103. THE PETROLOGY AND GEOCHEMISTRY OF BASALTS FROM SITE 396, LEGS 45 AND 46 OF THE DEEP SEA DRILLING PROJECT

M. A. Dungan,¹ J. M. Rhodes,² P. E. Long,¹ D. P. Blanchard,³ J. C. Brannon,² and K. V. Rodgers²

ABSTRACT

Legs 45 and 46 of the Deep Sea Drilling Project sampled a total of 351 meters of basaltic basement at Site 396. Several compositionally distinct eruptive units are found at this site, each having the characteristics of evolved mid-ocean ridge tholeiite. The minor and trace element abundances of the Site 396 basalts are also typical of LREE-depleted mid-ocean ridge tholeiite. Basalts sampled include aphyric and phyric basalts, the latter containing abundant plagioclase and olivine phenocrysts. Microprobe analyses of olivine microphenocrysts and coexisting glass in both basalt types yield a KD=0.27 for Fe-Mg partitioning between olivine and liquid. Application of this KD to phenocryst-bulk rock pairs indicates that many of the phenocrysts are more magnesian than the presumed equilibrium composition and must have been derived from a more primitive magma. One-atmosphere melting studies confirm this discrepancy. The diversity of zoning patterns in the plagioclase phenocrysts in the phyric basalts similarly indicates a mixed parentage for this phase. In addition, both the olivine and plagioclase phenocrysts contain Mg-rich, Ca-rich, Ti-poor melt inclusions which have compositional characteristics of more "primitive" magmas. Integration of these observations with major and trace element chemical data indicates that mixing of magmas and their attendant phenocrysts played an important role in the generation of these basalts. We suggest that mixing occurs as "primitive" picritic magmas are injected into zoned, fractionating magma chambers.

The basalts recovered from Site 395 are very similar to the Site 396 lavas in mineralogy, mineral chemistry, and bulk composition. The nearly identical trace element systematics of basalts from the two sites indicate derivation of these LIL-depleted magmas from a similar, compositionally homogeneous mantle source.

INTRODUCTION

A total of 351 meters of volcanic basement was sampled during Legs 45 and 46 at Site 396 (Hole 396 = 96 m; Hole 396B = 355 m), the vast majority of which consists of basaltic pillow lava. Hole 396B also includes a thin cooling unit (9 m) believed to be a single massive flow. Drilling in Hole 396B was terminated after the caving-in of a clastic unit comprised of fragments of pillow basalt. Emphasis in this paper has been placed on basalts from Hole 396B although data from Hole 396 are included.

We report 103 major element analyses on selected samples from Holes 396B and 396; 94 analyses of the minor and trace elements Rb, Sr, Y, Zr, and Nb, and 28 analyses of La, Ce, Sm, Eu, Tb, Yb, Lu, Hf, Cr, Sc, and Ni. These data are listed in Tables 1 and 2. Some of the individual rock samples obtained by onboard sampling were split into two sub-samples of either relatively fresh and altered

material or the glassy rind which was separated from the adjacent crystalline material (see Table 1). Where samples listed in Table 2 have multiple sub-samples, the material analyzed by neutron activation was the glassy or fresh split. Samples are listed throughout the tables in order of increasing depth, with the exception of JSC No. 215 (396B-15-5, 58-63 cm) which in fact belongs stratigraphically between JSC Nos. 221 and 222. Also indicated in Tables 1 and 2 are the major magmatic units, which were initially identified on the basis of shipboard X-ray fluorescence analyses, and modified slightly in the light of newly acquired data. The oxidation ratio (O.R.) in Table 1 is given as Fe²O₃/(total iron as FeO). The atomic ratio Mg/(Mg + Fe⁺²) is given as Mg' in this table and has been calculated after adjustment to a fixed oxidation state of iron such that $Fe^{+3}/(total iron as Fe^{+2}) = 0.1$ (Bass, 1971). The same convention for $Fe^{+3}/(Fe^{+2} + Fe^{+3})$ has been used in the CIPW norm calculations that are referred to in the text and illustrated in Figure 1. Table 3 is a listing of average compositions of the five chemically defined units in Hole 396B. The averages were calculated after exclusion of analyses of highly altered rocks (O.R. >0.4, H₂O > 2.0, and obvious loss of MgO relative to fresh samples).

¹Geology Branch, NASA Johnson Space Center, Houston, Texas.

²Lockheed Electronics Co., Houston, Texas.

³Geochemistry Branch, NASA Johnson Space Center, Houston, Texas.

Sample (Interval in cm)	4-1, 119-122	4-2, 75-75	6-1, 73-78	7-1, 10-14	7-1, 10-14	7-1, 42-46	7-1, 50-57	7-2, 16-20	7-2, 70-77	7-2, 118-122	7-2, 118-122	8-1, 76-82	8-1, 76-82	8-1, 84-94
JSC No.	180	181	182	183	183	184	185 (Std)	187	188	189	189	190	190	191
Unit	A ₁	AI	A ₁	A	A ₁	A ₁	A ₂	A ₂	A ₂					
Basalt Type				Glass			254			Fresh	Altered	Rock	Glass	Fresh
SiO ₂	50.01	48.03	50.22	49.32	49.52	48.81	49.24	49.23	49.03	49.10	48.87	49.18	49.78	49.26
TiO ₂	1.42	1.47	1.41	1.40	1.40	1.42	1.40	1.44	1.40	1.39	1.38	1.56	1.51	1.53
Al203	15.40	15.60	15.50	15.37	15.53	15.62	15.46	15.70	15.32	15.30	15.44	15.90	15.10	15.59
Fe2O3	2.10	2.52	4.54	1.75	3.30	3.81	3.58	2.74	4.19	3.12	3.71	2.22	4.64	4.59
FeO	7.40	6.15	4.67	7.61	6.26	5.90	5.98	6.99	5.51	6.06	.5.69	7.84	5.32	5.51
MnO	0.17	0.19	0.18	0.16	0.21	0.20	0.16	0.20	0.21	0.16	0.19	0.21	0.17	0.21
MgO	7.93	8.03	6.14	7.92	7.98	7.42	7.72	5.40	6.10	8.01	7.43	6.66	7.86	6.94
CaO	10.82	11.58	11.50	11.26	11.30	11.64	11.63	11.79	11.44	11.76	12.08	11.62	10.73	11.50
Na ₂ O	2.71	2.70	2.75	2.73	2.70	2.67	2.54	2.68	2.58					
K20	0.28	0.22	0.25	0.16	0.16	0.17	0.18	0.14	0.24	0.23	0.28	0.15	0.20	0.19
P205	0.12	0.12	0.12	0.10	0.10	0.11	0.11	0.12	0.11	0.12	0.11	0.15	0.12	0.12
S	0.11	0.07	0.02	0.09	0.11	0.07	0.06	0.07	0.04	0.03	0.04	0.06	0.11	0.05
Total H ₂ O	1.02	1.53	2.52	1.40	1.95	1.63	1.64	1.52	2.09	1.76	1.92	1.52	1.94	2.00
Total	99.49	100.06	99.82	99.27	100.56	99.47	99.70	98.02	98.26	99.80	99.82	99.84	100.30	100.28
Total Fe as FeO	9.29	9.32	8.76	9.18	9.23	9.33	9.20	9.46	9.28	8.87	9.03	9.84	9.50	9.64
Mg' value	0.628	0.630	0.581	0.631	0.631	0.612	0.624	0.531	0.566	0.641	0.620	0.573	0.621	0.588
O.R.	0.226	0.364	0.493	0.187	0.345	0.392	0.374	0.282	0.432	0.352	0.395	0.221	0.466	0.454
Trace elements (ppm)														
Rb	1.4	1.6	4.0		0.8	0.9	1.8	1.0	3.2	2.7		0.3		2.1
Sr	119	122	120		122	122	121	123	119	122		132		131
Y	30.2	31.6	30.2		31.7	31.5	30.2	30.9	28.9	29.5		34.8		33.9
Zr	96	93	93		93	93	94	93	93	87		103		103
Nb	1.7	1.9	2.0		1.8	1.7	2.1	1.1	1.8	1.6		1.5		2.9
Ni	1.111													

 TABLE 1

 Major and Trace Element Analyses of Basalts From Hole 396B, DSDP Leg 46

TABLE 1 – Continued

			and the second s											
Sample (Interval in cm)	13-1, 30-33	13-1, 102-105	13-1, 102-105	13-2, 21-25	13-2, 57-58	13-2, 130-134	13-2, 137-140	13-3, 3-5	14-1. 9-13	14-1, 9-13	14-1, 21-25	14-2, 39-46	14-2, 57-61	15-2, 54-61
JSC No.	201	202	202	203	204	205	206	207	208	208	209	210	211	212
Unit	A ₂	A ₂	A2	A ₂	A ₂	A2	A.2	A ₂						
Basalt Type	17	Glass	Rock	Glass			-	5	Glass	Rock	1.77		2550	
SiO ₂	50.16	49.39	48.88	48.92	50.28	49.38	50.17	49.18	49.37	49.01	49.24	49.26	48.64	48.62
TiO ₂	1.51	1.56	1.51	1.54	1.51	1.51	1.50	1.63	1.62	1.62	1.64	1.62	1.64	1.58
Al2O3	15.22	15.70	15.10	15.03	15.26	15.31	15.20	15.20	15.10	1.546	15.44	15.12	15.27	14.74
Fe ₂ O ₃	2.60	1.42	3.03	2.42	3.39	2.97	2.16	5.28	1.19	2.63	3.39	3.88	3.10	5.08
FeO	7.14	8.45	6.89	7.54	5.83	6.85	7.50	4.55	8.82	7.55	6.97	6.29	7.25	5.63
MnO	0.19	0.21	0.18	0.19	0.19	0.20	0.17	0.16	0.18	0.19	0.20	0.19	0.20	0.20
MgO	8.00	7.12	7.81	7.12	7.60	7.82	7.84	7.04	7.66	7.38	7.17	7.30	7.27	6.96
CaO	11.22	11.44	10.22	10.94	11.14	11.19	11.12	10.80	10.65	10.84	10.86	10.69	10.84	11.15
Na ₂ O	2.71	2.85	2.78	2.77	2.87	2.85	2.83	3.11	2.94	2.98	3.10	2.98	3.06	3.14
K ₂ O	0.22	0.17	0.38	0.16	0.25	0.22	0.14	0.27	0.15	0.22	0.26	0.37	0.27	0.29
P2O5	0.14	0.14	0.10	0.14	0.14	0.10	0.11	0.12	0.15	0.14	0.16	0.14	0.15	0.15
S	0.08	0.08	0.10	0.08	0.03	0.06	0.10	0.00	0.11	0.08	0.07	0.03	0.06	0.02
Total H ₂ O	1.47	1.53	2.40	1.40	2.47	1.97	1.21	2.52	0.98	1.32	1.68	1.86	1.40	2.09
Total	100.66	100.06	99.37	98.25	100.96	100.43	100.06	99.85	98.92	99.41	100.18	99.73	99.15	99.65
Total Fe as FeO	9.48	9.73	9.62	9.72	8.88	9.52	9.44	9.30	9.89	9.92	10.02	9.79	10.04	10.20
Mg' value	0.626	0.592	0.6116	0.592	0.629	0.619	0.622	0.600	0.618	0.596	0.586	0.596	0.589	0.575
O.R.	0.267	0.144	0.305	0.243	0.368	0.302	0.224	0.537	0.120	0.258	0.327	0.382	0.300	0.474
Trace elements (ppm)														
Rb	1.3		1.1	0.7	2.8	1.6	0.8	3.9	1.4	1.3		4.5	2.0	4.3
Sr	121		131	125	128	125	125	149	133	142		134	138	151
Y	33.1		34.1	31.9	33.1	32.6	33.1	35.2	35.2	36.3		33.7	35.6	33.6
Zr	100		105	104	103	101	102	118	120	119		113	118	112
Nb	2.0		2.1	2.3	1.7	2.4	1.5	2.3	2.1	2.2		1.7	1.9	1.7
Ni														

8-1, 84-94	9-2, 74-82	9-2, 74-82	9-3, 19-23	10-1, 96-101	10-2, 14-18	10-2, 14-18	10-2, 29-33	11-1, 70-73	11-1, 78-86	11-1, 78-86	11-2, 36-40	11-2, 36-40	12-1, 117-120
191	192	192	193	194	195	195	196	197	198	198	199	199	200
A2	A2	A ₂	A ₂	A2	A2	A2	A2	A ₂	A2	A ₂	A ₂	A ₂	A ₂
Altered	Glass	Rock			Glass			_	Fresh	Altered	Glass	_	
48.51	49.90	49.46	49.21	49.42	50.49	50.19	49.58	48.88	49.20	49.12	50.39	49.67	49.98
1.59	1.54	1.51	1.50	1.54	1.51	1.53	1.54	1.53	1.50	1.54	1.52	1.51	1.48
16.00	15.38	15.00	15.01	15.36	14.80	15.33	15.43	15.55	14.96	15.46	15.29	15.31	15.13
5.67	1.20	2.86	4.50	2.14	0.38	1.84	2.81	2.06	3.20	4.51	0.73	1.81	3.57
4.79	8.52	6.92	4.92	7.65	9.09	7.87	7.08	7.73	6.58	5.50	8.84	7.81	5.85
0.19	0.20	0.18	0.18	0.19	0.20	0.20	0.20	0.20	0.20	0.20	0.16	0.20	0.18
6.06	7.33	7.77	7.60	7.69	7.86	7.75	7.28	7.42	7.68	6.26	8.17	7.83	7.65
11.82	11.31	10.68	11.12	11.30	11.06	11.24	11.36	11.13	11.14	11.47	11.14	11.18	11.06
2.89	2.68	2.79	2.81	2.74	2.73	2.68	2.74	2.84	2.78	2.94	2.78	2.67	2.88
0.20	0.18	0.23	0.23	0.16	0.12	0.14	0.18	0.19	0.25	0.22	0.14	0.15	0.26
0.14	0.14	0.09	0.10	0.11	0.10	0.12	0.13	0.11	0.13	0.14	0.12	0.12	0.15
0.03	0.07	0.10	0.00	0.08	0.11	0.08	0.06	0.08	0.04	0.04	0.12	0.08	0.03
2.43	1.44	1.60	2.66	1.62	0.49	1.69	1.49	2.60f	1.94	2.72	0.74	1.30	2.53
100.32	99.81	99.19	99.84	100.00	98.93	100.65	99.88	100.19	99.60	100.20	100.14	99.64	100.75
9.89	9.60	9.49	8.97	9.58	9.43	9.53	9.61	9.58	9.46	9.56	9.50	9.44	9.06
0.548	0.602	0.619	0.627	0.614	0.623	0.617	0.600	0.605	0.617	0.565	0.630	0.622	0.626
0.542	0.123	0.286	0.478	0.219	0.040	0.189	0.284	0.210	0.327	0.450	0.076	0.188	0.379
2.3		1.0	3.1	1.0	0.9	1.0	1.2	1.4	3.3	2.9	0.9	0.9	3.2
133		127	144	127	114	123	129	130	124	131	120	125	133
34.0		32.5	32.3	33.2	31.3	32.4	33.7	32.9	32.3	33.9	25.3	33.7	31.1
107		103	102	105	99	102	104	105	101	106	104	104	98
1.5		2.2	1.8	2.1	2.0	2.4	2.1	2.0	1.5	1.8	1.9	2.0	2.2

TABLE 1 - Continued

TABLE 1 – Continued

15-2, 106-111	15-2, 120-133	15-5, 58-63	15-3, 25-33	15-3, 25-33	15-3, 40-51	15-3, 112-117	15-4, 20-26	15-4, 85-90	15-4, 142-149	15-5, 80-85	16-1, 20-24	16-1, 50-55	16-2, 3-16
213	214 (Std)	215	216	216	217	218	219	220	221	222	223	224	225
A ₃	A ₃	A ₃	A ₃	A ₃	A ₃	A ₃	A ₃	A ₃	A ₃	A ₃	в	В	в
			Fresh	Altered		2	2	2		1.55			Fresh
48.78	49.02	49.03	49.36	48.98	49.06	47.97	49.30	49.30	49.24	48.79	49.51	47.22	48.46
1.60	1.61	1.56	1.59	1.61	1.61	1.59	1.60	1.57	1.60	1.60	1.23	1.21	1.19
14.97	14.97	15.06	14.84	14.94	15.36	15.30	15.05	15.05	14.98	15.04	16.74	17.49	16.75
2.39	2.20	4.26	2.69	5.14	5.13	5.57	2.40	2.76	2.78	4.52	3.88	4.02	3.37
7.60	7.68	5.76	6.95	5.09	5.14	4.77	7.60	7.18	7.04	5.52	4.71	4.99	5.16
0.18	0.15	0.20	0.19	0.19	0121	0.21	0.19	0.17	0.20	0.20	0.19	0.19	0.18
7.94	7.96	7.38	7.50	7.22	6.84	5.68	7.51	7.82	7.45	7.33	6.60	6.58	7.47
10.56	10.58	10.52	10.46	10.59	10.70	11.72	10.55	10.52	10.57	10.59	11.98	12.16	11.83
3.10	2.97	2.96	2.89	2.85	2.92	3.12	2.89	2.85	2.75	2.91	2.66	2.65	2.60
0.12	0.12	0.31	0.14	0.26	0.27	0.22	0.16	0.13	0.19	0.28	0.19	0.15	0.22
0.13	0.13	0.12	0.14	0.16	0.15	0.14	0.15	0.14	0.15	0.12	0.09	0.08	0.09
0.11	0.12	0.011	0.15	0.03	0.01	0.00	0.13	0.12	0.13	0.02	0.00	0.02	0.02
1.98	2.35	2.27	2.42	2.29	2.52	2.54	2.16	2.05	2.38	2.31	2.47	1.78	2.00
99.46	99.87	99.46	99.33	99.35	99.92	98.83	99.68	99.67	99.46	99.30	100.25	98.54	99.34
9.75	9.66	9.60	9.37	9.72	9.76	9.78	9.76	9.66	9.54	9.59	8.20	8.61	8.19
0.617	0.620	0.604	0.613	0.595	0.581	0.535	0.604	0.616	0.607	0.602	01615	0.602	0.644
0.239	0.223	0.425	0.279	0.502	0.500	0.539	0.240	0.278	0.283	0.450	0.452	0.446	0.395
1.0	0.9	3.7		3.6	0.4	3.5	19	1.2	17	3.4	27	1.5	2.5
136	136	142		143	145	152	135	137	134	148	127	132	126
35.0	35.2	34.3		35.3	34.1	33.0	34.8	32.9	33.9	35.8	26.0	24.5	24.5
117	116	112		113	114	111	116	109	114	119	77	78	81
2.7	1.5	2.5		2.5	19	1.8	17	1.6	2.1	1.6	1.1	1.2	0.8

Sample 16-2, 16-3, 20-1, 61-64 20-1, 16-3, 16-5, 17-3, 17-3, 17-4, 18-1, 18-2, 18-2, 20-1, (Interval in cm) 3-16 46-51 46-51 130-134 73-81 73-81 4-11 3-11 124-131 9-14 102-104 136-138 JSC No. 225 226 226 227 228 228 231 232 233 234 235 236 229 230 Unit В В В В В В В В В B В В B₁ B Basalt Type Altered Glass Glass Fresh Altered SiO₂ 46.69 49.46 48.27 48.67 48.02 47.76 46.72 49.59 49.13 48.96 49.02 48.87 49.22 49.28 TiO₂ 1.29 1.23 1.21 1.17 1.24 1.30 1.28 1.20 1.18 1.16 1.17 1.12 1.14 1.13 Al203 17.96 16.70 17.46 16.78 16.43 17.88 18.71 18.46 16.93 16.81 16.7-16.78 17.24 17.29 Fe203 5.20 1.06 3.46 3.69 3.88 5.57 5.70 3.72 4.23 1.44 3.69 3.46 3.24 1.23 FeO 4.32 7.55 5.30 4.82 5.07 4.00 3.74 4.70 4.33 6.74 4.83 4.85 4.88 6.98 MnO 0.21 0.16 0.18 0.15 0.19 0.19 0.21 0.16 0.17 0.14 0.18 0.18 0.18 0.15 MgO 4.82 7.66 6.70 7.20 6.33 4.77 4.23 7.15 7.38 7.16 7.18 7.48 7.07 7.70 CaO 12.50 11.54 12.04 11.74 11.94 11.46 12.31 12.63 12.62 11.98 11.76 11.82 11.76 11.82 Na₂O 2.80 2.64 2.69 2.62 2.67 2.73 2.85 2.72 2.51 2.63 2.64 2.71 2.58 K20 0.16 0.17 0.16 0.16 0.14 0.15 0.24 0.21 0.20 0.08 0.19 0.21 0.21 0.21 P205 0.12 0.07 0.10 0.10 0.07 0.11 0.08 0.08 0.07 0.17 0.13 0.11 0.09 0.09 S 0.00 0.10 0.04 0.02 0.04 0.02 0.00 0.02 0.02 0.12 0.02 0.00 0.03 0.10 Total H₂O 2.40 1.03 1.82 2.18 1.54 2.26 2.95 2.25 2.27 2.04 2.07 2.31 2.27 1.49 Total 98.51 99.37 99.43 98.93 99.37 100.26 99.13 100.28 99.05 99.54 99.79 100.24 99.68 Total Fe as FeO 9.00 8.50 8.41 8.14 9.01 8.87 8.05 8.04 8.15 7.96 7.80 8.09 8.56 8.14 Mg' value 0.515 0.641 0.612 0.637 0.594 0.511 0.486 0.638 0.642 0.638 0.636 0.650 0.642 0.653 O.R. 0.546 0.123 0.395 0.434 0.434 0.582 0.604 0.442 0.494 0.176 0.433 0.416 0.399 0.150 Trace elements (ppm) Rb 2.6 1.2 2.3 2.9 2.5 0.9 2.4 3.1 2.8 1.7 1.1 1.1 2.6 Sr 131 127 127 130 137 135 132 127 123 129 131 126 127 Y 27.7 26.5 25.3 27.4 28.1 28.4 25.1 24.3 24.7 23.8 24.1 24.7 24.0 Zr 77 71 74 77 74 73 72 74 79 79 75 75 82 Nb 1.6 1.0 1.4 1.0 1.3 1.8 1.3 1.1 1.5 1.0 1.1 1.5 2.4 Ni

TABLE 1 - Continued

TABLE 1 - Continued

Sample (Interval in cm)	22-2, 75-80	22-3, 28-38	22-3, 81-90	22-3, 137-143	23-1, 46-50	24-1, 43-48	24-1, 94-98	30-1, 77-80	32-1, 3-8	32-1, 30-34	32-1, 34-36	32-1, 101-106
JSC No.	248	249 (STD.)	250	251	252	254	255	257	258	259	260	261
Unit	в	В	в	в	С	С	с	С	D	С	С	D
Basalt Type												
SiO ₂	48.63	48.24	47.44	48.88	48.11	49.39	47.92	50.69	50.36	48.59	49.80	48.71
TiO ₂	0.97	0.96	0.98	0.96	1.56	1.53	1.50	1.49	1.32	1.49	1.51	1.20
Al203	17.82	17.55	17.76	17.45	16.28	16.01	15.62	16.21	17.12	16.33	16.46	17.14
Fe2O3	3.08	2.96	3.13	1.79	4.53	4.46	3.09	1.58	2.46	3.28	3.26	3.20
FeO	4.75	4.81	4.70	5.86	5.42	4.41	6.22	7.64	5.86	6.19	6.20	4.98
MnO	0.18	0.13	0.17	0.18	0.19	0.20	0.18	0.19	0.20	0.15	0.17	0.17
MgO	7.68	7.75	7.34	8.27	6.59	6.74	7.66	7.94	6.94	7.11	7.10	7.04
CaO	11.89	12.12	12.00	12.20	11.26	11.29	11.22	11.24	11.74	11.46	11.52	11.64
Na ₂ O	2.57	2.43	2.47	2.48	2.90	2.92	2.78	2.82	2.79	2.74	2.79	2.75
K20	0.12	0.18	0.12	0.09	0.20	0.29	0.24	0.19	0.31	0.27	0.25	0.24.
P205	0.11	0.07	0.05	0.08	0.16	0.14	0.11	0.12	0.14	0.13	0.14	0.11
S	0.04	0.02	0.03	09	0.03	0.00	0.03	0.09	0.05	0.08	0.09	0.01
Total H ₂ O	2.91	2.19	3.01	1.60	2.35	2.88	1.87	1.01	1.44	1.58	1.64	2.20
Total	100.74	99.41	99.21	99.93	99.58	100.26	98.44	100.20	100.72	99.40	99.28	99.39
Total Fe as FeO	7.52	7.47	7.52	7.47	9.50	8.42	9.00	9.06	8.07	9.14	9.13	7.86
Mg' value	0.669	0.673	0.659	0.687	0.579	0.613	0.627	0.634	0.630	0.606	0.606	0.639
O.R.	0.393	0.381	0.400	0.234	0.455	0.503	0.331	0.171	0.296	0.346	0.345	0.391
Trace elements (ppm)												
Rb	1.1	2.5	1.2	0.6	0.7	4.3	2.3		3.1	1.7	1.5	3.3
Sr	113	119	116	123	161	161	157		152	156	154	158
Y	20.7	21.0	21.1	20.3	35.5	32.2	31.4		27.1	31.3	32.0	25.4
Zr	57	59	60	58	110	111	109		91	107	108	84
Nb	0.9	0.5	0.7	0.8	4.1	3.3	3.3		2.9	2.9	3.8	3.4
Ni												

 TABLE 1 - Continued

20-1, 136-138	20-2, 58-67	20-3, 109-111	20-3, 109-111	20-4, 13-16	20-4, 13-16	20-5, 3-10	20-5, 71-75	20-6, 27-34	20-6, 44-53	21-1, 13-16	22-1, 8-13	22-1, 88-92	22-2, 7-13
236	237	238	239	239	239	240	241	242	243	244	245	246	247
В	В	В	В	в	в	в	в	в	в	в	В	в	В
		Glass		Glass	Rock								
48.12	49.70	48.78	48.58	49.61	49.40	49.34	48.60	49.15	48.22	47.96	47.95	48.02	48.44
1.18	1.15	1.06	1.10	1.04	1.09	1.10	1.01	0.98	0.94	1.00	0.93	0.96	0.93
17.70	17.78	17.13	18.10	17.57	16.87	16.88	18.24	17.55	17.21	18.54	17.65	17.34	17.57
3.61	3.16	1.16	3.42	1.16	3.20	4.44	3.64	2.24	2.96	2.98	2.94	3.26	2.27
5.05	5.30	6.94	5.16	6.82	5.16	4.16	4.35	5.49	4.64	4.85	4.54	4.62	5.14
0.17	0.19	0.14	0.17	0.13	0.18	0.19	0.18	0.17	0.17	0.15	0.16	0.19	0.16
6.09	6.74	7.52	6.77	7.71	7.07	7.15	6.97	7.97	7.90	6.97	7.68	7.80	7.42
12.25	12.22	11.71	12.62	11.80	12.11	11.97	12.01	12.26	11.80	11.99	11.87	11.89	12.17
2.58	2.63	2.48	2.48	2.58	2.68	2.63	2.64	2.57	2.58	2.48	2.64	2.50	2.57
0.16	0.17	0.20	0.13	0.19	0.18	0.27	0.12	0.13	0.16	0.14	0.14	0.12	0.11
0.09	0.11	0.06	0.06	0.08	0.10	0.09	0.09	0.07	0.07	0.06	0.07	0.09	0.06
0.02	0.05	0.08	0.03	0109	0.02	0.02	0.04	0.08	0.01	0.04	0.01	0.04	0.08
2.21	1.79	1.71	1.59	1.35	1.79	1.90	2.23	1.93	2.29	2.67	2.77	2.81	1.70
99.24	100.99	98.97	100.21	100.13	99.84	100.15	100.12	100.59	98.95	100.83	99.36	99.64	98.62
8.30	8.14	7.98	8.24	7.86	8.04	8.16	7.63	7.51	7.30	7.53	7.19	7.55	7.18
0.592	0.621	0.651	0.619	0.660	0.635	0.634	0.644	0.677	0.682	0.647	0.679	0.672	0.672
0.417	0.374	0.143	0.399	0.145	0.383	0.516	0.456	0.290	0.389	0.381	0.393	0.414	0.306
1.2	1.7	1.8	0.8	2.8	3.1	5.6	0.7	1.4	27	1.0	2.2	1.5	1.5
128	128	123	124	124	122	121	119	119	118	122	111	112	123
25.4	24.6	21.9	22.4	23.9	22.5	24.2	22.2	24.5	20.1	20.7	20.1	21.1	19.7
73	72	65	65	66	63	68	61	68	57	58	55	59	56
1.4	1.6	0.5	1.3	1.0	1.5	0.7	1.0	1.0	1.0	0.7	1.8	0.6	1.4

However, these average compositions still reflect minor effects of compositional changes produced by basalt-seawater interaction. Table 4 is a listing of 89 microprobe analyses of natural glasses that occur in basalts at both Sites 395 and 396. The same notations and conventions that apply to the bulk rock data in Tables 1 and 2 are used in Table 4. Sample numbers in the JSC series from Site 396 are equivalent to the same numbers used in Rhodes et al. (1978). In addition to microprobe analyses of natural glasses, three-element reconnaissance microprobe analyses of olivine and plagioclase phenocrysts and microphenocrysts are presented for a representative suite of rock samples. Table 5 is a representative listing of spinel analyses (six elements) from phyric basalts in Holes 396 and 396B.

In addition, we have performed one-atmosphere melting experiments on three natural rock powders to determine their melting relations. The compositions of mineral phases coexisting with liquid in these experimental charges have been determined as a function of temperature (Table 6). Linear cooling-rate experiments have been performed on all three rocks at three cooling rates to determine the dependence of textural variation on cooling history.

Our purpose is to relate the mineralogy and mineral chemistry of the various flow units to the bulk chemistry and the crystallization histories of the individual samples. Integration of these data with the results of experimental melting studies provides some constraints on the fractionation of the units and their interrelationships. This combination of techniques has led us to the conclusion that the mixing of magmas is an important factor in the differentiation of the Hole 396B basalts.

ANALYTICAL TECHNIQUES

The major element data were obtained by X-ray fluorescence analysis (XRF) of fused glass discs, prepared by fusing the sample with a lanthanum-bearing lithium borate fusion mixture (Norrish and Hutton, 1969). FeO was determined titrimetrically using the modified cold acid digestion method of Wilson (Maxwell, 1968); Fe₂O₃ was obtained by difference from the XRF total iron value. Na₂O was obtained on a separate 20 to 30 mg aliquot by instrumental neutron activation analysis (INAA). Total water content was measured coulometrically using a DuPont moisture analyzer, in which the sample is fused with a lead oxide flux.

The trace elements (Rb, Sr, Y, Zr, Nb, and Ni) were determined by XRF analysis on pressed powder pellets. Corrections were made for non-linear background, tube contamination, and inter-element interferences (Norrish and Chappell, 1967). Corrections for matrix effects were based on a modification of the Compton scattering method (Reynolds, 1967), using the Ag-Compton peak. Additional trace element data (Table 2; La, Ce, Sm, Eu, Tb, Yb, Lu, Hf, Cr, Sc, and Ni) were obtained by INAA following the methods of Jacobs et al. (in press).

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TABLE 2 Trace Element Abundances (ppm) in Selected Samples From Holes 396 and 396B

Hole	396	396	396	396	396B	396B	396B	396B	396B	396B	396B	396B	396B	396B
Sample (Interval in cm)	13-1, 73-76	15-1, 110-115	23-1, 58-61	25-1, 134-139	4-1, 119-122	7-1, 50-57	7-2, 118-122	8-1, 76-82	9-2, 74-82	10-2, 14-18	13-1, 102-105	13-3, 3-5	14-1, 9-13	15-2, 120-133
Depth (m)	109	128	202	221	154	176	182	185	199	209	221	225	226	238
Unit	-	1.77		7	A ₁	A ₁	A ₁	A2	A ₂	A2	A ₂	Α3	A ₃	Α3
JSC No.	177	173	172	170	180	185 (Std)	189	190	192	195	203	207	208	214 (Std)
Sc	38.8	33.4	34.5	35.0	38.6	38.2	38.7	38.7	38.6	38.7	39.1	38.8	39.5	38.6
Cr	310	440	300	290	350	340	300	310	300	300	300	290	300	300
Ni	115	175	90	70	140	150	80	100	110	95	120	100	110	130
La	3.64	2.72	2.54	2 75	2.99	2.88	3.1	3.21	3.21	3 34	3.16	3 75	3 76	3.65
Ce	11.5	8.9	8.4	8.9	9.9	10.0	10.6	10.4	10.7	10.7	10.8	11.5	12.0	12.5
Sm	3.85	2.82	2.99	3.02	3 25	3.25	3.51	3.48	3 4 4	3.62	3.52	3.94	4.06	3.96
Eu	1.38	1.04	1.11	1.12	1.18	1.18	1.29	1.24	1.25	1.26	1.27	1 44	1.43	1.41
Tb	1.0	0.71	0.78	0.85	0.84	0.84	0.88	0.89	0.94	0.93	0.93	0.96	0.96	1.0
Yb	3.5	2.48	2.79	3.0	3.2	3.2	3.2	3.2	3.3	3.6	3.5	3.6	3.7	3.8
Lu	0.54	0.39	0.44	0.45	0.45	0.49	0.50	0.52	0.52	0.53	0.52	0.57	0.61	0.55
Hf	3.1	2.3	2.4	2.4	2.5	2.4	3.1	2.8	2.7	2.7	2.7	2.7	3.1	3.1



e.

Figure 1. Normative olivine-plagioclase-pyroxene relationships in basalts from both Legs 45 and 46. The empirically determined olivine-plagioclase cotectic is from Shido et al. (1971).

 TABLE 2 - Continued

396B	396B	396B	396B	396B	396B	396B	396B	396B	396B	396B	396B	396B	396B
15-4, 85-90	16-3, 46-51	16-5, 130-134	17-4, 75-81	18-1, 124-131	20-1, 136-138	20-3, 109-111	21-2, 13-16	22-3, 28-38	23-1, 46-50	24-1, 94-98	30-1, 77-80	32-1. 30-34	32-1, 34-36
242	249	254	273	275	288	291	297	311	318	333	382	389	389
A ₃	В	в	в	В	В	В	в	в	С	С	С	С	С
220	226	227	230	232	236	238	244	249 (Std)	252	255	257	259	260
39.9	35.2	34.3	33.5	33.2	33.2	32.6	32.1	31.7	38.6	37.4	36.0	36.5	37.0
295	320	330	315	320	340	350	340	370	320	330	310	320	310
140	100	120	120	90	120	120	150	110	130	130	110	100	110
3.17	2.53	2.44	2.31	2.43	2.30	1.95	2.07	1.89	4.39	4.19	3.97	3.97	4.10
11.4	8.0	8.5	8.2	7.9	8.0	6.9	6.6	6.4	13.0	13.2	12.0	12.0	12.5
4.0	2.87	2.83	2.71	2.68	2.69	2.42	2.31	2.33	3.81	3.55	3.62	3.62	3.56
1.45	1.08	1.04	1.06	1.05	0.99	0.93	0.99	0.89	1.28	1.26	1.26	1.26	1.30
0.97	0.79	0.78	0.69	0.78	0.65	0.63	0.64	0.60	1.0	0.86	0.89	0.89	0.94
3.7	2.9	2.7	2.5	2.7	2.5	2.4	2.2	2.2	3.6	3.3	3.4	3.4	3.4
0.58	0.41	0.43	0.39	0.40	0.43	0.40	0.34	0.36	0.53	0.53	0.50	0.50	0.55
3.5	2.2	2.1	2.5	2.1	1.9	1.8	1.8	1.6	3.0	2.7	2.6	2.8	3.0

 TABLE 3

 Average Compositions of Chemically Defined Basalt Types From Hole 396B

	А	1	A	1	A	2	A	2	A	3	A ₃	(0		С	B		j	в
	Ro (7	ock ()	Glas (3)	s	Re (2	ock	Gl: (1	ass 0)	Rc (1	ock 2)	Glass (1)	Ro (e	ock 5)	G	lass (8)	Rc (2	ck 6)	GI (?	ass 8)
SiO	49.28	±0.39	50.38	±0.13	49.65	±0.51	50,63	±0.19	49.11	±0.25	50.20	49.08	±1.07	49.75	±0.12	48.70	±0.58	50.59	±0.17
TiO ₂	1.40	±0.01	1.35	±0.03	1.52	±0.02	1.47	±0.02	1.61	±0.02	1.58	1.51	±0.03	1.47	±0.02	1.08	±0.11	1.29	±0.09
Al203	15.44	=0.10	15.19	±0.02	15.24	±0.22	14.97	±0.01	15.11	±0.19	15.08	16.15	±0.30	15.62	±0.05	17.31	±0.51	15.02	±0.10
Cr2O3			0.05	±0.01			0.04	±0.01			0.05			0.04	±0.001			0.05	
FeO	9.16	±0.16	9.43	±0.01	9.32	±0.69	9.71	±0.06	9.75	±0.20	9.91	9.04	±0.35	9.39	±0.03	7.84	±0.39	9.42	±0.32
MnO	0.18	±0.02	0.17	±0.01	0.19	±0.01	0.18	±0.01	0.19	±0.01	0.17	0.18	±0.03	0.17	±0.01	0.17	±0.02	0.18	±0.01
MgO	7.86	±0.22	8.03	±0.02	7.63	±0.31	7.85	±0.06	7.52	±0.27	7.26	7.19	±0.52	7.78	±0.06	7.40	±0.42	7.79	±0.16
CaO	11.49	±0.41	11.67	±0.06	11.11	±0.28	11.39	±0.04	10.64	±0.14	11.04	11.33	±0.13	11.39	±0.09	11.92	±0.21	12.02	±0.14
Na ₂ O	2.68	±0.07	2.66	±0.03	2.78	±0.06	2.77	±0.03	2.95	±0.10	2.96	2.83	±0.07	2.89	±0.03	2.59	±0.08	2.69	±0.05
K20	0.22	±0.05	0.12	±0.01	0.20	±0.06	0.13	±0.004	0.20	±0.08	0.12	0.24	±0.04	0.19	±0.01	0.16	±0.04	0.11	±0.01
PoOs	0.11	±0.01	0.14	±0.01	0.12	±0.02	0.14	+0.01	0.14	+0.01	0.17	0.13	±0.02	0.16	±0.01	0.08	±0.02	0.12	±0.02
s	0.07	±0.03		± .	0.08	±0.03			0.09	±0.04		0.06	±0.03			0.05	±0.03		
Mg^1	0.629	±0.007	0.627	±0.0005	0.61	5 ±0.012	0.616	5±0.012	0.60	5 ±0.011	0.592	0.61	1 ±0.002	0.62	2 ±0.001	0.65	±0.021	0.621	±0.012
Rb	1.7	±0.7			1.6	±0.9			1.9	±1.1		2.0	±1.5			1.9	±0.9		
Sr	119	±4			127	±6			137	±5		158	±3			123	±6		
Y	30.6	±1.0			32.4	±2			34.8	±1.1		32.5	±1.7			23	±2		
Zr	93	±3			103	±2			116	±3		109	±2			67	±8		
Nb	1.8	±0.2			2.0	±0.3			1.9	±0.4		3.5	±0.5			1.1	±0.4		
	A,	A ₂	A ₂	В	(:													
	(3)	(4)	(4)	(8)	(\$	5)													
La	2.99	3.23	3.73	2.2	4 4.	12													
Le	10.2	10.6	11.9	7.6	12.	5													
Sm	3.34	3.52	3.99	2.6	1 3.	63													
Fu	1.24	1.26	1.43	1.0	0 1.	27													
Tb	0.87	0.92	0.97	0.7	0 0.	92													
Yb	3.2	3.4	0.37	2.5	3.	4													
Lu	0.50	0.52	0.58	0.4	0 0.	52													
Hf	2.8	2.7	3.1	2.0	2.	8													
Sc	38.5	38.8	39.2	33.2	37.	1													
Cr	330	305	295	335	320														
Nī	125	105	120	115	115														
La/Sm	0.90	0.92	0.93	0.8	6 1.	13													
La/Yb	0.93	0.95	1.00	0.9	0 1.	21													
Zr/Ng	\$1.7	51.5	61.0	60.9	31.	1													
Zr/Y	3.04	3.18	3.33	2.9	1 3.	35													
Sr/Zr	1.28	1.23	1.18	1.8	4 1.	45													
Sm/Eu	2.69	2.79	2.79	2.6	1 2.	86													

Microprobe analyses were performed on a three-channel ARL-EMX instrument at standard operating conditions using natural mineral standards.

BASALT CHEMISTRY

All the basalts recovered from Holes 396 and 396B are olivine and hypersthene-normative and plot in the olivine

tholeiite field of the basalt tetrahedron (Yoder and Tilley, 1962). Alkali basalts and transitional tholeiites are conspicuously absent, as are quartz tholeiites. They have the overall compositional characteristics typical of mid-ocean ridge tholeiites, as is evidenced by their relatively constant SiO₂ concentrations and low TiO₂ abundances, together with low total alkali content and

5207070-003						Hold	396B							
Sample (Interval in cm)	4-1, 119-122	7-1, 10-14	7-2, 16-20	8-1, 76-82	9-2, 74-82	10-1, 96-101	10-2, 29-33	11-1, 70-73	11-1, 78-86	13-1, 102-105	13-2, 21-25	13-2, 130-134	13-2, 137-140	14-1, 9-13
Unit	A ₁	A ₁	А1	A2	A2	A2	A ₂	A2	A2	A2	A2	A2	A2	A3
JSC No.	180	183	187	190	192	194	195	197	198	202	203	205	206	208
SiO ₂	50.39	50.24	50.50	50.55	50.43	50.49	50.94	50.77	50.68	50.60	50.76	50.76	50.32	50.20
TiO ₂	1.34	1.38	1.33	1.45	1.47	1.47	1.47	1.43	1.47	1.48	1.48	1.49	1.45	1.58
Al2O3	15.20	15.17	15.21	14.99	14.96	14.96	14.98	14.97	14.97	14.97	14.98	15.00	14.95	15.08
Cr ₂ O ₃	0.04	0.06	0.04	0.05	0.02	0.04	0.04	0.05	0.04	0.04	0.03	0.04	0.05	0.05
FeO	9.44	9.42	9.44	9.70	9.75	9.78	9.67	9.71	9.80	9.67	9.72	9.74	9.59	9.91
MnO	0.18	0.18	0.16	0.17	0.18	0.18	0.19	0.18	0.18	0.16	0.17	0.18	0.19	0.17
MgO	8.02	8.06	8.02	7.95	7.82	7.89	7.84	7.87	7.88	7.76	7.84	7.88	7.78	7.26
CaO	11.74	11.62	11.66	11.41	11.43	11.40	11.40	11.42	11.35	11.41	11.42	11.38	11.31	11.04
Na ₂ O	2.65	2.70	2.64	2.78	2.78	2.78	2.79	2.78	2.80	2.77	2.75	2.77	2.70	2.96
K20	0.12	0.12	0.11	0.13	0.12	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.12	0.12
P205	0.13	0.14	0.14	0.14	0.15	0.16	0.12	0.13	0.13	0.15	0.14	0.15	0.16	0.17
Total	99.25	99.09	99.25	99.32	99.09	99.28	99.57	99.44	99.43	99.11	99.42	99.52	98.62	98.44
Mg'	0.627	0.628	0.627	0.619	0.614	0.615	0.616	0.616	0.614	0.614	0.615	0.616	0.616	0.592
q	-	-	-	÷=0		-	-	-	-		140 C	1	-	-
or	0.71 ^a	_		0.77 ^a	-		12	_	-	1.2.4	100	12	-	0.71
ab	22.51	-	-	23.52	-	120	177		-	-	77	-	-	25.05
an	29.15	-	-	27.99	-	-	19 1	-	-	-		-	-	27.51
di	22.82	\rightarrow	-	22.61	-	-		-	\sim	-	-	-	-	21.50
hy	14.36	-	-	15.10	-	-	100	-		-	141	-	<u>140</u>	13.86
ol	5.30		_	4.69	-	-	-	-	-	-	-		100	4.98
mgt	1.52	-	-	1.57	-	-	-	-	-		-	-	77.2	1.59
chr	0.06	-	-	0.06	-	-		-	100			0.00	-	0.07
il	2.56	H0	-	2.79	-	-	0.00		-	-	-	0.4	-	3.00
ap	0.28	1	-	0.33	-	221	12	(22)	12	-	227	152		9.37
phase	res.	res.	res.	res.	res.	res.	res.	res.	res.	res.	res.	res.	res.	res.

 TABLE 4

 Electron Microprobe Analyses of Residual Glasses and Glass Inclusions in Olivine and Plagioclase

 TABLE 4 - Continued

	Hole	396B	Hole 396	Hole 395									9	Hole 395A
Sample (Interval in cm)	30-1, 77-80	32-1, 34-36	15-1, 110-115	18-2, 43-46	17-1, 46-55	26-2, 125-129	28-1, 116-122	56-3, 62-65	17-1, 46-55	26-2, 125-129	26-2, 125-129	29-1, 125-131	28-1, 116-122	28-1, 116-122
Unit	С	С	в	P1	P ₃	P4	P ₅	A3	P ₃	P4	P ₄	P ₅	P ₅	P ₅
JSC No.	257	260	173	115	131	137	140	154	131-1	137-1	137-2	141-1	140-1	140-2
SiO ₂	49.65	49.87	50.23	50.69	51.03	51.07	50.65	50.44	51.69	51.35	51.28	51.51	50.78	50.57
TiO ₂	1.48	1.49	1.34	1.44	1.38	1.47	1.58	1.73	1.34	1.18	1.15	1.08	1.48	1.57
Al203	15.55	15.65	15.64	14.23	14.49	14.34	14.75	14.93	17.45	15.11	15.21	17.69	14.29	14.03
Cr2O3	0.04	0.05	0.05	0.04	0.06	0.04	0.04	0.03	0.05	0.04	0.04	0.05	0.05	0.05
FeO	9.39	9.44	9.06	9.98	9.06	9.98	9.88	9.90	7.58	9.61	9.67	7.62	10.13	10.09
MnO	0.16	0.19	0.18	0.14	0.16	0.17	0.20	0.21	0.13	0.15	0.16	0.16	0.17	0.18
MgO	7.72	7.73	7.94	7.42	7.63	7.28	7.24	7.51	4.35	6.89	6.27	3.59	7.50	7.50
CaO	11.40	11.50	11.32	11.77	11.96	11.58	11.50	10.79	13.20	12.37	12.92	14.78	11.50	11.48
Na ₂ O	2.86	2.88	2.83	2.59	2.51	2.83	3.07	2.93	3.02	2.60	2.56	2.73	3.01	3.01
K20	0.18	0.18	0.13	0.11	0.11	0.12	0.12	0.15	0.12	0.10	0.09	0.06	0.14	0.14
P205	0.15	0.15	1.2	21	-	_	22	_	1217	_	-	2	0.11	0.15
Total	98.58	99.17	98.73	98.41	99.21	98.80	99.40	99.02	98.93	99.40	99.33	99.27	99.16	98.77
Mg'	0.620	0.619	0.634	0.600	0.605	0.593	0.583	0.591	0.532	0.587	0.592	0.483	0.594	0.595
q	-		-	201		_	-	_	1.29	-	0.27	1.75	76.00	12
or	22	+	0.77	0.65	0.65	0.71	0.71	0.89	0.71	0.59	0.59	0.35	0.83	0.83
ab	175	-	23.95	21.92	21.24	23.95	25.98	24.79	25.56	22.00	21.66	23.10	25.47	25.47
an	-		29.59	26.88	27.95	26.07	26.11	27.14	33.71	29.26	29.72	35.84	25.07	24.36
di	-	14	21.65	25.80	25.68	25.70	25.37	21.61	26.21	26.34	28.31	31.17	25.66	25.96
hy	S	12	11.70	17.83	18.67	15.86	9.34	14.33	7.71	17.31	15.12	3.79	11.37	11.43
ol	20	122	7.09	1.04	0.84	2.18	7.30	5.39	-	0.15	-	-	6.12	5.83
mgt			1.45	1.61	1.59	1.59	1.65	1.65	1.22	1.55	1.55	1.23	1.64	1.62
chr	100	-	0.07	0.06	0.09	0.06	0.04	0.07	0.07	0.06	0.06	0.07	0.07	0.07
il.	94 S	-	2.54	2.73	2.62	2.79	3.00	3.29	2.54	2.24	2.18	2.05	2.81	2.98
ap	141	04	2000	04234.2	-	-	-	-	-	-	-	-	0.24	0.33
phase	res.	res.	res.	res.	res.	res.	res.	res.	oliv.	oliv.	oliv.	oliv.	plag.	plag.

TABLE 4 – Continued

					Hol	e 396B							
16-3, 46-51	17-4, 4-11	20-1, 136-138	20-2, 58-67	20-3, 109-111	20-4, 13-16	20-5, 71-75	22-3, 28-38	23-1, 46-50	23-1, 52-55	23-1, 52-55	23-1, 52-55	23-1, 52-55	26-1, 7-8
в	В	в	в	в	в	в	в	С	С	С	С	С	С
226	229	236	237	238	239	241	249	252	253-1	253-2	253-3	253-4	256
50.52	50.71	50.53	50.47	50.78	50.27	50.72	50.69	49.65	49.65	49.76	49.72	49.72	49.98
1.38	1.34	1.40	1.36	1.23	1.24	1.24	1.15	1.48	1.45	1.45	1.47	1.47	1.49
14.90	14.89	14.99	14.95	15.05	15.14	15.09	15.16	15.55	15.60	15.64	15.64	15.63	15.67
0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.03	0.05	0.03	0.05	0.05	0.04
9.84	9.65	9.64	9.69	9.17	9.24	9.14	8.97	9.39	9.40	9.39	9.35	9.38	9.35
0.19	0.17	0.18	0.16	0.17	0.17	0.18	0.19	0.16	0.16	0.16	0.17	0.16	0.16
7.69	7.55	7.72	7.70	7.87	7.95	7.85	8.02	7.72	7.90	7.80	7.80	7.79	7.79
11.81	11.89	11.94	11.91	12.12	12.15	12.13	12.18	11.40	11.32	11.36	11.26	11.33	11.51
2.73	2.75	2.74	2.70	2.64	2.65	2.64	2.63	2.86	2.91	2.87	2.93	2.90	2.93
0.12	0.12	0.11	0.12	0.11	0.11	0.11	0.11	0.18	0.18	0.20	0.19	0.20	0.19
0.12	0.15	0.12	0.14	0.10	0.10	0.10	0.10	0.15	0.14	0.16	0.15	0.17	0.18
99.35	99.27	99.42	99.25	99.29	99.07	99.25	99.25	98.57	98.76	98.82	98.73	98.80	99.29
0.607	0.608	0.613	0.611	0.630	0.630	0.630	0.639	0.620	0.625	0.622	0.623	0.622	0.622
-	-	-	-	-	-	1.77	-	-	-	-	-	-	-2-
0.71	0.71	0.65	0.71	0.65	0.65	0.65	0.65	1.12 ^a		-	-	et (1.77
23.10	23.27	23.19	22.85	22.34	22.42	22.34	22.26	23.69	-	-	-	-	0.000
28.05	27.93	28.28	28.32	28.89	29.09	29.00	29.24	29.49	-	10	(#C	-	-
24.40	24.68	24.72	24.47	25.00	24.95	24.95	24.93	21.32	-	-	-	21	722
13.40	14.07	12.70	13.49	14.27	11.61	14.03	13.34	10.60	-		1.77	57.2	
5.26	4.23	5.45	5.00	4.14	6.32	4.26	5.01	7.95	-		-	-	1.00
1.58	1.55	1.55	1.57	1.48	1.49	1.46	1.45	1.51	-		2 -		100
0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.06	-		22	24	12
2.62	2.54	2.66	2.58	2.34	2.36	2.36	2.18	2.79	-			20	
0.26	0.33	0.26	0.31	0.22	0.22	0.22	0.22	0.33			-	-	100
res.	res.	res.	res.	res.	res,	res.	res.	res.	res.	res.	res.	res.	res.

 TABLE 4 - Continued

	Hole 395A							Hole 395							
28-1, 116-122	18-2, 43-46	18-2, 43-46	18-2, 43-46	18-2, 43-46	18-2, 43-46	18-2, 43-46									
P ₅	P1	P ₁	PI	P ₁	P ₁	P1									
140-3	140-4	140-5	140-6	140-7	140-8	140-9	140-10	115-1	115-2	115-3	115-4	115-5	115-6		
50.64	50.42	50.46	50.89	50.74	51.05	50.43	50.61	49.61	49.56	50.63	51.70	51.06	50.81		
1.60	1.51	1.57	1.06	1.15	1.37	1.23	1.18	0.86	0.85	1.47	1.46	1.08	1.16		
14.63	15.34	16.00	14.62	14.67	15.10	14.87	16.62	14.28	14.19	14.42	17.13	14.51	14.64		
0.05	0.04	0.05	0.04	0.05	0.04	0.03	0.04	0.06	0.06	0.03	0.03	0.06	0.06		
9.93	9.83	9.72	9.77	10.10	9.70	10.03	7.61	9.39	9.27	10.31	7.85	8.99	9.40		
0.17	0.18	0.17	0.18	0.18	0.19	0.18	0.20	0.13	0.14	0.16	0.12	0.15	0.18		
7.43	6.28	6.04	7.68	7.71	7.14	7.95	7.29	10.00	10.00	6.31	4.00	8.24	8.52		
11.51	12.27	12.97	11.48	11.53	11.48	11.30	12.64	11.89	11.96	12.53	12.69	12.42	11.77		
3.04	2.92	2.89	3.02	2.96	3.15	2.96	2.73	2.21	2.21	2.57	2.81	2.56	2.58		
0.16	0.13	0.11	0.14	0.14	0.11	0.13	0.10	0.07	0.07	0.11	0.12	0.11	0.10		
0.14	0.14	0.14	0.07	0.09	200		-	-			77.0	0.09	0.09		
99.20	99.06	100.12	98.95	99.32	99.33	99.11	99.02	98.50	98.31	98.54	97.91	99.27	99.32		
0.597	0.558	0.552	0.609	0.602	0.593	0.611	0.655	0.678	0.681	0.548	0.502	0.645	0.642		
-	-	-	-	-	-	-	-		-	0.15	3.46	-	_		
0.95	0.77	0.65	0.83	0.83	0.65	0.77	0.59	0.41	0.41	0.65	0.71	0.65	0.59		
25.72	24.71	24.46	25.56	25.05	26.66	25.05	23.10	18.70	18.70	21.75	23.78	21.66	21.83		
25.80	28.37	30.36	25.92	26.33	26.74	26.91	31.16	28.84	28.59	27.49	33.77	27.78	28.07		
24.94	26.06	27.30	25.06	24.86	24.76	23.85	25.63	24.46	24.94	28.58	24.15	27.12	24.27		
10.37	10.20	7.29	10.42	10.46	9.83	9.45	10.59	13.69	13.31	15.55	8.04	14.61	15.89		
6.62	4.16	5.25	7.46	7.83	6.59	9.22	3.90	9.27	9.26	-	-	3.76	4.76		
1.59	1.58	1.57	1.58	1.62	1.57	1.61	1.23	1.51	1.49	1.67	1.26	1.45	1.51		
0.07	0.06	0.07	0.06	0.07	0.06	0.04	0.06	0.09	0.09	0.04	0.04	0.09	0.09		
3.04	2.87	2.98	2.01	2.18	2.60	2.34	2.24	1.63	1.61	2.79	2.77	2.05	2.20		
0.31	0.31	0.31	0.15	0.20		-	-	-	-	-	-	0.20	0.20		
oliv.	oliv.	plag.	plag.	plag.	oliv.	plag.	oliv.	plag.	plag.	oliv.	oliv.	plag.	plag.		

TABLE 4 - Continued

	Hole 395							Hole 395A				Hole 396B		
Sample (Interval in cm)	18-2, 43-46	18-2, 43-46	18-2, 43-46	18-2, 43-46	18-2, 43-46	18-2, 43-46	18-2, 49-51	18-2, 49-51	16-3, 46-51	16-3, 46-51	16-3, 46-51	16-3, 46-51	20-1, 136-138	20-1, 136-138
Unit	P ₁	P 1	P1	PI	P ₁	P1	P ₁	P1	В	В	в	в	В	в
JSC No.	115-7	115-8	115-9	115-10	115-11	115-12	45G-1	45G-2	226-1	226-2	226-3	226-4	236-1	236-2
SiO ₂	50.58	52.24	52.13	52.17	52.23	52.45	51.22	51.89	50.43	50.38	50.07	50.81	50.54	50.51
TiO ₂	1.21	0.80	0.82	0.84	0.80	0.84	0.77	1.01	1.06	1.23	0.81	1.16	1.11	1.01
Al ₂ O ₃	14.58	13.88	14.11	13.88	13.93	13.99	16.98	16.50	16.12	14.78	17.79	15.88	15.45	16.54
Cr2O3	0.05	0.05	0.05	0.04	0.05	0.06	0.07	0.07	0.05	0.06	0.05	0.05	0.06	0.05
FeO	9.39	8.61	8.49	8.69	8.27	8.40	7.80	7.75	8.21	10.04	6.67	9.18	9.39	7.92
MnO	0.14	0.16	0.17	0.14	0.13	0.15	0.15	0.15	0.14	0.11	0.10	0.16	0.18	0.14
MgO	8.46	8.79	8.66	8.80	8.70	8.66	5.33	4.73	6.72	7.73	7.91	7.67	6.83	7.61
CaO	11.39	12.18	12.12	12.29	12.18	12.26	15.11	15.09	13.54	11.68	12.28	11.83	13.26	13.00
Na ₂ O	2.04	2.36	2.36	2.38	2.38	2.39	2.00	2.20	2.51	2.92	2.35	2.80	2.45	2.49
K20	0.11	0.09	0.09	0.09	0.09	0.09	0.04	0.06	0.10	0.14	0.06	0.12	0.09	0.11
P205	0.07	0.05	0.05	0.05	0.06	0.06	0.05	0.07	0.11	0.09	0.06	0.08	0.10	0.09
Total	98.02	99.21	99.05	99.37	98.82	99.35	99.52	99.52	98.99	99.16	99.15	99.74	99.46	99.47
Mg'	0.641	0.669	0.670	0.667	0.676	0.671	0.575	0.547	0.618	0.604	0.701	0.623	0.590	0.656
q	1.16	0.61	0.71	0.30	0.89	0.92	2.26	3.33	199	-	-	-	-	C++
or	0.65	0.53	0.63	0.53	0.53	0.53	0.24	0.35	0.59	0.83	0.35	0.71	0.53	0.65
ab	17.26	19.97	19.97	20.14	20.14	20.22	16.92	18.62	21.24	24.71	19.89	23.69	20.73	21.07
an	30.30	27.02	27.64	26.93	27.06	27.18	37.24	34.97	32.42	26.81	37.82	30.41	30.90	33.63
di	21.01	26.91	26.16	27.43	26.79	27.03	30.79	32.56	27.86	25.05	22.40	22.71	28.13	24.66
hy	23.71	21.18	21.02	20.98	20.44	20.39	9.23	6.36	10.41	9.13	10.36	12.26	21.84	11.33
ol	-	-	-	27	_	<u> </u>	_	-	2.91	8.51	5.59	6.14	2.43	4.76
mgt	1.51	1.39	1.36	1.41	1.33	1.35	1.26	1.25	1.32	1.62	1.07	1.48	1.51	1.28
chr	0.07	0.07	0.07	0.06	0.07	0.09	0.10	0.10	0.07	0.09	0.07	0.07	0.09	0.07
il	2.30	1.52	1.56	1.60	1.52	1.60	1.46	1.92	2.01	2.34	1.54	2.20	2.11	1.92
ap	0.15	0.11	0.11	0.11	0.13	0.13	0.11	0.15	0.24	0.20	0.13	0.17	0.22	0.20
phase	plag.	plag.	plag.	plag.	plag.	plag.	oliv.	oliv.						

TABLE 4 – Continued

		Hole 396E	3		
Sample (Interval in cm)	20-4, 13-16	20-5, 71-75	22-3, 28-38	22-3, 28-38	22-3, 28-38
Unit	В	в	в	в	в
JSC No.	239-8	241-1	249-1	249-2	249-3
SiO ₂	50.58	51.67	50?81	50.50	50.41
TiO ₂	1.13	1.30	0.91	1.16	1.16
Al2O3	15.29	19.80	16.30	16.54	16.19
Cr2O3	0.05	0.06	0.06	0.06	0.05
FeO	9.46	5.92	7.49	8.26	8.25
MnO	0.17	0.14	0.15	0.14	0.15
MgO	8.29	2.71	7.96	5.34	5.87
CaO	11.91	15.71	13.33	14.27	14.26
Na ₂ O	2.74	2.65	2.42	2.60	2.58
K20	0.12	0.11	0.10	0.11	0.11
P205	0.09	0.12	0.09	0.11	0.09
Total	99.83	100.19	99.62	99.09	99.12
Mg'	0.634	0.476	0.680	0.561	0.585
q	-	2.76	-	+	-
от	0.71	0.65	0.59	0.65	0.65
ab	23.19	22.42	20.48	22.00	21.83
an	29.07	41.81	33.32	33.14	32.27
di	24.05	28.29	26.18	30.45	31.12
hy	10.70	1.77	11.64	7.98	6.80
ol	8.27		4.28	1.10	2.74
mgt	1.52	0.96	1.20	1.33	1.33
chr	0.07	0.09	0.09	0.09	0.07
il	2.15	2.47	1.73	2.20	2.20
ap	0.20	0.26	0.20	0.24	0.20
phase	plag.	oliv.	oliv.	oliv.	oliv.

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TABLE 4 – Continued

					Ho	e 396B							
20-1, 136-138	20-1, 136-138	20-2, 58-67	20-3, 109-111	20-3, 109-111	20-3, 109-111	20-3, 109-111	20-4, 13-16						
в	В	в	В	в	в	в	В	в	В	в	в	в	в
236-3	236-4	237-1	238-1	238-2	238-3	238-4	239-1	239-2	239-3	239-4	239-5	239-6	239-7
50.54	50.57	51.79	51.00	50.70	51.72	50.85	50.77	51.12	50.64	50.47	50.94	50.42	50.72
1.40	1.38	0.84	0.90	1.04	1.25	1.31	1.17	1.06	1.09	1.07	1.08	1.07	1.02
14.88	14.93	14.16	17.78	15.94	16.17	26.47	14.77	14.92	15.05	14.90	14.99	15.60	15.58
0.05	0.04	0.06	0.05	0.05	0.07	0.06	0.06	0.05	0.06	0.08	0.07	0.07	0.06
9.90	9.63	8.45	7.88	8.71	8.24	9.18	8.34	8.43	8.72	8.94	8.71	8.63	8.72
0.19	0.17	0.13	0.17	0.15	0.17	0.14	0.15	0.14	0.16	0.17	0.15	0.16	0.16
8.01	7.82	8.80	4.94	7.81	5.67	5.73	9.20	8.82	8.54	8.67	8.56	8.63	8.67
11.72	11.91	12.37	14.90	12.87	13.16	13.85	12.38	12.38	12.34	12.60	12.33	12.21	12.38
2.77	2.70	2.36	2.35	2.47	2.79	2.46	2.40	2.50	2.60	2.48	2.58	2.53	2.56
0.13	0.12	0.08	0.06	0.10	0.12	0.09	0.10	0.11	0.12	0.11	0.12	0.13	0.12
0.11	0.12	0.05	0.07	0.08	0.09	0.09	0.08	0.11	0.09	0.10	0.11	0.07	0.09
99.70	99.39	99.09	100.10	99.92	99.45	100.23	99.42	99.64	99.41	99.59	99.64	99.52	100.08
0.616	0.617	0.673	0.554	0.640	0.577	0.553	0.686	0.674	0.660	0.658	0.661	0.644	0.663
-		Creek.	0.65	-	0.81	0.03		÷	-	-	-		-
0.77	0.71	0.47	0.35	0.59	0.71	0.53	0.59	0.65	0.71	0.65	0.71	0.77	0.71
23.44	22.85	19.97	19.89	20.90	23.61	20.82	20.31	21.16	22.00	20.99	21.83	21.41	21.66
27.79	28.27	27.81	37.79	32.11	31.24	33.63	29.23	29.17	29.04	29.20	28.97	30.83	30.67
24.27	24.60	27.01	29.45	25.48	27.51	28.45	25.67	25.63	25.71	26.60	25.64	23.83	24.55
12.09	13.46	20.72	8.85	12.47	11.66	12.61	14.85	14.93	11.52	11.40	13.23	11.82	11.33
6.89	5.13	0.06	-	4.85	_	-	5.04	4.52	6.76	7.05	5.56	7.29	7.63
1.59	1.55	1.36	1.28	1.41	1.33	1.48	1.35	1.36	1.41	1.44	1.41	1.39	1.41
0.07	0.06	0.09	0.07	0.07	0.10	0.09	0.09	0.07	0.09	0.12	0.10	0.10	0.09
2.66	2.62	1.60	1.71	1.98	2.37	2.49	2.22	2.01	2.07	2.03	2.05	2.03	1.94
0.24	0.26	0.11	0.15	0.17	0.20	0.20	0.17	0.24	0.20	0.22	0.24	0.15	1.20
plag.	plag.	oliv.	oliv.	oliv.	oliv.	oliv.	plag.						

K₂O/Na₂O ratios (e.g., Engel et al., 1965; Melson et al., 1976). K₂O abundances are characteristically low in the majority of samples (<0.2%) and, where comparative data are available, do not differ significantly from the K₂O content of basaltic glass from the same samples. A few samples have higher K₂O contents not related to basalt type, presumably the result of seawater alteration, although this is not always correlated with total water content or the oxidation ratio.

The majority of samples selected for analysis were relatively fresh, with total water contents usually less than 2 per cent and with oxidation ratios mostly below 0.4. Consequently, it was hoped that the major or trace element chemistry of these samples would not have been significantly modified by seawater alteration. The mobile elements K, Rb, and S are notable exceptions. The effects of alteration of sulfur are particularly pronounced, and there is a marked inverse correlation between the oxidation ratio and the sulfur content. It would appear from this relationship that unaltered samples should contain about 0.14 per cent sulfur, a value somewhat greater than that proposed by Moore and Fabbi (1971) as typical for unaltered basalts recovered from deep water. Many of the samples, particularly those which are obviously altered, also have lost substantial amounts of MgO.

Two broad basalt types, differing fundamentally in both petrography and whole-rock chemistry, are prevalent at Site 396. These are, respectively, the aphyric (sparsely phyric of the Site Report, this volume) and phyric basalts. The aphyric basalts contain less than 1 per cent megascopic phenocrysts, but contain microphenocrysts of olivine and plagioclase, whereas the phyric basalts contain abundant (10 to 30%) plagioclase phenocrysts, together with phenocrysts of olivine and minor chromian spinel.

Chemically, the phyric basalts are distinguished from the aphyric basalts by higher Al₂O₃ (16.4 to 18.7%) and CaO (11.5 to 12.3%) concentrations, and by lower SiO₂, FeO, and MgO concentrations. These differences are reflected in higher normative plagioclase contents and in lower Ab/(Ab+An) ratios in the phyric basalts. Although both total iron and MgO are lower in the phyric basalts; Mg' values tend to be higher, an indication that they are more "primitive" than the aphyric basalts (Figures 2 and 3). TiO2, and most other minor and magmaphile trace element abundances are markedly lower in the phyric basalts (Figure 2). Strontium, on the other hand, is higher in the phyric basalts, both in absolute terms and with respect to other magmaphile elements. Consequently, Sr/Zr ratios are distinctly different in the two basalt types, varying somewhat more in the phyric basalts (1.7 to 2.2) in contrast to the lower values (1.15 to 1.30 and 1.5 to 1.9) found in the two aphyric units (Table 3).

Figure 1 illustrates the normative olivine, plagioclase, and pyroxene relationships for these basalts, relative to the inferred olivine-plagioclase cotectic of Shido et al. (1971). All the aphyric basalts plot in the olivine tholeiite field,

	1	2	3	4	5	6	7	8	9
Unit	A ₃	В	В	В	В	В	D	В	В
JSC No.	209	235	235	226	226	226	758	258	259
TiO ₂	0.34	0.72	0.42	0.64	0.33	1.00	0.92	0.69	1.05
Al203	35.9	24.7	32.5	24.8	35.8	24.4	23.2	27.3	25.8
Cr ₂ O ₃	27.4	38.7	31.7	36.9	24.1	36.1	38.8	34.7	34.8
Fe2O3*	6.4	7.3	6.6	8.0	5.5	8.2	8.3	8.3	7.9
FeO	12.7	13.3	11.5	14.4	10.7	15.2	13.4	13.1	13.8
MnO	0.18	0.25	0.21	0.29	0.17	0.29	0.26	0.23	0.25
MgO	16.2	15.0	16.8	14.0	17.5	13.6	14.8	15.3	14.6
Total	99.1	100.0	99.7	99.0	99.1	98.8	99.7	99.6	98.2
Ti	0.060	0.134	0.075	0.121	0.058	0.190	0.173	0.127	0.198
Cr	9.946	7.180	9.051	7.324	9.816	7.255	6.828	7.881	7.609
Al	5.090	7.544	5.920	7.307	5.351	7.198	7.658	6.717	6.882
Fe ⁺³	1.105	1.318	1.152	1.470	0.943	1.520	1.521	1.495	1.452
Fe ⁺²	2.448	2.68	2.224	2.951	2.047	3.134	2.739	2.625	2.822
Mn	0.036	0.052	0.042	0.062	0.033	0.062	0.055	0.048	0.053
Ms	5.674	5.512	5.915	5.226	6.066	5.112	5.507	5.583	5.443
Total	24.422	24.505	24.440	24.564	24.359	24.584	24.584	24.574	24.557
Total	3.6161	4.083	3.438	4.525	3.034	4.767	4.364	4.218	4.373
Cr/Cr+Al	0.339	0.512	0.395	0.499	0.353	0.498	0.529	0.460	0.475
Mg/Mg+Fe	0.611	0.574	0.632	0.536	0.667	0.517	0.588	0.570	0.554

TABLE 5 Microprobe Analyses of Chromium Spinel in Phyric Basalts

Note: *Fe₂O₃ calculated on the assumption of stoichiometry. JSC Rock numbers correspond to DSDP sample numbers listed in Table 1. (1) Spinel included in the average of a plagioclase in a glomorophyric aggregate; (2, 3) Two grains included in the same plagioclase phenocryst; (4, 5) Spinel grains included in olivine and plagioclase phenocrysts, respectively, from the same rock; (6) Groundmass spinel (web-shaped) from same rock as 4 and 5; (7, 9) Groundmass spinel from Unit D basalt; (8) Spinel grain in olivine phenocryst.

TABLE 6
Compositions of Olivine and Plagioclase From Microprobe Analyses in
Melting Experiments on Three Rocks From Hole 396B

	Sample 7-1	, 42-46 cm	Sample 30-	1, 77-80 cm	Sample 22-3, 28-38 cm		
Temperature (°C)	Fo Content of Olivine	An Content of Plagioclase	Fo Content of Olivine	An Content of Plagioclase	Fo Content of Olivine	An Content of Plagioclase	
1225						83.8 ±0.9 (4)	
1200				81.4 ±0.3 (2)	87.0 ±0.1 (8)	79.0 ±1.6 (5)	
1175	$83.6 \pm 0.2 (4)^{a}$	74.3 ±0.6 (6)	84.0 ±0.3 (5)	73.1 ±0.8 (9)	86.0 ±0.8 (7)	77.5 ±1.8 (4)	
1150	81.2 ±0.45 (5)	67.2 ±1.4 (5)	79.7 ±1.7 (5)	65.5 ±0.5 (6)	78.0 ±0.2 (6)	67.4 ±0.8 (4)	

^a Error limits are 1 sigma based on the number of analyses shown in parentheses.

within a tightly controlled elongate group sub-parallel to the inferred cotectic. In contrast, the phyric basalts plot predominantly within the plagioclase tholeiite field and are scattered widely. Those phyric basalts plotting close to the inferred cotectic, or just within the olivine tholeiite field, have the lowest Al₂O₃ content. Presumably, they contain fewer plagioclase phenocrysts than the majority of samples, and may be closer to melt compositions.

Initial studies, based on shipboard X-ray fluorescence analyses, recognized seven compositionally distinct magmatic units and sub-units within the three major basalt types. These were, in order of increasing depth below the sediment-basement interface, A1, A2, A3, B1, B2, C, and D.

Our data essentially confirm these subdivisions, subject to minor revisions in the light of the more recent and comprehensive analyses. Average values, calculated from the data in Table 1, are given in Table 3. The only change we have made in the classificatory scheme is to combine the sub-units of B into a single unit because it is a chemically, magnetically, and stratigraphically coherent unit which exhibits substantial internal variation in composition. "Unit D" consists of several clasts of phyric basalt mixed with the more abundant Type C that comprises the lower clastic unit



Figure 2. Chondrite-normalized REE abundances in basalts from Legs 45 and 46. Chemically defined units used in this paper and in Rhodes et al. (1978) are used here. Note the similarity in both total abundances and La/Sm at the two sites.



Figure 3. FeO-MgO relationships in altered and fresh basalts of Hole 396B. Reference lines are for constant Mg'.

in Hole 396B and is, therefore, not actually a stratigraphic unit in itself.

The minor and trace element abundances of the Site 396 basalts are within the range of typical mid-ocean ridge tholeiites (Kay et al., 1970; Schilling, 1971, 1975; Pearce and Cann, 1973; Hart, 1976; Bryan et al., 1976; Erlank and Kable, 1976). This is illustrated (Figure 2, Table 3) by the chondrite-normalized rare-earth patterns, which range between 13 and 24 times chondritic abundances for Sm, and which display the light rare-earth depletion typical of "normal" or Type I ocean ridge basalts (Bryan et al., 1976). Mg' values in these rocks are variable, ranging from about 0.59 to 0.69 (Figure 2), which is within the range characteristic of mid-ocean ridge basalts but is lower than the values found in the most primitive basalts identified to date (Frey et al., 1974; Bryan and Moore, 1976; Rhodes et al., 1978). These values, together with low Ni concentrations, moderately high magmaphile element abundances, and the presence of multiple phenocryst phases are taken as evidence that these basalts have undergone substantial differentiation.

The chondrite-normalized REE patterns of the basalts at Site 395 are also shown on Figure 2. Note that the abundances and degree of LREE-depletion are virtually identical at both sites with the exception of Unit C (Hole 396B) which has higher La/Sm and other magmaphile element ratios that differ markedly from Units A and B and the Site 395 basalts. The remaining aphyric and phyric units exhibit small variations in trace element ratios which are, in terms of general trends, consistent with very small amounts of fractional crystallization. Figure 4 is an example of two elements, Zr and Y, that vary systematically with increasing degree of fractionation within Units A and B. Note, however, that as the basalts become increasingly evolved, the Zr/Y ratio increases slightly from 2.8 at the base of Unit B to 3.3 in A₃. Other ratios change systematically as well; e.g., La/Sm, La/Yb, and Sm/Eu increase whereas Sr/Zr decreases. Rhodes et al. (1978) have modeled the possible relationships among several units at Site 395 and found that the degrees of magmaphile element-enrichment for different elements are not consistent in detail with a simple fractional crystallization scheme. An additional mechanism that will provide enrichment of the incompatible elements is required.

One of the most useful indicators of differentiation in basaltic rocks is the atomic ratio $Mg/(Mg + Fe^{+2})$, or Mg', which is very sensitive to olivine fractionation; e.g., removal of 5 per cent olivine from a liquid with an Mg' of 0.64 lowers the ratio to 0.56. Unfortunately, the Mg' of some of the basalts in Hole 396B has been modified by seawater alteration as MgO is lost during this process. Figure 3 is a plot of MgO versus FeO in Hole 396B basalts. Constant Mg' reference lines and average glass compositions from sub-units A1, A2, and A3 and Unit C are also included. Olivine control lines on this diagram are sub-horizontal with slightly negative slopes. Because large changes in MgO content occur in response to small amounts of olivine fractionation, distinguishing variations in Mg' due to magmatic and alteration processes is difficult, particularly since alteration indexes do not always agree with the intensity of chemical change. However, the evidence that alteration among the aphyric lavas has produced much of the MgO variation is strong due to the relative paucity of phenocrysts. Magnesium loss has also occurred in the phyric rocks as fresh, relatively evolved samples from Unit B have Mg' values around 0.63 to 0.64 and there are strongly altered samples with Mg' ≈ 0.5 .

CHEMICAL STRATIGRAPHY AND PETROGRAPHY

Unit A

The uppermost 88 meters of basaltic bedrock in Hole 396B are comprised of very sparsely phyric basalt (hereafter referred to as aphyric basalt for convenience). Three chemically defined sub-units are recognized (A1, A2, and A₃). This breakdown is consistent for major, minor, and trace element analyses of bulk rocks as well as microprobe analysis of residual glasses in pillow rinds. As discussed previously, the major element chemistry of these rocks has been disturbed to varying degrees by alteration caused by basalt-seawater interaction. However, relatively non-labile, magmaphile elements such as Ti, Zr, Y, and REE are excellent indicators for the purpose of defining individual units (Table 3). The stratigraphic sub-units of A, recognized here on the basis of bulk and glass chemistry, are the same as originally defined on the basis of shipboard analyses and generally are supported by inferred lithologic breaks and magnetic reversal stratigraphy.

The stratigraphic-chemical progression, upsection from A_3 to A_1 , is from more evolved at the base (A_3) to a more "primitive" composition (A_1) at the top, with A_2 being intermediate in stratigraphic position and chemistry. Within



Figure 4. Zirconium-yttrium relationships in basalts of Hole 396B. The reference here is for a constant ratio of 3.0.

this progression $(A_3 \rightarrow A_2 \rightarrow A_1)$, TiO₂, Na₂O, FeO, and total REE all decrease whereas CaO, MgO, and Mg/(Mg+Fe) increase. A second subdivision between A₁ and A₂ on the one hand, and A₃ on the other, is recognized on the basis of CaO/Al₂O₃ in glassy pillow rinds. Both A₁ and A₂ have CaO/Al₂O₃ of 0.77 to 0.76, in contrast with A₃ which has CaO/Al₂O₃ = 0.74. Basalts in Sub-unit A₃ have lower CaO than those in A₁ and A₂ but their Al₂O₃ contents are intermediate. In addition, the stable magnetic inclinations of A₁ and A₂ are approximately +15°, as opposed to the -70° measured for A₃.

Textures of the rapidly cooled parts of A1, A2, and A3 are similar in that all three contain microphenocrysts of olivine and plagioclase on eruption. Pyroxene occurs only as a groundmass phase; chromian spinel is absent. The major textural-mineralogical difference among the units is that A1 and A2 are composed entirely of pillow basalt and A3 is a 10-meter cooling unit with a pillowed carapace and a massive interior that is substantially more coarse grained than the pillow interiors in A1 and A2. Kirkpatrick (this volume) describes the textural progression from glassy pillow margin to intersertal pillow interior. However, it can be noted here that the combination of plagioclase spherulites grading into more slowly cooled intersertal basalt is characteristic of multiply saturated ocean floor tholeiites. Chemically similar basalts in Holes 395 and 395A that have olivine alone on the liquidus are characterized by substantially different textures (Dungan et al., 1978).

All three sub-units also contain sparse anhedral grains of plagioclase and olivine that are distinctly larger than the microphenocrysts. In contrast to skeletal and euhedral morphologies of the microphenocrysts, these grains are generally rounded and embayed suggesting resorption and disequilibrium. As these grains have compositions different from those of the microphenocrysts as well, they are inferred to have crystallized from more primitive melts or in some cases more evolved melts than those in which they are now found.

Sample 396-14-6, 94-100 cm is the stratigraphically highest basalt analyzed by us from Hole 396. It is representative of a small amount of aphyric basalt mixed with foraminiferal ooze at the basement-sediment interface. Its major element composition resembles that of A₂ (Hole 396B) and may be equivalent. However, the magnetic inclination of this sample is -20° which does not agree with that of any of the sub-units of A (Hole 396B). These magnetic data, the small thickness of aphyric basalt, and the high degree of alteration of this sample suggest that this is a loose block derived from adjacent flows of A.

Unit B

Underlying Unit A is a section of abundantly phyric pillow lavas (61 m). These are distinct, both chemically and petrographically, from the aphyric Unit A. Plagioclase and olivine phenocrysts are abundant (10 to 20%) and, in contrast to A, minor chromian spinel is present. Spinel crystals are found as inclusions in both plagioclase and olivine and as microphenocrysts in the groundmass where they typically have a vermiform habit. Clinopyroxene appears only as a groundmass phase. Although Unit B is a coherent stratigraphic and magnetic unit, it encompasses substantial chemical variability. On the basis of chemical analyses onboard ship and in this study, a chemical break in Unit B is recognized in Core 20 between Sections 2 and 3, the lower unit being the more primitive. This difference is also present in the residual, glassy selvages above and below the break defined by the bulk analyses. However, there are also gradational chemical changes throughout Unit B in the same sense as those which define the discontinuous change in Core 20. This is in contrast to the Sub-units of A which exhibit very slight internal variation.

The absolute chemical changes from the base to the top of the unit are as follows: (1) Na₂O, FeO, and TiO₂ increase more or less regularly except for minor perturbations and the aforementioned discontinuity; (2) MgO and Mg/(Mg+Fe) decrease; (3) CaO and Al₂O₃ are variable from sample to sample, but do not define clearcut trends from base to top (however, CaO and Al₂O₃ correlate, suggesting that irregular plagioclase distribution is the cause for the lack of systematic variation); and (4) SiO₂, K₂O, and P₂O₅ tend to increase upward with substantial scatter that may be related in part to degree of alteration and/or analytical precision.

The sense of the chemical trends in Unit B, with respect to stratigraphic position, are the reverse of these among the sub-units of A, i.e., the more evolved compositions occur at the base rather than at the top. These generalizations have been made on the basis of only relatively fresh samples because many of the Unit B phyric rocks have undergone chemical alterations similar to these recognized in Unit A. Analyses labeled "glass" in Table 1 are glassy pillow rinds containing crystals in equivalent amounts to the pillow interiors and are not glass analyses as such. These are the least altered samples available, and considerable reliance has been placed on these for both classification and petrologic purposes.

The vast majority of the basalts in Hole 396 are phyric pillow lavas essentially equivalent in petrography, mineral chemistry, and chemical composition to the upper part of Unit B (Hole 396B). However, the magnetic inclinations of the phyric basalts in Core 14 through the upper portion of Core 22 (Hole 396) are $\approx +40^{\circ}$, as opposed to the remainder of Hole 396 and the entire thickness of Unit B (Hole 396B) which is -10° . Thus, the lower portion of Hole 396 probably correlates directly with Unit B (Hole 396B); Unit A is all but absent and there is an additional phyric unit at the top of Hole 396 that is lacking in Hole 396B.

Unit C

The lowermost 90 meters of drilling in Hole 396B penetrated sparsely phyric basalt that occurs as fragments in what appears to be a clastic unit rather than a coherent sequence of pillows. This inference is based on the low recovery achieved in this depth interval, extensive caving of the walls and bedded hyaloclastites (Site Report, this volume) that are present in the recovered material. With the exception of some fragments of phyric basalt in Core 32 ("Unit D") that are petrographically and chemically distinct, the sparsely phyric basalts within this clastic interval (Cores 23 to 32) are chemically coherent. They generally resemble the A2 and A1 basalts in composition, but there are small, systematic differences in both major and trace elements. Although C and A2 have essentially identical TiO2 and CaO contents, the Unit C basalts are characterized by higher Al₂O₃, FeO, Na₂O, K₂O, Sr, La/Sm, Zr, substantially higher Nb, and slightly lower SiO₂. Again, detailed comparisons must be made on the

relatively few unaltered samples that have not undergone major element redistribution due to interaction with seawater.

MINERAL CHEMISTRY

Olivine

Unit A contains two petrographic types of olivine: (1) abundant microphenocrysts and (2) sparse, larger anhedral grains. The microphenocrysts in Unit A are progressively more magnesian from A1 to A2 to A3 in accordance with the change in bulk chemistry. Microphenocryst compositions in the three sub-units are $A_3 = F_{084.3\pm0.3}$, $A_2 = F_{085.0\pm0.3}$, and $A_1 = F_{086.1\pm0.3}$. The larger, anhedral crystals do not exhibit this compositional correlation; some of these large grains are more magnesian than the associated microphenocrysts, whereas others are more iron rich. The latter are conspicuously evidenced by reverse zoning accompanied by irregular rim overgrowths on the anhedral cores. Olivine microphenocrysts in Unit C are similar in composition to those in A1 (Fos6.2±0.3) in accordance with the very similar bulk compositions of the two units. One of the two samples of C from which we have analyzed olivine contains a glomerophyric aggregate of plagioclase plus olivine of the composition Foss-87.

The compositional variation of olivine in the phyric Unit B is much larger and more complex. Figure 5 illustrates the relationships between olivine composition and coexisting melt composition. Roeder and Emslie (1970) have shown that olivine composition is a function of the $Mg/(Mg + Fe^{+2})$ of the liquid from which it crystallizes. Reference curves for Fe-Mg partitioning between olivine and liquid are also plotted on Figure 5. Three olivine-liquid relationships are shown by different symbols. In the first, microphenocrysts in aphyric and porphyritic basalts are plotted against the coexisting residual glass composition (both mineral and glass data are microprobe analyses). These data define a KD of 0.27 for the range of Mg/(Mg+Fe⁺²) from 0.58 and 0.64. This value is presumed to be the equilibrium Fe-Mg partition coefficient for olivine and liquid in these rocks. The second set of data is comprised of a total of 70 olivine analyses from four porphyritic basalts from Unit B plotted against the bulk rock composition (Table 1). Most of the analyses represent core compositions of phenocrysts although rims also were analyzed. With the exception of rare, reversely zoned olivine crystals (triangles), the most iron-rich compositions in each rock are those microphenocrysts coexisting with residual glass whose compositions yield a KD of 0.27. Under equilibrium conditions, the most magnesium olivine predicted for those rocks also should give a KD of 0.27. On the contrary, many of the phenocrysts are more forsteritic than predicted by this method. As these more magnesian crystals must have had a marked effect in changing the Mg/(Mg+Fe⁺²) toward higher values, the present bulk rock compositions must be a combination of a liquid (±plagioclase crystals) that have gained some magnesian olivine phenocrysts, making minimal the discrepancy between predicted and observed olivine compositions. A similar relationship was recognized in porphyritic basalts of Holes 395 and 395A (Dungan et al., 1978). In addition to the disequilibrium indicated by these forsteritic phenocrysts, there are also phenocrysts that



Figure 5. Plot of olivine and "coexisting liquid" for microphenocrysts in glass and phenocrysts and their bulk rock composition. Reference lines for Fe-Mg partitioning values (K_D) of 0.27 and 0.33 are calculated after Roeder and Emslie (1970).

show reverse zoning from cores more iron rich than the microphenocrysts in both aphyric and phyric lavas.

Plagioclase

One-atmosphere melting experiments on three natural rock powders representative of the three chemical units of Hole 396B indicate that plagioclase is the liquidus phase in all three rock types. The aphyric rocks from A and C are shown to be essentially cotectic, with olivine and plagioclase appearing within 5 to 10°C of each other. In the porphyritic sample (Unit B), spinel and then olivine follow plagioclase in the crystallization sequence over a temperature interval of about 35°C. Compositions of the phases occurring in the experimental runs are shown in Figure 6 and Table 6.

Microprobe analyses of natural plagioclases in a few of the Leg 46 basalts and in the experimentally produced charges are three element analyses (K-Ca-Na) that have been converted directly to molecular end-member components without matrix corrections. The use of natural standards with compositions near the unknowns results in close approximations to the actual values. Sub-units A₁ and A₂ contain microphenocrysts of An₆₅₋₆₈, and A₃ has more sodic plagioclases of An₆₁₋₆₅. However, the larger anhedral grains which typically exhibit textural evidence of resorption are more calcic (An₇₄₋₈₆) than the microphenocrysts. A similar situation obtains in Unit C which has microphenocrysts of An₇₁₋₇₄ and larger euhedral and anhedral grains that are as calcic as An₈₄. Only one porphyritic basalt (Sample 396B-22-3, 28-38 cm) has been analyzed in reconnaissance for plagioclase compositions. A pattern very much like the porphyritic Leg 45 basalts (Dungan et al., 1978) is present. Rim compositions in glass are An₆₉₋₇₂ and core compositions of phenocrysts range from An₇₅ to An₈₅. Many additional analyses are needed to fully document the range of compositions in the phyric rocks, particularly since there is a diversity of zoning patterns present. Additional studies currently are being conducted.

Spinel

Chromian spinel has been recognized as a microphenocryst phase only in phyric basalts in Holes 396 and 396B. It occurs throughout Unit B and in both clasts of the phyric basalt in Core 32 ("Unit D"). The single occurrence of spinel in either aphyric unit is an included grain in a glomerophyric aggregate of calcic plagioclase (An85-83) in Sample 396B-14-1, 21-25 cm (Sub-unit A3; JSC No. 209). Table 4 contains some representative microprobe analyses of spinels in these rocks and Figure 7 is a Cr/(Cr+AI) versus Mg/(Mg+Fe) plot of 70 analyses from basalts in Unit B (Hole 396B). An additional 20 analyses from phyric basalts in Hole 396 span the same range of compositions as those from 396B, as do those from phyric basalts in Hole 395. The one-atmosphere phase relations of



Figure 6. Mineralogy as function of temperature produced in one-atmosphere melting experiments on three select basalts from Hole 396B. These three are representative of the three major basalt units.

Sample 396B-22-3, 28-38 cm indicate that spinel is a near liquidus phase and is stable over at least 50°C (1225° to 1175°C). This is a somewhat larger temperature interval than was found in melting experiments with Sample 395A-27-2, 111-116 cm, a phyric basalt that is similar in composition.

In accordance with its larger stability field in the Hole 396B composition, spinel is more abundant in the phyric basalts of Unit B (396B) than in any of the phyric units at Site 395. The spinels at these two sites are similar to those analyzed in other moderately evolved ocean floor tholeites ($TiO_2 < 1.5\%$, Cr/(Cr+Al) = 0.3 to 0.6, and Mg/(Mg+Fe) = 0.7 to 0.45). Highly aluminous, chrome-poor spinels, such as those which occur in rare, magnesian, primitive tholeites that have been recovered from some localities of the Atlantic sea floor (Frey et al., 1974; Sigurdsson and Schilling, 1976) are not present.

As noted on Figure 5, the spinel crystals in the Hole 396B basalts occur as inclusions within olivine and plagioclase phenocrysts and as isolated grains within the groundmass. Spinel crystals that are attached to the outer surfaces of grains in glomerophyric aggregates are classed as groundmass grains. The included grains are euhedral or subhedral and typically contain small (<10 μ m) melt inclusions indicating that they are magmatic crystals. The groundmass grains exhibit two distinct morphologies. Many are equant and euhedral to subhedral, whereas others have a vermiform habit. The latter texture is somewhat enigmatic in that it may signify resorption or it may form as a function of rapid growth, i.e., analogous to skeletal growth in silicates.

There is a correlation between petrography and chemical variations within the composite of spinel analyses from Unit B. The groundmass spinels have Cr/(Cr+Al) ratios within the higher part of the range defined by those that occur as inclusions, particularly in plagioclase. Spinel crystals included in olivine phenocrysts and in the groundmass have lower Mg/(Mg+Fe) compared to those within plagioclase. The generally higher Cr/(Cr+Al) and lower Mg/(Mg+Fe) of the groundmass spinels, as compared to the inclusions, mirrors the limited zoning found in individual grains (from core to rim). Similarly, analyses of spinels produced experimentally at 1225° and 1200°C show the same trend. These are displaced to higher Mg/(Mg+Fe) for a given Cr/(Cr+Al) than the natural spinels. This is probably a result of the composite nature of the rocks in that they have gained olivine phenocrysts, thus producing a bulk liquid composition with an artificially high Mg/(Mg+Fe).

Microprobe Analyses of Residual Glasses and Melt Inclusions

An extensive survey of natural glass compositions in aphyric and porphyritic basalts from Sites 395 and 396 (Legs 45 and 46) has been undertaken. Eleven element microprobe analyses, corrected for matrix effects by the Bence-Albee method, are presented in Table 4. These include glassy selvages from quenched pillow rinds (residual glasses) and glass trapped in plagioclase and olivine phenocrysts (melt inclusions). Four three-element passes were made on each residual glass selvage or melt inclusion. For the selvages and larger melt inclusions (>25 μ m), 10 to 12 points were counted for 20 to 30 seconds and



Figure 7. Cr/(Cr+Al) versus Mg/(Mg+Fe) in chromian spinels of Site 396 phyric basalts.

then averaged. The residual glasses and melt inclusions are discussed separately below.

Residual Glasses

We have found evidence at both Site 395 (Dungan et al., 1978) and Site 396 suggesting the phyric basalts are comprised of mixtures of at least two liquids and their crystals. The critical part of this evidence is the presence of phenocrysts that are not in equilibrium with the liquids in which they occur or, more importantly, with liquids corresponding to the bulk rock compositions. Consequently, bulk rock analyses of the phyric basalts cannot be treated in petrologic calculations as liquids. The residual glasses are then the only available material that represent relevant liquid compositions. Microprobe analyses of natural glass circumvents another problem that hampers interpretation of bulk rock chemical data in that they have not been modified by interaction with seawater as have most of the rocks.

One of the most striking compositional characteristics of the residual glasses at Sites 395 and 396 is the similarity of the glasses associated with aphyric basalts (which approximate bulk rock compositions) and the residual glasses in the phyric rocks. This similarity is evidenced by the elemental ratio Mg/(Mg+Fe⁺²) which is a sensitive indicator of olivine fractionation. At both sites, the residual glasses associated with aphyric and phyric basalts have essentially the same Mg/(Mg+Fe⁺²). This is illustrated by Figures 7 and 8 in which TiO2, Al2O3, CaO, CaO/Al2O3, and Na₂O are plotted against Mg/(Mg+Fe⁺²). The glasses at Site 395 are more evolved, i.e., lower Mg/(Mg+Fe⁺²) and higher TiO2, than those at Site 396; the differences between phyric and aphyric are larger for a given $Mg/(Mg+Fe^{+2})$ than at Site 396. However, in terms of elemental trends within related groups of rocks and the sense of the compositional differences between the phyric and aphyric glasses, the same relationships hold at both sites.

The most primitive glasses are those from the lower part of Unit B (Section 396B-20-3), but those from the upper part of this unit have Mg/(Mg+Fe⁺²) values that overlap with A₁ and A₂. Both groups have the same K₂O, Al₂O₃, and SiO₂. However, the glasses in aphyric rocks have higher TiO₂ and Na₂O, and lower CaO. The four residual glasses from Site 395 exhibit the same compositional pattern with respect to the single analysis of glass from the evolved aphyric Sub-unit A₃ (Hole 395A).

Unit C (Hole 396B), which is comprised of sparsely phyric basalts, has trace element characteristics distinct from Units A and B. Its residual glass chemistry is very similar in general character to the upper aphyric unit (particularly Sub-units A₁ and A₂) but is distinct in detail. The Unit C glasses have the same Mg/(Mg+Fe⁺²), TiO₂, CaO, and FeO as A₂; but are higher in Al₂O₃, Na₂O, and K₂O, and lower in CaO/Al₂O₃ and SiO₂.

Discussion of Residual Glass Data

Fractional crystallization of the observed phenocryst phases (olivine and plagioclase) is not sufficient to relate residual glasses of the three chemical units of Hole 396B. A relationship between Unit C on the one hand and either B or A on the other has been ruled out on the basis of its contrasting trace element systematics. However, the ratios of magmaphile elements in Units A and B are nearly the same. These ratios vary in a way compatible with small amounts of crystal fractionation of the observed phenocrysts. That Units B and A are not related by fractional crystallization of olivine and plagioclase is clearly demonstrated by the glass compositions. All the glasses contain microphenocrysts of olivine. As the ratio $Mg/(Mg+Fe^{+2})$ is very sensitive to olivine fractionation, removal of olivine is precluded by the similar Mg/(Mg+Fe⁺²) of the glasses. Plagioclase fractionation from the Unit B glasses would explain the higher TiO2 and lower CaO in the aphyric glasses (at a fixed



Figure 8. TiO2 versus Mg' relationships in natural residual glasses and glass melt inclusions from basalts of Sites 395 and 396.

Mg/(Mg+Fe⁺²), but this cannot be accomplished at a constant Al₂O₃ as is required by the compositional data. Clinopyroxene is an additional phenocryst phase in the Site 395 phyric basalts, and here again the oxide variations at a constant Mg/(Mg+Fe⁺²) cannot be produced by fractional crystallization alone, although the trace element systematics again are compatible with a cogenetic relationship.

As shown on Figures 7 and 8, there are systematic chemical trends within the two phyric groups and the sub-units of A. In all cases, as Mg/(Mg+Fe⁺²) decreases, the levels of Na₂O, TiO₂, FeO, and SiO₂ increase and the CaO/Al₂O₃ decreases. The increases in TiO₂, etc. are to be expected from fractional crystallization of olivine and plagioclase, but the decrease in CaO/Al2O3 is in the reverse sense to that caused by the subtraction of plagioclase. Clinopyroxene has a very high CaO/Al₂O₃ ratio (≈5) and the removal of small amounts of this phase could produce a decrease in this parameter. In the Site 395 phyric basalts, which do contain clinopyroxene phenocrysts, the decreasing CaO/Al₂O₃ trend with decreasing Mg/(Mg+Fe⁺²) is the most marked of any group. Where clinopyroxene is lacking as a phenocryst in Hole 396B, the role of this phase in a simple fractionation model is highly problematic.

Melt Inclusions

Relative to the residual glasses, the melt inclusions trapped within olivine and plagioclase phenocrysts exhibit substantial compositional variation. Part of the diversity and deviation from residual glass compositions is due to crystallization of the host phase from the trapped melt. This effect is more pronounced in those included in olivine than for melts within plagioclase. A second reason for the wide range of compositions is that the melt inclusions represent trapped liquids of varying parental composition. This is illustrated in Figure 7 by the wide range of TiO2 contents present in melt inclusions in olivine phenocrysts from both sites. An example of the effect of olivine fractionation of a likely parental liquid shows that the total variation in TiO2 is several times greater than the amount that can be accounted for by olivine fractionation. Note that several of the melt inclusions (in both plagioclase and olivine) have TiO2 contents less than 1.0 weight per cent and that values around 0.8 weight per cent TiO₂ are not uncommon. As the lowest TiO_2 in a phyric basalt from Hole 396B has $TiO_2 = 0.93$, these low TiO2 melt inclusions must be trapped liquids of an original parent composition more primitive than the composition of the bulk rock in which they occur. Similarly, many of the melt inclusions have CaO/Al2O3 ratios greater than 0.83 which is the maximum value for the residual glasses. This feature is illustrated in Figures 9 and 10. Note that there is a broad correlation between decreasing CaO/Al₂O₃ and increasing TiO among the melt inclusions. Although this trend mimics the trends defined by the individual basalt units (e.g., A, B, or Site 395 phyric basalts), it cannot be produced by any combination of olivine and plagioclase fractionation unless plagioclase is resorbed back into the liquid rather than removed.

Using the available compositional data from the melt inclusions and the constraint that a primary mantle derived melt should have $Mg/(Mg+Fe^{+2}) = 0.72$, an estimate of the



Figure 9. Compositional relationships among natural residual glasses and bulk rock at Sites 395 and 396.



Figure 10. CaO/Al₂O₃ versus TiO₂ in natural residual glasses and bulk rock at Sites 395 and 396.

primitive composition has been graphically derived using oxide versus oxide and oxide versus oxide ratio plots. The following composition has been inferred on this basis: SiO2 $= 49.0, TiO_2 = 0.75, FeO = 8.3, MnO = 0.15, MgO =$ $10.5, CaO = 13.5, Al_2O_3 = 15.0, Na_2O = 1.9, K_2O =$ 0.05, and $P_2O_5 = 0.05$. This model magma remains to be tested by quantitative calculations involving fractionation of melt inclusions by crystallization of the host phase, but the inferred composition very closely resembles picritic ocean floor tholeiites from other localities (Frey et al., 1974; Blanchard et al., 1976; Bryan and Moore, 1976; Rhodes, unpublished data) that have been interpreted as primary mantle melts. A very significant geochemical characteristic of these primitive magmas is the high CaO/Al₂O₃. The tendency for lower CaO/Al2O3 with increasing fractionation and the apparent need for clinopyroxene fractionation is similarly an important feature of the residual glasses.

EXPERIMENTAL DATA

Introduction

Three representative samples of Leg 46 basalts have been selected for determination of their one-atmosphere phase relations and mineral compositions. The purpose of these experiments was to constrain the possible crystallization and fractionation histories of the basalts at the Leg 46 site and to determine if the phenocrysts in the natural rocks have compositions consistent with growth from their host. In addition, we have performed controlled cooling-rate experiments to establish a basis for the interpretation of textures in the natural basalts. The preliminary results of the experiments reported here allow us to draw several significant conclusions regarding the evolution and emplacement of basalts at Site 396.

Experimental Techniques

Both the melting and cooling rate experiments were performed using the technique described in detail by Donaldson et al. (1976) in which samples are suspended on a Pt wire loop in a vertical tube furnace. Oxygen fugacity in the furnace was controlled by mixing H and CO₂ and was measured using a modified Sato cell calibrated against the Ni-NiO buffer curve. In all the melting experiments, f_{o_2} was maintained at 0.5 (±0.1) log unit below the QFM buffer curve. The temperatures of the furnace are believed to be accurate within 3°C. Approximately 100 mg of finely ground rock powder was used for each run. For the melting runs, the sample was held at temperature for 24 to 72 hours and then quenched. The cooling-rate runs were held at 1250°C for 24 hours then cooled to 1000°C at rates of 2°, 10°, and 30°C per hour.

The experimental conditions described above do not duplicate conditions on the sea floor, at the time of eruption; e.g., there was roughly 0.5 kb of hydrostatic pressure on the rocks at that time. Thus, the conclusions we draw from these experiments are based on the assumptions that a small pressure difference and the presence of seawater in the natural environment would not significantly alter the phase relations, textures, or mineral chemistry relative to the natural system. We feel these assumptions are valid based on available high pressure data for basaltic systems (e.g., see Fujii et al., 1978) and the probable kinetic factors limiting the interaction of basalt and seawater. The f_{0_x} values used were based on a compilation of estimated T versus f_{0_x} data for deep-sea basalts.

Experimental Results

The results of the melting experiments are presented in Figure 6, and the compositions of plagioclase and olivine are tabulated as a function of temperature in Table 6. All three samples studied have plagioclase as the liquidus phase, but the sample from Unit B (396B-22-3, 28-38 cm) has a significantly higher liquidus than the two aphyric rocks. Plagioclase appears in Sample 396B-22-3, 28-38 cm at about 1245°C. At 1225°C, plagioclase (Ans4) coexists with chrome spinel; by 1200°C olivine (Fos7) joins the spinel and plagioclase (An79). This same mineral assemblage still coexists with liquid at 1175°C at which temperature the plagioclase composition is An77 and that of olivine is Fos6. At 1150°C, spinel is no longer present; instead, clinopyroxene coexists with plagioclase (An67), olivine (Fo78), and liquid.

Samples 396B-7-1, 42-46 cm and 396B-30-1, 77-80 cm have liquidus temperatures of about 1200° to 1195° C. In both of these samples, plagioclase is joined by olivine within 10 degrees of the temperature of appearance of the plagioclase. In Sample 396B-30-1, 77-80 cm, plagioclase (Ans1) appears at slightly above 1200° C and at 1175° C plagioclase (An73) coexists with olivine (Fos4) and liquid. Clinopyroxene appears at about 1170° C; at 1150° C, plagioclase (An65), olivine (Fos6), pyroxene, and liquid all coexist.

In Sample 396B-7-1, 42-46 cm, plagioclase is estimated to first appear at about 1195°C; by 1175°C, plagioclase

 (An_{74}) and olivine (Fo_{84}) coexist with liquid. At 1150°C, plagioclase (An_{67}) , olivine (Fo_{81}) , and clinopyroxene all coexist with liquid.

The compositions of three experimentally produced chromian spinels in 1200° and 1250°C runs with Sample 396B-22-3, 28-38 cm are plotted on Figure 7. Their Cr/Cr+Al and Mg/Mg+Fe ratios agree well with those in the natural rock and, furthermore, they show a consistent variation with temperature which in turn mimics compositional trends in the natural spinels.

Cooling Rate Experiments

The linear cooling rate experiments for Sample 396B-22-3, 28-38 cm produced textures ranging from porphyritic at $2^{\circ}/hr$ to fan-spherulitic at $30^{\circ}/hr$. In the $2^{\circ}/hr$ run, slightly skeletal, tabular plagioclase laths up to 3 mm in length by 0.2 mm wide are set in a groundmass of much finer grained plagioclase laths, subhedral equant olivine grains (<0.2 mm), and sheaf-like aggregates of fine-grained acicular clinopyroxene. Wedges and laths of titanomagnetite are common throughout the charge and, in some parts of it, they show a peculiar subparallel alignment roughly perpendicular to the largest face of a plagioclase lath.

A cooling rate of 10°/hr produced a texture that is similar to that of the 2°/hr run, but the plagioclase laths are thinner and are partly fan-spherulitic. In addition, there are very few equant olivine grains. Instead, they are either very thin-chained olivines oriented subparallel to plagioclase laths or they occur as very fine-grained spherulitic aggregates. Clinopyroxene also occurs as fine-grained spherulitic aggregates, some of which appear to be partly intergrown with the margins of plagioclase laths.

The 30°/hr run produced a texture in which plagioclase is again the dominant mineral, but it occurs as radiating aggregates of acicular, partly skeletal grains which appear in transmitted light to merge with a fine-grained groundmass. In reflected light, it is obvious that olivine and/or pyroxene grains are arranged perpendicular to surfaces of plagioclase laths, imparting a dendritic appearance to them. The only truly dendritic crystals are, however, some of the groundmass olivines.

The textural changes in Sample 396B-22-3, 28-38 cm with increasing cooling rate can be summarized as follows: (1) plagioclase becomes more acicular and fan-spherulitic, (2) grain boundaries of the larger plagioclases become less and less distinct, and (3) olivine morphology changes from sub-equant to chain-like to dendritic. There is also a general decrease in groundmass grain size.

Cooling rate experiments for Sample 396B-30-1, 77-80 cm produced only olivine plus residual glass. The olivine morphologies and the proportions of crystals to glass, however, change systematically with cooling rate. At 2°/hr euhedral, chained olivine crystals are distributed uniformly throughout the charge. They are sub-equant and partly skeletal and make up 7 to 15 per cent of the charge (visual estimate) with a grain size of about 0.1 to 0.2 mm. In some parts of the charge, the chain-links ofolivine are arranged like stylized tree branches.

The 10°/hr run produced numerous pinwheels of olivine dendrites which in cross-section appear to be chained

olivines. The average diameter of the pinwheels is less than a millimeter and their thickness is about 0.05 mm. Olivine makes up no more than 5 per cent of the charge.

The 30° /hr charge is grossly similar to the 10° /hr one, but the olivine pinwheels are less abundant and are smaller. The pinwheels are more plumose and each one consists of several subparallel dendrite stems which are generally less than 0.5 mm in length.

Sample 396B-7-1, 42-46 cm, when cooled at $2^{\circ}/hr$, produced radiating acicular plagioclase (<0.8 mm) interspersed with granular to elongate olivine grains (-0.5 mm) and very fine grained plumose clinopyroxene. Tabular titanomagnetite grains are also present; they commonly are approximately perpendicular to the long dimension of the plagioclase grains. The $10^{\circ}/hr$ run for Sample 396B-7-1, 42-46 cm, however, looks very much like the $10^{\circ}/hr$ run for Sample 396B-30-1, 77-80 cm. The main difference is that less olivine is present in Sample 396B-7-1, 42-46 cm. A similar similarity occurs at $30^{\circ}/hr$. At this cooling rate, Sample 396B-7-1, 42-46 cm produced only a few compact flattened ovoids of fine-grained olivine dendrites possessing pinwheel geometry.

Comparison of textures produced in the cooling rate experiments on thin sections of Sample 396B-22-3, 28-38 cm with other samples of similar composition suggest a range of cooling rates from about 2° to $5^{\circ}/hr$ for the interior parts of pillows. This estimate is based on the groundmass textures of the rocks and assumes (1) that phenocrysts present at eruption did not exert a profound effect on groundmass textures and (2) that there was no time lag for nucleation of plagioclase in the experimental runs. The latter assumption is probably valid since some plagioclase was present at the start of the drop and this could serve as nucleation sites.

Direct interpretation of the cooling rate experiments for Samples 396B-7-1, 42-46 cm and 396B-30-1, 77-80 cm is difficult because both of these samples have a much lower liquidus than 396B-22-3, 28-38 cm; all three samples were cooled simultaneously in the same furnace. Thus, Samples 396B-7-1, 42-46 cm and 396B-30-1, 77-80 cm were superheated about 50°C at the start of the cooling rate experiments. This is reflected in the suppression of plagioclase nucleation in Sample 396B-30-1, 77-80 cm even at 2°/hr. This suggests that the ability of the melt to re-equilibrate in response to decreasing temperature is even slower than 2°/hr and that the effective supercooling of the melt probably increases continuously during the cooling rate experiments. Olivine morphologies are controlled in part by the degree of supercooling as shown by Donaldson (1976), and these experiments suggest that the nucleation delay caused by superheat may result in greater undercoolings at the time of olivine growth. Thus, if there are any naturally superheated basaltic magmas, this presents an additional variable to be considered in the interpretation of olivine morphologies as indicators of cooling rate.

DISCUSSION

The chondrite-normalized rare-earth abundances for the Site 396 samples (Figure 2) show them to be "normal" LIL element-depleted basalts. They are light-rare earth depleted, with La/Sm and La/Yb ratios less than 1.0, similar to the Type I basalts of Bryan et al. (1976). The Nb content of these basalts is low, resulting in high Zr/Nb ratios similar to those observed in other LIL element-depleted basalts (Pearce and Cann, 1973; Erlank and Kable, 1976; Rhodes et al., 1976), and considerably higher than the Zr/Nb ratios (<10) of oceanic islands and "anomalous" Type II basalts sampled on the Mid-Atlantic Ridge at 45°N and in the FAMOUS area (Erlank and Kable, 1976; Rhodes et al., unpublished data).

The chemical differences among the residual glasses of the various units at Site 396 preclude their being related by fractional crystallization of the observed phenocrysts. On the other hand, the trace element ratios in Sub-units A_1 , A_2 , and A3 and in Unit B are quite similar and vary in a general way that is compatible with small amounts of crystal fractionation. An obvious exception is the ratio of Sr to other magmaphile elements. This is illustrated by the Sr/Zr ratio, which is relatively constant in the aphyric units where Sr tends to behave as a magmaphile element, but is both distinctly different and more variable within Unit B where the irregular distribution of plagioclase exerts a partial control. This effect is less marked at Site 396 than in the phyric basalts at Site 395, where CaO and Al₂O₃ variations indicate much more heterogeneity in the content of plagioclase phenocrysts. Despite these small differences, we deduce that these ratios approximately reflect the characteristics of the mantle source region, and that the basalts of Units A and B were derived from an essentially similar and homogeneous LIL-element depleted mantle source. Similar ratios are observed in basalts from Holes 395 (Table 2) and 395A (Rhodes et al., 1978), implying a widespread and homogeneous mantle source for basaltic volcanism along this section of the Mid-Atlantic Ridge. This contrasts markedly with the wide variations in magmaphile element ratios found in Leg 37 basalts, both within and between holes (Blanchard et al., 1976), and the apparent necessity to postulate a complex and heterogeneous mantle source for the basalts in that region.

Although these basalts appear ultimately to have been derived by partial melting of a common source, all are evolved and have undergone moderate amounts of differentiation. Evidence of this is provided by the low Mg' values (0.59-0.69), low Ni concentrations (<180 ppm), moderate magmaphile element abundances (e.g., TiO₂ = 0.95 to 1.6%), and the presence of multiple phenocryst phases in all the basalts. Since the compositional variations within the individual basalt groups is small, we suggest that the magma compositions were established by differentiation within shallow magma chambers, followed by episodic eruption onto the sea floor, with little or no fractionation at the surface or enroute to the surface.

There can be little doubt that the compositions of the glassy and variolitic aphyric basalts are close to those of magmatic liquids. The compositions of the phyric basalts are more enigmatic. Several lines of evidence indicate that these rocks are far removed from liquid compositions:

a) Compilations of basaltic glass compositions (Melson et al., 1976) indicate that magmatic liquids with more than 17 per cent Al₂O₃ are extremely rare. Similarly, the glassy

selvages on the phyric basalt pillows are much lower in Al_2O_3 and not substantially different from the aphyric basalts (Figure 4).

b) The wide scatter of compositions in the normative olivine-plagioclase-pyroxene diagram (Figure 1) is suggestive of plagioclase and olivine addition to liquids close to the inferred olivine-plagioclase cotectic.

c) Experimental, textural and compositional evidence indicates that the most magnesian olivine phenocrysts in the phyric basalts are too forsteritic to have crystallized from melts having the compositions of the phyric basalts, but are derived instead from more "primitive" basalts.

d) Glass melt inclusions within olivine and plagioclase phenocrysts record entrapment of this more primitive liquid and provide insight into its composition. Its general characteristics are high CaO/Al₂O₃ (>0.85), low TiO₂ (<0.80 wt%), and high Mg' (>0.70).

e) The trend of decreasing CaO/Al₂O₃ with increasing TiO₂ and decreasing Mg' among related residual glasses implies that clinopyroxene fractionation plays a role in the overall differentiation scheme despite its absence as a phenocryst at Site 396. The geochemical imprint of the clinopyroxene fractionation may be imparted to the observed residual liquids by mixing of a low CaO/Al₂O₃ evolved magma with primitive liquids characterized by higher CaO/Al₂O₃.

From this evidence, we think that the phyric basalts have a mixed heritage, resulting from mixing of consanguineous "primitive" and evolved magmas and their attendant phenocrysts. If this interpretation is correct, the higher Mg'-values, normative An/(Ab+An) ratios, and lower magmaphile element abundances of the phyric basalts relative to the aphyric ones are due in part to the addition of up to 20 per cent plagioclase and 5 per cent olivine phenocrysts. The glassy rims on phyric basalt pillows probably provide the most reliable of the melt compositions. They have Mg' values comparable to those of the more evolved aphyric basalts (0.60 to 0.63), but are distinguished from them by lower TiO2 values (Figure 2) and by higher CaO/Al₂O₃ ratios. Thus, the phyric basalts are not simply related to any of the aphyric basalt types by processes of plagioclase and olivine accumulation.

CONCLUSIONS

Thus, we have several discrete magma types at Site 396, both phyric and aphyric, that are not related directly by crystal fractionation, but which appear to have been derived from similar mantle source materials. The prevailing interpretation of such relationships is that each basalt type represents an evolved derivative of more "primitive" basaltic magmas that resulted from varying amounts of melting. The evidence, presented here, of magma mixing in the phyric basalts suggests that such a model may be unduly simple. We suggest instead that magma mixing of consanguineous evolved and "primitive" basalts explains many of the characteristics of typical ocean floor tholeiites. A subsequent publication documenting the role of magma mixing in these and other ocean floor basalts is in preparation.

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