40. PETROLOGY AND GEOCHEMISTRY OF ROCKS FROM THE ANGOLA BASIN ADJACENT TO THE WALVIS RIDGE: DEEP SEA DRILLING PROJECT LEG 75, SITE 530[1]

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ABSTRACT

Deep Sea Drilling Project Leg 75 drilled into igneous basement in the Angola Basin at Site 530, located about 20 km north of the escarpment at the eastern end of the Walvis Ridge. Petrographic and geochemical characteristics of the basalts indicate that the basement is quite uniform, variations in chemical composition being related to weathering, crystal fractionation, and the modal abundances of individual minerals.

These basalts are similar to those drilled at Sites 527 and 528 on the central section of the Walvis Ridge, but are less enriched in incompatible elements than basalts dredged from the eastern end of the Walvis Ridge. They show distinct compositional differences from mid-ocean ridge basalts, which suggests that the Walvis Ridge hot spot has influenced the basement of the southern part of the Angola Basin. Comparison of the chemistry of Site 530 basalts with those drilled during Leg 74 indicates that the implied variation in mantle source is not in accord with any simple along-ridge progression, but may be related to vertical zonation within the volcanic pile.

INTRODUCTION

The Walvis Ridge is one of the major structural features in the South Atlantic. This aseismic ridge is believed to have originated by the passage of the African plate over a hot spot (Dietz and Holden, 1970; Morgan, 1971). The island of Tristan da Cunha is thought to be the present-day surface expression of the hot spot, and the Rio Grande Rise the western counterpart of the Walvis Ridge on the South American Plate. The Walvis Ridge is a linear feature rising more than 2 km above the surrounding ocean floor and extending from the Mid-Atlantic Ridge to the coast-line of Africa. Its SW-NE orientation and the lack of any deep passages through the Ridge limit the northward flow of bottom waters in the eastern Atlantic. Hence, the Walvis Ridge has played a major role in paleocirculation of the Atlantic Ocean, particularly for the paleoenvironments of the Angola Basin to the north of the Ridge.

During Deep Sea Drilling Project (DSDP) Leg 75, basement rocks were recovered at Site 530, located about 20 km north of the Walvis escarpment in the southeastern corner of the Angola Basin (Fig. 1). These provided the opportunity to investigate the geochemistry of the basalts in this area and to determine whether hot-spot volcanism, believed to have formed the Walvis Ridge, influenced the chemistry of the basement rocks in the adjacent basin.

Previous studies of the chemistry of basalts from the Walvis Ridge have shown them to be quite distinct from those erupted at the Mid-Atlantic Ridge. Basalts dredged from crust about 110 m.y. old at the eastern end of the Walvis Ridge are generally tholeiitic, but much more enriched in incompatible elements, such as Ti, K, Sr, and Y than are mid-ocean ridge basalts (MORB) (Hekinian, 1972; Hekinian and Thompson, 1976). Further studies of rocks dredged at different locations along the Ridge have also indicated that basalts from the eastern end are characterized by Zr/Nb ratios of about 10, whereas MORBs generally exhibit Zr/Nb ratios of 20 or greater (Humphris and Thompson, 1982).

Thompson and Humphris (in press) have reported on basalts from three sites drilled during DSDP Leg 74 on a segment of the Walvis Ridge about 68 to 70 m.y. old. These drilled samples showed distinct chemical differences from MORBs and from basalts recently erupted on Tristan da Cunha. All these studies indicate that the Walvis Ridge originated from a mantle source that has differed in composition at different times in the past.

In this chapter we will discuss the petrography and chemistry of the basalts recovered from Site 530 as an indication of whether the upper basement at this location originated at the Mid-Atlantic Ridge from a mantle source producing typical mid-ocean ridge basalts, or whether the source was influenced by its proximity to the Walvis Ridge hot spot.

SAMPLE LOCATIONS AND ANALYTICAL METHODS

Hole 530A was drilled in the southeast corner of the Angola Basin in a water depth of 4629 m. Basement was encountered at a depth of 1103 m below the sediment surface, and 19 m of basalt were penetrated. Based on paleontologic evidence, the age of the oldest sediment overlying the basement was late Albian (ca. 102.5 m.y.); this cannot be confirmed with magnetics data because the magnetic lineations are not distinct at this site. The seismic stratigraphic sequence obtained for this hole was typical for the entire deep part of the basin. In addition to the basement rock, small basaltic pebbles were found to be scattered throughout the sedimentary sequence at higher levels.

Samples of both the basement and pebbles found higher in the sedimentary sequence were obtained for study. Three pieces of rock obtained from the core catcher of Core 3 were quite distinct in appearance, and hence were designated pebbles A, B, and C, and analyzed individually. Another basaltic pebble was analyzed from lower down in the sediment sequence in Core 37. Seven samples of basalt from the 19 m of basement were analyzed.

[1] Hay, W. W., Sibuet, J.-C., et al., *Init. Repts. DSDP*, 75: Washington (U.S. Govt. Printing Office).

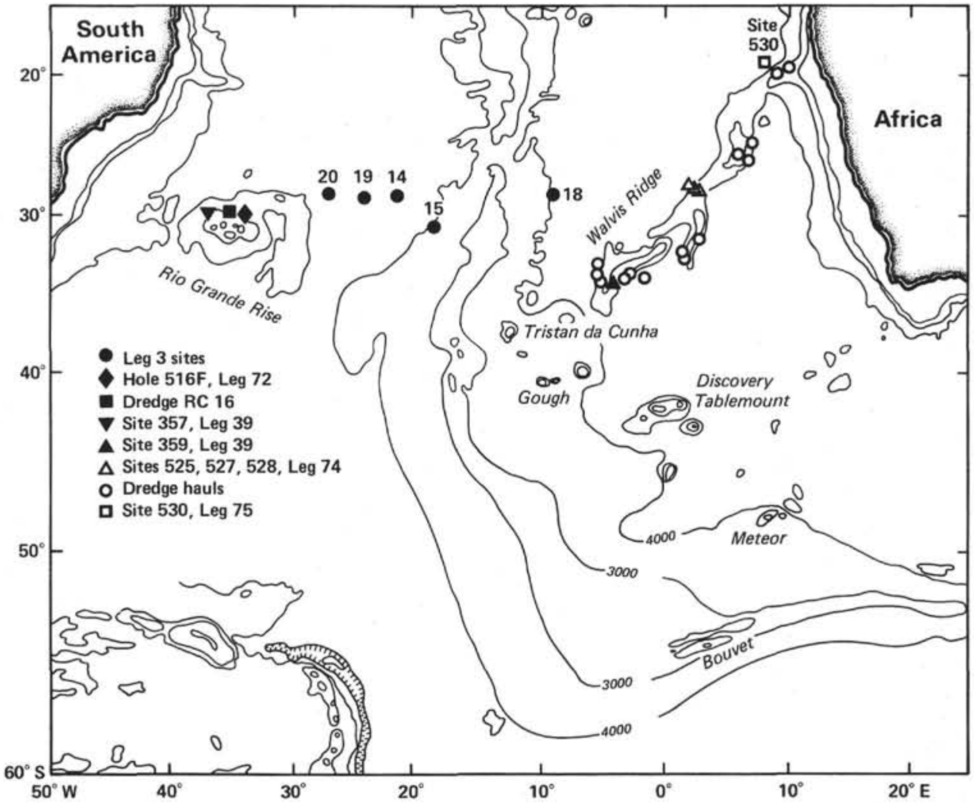

Figure 1. Map of the South Atlantic showing location of DSDP Site 530. Other DSDP sites and dredge hauls on the Walvis Ridge and Rio Grande Rise are also shown.

The samples were analyzed for major and trace elements by X-ray fluorescence spectrometry using the technique of Schroeder et al. (1980). Precision and accuracy for the major elements are between ±1 and 3% and about ±5% for the trace elements. Ferrous iron concentrations were determined by titration (Jen, 1973), and H_2O^+ and CO_2 were analyzed using a Perkin Elmer 240B CHN analyzer (Skinner et al., 1981).

PETROGRAPHY

The basalts recovered from the basement of Hole 530A are quite similar in their phenocryst and microphenocryst assemblages, the major differences being textural. Individual flow units cannot be defined from the samples studied, although one glassy margin was identified by the shipboard party. Textures vary from a quenched basalt with microlites disseminated throughout a glassy matrix (e.g., Sample 530A-107-2, 41–43 cm) to more crystalline samples in which phenocrysts and microphenocrysts occur in an intergranular matrix (e.g., Sample 530A-107-1, 48–50 cm). Vesicles are uncommon, suggesting that the unit was erupted in deep water.

Mineralogically, the basalts are composed dominantly of plagioclase, pyroxene, and iron oxides. Rare euhedral pyroxene phenocrysts up to 2 mm long, and occasional large euhedral plagioclase phenocrysts up to 1 mm long, occur in a few samples (e.g., Samples 530A-107-1, 48–50 cm; 530A-108-2, 10–12 cm; and 530A-108-2, 105–107 cm). However, more typically, plagioclase, often in the form of laths, and euhedral to subhedral pyroxene microphenocrysts occur together as glomerocrysts (e.g., Samples 530A-107-2, 41–43 cm and 530A-108-1, 44–46 cm). The groundmass generally consists of randomly oriented microlites of plagioclase and intergranular pyroxene in a fine-grained to glassy matrix. A noticeable feature is the presence of iron oxides (a few percent by volume) scattered throughout the matrix in the basement samples studied.

All of the samples are weathered to some degree. Partial replacement of some microphenocrysts by calcite, and amygdales filled with calcite, are common, particularly in the more weathered samples (e.g., Sample 530A-107-2, 41–43 cm). Brown and green clay minerals, together with calcite, have replaced patches of what might have originally been glass in the matrix.

The basaltic basement at this site therefore differs markedly from typical MORB. Mineralogically, the basalts resemble more closely both dredged and drilled samples recovered from the Walvis Ridge (e.g., Hekinian, 1972; Humphris and Thompson, 1982; Thompson and Humphris, in press), particularly in their pyroxene and iron oxide contents.

The basaltic pebbles from higher up in the hole that were recovered in sections of the sedimentary sequence are quite variable petrographically. The three core-catcher samples are totally different from each other. Sample 530A-3,CC (Pebble A) appears to be composed of a few anhedral pyroxene and plagioclase crystals cemented together by calcite. No small pieces of basalt were observed in thin section. Sample 530A-3,CC (Pebble B) is a highly weathered, fine-grained, aphyric basalt, consisting of thin plagioclase laths, numerous small grains of iron oxides, and considerable alteration of the rest of the matrix to calcite and green clay minerals. Sample 530A-3,CC (Pebble C) is an almost holocrystalline basalt consisting dominantly of euhedral or lathlike plagioclase with intergranular pyroxene and aggregations of large grains of iron oxides. Patchy weathering to a green clay mineral has also occurred.

The sample from Core 37 (Sample 530A-37-3, 100–104 cm) is a piece of highly weathered basalt penetrated by large calcite veins, and with numerous amygdales filled with calcite. Minerals that can still be identified include laths of plagioclase and grains of iron oxides in a brown, highly weathered matrix. There is also evidence of a mineral exhibiting high birefringence and oblique extinction, which might possibly have been pyroxene.

All of these basaltic pebbles are probably derived from the adjacent Walvis Ridge. The sedimentary column shows evidence of slumping of material from the flanks of the Ridge, and it is probable that some volcanics were also moved downslope. In addition, the possibility exists that the pebbles fell into the hole during drilling and were actually deposited higher in the sequence. Hence, it is not possible to derive with certainty any information on the origin or age of these pebbles from their location within the sedimentary stratigraphic sequence.

CHEMISTRY

Within Site Variations

Basement Rocks

Major and trace element analyses of samples from Cores 107 and 108 are presented in Table 1 and indicate that all the basalts are geochemically similar. The only minor differences are seen in the two samples from Section 108-2; their slightly lower concentrations of TiO_2, Na_2O, V, and Zr suggest that they might be slightly less evolved than the overlying basement. However, the apparent depletion in these elements is accompanied by higher concentrations of K_2O and Rb and quite variable Cr, Co, and Ni contents. Some of these differences are shown in Figure 2. It should be emphasized that the differences between Section 108-2 and the overlying basalt are quite small and, in addition, that both of these samples are more crystalline than any other samples studied. Many of the trends seen in Figure 2 can be accounted for by differences in the degree of crystal fractionation and the modal content of individual minerals. Subsequent weathering has also affected the chemical composition of the basalts, notably the K_2O and Rb concentrations. Since all the samples are so geochemically similar, it is possible to represent the basement at Hole 530A by an average chemical composition for comparison with rocks from other parts of the South Atlantic.

Basaltic Pebbles

Major and trace element analyses of the pieces of basalt recovered during drilling in the overlying sediment are shown in Table 2. All of them are geochemically distinct from each other and from the basement at this site.

Table 1. Major and trace element analyses of basalts, Hole 530A.

Component	Sample (interval in cm) 107-1, 48–50	107-2, 41–44	107-2, 142–144	107-3, 27–29	108-1, 44–46	108-2, 10–12	108-2, 105–107
Major element oxides (wt.%)[a]							
SiO_2	49.98	49.36	49.72	49.68	50.15	49.23	49.89
TiO_2	1.90	1.85	1.86	1.76	1.86	1.70	1.72
Al_2O_3	16.52	16.48	16.25	15.52	16.14	15.44	15.99
FeO*	9.61	9.91	9.58	10.35	9.62	10.75	10.54
MnO	0.31	0.32	0.30	0.30	0.28	0.25	0.24
MgO	8.38	7.48	8.21	7.82	8.39	8.08	8.05
CaO	10.02	10.90	10.59	11.29	10.74	10.68	10.11
Na_2O	2.81	2.78	2.74	2.65	2.77	2.42	2.52
K_2O	0.09	0.35	0.10	0.36	0.10	0.54	0.55
P_2O_5	0.28	0.25	0.26	0.23	0.25	0.26	0.26
Total	99.90	99.68	99.61	99.96	100.30	99.35	99.86
Other analyses							
FeO	4.15	4.15	4.35	4.54	4.35	4.51	4.31
Fe_2O_3	6.07	6.40	5.81	6.46	5.86	6.93	6.92
H_2O^+	1.49	1.55	0.81	1.26	1.28	1.42	1.58
H_2O^-	3.16	4.32	2.51	2.85	2.96	2.58	3.45
CO_2	0.20	1.42	0.21	0.87	0.15	0.22	0.20
Trace elements (ppm)[b]							
Rb	1.9	8.1	1.5	10.1	1.9	15.4	15.8
V	355	337	342	319	341	302	312
Cr	91	90	84	86	89	94	91
Co	46	72	42	46	44	33	39
Ni	74	124	70	81	73	66	79
Cu	68	69	69	65	68	73	71
Zn	77	84	79	75	76	72	73
Sr	285	265	267	255	271	257	274
Ba	119	149	121	124	133	122	146
Y	36	32	37	34	38	32	30
Zr	139	131	134	131	135	127	128
Nb	21.2	20.5	20.7	20.7	20.2	20.7	21.2

[a] Volatile-free basis after ignition at 1000°C.
[b] Dried at 110°C.

They are highly weathered and contain over 4.8 wt.% H_2O; hence, any compositional comparisons have to be limited to elements least affected by weathering. The chemical composition obtained for Pebble A is clearly dominated by calcium carbonate and hence has not been used in any further discussion. The analysis total for Pebble B is very low, probably as a result of the high degree of weathering exhibited by replacement of groundmass by clay minerals and calcite. Pebble C—the most crystalline of all—differs markedly from the underlying basement, having higher concentrations of Zr, Ba, Sr, and Rb, and lower Nb, Y, Cu, Ni, Cr, and V contents. Its FeO*/MgO ratio is also higher (1.61) than in the basement rocks. Some of these differences can be explained by the dominance of plagioclase in this sample; however, the variations in the incompatible elements, particularly Zr, Y, and Nb, suggest that this sample is unrelated to that recovered in Cores 107 and 108.

Sample 530A-37-3 is also chemically distinct, exhibiting a very high TiO_2 content (3.14 wt.%), an FeO*/MgO ratio of 1.97, and high concentrations of Zr and Nb, compared with the other basalts recovered from this hole.

Regional Geochemical Comparison

Table 3 presents some average compositions of previously analyzed basalts from the Walvis Ridge, the Rio Grande Rise, Tristan da Cunha, and the Mid-Atlantic Ridge at this latitude. Based on their overall chemistry,

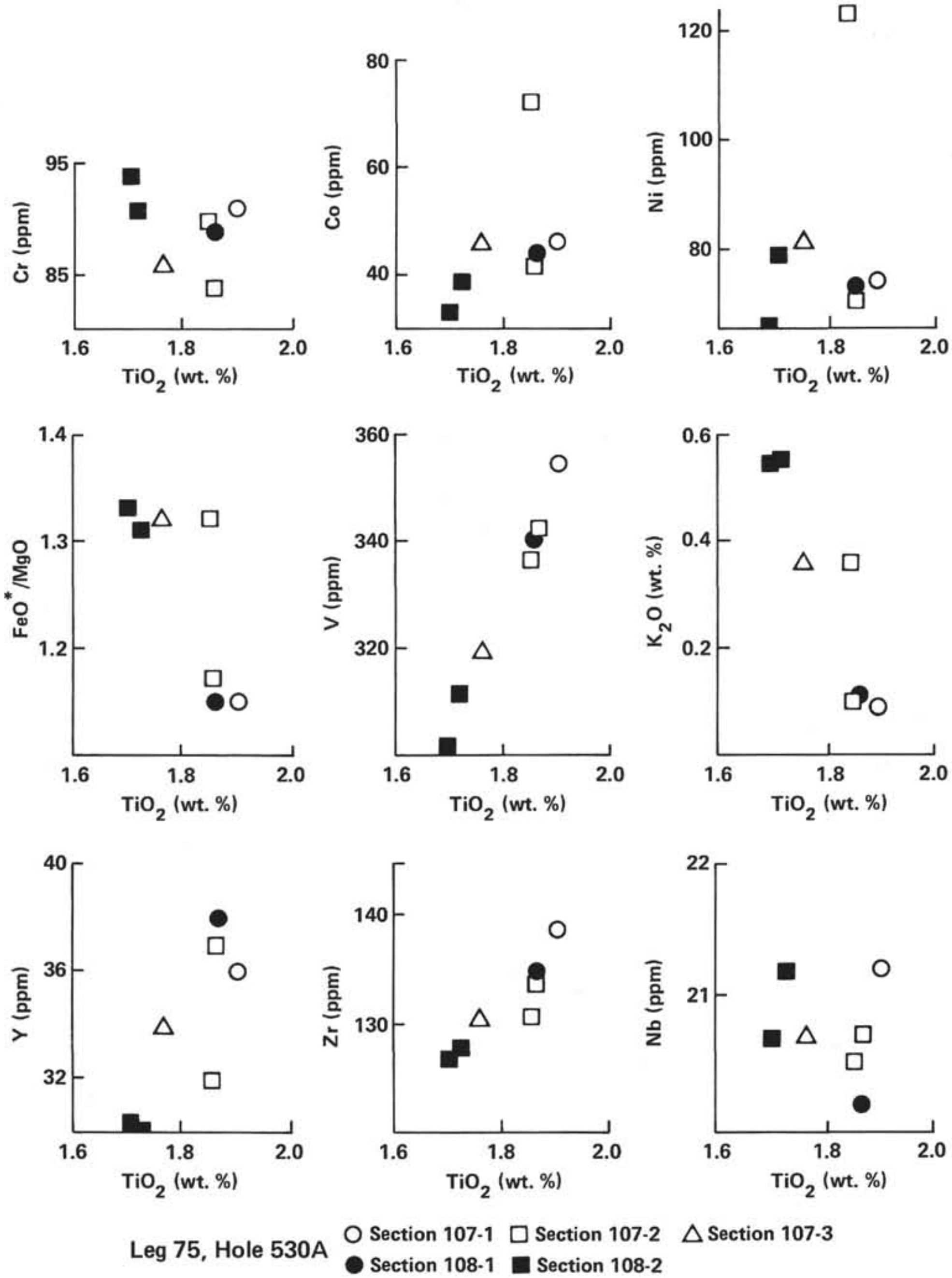

Figure 2. Plots of selected major-element oxides and trace elements versus TiO_2 for the basement rocks at Hole 530A.

the Site 530 basement basalts are quite distinct from the Mid-Atlantic Ridge basalts that were drilled at about 30°S and range in age up to 50 m.y. (Frey et al., 1974). However, they are quite similar to basalts drilled during Leg 74 on the Walvis Ridge, in particular the basement at Sites 527 and 528, both located on the northwestern flank of the central section of the Ridge (see Fig. 1). They are not as enriched in incompatible elements as are basalts from other parts of the Walvis Ridge, Tristan da Cunha, or the Rio Grande Rise.

Comparison of the chemical compositions of the basaltic pebbles recovered from the sediments with the average analyses for rocks from the Walvis Ridge suggest similarities. They are both enriched in incompatible elements and fall within the range of compositions previously observed on the Ridge (Humphris and Thompson, 1982).

On an alkalis-silica diagram (Fig. 3), all the Hole 530A basement basalts plot in the field of Hawaiian tholeiites and, more specifically, in the field of basalts from DSDP Leg 74, Sites 527 and 528. The field for basalts dredged from the Walvis Ridge extends across the tholeiitic-alkaline boundary, and two of the pebbles—Samples 530A-3,CC (Pebble C) and 530A-37-3—plot within this field, one on either side of the boundary. Hence, although the Hole 530A basement rocks are no-

Table 2. Major and trace element analyses of basaltic pebbles recovered from sedimentary sequence.

Component	Sample 530A-3,CC Pebble A	Pebble B	Pebble C	Section 530A-37-3
Major elements (wt.%)[a]				
SiO_2	29.74	49.38	52.85	45.40
TiO_2	2.45	2.07	1.91	3.14
Al_2O_3	8.26	14.47	15.97	14.66
FeO*	8.35	7.80	8.96	11.02
MnO	0.18	0.10	0.10	0.11
MgO	6.05	3.66	5.56	5.59
CaO	33.52	7.67	9.44	14.46
Na_2O	1.65	1.79	2.37	3.06
K_2O	1.47	6.35	1.37	1.03
P_2O_5	1.19	1.61	0.22	0.21
Total	92.86	94.90	98.75	98.68
Other analyses				
FeO	3.85	3.16	4.05	2.34
Fe_2O_3	5.00	5.16	5.46	9.65
H_2O^+	3.06	2.75	1.49	2.17
H_2O^-	6.75	5.90	3.39	3.93
CO_2	20.79	3.66	0.17	5.49
Trace elements (ppm)[b]				
Rb	18.5	56.0	39.6	18.1
V	73	144	232	213
Cr	286	309	51	189
Co	30	29	31	58
Ni	133	103	48	201
Cu	33	47	39	42
Zn	60	66	74	307
Sr	226	220	344	492
Ba	1682	4218	424	239
Y	26	60	27	26
Zr	117	143	152	219
Nb	24.2	49.6	13.6	44.2

[a] Volatile-free basis after ignition at 1000°C.
[b] Dried at 110°C.

ticeably enriched in incompatible elements compared with mid-ocean ridge basalts, they do not show such marked alkaline affinities as the dredged Walvis Ridge basalts.

This is further illustrated in Figure 4, a plot of TiO_2 versus Zr concentrations, in which the Leg 75 data are plotted together with fields for other analyzed basalts from the region. The basement basalt and the Core 3 pebble are enriched in these elements compared with MORBs, but do not exhibit the large enrichments displayed by the dredged Walvis Ridge basalts, the Rio Grande Rise basalts, and Tristan da Cunha basalts. DSDP Leg 74 Sites 527 and 528 also fall in this intermediate range of enrichments.

Figure 5 shows a plot of Nb versus Zr concentrations, the ratio of which is a good indicator of the source region of the basalt (Erlank and Kable, 1976). Humphris and Thompson (1982) and Thompson and Humphris (in press) have previously used this ratio to demonstrate systematic changes in the mantle source for the Walvis Ridge with time, illustrated by the large variations in the Zr/Nb ratio. MORBs, with Zr/Nb ratios of greater than 20, represent one end member; the other is Tristan da Cunha basalts with Zr/Nb ratios of about 3.5. The compositions of Walvis Ridge and Rio Grande Rise basalts cannot easily be derived by mixing of these two end members (Humphris and Thompson, 1982). Hence, they concluded that the Walvis Ridge was probably derived from mantle sources of variable composition.

The basement rocks from Site 530 are characterized by a Zr/Nb ratio of 6–7. They plot on the same line as do Sites 527 and 528, both drilled on the central section of the Walvis Ridge, and as dredged basalts from the central section of the Ridge. This suggests that the basement in the Angola Basin adjacent to the eastern end of the Walvis Ridge was derived from a mantle source similar to that which produced the basalts found in the Central Section. Basalts dredged from the eastern end of the Walvis Ridge are characterized by Zr/Nb ratios of 10, which indicates a different mantle source. Basaltic Pebble C from Core 3 has a Zr/Nb ratio of 11 and hence is quite probably derived from slumping along the northern flank of the eastern end of the Walvis Ridge.

These data therefore indicate that the hot spot that created the Walvis Ridge has influenced the basement characteristics at least out to 20 km north of the feature itself. The full lateral extent of the hot spot influence, however, cannot be determined at present, although the similarity of the seismic stratigraphic sequence at Hole 530A to that for the entire deep part of the Angola Basin suggests that it may extend for several hundred km. The present-day hot spot, centered at Tristan da Cunha, about 400 km from the axis of the Mid-Atlantic Ridge, has been shown to influence the geochemical characteristics of basalts erupting at the mid-ocean ridge (Schilling et al., 1981). Basalts recovered from the Mid-Atlantic Ridge at about 37°S are slightly enriched in incompatible elements compared with typical MORB's, and have Zr/Nb ratios of 14–16. Hence, a large area of influence for a hot spot may not be unreasonable.

These data also have important implications concerning the origin of the Walvis Ridge. They provide additional evidence that the Ridge was derived from mantle sources with different Zr/Nb ratios. However, it is now clear that the variation is not a simple along-ridge (i.e., time) progression, but is more complex. The basement at Site 530 (84–102 m.y.), north of the eastern end of the Walvis Ridge, is geochemically similar to the basement drilled during DSDP Leg 74 at Sites 527 and 528 (both about 68 m.y.) on the central section of this Ridge. This suggests that, unlike other hot spots, volcanism produced basalts with similar geochemical characteristics continuously over a period of at least 20 m.y. However, there is also a smaller scale variation evident in that basalts from Site 525, drilled on the crest of the Ridge, are unlike those from Sites 527, 528, and 530. Comparison of the water depths at Sites 525, 527, and 528 (2467, 4428, and 3800 m, respectively) with that at Site 530 (4629 m) suggests that there may be a vertical zonation within the volcanic pile, similar to that seen on volcanic islands, with the erupted basalts becoming more alkaline and more enriched in incompatible elements towards the crest. Rare-earth elements and isotopic data will be needed to test this hypothesis further.

Table 3. Comparative average analyses of basalts from the Rio Grande Rise, Walvis Ridge, Tristan da Cunha, Site 530, and the MidAtlantic Ridge.

	Rio Grande Rise		Walvis Ridge						
Component	Leg 72 Hole 516F[a]	Dredge RC16[b]	E. Walvis Ridge[c]	Leg 74 Site 525[d]	Leg 74 Site 527[e]	Leg 74 Site 528[f]	Tristan da Cunha[g]	Leg 75 Site 530[h]	Mid-Atlantic Ridge, S. Atlantic[i]
Major element oxides (wt.%)									
SiO_2	50.48	47.33	51.14	52.17	50.10	49.99	46.7	49.72	50.74
TiO_2	2.51	3.25	3.03	2.92	1.83	1.93	3.6	1.81	1.03
Al_2O_3	15.12	14.90	16.53	17.92	15.33	16.46	17.3	16.05	15.83
FeO^*	12.76	9.60	11.96	9.11	12.06	11.02	10.4	10.05	9.05
MnO	0.17	0.17		0.08	0.19	0.20		0.29	0.15
MgO	5.23	7.19	2.37	3.49	6.40	6.26	4.7	8.06	8.78
CaO	10.61	10.15	7.08	8.64	10.38	9.98	9.7	10.62	12.20
Na_2O	2.61	3.57	2.91	3.42	2.67	2.82	4.1	2.67	2.32
K_2O	0.28	1.73	2.19	0.94	0.59	1.01	3.0	0.30	0.06
P_2O_5	0.21	0.75		0.30	0.25	0.28		0.26	
Trace elements (ppm)									
Rb	6.5	2.8		15	11	16	173	8	
V	380	271	437	353	360	366	230	330	233
Cr	32	146	73	139	45	35	28	89	500
Co	49	45	62	62	42	43	18	46	49
Ni	52	106	55	53	45	42	10	81	174
Cu	198	55	110	79	142	113		69	102
Zn	112	103		139	80	79		77	
Sr	360	928	318	482	159	302	1167	268	124
Ba	176	1156	384	403	197	350	913	131	13
Y	38	25	46	37	39	35	45	34	35
Zr	180	293	200	251	125	142	325	132	91
Nb	13.7	70	20	23	17	24	112	21	<5

Note: Blank spaces = not analyzed.

[a] Ave. of 13 basalts (Thompson et al., in press).
[b] Mean of 3 basalts (Fodor et al., 1977).
[c] Mean of 7 basalts (Hekinian, 1972; Hekinian and Thompson, 1976).
[d] Ave. of 13 basalts (Thompson and Humphris, in press).
[e] Ave. of 6 basalts (Thompson and Humphris, in press).
[f] Ave. of 10 basalts (Thompson and Humphris, in press).
[g] Ave. of 10 analyses (Baker et al., 1964).
[h] Ave. of 7 basalts (this chapter, Table 1).
[i] Ave. of 7 basalt glass analyses, DSDP Leg 3 (Frey et al., 1974).

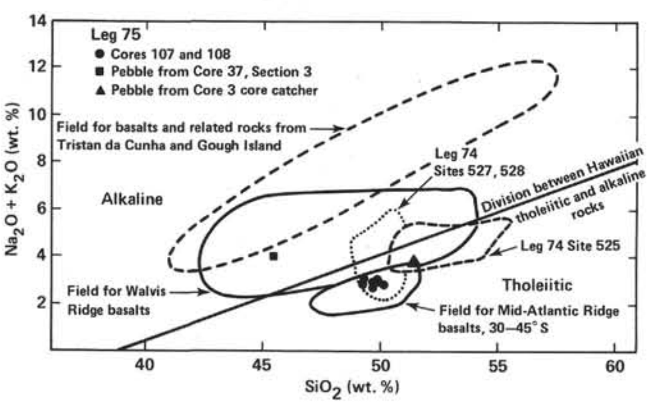

Figure 3. Alkalis-silica diagram showing the fields of alkaline and tholeiitic basalts (after MacDonald and Katsura, 1964). The field for basalts from Tristan da Cunha is from data of Baker et al. (1964) and Humphris and Thompson (1982); the data for the Walvis Ridge dredged basalts are from Hekinian (1972) and Humphris and Thompson (1982); the data for Leg 74 are from Thompson and Humphris (in press); and the data for Mid-Atlantic Ridge basalts are from Frey et al. (1974), Humphris and Thompson (1982), Schilling et al. (1981).

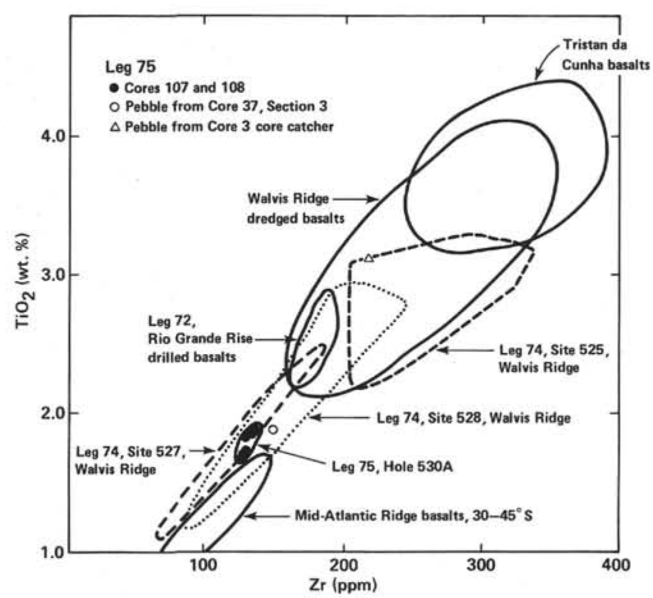

Figure 4. Plot of TiO_2 versus Zr for Hole 530A and other basalts. Data sources as in Figure 3, with data for Rio Grande Rise from Thompson et al., in press.

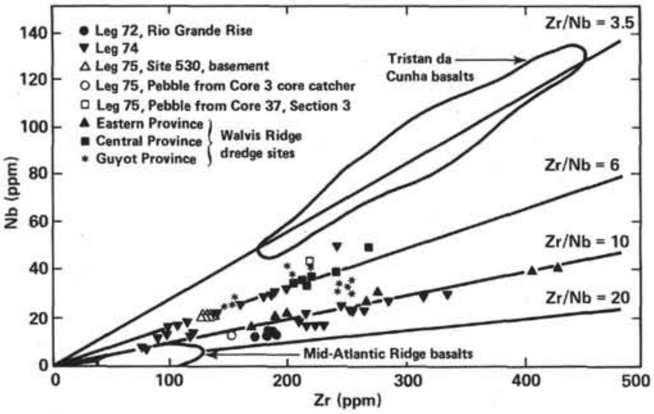

Figure 5. Nb versus Zr concentrations in basalts from Hole 530A, and other areas. Data for Tristan da Cunha and the Walvis Ridge are from Humphris and Thompson (1982); the other sources are as in Figure 3.

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REFERENCES

Baker, P. E., Gass, I. G., Harris, P. G., and le Maitre, R. W., 1964. The volcanological report of the Royal Society expedition to Tristan da Cunha, 1962. *Phil. Trans. Roy. Soc. London A,* 256: 439–575.

Dietz, R. S., and Holden, J. C., 1970. Reconstruction of Pangaea: Spreading and dispersion of continents, Permian to Recent. *J. Geophys. Res.,* 75:4939–4956.

Erlank, A. J., and Kable, E. J. D., 1976. The significance of incompatible elements in Mid-Atlantic Ridge basalts from 45°N with particular reference to Zr/Nb. *Contrib. Mineral. Petrol.,* 54: 281–291.

Fodor, R. V., Husler, J. W., and Kumar, N., 1977. Petrology of volcanic rocks from an aseismic rise: Implications for the origin of the Rio Grande Rise, South Atlantic Ocean. *Earth Planet. Sci. Lett.,* 35:225–233.

Frey, F. A., Bryan, W. B., and Thompson, G., 1974. Atlantic Ocean floor: Geochemistry and petrology of basalts from Legs 2 and 3 of the Deep Sea Drilling Project. *J. Geophys. Res.,* 79:5507–5527.

Hekinian, R., 1972. Volcanics from the Walvis Ridge in the Southeast Atlantic Ocean. *Nature,* 239:91–93.

Hekinian, R., and Thompson, G., 1976. Comparative geochemistry of volcanics from rift valleys, transform faults, and aseismic ridges. *Contr. Mineral. Petrol.,* 57:145–162.

Humphris, S. E., and Thompson, G., 1982. A geochemical study of rocks from the Walvis Ridge, South Atlantic. *Chem. Geol.,* 36: 253–274.

Jen, L. A., 1973. The determination of iron (11) in silicate rocks and minerals. *Anal. Chim. Acta,* 66:315–318.

MacDonald, G. A., and Katsura, I., 1964. Chemical composition of Hawaiian lavas. *J. Petrol.,* 5:82–133.

Morgan, J., 1971. Convection plumes in the lower mantle. *Nature,* 230:42–43.

Schilling, J. G., Kingsley, R., Humphris, S. E., and Thompson, G., 1981. Tristan da Cunha hot spot. *EOS,* 62:424.

Schroeder, B., Thompson, G., Sulanowska, M., and Ludden, J. N., 1980. Analysis of geologic materials using an automated X-ray fluorescence system. *X-ray Spectrometry,* 9:198–205.

Skinner, N. G., Brown, F. W., and Flanagan, F. J., 1981. The H_2O^+ contents of some geochemical standards predicted by a calibration line. *Geostandards Newsletter,* 5:3–12.

Thompson, G., and Humphris, S. E., in press. Petrology and geochemistry of rocks from the Walvis Ridge: DSDP Leg 74, Sites 525, 527 and 528. *In* Moore, T. C., Jr., Rabinowitz, P. D., et al., *Init. Repts. DSDP,* 74: Washington (U.S. Govt. Printing Office).

Thompson, G., Humphris, S. E., and Schilling, J.-G., in press. Petrology and geochemistry of basaltic rocks from Rio Grande Rise, South Atlantic: Deep Sea Drilling Project Leg 72, Hole 516F. *In* Barker, P. F., Carlson, R. L., Johnson, D. A., et al., *Init. Repts. DSDP,* 72: Washington, D.C. (U.S. Govt. Printing Office).

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