54. TERTIARY EXPLOSIVE VOLCANIC ACTIVITY IN THE EASTERN EQUATORIAL PACIFIC OCEAN: SITES 320 AND 321, DSDP LEG 34

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ABSTRACT

Samples from Sites 320 and 321 show moderate amounts of acidic (rhyolitic) volcanic materials in the late Miocene to Recent and sparse, apparently also acidic, debris in the early Miocene to Eocene. The former originates from the Peruvian rhyolites and the latter possibly comes from the East Pacific Rise.

Mineralogically the samples are dominantly glass-feldspar (including K-feldspar in conspicuous amounts) biotite, with only minor hornblende, clinopyroxene, and orthopyroxene. Two occurrences of muscovite (evidently volcanic) are noteworthy. Authigenic minerals of significance include abundant phillipsite, much coexisting with glass, and one occurrence of a hexagonal prism of quartz.

INTRODUCTION

An investigation of the dispersed volcanic constituents at two sites near the west coast of South America was undertaken in order to determine the nature and extent of Tertiary explosive volcanic activity in this area. The method consisted of sieving out the $>325\mu$ particulate fraction from 2-cc samples. Results should be compared with those from the western Pacific (Donnelly, 1975).

The present area was selected for being close to the region of Andean volcanic activity, and hence, is potentially valuable in elucidating the volcanic history of that chain. However, the two sites are also within a broad oceanic area reputed to have undergone a more alkalic and siliceous volcanic activity (Bonnatti and Arrhenius, 1970).

The two sites, 320 and 321, are located about 500 km west of the Peruvian coast (Figure 1). Site 321 is west of the northern part of the Quaternary rhyolite formation of central and southern Peru (Zeil and Pichler, 1967), while 320 is located west of a gap in the volcanic activity between the Peruvian zone and the more northerly Ecuadorian zone.

Products of Tertiary volcanism, dominantly andesites, are scattered virtually continuously along the Andean chain (Gerth, 1955; Sauer, 1971). In the Miocene, spectacular rhyolitic volcanism occurred discontinuously along the chain, with a gap between 4° and 9° south latitude. Recent activity volcanism shows an even larger gap—between about 3° and 16° south latitude. Gerth (1955) relates this rhyolitic volcanism with the uplift of the Andes, but does not set its onset more exactly than Miocene.

VOLCANIC MINERALOGY OF SITES 320 AND 321

In general, the volcanic mineralogy is not broadly typical of the Tertiary calcalkalic mineralogy seen in Leg 15 and 31 studies, but is more reminiscent of Cretaceous materials (termed subalkalic) of Leg 15 (Donnelly, 1973, 1975). Thus, hornblende, clinopyroxene, and orthopyroxene are relatively scarce, and biotite is by far the most widespread mafic mineral. Alkali feldspar is relatively abundant, though subordinate to plagioclase.

Glass

Virtually all of the glass seen at the two sites was clear and either sharp or rounded by corrosion. At both sites it persisted into the Paleogene, and, notably, coexisted in abundance with phillipsite in one core (321, 7; late Miocene), and less commonly, in Core 321, 9. At Site 292 in the Western Pacific (Donnelly, 1975) an excellent case can be made for the replacement of glass by phillipsite, with fresh glass above, and below a glassless, zeolitic zone. At Site 321, in contrast, glass is the predominant volcanic constitutent down through Core 6, less abundant and coexistent with phillipsite in Core 7, absent in Core 8 (phillipsite was seen in only one sample), scarce but coexistant with phillipsite in Cores 9 and 10, and present in Core 13. Phillipsite was absent from the residues below Core 10.

At Site 320, glass is dominant in Quaternary Hole 320, Core 1 and Hole 320A, Core 1, represented by a few large flakes in Hole 320, Cores 2 and 3 (early Miocene), and conspicuous (flakes nearly 1 mm in width) in Hole 320B Cores 1 and 2 (late Oligocene).

Plagioclase

Plagioclase is the dominant volcanic mineral. Its appearance is unexceptional; it is angular, sparsely twinned, generally zoned, and commonly of low refractive index.

K-feldspar

K-feldspar is subordinate to plagioclase but relatively more common in the residues than in Leg 15 and 32 occurrences. It is clear, somewhat zoned optically, and

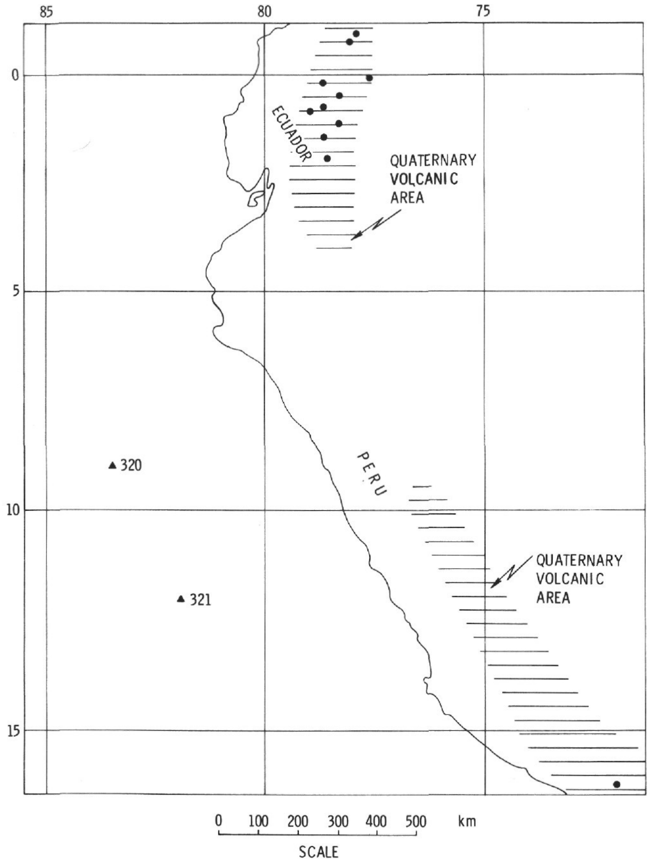

Figure 1. *Map showing the location of Sites 320 and 321, along with the Peruvian and Ecuadorian Quaternary rhyolite area and Recent volcanoes (black dots).*

rarely twinned. In Site 320, it was seen only in Sample 320-3-2, 88 cm. At Site 321 it is numerous in Cores 4, 5, 6, and 7; in the latter two cores it perhaps comprises 10% or more of the total feldspar fraction.

Quartz

Volcanic quartz is scarce at the two sites. At 321-5-4, 97 cm rounded quartz, similar to that seen in Legs 15 and 31, was found. Deeper occurrences at Site 321 (Cores 9 and 10) are cloudier and not necessarily volcanic in origin.

Biotite

Biotite is the dominant mafic mineral at both sites, in conspicuous contrast to Leg 15 and 31 occurrences. Cores in which biotite is especially conspicuous are Hole 320, Cores 1 and 3; Hole 320B, Core 1; and Site 321, Cores 2, 3, 4, 5, 6, and 7. In many samples from Core 5 of Site 321 biotite comprises one-fifth of the entire mineral fraction.

Muscovite

Clear flakes of muscovite, marginally slightly altered to an unknown mineral, are found in one section each from the two sites (both Quaternary). Volcanic muscovite phenocrysts are exceedingly rare and these occurrences are noteworthy. The clarity and large angle 2V shows that these grains are not some sort of alteration product of biotite (with which it coexists at Site 321).

Hornblende

This mineral, which in Legs 15 and 31 is the dominant calcalkaline mafic mineral, is very scarce at the two present sites. It occurs in Hole 320, Core 2 and at Site 321, Cores 2, 4, 5, 6, and 7, being most abundant (but still less than 1% of the total volcanic fraction) at Site 321, Core 5.

Red hornblende was found only in Sample 321-5-5, 87 cm.

Clinopyroxene

Clinopyroxene, greenish and more or less characteristically etched, is a rare mineral, being found only in seven samples, all from Site 321, Cores 2, 5, 6, and 7.

Orthopyroxene

This mineral, which is pleochroic and terminally etched, was found in three samples from Site 321, Cores 5 and 6.

Zircon

Considering the relative abundance of zircon in biotite-rich samples from Legs 15 and 31, its discovery in only one sample from the present leg is unusual. A large prism ($15 \times 40\mu$) was found in 321-6-6, 114 cm.

AUTHIGENIC SILICATES

Phillipsite

Large phillipsite "crosses" are conspicuous at Site 321, Cores 7, 8, 9, and 10. In many occurrences it coexists with glass flakes, which, though rounded, are fairly common. Although the appearance of phillipsite corresponds to a diminution of abundance of glass (relative to plagioclase), the persistent co-occurrence of these two generally incompatible substances is worthy of note.

Authigenic K-feldspar

Leg 34 yielded far fewer indisputable examples of this mineral than did Legs 15 and 31. Examples tentatively referred to this category are almost all anhedral, full of inclusions, and uncommonly cored. The examples seen were from Hole 320B, Core 1, and Site 321, Cores 5, 9, and 10.

Quartz

A small hexagonal prismatic bipyramid, the only such crystal seen in the examination of several thousand slides of deep-sea sediments, was found in Sample 321-7-2, 97 cm. The crystal form suggests an authigenic origin.

SUMMARY OF VOLCANIC ACTIVITY

Site 320 shows only limited volcanic debris (Table 1). The Quaternary cores (Hole 320, Core 1 and Hole 320A, Core 1) show one spectacular event and only scattered, sparse debris elsewhere in the cores. The debris is dominantly clear glass, with a minor mineral content.

TABLE 1
Volcanic and Other Constituents From Site 320 and 321 Samples

Sample (Interval in cm)	Depth (m)	Wt Res	Volc (%)	Glass (%)	Flsp (%)	AF	Bi	Hb	Cpx	Opx	Q	Other	Authigenic
Hole 320													
1-1, 60	6.90	0.0186	0										
1-2, 78	8.28	0.0181	0										
1-3, 73	9.73	0.0222	tr		tr								
1-4, 64	11.14	0.0268	0										
1-5, 75	12.75	0.0306	2	100									
1-6, 80	14.30	0.0193	tr	80	20		p						
2-1, 116	74.66	0.0074	5	90	10			tr					
2-2, 114	76.14	0.0096	2	p L	p								
3-2, 88	104.38	tr	tr			p							
3-3, 76	105.76	0.0014	0										
3-4, 85	107.35	tr	tr	p L									
3-5, 81	108.81	0.0005	tr	p L									
3-6, 96	110.46	0.0006	0										
Hole 320A													
1-1, 78	0.78	0.0148	tr	p	p								
1-2, 98	2.48	0.0186	0										
1-3, 74	3.74	0.0108	0.5	100									
1-4, 78 S	5.28	0.0976	95	98	2							Musc	
1-4, 100	5.50	0.0314	40	99	1							Musc	
1-5, 77	6.77	0.0228	tr	100									
1-6, 90	8.40	0.0366	tr	100									
Hole 320B													
1-1, 90	136.90	0.0022	0										
1-2, 84	138.34	0.0020	tr	100			p						AKF, Glauc
1-3, 88	139.88	tr	2	80	20								
1-4, 87	141.37	0.0015	0										
1-5, 82	142.82	0.0032	0										
1-6, 72	144.22	tr	10	75	25		p						
2-1, 92	146.42	tr	10	100 L									
2-2, 82	147.81	0.0015	1	100									
2-3, 97	149.47	0.0011	0										
2-4, 80	150.80	0.0010	10	100 L									
2-5, 59	152.09	0.0027	10	100 L									
Site 321													
1-1, 116	1.16	0.0290	0	0	0								
2-2, 96	3.96	0.0315	tr	tr									
2-4, 88	6.88	0.0410	20	98	2		tr	tr	tr				
3-3, 77	14.77	0.0050	25	97	2		1						
3-6, 123	19.73	0.0016	2	90	10								
4-2, 74 S	22.74	0.0261	85	97	2		1	s					
4-2, 95	22.95	0.0504	85	98	2	p	p					Musc	
5-2, 120 S	32.70	0.0085	75	95	5		tr						
5-2, 75	32.25	0.0302	50	95	5			tr					
5-3, 74	33.74	0.0178	15	98	2								
5-3, 115 S	34.15	0.0057	10	98	2	tr		tr					
5-4, 91 S	35.41	0.0089	95	95	4	tr	1	s	s	tr			
5-4, 97	35.47	0.0887	95	95	4	p	1	s	s	tr	R		
5-5, 87	36.87	0.0508	95	95	4		1	s				red Hb	
5-5, 108 S	37.08	tr	10	70	30				tr				
5-6, 76	38.26	0.0765	85	95			5						AKF
5-6, 109 S	38.59	0.0209	95	95	4		1					Br G	
6-1, 90	40.40	0.0243	50	95	3	p	2						
6-2, 58 S	41.58	0.0122	95	95	5	?a	p	tr				Br G	?AKF
6-2, 94	41.94	0.0752	95	99	1	?a	p					Br G	
6-3, 88 S	43.38	0.0187	95	95	5	?a	p	tr					
6-3, 107	43.57	0.0465	70	95	5	p	p	s	tr				
6-4, 90	44.90	0.0130	5	98	2	?a	p						
6-4, 97 S	44.97	0.0027	50	85	12		p	3					
6-5, 65 S	46.15	0.0120	10	98	2								
6-5, 112	46.62	0.0106	10	90	10		p	tr				FD	
6-6, 68	47.68	0.0480	5	95	5		p						
6-6, 114 S	48.14	0.0640	90	90	8		2	s		tr		Z	
7-1, 118	50.18	0.0047	2	20	80	p		tr					Phil

TABLE 1 – *Continued*

Sample (Interval in cm)	Depth (m)	Wt Res	Volc (%)	Glass (%)	Flsp (%)	AF	Bi	Hb	Cpx	Opx	Q	Other	Authigenic
7-2, 97 S	51.47	0.0070	2	15	85	c	p						Phil; Qhex
7-2, 104	51.54	0.0198	2	0	95		5	tr					Phil
7-3, 94 S	52.94	0.0102	10	30	63		5	2					Phil
7-3, 111	53.11	0.0116	10	10	90	a	p	tr					Phil
7-4, 98 S	54.48	0.0022	5	10	90	p	p	tr					Phil
7-4, 118	54.68	0.0045	5	15	75		p						Phil
7-5, 92 S	55.92	0.0167	5	15	75		p	s					Phil
7-5, 100	56.00	0.0293	10	0	98	p	2	tr					Phil
7-6, 84 S	57.34	0.0044	5	10	90	a	p	tr					Phil
7-6, 136	57.86	tr	15	15	85	a	p						Phil, Glauc
8-1, 108	59.58	0											
8-2, 106	61.06	0											
8-3, 90	62.40	tr	tr	0	100								
8-4, 136	64.36	tr	tr	0	100								
8-5, 85	65.35	0											Phil
8-6, 125	67.25	0											
9-1, 85	68.85	0.0188	1	25	75								Phil, Glauc
9-2, 62	70.12	tr	tr		100						d/v		Phil
9-3, 124	72.24	tr	1		100						d/v		Phil, AKF
9-4, 78	73.28	0.0023	0										Phil
9-5, 95	74.95	0.0016	tr		100								Phil
9-6, 115	76.65	tr	1	100									Phil
10-1, 130	78.80	tr	tr	100									Phil
10-2, 129	90.29	tr									d/v		Phil, ?AKF
10-3, 90	81.40	tr	tr	p	p						d/v		
10-4, 112	83.12	tr	2	100									Phil
11-2, 101	89.51	tr	0										Glauc
11-3, 98	90.98	tr	0										
11-4, 86	92.36	0											
12-1, 88	106.88	tr	0										
12-1, 130	107.30	tr	tr	p									
13-1, 104	116.54	tr	5	100									
13-2, 94	117.94	tr	80	20									
13-3, 52	119.02	tr	0.5	p	p							FD	Glauc

Note: Materials are all coarser than 325 mesh (about 45μ). S in interval means shipboard sample. Wt Res = g or residue from 2-cc sample; tr = trace, % volc and % flsp are percents clear glass and total feldspar in volcanic fraction, L means large flakes; AF = alkali feldspar, presumed to be volcanic, p = present, a = abundant, c = common, Bi = biotite, symbols as for AF, numbers for percentages of total volcanic fraction; Hb = hornblende, Cpx = clinopyroxene, Opx = orthopyroxene, symbols as for AF, Bi, s = several grains seen; Q = quartz, R = rounded volcanic grain, d/v = detrial or volcanic; Other = miscellaneous, musc = muscovite; red Hb = red hornblende, Z = zircon, Br G = brown (basaltic) glass, FD = fish debris; Authigenic, AKF = authigenic K feldspar, Phil = phillipsite, Glauc = glauconite, Qhex = bipyramidal quartz prism.

Early Miocene to late Oligocene cores (Hole 320, Cores 2 and 3; Hole 320B, Cores 1 and 2) show very little volcanic material. The presence of large glass flakes (to 0.5 mm) suggests a local source, possibly the contemporary East Pacific Rise.

Site 321 samples show a moderate amount of volcanic activity in the late Miocene to Recent cores (1-7). Accumulation rates (Figure 2) of volcanic material were estimated from the formula:

$$\text{rate (g/cm}^2\text{ m.y.)} = \text{wt volc. material (g/2 cc)} \times \text{total accumulation rate (m/m.y.)} \times 50$$

The apparent abrupt downward decrease in glass accumulation rate in Core 7 is probably the result of its diagenetic replacement in part by phillipsite; the estimated accumulation of feldspar is more uniform. The character of the Neogene debris (biotite most abundant mafic mineral; K-feldspar conspicuous) supports its origin from Peruvian rhyolites (Zeil and Pichler, 1967). However, in contrast with these Peruvian rhyolites, plagioclase is the more abundant feldspar in the Site 321 occurrence. The Paleogene of Site 321 shows only limited volcanic activity. Authigenic minerals are conspicuous; some phillipsite coexists with glass. As at Site 320, clear glass flakes appear near the base of the site (Core 13), suggesting a nearby (East Pacific Rise) source.

ORIGIN OF THE VOLCANIC MATERIALS

Although clearly of Peruvian origin, the rate of accumulation of the Neogene volcanic material at Site 321 (Figure 2) is at least an order of magnitude less than that of calcalkalic materials from Sites 292 and 296 in the West Pacific (Donnelly, 1975). Although the rate of Peruvian Neogene volcanic activity could have been correspondingly less, the different mineralogic character of the materials (subalkalic versus calcalkalic) makes such a comparison tenuous. A further problem is that the Leg 34 sites lie upwind of Peru for high-altitude winds (200 mb). Unpublished results from Central America suggest that these winds are more important than low altitude

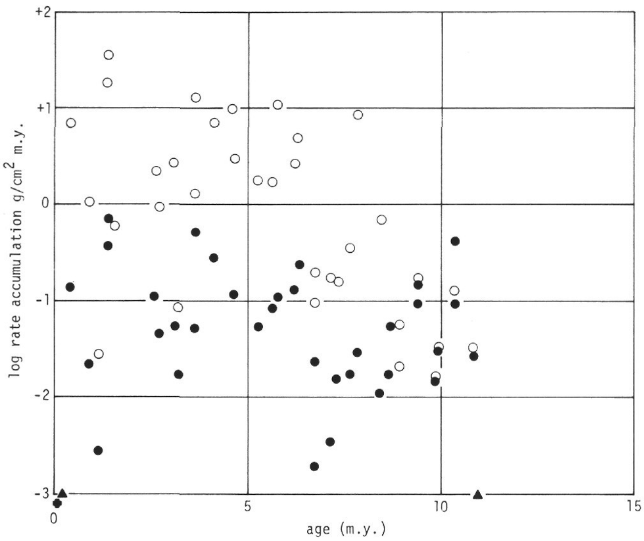

Figure 2. *Plot of log rate of accumulation in g/cm² m.y. against age in m.y. for the Neogene at Site 321. Total volcanic material shown as open circles, total feldspar as black dots, samples with zero volcanic material as crosses, and samples with a trace of volcanic material as black triangles. Sediment accumulation rates used for these calculations are 17.3 m/m.y. in Cores 1-4, and 3.06 m/m.y. in Cores 5-7.*

winds for dispersal of ash for distances of several hundred kilometers. Hence, the bulk of the debris from the Peruvian centers may have been transported eastward, rather than over the Pacific.

The coarse, clear glass flakes near the base of both Sites 320 and 321 support Paleogene acidic volcanic activity of the East Pacific Rise, much as Bonatti and Arrhenius (1970) suggested for the recent.

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REFERENCES

Bonatti, E. and Arrhenius, G., 1970. Acidic rocks on the Pacific Ocean floor. *In* Maxwell, A. (Ed.), The sea, v. 4: New York (Wiley-Interscience), p. 445-464.

Donnelly, T.W., 1973. Circum-Carribean explosive volcanic activity: evidence from Leg 15 sediments. *In* Edgar, N.T., Saunders, J.B., et al., Initial Reports of the Deep Sea Drilling Project, Volume 15: Washington (U.S. Government Printing Office), p. 969-988.

________, 1974. Neogene explosive activity of the western Pacific: Sites 292 and 296, DSDP Leg 31. *In* Ingle, J.C., Karig, D.E., et al., Initial Reports of the Deep Sea Drilling Project, Volume 31: Washington (U.S. Government Printing Office), p. 577-598.

Gerth, H., 1955. Der geologische Bau der südamerikanischen Kordillere: Berlin (Gebrud. Borntraeger).

Sauer, W., 1971. Geologie von Ecuador: Berlin: (Gebrud. Borntraeger).

Zeil, W. and Pichler, H., 1967. Die känozoische Rhyolith-Formation in mittleren Abschnitt der Anden: Geol. Rundschau, v. 57, p. 48-81.