15. OCCURRENCES OF AIR-FALL VOLCANIC ASH DERIVED FROM THE LESSER ANTILLES ARC AT LEG 78A DRILL SITES[1]

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ABSTRACT

Air-fall volcanic ash recovered at Deep Sea Drilling Project Sites 541, 542, and 543 on and east of the toe of the Barbados Ridge delineate middle and late Miocene, early Pliocene, and Pleistocene–Quaternary pulses of explosive volcanism in the Lesser Antilles arc. The ash beds at Site 541 allow precise correlation of intervals repeated by a probable reverse fault at this convergent margin.

INTRODUCTION

This chapter briefly summarizes the occurrence of air-fall volcanic ash at three sites (541, 542, and 543) drilled during Leg 78A near the deformation front of the Barbados Ridge complex east of the Lesser Antilles arc (Fig. 1). The ashes are important for establishing the timing of explosive volcanism in the arc, heretofore inferred from geological relationships on the islands (dated only in a general way by sparse biostratigraphic data and radiometric ages) and from surface piston cores east of the arc that document Quaternary explosive eruptions (Sigurdsson et al., 1980). In addition, Site 541 demonstrates the usefulness of ash beds in determining precise vertical offsets along high-angle reverse faults at convergent margins such as this where accretion of sediments is occurring.

OCCURRENCE AND LITHOLOGY OF ASHES

Nearly 250 volcanic ash layers up to 7 cm thick were recovered in cores from three sites drilled during DSDP Leg 78A. Most of these ash layers were recovered at Site 541, near the toe of the Barbados Ridge complex (Fig. 1), where a section was cored continuously from the seafloor through Miocene sediments into a complex zone of deformation coinciding with an active décollement at this convergent margin (Site 541 report, this volume). Fewer ash beds were recovered at Site 542, which is only a few kilometers seaward of Site 541. Recovery of sediments of all types was limited here by discontinuous coring above the décollement. At Site 543, the reference site east of the deformation front of the Barbados Ridge (Fig. 1), a condensed Neogene section containing many ash beds overlies Paleogene and Upper Cretaceous pelagic clays, radiolarian muds, and igneous basement. Scattered ash beds occur below the Miocene into the lower Eocene, but these are much more altered to clays than the younger ashes.

Separate ash occurrences, their age, color, and thickness, are listed in Table 1. The thicker ashes commonly have flat bases and bioturbated tops (Fig. 2). Some ashes are gray, others nearly black. Many have high concentrations of plagioclase, lesser quartz, and minor pyroxenes and opaque minerals owing to density-sorting processes in the atmosphere (e.g., Sigurdsson et al., 1980). None shows evidence of being turbidites or even has significant grading of the type that can also be produced by atmospheric processes.

Coring deformation is severe in the topmost cores, especially in the upper 150 m cored at Site 543. Although the continuously cored section at Site 541 is less disturbed by coring, it is complicated by several faults, as documented by nannofossil biostratigraphy (Bergen, this volume). The faults are evidently high-angle reverse faults produced by the general processes of plate convergence, formation of a décollement further down in the section, and sediment accretion (Moore and Biju-Duval, this volume). The presence of ash beds is also obscured along shear zones that are particularly prominent in Cores 25 to 30 and 40 to 50, the latter cores occurring in the vicinity of the décollement (Cowan et al., this volume). Where coring and tectonic disturbance are minimal, as elsewhere at Site 541, ash beds are useful as indicators of precise correlation of units offset along faults. Figure 3 shows the correlation of ash beds and nannofossil zones (Bergen, this volume) between portions of Tectonic Units A and B, which are the principal repeated intervals above the décollement at Site 541 (see Site 541 report, this volume). The ash beds define a vertical offset of 158.5 m at this interval along the fault. This compares well with the estimate of 156 m calculated by Moore and Biju-Duval (this volume) by adding together individual offsets in the nannofossil biostratigraphy determined by Bergen (this volume).

All the ash beds at Sites 541 to 543 are air-fall ashes, because the bathymetric high of the Barbados Ridge complex isolates the sites from submarine pyroclastic turbidites originating at the arc. This high has existed since the Miocene (Westbrook, 1982). Sigurdsson et al. (1980) have shown that the Quaternary Roseau ash was dispersed in the upper atmosphere over 600 km east of its source on the island of Dominica (Fig. 1). I infer a similar general pattern of eruption, atmosphere dispersal, and submarine deposition for all the Leg 78A ashes, al-

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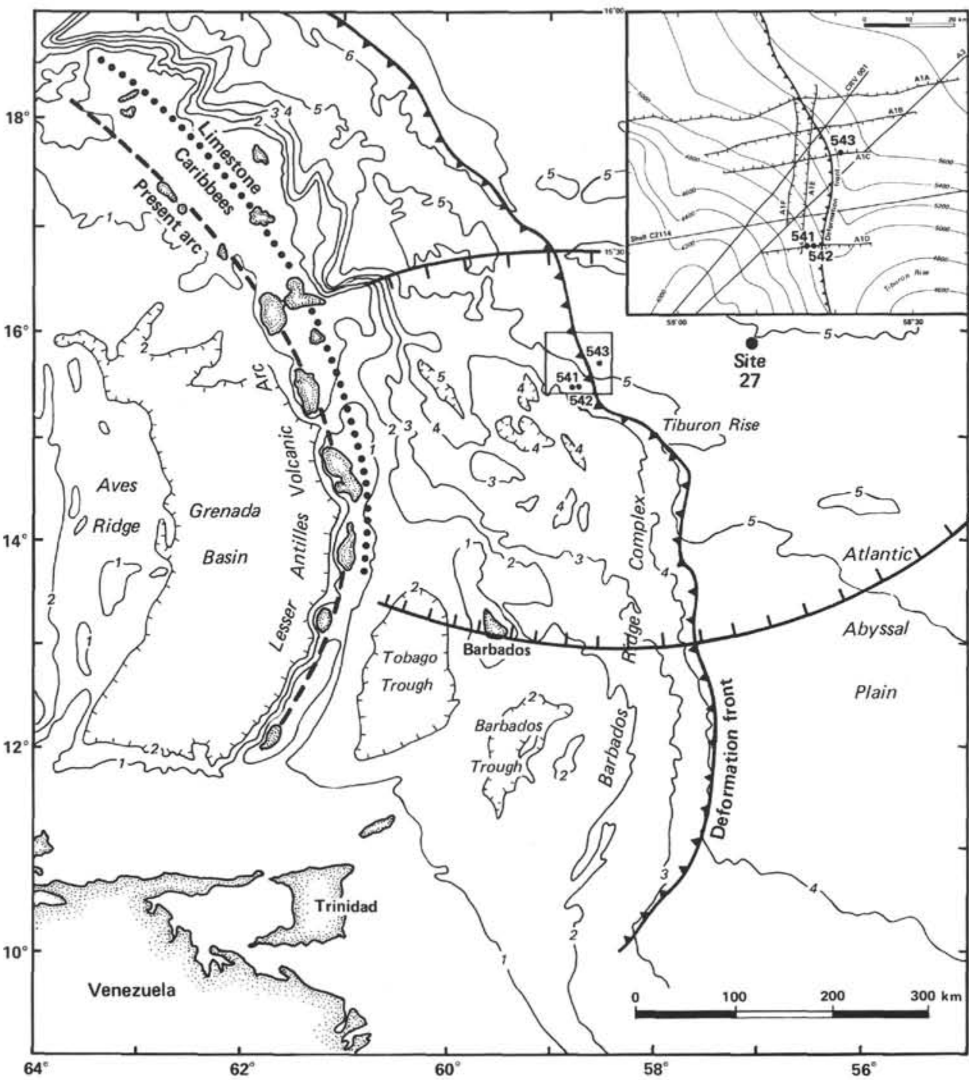

Figure 1. Location of the Leg 78A drill sites, the Lesser Antilles arc, and the Barbados Ridge complex. The divergence between the Limestone Caribbees and presently active arc at the northern end of the chain is also shown. The heavy dotted line gives the distribution of the 1-cm isopach of the Roseau ash east of its source at Dominica (after Carey and Sigurdsson, 1980).

though the direction and extent of ash dispersal are clearly dependent to some extent on climatic factors that have not been constant since the Miocene.

TEPHROCHRONOLOGY

A combination of information from Site 541 (post-middle Miocene), Site 543 (pre-middle Miocene), and a Quaternary piston core 50 km east of Martinique (Sigurdsson et al., 1980) document the frequency of explosive eruptions from the Lesser Antilles arc (Fig. 4). Unfortunately, Quaternary cores from Leg 78A are too disturbed by coring to provide information of this type.

Ages were assigned to ash beds using the nannofossil biostratigraphy of Bergen (this volume) for late Miocene and younger sediments, and the radiolarian biostratigraphy of Renz (this volume) for older sediments. Absolute ages for nannofossil zonal boundaries that are listed in Bukry (1975) and radiolarian zonal boundaries listed in Kling (1982) allowed interpolation of ash beds by depth. Fault repetition at Site 541 is accounted for by separately totalling the number of ash beds in each repeated nannofossil zone, and using the larger number (assuming that the discrepancy results from incomplete recovery and/or core disturbance in one of the intervals).

Major pulses of explosive Lesser Antilles volcanism occurred in the early and middle Miocene, the early Pliocene, and the Pleistocene–Quaternary, with possible minor pulses in the late middle Miocene and latest Miocene (Fig. 4). The early-to-middle Miocene pulse is documented from Site 543, which has been moving toward the Lesser Antilles as the North American Plate has converged on the arc. The ashes are thus probably underrepresented compared with locations such as Site 541, which have remained at a fixed distance closer to the arc since the Miocene (neglecting minor effects of section shortening related to accretion; Moore and Biju-Duval, this volume). Nevertheless, the three major pulses of explosive volcanism coincide with those documented by drilling adjacent to circum-Pacific arcs (cf., Kennett and

Table 1. Occurrences of Volcanic Ash at Leg 78A drill sites.

Sample occurrence (core-section, cm level)	Age-zone		Thickness (cm)	Color	Comments
Hole 451					
2-5, 120			?	Black	Smeared out
3-2, 80 and 115			?	Gray	Blebs
[a]3-4, 55			2–3	Gray	Smeared out
[a]4-3, 140			2–3	Black	Arched
4-7, 50		*Pseudo-emilianna lacunosa*	?	Gray	Bleb
5-2, 30	early Pleistocene		<1	?	Bioturbated
5-2, 60			?	Gray	Blebs
[a]5-3, 82			2	Grayish brown	Slightly smeared
7-2, 27			?	Dark gray	Bioturbated
[a]8-2, 33			2	Black	
8-7, 43		*H. selii*	1	Gray	
9-2, 40–90		*C. macintyrei*	?	Black	Bioturbated
		← Fault			
10-1, 96		*H. selii*	1	Black	
11-3, 20–30			?	Gray	Crystal ash
[a]12-7, 30		CN12d	3	Gray	
[a]12,CC			5	Black	
13-3, 100		CN12b	<1	Gray	3 laminae
13-7, 40			<1	Gray	
15-5, 120			1–2	Gray	Bioturbated
16-1, 50			<1	Gray	Bioturbated
[a]16-2, 50		CN12a	2	Black	Bioturbated
16-3, 28			<0.5	Gray	
16-3, 130	late Pliocene		<0.5	Gray	
16-4, 90			<0.5	Gray	Bioturbated
16-5, 25			<0.5	Gray	Bioturbated
16-5, 55			<0.5	Gray	Bioturbated
[a]16-5, 142			7	Black	
[a]16-6, 3			4	Black	
16-6, 32		CN11b	<1	Gray	Bioturbated
16-6, 80			1		Bioturbated
17-1, 60			2	Black	Tilted
17-2, 100			?		Bioturbated
17-4, 140			?		Bioturbated
17-5, 60			?		Bioturbated
[a]17-6, 50			2	Gray	
17-6, 118			1–2	Black	Bioturbated
18-1, 60			0–5		Bioturbated
[a]18-1, 140		CN11a	7	Black	Tilted
18-2, 90			?		Bioturbated
[a]18-2, 135			3	Black	
18-4, 35			?		Bioturbated
18-4, 65			?		Bioturbated
18-5, 55			?		Bioturbated
19-1, 10	early Pliocene	CN10c	?	Black	Bleb
19-1, 40			1	Black	
19-6, 115		CN10b	1–2	Gray	Dispersed by burrowing
		← Fault			
[a]20-1, 119			7	Black	
[a]20-3, 15			4	Black	
20-3, 77		CN11a	1		Burrowed
20-5, 15			1–2	Gray	Bioturbated
20-6, 135			?		Bioturbated
20-7, 3			?	Gray	Bioturbated
22-1, 63			?		Bioturbated
22-3, 70		CN10c	1–2	Gray	Bioturbated
[a]22-4, 18		← Fault	2	Gray	Bioturbated
23-2, 80		CN9b	?	Gray	Bioturbated
[a]23-5, 40			2	Gray	Bioturbated
25-4, 12			?	Gray	Swirled and mixed
27-1, 90			?		Bioturbated
27-2, 80		Barren	?		Bioturbated
27-4, 40			?		Bioturbated
27-5, 28			?		Bioturbated
27-6, 140			?		Bioturbated
28-2, 130			?		Bioturbated
[a]28-3, 70		CN9a	10	Gray	Partially bioturbated
29-3, 145	late Pliocene		?		Disturbed by rotation
29-5, 75			?		Burrowed
30-1, 2		CN9b	?	Black	Burrowed
30-3, 45			?		
31-5, 30			?		Bioturbated
31,CC			?	Black	Disturbed
32-1, 150		CN12a	?		Bioturbated
32-4, 20–50		Small	?		Bioturbated zone
32-5, 110		← fault	?		Bioturbated
[a]32-6, 143			2.5	Gray	Bioturbated top
33-3, 80			?		Bioturbated
[a]33-3, 135			4	Black	
[a]33-4, 7		CN11b	7	Black	
33-4, 35			?		Bioturbated
33-4, 65			?	Black	1-cm bleb
[a]33-5, 20			Several cm	Gray	
34-1, 35–50			?	Gray	Mixed zone
34-1, 90			?		Bioturbated
34-2, 25			?		Bioturbated
34-2, 56			?		Bioturbated
34-3, 25			?		Bioturbated
34-3, 40			?		Bioturbated
34-3, 65	early Pliocene		?		Bioturbated
34-4, 25			?		Bioturbated
34-4, 134			?		Bioturbated
34-5, 15		CN11a	?		Bioturbated
[a]34-5, 75			6	Black	Tilted

Table 1. (Continued).

Sample occurrence (core-section, cm level)	Age-zone		Thickness (cm)	Color	Comments
Hole 451 (Cont.)					
[a]34-6, 50			3	Black	Bioturbated top, tilted
34-6, 90			?		
35-1, 45			?		Bioturbated
35-1, 60			?		Bioturbated
35-1, 150			?		Bioturbated
35-3, 44			?		Bioturbated
35-5, 70		CN10c	?		Bioturbated
37-3, 80			1	Gray	
[a]37-4, 82			3	Greenish gray	
[a]37-5, 76			4	Black	
37-6, 72	late Miocene	CN9b	?		Bioturbated
[a]38-6, 62			6	Black	Indurated tuff
40-4, 55–75			?		Bioturbated zone
[a]41-3, 26			6	Black	Indurated tuff
41-6, 55–74		CN9a	?		Bioturbated zone
43-5, 70			1		Tuff
43-5, 106–110		Barren			Ashy mudstone
43-6, 90					
48-5, 56			2	Black	
48-5, 147			1.5	Black	
49-3, 40			<1		Altered
49-3, 115		*C. costada*	~1	Gray	Altered
49-4, 70	early Miocene		<1	Gray	Altered
49-4, 82			<1	Gray	Altered
49-5, 112, 119			?		Sheared out and dispersed
50-3, 40		*S. del-*	~1		
50-3, 50–65		*montensi*	?		Sheared out and dispersed
Hole 542					
[a]1-1, 15–20			7	Gray	Smeared out
1-1, 122–150			Several small?		Bioturbated
[a]1-2, 90–100			3	Black	Bioturbated top
[a]1-2, 130–140		CN11a	2 (originally)	Gray	Bioturbated, dispersed
[a]1-3, 55–65			10	Black	
[a]1-4, 44–48	early		4	Black	Bioturbated top
1-6, 70	Pliocene		1	Gray	Dispersed
[a]2-1, 0–8			>3	Gray	Disturbed
[a]2-2, 88–92			>2	Gray	Dispersed
[a]2-2, 120–125		CN10c	>2	Gray	Dispersed
2-3, 39–40			1	Gray	Dispersed
2-3, 133–134			1	Gray	Dispersed
3-1, 20–22			1–2	Gray	Dispersed
3-2, 94–95		CN10b	1	Gray	Dispersed
[a]3-3, 58–65			7	Gray	Bioturbated top
4-1, 40–41	late		<0.5	Gray	Dispersed
4-1, 120–121		CN9b	<0.5	Gray	Dispersed
4-3, 140–141	Miocene		<0.5	Gray	Dispersed
Hole 542A					
1-1, 58–59			<1	Gray	Dispersed
1-2, 110–111			<1	Gray	Dispersed
1-2, 130–131		CN11	<1	Gray	Dispersed
[a]1-3, 38–41	early		2	Gray	Bioturbated
1-3, 90–91	Pliocene		<1	Gray	Dispersed
1-5, 20			<1	Black	
[a]1-5, 40–52		CN10c	12	Gray	Bioturbated top
[a]2-2, 30–42			10	Gray	Top bioturbated
2-2, 110–111			<1	Gray	Dispersed
2-4, 55–57			1–2	Gray	Dispersed
2-4, 130–132			1–2	Gray	Dispersed
2-5, 70–75			?	Gray	Dispersed
2-6, 70–75			<1	Gray	Dispersed
3-1, 112–113			<0.5	Gray	Dispersed
3-2, 25–26			<0.5	Gray	Dispersed
3-2, 83–93			? (several small?)	Gray	Dispersed
3-5, 130–131			<0.5	Gray	Dispersed
3-5, 140–141			<0.5	Gray	Dispersed
[a]4-1, 25–30	late Miocene	CN9a	2–3	Gray	Top dispersed
4-1, 130–132			<2	Gray	Dispersed
4-4, 36–36			<0.5	Gray	Dispersed
4-5, 120–121			<0.5	Gray	Dispersed
5-4, 110–111			<0.5	Gray	Dispersed
10-1, 0–2			<1	Gray	Dispersed
10-4, 42–46			<2	Gray	Disturbed
10-4, 55–56			<0.5	Gray	Disturbed
10-4, 77–79			<0.5	Gray	Disturbed
10-5, 22–23			<0.5	Gray	Disturbed
Hole 453					
1	early Pleistocene				Sections 1 and 2 have vitric mud representing concentrated ash beds disturbed by drilling. Sections 5 to 7 have dispersed lumps of ash in a disturbed vitric-mud matrix.
2	early Pleistocene				Disturbed lumps of ash in a vitric mud matrix.
3	early Pleistocene				Disturbed through Section 2.
3-3, 85–110			25	Olive gray	Ashy mud
3-4, 50–80	early	*C. mac-*	30	Olive gray	Ashy mud
3-4, 95–100	Pleistocene	*intyrei*	5	Olive gray	Ashy mud
3-5, 132–138			3	Olive gray	Ashy mud

Table 1. (Continued).

Sample occurrence (core-section, cm level)	Age-zone		Thickness (cm)	Color	Comments
Hole 453 (Cont.)					
3-6, 15			<2	Olive gray	Ashy mud, disturbed
4-1, 40-45			3-4	Olive gray	Disturbed lump
4-1, 55-61			3?	Olive gray	Disturbed lump
4-1, 73-9			5-7	Olive gray	Disturbed lump
4-2, 15-25			5?	Olive gray	Disturbed lump
4-3, 35-60			10?	Olive gray	Ashy mud; disturbed bed
4-3, 140 to 4-4, 20			5?	Olive gray	Very disturbed
4-4, 120		CN12d	2	Olive gray	Disturbed
4-5, 20-40			?	Olive gray	Disturbed ashy mud
[a]4-5, 62-75	late Pliocene		5	Dark gray	Bioturbated top
4-5, 95-100			?	Olive gray	Ashy mud
4-6, 20-30			?	Olive gray	Disturbed lump
4-6, 139-142			2	Olive gray	Ashy mud
4-6, 147-150			?	Olive gray	Ashy mud
5		CN12b			Has dispersed lumps of ash in highly deformed Sections 1 and 2.
6-6, 125			<1	Dusky yellow green	Disturbed
7		CN12a			Has dispersed lumps of ash in highly deformed mud in Section 1.
[a]7-3, 113-116			2-3	Very dark gray	Bed
8-1, 40-50			?	Olive gray	Ashy mud
8-1, 90-100			?	Olive gray	Disturbed ashy mud
[a]8-1, 148-150			2?	Brownish black	Lump
[a]8-2, 8-10	late Miocene to early Pliocene		1-2	Brownish black	Curved bed
[a]8-2, 90-95		Forams N17-N20	4-5	Brownish black	Bed
8-3, 5-10			?	Olive gray	Ashy mud
8-3, 20-90			Several	Olive gray	Lumps of ash this interval
8-5, 82-85			?	Olive gray	Ashy mud
9-3, 15-20			5	Olive gray	Ashy turbidite
10					Has numerous ashy patches up to 0.5 cm scattered in Sections 1 to 4.
11					Has dispersed ashy spots throughout Sections 1 and 2.
[a]11-3, 127-131			3	Brownish black	Undisturbed
12					Has only dispersed ash, no beds.
13-3, 100-110			?	Greenish gray	Disturbed ashy mud
13-3, 130-140			?	Olive	Disturbed ashy mud
13-4, 80-95		Barren	?	Greenish gray	Altered disturbed ashy mud
13-5, 80-117			?	Greenish gray	Altered disturbed ashy mud
[a]14-1, 55-57			1-2	Black	Bed
14-1, 74-75			1	Gray	Thin bed
[a]14-2, 50-55			5	Dark gray	Bioturbated top
15 and 16					No distinct ash beds in relatively undisturbed Cores 15 and 16.
[a]17-1, 130-135			5	Black	Bioturbated top
[a]17-1, 142-144	middle Miocene		2	Very dark gray	
[a]17-5, 32-37		*D. alata*	2-5	Dark gray	Partly dispersed by bioturbation
[a]18-1, 57-58			<1	Black	
[a]18-1, 106-108			<2	Black	
[a]18-2, 113-119			2-3	Black	Partly dispersed by bioturbation
18-3, 99-100			<1	Gray	
[a]18-3, 125-128			1-2	Black	Dispersed by burrows
[a]18-5, 50-56			2-3	Black	Partly dispersed by burrows
[a]18-5, 85-105	early Miocene		?	Black	Abundant ash in drilling breccia
[a]18-6, 80-82		*C. costata*	1-2	Black	Dispersed by burrows
[a]19-1, 81-83			1-2	Brownish black	Dispersed by burrows
[a]19-3, 23-27			1-2	Black	Dispersed by burrows
[a]19-5, 120-123			1-2	Olive black	Dispersed by burrows
[a]19-7, 5-6			1	Dark gray	Dispersed by burrows
20-4, 10-18			2-3	Very dark gray	May be 2 redistributed
21 and 22					No recovery. Below this, ash is virtually nonexistent, isolated occurrences as noted.
	Oligocene				
27-1, 65-66			<1		Altered
32-4, 66-68 (?)	middle Eocene		<2	Light greenish gray	Feldspathic mudstone
34-2, 42-43			1	Greenish gray	Altered
Hole 543A					
1	Quaternary				Core 1 is the mud-line core—very disturbed, generally vitric mud.
1-2, 85-95				Olive gray	Ashy mud
1-2, 131-137			3-4	Light brownish gray	May be Roseau ash
1-4, 20-35			?	Dark gray	Ashy mud
2-1, 86					Cores 2-10 are Eocene to Campanian, continuous in cored interval with the cores of Hole 543. Cores 543A-2, 3, and 5 contain tiny, horizontal, light greenish gray smectite-rich beds that are probably altered volcanic ash. All but one are less than 1 cm in thickness.
2-1, 91					
2-2, 50	middle Eocene				
2-2, 60					
2-2, 61					
2CC, 15					
3-1, 21					
3-1, 29	early Eocene				
3-1, 64			2		
5-2, 31-33					

Note: Color is indicated for unbioturbated and undisturbed beds.
[a] These ash beds ≥2 cm in thickness. They are the major ash beds of Figure 4.

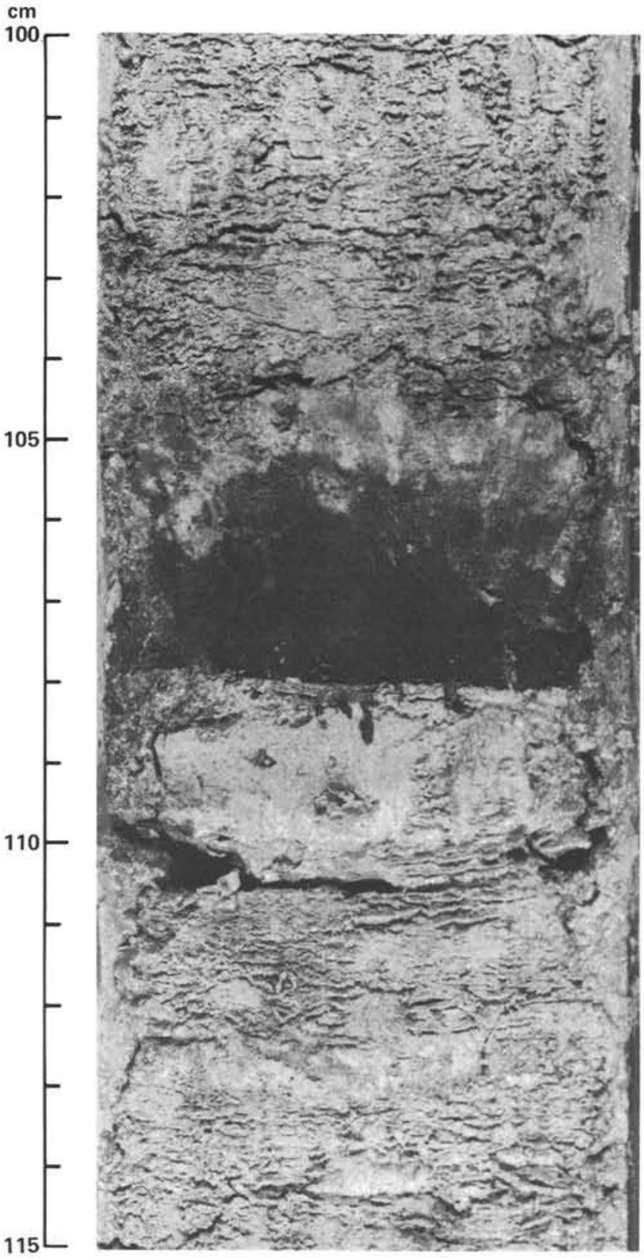

Figure 2. Photograph of a typical thick ash bed, with a flat bottom and bioturbated top (Sample 543-18-1, 100–115 cm).

Thunnell, 1977; Cadet and Fujioka, 1980; Cadet, Thisse, et al., 1982; Cadet, Pouclet, et al., 1982). This synchroneity supports a global, plate-tectonic control rather than a local control on arc magmatism (Kennett, 1981). The long hiatus in the late Miocene corresponds with a shift in Lesser Antilles volcanism in the northern part of the arc from sources in the Limestone Caribbees (Fig. 1) to sources in the more westerly arc of presently active volcanoes (Martin-Kaye, 1969; Tomblin, 1975; Westercamp, 1979).

Geochemical and mineralogical studies are currently in progress to evaluate the significance of the ash stratigraphy to the petrological evolution of the Lesser Antilles arc.

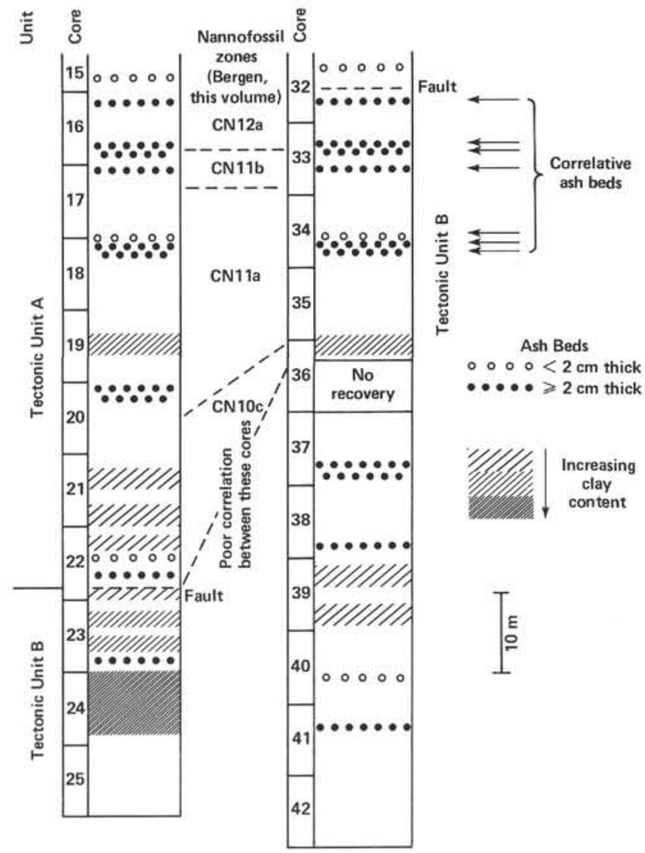

Figure 3. Correlation of Site 541 ash beds and nannofossil zones between portions of Tectonic Units A and B, which have been repeated by faulting. The correspondence was first suggested by the similarity in thickness and spacing of pairs of closely spaced ash beds near the base of Core 16 and the top of Core 33. Comparison of the sections above and below demonstrated that seven ash beds, altogether, could be matched in the two intervals. Nannofossil zonal boundaries are from Bergen (this volume).

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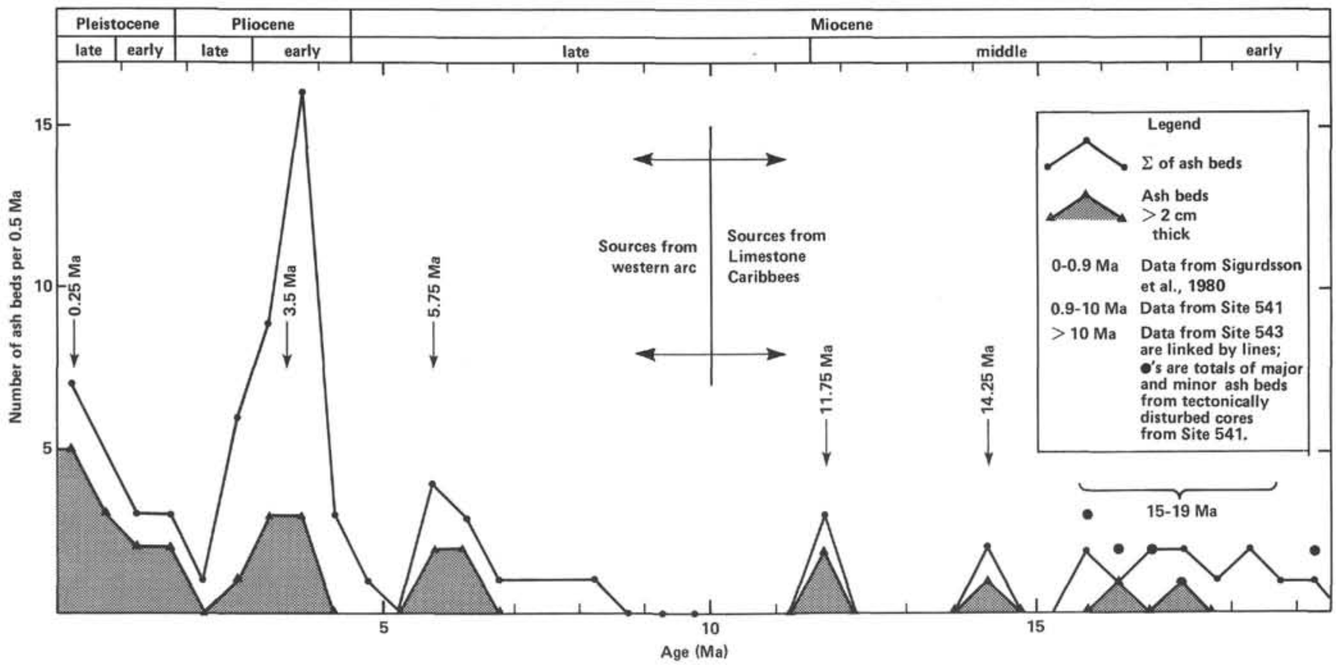

Figure 4. Abundances of ash beds (number per 0.5 Ma) plotted versus absolute age. Stippled pattern represents number of major ash beds (≥2 cm thick).