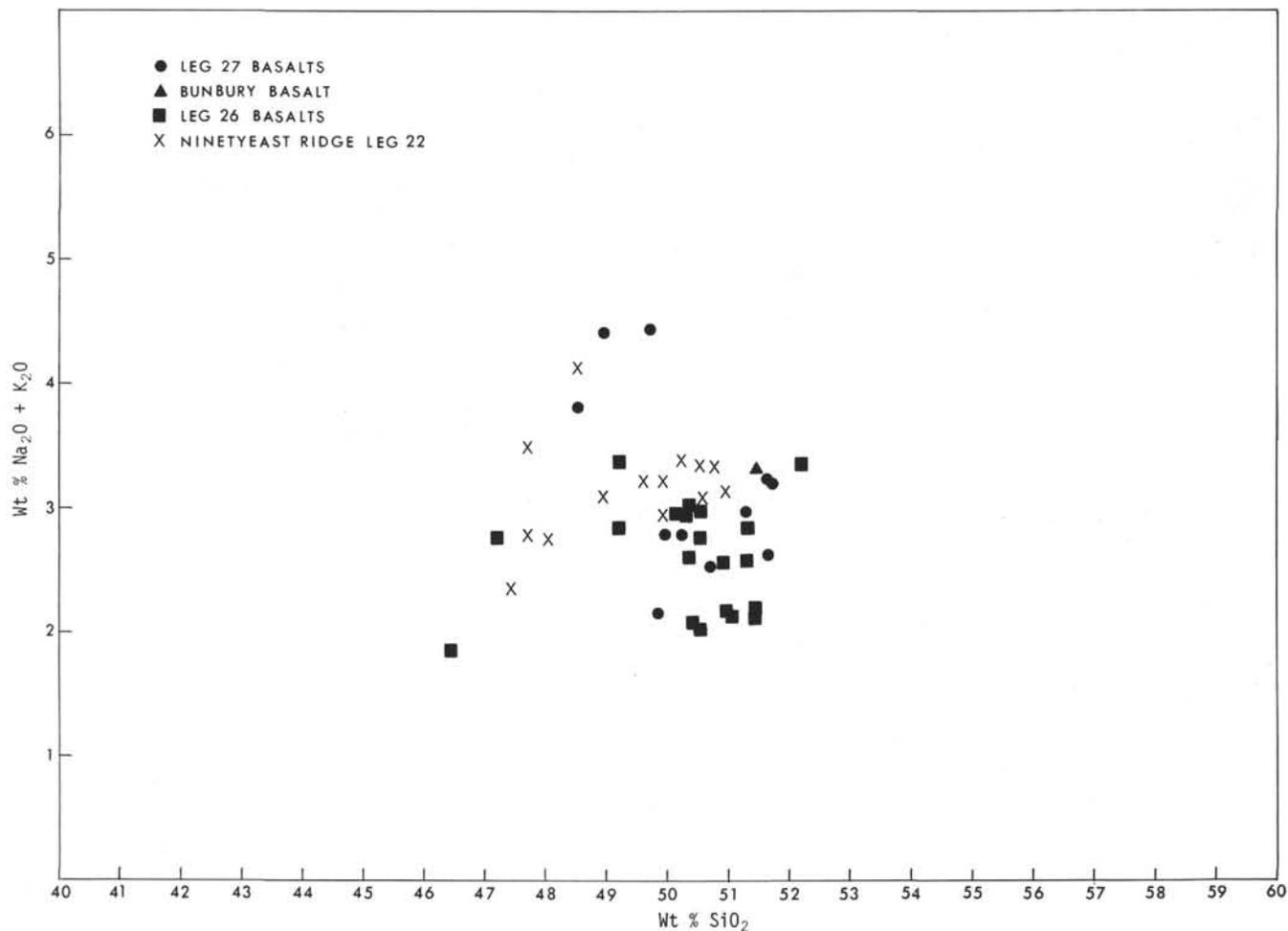


Figure 3. Alkali-silica diagram for basalts of the Indian Ocean. Source of data same as in Figure 2.

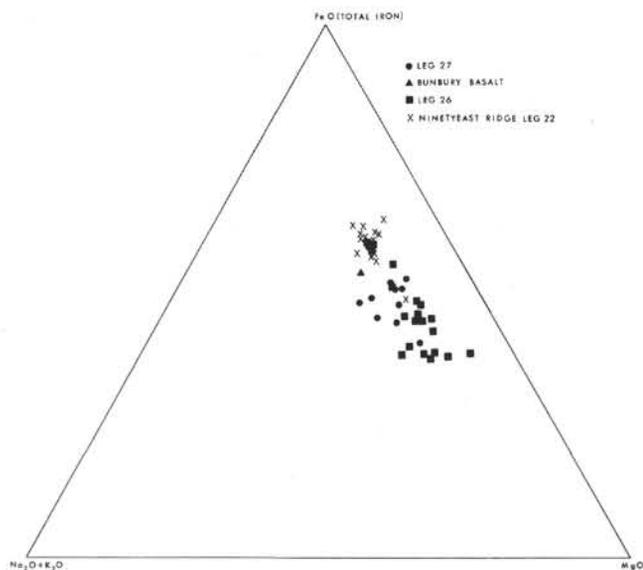


Figure 4. AFM diagram for basalts of the Indian Ocean. Source of data same as in Figure 2.

This is probably due to the presence of secondary calcite. Likewise, the relatively high alkalis, particularly K_2O , and the relatively low silica may be due to alteration. This unit is relatively depleted in most trace elements and thus has a distribution pattern similar to basalts from Sites 259 and 261 (Unit A).

Discussion

In recent years an abundance of chemical data pertaining to oceanic basalts has been obtained (Frey and Haskin, 1964; Engel et al., 1965; Cann, 1970; Kay et al., 1970; Hart, 1971; Schilling, 1971; Miyashiro et al., 1969). From the data presented in Tables 1 and 2 and Figures 1 through 5 it can be seen that most of the basalts from Leg 27 are similar to abyssal tholeiites found elsewhere in the Indian Ocean. Basalts from Sites 259 and 261 (Unit C) lie well within the compositional range of samples from midoceanic ridges of the Atlantic, Pacific, and Indian oceans. With one exception they are quartz or hypersthene normative, and fresh specimens have relatively low K_2O contents. They are all depleted in the large cation (K-type) group of trace elements as well as the highly charged cation (Zr type) group. Their light-element-depleted REE patterns are also very characteristic. Based on their lithology, stratigraphy,

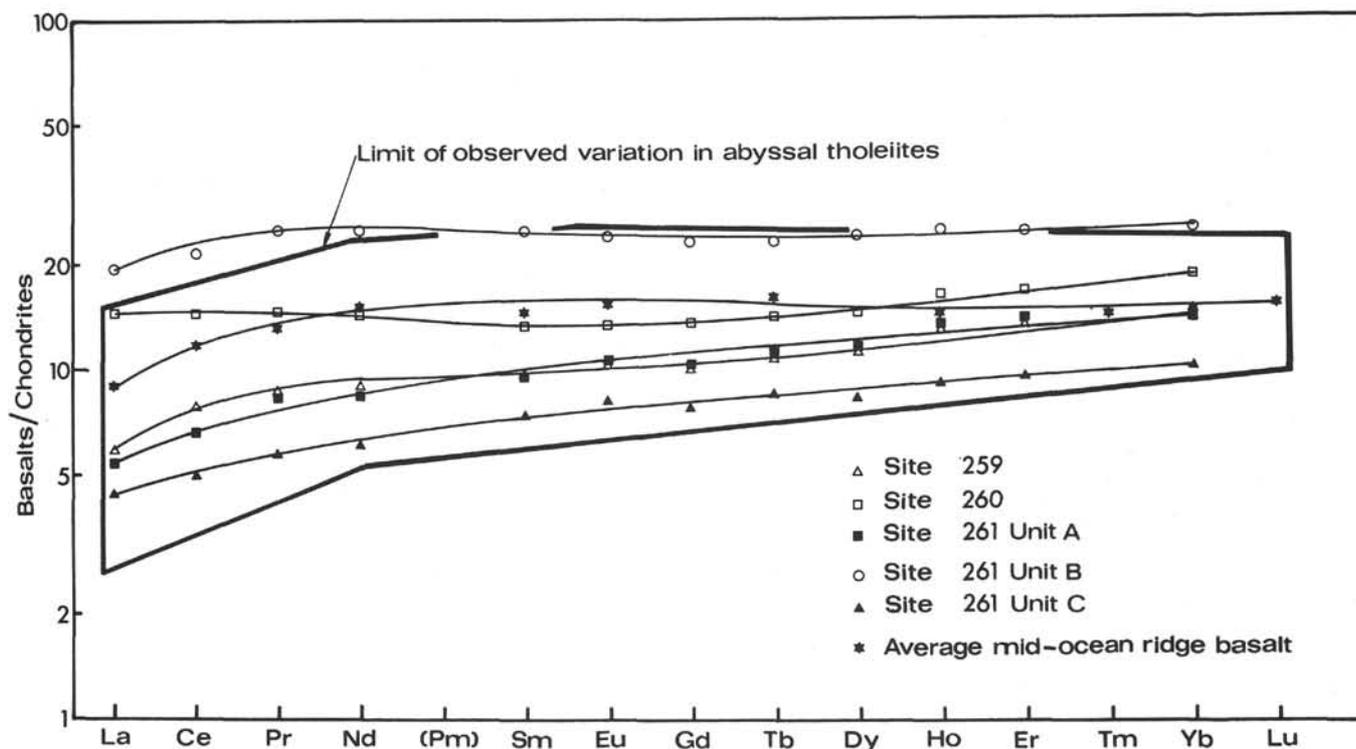


Figure 5. REE in oceanic basalts normalized to abundances in chondrites (columns 1-6 in Table 2). The average midocean ridge basalt is from Schilling (1971). The limit of observed variation in abyssal tholeiites has been compiled from Kay et al. (1970) and Schilling (1971).

and chemistry, these basalts are interpreted as oceanic ridge basalts formed during Upper Jurassic and Lower Cretaceous sea-floor spreading in the eastern Indian Ocean. The freshest of these basalts compares favorably with the terrestrial Bunbury Basalt of the Perth Basin (Table 1) which has been interpreted as marking the initial rifting along the Australian continental margin (Veevers and Johnstone, this volume). Weathering and low-temperature alteration are probably responsible for most of the chemical variations in these basalts, although some original differences may have existed between the two sites. Most of these basalts show clear petrographic evidence of alteration, and they all have relatively high weight losses upon ignition, suggesting high H₂O and CO₂ contents. Comparison of closely adjacent specimens from the same unit provides strong evidence for remobilization of certain elements, most notably K, Ba, U, and Th and to a lesser extent Si, Ca, Na, and P.

The sills at Sites 260 and 261 (Unit A) are also composed of quartz-normative, low-potassium tholeiite. The sill at Site 261 is chemically similar to the basal basalts at Sites 259 and 261, but the basalt at Site 260 shows minor but significant differences in trace-element composition from what is generally regarded as typical abyssal tholeiite (Table 2). In particular, this basalt has a relatively unfractionated REE pattern with La/Yb > 1.

The middle unit at Site 261 (Unit B) is significantly more alkalic than other abyssal basalts from Leg 27 and from elsewhere in the Indian Ocean (Figure 3). The alkalic character is indicated by the relatively high total

alkalis and P₂O₅ and by the high TiO₂. The high TiO₂ is a good indication that the high alkalis are not due solely to alteration. This basalt also has a relatively unfractionated REE pattern with La/Yb > 1, and a strong REE enrichment relative to chondrites (Figure 5).

CONCLUSIONS

1. The basal basalts at Sites 259 and 261 represent oceanic basement erupted during Upper Jurassic to Lower Cretaceous rifting off the west coast of Australia. The chemical compositions of these rocks reflect extensive low-temperature alteration resulting in remobilization of K, Ba, U, Th, and, perhaps, Si, Ca, Na, and P. The original basalt was probably low-potassium tholeiite or olivine tholeiite. Slight differences in composition between the basalts of these two sites may reflect original compositional differences or different degrees of alteration, or both.

2. The basalt encountered at Site 260 and the upper unit at Site 261 are interpreted as sills. At Site 260 the sill intrudes sediment of lower to middle Albian age and is probably much younger than the basement at adjacent sites. At Site 261 the sill intruded at the base of the sedimentary sequence and the relative age is unknown. Both sills consist of tholeiitic basalt, but at Site 260 the rock is somewhat different chemically from typical abyssal tholeiites. The sills are relatively fresh and their present composition probably closely approximates their original composition.

3. The middle unit at Site 261 (Unit B) consists of relatively alkalic basalt distinctly different from typical ocean ridge tholeiites. This basalt, which may be either a

flow or a fine-grained sill, probably represents intraplate volcanic activity at some time after formation of the basement.

4. The oldest basalts known from the Indian Ocean (Sites 259 and 261) are remarkably similar in chemical composition to young basalt dredged from modern ridge crests, indicating that the nature of oceanic basalts has not changed significantly for at least the last 130 m.y.

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