

18. COMPOSITIONS, STRATIGRAPHY, AND ALTERATION OF PILLOW BASALTS, DEEP SEA DRILLING PROJECT HOLE 543A, NEAR THE BARBADOS RIDGE¹

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ABSTRACT

Four chemically distinct basalts were cored in 44 m of basement penetration at Deep Sea Drilling Project Site 543, in Upper Cretaceous crust just seaward of the deformation front of the Barbados Ridge and north of the Tiburon Rise. All four types are moderately fractionated abyssal tholeiites. The four types have different magnetic inclinations, all of reversed polarity, suggesting eruption at different times which recorded secular variation of the earth's magnetic field.

Extensive replacement of plagioclase by K-feldspar has occurred at the top of the basalts, giving analyses with K₂O contents up to 5%. The earliest stages of alteration were dominantly oxidative, resulting in fractures lined with celadonite and dioctahedral smectite, and pervasive replacement of olivine and most intersertal glass with iron hydroxides and green clay minerals. Later, non-oxidative alteration resulted in formation of olive-green clays and pyrite veins in a portion of the rocks. Basalts affected by this alteration actually lost K₂O (to abundances *lower* than in adjacent fresh basalt glasses), and gained MgO (to abundances *higher* than in the glasses). Finally, fractures and interpillow voids were lined with calcite, sealing in much fresh glass. Oxygen-isotope measurements on the calcite (Claypool, this volume) indicate that this occurred at 12 to 25°C. Either altering fluids were warm or the basalts had become buried with a considerable thickness of sediments, such that temperatures increased until a conductive thermal gradient was established, when the veining occurred.

INTRODUCTION

During Leg 78A, basalts were cored for 44 m at the bottom of Hole 543A on the seaward side of the deformation front of the Barbados Ridge complex (Fig. 1). The oldest of the 455 m of sediments above the basalts are Campanian (Upper Cretaceous; Bergen, this volume), so the basalts should be representative of lavas presently being subducted beneath the Lesser Antilles arc to the west. The basalts are altered, and it is particularly important to understand this alteration in view of the contribution subducted basalts may make to island-arc magmas.

We have obtained X-ray fluorescence (XRF) major-oxide and trace-element analyses of 21 basalts recovered in Hole 543A (Table 1). In addition to the XRF analyses, we have also obtained electron microprobe analyses of fresh basalt glasses for a portion of the basalts (Table 2). We use these data, the chemical data of Bougault et al. (this volume), and the paleomagnetic data of Wilson (this volume) to define the chemical and magnetic stratigraphy of the basalts. This stratigraphy sets the stage for a consideration of zones of contrasting alteration within the basalts.

PROCEDURES

Samples for the XRF and electron microprobe analyses were taken on board *Glomar Challenger* during Leg 78A. Wherever possible, the

XRF samples have corresponding thin sections. Procedures for the XRF analyses are given by Marsh et al. (1983). Procedures for electron microprobe analyses of glasses are given by Melson et al. (1976). Those authors, and Melson (1979), defined criteria for the identification of glass groups (averages of analyses of glass—from a dredge or taken in stratigraphic order from a drill hole—that are identical to within the precision of the microprobe technique). On this basis, the glass analyses of Hole 543A constitute one glass group (spanning the lower half of Core 12 through Core 16). The average of these analyses and the CIPW norm are given in Table 3. The XRF analyses of basalts from these cores, though influenced by alteration and the variable presence of phenocrysts, are also very uniform. No fresh glass was recovered in Cores 10, 11, or the top half of 12. Nevertheless, the whole-rock analyses define three additional chemical types in these uppermost cores, despite the alteration of the rocks and the lack of glass analyses.

LITHOLOGY AND PETROGRAPHY

Of the 44 m of basalt drilled, 35.9 m were recovered. The proportion recovered, 81%, is high compared with typical recovery obtained by drilling younger crust. Recovery was no doubt enhanced by alteration and the presence of 2- to 3-cm-thick calcite rinds adjacent to glassy pillow margins in and below Core 12. The recovery was sufficiently high that 59 separate cooling units, all pillows between 60 and 150 cm thick, were identified, as indicated on the basalt description sheets at the end of the Site 543 report (this volume). Pillows were cored through their centers, giving curved glassy margins at the tops and bottoms of the cooling units; along their edges, giving curved margins along the edges of several consecutive pieces in the cores; and at places where pillows budded one from another, giving glass margins sharply turned back upon themselves (Fig. 2). Several interpillow and intrafracture sediments were cored, representing largely calcareous material that sifted down into void spaces after the pillows were frozen and fractured.

¹ Biju-Duval, B., Moore, J. C., et al., *Init. Repts. DSDP, 78A*: Washington (U.S. Govt. Printing Office).

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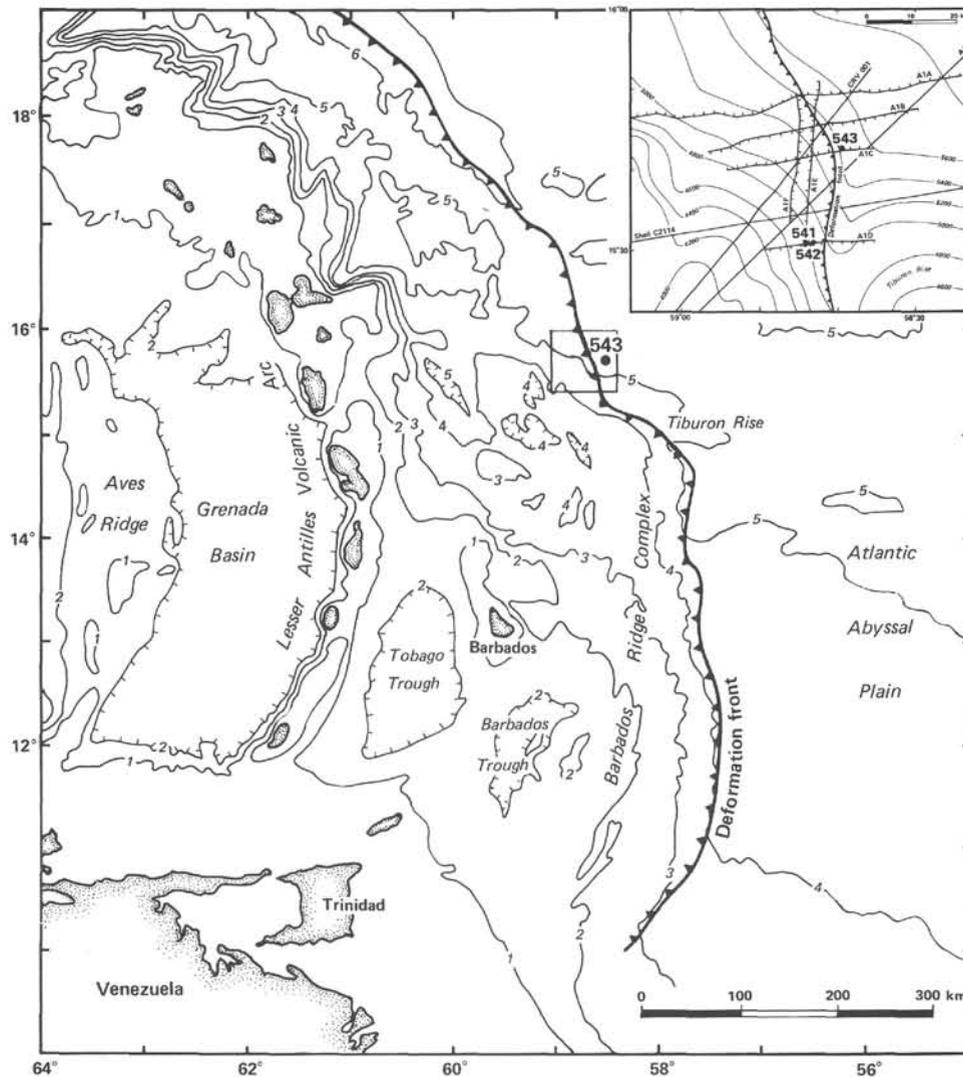


Figure 1. Location of Site 543, east of the deformation front of the Barbados Ridge and north of the Tiburon Rise. Contours in km. Inset shows location of all Leg 78A sites with respect to the eastern edge of the Barbados Ridge at the deformation front.

The lavas are variably phryic to aphyric, with plagioclase, altered olivine, clinopyroxene, and rare Cr-spinel phenocrysts. Mineral compositions are reported by Bougault et al. (this volume). Plagioclase occurs in clumps or glomerocysts of anhedral crystals, many with inclusions of devitrified glass, and as smaller tabular crystals scattered throughout the rock. Glomerocysts of plagioclase plus (altered) olivine and of plagioclase plus clinopyroxene also occur. The groundmass of the basalts varies greatly in texture depending on distance from pillow rims, from spherulitic at the rims to microlitic and hyalopilitic in pillow interiors.

Alteration is extensive in cores 10 through 12, and pervasive transformation of the basalts to clays and iron hydroxides gives the rocks a dark grayish brown color. Oxidation is most intense adjacent to fractures. The plagioclase phenocrysts in these upper cores are partly to completely replaced by K-feldspar (see mineral analyses in Bougault et al., this volume) and pale yellow clay minerals (Fig. 3, A and B). Where narrow calcite veins cross these feldspars, almost perfectly shaped calcite rhombs

now occupy the interiors of the altered plagioclase (Fig. 3, C and D). Through Core 13, calcite lines fractures, but below this calcite is joined by green clays. The basalts are fresh enough below Core 12, Section 3 to contain glass, and most of them are gray rather than brownish gray. Vein minerals identified by shipboard X-ray diffraction are celadonite, mixed-layer clays, and dioctahedral smectite. The association of celadonite and mixed-layer clays forms distinctive dark bluish green encrustations on fracture surfaces in Cores 14 and 15 and in Core 16, Section 5. Trioctahedral smectite was identified in an unusual waxy pale green material cementing altered glass in Core 11, Section 1. Pyrite is present in thin sections from Cores 12 through 15, where it occurs in veins and between silicate mineral grains in the basalts next to veins. It is usually associated with a dull brown or olive-green clay mineral.

CHEMICAL AND MAGNETIC STRATIGRAPHY

The analyses (Table 1) define four distinctive lava compositions, based chiefly on the TiO_2 and Zr contents,

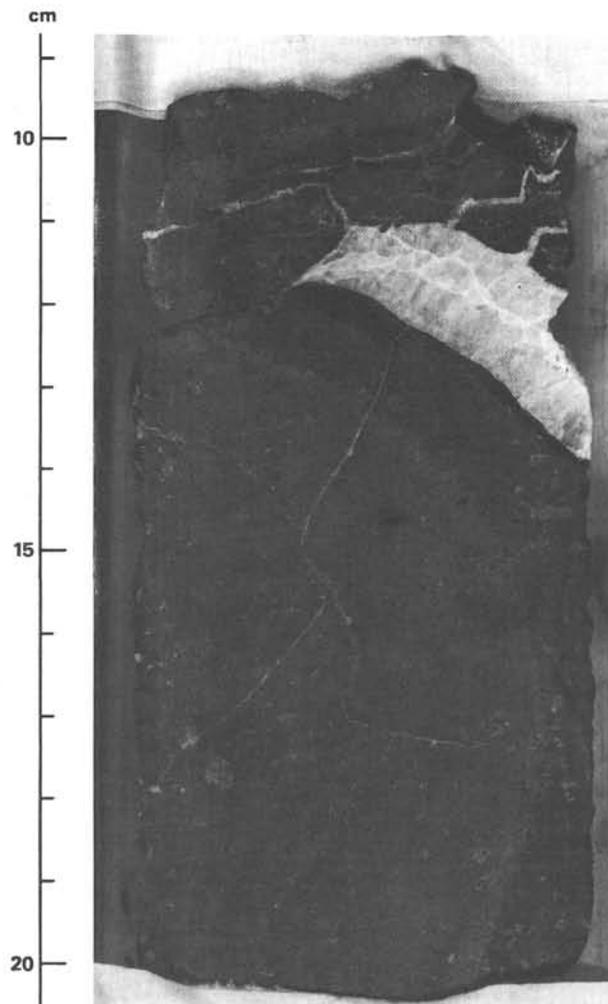


Figure 2. Intersection of two glass pillow margins cemented by calcite. Sample 543A-15-5 (Piece 2, 10-20 cm).

which are sensitive discriminants of both fractionation and partial melting, and which are not greatly affected even by alteration as extensive as that in the uppermost cores. The inferred stratigraphy is shown in Figure 4, in which TiO_2 contents from Table 1 and from Bougault et al. (this volume) are plotted versus depth. The glasses analyzed, as mentioned earlier, all come from the deepest cored of the four chemical types, and show even less variation in their analyses (Tables 2 and 3) than whole-rock analyses of the same unit (Table 1).

Also indicated in Figure 4 are averages of stable magnetic inclination for samples from each of the four chemical types (from Wilson, this volume). Each chemical unit has a different magnetic inclination and each is reversed, suggesting that four eruptions took place in a single reversed-polarity epoch in which secular variations of the earth's magnetic field occurred, giving inclinations which differ by up to 20° (Wilson, this volume).

The uppermost cores in which there appear to be several chemical types are also the most altered, as indicated by the high abundances of K_2O , Rb, and Ba in the

samples from these cores (Table 1). Abundances of Y, Nb, and Zr, however, show no correlative fluctuations, and demonstrate that the original rocks were all depleted abyssal tholeiites. The most fractionated chemical type is that of Chemical Unit 3 (Fig. 4), a thin zone of aphyric basalt for which there are only two analyses, one each in Bougault et al. (this volume) and our Table 1. The analysis reported here has over 2.2% TiO_2 and 422 ppm V. However, the analysis also has high Cr and Ni for its TiO_2 and V contents, suggesting that it may be a hybrid composition representing a mixture between olivine tholeiite, high in Cr and Ni, and ferrobasalt, high in V and TiO_2 (cf. Rhodes and Dungan, 1979).

Extensive alteration makes impossible a full petrogenetic appraisal of the basalts, particularly the upper three chemical types. There are the large fluctuations in K_2O contents (reflecting clays and K-feldspar), high CaO contents in some samples (reflecting calcite and unaltered calcic plagioclase phenocrysts), and variable $\text{Fe}_2\text{O}_3(\text{T})$ and MgO contents (reflecting predominance of either Fe- or Mg-rich clays, or both). Chemical Units 1, 2, and

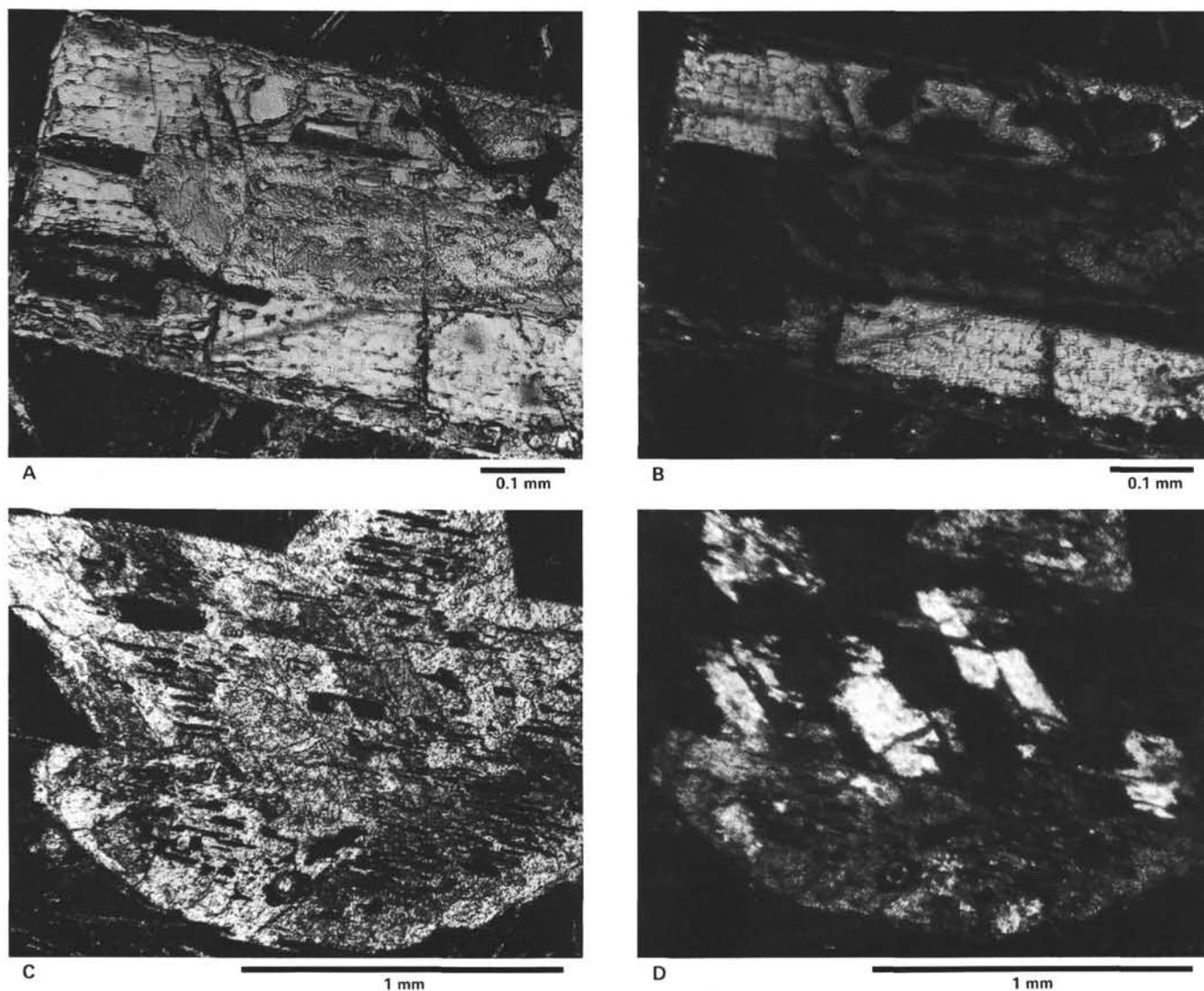


Figure 3. Photomicrographs of calcic plagioclase phenocrysts partially replaced by K-feldspar, pale yellow clays, and calcite. A and B. Sample 543A-11-1 (Piece 5b, 50–52 cm). Plane and cross-polarized light, respectively. Core of plagioclase replaced by K-feldspar (gray in A) and clays (black in B). C and D. Sample 543A-10-2 (Piece 9a, 102–105 cm). Plane and cross-polarized light, respectively. Calcite rhombs in rounded plagioclase, with devitrified glass inclusions, that has been completely replaced by K-feldspar.

4 have similar TiO_2 and Zr contents and variable proportions of the same phenocryst assemblage (plagioclase + [altered] olivine + clinopyroxene + rare Cr-spinel). The similarities of Units 1 and 2 to Unit 4, for which we have an average glass composition (Table 3), indicate that they all were moderately fractionated basalt types before their alteration.

CHEMICAL ASPECTS OF ALTERATION

The uppermost zone of alteration in which K-feldspar is well developed is clearly indicated on the plot of K_2O versus depth in Figure 4. Rb and Ba are enriched proportionally to K_2O (Table 1). Below this zone, there are two zones of moderate K_2O enrichment, separated by an interval with virtually no K_2O enrichment (Fig. 4). In some samples from this latter zone, there is even depletion in K_2O compared with the glasses (e.g., analyses 11, 13, and 15 of Table 1).

The zones just described correspond to occurrences in thin sections (most of them are from analyzed samples) of clay minerals with different colors plus associated nonsilicates (indicated in Fig. 4): respectively, blue green = celadonite(?) \pm iron oxyhydroxides, and olive green = saponite(?) + pyrite \pm chlorite (see microprobe analysis of chlorite, Bougault et al., this volume). That the olive-green clays are probably saponite is suggested by the very low K_2O contents of the basalts from Core 12, Section 4 through Core 15, and, in some of them, higher MgO contents than in the glasses (compare Tables 1 and 3). Thin sections of the analyzed samples from this interval contain up to 20% of the clay, largely replacing intersertal glass. In certain ocean crust basalts, saponites have been found in which the clay has nearly 25% MgO and less than 0.02% K_2O (e.g., Andrews et al., 1983). The low K_2O contents of samples from Cores 12 through 15 thus do not reflect lack of alteration.

Table 1. Major-oxide and trace-element analyses of basalts from Hole 543A.

Analysis no.	Chemical type																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Core-section: Interval (cm)	10-1	10-1	10-2	11-1	11-1	12-2	12-3	12-4	13-1	13-3	13-5	13-5	14-1	15-1	15-3	15-5	15-5	16-1	16-3	16-5	16-7
Piece	56-61	115-120	102-110	30-34	50-54	70-75	40-43	128-133	18-22	79-82	72-75	146-148	37-40	49-55	98-102	22-28	90-94	89-92	108-114	132-138	60-64
	4	8C	9A	5A	5B	1H	1C	10	2B	2B	2C	2L	2B	2C	3A	3A	3C	20	7	5	3A
SiO ₂	49.50	47.70	50.40	49.80	50.00	52.00	50.00	51.00	49.10	50.80	50.40	48.20	49.60	49.90	50.00	48.90	48.30	49.50	50.70	50.30	48.80
TiO ₂	1.57	1.50	1.58	1.94	1.75	2.21	1.60	1.71	1.54	1.72	1.86	1.55	1.59	1.61	1.60	1.62	1.60	1.54	1.60	1.79	1.69
Al ₂ O ₃	16.80	14.10	17.80	16.00	14.80	14.70	14.90	14.40	13.90	14.40	14.60	13.70	14.90	14.10	14.60	14.10	13.60	14.20	14.30	14.00	13.80
Fe ₂ O ₃ (T) ^a	11.29	10.99	11.78	11.95	11.02	9.44	11.04	10.33	11.26	10.46	10.00	12.25	9.92	11.00	10.16	12.57	10.93	10.99	10.34	10.22	11.23
MnO	0.17	0.22	0.20	0.17	0.18	0.18	0.18	0.17	0.18	0.20	0.22	0.17	0.17	0.18	0.16	0.16	0.18	0.18	0.16	0.16	0.18
MgO	1.80	6.10	3.30	7.60	8.40	8.90	8.30	7.70	6.70	8.10	7.70	6.40	7.80	7.50	8.00	5.90	6.80	7.30	6.40	6.70	6.50
CaO	10.37	14.64	6.10	7.89	11.37	9.73	11.19	11.07	13.35	11.50	12.41	13.55	11.14	12.02	11.10	11.93	12.72	11.87	12.05	11.26	11.49
Na ₂ O	2.16	2.39	1.82	2.86	2.61	2.78	2.45	2.64	2.37	2.60	2.57	2.34	2.53	2.54	2.38	2.35	2.49	2.53	2.63	2.63	2.43
K ₂ O	3.73	0.95	5.00	1.56	0.46	0.87	0.81	0.55	0.28	0.27	0.05	0.27	0.05	0.22	0.06	0.56	0.32	0.18	0.61	0.53	0.43
P ₂ O ₅	0.15	0.15	0.21	0.19	0.15	0.17	0.13	0.14	0.12	0.15	0.12	0.14	0.15	0.14	0.15	0.16	0.15	0.13	0.14	0.15	0.15
Total:	97.54	98.73	98.19	99.96	100.75	100.98	100.61	99.72	98.80	100.19	99.70	98.57	97.84	99.21	96.36	98.27	96.95	98.38	98.83	97.74	96.75
Cr	307	380	329	291	296	294	294	302	295	304	303	288	293	286	270	293	286	287	309	294	277
V	351	328	252	395	354	422	325	345	323	349	329	339	301	322	302	371	330	322	337	356	348
Ni	95	98	87	78	109	108	73	89	89	95	108	94	117	87	116	92	89	83	84	100	88
Zn	92	74	120	97	80	89	85	74	72	74	71	78	66	71	66	86	77	69	79	78	77
Rb	29	10	40	16	8	12	9	14	8	6	1	6	1	6	1	9	8	5	15	15	10
Sr	142	159	128	150	137	143	128	133	130	129	133	135	131	133	149	135	136	130	132	134	138
Y	36	29	34	40	36	42	32	36	33	33	33	33	32	33	32	35	33	32	33	35	36
Zr	105	97	103	128	117	149	104	115	103	109	107	101	100	106	106	108	105	102	99	117	116
Nb	3	3	4	3	3	4	3	4	3	3	3	3	2	3	4	3	2	3	3	3	3
Ga	17	18	17	19	19	21	19	19	18	19	18	19	18	18	19	17	17	17	18	18	18
Ba	55	17	180	23	9	14	22	7	8	5	8	13	4	7	8	24	8	4	7	9	12
La	6	3	5	6	6	6	5	4	6	5	4	3	5	5	6	6	4	4	5	4	4
Ce	17	11	12	13	12	15	10	11	13	13	12	10	11	11	11	12	8	10	11	12	10
Nd	11	7	8	9	9	13	9	9	8	9	8	7	8	8	8	10	7	6	8	10	9
Pb	9	1	0	4	0	3	4	7	3	4	2	0	4	4	2	4	2	0	2	4	3
Th	3	2	0	2	0	3	1	2	2	2	2	1	2	2	3	2	1	0	3	3	1
U	0	0	0	0	0	0	0	0	0	1	6	1	0	0	1	0	0	0	0	1	0

^a Fe₂O₃ (T) = all iron as Fe₂O₃.

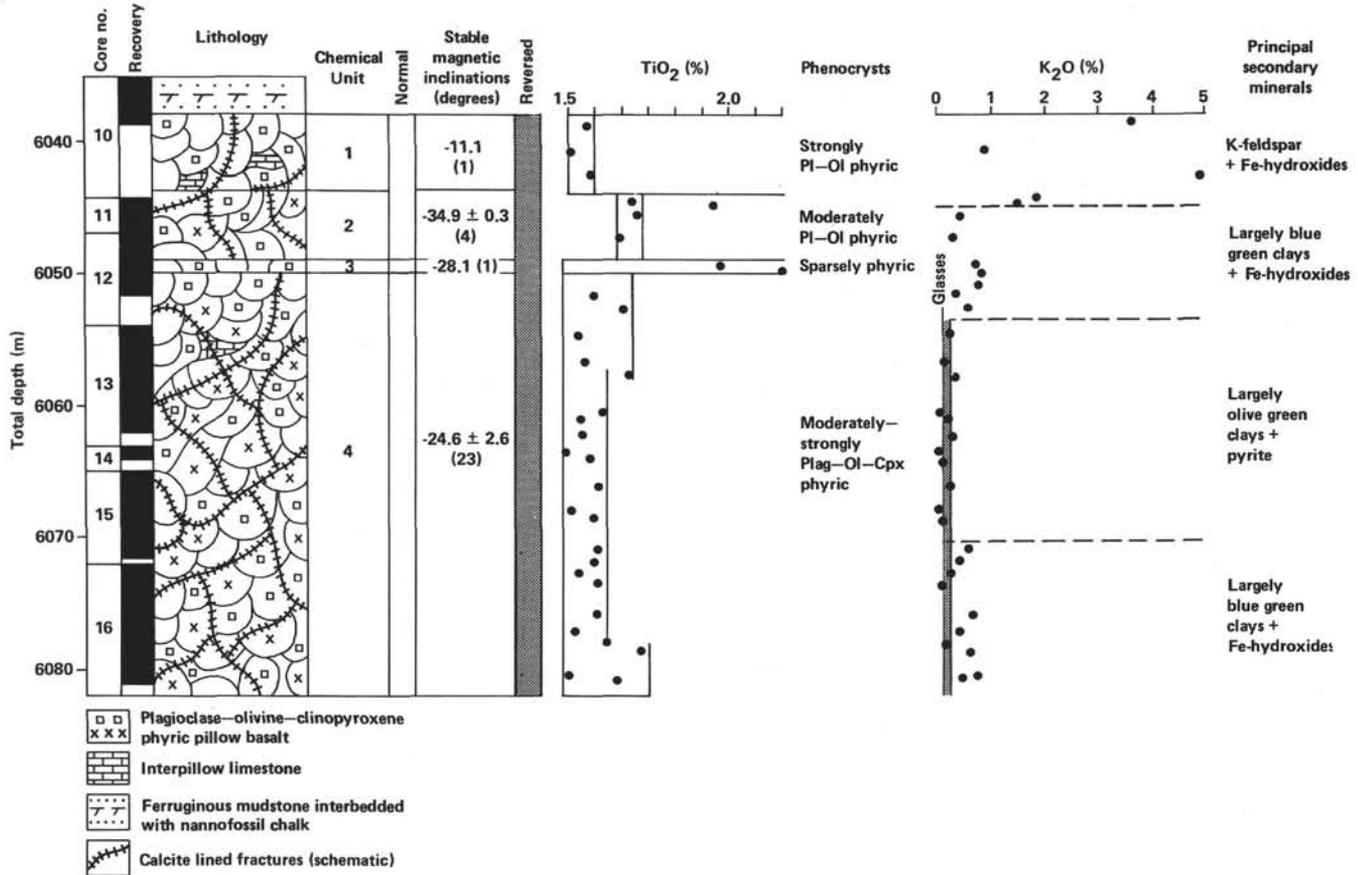


Figure 4. Summary lithology of Hole 543A basalts, giving chemical units, their average magnetic inclinations (number of samples in parentheses), polarities, phenocryst distribution, plots of TiO₂ and K₂O versus depth, and the distribution of principal secondary minerals observed in thin section. Magnetic data are from Wilson (this volume).

Table 2. Electron microprobe analyses of basalt glasses, Hole 543A.^a

Core-section, interval (cm)	SiO ₂	Al ₂ O ₃	FeO* ^b	MgO	CaO	Na ₂ O	K ₂ O	TiO ₂	P ₂ O ₅	Sum	VG number
12-4, 72	51.00	15.04	9.65	7.17	11.47	2.76	0.12	1.66	0.12	98.99	6016
12-4, 83	51.19	14.89	9.56	7.33	11.45	2.67	0.12	1.65	0.14	99.00	6017
13-1, 48	50.96	15.04	9.72	7.34	11.38	2.69	0.13	1.66	0.12	99.04	6018
13-1, 147	51.29	14.94	9.82	7.28	11.33	2.76	0.12	1.63	0.15	99.32	6019
13-2, 105	51.64	14.79	10.00	7.18	11.27	2.75	0.13	1.67	0.14	99.57	6020
13-3, 98	51.97	15.07	9.65	7.30	11.47	2.60	0.11	1.64	0.16	99.97	6021
13-4, 129	51.60	15.10	9.87	7.25	11.27	2.79	0.12	1.63	0.15	99.78	6022
13-5, 97	51.96	15.14	9.87	7.29	11.40	2.75	0.14	1.67	0.16	100.38	6023
13-7, 7	51.74	15.13	9.88	7.34	11.48	2.77	0.13	1.61	0.14	100.22	6024
14-1, 57	50.93	15.13	9.96	7.15	11.35	2.80	0.14	1.69	0.15	99.30	6025
15-1, 7	51.62	15.27	9.87	7.30	11.33	2.71	0.12	1.61	0.15	99.98	6026
15-2, 3	51.09	14.91	9.91	7.09	11.20	2.87	0.15	1.72	0.16	99.10	6027
15-3, 137	51.44	15.11	9.69	7.30	11.48	2.74	0.13	1.62	0.14	99.65	6028
15-5, 22	50.93	15.16	9.99	7.24	11.42	2.79	0.12	1.65	0.15	99.45	6029
16-1, 70	51.85	15.03	9.82	7.35	11.57	2.75	0.12	1.59	0.16	100.24	6030
16-3, 15	51.26	14.96	9.60	7.24	11.44	2.68	0.12	1.62	0.15	99.07	6031
16-4, 116	51.15	15.03	10.06	7.16	11.32	2.85	0.12	1.70	0.16	99.55	6032
16-6, 124	50.80	14.80	10.11	7.01	11.15	2.86	0.16	1.81	0.16	98.86	6033
16-7, 65	51.37	15.07	9.91	7.20	11.33	2.79	0.13	1.68	0.14	99.62	6034
16-7, 110	51.35	14.86	9.83	7.11	11.18	2.76	0.14	1.74	0.16	99.13	6035

^a Note: T. O'Hearn, Smithsonian Institute, analyst.^b FeO* = all iron as FeO.

Table 3. Average of glass analyses (%) of Table 2, standard deviations, and CIPW norm.

	Average analysis	CIPW norm ^a	
SiO ₂	51.36 ± 0.36	Q	0.42
Al ₂ O ₃	15.02 ± 0.13	Or	0.77
FeO* ^b	9.84 ± 0.15	Ab	23.33
MgO	7.23 ± 0.10	An	28.19
CaO	11.37 ± 0.11	Wo	11.62
Na ₂ O	2.76 ± 0.07	Di	6.67
K ₂ O	0.13 ± 0.01	Fs	4.41
TiO ₂	1.66 ± 0.15	Hy	11.26
P ₂ O ₅	0.05 ± 0.01	Fs	7.45
Total:	99.42	Mt	2.03
		Il	3.16
Mg/(Mg + Fe ²⁺)	0.600 ^a	Ap	0.12
		Σ	99.42

^a Norm and Mg/(Mg + Fe²⁺) calculated assuming Fe²⁺/(Fe³⁺ + Fe²⁺) = 0.86^b FeO* = all iron as FeO.

Rather, these samples are pervasively altered, with no fresh olivine and no fresh intersertal glass. The principal clay mineral in the rocks therefore must have extremely low K₂O contents. The association of these clays with pyrite implies that this level of basement experienced non-oxidative conditions that were, at least locally, reducing.

At the top of the basalts, however, and in Core 16, the presence of iron oxyhydroxides, celadonite, and dioctahedral smectite indicates oxidative conditions of alteration. This association includes K-feldspar in the uppermost cores. This alteration is very similar to that which occurred in basalts cored in DSDP Hole 417A, north-west of Site 543 in North Atlantic Lower Cretaceous (110-Ma-old) crust (e.g., Donnelly et al., 1980), and hence may be fairly characteristic of old ocean crust.

From the middle of Core 12 into Core 15, the pervasive alteration of the basalts to clays both high in MgO and low in K₂O is similar, however, to that which affected much of Hole 504B, Costa Rica Rift, between about 200 and 500 m below the top of basement. There, al-

though the rocks are also pervasively altered in the ground-mass, K₂O abundances are not enriched. The principal clay mineral is Mg-rich (saponite), and it is associated with pyrite (e.g., Honnorez et al., 1983). This alteration in Hole 504B is inferred to have occurred in non-oxidation conditions and possibly at low water/rock ratios, following an initial oxidative stage of alteration (Barrett and Friedrichsen, 1983). The low water/rock ratios and lack of availability of oxygen imply that the alteration probably occurred after basement was sealed with a thick accumulation of sediment (e.g., CRRUST, 1982).

The altered basalts at Site 543 thus appear to combine attributes of two strikingly different types of alteration, one oxidative and probably involving large fluxes of seawater through the rocks, causing the dramatic enrichment in K₂O, Rb, and Ba in a narrow zone at the top of the basalts (e.g., Donnelly et al., 1980), the other non-oxidative and at perhaps low water/rock ratios. The former type probably occurred before the rocks were buried by sediment, the latter (by analogy with Hole 504B) after burial. The final alteration of basalts at Site 543 was the extensive veining with calcite, which clearly followed veining with pyrite, since calcite occupies the center of pyritic veins. Oxygen-isotope analyses of the calcite give temperatures of 12 to 25°C (Claypool, this volume), indicating slightly elevated temperatures for fluids which produced the calcite. Given the late stage of formation of calcite in the rocks, these temperatures suggest either elevated pore-fluid temperatures, or that sediment burial by that time had effectively sealed the crust and the temperature had increased conductively to levels appropriate for the thickness of sediment and age of the crust.

Superposition of non-oxidative alteration on rocks already oxidatively altered clearly removed K₂O, Ba, Rb, and other elements from them. This probably affected mainly clay minerals, assuming that most intersertal glass was altered. Clearly, the impact of this was minimal in Cores 10 through 12, which are extremely K₂O-enriched. The lack of pyrite in basalts at the top and bottom of the cored basement is hard to understand, however, if the non-oxidative, pyrite-forming alteration was perva-

sive, affecting all basalts equally. The impression given by the restricted occurrence of pyrite is that this alteration, like that which produced the K-feldspars at the top of basement, was concentrated in a narrow zone of basement in Cores 12 through 15. This interval, then, appears to have been subjected selectively to flux of oxygen-depleted fluids, which produced their particular alteration by reaction with previously altered rocks. The fluid compositions, then, may have been more significant than water/rock ratios in causing this alteration.

A COMMENT ON THE COMPOSITION OF SUBDUCTED CRUST

If the basalts of Hole 543A are representative of altered ocean crust in general (as suggested by the similarly altered crust at Sites 417 and 418 northwest of Site 543), then that crust is on the average enriched in K_2O , Ba, and Rb. Most of these elements are located in exchangeable sites in hydrous layer-lattice silicates plus alkali feldspar. If, during the course of subduction, compressional dewatering of such rocks occurs under oxygen-depleted conditions (analogous to the conditions of non-oxidative alteration described here), or under conditions where the principal stable layer-lattice silicate is chlorite, then these elements will be easily removed from the rocks, since no room will exist for them in lattice structures of minerals then forming in the rocks. Under appropriate conditions, the mobilized elements could find their way into the sources of arc magmas, and perhaps account for enrichments of K_2O , Rb, and Ba relative to TiO_2 , Zr, and rare-earth elements in island-arc lavas. This possibility clearly has to be weighed against potential contributions to arc magmas by subducted sediments, but altered ocean crust by itself would seem to be quite capable of supplying large-ion lithophile elements to the mantle beneath island arcs. Indeed, altered ocean crust might be the only source of enrichment in such elements in arc magmas lacking certifiable sedimentary isotopic signatures (e.g., lavas from the Mariana arc; Meijer, 1976).

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