32. BASALTIC GLASSES FROM THE MARIANA TROUGH[1]

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ABSTRACT

The tectonic character oceanic crustal generation in the Mariana Trough, an active, extensional, back-arc basin, is similar in many ways to that at normal mid-ocean ridges. Thus it might be expected that the basalts erupted in the basin would be like normal mid-ocean ridge basalt. Basaltic glasses from each environment show consistent differences, however, Mariana Trough basaltic glasses have lower total iron and TiO_2 and higher Al_2O_3 at a given MgO concentration. The rare earth patterns for Mariana Trough glasses are essentially flat relative to chondrite. Incompatible element abundances are higher for the trough basalts than for ridge basalts. The volatile content of trough basalts is high (approximately 1% H_2O).

These compositional characteristics are also true of basalts from other active marginal basins and suggest that the sources of these lavas differ from those of normal mid-ocean ridge basalts. Part of the reason for these differences may be the peculiar tectonic environment of active back-arc basins, in particular their location above the subducted oceanic lithospheric plate.

INTRODUCTION

Geologic Setting

The Mariana Trough (Fig. 1) is a young extensional basin situated between the volcanically active Mariana Island arc and the West Mariana Ridge, a remnant arc. Spreading began there approximately 6 Ma (Fryer and Hussong, this volume). Patterns of magnetic anomalies throughout the basin (Hussong and Fryer, 1980), seismicity in the central portion (Hussong and Sinton, 1979), the morphology of the spreading center (Uyeda and Hussong, 1978), and the increase in seismic velocities with age of crustal layers (Ambos and Hussong, 1979) are similar to features of slowly spreading segments of normal mid-ocean ridges. There are a number of ways in which the Mariana Trough differs tectonically from normal mid-ocean ridges, however. It is situated very close to a convergent plate boundary, and the changes of spreading direction within the basin noted by Hussong and Fryer (1980) are probably related to the convergence. At 18°N the spreading rate is much slower (1.65 cm/y., according to Hussong and Fryer [1980]) and the central graben is deeper (4600 m, Fryer and Hussong [this volume]) than encountered at other spreading ridges. Seismic refraction studies show that crust and mantle velocities are lower than at mid-ocean ridges (Ambos and Hussong, 1979). Gravity models suggest a mass deficiency at depth, indicating mantle densities that are lower than normal (Sager, 1980). It is suspected that the degree of fracturing of the crust, at least at this latitude, is greater than is usually encountered at mid-ocean ridges (Ambos, 1980; Fryer and Hussong, this volume). The fractured nature of the crust may account for the low-magnitude earthquakes ($M <$ 3; Hussong and Sinton, 1979) and the high degree of hydrothermal activity in the region (see site chapters for Sites 453 and 456 and Uyeda and Horai, this volume).

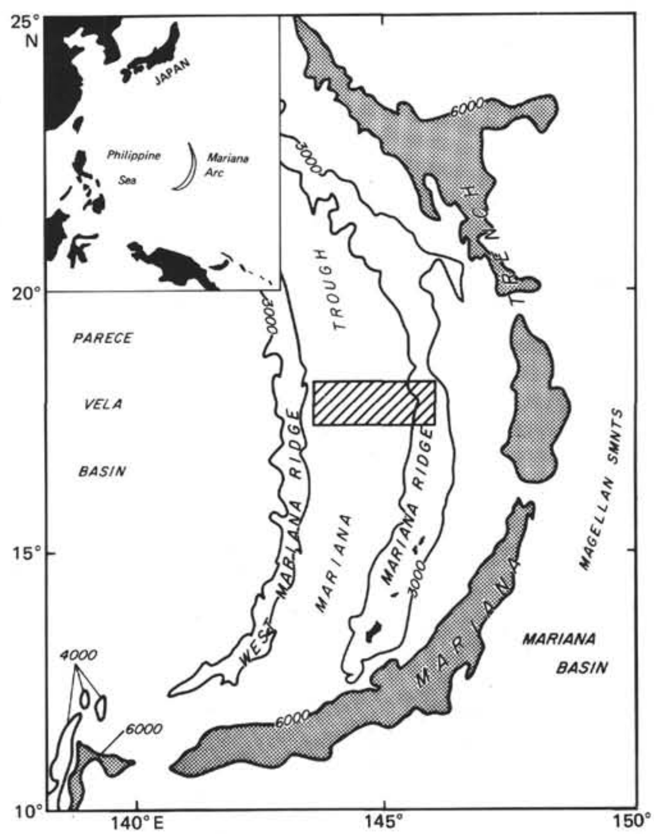

Figure 1. Position of the Mariana arc-basin system in the western Pacific. DSDP Sites 453 to 456 were drilled in the Mariana Trough.

These similarities and differences of mid-ocean ridge and Mariana Trough tectonics raise some basic questions concerning magma genesis in the back-arc basin.

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How do Mariana Trough basalts and other back-arc basin basalts compare with mid-ocean ridge basalt (MORB)? How is magma composition related to the tectonic setting of the Mariana Trough? Have these relationships changed with time?

Sampling

Prior to 1977, samples were dredged from the central portion of the Mariana Trough (Fig. 2) on two cruises by the Scripps Institution of Oceanography. The compositions of some of these samples are reported in Hart et al. (1972) and Meijer (1976). In preparation for Leg 60 of the Deep Sea Drilling Project, detailed surveys of the prospective sites were carried out by the Hawaii Institute of Geophysics (HIG) during 1976 and 1977. Dredging was done in the vicinity of each proposed drilling site, but only those stations from the central portion of the basin yielded fresh basalts. During Leg 60, four locations were drilled in the trough (Fig. 2). Of these, only two sites (454 and 456) penetrated igneous rocks of the marginal basin crust.

Many of the samples collected in the dredging operations and in subsequent DSDP drilling are fragments of basaltic pillow lavas. They have glassy rims (0.1-1 cm thick), spherulitic to variolitic margins (up to 4 cm thick), and fine-grained hypocrystalline interiors. The rocks from dredge hauls 13 and 14 are sparsely porphyritic, containing skeletal microphenocrysts of plagioclase and olivine, which generally occcur in small crystal clumps. Spinel inclusions occur in olivine and plagioclase phenocrysts in some of the dredge 13 and 14 samples. A large number of aphyric and porphyritic pillow fragments were retrieved in dredge haul 3. In addition to skeletal olivine and plagioclase in the dredge 3 pillow fragments, there are also some rounded and embayed plagioclase and pyroxene phenocrysts. No spinel was observed in any of these rocks. The groundmass of the rocks from all three dredge locations varies from hyaline to hypocrystalline. In most, microlitic to very small skeletal laths of plagioclase are the dominant groundmass phase. Many of the rocks contain globulites and margarites of pyroxene(?). Minute grains of olivine occur in the groundmass of some of the rocks from dredge 13. Most of the rocks chosen for this study are very fresh. Some of them contain a small amount of secondary clays occurring as vesicle linings or vein fillings. The vesicularity of these rocks is generally greater than 10% by volume. The thin sections described in Table 1 were cut from the outer glassy portions of the samples, where vesicle development is lowest.

The DSDP samples are aphyric to sparsely porphyritic with plagioclase and olivine phenocrysts. Although the glass samples from the cores were too small to permit thin sectioning, descriptions of the lithologic units from which these samples were taken are included in the petrology sections of site chapters 454 and 456.

Small chips from the glassy rims of 30 of the freshest pillow fragments retrieved in HIG dredge hauls 3, 13, and 14 were chosen for analysis. Only seven pillow fragments containing fresh glassy basalt were recovered from DSDP sites in the Mariana Trough. All of these were analyzed. In addition to these, a number of samples of basaltic glass from several other marginal basins were analyzed—one from the Lau Basin, two from the Parece Vela Basin, and five from the Scotia Sea. The Lau Basin, located between the Lau and Tonga Kermadec Ridges, shows evidence of currently active extension but appears to have a complicated pattern of spreading (Hawkins, 1976a). Both the Parece Vela Basin and the Scotia Sea show normal mid-ocean ridge spreading patterns (Langseth and Mrozowski, in press; Barker, 1970). The Parece Vela Basin, bounded on the west by the Palau-Kyushu Ridge and on the east by the West Mariana Ridge, was actively spreading from Oligocene to Miocene time (Scott et al., in press). The Scotia Sea is a currently active marginal basin similar in many respects to the Mariana Trough (Barker, 1970; Saunders et al., in press). Comparison of Mariana Trough basalts with basalts from these other marginal basins allows us to examine the consistency of compositions among marginal basin lavas.

ANALYTICAL PROCEDURES

Although numerous investigators have studied the composition of MORB (Engel and Engel, 1964; Miyashiro et al., 1970; Byerly et al., 1975; Melson et al., 1976), the rocks which were studied vary widely in degree of crystallinity and in character and extent of alteration. Furthermore, the techniques used to analyze these rocks differ considerably. Most commonly the basalts collected in the ocean ridge provinces are fragments of pillow lava with quenched, glassy rims representing the liquid composition of the lavas at the time they were erupted. If only fresh portions of the glassy rims are chosen for analysis, the problems of variation in degree of crystallinity and alteration among samples can be avoided. Thousands of basaltic glasses from mid-ocean ridge provinces have been analyzed for major element composition by microprobe at the Smithsonian Institution (Melson et al., 1976). The technique is described in Byerly et al. (1975). The back-arc basin glasses chosen for the present study were analyzed by microprobe (Table 2) at the Smithsonian Institution using the same technique as for MORB analyses. Thus the Smithsonian glass file provides a large body of data with which to compare the major element composition of our back-arc basin samples.

Analysis of selected samples for certain rare earth (Ce, Nd, Sm, Eu, Gd, Dy, Er, Yb, Lu) and other minor and trace element (Li, K, Rb, Sr, Ba) compositions (Table 3) were performed by mass spectrometry at the Hawaii Institute of Geophysics, using stable isotope dilution methods. This technique is described in Webster (1960) and Schnetzler et al. (1967) as modified by Schuhmann et al. (1980).

CHEMICAL ANALYSES

Basalts from normal mid-ocean ridge segments (N-MORB)—that is, those not influenced by the peculiar chemistry of melting anomalies (''mantle plumes''

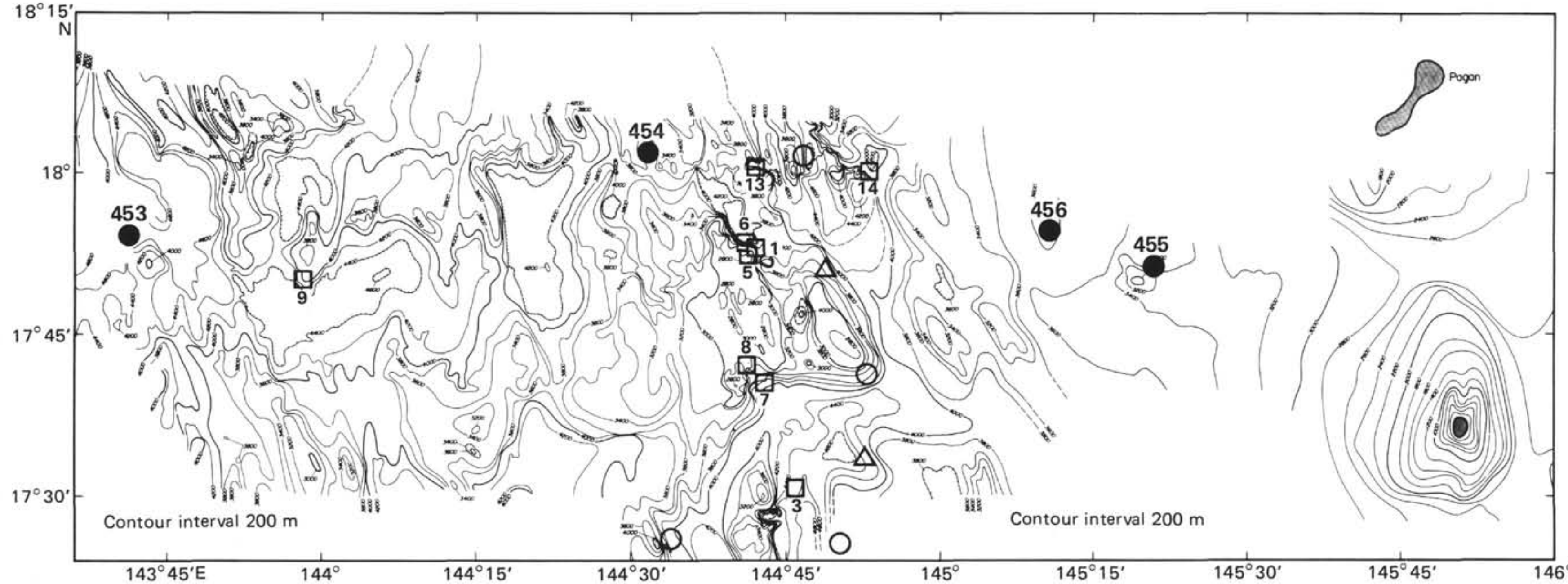

Figure 2. Bathymetry map of the Mariana Trough at about 18°N showing locations of HIG dredge sites (open squares) and DSDP Sites 453 to 456 (filled circles). Open triangles and open circles are locations of SIO dredges (Hart et al., 1972). Glasses analyzed are from dredge sites 3, 13, and 14 and DSDP Site 454.

Table 1. Petrologic description of basalt samples dredged from the Mariana Trough.[a]

	Phenocrysts				Groundmass						
Sample[b]	Pl.	Ol.	Px.	Sp.	Pl.	Ol.	Px.	Ores	Glass	Alt.	Ves.
M0302		2			10		10	Tr	47	30	1
M0310	12	5			13		10		67		4
M0338	8	1	Tr		15		18	Tr	54		3
M0370	2	2			3		3		85		5
M0373	7	1			15		18		45	4	10
M0379	1	2			20		20		67	5	5
M0380	5	2			3		1		86	1	2
M03100	8	6			3		2	Tr	77		3
M03101	6	4			5		4		71	2	8
M03102					1				97		2
M1300		2		Tr	15	4	12	Tr	57	2	7
M1316	4	2			2		3	1	82	3	3
M1330	5	3			4		10		66		12
M1349	4	3			3		5	Tr	76	Tr	8
M1355	2	2			15	5	10		61	2	3
M1371	3	2			7		5		68		15
M1372	3	1		Tr	3	2	5		84	Tr	1
M1380		Tr		Tr	10	3	10		65	3	8
M1381		1		Tr	8	Tr	10		72	1	7
M1396	1	2		Tr	10	1	8		74	Tr	3
M1417	20	6							64		10
M1419	1	1			5		3	Tr	82		7
M1441	2	1			3		1	1	89		3
M1463	10	6						Tr	79	3	1
M14104	1	3		1	10		Tr		64		5
M14106	Tr	3		1	5		5		80		10

Note: Pl. = plagioclase; Ol. = olivine; Px. = pyroxene; Sp. = spinel; Ores = opaque minerals; Alt. = secondary minerals (mainly brown and green clays); Ves. = vesicles.

[a] Volume percent estimated from thin section.

[b] Samples M03, M13, and M14 are from dredges 3, 13, and 14 (Fig. 2).

or "hot spots") or propagating rifts—have a distinctive set of major element compositional traits (see Table 2). These basalts have low values of K_2O (0.1–0.5 wt.%), TiO_2 (1.0–2.0 wt.%), total iron (6.5–12.0 wt.%), and P_2O_5 (0.08–0.23 wt.%) but high values of CaO (10.5–12.5 wt.%) and Al_2O_3 (15.0–18.0 wt.%) (Engel and Engel, 1964; Engel et al., 1965; Aumento, 1968; Miyashiro et al., 1970; Kay et al., 1970; Melson et al., 1976). Major element composition of the back-arc basin (BAB) basaltic glasses for our study do show these characteristics, but the BAB glasses also have a distinctive set of compositional traits and show certain differences from those of N-MORB glasses. A comparison of liquid trends on MgO variation diagrams (Fig. 3A–C) for N-MORB versus BAB glasses shows displacement of the trends for total iron (FeO^t) (2.5 wt.% < MORB), TiO_2 (0.5 wt.% < MORB), Al_2O_3 (2.0 wt.% > MORB). When the BAB glasses are compared with MORB glasses affected by proximity to mantle plume or hot spot sources (P-MORB), the FeO^t and Al_2O_3 trends remain distinct, whereas that of TiO_2 does not (Fig. 3C).

Some trace element abundances also help to distinguish MORB and the BAB glasses. N-MORB shows light rare earth element (REE) depletion, and P-MORB shows light REE enrichment with respect to chondritic abundances (Schilling, 1975b; Sun et al., 1979). REE patterns for the Mariana Trough glasses are essentially flat with respect to chondrite and fall near the upper limit for MORB (Fig. 4). Plots of REE for whole-rock samples from the Scotia Sea show patterns similar to the Mariana Trough glasses (Tarney et al., 1977). REE patterns of BAB are more similar to those of MORB transitional between P- and N-MORB (T-MORB), except that BAB lack the slightly concave upward pattern of the light REE that is characteristic of T-MORB (e.g., White and Bryan, 1977; Sun et al., 1979).

Incompatible element abundances are generally higher for the Mariana Trough glasses, and ratios of K/Ba, Ce/Ba, Sr/Ba, and K/Rb are lower than N-MORB but similar to T- and P-MORB (Table 3).

DISCUSSION

This chapter presents the results of initial investigations of the basaltic glasses gathered in site surveys and during Leg 60 drilling in the Mariana Trough. Detailed interpretation of these data will be presented elsewhere. At this stage of our investigations it is important to note the major and distinctive characteristics of the Mariana Trough glass compositions and to consider whether these compositions imply tectonic control of magma genesis in the active marginal basin environment.

Previous investigations of BAB basalts have led to the conclusion that, with regard to major element composition, there is little difference between MORB and BAB basalts (Hart et al., 1972; Hawkins, 1974, 1976a, 1976b, 1977; Hawkins and Batiza, 1975; Gill, 1976; Tarney et al., 1977; Saunders et al., in press; Mattey et al., in press). But trace element analysis shows that in many cases the BAB lavas are intermediate between MORB and basalt of the island arc tholeiitic series (Gill, 1976; Saunders et al., in press; Tarney et al., 1977; Fryer, 1980; Wood et al., this volume). Most of these investigations deal exclusively with whole-rock analyses. The data here demonstrate that major element compositions of BAB basaltic glasses are distinctive. The trends for BAB and MORB glasses in MgO variation diagrams (Fig. 3) indicate control by mineral fractionation, primarily olivine, for the lavas erupted in these environments.

The observed depletion in total iron and TiO_2 and enrichment in Al_2O_3 may be related to mineralogy of the source. For example, melting of a plagioclase peridotite at low pressure could produce enrichment in Al_2O_3 and consequent relative depletion in iron and TiO_2. It seems more likely that the major element composition of the BAB glasses reflects the extent to which the volatile content of the lavas controls the order and composition of phases crystallizing during fractionation of the magmas. Glass samples from the Mariana Trough and the Scotia Sea have high contents of H_2O, CO_2, F, and Cl (Garcia et al., 1979). Under hydrous conditions the field of stability of olivine is greatly expanded, plagioclase crystallization is inhibited, and the relative amounts of crystallization of pyroxene and amphibole vary (Hamilton, 1964; Green and Ringwood, 1968). These effects may explain the relative depletion in iron and TiO_2 and the enrichment in Al_2O_3 characteristic of BAB lavas.

We are currently analyzing glass samples from the Parece Vela and Lau basins for volatile content. If high volatile content of BAB lavas is a consistent trait, the presence of volatiles may be explained in a number of ways: (1) Alteration of submarine lavas, particularly in regions with high hydrothermal activity, would increase

Table 2. Results of microprobe analysis of basaltic glasses from the Mariana Trough, Lau Basin, Parece Vela Basin, and the Scotian Sea.

Sample[a]	SiO_2	Al_2O_3	FeO^t	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	Total	Source[b]
M0302	48.85	17.04	9.81	8.10	10.72	2.98	0.20	1.18	0.15	99.03	MT
M0310	51.79	15.95	8.99	6.35	10.60	3.25	0.33	1.53	0.18	98.97	MT
M0311	52.53	16.01	9.58	5.16	9.14	3.73	0.41	1.75	0.21	98.52	MT
M0338	51.24	16.10	8.94	6.16	10.39	3.36	0.38	1.53	0.18	98.28	MT
M0338[c]	51.59	15.98	9.11	6.17	10.56	3.30	0.34	1.54	0.16	98.75	MT
M0360	51.77	15.55	9.36	6.74	11.04	3.07	0.25	1.63	0.16	99.57	MT
M0370	50.88	16.03	8.42	6.65	10.68	2.96	0.28	1.31	0.16	97.37	MT
M0373	51.76	15.92	8.82	6.39	10.55	3.27	0.26	1.52	0.16	98.65	MT
M0379	49.44	17.12	9.79	7.49	11.01	2.84	0.25	1.15	0.12	99.21	MT
M0380	51.47	15.23	9.61	6.40	10.56	3.27	0.26	1.74	0.17	98.71	MT
M03100	50.63	15.31	9.81	6.25	10.52	3.35	0.31	1.75	0.20	98.13	MT
M03101	51.90	15.55	9.31	6.79	11.32	3.01	0.24	1.56	0.19	99.87	MT
M03102	50.44	15.56	9.30	6.57	10.43	3.40	0.36	1.47	0.17	97.70	MT
M1300	51.04	17.15	7.59	7.54	11.84	2.70	0.17	1.06	0.12	99.09	MT
M1316	51.50	16.22	8.51	6.67	11.25	2.86	0.20	1.35	0.16	98.56	MT
M1330	51.27	15.96	8.43	6.71	11.21	2.86	0.20	1.37	0.15	98.16	MT
M1349	51.72	16.26	8.68	6.78	11.21	3.00	0.18	1.37	0.15	99.35	MT
M1355	51.64	16.37	8.55	7.42	11.30	3.09	0.12	1.30	0.13	99.92	MT
M1371	51.43	16.40	8.68	6.83	11.21	3.13	0.20	1.37	0.13	99.38	MT
M1372	51.40	16.19	8.56	7.00	11.27	3.00	0.21	1.39	0.16	99.18	MT
M1380	50.54	17.13	7.71	7.68	11.73	3.00	0.19	1.13	0.14	99.25	MT
M1381	50.67	17.08	7.66	7.93	11.84	2.93	0.18	1.09	0.13	99.51	MT
M1396	51.27	17.28	7.72	7.36	11.80	2.81	0.20	1.13	0.13	99.70	MT
M1410	50.51	17.59	8.01	7.01	11.65	2.67	0.26	1.15	0.13	98.98	MT
M1417	49.38	17.89	8.68	5.77	12.06	3.61	0.23	1.46	0.17	99.25	MT
M1419	50.68	17.20	7.89	6.90	11.44	2.66	0.27	1.14	0.14	98.32	MT
M1441	51.22	16.32	9.17	6.94	11.20	3.11	0.19	1.39	0.16	99.70	MT
M1463	50.15	15.98	9.76	6.89	11.84	3.49	0.18	1.59	0.18	100.06	MT
M14104	50.83	17.19	7.74	7.21	11.59	2.59	0.20	1.13	0.16	98.64	MT
M14106	49.96	16.92	7.83	7.26	11.52	2.65	0.27	1.06	0.13	97.60	MT
M454-4-CC	50.24	16.56	7.73	8.09	12.19	2.42	0.19	1.01	0.12	98.55	MT
M454-8-1	50.17	16.88	7.55	7.89	12.46	2.35	0.19	0.90	0.14	98.53	MT
M454-11-1	50.92	17.08	7.48	7.94	12.72	2.44	0.18	0.89	0.11	99.76	MT
M454-14-1	52.69	17.01	7.86	6.88	11.10	2.67	0.26	1.19	0.12	99.78	MT
M454-14-1	52.79	16.83	7.89	7.18	10.99	2.67	0.24	1.15	0.13	99.87	MT
M454-16-1	52.34	16.78	7.92	6.89	11.06	2.54	0.26	1.17	0.15	99.11	MT
M454-19-1	51.08	16.58	8.32	7.30	11.85	2.65	0.15	1.13	0.13	99.19	MT
SS20.13	51.70	16.23	8.14	6.99	11.14	3.11	0.25	1.37	0.20	99.13	SS
SS20.31	52.16	16.19	8.12	7.04	11.21	3.07	0.26	1.42	0.17	99.64	SS
SS20.35	51.69	16.36	7.99	7.09	11.24	3.09	0.23	1.34	0.16	99.19	SS
SS20.43	51.58	16.39	8.22	7.08	11.21	3.10	0.25	1.37	0.18	99.46	SS
SS23.4	51.34	15.99	8.91	6.69	11.36	3.38	0.35	1.54	0.20	99.76	SS
L203-6-3	51.99	16.18	7.52	7.14	12.64	2.07	0.28	0.70	0.16	98.68	LB
P54-8-1	50.11	17.36	9.29	8.06	11.26	2.94	0.11	0.99	0.11	100.23	PVB
P149-17-3	48.90	16.58	9.36	7.59	11.76	2.43	0.22	0.96	0.10	97.60	PVB
MORB-1	49.34	17.04	9.97	7.19	11.72	2.73	0.16	1.49	0.16	99.80	A
MORB-2	50.47	15.31	10.42	7.46	11.48	2.64	0.16	1.58	0.13	99.65	M

Note: Analyst, Timothy O'Hearn.

[a] Samples M03, M13, and M14 are from dredges 3, 13, and 14, respectively (Fig. 2). M454 samples are from DSDP Site 454.

[b] MT = Mariana Trough basaltic glass (this study); LB = Lau Basin basaltic glass (this study); PVB = Parece Vela Basin basaltic glass (this study); SS = Scotia Sea basaltic glass (this study); A = average mid-ocean ridge basalt (Aumento, 1968); M = average of basaltic glass from normal sections of the East Pacific Rise and the Mid-Atlantic Ridge; total: 64 samples (Melson et al., 1976).

[c] Duplicate analysis.

Table 3. Rare-earth element and large ion lithophile element abundances for selected basaltic glass samples from the Mariana Trough.

Sample[a]	M0379	M03102	M1300	M1316	M1417	M1419
Ce	11.2	16.1	10.5	11.5	15.0	11.6
Nd	8.36	12.3	8.64	10.3	10.9	9.52
Sm	2.73	3.82	2.66	3.38	3.19	2.91
Eu	1.08	1.38	1.03	1.25	1.25	1.08
Gd			3.83	4.49		
Dy	4.72	5.60	4.24	5.22	4.63	4.64
Er	3.28	3.48	2.51	3.27	2.90	2.94
Yb	3.18	3.27	2.40	3.09	2.92	2.67
Lu	0.47	0.50	0.35	0.45	0.42	0.40
Ba	38.4	75.2	31.0	35.1	66.0	48.4
K	1729	2338	1758	1993	1778	2350
Rb	2.34	3.93	2.48	3.00	1.37	3.52
Sr	147	182	176	161	212	166
Li	5.16	7.01	5.20	6.05	5.95	5.89

[a] See Note b, Table 1.

the volatile content of the lavas. However, the samples chosen for analysis in this study were fresh glasses, thus the problem of alteration does not apply. (2) Logging data (density) from Site 454 in the Mariana Trough indicate that some flows may be interbedded with sediment layers (see site chapter for Site 454, this volume). It has been suggested that the environment at this site would be suitable for sediment assimilation into the lavas erupted there (Wood et al., this volume). It is possible that the high water content of the glasses is a result of assimilation of sediment into the lavas. It seems unlikely, however, that the high water content also noted in inclusions in plagioclase phenocrysts (xenocrysts?) by Garcia et al. (1979) in the same samples derived from the incorporation of sediment into the lava. (3) Finally, the high volatile content of the BAB lavas may be related to the tectonic environment in which they formed. Each of the active back-arc basins from which we have

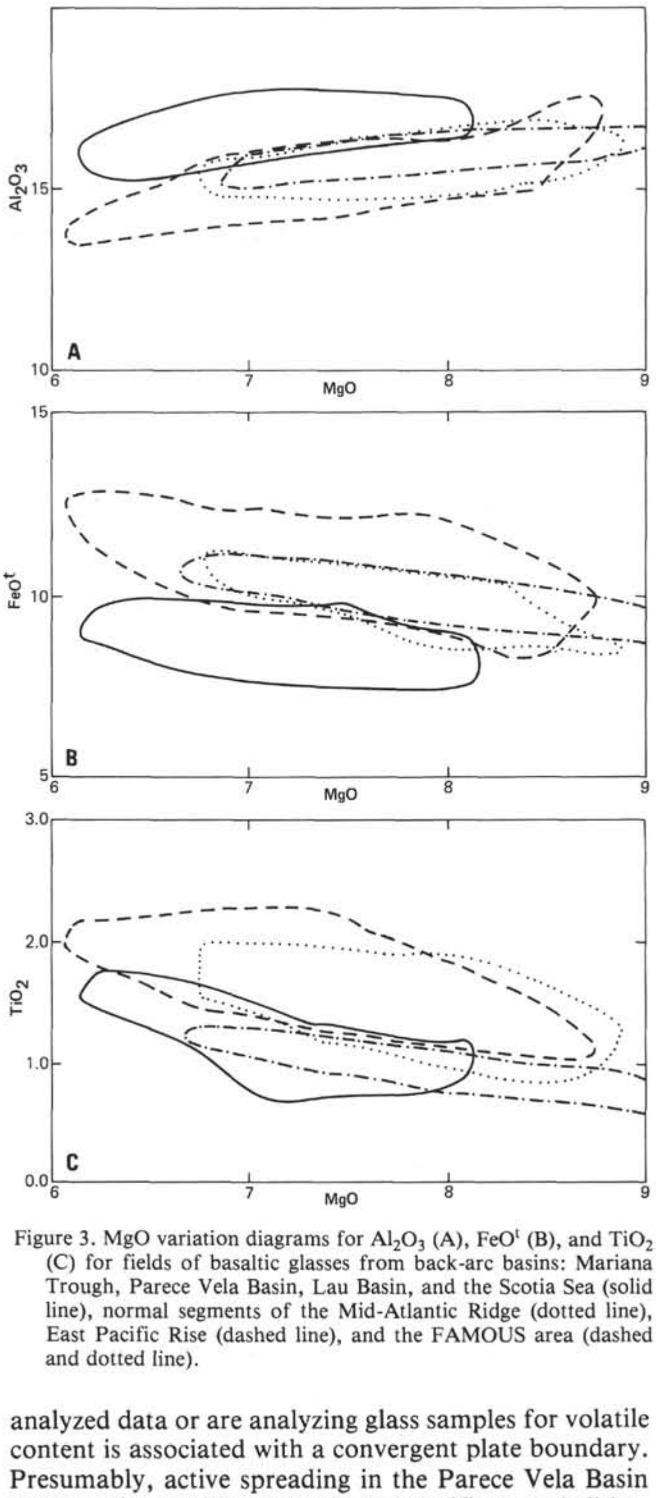

Figure 3. MgO variation diagrams for Al_2O_3 (A), FeO^t (B), and TiO_2 (C) for fields of basaltic glasses from back-arc basins: Mariana Trough, Parece Vela Basin, Lau Basin, and the Scotia Sea (solid line), normal segments of the Mid-Atlantic Ridge (dotted line), East Pacific Rise (dashed line), and the FAMOUS area (dashed and dotted line).

analyzed data or are analyzing glass samples for volatile content is associated with a convergent plate boundary. Presumably, active spreading in the Parece Vela Basin was associated with subduction of Pacific oceanic lithosphere before the opening of the Mariana Trough (Scott et al., in press). Volatile constituents of the subsiding oceanic plate are likely to permeate the overlying mantle to some extent. The Mariana Trough is a narrow basin and the subduction zone lies close to the spreading center. Thus volatiles in the basaltic glasses from that basin may more readily be assumed to originate in the subducted slab. In other back-arc basins, such as the Scotia Sea, the Benioff zone is much farther from the spreading center (see, for example, Barker, 1970). It is possible that convection patterns set up in the mantle above the subsiding plate (see Andrews and Sleep, 1973; Toksöz and Bird, 1977) could account for the lateral transport of volatiles necessary to enrich the regions below the spreading centers of such basins.

Analysis of existing trace element data collected so far impose several possible constraints on the nature and previous melting history of BAB lavas. The Mariana Trough glasses do not show the light REE depletion characteristic of normal MORB (Fig. 4). Patterns of REE for Mariana Trough glass and Scotia Sea whole-rock analyses are essentially flat relative to chondrites. and lie near the upper limit of the field of MORB at 15 to 20 times chondritic abundances.

If the sources of the lavas erupted in these back-arc basins had not been subject to previous episodes of melting they should have retained a primordial "chondritic" pattern of REE abundances. Basaltic liquids derived at high degrees of melting of such an undepleted source would be slightly enriched in light REE (Philpotts et al., 1972; Schilling, 1975b; Yoder, 1976). Relative enrichment in light rare earths is characteristic of "plume" magmas (Schilling, 1973a, 1973b, 1975a) with an undepleted source region different from and presumably deeper than the source region for normal MORB. The Philippine Sea plate is composed of normal MORB, depleted in light REE (Mattey et al., in press; Scott et al., in press). Thus the mantle source of those lavas has undergone at least one episode of melting. In order to produce magmas with chondritic REE patterns in a marginal basin formed adjacent to the Philippine Sea, a previously undepleted source, possibly material from deeper in the mantle, might be required.

Chondritic REE patterns can also occur in lavas produced from a very small degree of partial melting of a source that has experienced a previous episode of melting. The light REE are more strongly partitioned into a liquid in equilibrium with the common rock forming minerals (except for plagioclase) than are the heavy REE (Schnetzler and Philpotts, 1970). The concentration of a given REE in a liquid may be calculated according to the relationship presented by Schilling (1975b, Appendix I):

$$C_L{}^i = \frac{C_P{}^i}{Y(\sum_{j=i}^{j=n} K_j^i E_j) + \sum_{j=i}^{j=n} K_j^i X_j},$$

where

i = rare earth element,
j = phase,
C_L = concentration of rare earth element in liquid,
C_p = concentration of rare earth element in parent material,

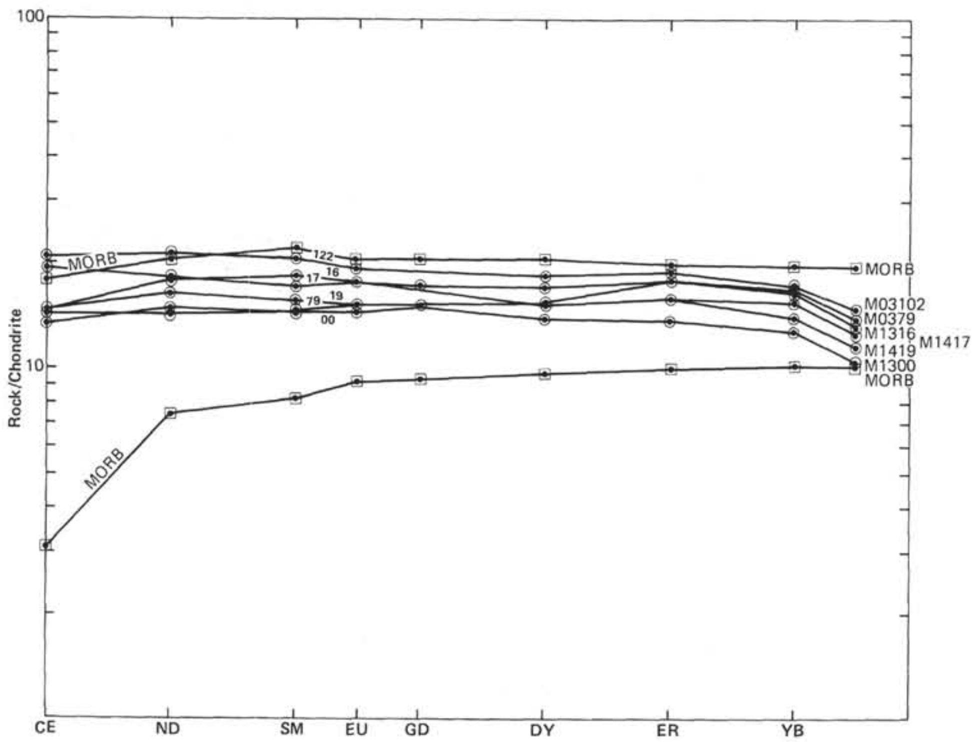

Figure 4. Chondrite normalized values of rare earth elements for six basaltic glasses from the Mariana Trough (circles) compared with the range of values for N-type MORB (squares).

Y = weight fraction of liquid (degree of melting),

K = partition coefficient between residual phase and liquid,

E = eutectic proportion in weight percent of phase j, and

X = fraction of residual phase remaining in equilibrium with liquid in weight percent.

From this relationship it can be seen that a very small amount of liquid in equilibrium with a light-REE-depleted source could segregate to produce a magma with a chondritic pattern. Even slightly greater amounts of melting would alter the REE signature considerably, however. It is unlikely that the marginal basin basalts represent such very small degrees of partial melting, since overall abundances fall within the field of N-MORB, and generation of MORB requires approximately 20 to 30% partial melting (Schilling, 1975b).

The patterns of REE abundances in rocks are influenced by the mineralogy of the source as well as by its melting history. The solid–liquid partition coefficients (C_S/C_L) of heavy REE in pyroxene and garnet are greater than those in the light REE, olivine shows little difference, and plagioclase is the only common rock-forming mineral in which C_S/C_L is greater for the light REE than for the heavy REE (Schnetzler and Philpotts, 1970). If plagioclase were an important component in the source of BAB, there should be a noticeable positive Eu anomaly in MBB lavas, since Eu is strongly partitioned into plagioclase. No such anomaly is present in our data.

Another indication of the character of the source derives from the incompatible element ratios of the Mariana Trough glasses (Table 3). These indicate that the source for BAB is indeed different from that of N-MORB. Ba concentration in the BAB samples is higher than that of MORB, and ratios of K/Ba, Ce/Ba, Sr/Ba, and K/Rb are lower than for N-MORB. Rb is depleted with respect to Sr in BAB lavas, indicating that the source for BAB may have experienced loss of melt in some previous event. Isotope ratios $^{87}Sr/^{86}Sr$ values from Mariana Trough basalts range from 0.7026 to 0.7029 (Hart et al., 1972; Meijer, 1976; Melchior and Hawkins, 1980), also implying a previous depletion event. The higher concentrations of Sr, Ba, Rb, and light REE in BAB relative to N-MORB probably reflects a later enrichment of the BAB source region with these elements.

It is obvious that interpretation of the present data is inconclusive regarding history of the source material for BAB magmas. One method which has proven useful for determining previous melting history of mantle source regions is Nd isotope studies (DePaolo and Wasserburg, 1976; O'Nions et al., 1977). We have selected samples representative of the range of rare earth values among the Mariana Trough glasses for Nd isotope analysis. These analyses will be completed shortly.

CONCLUSIONS

The data presented here, although preliminary, do permit several conclusions concerning the composition and generation of basalts in active back-arc basins: (1) Fresh basaltic glasses from all the active back-arc basins studied are similar in major and trace element compositions. (2) They differ from MORB in having higher Al_2O_3 and lower FeO^t for a given MgO concentration. Trace element abundances in the BAB lavas are more like P-MORB than N-MORB in having relatively higher concentrations of light REE and incompatible elements and lower ratios of K/Ba, Ce/Ba, Sr/Ba, and K/Rb. (3) With respect to Sr, K, Ba, and Rb concentrations, the sources for basalts from active back-arc basins are more like those of mantle plumes or hot spots than normal ridge segments. The sources for BAB are not as enriched in light REE as those of plume basalts, however probably the enriched lithophile elements Sr, K, Ba, and Rb and light REE concentrations reflect enrichment of the source regions of BAB with these elements. (4) The source of the volatile and enriched lithophile elements is problematic, but we feel that hydrous fluids or vapors derived from the subsiding oceanic lithospheric plate may enrich the source regions of BAB magmas with these elements.

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