20. RHYOLITIC AND BASALTIC ASHES FROM THE GALAPAGOS MOUNDS AREA, LEG 70, DEEP SEA DRILLING PROJECT¹

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ABSTRACT

Ashes occurring both as distinct layers and mixed with pelagic sediments of the hydrothermal mounds lying south of the Galapagos Rift are mainly rhyolitic and basaltic. The ashes, of rhyolitic to intermediate composition, appear to belong to a calc-alkalic series and were probably derived from Plinian eruptions in Ecuador or Colombia. Basaltic ashes are made of nonvesicular sideromelane spalling shards and are of tholeitic composition. They probably were derived locally from fault scarps. Most rhyolitic and basaltic glass shards studied are fresh except for hydration of the rhyolitic shards. Some shards are severely altered, however. Basaltic ash may be more common in pelagic sediments deposited near accretion zones and may be a source of silica and other elements released during diagenesis.

INTRODUCTION

During Leg 70 of the Deep Sea Drilling Project (DSDP) (November-December 1979), 32 holes were drilled at five sites at about 1°N, 86°W near the Galapagos Spreading Center (Honnorez et al., 1981) (Figs. 1, 2). Sites 506 to 509 were on or just off hydrothermal mounds, which are low hills 20 to 30 meters high and up to 50 meters in diameter. The mounds generally have Mn-oxide crusts and are rich in green nontronitic clays believed to have formed by the interaction of rising hydrothermal solutions with seawater and pelagic sediments.

The main purpose of Leg 70 was to study the lithology and physical and chemical properties of the hydrothermal mounds and the underlying basement. Hole 510 was drilled on older crust to study basement composition. Volcanic glass was found in a few discrete ash layers (Sites 509 and 510) and dispersed in the pelagic sediment in Holes 506D and 507D. The present chapter describes the shape, color, refractive index (RI), and chemical composition of ten ash samples and briefly discusses their origin and alteration.

METHODS

Methods to concentrate and clean the volcanic glass and to precisely measure refractive indices are described in Schmincke, 1981. Methods for bulk-rock chemical analyses (XRF, titration, etc.) are described in Flower et al. (in press). The microprobe analyses were carried out with an automated CAMEBAX system, using a 10 to 20-mm-wide defocussed beam. The agreement between microprobe spot analyses of sideromelane shards and XRF analysis of the purified bulk-glass sample is excellent, including easily volatilized elements such as Na.

DATA

Eighteen samples, dominantly silty carbonaceous ooze selected from unusual ash abundance in smear slides, were studied initially by examining the insoluble residue of the 63–125 μ m fraction under the binocular. Two

main types of glass shards were found: basaltic and rhyolitic (Figs. 2, 3; Tables 1-4). These can be easily distinguished from each other by color, size, vesicularity, shape, RI, and chemical composition. Samples that contain rhyolitic shards only are from Holes 510 and the top part of Holes 506D and 507D, whereas all shards in the sample from 507H are basaltic. Samples from Holes 509, 506D, 507F, and the lower two thirds of 507D contain both basaltic and rhyolitic shards and some that are of intermediate composition. Of the 18 samples received, three (506D-4-2, 30-32 cm; 507D-3-2, 58-60 cm; and 509-4-2, 66-68 cm) may be regarded as distinct ash layers because of the abundance of shards, whereas the remainder contain variable amounts of shards dispersed in nonvolcanic silt. Nine samples were selected for more detailed analysis (Table 1); the remaining nine all contain less than 50% of glass shards in the insoluble residue of the 63-125 µm fraction. Three of these are also shown in Figures 2 and 3.

RHYOLITIC AND INTERMEDIATE SHARDS

Rhyolitic shards make up more than 90% of the 63-125 μ m fraction in Samples 506D-4-2, 30-32 cm; 507D-3-2, 58-60 cm; 509-4-2, 66-68 cm; 510-7-5, 50-52 cm and, 55-58 cm; and 510-7-6, 34-36 cm and are less common in five other samples (Fig. 2, Table 1). They are colorless and have mostly platy bubble walls and, less commonly, bubble junctions. Tubular pumice shards are generally present in minor amounts. Refractive indices vary from 1.499 to 1.503. Shards of higher RI (intermediate composition) dominate in Sample 507D-10-3, 20-23 cm, are common in Sample 507D-5-3, 78-80 cm, and occur in accessory amounts in Samples 507F-7-3, 74-76 cm and 510-7-6, 34-36 cm. The shards are probably of rhyodacitic to dacitic composition.

Microprobe analyses of shards from four ash samples also indicate rhyolitic composition (Table 2); the silica values are too high as a result of the correction procedures used. Shards from Holes 506D and 509 are very similar in composition but differ from shards from Hole 507D, which is distinctly more fractionated. At least two subpopulations occur in Hole 506D. Ash layers from

¹ Cann, J. R., Langseth, M. G., Honnorez, J., Von Herzen, R. P., White, S. M., et al., *Init. Repts. DSDP*, 69: Washington (U.S. Govt. Printing Office).



Figure 1. Map of equatorial central Pacific showing the drilling area of Fig. 2 (rectangle). (E.R. = Ecuador Rift. C.R.R. = Costa Rica Rift. Dash-dot lines from Ninkovich and Shackleton [1975]. Dashed line shows area of cores with ash layers (*JOIDES Journal*, 6(1), 1980, p. 17). Location of deep crustal hole, 504B, also shown.)

Hole 510 differ from those of Holes 506 to 509 not only in their composition (high Fe, low Ca, Mg) but also in the absence of basaltic shards. The ash layers of Hole 510 are also much older (Shipboard Scientific Party, in press a), and the site lies about 125 km NNE of the Site 506 to 509 area (Fig. 2).

Discussion

Honnorez et al. (1981) discount the suggestion of Lonsdale (1977) that prominent reflectors within the area are ash layers because, as they note, "we found only one ash layer in one of our cores" (p. 470). This presumably is the layer at Site 509. The data presented here indicate that ash is more common within the 20- to 30-meter-thick sedimentary section in the mounds area. Among the ash samples analyzed chemically, those from Holes 509 and 506D may possibly be correlative, judging from their similar composition (RI and microprobe), depth in the core, and proximity of the sites. The prominent ash layer at the top of Hole 507D is chemically distinct and younger. If one includes ash deposits studied optically only, there may be at least three distinct ash layers in the mounds area, dominated by rhyolitic to chemically intermediate shards (507D, 509, two in 506D), as well as about four others farther down in the sections containing only some silicic shards (Hole 507F samples in Table 1 and Sample 507F-5-2, 31-39 cm; Samples 506D-7-1, 133-136 cm and 506D-7-2, 70-72 cm; Sample 507D-5-3, 78-80 cm; and Sample 507D-10-3, 20-23 cm).

All sites lie in an area west of a belt of Quaternary volcanoes located in Ecuador and Colombia. High-altitude winds blow westward in this area (Fig. 1), suggesting that the ashes are derived from volcanoes situated in the northwestern part of South America. The eruptions responsible for the younger ashes must have occurred in the late Quaternary; based on paleontological evidence, the shards analyzed in Holes 506D and 507D probably are younger than 0.2 m.y. (Shipboard Scientific Party, in press b and c). The source of the Pliocene ashes (2.6-3 m.y.) at Site 510 is more speculative, but it may have been located in the same general region.

The ash layers occur outside the published limits of the most widespread ash layer "L" in the eastern equatorial Pacific (Fig. 1) collected by piston cores (Bowles et al., 1973; Ninkovich and Shackleton, 1975). The age of ash layer "L" is assumed to be about 230,000 yr. (Bowles et al., 1973; Ninkovich and Shackleton, 1975). Only minor and trace element concentrations were determined by Bowles et al., but the TiO₂ concentration of approximately 0.25% is similar to that of glass shards in Holes 509 and 506D. On the other hand, the bulk composition of shards from ash layer "L," published by Ninkovich and Shackleton (1975), is distinctly more mafic than the microprobe analyses of this study, while the refractive indices (1.498-1.502) are lower than those reported here. Very large Plinian eruptions such as that producing the tephra of layer "L" are likely to have tapped several layers of a zoned magma column, as is generally the case for silicic magma chambers, with the more silicic tephra generally being transported farther than the later more mafic ash. Additional data on the compositions of shards and more precise age determinations of the ash layers occurring in the mounds area are needed before possible correlations with layers such as "L" can be discussed more profitably.

The Galapagos Islands are not a likely source for the layers studied here, because differentiated rocks are very rare and of quartz-trachytic composition (McBirney and Williams, 1969). Moreover, the ash layers should have been deposited westwards of their eruptive source, owing to the prevailing easterly high-altitude wind direc-



Figure 2. Stratigraphic sections showing position and composition of main ash layers studied and area of drilling.

tions (Ninkovich and Shackleton, 1975). Also, the rhyolites may belong to a calk-alkalic series, further suggesting sources in South or Central America.

Highly radiogenic Pb-isotope compositions were measured in two nontronite samples in Holes 507F and 509B at depths of 4.0 and 3.5 meters (Barrett and Friedrichsen, in press) and were tentatively interpreted as reflecting the replacement of ocean-island derived ash. Data presented here do not exclude such an origin, although derivation of widespread silicic ashes in this area from sources other than in South or Central America seems unlikely. Alteration in the samples studied is not severe enough to generate a clay-rich layer. The surprising freshness of many shards indicates that the pH, chemical composition, and/or time of percolation of the hydrothermal solutions through the ash layers which caused formation of the nontronite clays were generally insufficient to alter the glass pervasively. Derivation of basaltic glass shards from local sources is more plausible, as will be discussed below.

The silicic shards analyzed are reasonably fresh, judging from their isotropic appearance, high totals, and element concentrations. The low totals found, around 95%, are typical of submarine glass shards of rhyolitic composition (Scheidegger et al., 1978). They are interpreted as largely resulting from hydration, accompanied by only minor modification of mobile elements such as K, Na, Ca, and Mg. Shards in some layers show strong partial dissolution and alteration to an amorphous substance.

BASALTIC ASH

Basaltic shards make up from 50% to 99% in three samples (Samples 507F-7-3, 74-76 cm; 507F-8-1, 56-58 cm; and 507H-2-2, 27-29 cm). The sample from Hole 507H contains only basaltic shards, while sparse rhyolitic to intermediate shards occur in the Hole 507F samples. Basaltic shards are moderately common or accessory in four other samples from the area but were not found at Site 510. The shards are brown, nonvesicular, and show dominantly curved, blocky to cuneiform shapes. Refractive indices are uniformly around 1.604. Microprobe analyses of shards from two samples (Table 3) show high totals. Moreover, shards in the sample from Hole 507H were sufficiently abundant to make a very clean concentrate which enabled determination of major and trace elements by XRF, as well as H₂O, CO₂, and Fe²⁺ determinations. The agreement between the microprobe and whole-rock analysis is remarkably good, with the exception of significantly higher MnO₂ in the bulk-glass analysis (Table 3). The composition of the glasses corresponds to low K-MORB. The SiO₂ values are slightly too high, as a result of microprobe correction procedures.

Discussion

The sideromelane shards are tholeiitic in composition and roughly correspond to FETI basalts typical of East Pacific Rise and Galapagos Rift basalts (Natland and Melson, 1980). Shard composition from Cores 7 and 8 (Hole 507F) are practically identical; those from Site 509 are distinctly more mafic (higher Mg, Ca) and lower in Fe and Ti. The Site 507 compositions reported here are very similar to those obtained on glassy rinds of basalts underlying sediments at Sites 506 to 509 (Natland and Melson, unpubl. data).

The presence of scattered shards of sideromelane and even of distinct sideromelane ash layers—in pelagic sediments overlying basement poses several problems (see also Scheidegger, 1973; Schmincke, in press).

1) Process of formation. Shards have most likely formed by spalling off glassy pillow rinds or flow tops, as judged by their curved form and the absence of vesicles in the glass. Submarine lava fountaining is another process that may result in especially voluminous sideromelane shard formation because the high ratio of surface area to volume and the small diameter of the resulting minipillows and irregular lava blebs generates both



Figure 3. Abundance, color, and refractive indices of shards from ash layers drilled during Leg 70.

Table 1. Abundance an	d physical	properties of	glass shards in	ashes from	Leg 70.
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Sample (interval in cm)	Sample Weight (g)	Insoluble Residue (g)	Organic and Carbonate Materials (wt. %)	Percent Glass in 63-125 μm	Refractive Index	Shape and Color of Shards
Hole 506D						
4-2, 30-32	8.5	6.43	24.4	99	1.5033 ± 0.0004	bj bw tp, — , 100%
5-3, 48-50	5.7	0.68	88.0	40	$\begin{array}{c} 1.5028 \pm 0.0004 \\ 1.6036 \pm 0.001 \end{array}$	bw tp bj, — , 60% spl cs, brown 40%
Hole 507D						
3-2, 58-60	6.0	4.78	21.0	99	1.4985 ± 0.0005	bw bj (spl tp), — , 100%
Hole 507F						
7-3, 74-76	9.9	4.58	53.7	99	1.6040 ± 0.001 1.5110 ± 0.0003	spl cs, brown, 90% bf bw,, 10%
8-1, 56-58	12.1	3.73	69.9	50	$\begin{array}{c} 1.6038 \pm 0.001 \\ 1.5021 \pm 0.0003 \end{array}$	spl cs, brown, 95% bj bw, — , 5%
Hole 509						
4-2, 66-68	17.5	13.44	23.2	95	$\begin{array}{c} 1.5031 \pm 0.0006 \\ 1.6035 \pm 0.001 \end{array}$	bw bj tp rb, — , 98% cs spl, brown, 2%
Hole 510						
7-5, 50-52	7.6	2.93	60.9	95	1.5110 ± 0.0006	bw tp bj, , 100%
7-5, 55-58	9.3	4.56	51.0	99	1.5102 ± 0.0006	bw bj tp, — , 100%
7-6, 34-36	12.6	7.40	41.3	99	$\begin{array}{c} 1.5100 \pm 0.0004 \\ 1.5146 \pm 0.0005 \end{array}$	bw bj (tp), — , 99% bw rb, — , 1%

Notes: spl = spalling, cs = cunciform, bj = bubble junction, bw = bubble wall, tp = tubular pumice, rb = round bubbles, — = colorless, br = brown.

				(i	Sampl nterval in	e n cm)				
	506D-4-2 (30-32) ^a		506D-4-2 (30-32) ^b		509-4-2 (66-68)		510-7-5 (50-52)		507D-3-2 (58-60)	
SiO ₂	72.19	75.86	71.98	77.02	72.06	75.69	70.17	74.47	75.05	78.58
TiO ₂	0.24	0.25	0.14	0.15	0.23	0.24	0.21	0.22	0.05	0.05
Al ₂ O ₃	13.03	13.69	12.67	13.56	13.25	13.92	11.96	12.69	11.98	12.54
FeO*	0.97	1.02	0.80	0.86	0.78	0.82	2.96	3.14	0.53	0.55
MnO	0.03	0.03	0.09	0.10	0.07	0.07	0.11	0.12	0.01	0.01
MgO	0.22	0.23	0.26	0.28	0.19	0.20	0.04	0.04	0.09	0.09
CaO	0.98	1.03	0.91	0.97	0.99	1.04	0.60	0.64	0.56	0.59
Na ₂ O	3.24	3.40	3.05	3.26	3.72	3.91	3.93	4.17	3.47	3.63
K ₂ O	4.21	4.42	3.51	3.76	3.91	4.11	4.24	4.50	3.77	3.95
P205	0.04	0.04	0.05	0.05	0.00	0.00	0.01	0.01	0.00	0.00
Total	95.16	100.00	93.46	100.00	95.20	100.00	94.22	100.00	95.51	100.00
D.I.	78.27		77.94		76.11		76.13		80.32	

Table 2. Microprobe chemical analyses of rhyolitic glass shards from ashes showing original and recalculated analyses.

Note: FeO* = total Fe as FeO. ^a Single shard. ^b Average of three shards of similar composition.

Table 3. Composition of sideromelane shards from ash layers as determined by microprobe and XRF.

	Sample (interval in cm)						
Component	507F-7-3 (74-76) ^a	507F-7-3 (74-76) ^b	507F-8-1 (56-58)	509-4-2 (66-68)			
Major oxides	(%)						
SiO ₂	51.60	51.10	51.64	52.46			
TiO ₂	1.91	1.85	1.78	1.36			
Al2Õ3	13.32	13.56	13.50	13.98			
FeO*	12.35	12.69	11.83	10.63			
MnO	0.07	0.21	0.12	0.13			
MgO	6.90	6.96	6.99	7.56			
CaO	10.54	10.92	10.73	11.36			
Na ₂ O	2.45	2.32	2.36	2.23			
K2Õ	0.08	0.07	0.07	0.03			
P205	0.15	0.16	0.11	0.08			
H20+		0.25	—	-			
$C\tilde{O}_2$		0.06	_	-			
Total	99.37	100.15	99.13	99.82			
Mg-value	53.4	52.9	54.8	59.3			
S		0.05	_				
Cl		0.01	-	_			
O/S,Cl		0.03	—	-			
Trace elemen	ts (ppm)						
Cr		150	_				
Co		78	_				
Ni		78	_	-			
Cu	 2	147		_			
Zn		105	—	-			
Rb		<11	_				
Sr		86					
Y		46	_	_			
Zr	-	115	—	-			
Nb		<11					
Ba		63		—			

Note: FeO^{*} = total Fe as FeO. FeO includes $Fe_2O_3 = 0.36\%$. ^a Microprobe analysis. ^b XRF analysis.

Table 4. Characteristic features of deep sea ashes.

Refractive Index	Color	Dominant Shape	Vesicularity	Composition	Structure	Alteration	Distance from Source
1.49-~1.53	Colorless	Bubble junction, bubble wall (platy), pum- ice shards	High	Rhyolitic to rhyodacitic	Discrete ash layers with sharp base and gradational top; dispersed in turbidites	Hydration dissolution; zeolitization	Tens to hundreds of km
~ 153-~ 1.56	Light brown to green	Bubble junction, bubble wall (platy), pum- ice shards	High to mod- erate	Dacite to andesite; tephrite	Discrete ash layers with sharp base and gradational top; dispersed in turbidites		Tens to hundreds of km
~ 1.56- ~ 1.61	Brown	Blocky to cunei- form (non- vesicular) to irregular (vesicular shards)	Low to absent in deep sea environment; vesicular near sea mounts or islands	Basaltic an- desite to basalt	Typically dis- persed; discrete layers near mid-ocean ridges, sea mounts, or islands	Partial to complete palagonitiza- tion; local dis- solution smec- titization; zeo- litization	Generally meters to kilometers except near islands

abundant glass and a clastic deposit from which small shards may become separated (Schmincke et al., 1978).

2) Site of formation. The fact that ash layers composed largely or entirely of sideromelane occur interbedded with pelagic sediment some 20 meters or more above basement suggests off-axis volcanism that occurred long after formation of crust at the ridge axis or derivation from axis basalt sequences exposed to submarine erosion along fault scarps and/or upward transport by bioturbation.

The absence of any constructional feature in the area that might indicate young volcanism (Lonsdale, 1977) is a major argument against off-axis volcanism, however. The area of hydrothermal mounds has been surveyed in detail by Lonsdale (1977) using deep-towed instruments. The main fault scarp in the general area is located 17 km south of the Galapagos Rift, about 7 km north of Site 507, but it is north-facing. It is sediment covered just north of Site 507 but has bare basalt exposures about 5 km south, about 10 km from Site 507. The smaller faults at 24 and 26 km south of the Rift are dominantly sediment covered. It is one of the characteristic features of the area that, as a result of the high productivity of surface waters above the Panama Basin, the sedimentation rate of pelagic ooze is about 50 m/m.y. (Lonsdale, 1977). The occurrence of pure sideromelane shards at Site 507H, 5.4 meters below the surface suggests deposition of the ash probably less than 0.1 m.y. ago. It is likely that a larger part of the north fault was exposed at that time, but the distance of some 7 km is still quite far. Major bare fault scarps may occur in the unsurveyed area east of Site 507, but this is speculative.

Microprobe analyses of six different sideromelane shards from Hole 507F gave identical results which, moreover, agree with the analysis of the bulk sample (Table 3). Such chemical homogeneity is surprising, since lavas studied from the nearby Galapagos Rift and at Leg 54 and Leg 70 sites show a wide range in basaltic composition (Natland and Melson, 1980; Natland, 1980), but chemical homogeneity in sideromelane shard populations has been noted in previous studies of similar deposits interbedded with pillow lavas or with sediments. It indicates that the shards were derived from a locally restricted source. Transport of shards by bottom currents from the accretion zone or distant basement scarps is unlikely, because this would almost certainly result in chemically heterogeneous populations. Moreover, deep-tow observations do not indicate the existence of bottom currents capable of such transport (e.g., Lonsdale, 1977).

3) Glass shards as sources of elements released during diagenesis of hydrothermal activity. The fact that basaltic glass shards evidently derived from nearby sources occur intermixed with shards of rhyolitic composition derived from land volcanoes more than 500 km away from the drill sites suggests that sideromelane shards may be more common in this environment than generally thought and may have been detected only by chance as a result of closer study of samples rich in shards of dominantly felsic composition. Since the depositional processes of the two types of shards should be independent of each other, sideromelane shards should be just as common in entirely nonvolcanic sediments as in those rich in rhyolitic shards. Dissolution features are generally not severe in the glass shards in the size range studied. However, smaller shards are likely to be more strongly altered because of their larger surface area. Elements released during alteration may significantly influence the composition of pore solutions and mineral phases precipitated from these.

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