41. COMPARISON OF CHEMICAL AND MAGNETIC STRATIGRAPHY OF BASEMENT ROCKS AT DSDP SITES 332 AND 395

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ABSTRACT

Deep drilling into oceanic basement at Sites 332 (36° 53 'N, 33° 39 'W; 583 m) and 395 (22° 45 'N, 46° 05 'W; 572 m) provides an opportunity to compare the origin of a major portion of Layer 2 at two places on the Mid-Atlantic Ridge. The sites are similar in that basement at each consists dominantly of relatively few chemically distinct basaltic units (18 in Holes 332A and 332B; 9 in Holes 395 and 395A). These units occur as composites of basaltic pillow lavas, thin flows, and glassy breccia zones as thin as a few meters and as thick as 209 meters. Only two closely spaced dolerite units, totaling 15 meters thick (in Hole 395A), have been confirmed as intrusive at either site. Holes 395 and 395A also contain gabbroic and ultramafic cobbles and boulders, interpreted as talus, both above and below the topmost aphyric basal unit. No plutonic rocks were cored at Site 332.

The chemical groups at both sites can be divided into strongly phyric types and moderately, sparsely, or aphyric types (less phyric types). The first group contains 15 to 25 per cent or more of phenocrysts of olivine, plagioclase, clinopyroxene, or combinations of these minerals. Many of the phenocrysts appear to have accumulated by mechanical processes (gravity settling or floating, and flow differentiation). The proportion of strongly phyric basalts in both Hole 395A and Hole 332B, curiously, is 38 per cent. Among the phyric basalt types in Hole 332B are olivine-rich basalts (oceanites), representing about 5 per cent of the interval cored. All other phyric basalts at both sites have plagioclase as the predominant phenocryst, with lesser olivine and/or clinopyroxene.

For the most part, the less phyric basalt types cannot be related to each other, or to phyric basalts, by crystal fractionation involving phases present in the rocks. Instead, chemical differences appear to have resulted largely from variations in the extent of melting in the mantle. All basalts are low-K and -Ti mid-ocean ridge basalts, but those of Site 332 are typically lower in Ti, Zr, and other low-partition-coefficient elements than those of Site 395. They thus appear to represent greater partial melts of the mantle than those of Site 395. Basalts of Site 395, however, appear to derive from a distinctly more depleted mantle than those of Site 332, and have La/Sm of about 0.8. At Site 332, less phyric basalts and most strongly plagioclase-phyric basalts have La/Sm of about 2.2. The olivine-rich basalts and oceanites have La/Sm of about 1.5.

At Site 332, there is evidence for minor crystal fractionation and accumulation between some less phyric types that erupted more or less simultaneously. Less phyric and strongly phyric types are interbedded repeatedly at intervals of tens of centimeters to meters in the deeper parts of Hole 332B. Apparently, either these came from different sources and magma chambers at essentially the same time, or the interval has been repeated numerous times by faulting. A third possibility is that the phyric basalts are closely spaced narrow intrusives into the less phyric basalts. The rock types at both Site 332 and Site 395 suggest that to explain the lava sequences, there must have been at least two magma reservoirs, repeatedly tapped.

There is little evidence for magma mixing among less phyric types at either Site 395 or Site 332, and none between strongly phyric and less phyric types. These is considerable mineralogic evidence for mixing within the phyric basalts of Site 395, but mixing has not been evaluated for phyric basalts of Site 332.

Site 332 contrasts with Site 395, in that chemical types requiring different sources recur repeatedly in the holes, but can have different magnetic inclinations or polarities. Magnetic inclinations in some units are not the same in Hole 332B as in chemically and spatially correlative units in Hole 332A. Fault replication of units may explain many of these relationships. Assuming that all repetition of units was caused by faulting and/or intrusives, only 11 distinct chemical types of basalts need be defined at Site 332. The alternative is that magma types chemically almost identical either persisted unchanged in the crust or mantle for periods long with respect to secular changes and even reversals in the earth's magnetic field, or were generated under identical conditions. At Site 395, although reversals occur in the section, units are not repeated by faulting, and all have inclinations close to the theoretically predicted ±40° for the latitude. Inclinations at Site 332 are generally much shallower than the predicted ±56°. The reversals at Site 395 imply that lavas took up to 10^5 years to accumulate, with thousands or tens of thousands of years between eruptive events (Johnson, Paleomagnetism of Igneous Rocks, this volume).

At both Site 332 and Site 395, the aphyric and less phyric basalt types represent the most fractionated basalt compositions, with a strong mode of Mg/(Mg + Fe) at about 0.60 to 0.65. This contrasts with a much wider range of compositions toward Fe- and Ti-enrichment exhibited by dredged and drilled rocks from such typical non-rifted fast-spreading centers as the East Pacific Rise, and it contrasts also with Iceland.

INTRODUCTION

Two holes where penetration into basement exceeded 500 meters have been drilled into Miocene or younger oceanic crust on the Mid-Atlantic Ridge. The first of these was Hole 332B, drilled on DSDP Leg 37. Along with the other holes drilled on that cruise, it was designed in part to complement the extensive geophysical, submersible, and deep-tow operations and observations of Project FAMOUS (French-American Mid-Ocean Undersea Study), conducted primarily on the axial portion of the Mid-Atlantic Ridge 35 kilometers to the east (Figure 1). Hole 332B penetrated 586 meters of basement, and was accompanied by a pilot hole, 332A, extending more than 300 meters into basement (Aumento, Melson, et al., 1977).

DSDP Legs 45 and 46 were designed to drill one or more deep holes into Mid-Atlantic Ridge oceanic crust as standards of comparison for two transects to be conducted during IPOD ocean-crust drilling in the North Atlantic. The two transects were (1) a series of holes on young oceanic crust between Iceland and the proposed targets for Legs 45 and 46 near 22°N, to test the possible influence of the Iceland and Azores geochemical anomalies on the Mid-Atlantic Ridge, and (2) a series of holes away from the Mid-Atlantic Ridge, into progressively older crust, to explore "crustal aging" phenomena, as well as temporal variations in magmatic processes and mantle source compositions along a "flow line" away from the Mid-Atlantic Ridge.

Two holes involving repeated re-entries were drilled on Legs 45 and 46. The first, 395A, penetrated 572 meters of basement and was accompanied by a pilot hole with 93 meters basement penetration. These holes and Hole 396 were drilled on Leg 45. Hole 396 served as a pilot hole for Hole 396B, drilled on Leg 46, which penetrated 263 meters into basement. The locations of Site 332, 395, and 396 are shown on Figure 1, and listed in Table 1.

Deep drilling into oceanic basement at Sites 332 and 395 provides an opportunity to compare major portions of Layer 2 at two places on the Mid-Atlantic Ridge. In addition, some of the objectives of the transect between Iceland and Site 395 and 396 can now be addressed, inasmuch as Site 332 is part of that transect. This paper compares the basic chemical and magnetic stratigraphy of Sites 332 and 395. Other comparisons will be drawn, especially with the FAMOUS area axial rift, Iceland, and eastern Pacific fast-spreading ridges. The purposes of this paper are to evaluate magmatic processes on the Mid-Atlantic Ridge, to consider lateral variations in the crust by attempting correlations between closely spaced holes at the two sites, and to estimate the extent of crustal modification by faulting. To the extent that magnetic stratigraphy constrains what can be said about magmatic and tectonic processes, the magnetic structure of the crust will also be considered. This is a subject which deep crustal drilling has complicated enormously. This paper will not consider Holes 396 and 396B, since they concern mainly the results of Leg 46 and will be dealt with elsewhere (Heirtzler, Dmitriev, et al., 1978; Natland, 1978).

LITHOLOGIC UNITS

The scientific staffs of Legs 37 and 45 identified three types of units in igneous basement at Sites 332 and 395: (1) lithologic units, (2) chemical units, and (3) magnetic units. These are summarized on Figures 2 and 3. These figures, and the discussion that follows, are based primarily on the relevant site chapters in this volume and in Volume 37 (Aumento, Melson, et al., 1977).

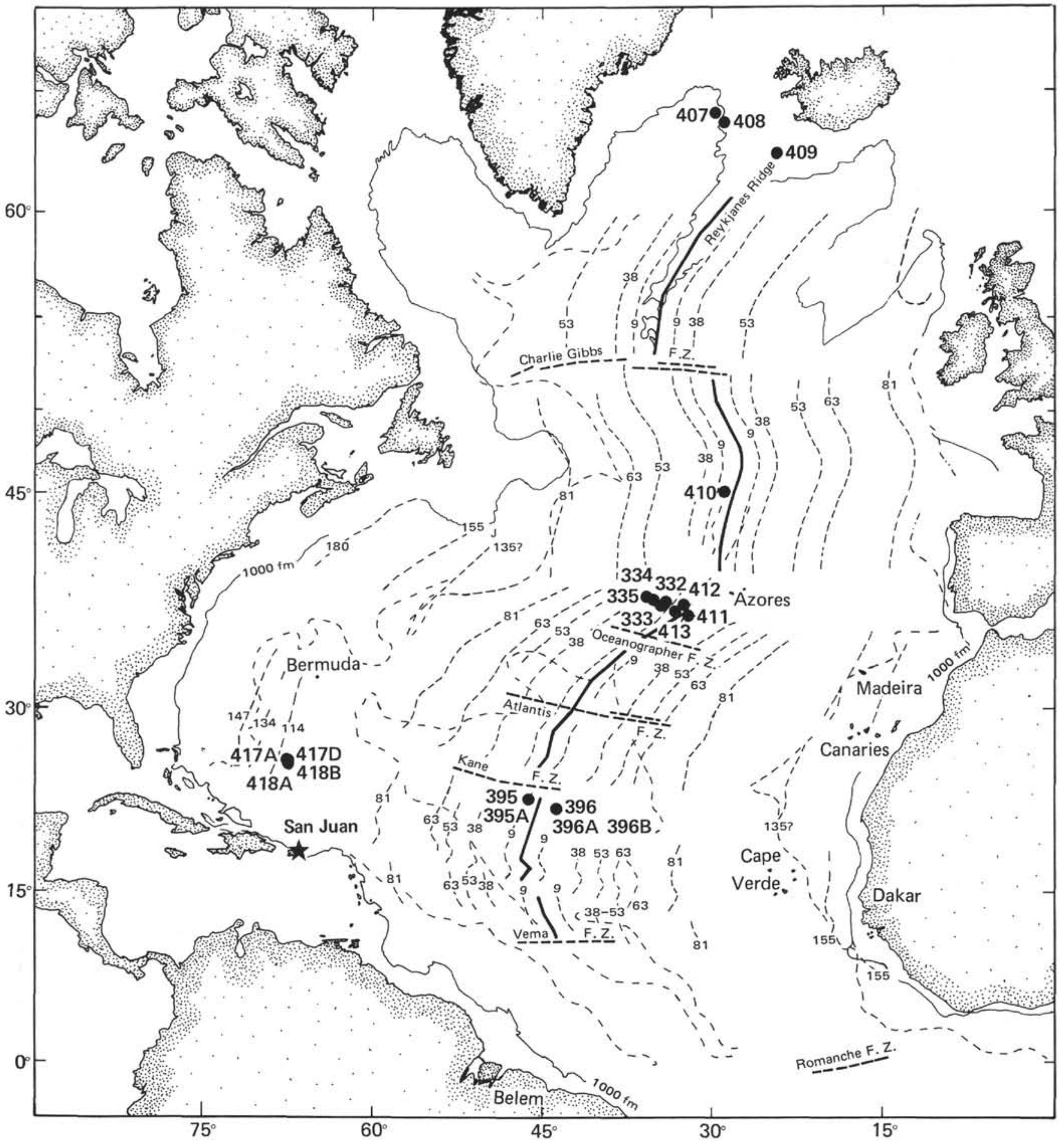


Figure 1. *Locations of DSDP North Atlantic Ocean crustal sites drilled on Legs 37, 45, 46, 49, and 51 through 53. Sites 412 through 414 are in the Mid-Atlantic Ridge median rift in the FAMOUS area. Inferred crustal ages out to 180 m.y. are shown.*

Lithologic units are defined on the basis of macroscopic features of the rocks (presence of pillow fragments or breccias, occurrence of thicker flows or intrusives, etc.), the abundance and proportions of phenocrysts, and the occurrence of other distinctive rock types (gabbros, serpentinites, etc.).

At Site 395, 27 lithologic units were thus defined, including four in Hole 395 (Figure 2). Four of these (two each in Holes 395 asnd 395A) include plutonic rocks. Four others were defined because they are largely or entirely breccias. Two others are dolerite intrusions, closely spaced near the bottom of Hole 395A. Most lithologic units are pillow basalts or fragments thereof, and either lack phenocrysts or contain abundant large plagioclase and lesser olivine phenocrysts, or plagioclase, olivine, and clinopyroxene phenocrysts. Altera-

TABLE 1
Location of Sites

Site	Location	Water Depth (m)	Depth to Basement
332	36°57.72'N 33°38.46'W (332B ~100 m NW of 332A)	1806-1818	~1958 (332A) ~1989 (332B)
395	22°45.35'N 46°04.90'W (395 <50 m from 395A*)	4484	4577 (395) ~4538 (395A)

*Not resolvable using satellite fixes.

tion increases generally downhole. In the upper part of Hole 395A, brownish gray altered zones are abundant next to joint or fracture surfaces, and many such zones contain cracks lined with secondary carbonates or clays. Alteration and fractures are more pervasive deeper in the hole (Cores 52 through 67).

Eighteen lithologic units at Site 332 (7 in Hole 332A, 11 in 332B) were also defined on the basis of macroscopic variability and the presence and abundance of phenocrysts. The major lithologic units are shown on Figure 3. The Leg 37 shipboard party divided these into 89 sub-units (Aumento, Melson, et al., 1977, Chapter 2). Twelve of these sub-units contained breccia zones, but no intrusives were positively identified. Most sub-units contain at least some phenocrysts, but the majority of basalts are only sparsely or moderately phyric, with plagioclase and rare olivine phenocrysts. Some units are distinctly porphyritic, including one strongly plagioclase-phyric unit at the top of Hole 332B and a number of thin strongly olivine-phyric units deeper in 332B. I follow Macdonald (1968) in terming tholeiitic basalts with abundant olivine "oceanites," to contrast them with alkalic picrites. A distinctive plagioclase-olivine-clinopyroxene phyric and glomerophyric basalt occurs in the deepest core of Hole 332A.

From paleontological data, the basalts of both Site 332 and Site 395 appear to have accumulated in an axial rift setting. The oldest sediments at the two sites are about 3.7 and 6.1 million years old, respectively.

CHEMICAL UNITS AND THEIR SIGNIFICANCE

During Legs 37 and 45, one or more samples per core were analyzed for major elements on board ship by X-ray fluorescence spectrometry (Bougault, 1977; Bougault et al., this volume). On Leg 45, Ni, Cr, Sr, and Zr were also routinely determined. According to these data, all the basalts of Sites 332 and 395 are low-K_2O mid-ocean ridge basalts.

In addition to the shipboard work on Leg 37, several other studies included numerous analyses of Site 332 basalts (Flower et al., 1977; Blanchard et al., 1976; Dmitriev, 1977; Gunn and Roobol, 1977). Each defined a downhole chemical stratigraphy differing somewhat from the others but without a uniform nomenclature.

Apart from the Leg 45 shipboard analyses, several other papers in this volume include numerous chemical

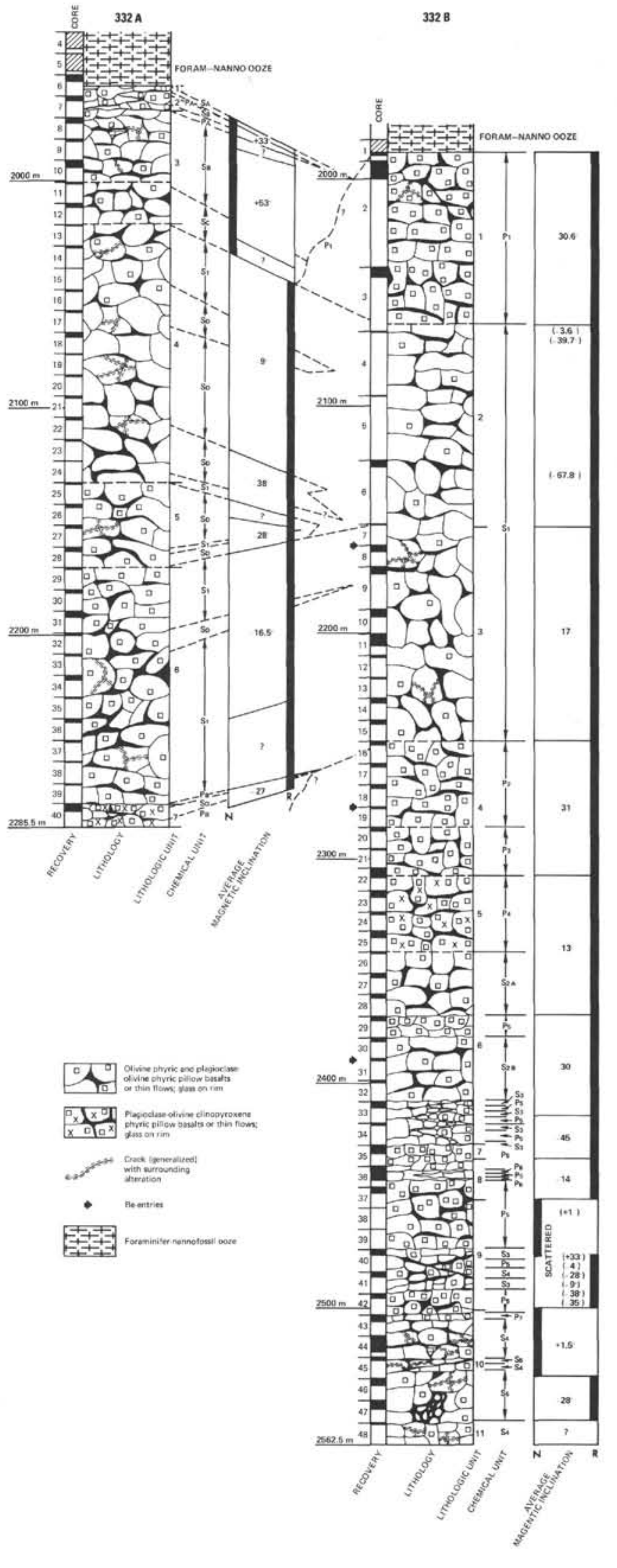


Figure 2. *Basement stratigraphy, Site 332. Unit boundaries assigned on basis of percentage of recovery of units within cores taken as percentage of interval cored.*

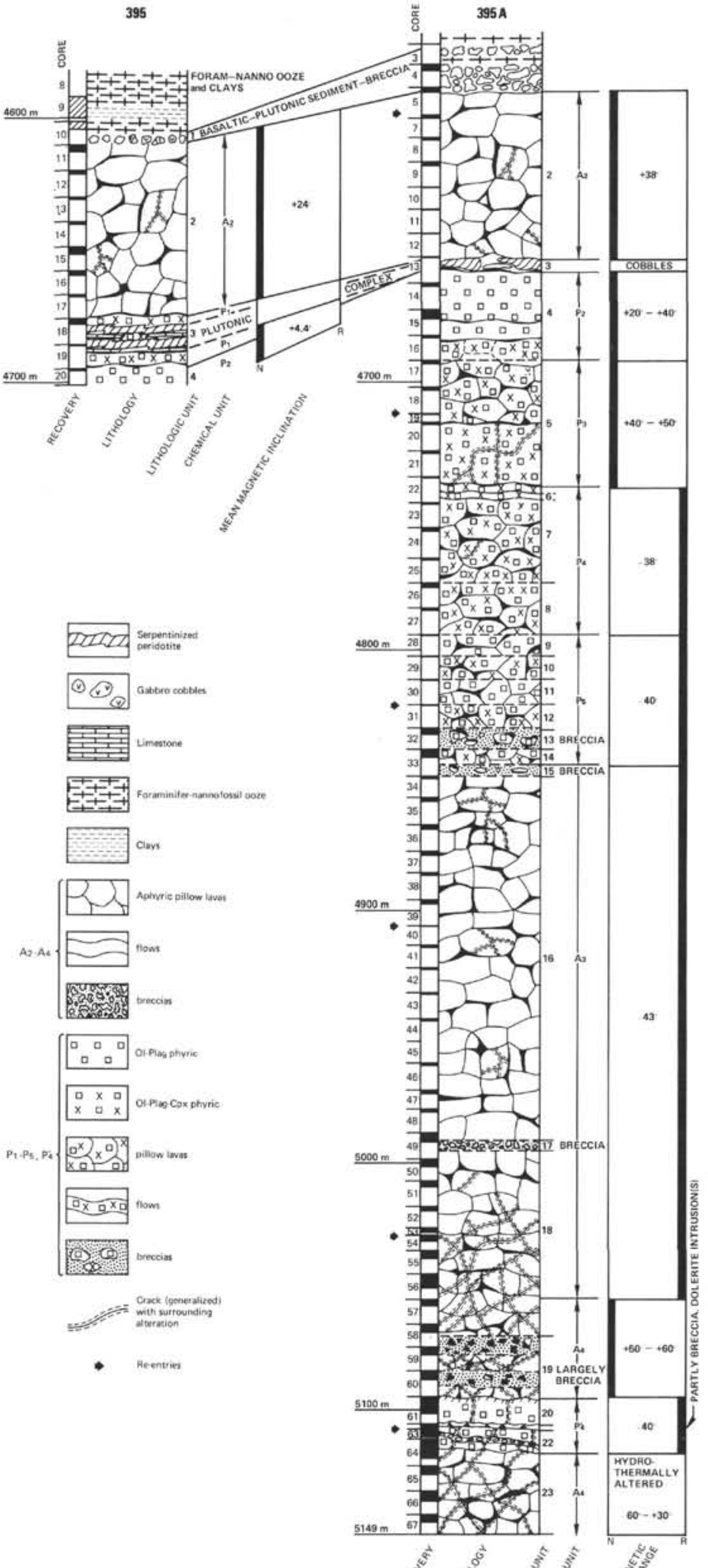


Figure 3. *Basement stratigraphy, Site 395. Unit boundaries assigned on basis of percentage of recovery of units within cores taken as percentage of interval cored.*

analyses of Site 395 basalts (Graham et al.; Zolotarev and Choporov; Propach et al.; Rhodes et al.). These studies either adhere to the chemical unit identification and nomenclature based on the shipboard analyses, or else make no attempt at redefinition.

Byerly and Wright (1978) defined a coherent chemical stratigraphy for all Leg 37 basalts by making quantitative corrections for interlaboratory chemical differences and for the effects of alteration. Several other studies demonstrated important trace-element differences among Site 332 basalts (Blanchard et al., 1976; Schilling et al., 1977; Bence and Taylor, 1977; O'Nions and Pankhurst, 1977; Puchelt et al., 1977), but none has attempted to integrate these data systematically into a presentation of chemical stratigraphy.

In order to provide the most comprehensive possible comparison with Site 395, I defined units for Site 332 by re-examining all data, correlating chemical and lithologic changes, incorporating trace-element data, and assessing possible chemical units for coherence of magnetic inclinations. These were the procedures used for Site 395. Site 332 proved considerably more complex than Site 395, and this is itself significant. The remainder of this section will deal largely with Site 332; this is primarily because the amount of data obtained on Site 332 is vast, chemical variations are subtle, and the site is complex—many units repeat several times in one or both of Holes 332A and 332B. To address the problems of correlating units between the two holes, and to consider possible structural modifications of the crust that might be evident in the chemical and magnetic stratigraphy, it was necessary to develop as clear a picture of Site 332 as possible.

For this paper, I have considered two primary sources of major-element data: the shipboard data (Bougault, 1977; Bougault et al., this volume) and the data of the NASA Johnson Space Center (Blanchard et al., 1976; Rhodes et al., this volume). Comparisons of interlaboratory standards (Wright, 1977) and of average analyses of homogeneous basaltic units (Byerly and Wright, 1978; Appendix, this volume) indicate that caution is necessary when comparing data of two or more laboratories. The procedure I followed was to evaluate chemical stratigraphy separately for the data from each laboratory, then combine the conclusions for each. This was a simple matter for Site 395, since unit boundaries for the two laboratories were identical. For Hole 332B the data coverage for the two laboratories was almost entirely adequate, but only the shipboard data comprehensively covered Hole 332A. One unit in Hole 332A was defined only by analyses of another laboratory. To check for completion, I scanned all data tabulated in order of depth in Chapter 2 of Aumento, Melson, et al. (1977), and the summary of units in Byerly and Wright (1978). The units in this paper differ only in detail from those of Byerly and Wright, chiefly in combining some of their "chemical types" which differ only by small accumulations of phenocrysts from a common parent.

Some elements proved more useful than others for discriminating basalt types. TiO_2, for example, can be measured with very high precision, and many of the basalt types at Sites 332 and 395 have the interesting and useful property that TiO_2 varies extremely little (usually less than 0.05%) in any given aphyric or sparsely phyric basalt chemical unit. TiO_2 also shows little or no variation among laboratories (Wright, 1977; Appendix, this volume). The differences in TiO_2 between aphyric and sparsely phyric chemical units are often larger than this by factors of 5 to 10. By and large, the group of chemical analyses by a given laboratory within each chemical unit also shows little variation in one or more other oxides or trace elements that either support the distinction based on TiO_2, or define distinctions sometimes not seen with TiO_2. The data can then be used to decide how, if at all, distinct chemical types are related.

This is illustrated in Figure 4 for Site 395, and in Figures 5 through 7 for Site 332. For Site 395, the Leg 45 shipboard party adopted the mnemonic symbol A for all aphyric basalt units, distinguishing them by numerical subscripts, and P for all phyric basalts. For Site 332, I adopted the symbol S for sparsely or moderately phyric basalts; aphyric basalts are rare, and are part of larger sparsely phyric or moderately phyric units. I retained P for all porphyritic units. Units in Hole 332A which have no counterparts in Hole 332B are designated by alphabetic subscripts. These units are shown on Figures 2 and 3, and the data clusters for each unit are identified on Figures 4 through 7.

The diagrams illustrate essentially flat TiO_2 trends for all aphyric or sparsely phyric basalt units. Up to 1 per cent or more variation can occur in MgO, total iron as FeO*, and CaO, in any given unit; TiO_2 varies by only 0.05 per cent or so. Because the Site 395 basalts with flat TiO_2 trends are aphyric; the distinctions among units are very sharp. None of the papers dealing with Site 332 basalts had identified similar trends, and it was important, once having seen them at Site 395, to determine if similar trends occur at Site 332. They do, although there is more overlap and the variation in TiO_2 is greater, probably because of the effect of a minor percentage of phenocrysts in the typically small (10 cm^3) samples. Similar flat TiO_2 trends occur at Site 396 (Hole 396B), and have been explained by Kirkpatrick (1978) as a consequence of simultaneous olivine fractionation and plagioclase resorption. Figures 4 through 7 show that many of the flat TiO_2 trends do not follow single-mineral control lines on all diagrams; nor can they be explained by combinations of olivine and plagioclase fractionation. Kirkpatrick's explanation is consistent with observations of rare, rounded (resorbed) plagioclase phenocrysts in aphyric or sparsely phyric basalts from Sites 395 and 396 (Figure 8; Dungan et al., 1978), and could have arisen simply by magma ascent. Fujii et al. (this volume) have established that Site 395 chemical type A_2 has both plagioclase and olivine near

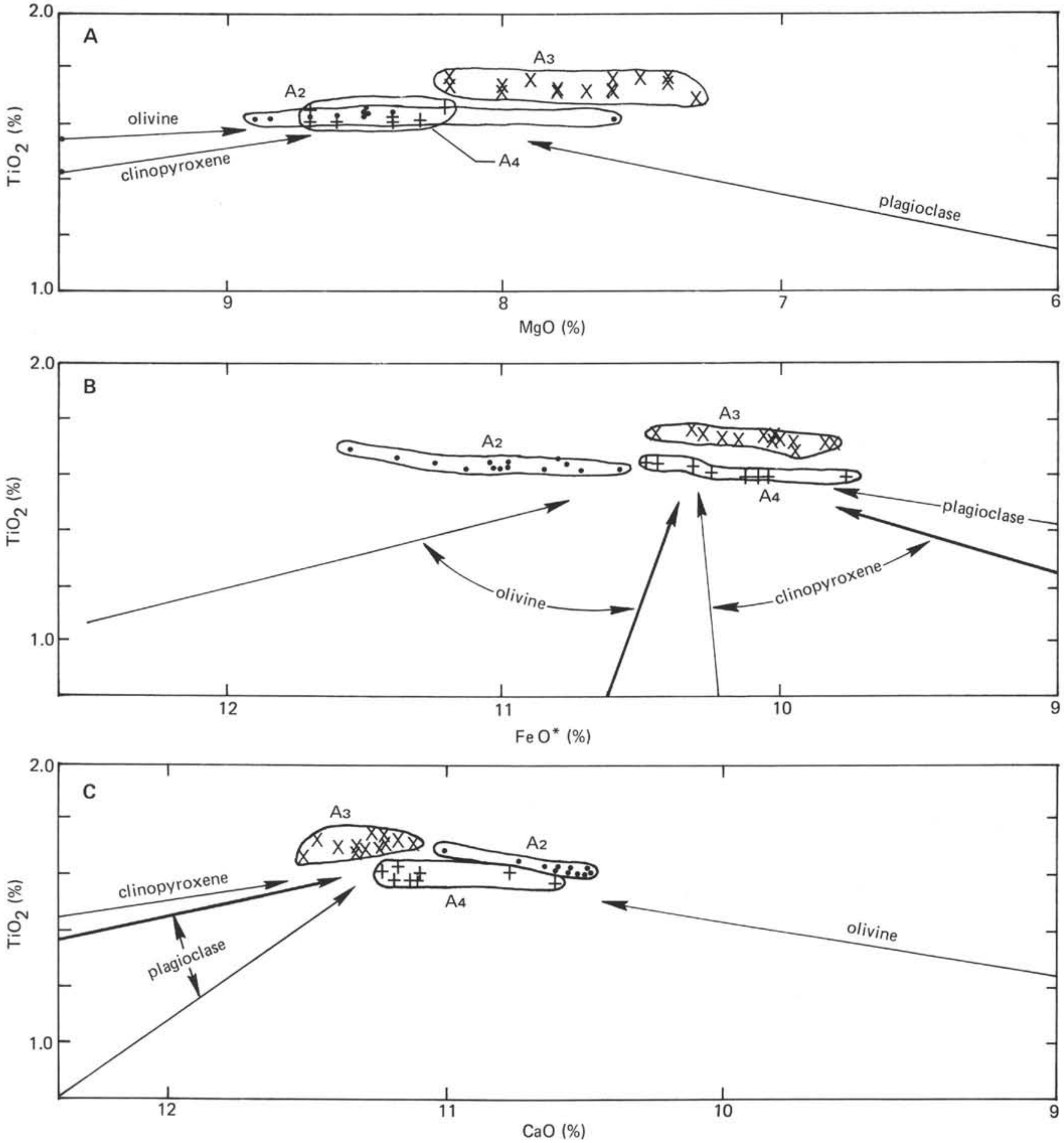


Figure 4. *Variation diagrams for Site 395. Aphyric units only are shown. Data from Bougault et al. (this volume) recalculated dry, reduced (total iron as FeO*), and normalized to 100 per cent. Representative mineral control lines are based on Natland (unpublished data) and analyses listed in Byerly and Wright (1978) from various sources. Where a range of compositions for a given mineral might be involved, the full range is shown, but the more likely potential control is closer to the thicker control lines.* (A) *TiO_2-MgO.* (B) *TiO_2-FeO*.* (C) *TiO_2-CaO.*

only olivine. During magma ascent at constant temperature, this basalt would have moved off a two-phase (olivine and plagioclase) cotectic, to a lower pressure regime where olivine alone crystallized. Previously formed plagioclase would then have been partially resorbed.

To show how narrow are the compositional ranges for the aphyric, sparsely phyric, and moderately phyric

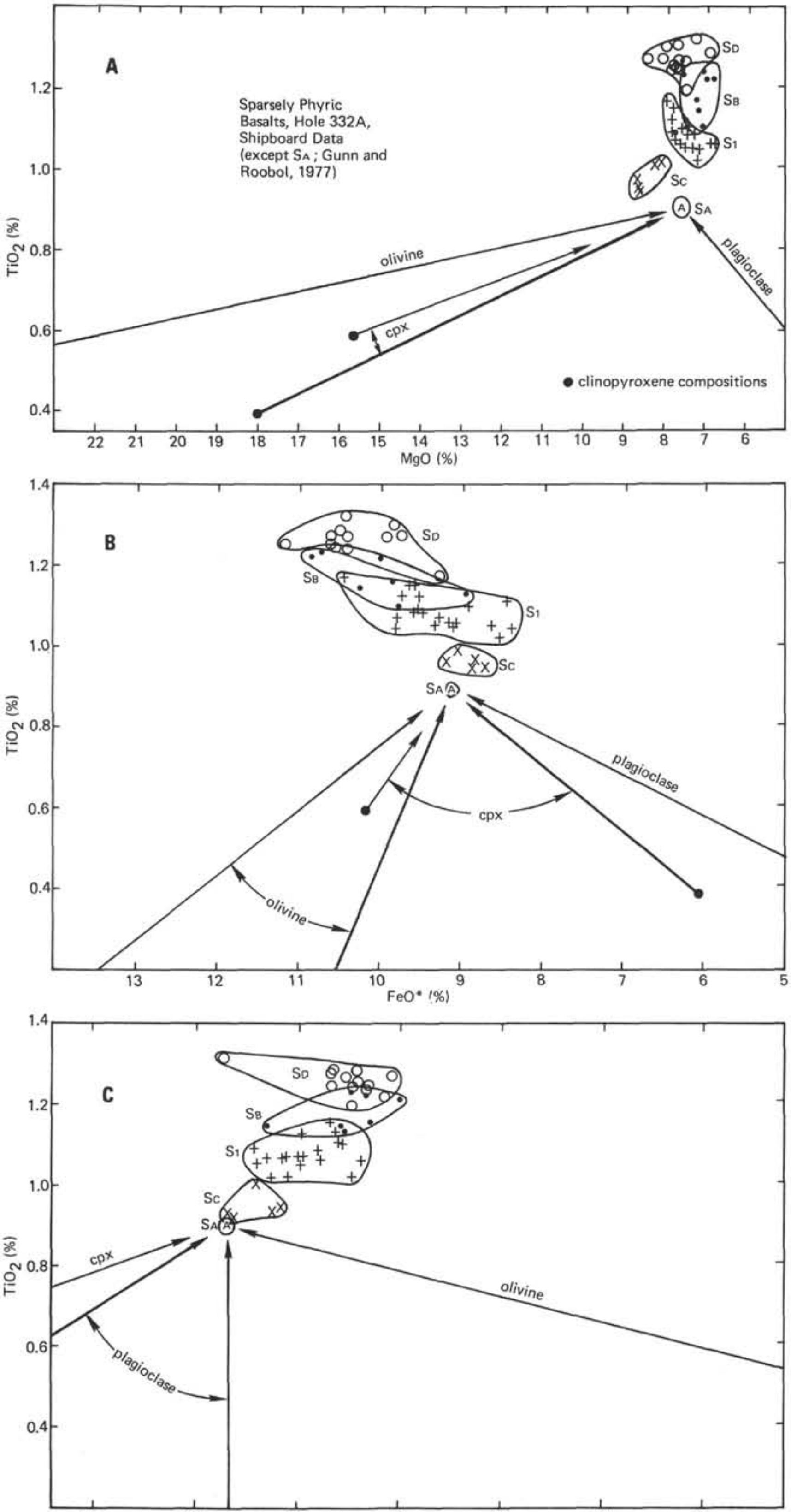


Figure 5. *Variation diagrams for Hole 332A sparsely phyric basalts. Data from Bougault (1977) recalculated dry, reduced (total iron as FeO*) and normalized to 100 per cent. Control lines are based on analyses listed in Byerly and Wright (1978) and plotted with the same conventions as in Figure 4.* (A) TiO_2-MgO. (B) TiO_2-FeO^*. (C) TiO_2-CaO.

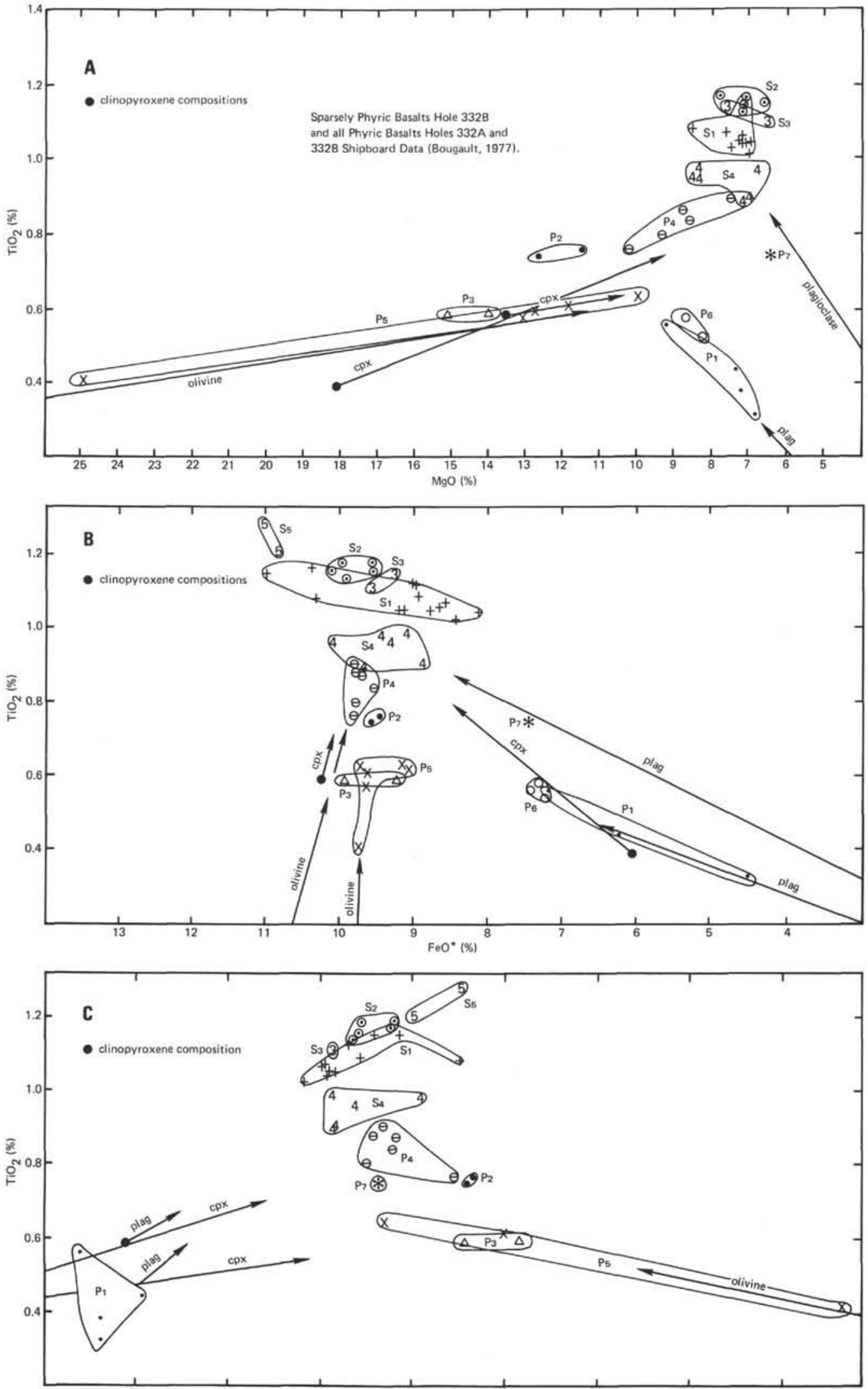


Figure 6. *Variation diagrams for Hole 332B sparsely phyric basalts and Holes 332A and 332B phyric basalts. Data from Bougault (1977) recalculated dry, reduced (total iron as FeO*), and normalized to 100 per cent. Data corrected for CaO in* $CaCO_3$ *Control lines plotted from same analysed as in Figure 5.* (A) TiO_2-MgO. (B) TiO_2-FeO^*. (C) TiO_2-CaO.

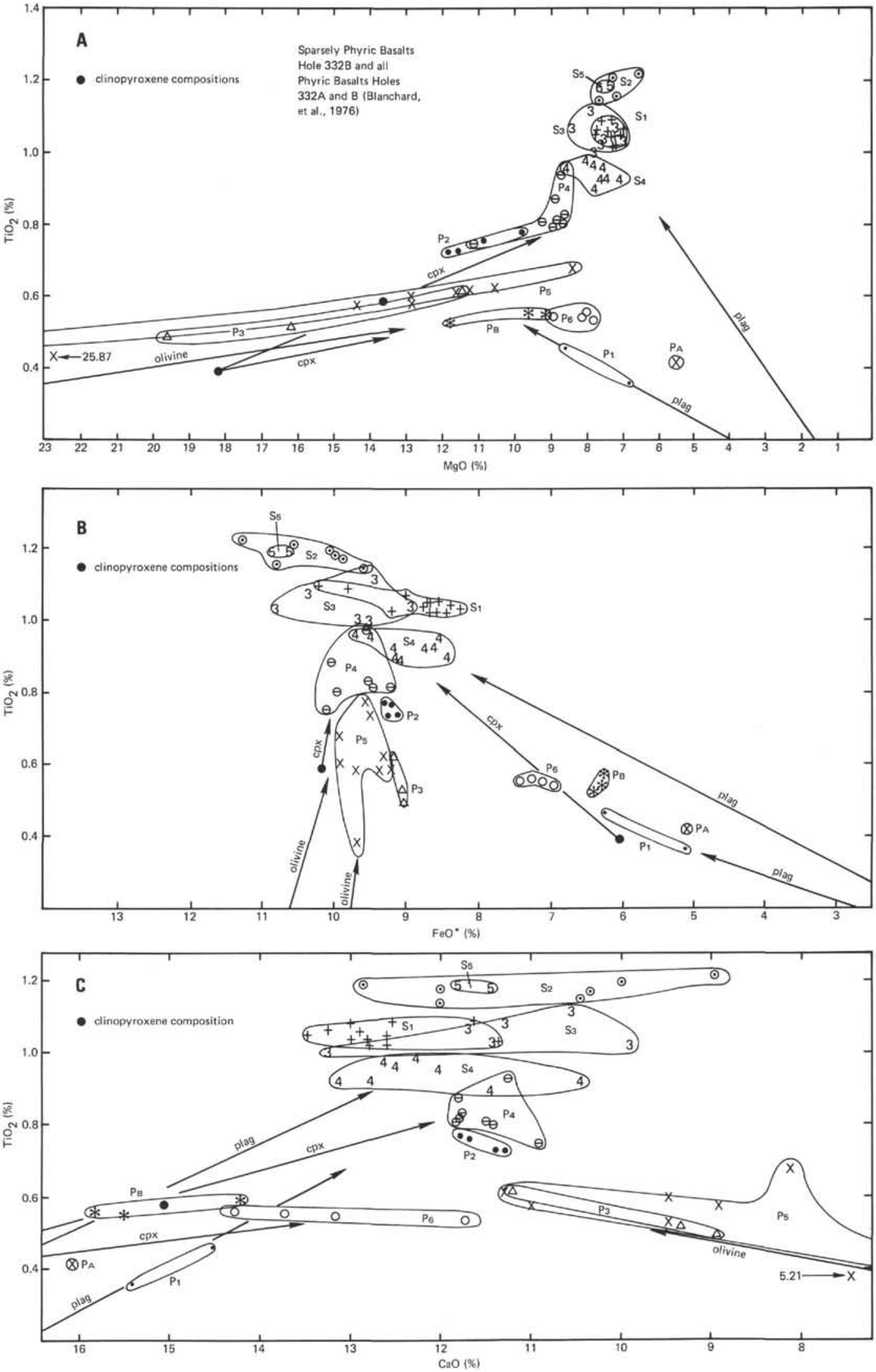


Figure 7. *Variation diagram for Hole 332B sparsely phyric basalts and Holes 332A and 332B phyric basalts. Data from Blanchard et al. (1976) recalculated dry, reduced (all iron as FeO*), and normalized to 100 per cent. Data corrected for CaO in* $CaCO_3$. *Control lines plotted from same analyses as in Figure 5.* (A) TiO_2-MgO. (B) TiO_2-FeO^*. (C) TiO_2-CaO.

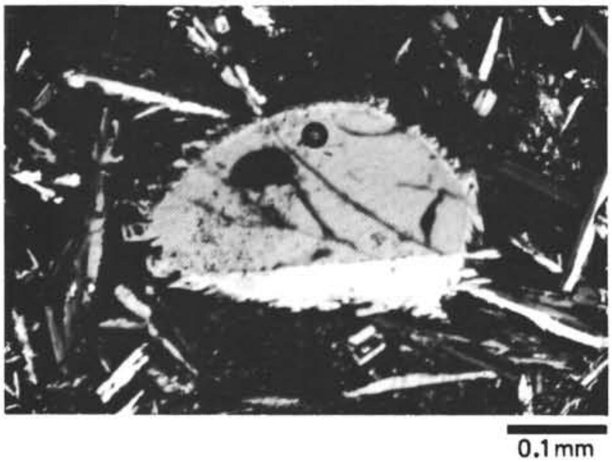


Figure 8. *A small rounded plagioclase xenocryst in a Site 395 type A_3 aphyric basalt, Sample 45-395-35-1, 109-133 cm (#3). The xenocryst has a thin rim of plagioclase needles formed during groundmass crystallization.*

the liquidus at elevated pressures, whereas at 1 atm it has units of Sites 332 and 395, Tables 2 and 3 list average analyses and standard deviations of these units from the two sites. The Site 395 data are from Bougault et al. (this volume). For Site 332, the data of Bougault (1977) and Blanchard et al. (1976) are listed. The data of Blanchard et al. are meager for Hole 332B, so for that hole only data of Bougault (1977), and one analysis of Gunn and Roobol (1977) are shown. Where full analyses are available, the data are listed dry, reduced, and normalized to 100 per cent. For the data of Bougault and coworkers, where Na_2O, P_2O_5, and MnO were generally not determined for Site 332, iron listed as Fe_2O_3 was first converted to FeO, the difference added to loss on ignition, and the average analysis normalized to 100 per cent minus the adjusted loss on ignition.

In general, especially when trace-element data have been considered, the various aphyric and sparsely phyric chemical types have come to be viewed as distinct magma batches unrelated by crystal fractionation (Blanchard et al., 1976; Bougault et al., this volume; Rhodes et al., this volume). Some elements of this conclusion, in terms of major elements, can be appreciated by examination of the flat TiO_2 trends of Figures 4 through 7. It is evident that the internal variation for each group is not "pointing toward" that of any other group on one or more of the three variation diagrams shown on each figure. Furthermore, combinations of olivine, plagioclase, and clinopyroxene in many cases cannot produce one group from another by crystal fractionation. This was shown for Site 332 by Byerly and Wright (1978), who identified three distinct sparsely phyric parental compositions which they related to five other sparsely phyric types by crystal accumulation, and only one type to another sparsely phyric type by crystal fractionation. In addition, they identified seven other distinct and independent phyric magma types.

One aspect of the problem of magma batch independence at Site 332 depends on rare earth elements.

TABLE 2
Average Chemical Analyses and Standard Deviations of Site 332 Sparsely and Moderately Phyric Basalts

Investigator	Gunn	Bougault	Bougault	Bougault	Bougault	Bougault	Bougault	Blanchard	Bougault	Blanchard	Bougault	Blanchard	Bougault	Blanchard	Bougault	Blanchard
Hole	332A	332A	332A	332A	332A	332A	332B	332B	332B	332B	332B	332B	332B	332B	332B	332B
Unit[a]	S_A (1)	S_B (8)	S_C (5)	S_D (11)	S_{1A} (8)[b]	S_{1B} (6)[b]	S_1 (13)	S_1 (16)	S_2 (5)	S_2 (7)	S_3 (2)	S_3 (5)	S_4 (5)	S_4 (9)	S_5 (1)	S_5 (2)
SiO_2	50.65	51.14 ±1.05	51.45 ±0.25	50.79 ±0.92	50.92 ±0.30	50.13 ±0.76	50.59 ±0.69	50.73 ±0.33	48.08 ±0.80	51.61 ±0.78	47.76	51.62 ±0.77	47.47 ±1.19	50.17 ±0.51	48.49	51.34
Al_2O_3	14.75	14.60 ±0.38	15.23 ±0.07	14.99 ±0.38	14.83 ±0.31	16.43 ±0.75	15.52 ±0.98	16.40 ±0.66	14.59 ±0.34	15.64 ±0.33	15.01	15.65 ±0.47	15.97 ±1.25	16.90 ±1.41	14.23	14.77
FeO*	9.09	10.05 ±0.61	8.93 ±0.17	10.21 ±0.49	9.21 ±0.61	9.09 ±0.87	9.16 ±0.74	8.88 ±0.53	9.55 ±0.26	10.29 ±0.58	9.01	9.82 ±0.76	8.99 ±0.34	9.24 ±0.45	10.64	10.72
MgO	7.44	7.06 ±0.20	8.45 ±0.19	7.62 ±0.33	7.69 ±0.37	7.33 ±0.40	7.54 ±0.43	7.27 ±0.24	6.98 ±0.48	7.32 ±0.44	6.80	7.72 ±0.03	7.28 ±1.03	7.86 ±0.53	7.17	7.50
CaO	13.60	12.21 ±0.29	13.41 ±0.23	12.39 ±0.44	12.67 ±0.27	13.00 ±0.18	12.81 ±0.29	12.81 ±0.43	12.10 ±0.29	10.88 ±1.27	12.27	10.97 ±0.73	12.19 ±0.55	12.03 ±0.81	11.75	11.55
Na_2O	2.09	–	–	–	–	–	–	2.34 ±0.14	2.30 ±0.15	2.48 ±0.10	–	2.61 ±0.25	–	2.38 ±0.30	2.05	2.44
K_2O	0.25	0.39 ±0.08	0.22 ±0.05	0.34 ±0.10	0.28 ±0.10	0.31 ±0.06	0.29 ±0.09	0.24 ±0.08	0.30 ±0.05	0.31 ±0.12	0.29	0.27 ±0.06	0.27 ±0.15	0.25 ±0.12	0.07	0.13
TiO_2	0.89	1.17 ±0.05	0.96 ±0.03	1.24 ±0.03	1.06 ±0.02	1.05 ±0.01	1.07 ±0.05	1.05 ±0.02	1.13 ±0.03	1.18 ±0.03	1.08	1.05 ±0.05	0.91 ±0.05	0.94 ±0.03	1.18	1.19
P_2O_5	0.09	0.18 ±0.02	0.14 ±0.01	0.19 ±0.01	0.17 ±0.05	0.18 ±0.01	0.17 ±0.04	0.11 ±0.01	0.14 ±0.01	0.12 ±0.01	–	0.12 ±0.02	–	0.10 ±0.01	0.12	0.12
MnO	0.17	–	–	–	–	–	–	0.15 ±0.02	0.16 ±0.01	0.17 ±0.02	–	0.19 ±0.03	–	0.15 ±0.04	0.18	0.17

[a] Note: Number of analyses in parentheses.

[b] S_{1A} and S_{1B} are possibly two closely-related chemical types; boundary is that between lithologic Units 5 and 6. Al_2O_3 is principal distinguishing oxide.

TABLE 3
Site 395, Major-Element Average Values and Standard Deviations for Aphyric Basalt Units (volatile-free concentrations, wt. %) (from Bougault et al., this volume)

Unit	A2*	A2	A3	A4	A4
Hole	395	395A	395A	395A above Core 61	395A below Core 61
No. Samples	6	6	16	4	4
SiO_2	49.37	49.45	49.73	49.37	48.90
	0.32	0.23	0.14	0.77	0.29
Al_2O_3	14.93	15.01	15.14	15.00	15.17
	0.12	0.14	0.22	0.36	0.10
Fe_2O_3 (t)	12.06	12.31	11.20	11.17	11.46
	0.15	0.23	0.19	0.23	0.23
MnO	0.18	0.18	0.18	0.18	0.20
	0.01	0.01	0.01	0.01	0.01
MgO	8.58	8.53	7.61	8.20	8.40
	0.20	0.15	0.25	0.14	0.18
CaO	10.53	10.60	11.29	10.97	11.09
	0.03	0.09	0.11	0.32	0.16
Na_2O	2.66	2.64	2.46	2.40	2.5
	0.02	0.04	0.06	0.04	
K_2O	0.11	0.14	0.21	0.20	0.23
	0.02	0.03	0.05	0.08	0.02
TiO_2	1.62	1.64	1.72	1.59	1.62
	0.01	0.01	0.02	0.01	0.02
P_2O_5	0.15	0.17	0.17	0.14	0.15
	0.01	0.01	0.01	0.01	0.01
Total	100.01	100.67	99.71	99.22	99.72
LoI	−0.93	−0.98	−1.34	−1.9	−2.87

In general, two groups can be distinguished: those with La/Sm between 1.8 and 2.4, and those with La/Sm between 1.2 and 1.6 (Figure 9). This distinction is also useful in defining chemical stratigraphy (Figures 10 and 11). In constructing these last two figures, I used the data of Blanchard et al. (1976), Bence and Taylor (1977), Schilling et al. (1977), and O'Nions and Pankhurst (1977). The data of Puchelt et al. (1977) show similar variations, but not the consistency of the other laboratories, so are not plotted on Figures 10 or 11. Among the four remaining laboratories, as can be seen, few rare-earth data are available for Hole 332A (Figure 10).

All these laboratories reported relatively light-rare-earth-depleted and light-rare-earth-enriched patterns for Site 332 basalts, but only Blanchard et al. (1976) clearly identified which types of basalts showed the relatively depleted patterns. By plotting La/Sm for all these laboratories versus depth, it became clear that all the relatively depleted basalts at Site 332 are porphyritic, and all but one of these (P_1) are olivine-rich basalts or oceanites (olivine-controlled basalts of Byerly and Wright, 1978). Figure 9, on which only the data of Blanchard et al. (1976) and Rhodes et al. (this volume) are plotted, illustrates the impossibility of deriving Site 332 sparsely phyric basalts from the phyric basalts with lower La/Sm. Where relative shifts in La/Sm can be produced by clinopyroxene fractionation (or by leaving it as a residuum during partial melting), shifts of the magnitude shown on Figure 9B would cause drastic changes in scandium, not seen on Figure 9A. The figure also illustrates the fundamental dichotomy between Site 395 and Site 332. This dichotomy was also demonstrated by Bougault et al. (this volume) for other low-partition-coefficient trace elements (Ta, Th, Tb, etc.). On Figure 9, not only do the general fields for the two sites fall on completely different parts of the diagrams, but the variation of La/Sm within one particular sparsely phyric unit of Site 332 (Unit S_4) exceeds that of the entire group of Site 395 basalts. This implies that the evolution of even a single magma type at Site 332 was more complex than at Site 395, and that crystal fractionation and accumulation patterns in the lavas were overprinted on fundamentally heterogeneous magma types, even in a single eruptive sequence.

Another important contrast is that Site 332 basalts have overall lower TiO_2 and Zr than Site 395 basalts, even though the mantle sources for the two suites appear to be similar in these elements (the basalt abundances fall on a single line on the TiO_2-Zr diagram of Bougault et al., this volume). They also have lower Na_2O (Tables 2 and 3). These relations imply that Site 332 basalts represent greater partial melts of the mantle than Site 395 basalts, even though that mantle appears to be enriched, by comparison, in light rare-earth and certain other trace elements.

How did the Site 332 basalts develp so heterogeneous an enrichment in light rare-earth elements? Mysen and Holloway (1977) argued from experimental and theoretical evidence that rare-earth heterogeneities could be produced in an initially homogeneous mantle source by partial extraction of magmas, then by continuing the melting of the remaining refractory mantle residuum. Langmuir et al. (1977) extended this concept to FAMOUS area basalts by proposing that "dynamic melting," involving different ranges in the extent of melting in the mantle, variably efficient filter pressing, re-melting of refractory residues, and zone refining, could produce differences in rare-earth abundances such as those at Site 332. Crystal fractionation and the effects of pressure on shifting phase boundaries during melting could produce other variations. The rare-earth data of Langmuir et al. (1977) for FAMOUS area basalts and one basalt from Unit P_2 of Site 332 are also plotted on Figure 9. They illustrate that essentially the same complex processes are occurring in the FAMOUS rift today as those which occurred at Site 332 when it was in an axial rift setting along the same segment of the Mid-Atlantic Ridge.

Rhodes et al. (this volume) and Dungan et al. (this volume, and 1978) argued that an important process in Site 395 and Site 396 phyric basalts is that of magma mixing. Their evidence is mineralogical and experimental. Calcic cores of strongly zoned plagioclases and magnesian cores of olivines could not be produced in 1-atm crystallization experiments on whole-rock compositions of Site 395 and Site 396 phyric basalts. The equilibrium plagioclases were more sodic and the olivines more iron rich than the cores of the phenocrysts. In addition, liquid inclusions in the phenocrysts were more "primitive" than natural glass compositions from the quench margins of phyric basalt pillows. These rela-

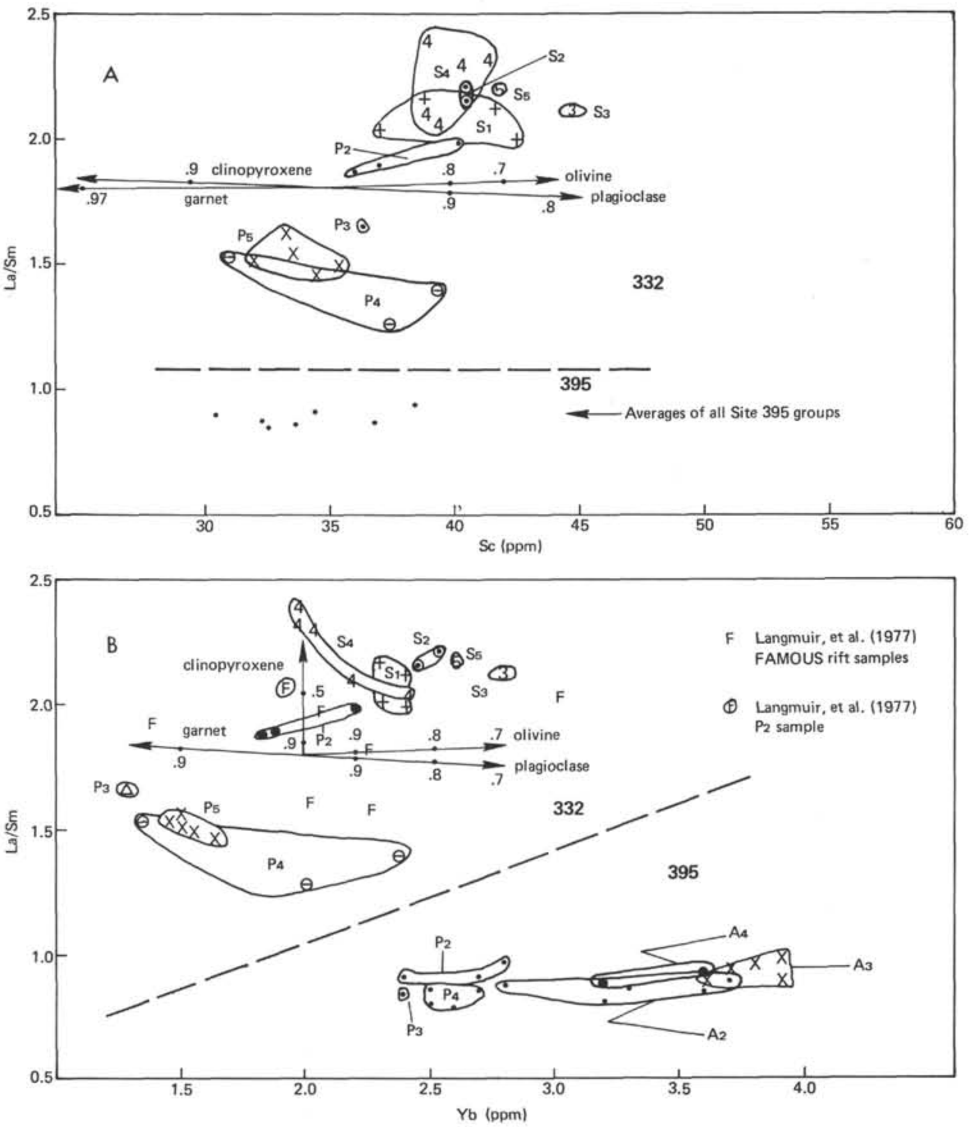


Figure 9. (A) *La/Sm versus Sc for Sites 332 and 395 and FAMOUS basalts (after Blanchard et al., 1976).* (B) *La/Sm versus Yb for Sites 332 and 395 and FAMOUS basalts (after Blanchard et al., 1976). Data from Blanchard et al. (1976), Rhodes et al. (this volume), and Langmuir et al. (1977). Liquid lines of descent are shown for single-mineral fractional crystallization. Index numbers refer to the fraction of the system that is liquid.*

tions suggested mixing of "primitive" lavas charged with phenocrysts into magma chambers containing more fractionated magmas, thus producing the strong zoning on the phenocrysts.

Detailed examination of crystal morphologies in the phyric basalts of Site 395 (Natland, this volume) confirms that this process more than likely occurred, but that the patterns of phenocryst crystallization and zoning are only partially explained by mixing. More than one "primitive" composition and more than one "fractionated" composition were probably involved, and crystallization occurred at a wide range of undercoolings, even among the phenocrysts.

Magma mixing has not been evaluated for Site 332, but photomicrographs in Blanchbard et al. (1976) show strongly zoned plagioclases with glass inclusions, and large megacrysts and glomerocrysts similar to those in the phyric basalts of Site 395. In addition, Dungan et al. (1978) evaluated the mineralogical evidence for mixing in some Site 396 basalts with relatively low phenocryst abundances, sufficiently low to show flat TiO_2 trends. In essence, although aphyric, sparsely phyric, or moderately phyric basalts appear to be compositions indepenedent of phyric basalt compositions, they too can show mineralogical evidence for a mixing history. This could be the explanation for the fairly great range in La/Sm shown by some Site 332 sparsely phyric basalts (e.g., Site 332, Type S_4 on Figure 8).

This may help explain the lack of variability in La/Sm at Site 395. There are no olivine-rich basalts or

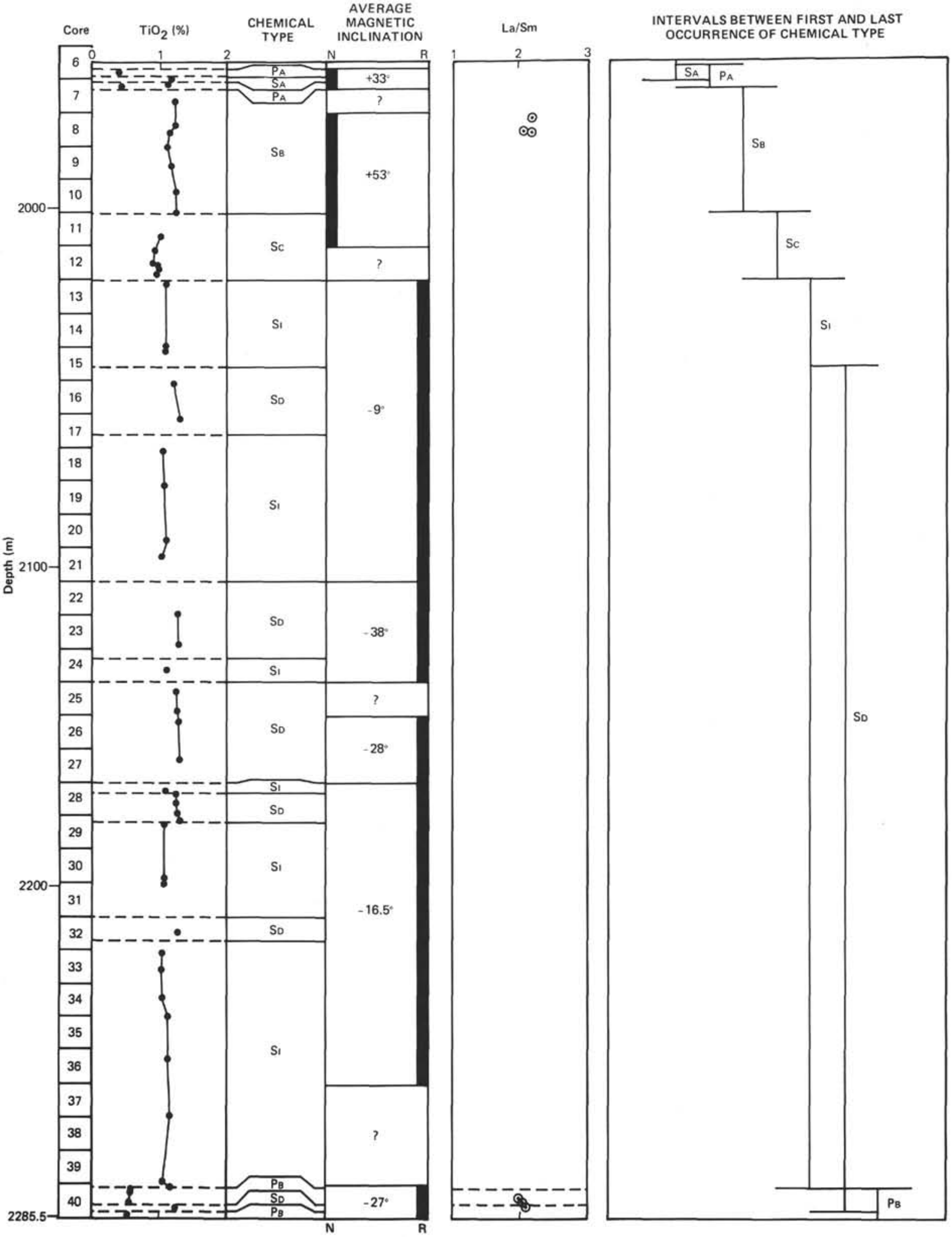


Figure 10. *TiO$_2$ versus depth, average magnetic inclinations of Hall and Ryall (1977) superunits versus depth, La/Sm versus depth, and stratigraphic range of chemical units for Hole 332A. Magnetic inclinations in parentheses are representative values in intervals where inclinations are scattered. Sample depths assigned assume that recovery within a core is porportional to the interval cored. TiO$_2$ data from Bougault (1977) and Blanchard et al. (1976), normalized as in Tables 1 and 2 (see text). Rare-earth element data from Blanchard et al. (1976) and Schilling et al. (1977).*

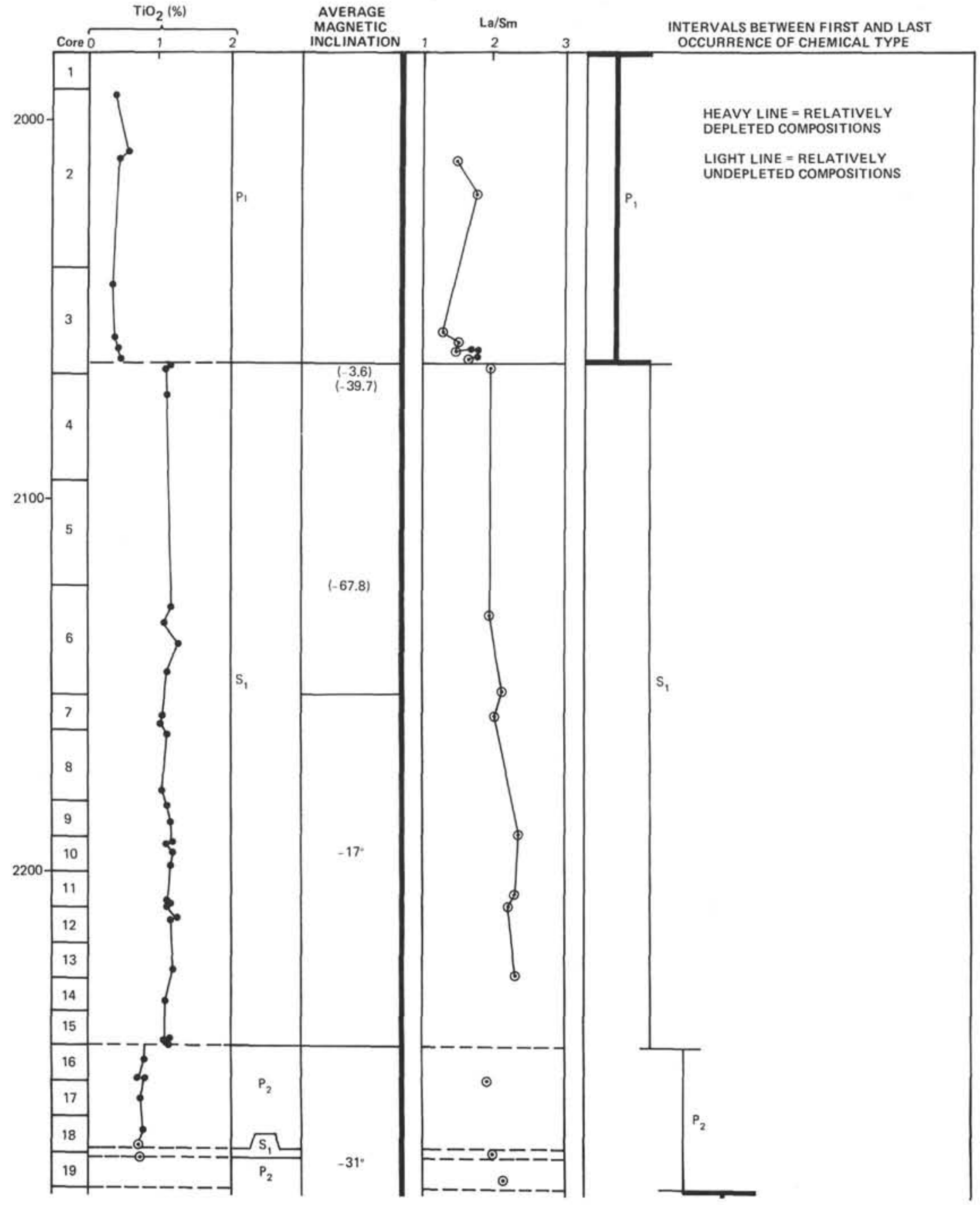
oceanites at Site 395, and as argued earlier, Site 395 basalts appear to represent smaller degrees of melting in the mantle than basalts of Site 332. Of all the minerals in the probable mantle source assemblage of these basalts (plagioclase peridotite; Fujii et al., this volume), clinopyroxene is the one most likely to affect La/Sm during melting (Frey et al., 1974; see Figure 8). Byerly and Wright (1978) inferred that clinopyroxene left in the mantle residuum by partial melting was a principal cause of compositional differences in Site 332 magma types. Fujii et al. (this volume) showed that, for a Site 395 aphyric basalt composition, near-eutectic melting of a plagioclase lherzolite at 8 kilobars pressure could have produced the basalt. At a depth of about 25 milometers, then, partial melting would contribute components of olivine, plagioclase, and clinopyroxene to the melt in near-constant proportions through a fairly wide range in the extent of melting, and no shift in La/Sm would occur, even though absolute rare-earth element abundances could vary. With depletion of the earliest melting phase of this assemblage (plagioclase), melt compositions would begin to change, perhaps abruptly (Presnall, 1969), and with them, the proportions of clinopyroxene entering the melt. An increased proportion of clinopyroxene would reduce La/Sm.

I propose that at Site 395 none of the basalts represent partial melts which involved depletion of plagioclase in the mantle — that they were essentially "eutectic" melts of plagioclase peridotite. At Site 332, the sparsely phyric basalts also represent this type of melting, but of a distinctly less depleted mantle source with perhaps a larger degree of partial melting (e.g., lower TiO_2, Na_2O, etc.). But several phyric basalts, most of them olivine controlled, represent greater partial melts, or separate partial melts of a refractory (plagioclase-free?) residuum, so they have much more abundant olivine and reduced La/Sm. Dispersion of La/Sm within any sparsely phyric unit could have resulted from minor hybridization between phyric and sparsely phyric basalt types.

Apart from the olivine-rich basalts and oceanites of Site 332, the ranges of compositions at Sites 332 and 395 are very similar. Figure 12 contains a histogram of Mg/(Mg + Fe) for all basalts of Legs 37, 45, and 46 (including Holes 396 and 396B). In constructing this histogram, unit averages were first compiled using shipboard data (Bougault, 1977; Bougault et al., this volume; Bougault et al., 1978), then the resulting Mg/(Mg + Fe) values were weighted according to the thicknesses of the units. As can be seen, there is a strong mode between Mg/(Mg + Fe) values of 0.60 to 0.65. The Leg 37 data are skewed toward higher Mg/(Mg + Fe), largely because of the olivine-rich basalts and oceanites. The restricted compositions and similarity of basalts recovered on Legs 37, 45, and 46 can only be appreciated by comparison with similar histograms constructed for Iceland (Figure 12B, based on number of analyses rather than unit thickness) and for the East Pacific Rise (Figure 12C, based on considerably less cumulative thickness of drill holes than the Mid-Atlantic Ridge). Rocks from the Mid-Atlantic Ridge drilled through Leg 46 essentially do not include basalts with $Mg/(Mg + Fe) < 0.55$, whereas such basalts comprise nearly 50 per cent of the basalts of Iceland and those recovered by drilling the East Pacific Rise. The fundamental contrast between the slow-spreading Mid-Atlantic Ridge and these other portions of the earth's ocean ridge system, then, is that basalts of a uniform and comparatively restricted range of compositions are produced.

In detail, what occur are individual magma batches not related to each other by crystal fractionation, and carrying a small internal variation probably produced on ascent from the mantle or the deep crust. Two contrasting magma types occur, one aphyric or sparsely phyric, the other strongly phyric. Elsewhere in this volume (Chapter 18), I have suggested that at Site 395 this requires at least two magma chambers and two plumbing systems, repeatedly replenished: one which eliminates phenocrysts or prevents them from growing, and one which concentrates them (by flotation, crystal settling, and/or flow differentiation). At Site 332, two or more magma chambers are also required, one for the group of sparsely phyric high-La/Sm basalts, one for the phyric lower-La/Sm basalts. The rare-earth data of Langmuir et al. (1977) on basalts from the Mid-Atlantic Ridge median rift in the FAMOUS area show similar variations, and so more than one magma chamber seems required there as well. The rare-earth data thus do not support the single-magma-chamber hypothesis for the FAMOUS area, proposed by Bryan et al. (1977) and based on major-element analyses of a suite of basalts including those analyzed by Langmuir et al. (1977). Site 332 includes most of the same types of basalts, and there the rare-earth data are supported by a detailed chemical stratigraphy based on many analyses of individual magma batches and chemical types. A mineralogically zoned median rift magma cupola at Site 332, similar to that of Bryan et al. (1977), cannot have produced interbedded olivine-rich and sparsely phyric basalts of diverse light-rare-earth-element enrichment. At least two magma chambers isolated from each other are required. One of these chambers could have produced some of the plagioclase accumulative basalts from the sparsely phyric basalts, however (except for Unit P_1 of Hole 332B, which has too low La/Sm).

Instead, both Site 332 and Site 395 suggest that closely spaced magma reservoirs with virtually no linkage supplied basalts alternately or simultaneously to the sites. I believe that this is consistent with a generally small magma chamber size at the Mid-Atlantic Ridge median rift, that multiple magma chambers are dispersed, isolated, and virtually unconnected along the rift. These erupt and are replenished infrequently (at periods long with respect to secular variations and even reversals in the earth's magnetic field). This would seem a natural consequence of a slow rate of magma genesis at a slow-spreading rifted median ridge. On the East Pacific Rise and Iceland, which differ structurally and morphologically from the Mid-Atlantic Ridge near Sites


TiO2 (%)
Core
0
1
2
AVERAGE MAGNETIC INCLINATION
La/Sm
1
2
3
INTERVALS BETWEEN FIRST AND LAST OCCURRENCE OF CHEMICAL TYPE
HEAVY LINE = RELATIVELY DEPLETED COMPOSITIONS
LIGHT LINE = RELATIVELY UNDEPLETED COMPOSITIONS
2000
2100
2200
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
P1
S1
P2
S1
P2
(-3.6)
(-39.7)
(-67.8)
-17°
-31°
P1
S1
P2

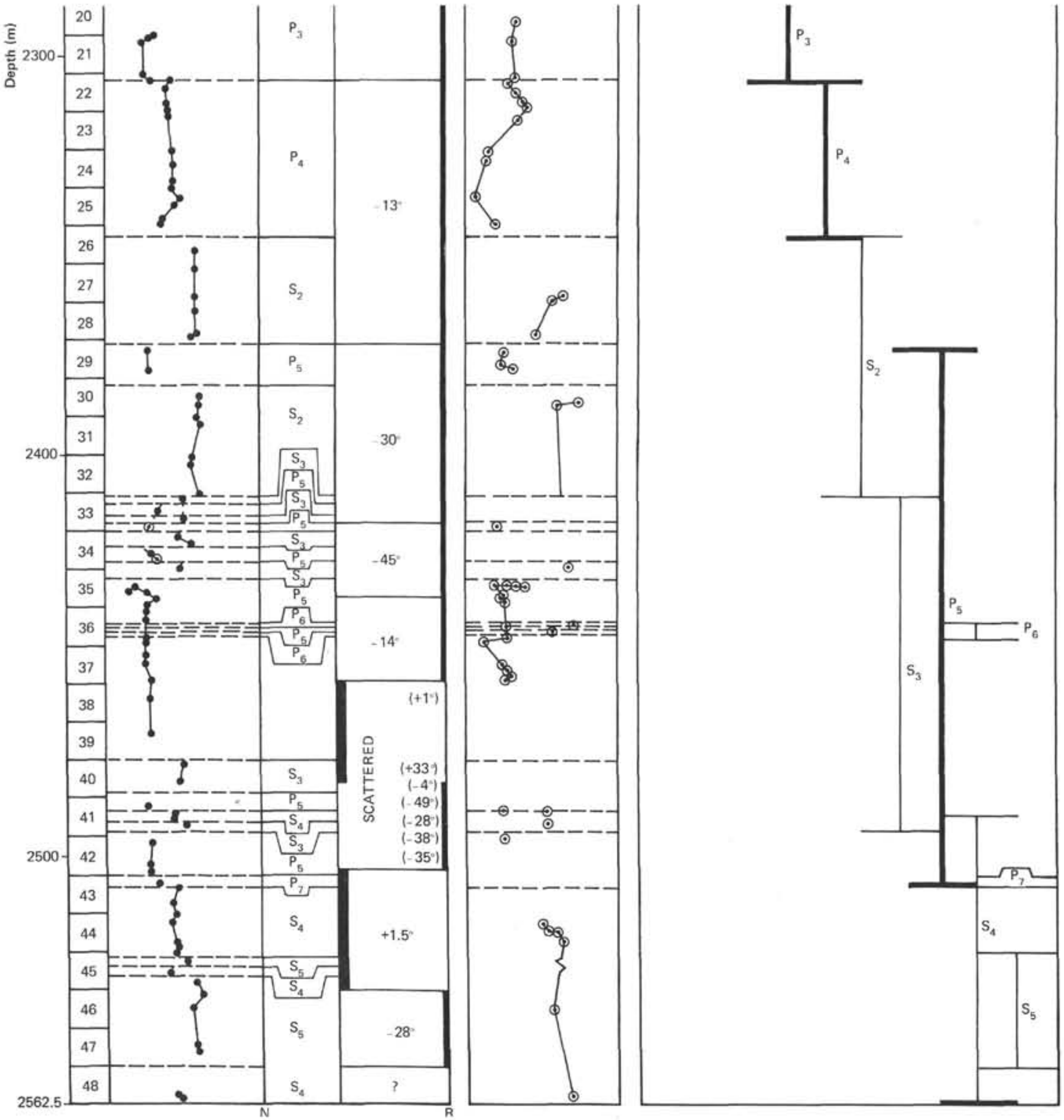


Figure 11. *TiO$_2$ versus depth, average magnetic inclination of Hall and Ryall (1977) superunits versus depth, La/Sm versus depth, and stratigraphic range of chemical units for Hole 332B. Magnetic inclinations in parentheses are representative values in intervals where inclinations are scattered. Depth assignments as in Figure 10. Data sources as in Figure 10, plus rare-earth element data of O'Nions and Pankhurst (1977) and Bence and Taylor (1977).*

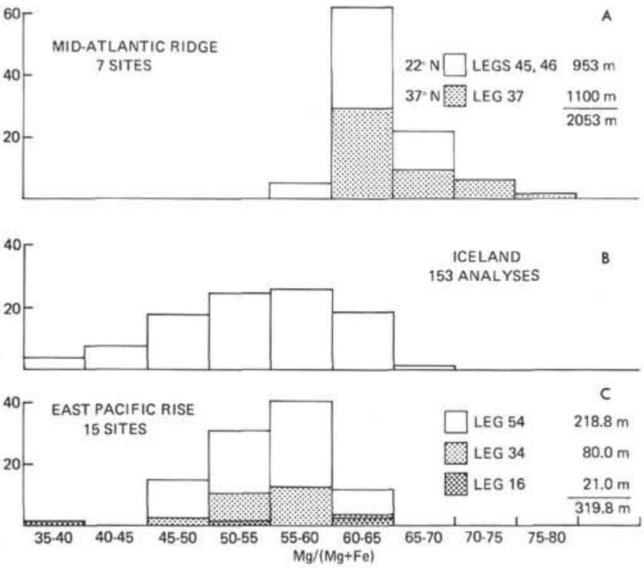


Figure 12. *Histogram of Mg/(Mg+Fe) for DSDP basalts from the Mid-Atlantic Ridge Sites 332 through 335 (Bougault, 1977); 395 (Bougault et al., this volume); and 396 (Bougault et al., this volume and 1978), compared with data from the East Pacific Rise (Yeats et al., 1973; Rhodes et al., 1976; and Rosendahl, Hekinian et al., in preparation). Histogram is constructed by weighting according to the thickness of clearly identified chemical units. Iceland data are based on number of analyses (35 from Sigvaldason, 1974; 118 from Jakobsson. 1972).*

332 and 395, the wider range in magma types requires that something entirely different be going on, something that promotes more extensive fractionation of the basalts. Elaboration of this must await detailed consideration of basalt compositions from these areas; such consideration is beyond the scope of this paper.

MAGNETIC UNITS

Magnetic units were defined in much the same way on Legs 37 and 45 (Hall and Ryall, 1977; Johnson, Paleomagnetism of igneous rocks, this volume). The magnetic inclinations of minicore samples taken from one or more oriented basalt pieces per core were measured. An oriented piece has an external surface cut by coring and a length greater than the core diameter. On Leg 37, minicores were taken from full-diameter cores. On Leg 45, they were taken from the working half of split cores. Apart from the effects of instrumental precision, inclinations can be in error by any amount a hole diverges from the vertical (generally less than 2°), by amounts caused by irregularities in the cored (outer) surface of the piece of basalt sampled, and by any divergence of the minicore sampler from a vertical relationship to the base plate supporting the basalts during sampling. Johnson, in Chapter 7 of this volume, determined that in adjacent samples from the same piece, the latter two errors could result in a combined difference in inclination of 10°. In general, however, the errors are less than this (or do not combine), and the resulting average inclinations of magnetic units have standard deviations of perhaps 5°. Magnetic units defined for Sites 332 and 395 are shown on Figures 2 and 3 by means of average inclinations or, where necessary, a range of inclinations.

In Hole 395A, basalts are either normally or reversely magnetized with an inclination of ±40°, matching the inclination expected from the latitude of the site. All magnetic and chemical unit boundaries coincide. Johnson (Paleomagnetism of igneous rocks, this volume) concluded that the basalts were emplaced over a period of time when short-period reversals within a longer polarity epoch were occurring. He proposed that the individual volcanic episodes were short ($\leq 10^2$ years) with respect to the time involved in secular variations of the earth's magnetic field (hence the strong coherence of each magnetic unit), and that the intervals between them were long (10^3 to 10^4 years), allowing reversals of the earth's field to occur.

Site 332 is enormously more complex magnetically. Hall and Ryall (1977) first determined mean inclinations on each lithologic sub-unit (as defined by the Leg 37 shipboard party), in several cases dividing these into further magnetic units, then grouped as many of these as possible into magnetic superunits. These superunits are essentially equivalent to the magnetic units of Site 395, and it is their mean magnetic inclinations which are shown on Figure 2. In Holes 332A and 332B, there are nine instances where one or more changes in inclination occur within lithologic sub-units. In the lower part of Hole 332B, four magnetic superunit boundaries occur within intervals of distinct chemical types (Figure 2). In lithologic Units 2, 8, and 9 of Hole 332B, scattered inclinations occur, and no magnetic superunits were defined. Where no magnetic data were determined for certain cores, question marks are shown on Figure 2.

Inclinations at Site 332 are generally much lower than the ±56° predicted for the latitude of the site, and average −4°. An exception is the upper part of Hole 332A, which has an average inclination of +53° and includes four chemical types not present in Hole 332B. The corresponding interval in Hole 332B has a negative average inclination of −30.6° and consists of one chemical type.

Lithologic Units 3 of Hole 332B and 6 of Hole 332A have very similar negative magnetic inclinations (Figure 2), and are similar chemically (Table 2). The inclinations of lithologic Units 4 of Hole 332B and 7 of Hole 332A are also similar, and the basalts of the two units are both phyric types. But phyric basalt P_B is relatively less depleted in light rare-earth elements (Figure 11) than phyric basalt P_2 (Figure 10), so the two types do not match chemically.

Hall and Ryall (1977) speculated that low inclinations of Site 332 and the poor correlation between the upper parts of Holes 332A and 332B result from a combination of "tectonic breaks" and possible eruption during a long-term departure from an axial dipole field. They pointed out that to explain the low inclinations entirely by faulting would require a dip to the south of 30° to 40°, whereas, so far as is known, only small dips (3°-10°) to the west occur in the area. Macdonald

(1977), citing inversions of near-bottom east-west magnetic profiles near Sites 332 and 333, lent support to the concept that the Site 332 basalts erupted during a magnetic transition. Apparently, shortly after the Gauss-Gilbert reversal, a short-period reversal of the earth's field also occurred (Atwater and Mudie, 1973; Klitgord, 1974), and may have lasted 25,000 years. This may have extended the effective duration of the longer term Gauss-Gilbert reversal and the consequent erratic behavior of the earth's magnetic field. Site 332 is in a crustal zone which probably recorded this complex behavior of the field between the Gauss and Gilbert epochs.

CORRELATIONS BETWEEN HOLES AND THE PROBLEM OF REPLICATION OF UNITS AT SITE 332

Holes 395 and 395A were so close together that no difference in their locations could be resolved by satellite fixes (Chapter 7, this volume). But the average inclination of chemical Unit A_2 in Hole 395 is 16° less than in Hole 395A, and one chemical unit, P_1, occurs only in Hole 395. Johnson (Paleomagnetism of igneous rocks, this volume) attributed the difference in inclinations to faulting.

At Site 332, where Hole 332A is 107 meters from Hole 332B, nearly 330 meters can be correlated between the two holes. But as Figure 2 shows, nothing above chemical Unit S_1 correlates between the holes; within S_1 in Hole 332A are several interlayers of type S_D not present in Hole 332B, and as already discussed, phyric type P_B at the bottom of Hole 332A is not the same chemically as the stratigraphically equivalent Unit P_2 in Hole 332B. Because S_D recurs in Hole 332A but not in Hole 332B, it is shown to pinch out between the holes on Figure 2. Units S_A through S_C in Hole 332B, with their positive inclination, are shown to overlie P_1 in 332B somewhere between the two holes on Figure 2. S_A through S_C probably erupted after a magnetic reversal which followed the eruption of P_1, whose negative inclinations are consistent with all deeper units in 332B.

Below Unit P_4 in Hole 332B, the stratigraphy becomes very complex. Assuming that the hole represents strictly an eruptive sequence, the recurrent interbeds of types S_3, P_5, and S_4 require availability of several strongly contrasting magma types through several possible shifts in the earth's magnetic field. It is in this lower part of Hole 332B that four magnetic breaks (superunit boundaries) occur within chemical units.

To consider the significance of the poor correlation between Holes 332A and 332B, and the downhole complexities of Hole 332B, it is necessary to establish a firm or at least consistent basis for evaluating eruptive sequences and possible tectonic replication of units. Elsewhere I have defined "rules of stratigraphic order" (Natland, 1978) to deal with basalt drill-hole chemical and magnetic stratigraphy, but Site 332 presents an unusual array of problems. Without biostratigraphic information, we cannot be talking rigorously about time-stratigraphic units. With poor recovery of contacts and without being able to view the lateral extent of whatever units we define, inferences must be based entirely on chemical and magnetic stratigraphy. Magnetic stratigraphy might give us some idea of the time sequence of events, but faulting and the possibility of instrusions can make this very difficult to apply.

Two independent sets of judgments must be made, one concerned with the significance of magnetic breaks in a basaltic sequence, the other dealing with how confidently magma types can be identified and considered to represent discrete eruptive events. Where Site 395 was straightforward on both counts, Site 332 strains the limits of the possible. If indeed the Site 332 basalts erupted during a period of erratic behavior of the earth's magnetic field, and if faulting has been shown to have occurred in several places (e.g., magnetic breaks within lithologic or chemical units), then what can confidently be said about the history of the earth's magnetic field at the site? And to what extent is it possible to establish an eruptive sequence?

On the other hand, if chemical types are only very subtly distinct, and recur in a lava sequence several times through a number of possible magnetic transitions, to what extent can we say that a particular magma composition persisted in the crust essentially unchanged through a long period of time (tens or hundreds of thousands of years, according to the magnetics specialists)? On Figures 10 and 11 I have indicated the overlap of availability of chemical types through magnetic transitions at Site 332. At several times at least two, and in some cases three, magma types were available to be tapped alternately or in sequence. This contrasts with no overlap whatever at Site 395.

Estimates of chemical-type overlap at Site 332 depend critically on defining chemical units, and then deciding whether they are co-magmatic (simply related by crystal fractionation or accumulation). This is by no means easy for this site. The crucial question is this: Do magma types represent single eruptive events, or a time-transgressive sequence of eruptive events? If a sequence of events, how was the sequence spaced with respect to variations in the earth's magnetic field? At Site 332, we have discussed the possibilities that crystal accumulation, fractionation, and magma mixing have occurred. Byerly and Wright (1978) have shown that virtually identical Site 332 sparsely phyric basalt types can be derived from different parents by different mechanisms (two of their chemical types which derive from different parents I have combined into type S_1). Though this may be, it soon becomes evident that this type of coincidence leaves little to be said with any confidence about eruptive sequences. Subtly but distinctly different magma types may have been part of the same eruptive event, may even have had different parents, may have been hybrids. Elsewhere (Natland, 1978), I have stated that "similar but not identical chemical units may have been part of the same eruptive sequence if, for example, magmas were being supplied simultaneously from more than one source, or if they reached the surface through different conduit systems. Factors other than crystal fractionation (such as magma mixing, fractional resorption of minerals, especially plagioclase, zone refining, local source heterogeneities, leaving various proportions of residual liquids behind, etc.) may have caused the subtle differences in composition. The interpretation that they were part of the same eruptive event is strengthened if they have the same or similar magnetic inclinations, and the same stratigraphic level in two holes, but is not precluded if they are different. Faulting may have occurred. The eruptive 'event' may have been several events closely spaced in time."

With this in mind, I shall state the case for maximum replication of units at Site 332, on the basis of Table 2 and Figures 5 through 7.

1) Unit P_5 may represent a complex dike swarm feeding unit P_3 (or P_5 may be P_3 repeated several times by faulting).
2) Units S_1 and S_3 may be equivalent.
3) Units S_A, S_C, and S_4 may be equivalent.
Units S_2, S_5, and S_D may be equivalent.
5) Bnit P_4 may be partially hybridized with any one of the sparsely phyric types (see especially Figure 7A). The "olivine-controlled" oortion of the hybrid could be equivalent to P_2.

The number of distinct chemical types would be reduced from 18 to 11. The site would have to be viewed as complexly faulted, with relatively few magma types repeated numerous times. The mechanism for the faulting could be (1) formation of inward-facing normal faults in the median rift, with throws between 20 to 200 meters, to form the inner wall of the rift (Macdonald and Luyendyk, 1977), and in the rift mountains, outward-facing faults appear to be 100 to 1000 meters apart (Macdonald and Atwater, 1978).
faults per hundred meters have been observed on the inner wall of the FAMOUS area median rift (Macdonald and Luyendyk, 1977), and in the rift mountains, faults appear to be 100 to 1000 meters apart (Macdonald and Atwater, 1978).

Since we do not know the rate of changes in the earth's magnetic field during a magnetic transition, and the basalts of Site 332 may be complexly faulted, there is very little we can say about the frequency of eruptive events at the site. In this respect, Site 395 is a better guide to the rate at which Layer 2 can accumulate on the Mid-Atlantic Ridge.

ACKNOWLEDGMENTS

This paper would not have been possible without the analytic work and shipboard descriptions of many people, most of them cited in the text.

I would like to thank Bill Melson for constructive criticism of the manuscript.

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