1. CRUISE OBJECTIVES AND MAJOR RESULTS, ANALYTICAL PROCEDURES, AND EXPLANATORY NOTES

W. G. Melson,[1] P. D. Rabinowitz,[2] J. H. Natland,[3] H. Bougault,[4] and H. P. Johnson[5]

CRUISE OBJECTIVES

Leg 45 of the Deep Sea Drilling Project was the inaugural cruise of the International Phase of Ocean Drilling. Its primary scientific objective was to develop an understanding of the composition, structure, and origin of oceanic crust by drilling as deeply into it as technology would permit.

The feasibility of drilling deep into the oceanic crust was demonstrated during Leg 37 when one hole was drilled 586 meters into basaltic volcanic rocks near the crest of the Mid-Atlantic Ridge at about 37°N. Drilling of this hole, 332B, required repeated retrieval of the drill string to replace worn bits. This was the first successful multiple re-entry hole in the history of DSDP. On the basis of the Leg 37 experience, the re-entry system was strengthened and improved, in the hope that a hole as deep or deeper would be drilled on Legs 45 and 46.

Legs 45 and 46 were conceived as a combined attempt either to drill a single deep hole into North Atlantic oceanic crust, using, if possible, all the time of both cruises, or, in the event of early loss of a deep hole, to drill holes in several surveyed areas in a roughly east-west transect, out to crust about 110 million years old. The areas of principal interest for Leg 45 were survey areas AT-5 (see Hussong et al., this volume), situated near 23°N, 46°W (Figures 1 through 3), and AT-6 (see Purdy et al., this volume), near 23°N, 43°W (Figures 4 and 5). The two survey areas are on opposite sides of the Mid-Atlantic Ridge, south of the Kane fracture zone in the vicinity of magnetic anomalies 4, 4′, and 5 (see Plate 1 in pocket). Both regions were generated along approximately the same segment of the Mid-Atlantic Ridge between 6 and 13 million years ago, and have since been separated by sea-floor spreading.

The drilling on Legs 45 and 46 was only the initial stage of a longer term program aimed at determining the petrologic, geochemical, magnetic, physical, and structural properties of the crust beneath the ocean floor, to obtain an understanding of the processes which produce these properties, and to outline the evolution of oceanic crust through time. At this writing, the North Atlantic portion of this program has been completed and crustal drilling is going on in the northern Pacific. The IPOD Atlantic crustal drilling program involves two transects. The first, as mentioned earlier, is an east-west transect of holes on progressively older crust. Its objectives were (1) to assess crustal "aging" phenomena, i.e., alteration, diagenesis, and cementation; and (2) to evaluate the consistency of petrologic and magmatic processes, as well as the mantle source composition of basalts, along a single sea-floor spreading "flow-line" away from the crest of the Mid-Atlantic Ridge. The second transect is a series of holes on young oceanic crust between Iceland and 23°N. The objectives of this transect were to evaluate petrologic and magmatic processes along the Mid-Atlantic Ridge, through areas of known geochemical and/or structural peculiarity, such as the Azores and Iceland. Holes drilled in survey areas AT-5 and AT-6 were therefore designed to provide the standard of comparison for other holes on both the north-south and east-west transects. On the basis of preliminary survey and dredge data, the Mid-Atlantic Ridge near 23°N, and indeed the entire east-west transect, was considered to be a structurally and geochemically typical slow-spreading segment of the world ridge system, not influenced by proposed mantle plumes beneath Iceland or the Azores (Morgan, 1971, 1972; Hart and Schilling, 1973).

During Leg 45, Holes 395 and 395A were drilled in survey area AT-5; Hole 395A was a multiple re-entry hole drilled to a depth of 571 meters into basement. Another hole, 396, was drilled in survey area AT-6. The initial objective of Leg 45, to maintain through the entire leg a single deep hole which would be reoccupied during Leg 46, was not achieved. Instead, during Leg 46, another multiple re-entry hole, 396B, was drilled to a depth of 266 meters into basement.

During Legs 51 through 53, several deep holes, including one over 550 meters into basement, Hole 418D, were drilled in survey area AT-2.3 (see Figure 1) on crust about 110 million years old. Survey areas AT-3 and AT-4, also on the east-west transect, have not been drilled.

During Leg 49, several holes were drilled near Iceland (Holes 407 through 409) and south of Iceland (Holes 410 through 413). These were all fairly shallow single-bit holes. These holes, together with those drilled on Leg 37 (Holes 332 through 335) and Legs 45 and 46, constitute the north-south transect (see Figure 1).

Three areas in the North Atlantic have thus been the subject of extensive survey work and successful (>500 m penetration) re-entry drilling into basement (holes >500 m indicated in brackets). These are (1) the Deep Drill area near the FAMOUS area at 37°N (Hole 332B);

[1]Smithsonian Institution, Washington, D.C.
[2]Lamont-Doherty Geological Observatory, Palisades, New York.
[3]Scripps Institution of Oceanography, Deep Sea Drilling Project, La Jolla, California.
[4]CNEXO, Centre Océanologique de Bretagne, Brest, France.
[5]University of Washington, Seattle, Washington.

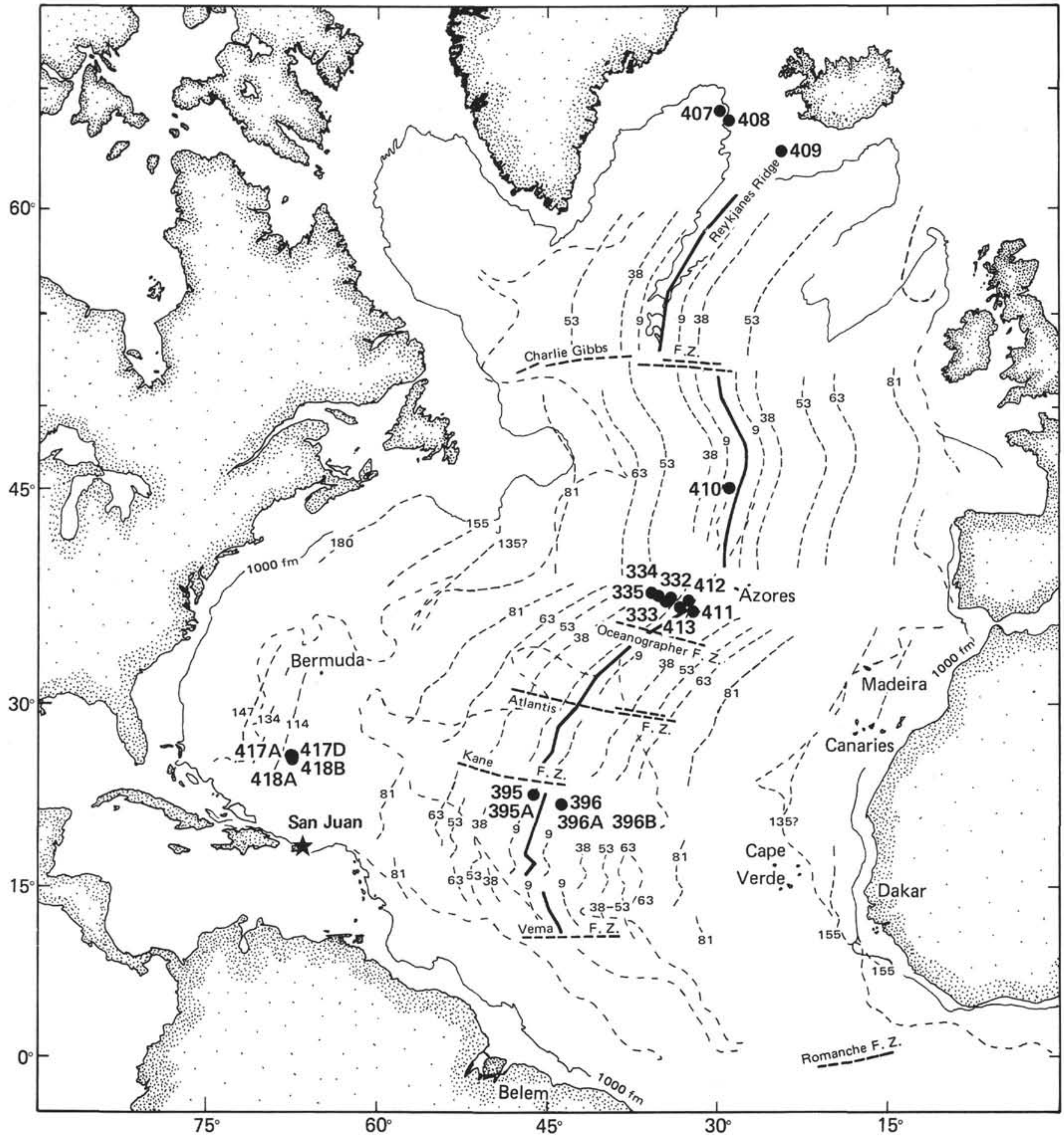

Figure 1. *Locations of sites drilled into North Atlantic Ocean crust, Legs 37, 45, 46, 49, and 51-53.*

(2) the intersection of the IPOD north-south and east-west transects south of the Kane fracture zone near 22°N (Hole 395A); and (3) a segment of Cretaceous oceanic crust on magnetic anomaly *M-O* on the Bermuda Rise (Hole 418D).

In addition, the north-south transect includes a short single-bit hole, on Site 410, at 45°N (Figure 1), in an area which has been extensively surveyed and dredged (Aumento et al., 1971).

Cruise Operations Summary

D/V *Glomar Challenger* left San Juan, Puerto Rico, on 30 November 1975, and completed its voyage 52 days later in San Juan, on 20 January 1976. Three holes were drilled, two in survey area AT-5, and one in survey area AT-6, all in middle to upper Miocene crust about 150 km on either side of the Mid-Atlantic Ridge (Site 395, west of ridge axis, latitude 22°45.35′N, longitude

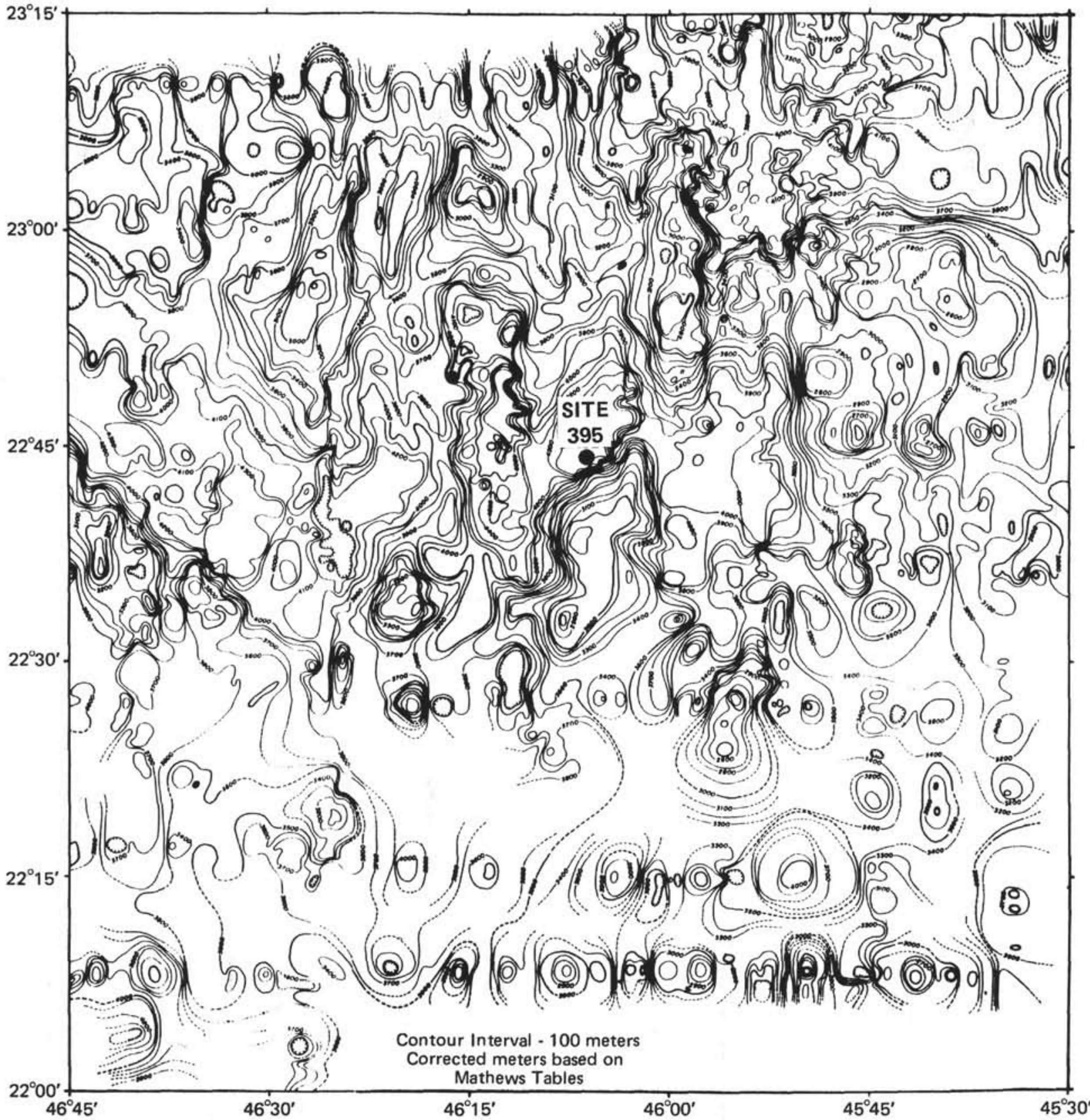

Figure 2. *Bathymetric chart of survey area AT-5 near the Mid-Atlantic Ridge (from Hussong et al., this volume). Contour interval is 100 meters.*

46°04.90′W; Site 396, east of ridge axis, latitude 22°58.88′N, longitude 43°30.95′W).

The original drilling program outlined in the Scientific Prospectus specified that single-bit pilot holes be drilled before deciding whether to seat a re-entry cone on the sea floor and drill a deep hole into the crust. Previous experience has shown that core bits can penetrate about 100 meters into basement before they must be replaced. In anticipation of 10 to 20 re-entries of a single site, the re-entry cone used by DSDP was redesigned to allow, among other things, casing to be placed below the cone into basement or other solid rock if the sediment cover proved sufficiently thin; the casing could then be cemented, leaving a permanent structure on the sea floor that would withstand the considerable stresses of repeatedly dropping heavy drill string through it.

Originally, the first pilot holes were planned for survey area AT-6. We felt, however, that basic scientific objectives of the projected North Atlantic crustal drilling plan could be met by drilling a preliminary hole at AT-5 en route to AT-6 from our port of departure, San Juan, Puerto Rico.

The first hole drilled in survey area AT-5 was therefore a single-bit pilot hole (395) aimed at confirming whether the basement rocks were suitable for deep

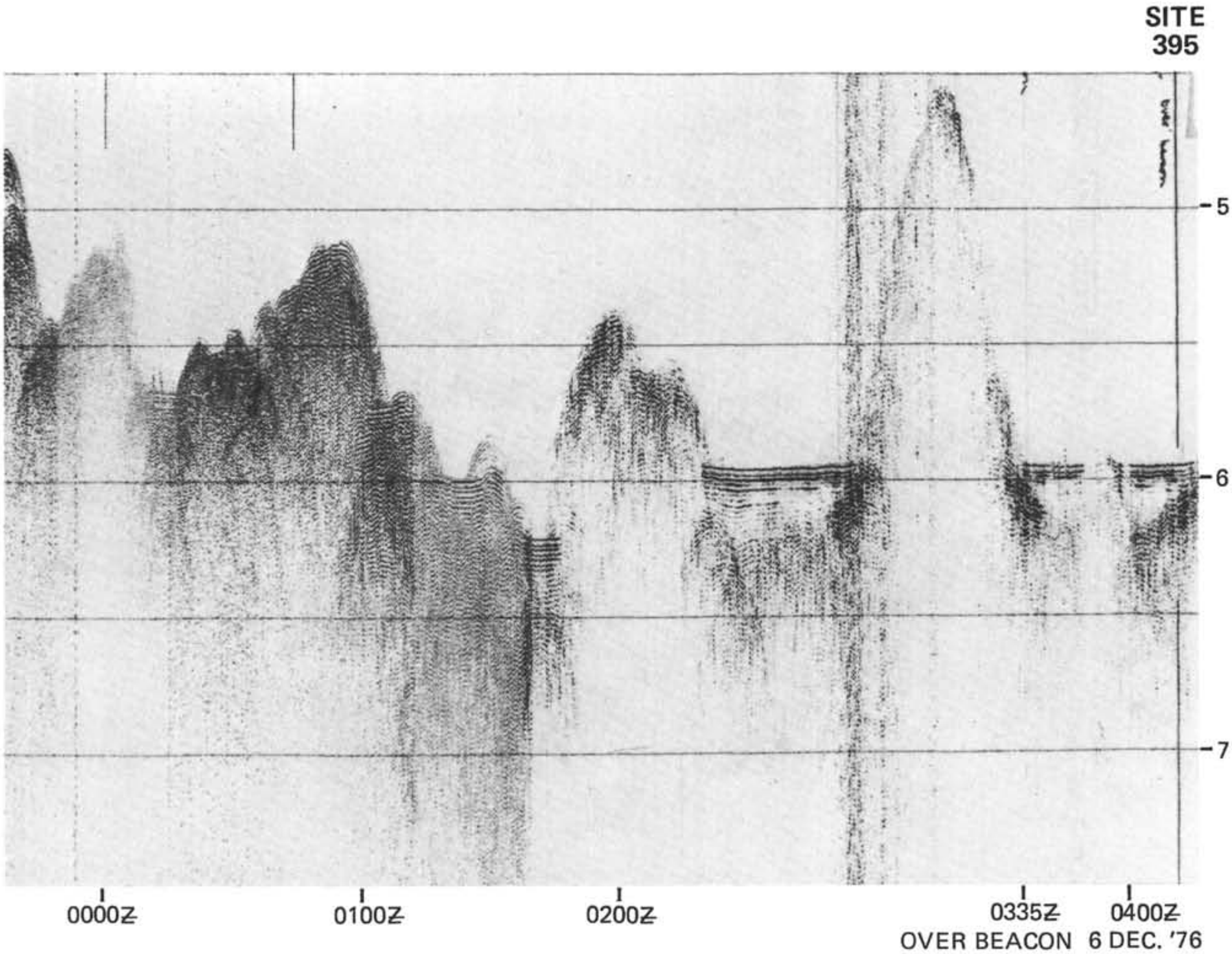

Figure 3. Glomar Challenger *seismic reflection profile obtained while passing over Site 395, Pond A, survey area AT-5.*

drilling. Ninety-three meters of sediment and 92 meters of basement rocks were continuously cored in 4484 meters of water before the bit was completely worn (Table 1).

Work at this hole suggested several advantages to deep drilling at AT-5 rather than AT-6. These were as follows:

1) The beacon dropped at target pond A[6] in survey area AT-5 (Figure 3) positioned the ship over a thickness of sediment suitable for placing casing to basement (93 m).

2) The site was on magnetic anomaly 4, and not in a magnetic transition zone as preliminary site survey data reduction had indicated (this eliminated the primary reason favoring AT-6 over AT-5).

3) Refraction results indicated that Layer 3 at AT-5 is situated about 1 km below sea floor, as compared with 1.7 km at Site 6.

4) Finally, Hole 395 yielded an interesting suite of gabbro and serpentinized peridotite breccias interlayered with basalt.

For these reasons, we attempted deep drilling at AT-5 rather than AT-6. Despite technical delays and problems, the re-entry cone was successfully placed and drilling operations conducted through it, beginning on 20 December 1975. Seven consecutive re-entries were made in the hole, resulting in cored rocks (Table 1). To our great disappointment, however, drilling conditions worsened dramatically during the seventh re-entry, a result of intense fracturing of the deepest basalts drilled, combined with widening of the hole beneath a more resistant formation. In this situation, cuttings could not be circulated beyond the widened portion of the hole. Even though cement was placed in the hole, drilling during the eighth re-entry was even worse than during the seventh. We abandoned the hole on 11 January 1976.

We then set course for AT-6, where we drilled a successful pilot hole, DSDP 396, which penetrated 125 meters of sediment and 96 meters of basalt. We left beacons over both Hole 395 and Hole 396, to allow the Leg 46 party to log Hole 395A and make their own re-entry attempt near Hole 396. Unfortunately, breakdown of the derrick prevented logging of Hole 395A during Leg 46, although the Leg 46 party succeeded in drilling 266 meters into basement at Hole 396B, which they did manage to log.

During Leg 45 we thus drilled two successful pilot holes and a single re-entry hole which penetrated 571 meters into basement, only 12 meters short of the deepest penetration so far, that of Hole 332B, Leg 37. Unlike Hole 332B, however, Hole 395A was con-

[6]Referred to as North Pond in Hussong et al. (this volume).

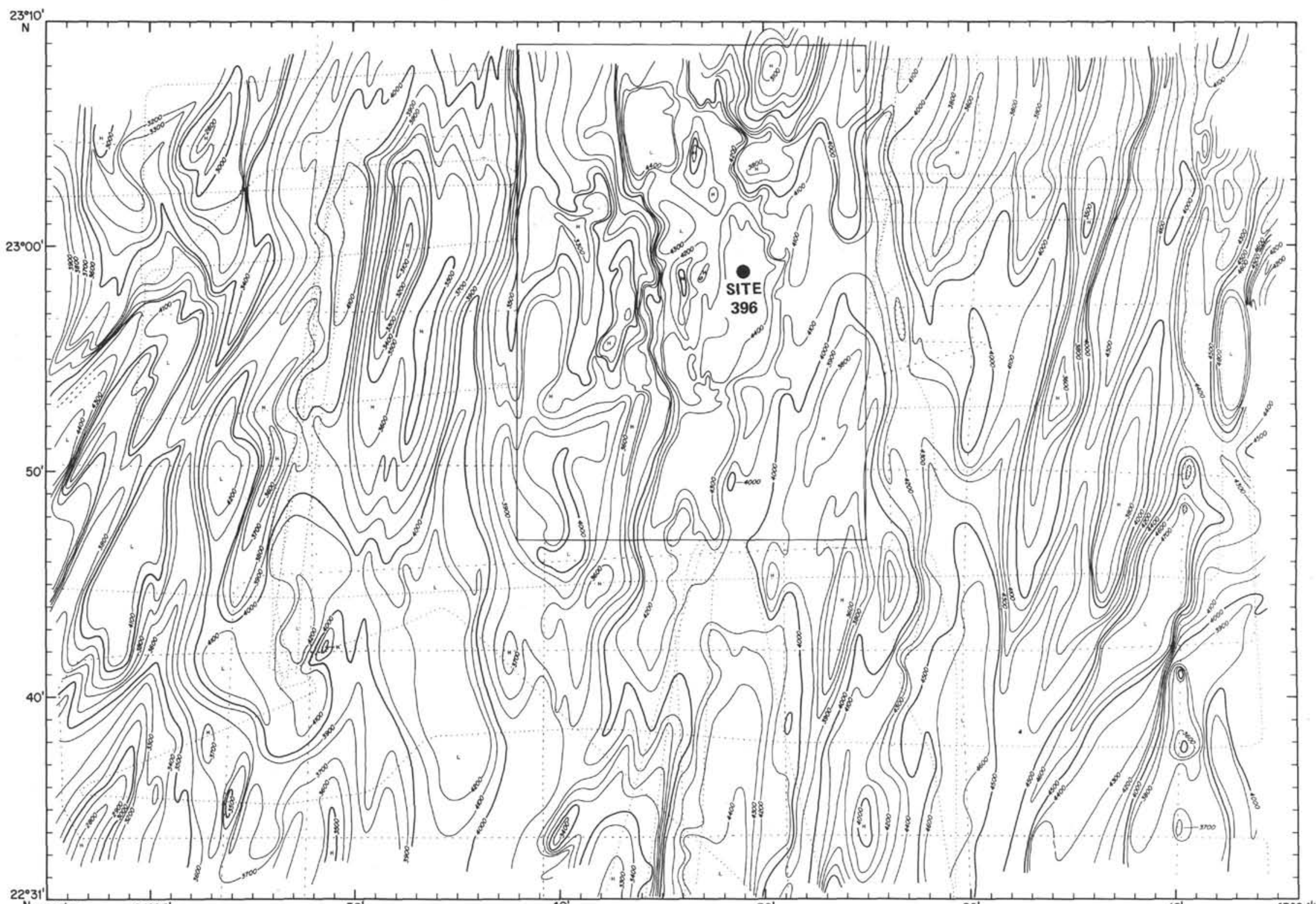

Figure 4. *Bathymetric chart of survey area AT-6 (from Purdy et al., this volume). Contour interval is 500 meters, corrected. See caption for Figure 1 of Purdy et al. (this volume) for further details.*

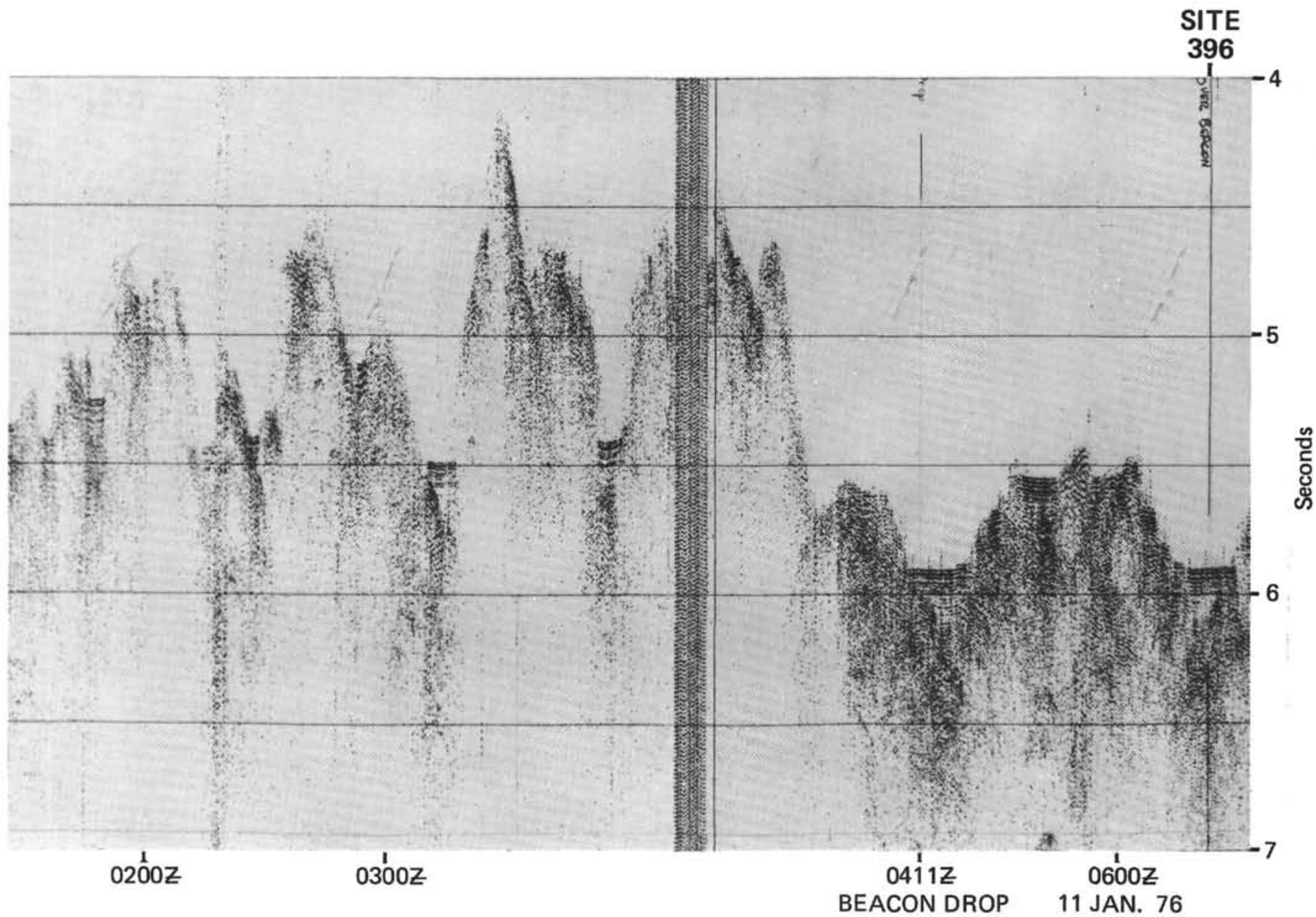

Figure 5. Glomar Challenger *reflection profile taken while passing over Site 396, obtained on Leg 45.*

tinuously cored. It was also drilled in much deeper water (4500 m, as against 2200 m).

Cruise Objectives and Summary of Results

The specific problems we were trying to solve on Leg 45 can be divided into three general categories, as presented below.

Chemical Stratigraphy and Petrogenesis of Lavas

In deep holes into oceanic crust, stratigraphic sampling, coupled with major- and trace-element chemical analyses, provide a detailed history of ridge-crest basalts, and of any variability that existed in the source regions of the basalts. The size of magma batches and the cooling history of the lavas can be estimated by the flow stratigraphy, repetitions in sequence of primitive and fractionated lavas, and by detailed examination of megacryst, phenocryst, and groundmass mineral compositions.

This work was greatly facilitated on Leg 45 by our ability to do most major-element and some trace-element analyses on board ship, using the CNEXO

TABLE 1
Site Summary Data, Leg 45

Hole	Dates (1975, 1976)	Latitude (N)	Longitude (W)	Water Depth (m)	Penetration (m)	No. of Cores	Meters Cored	Meters Recovered	Recovery (%)
395	6-9 Dec.	22°45.35′	46°04.90′	4484	184.65	20	184.7[a]	88.4	48
395A	9 Dec.-10 Jan.	22°45.35′	46°04.90′	4484	664.09	68[d]	587.9[b]	106.0	18
396	11-14 Jan.	22°58.88′	43°30.95′	4450	221.49	25	221.5[c]	133.3	60
						113	994.1	327.7	33

[a]91.7 meter basement rocks cored (11% recovery).

[b]571 meter basement rocks cored (18% recovery).

[c]96.0 meter basement rocks cored (33% recovery).

[d]Core 68 contained cuttings obtained while attempting to clean hole. The amount recovered was not added in total core recovery.

X-ray fluorescence unit (see Bougault et al., this volume). With this equipment we were able to define 9 major chemical units among basalts in our deepest hole, 395A, several of which correlate with units in the pilot hole, 395. Two major petrographic types of basalt were recovered, aphyric basalt and phyric basalts; the latter carry 15 to 30 per cent phenocrysts of olivine and plagioclase, with or without clinopyroxene. All are fairly typical moderately fractionated low-potassium mid-ocean ridge basalts. From both the shipboard and shore-based data, none of the aphyric basalt types can be related to each other by crystal fractionation processes, and few of the phyric basalts can be related either to each other or to aphyric basalts by crystal fractionation processes. (Bougault et al., this volume; Rhodes et al., this volume). Shallow fractionation and mixing processes do not appear to have contributed to the small but distinct chemical differences among the aphyric basalt types, although mixing has occurred within the phyric basalts (Rhodes et al., this volume; Dungan et al., this volume). The aphyric basalts have a very restricted range of compositions, suggesting that very nearly the same extent of shallow crystal fractionation from more primitive parents occurred, resulting in all these basalts.

Similar moderately fractionated, low-potassium mid-ocean ridge basalts were recovered in Hole 396. They too have experienced about the same degree of crystal fractionation as Site 395 basalts.

Compared with Leg 37 basalts, those from 23°N have higher TiO_2 contents (1.3 to 1.6% versus 0.9 to 1.2%) but similar Ti/Zr. They are also much more depleted in light rare-earth elements than basalts of Holes 332A, 332B, or 334 (Bougault et al., this volume; Rhodes et al., this volume). This suggests either that the 23°N basalts represent a smaller degree of partial melting of the mantle than these 37°N basalts, or that there is a lateral variation of mantle source compositions such that 37°N basalts are relatively enriched in light rare-earth elements (Bougault et al., this volume; Rhodes et al., this volume). Leg 37 basalts appear to have experienced about the same degree of fractionation as Leg 45 basalts, except for some picrites in Hole 332B which represent about 5 per cent of the material recovered in that hole. No picrites were recovered on Leg 45.

Structure and Origin of Layer 2

On Leg 45, we planned to relate the properties of the oceanic crust—as revealed by remote sensing studies made during the site surveys—to drilling results. Paramount among these properties are crustal layering and magnetic properties. Survey area AT-5 refraction data are complex (Hussong et al., this volume); Layers 2 and 3 vary in thickness and velocity. Layer 3 is about 1 km deep. The surface topography is too rugged to resolve Layer 2A velocities, although they are almost certainly less than 4 km/sec. Seismic refraction work over the Site 396 sediment pond (Purdy et al., this volume) reveals a typical oceanic crustal section. Layer 2A is about 400 meters thick, and has a low velocity of 3.5 km/sec. Layer 2B is about 1.5 km thick, with a velocity of 4.7 km/sec. Layer 3 is about 4 km thick, with a velocity of 6.9 km/sec. Mantle returns have a velocity of 8.0 km/sec. The proportion of flows to interbedded sediments and to rubble zones were carefully monitored during drilling at Hole 395A, and the acoustic properties of fresh basalts, altered basalts, and sediments determined. A thick sequence of pillow lavas and at least one fairly deep intrusion were drilled. Unfortunately, recovery was low (1 to 20%) through most of the section, and the hole was not logged. Since the sonic velocity of the recovered basalts was high (>5.5 km/sec; Schreiber and Rabinowitz, this volume), a significant proportion of what was drilled must be either unrecovered sediments and glass breccias, or void space.

In all the holes drilled on Leg 45, the magnetic stratigraphy of extrusive and intrusive basalts was traced. This work was done on-board ship using a Schönsted digital spinner magnetometer and demagnetization unit. Additional work on Curie temperatures and observations on opaque minerals were carried out ashore (Johnson, this volume, Chapters 15 and 16). Magnetic intensities were high and directions stable in almost all basalt samples taken on-board ship. Magnetic inclinations in Holes 395 and 395A clustered around the axial-centered dipole value of inclinations for the latitude of the site (±40°), but two reversals were encountered in Hole 395A. Johnson (this volume, Chapter 15) proposes that the basalts of Hole 395A erupted during a time of short-period reversals within a longer span of normal polarity. The small scatter in inclinations around the dipole value and the presence of several polarity units within the column indicate that formation of the upper 600 meters of oceanic crust is episodic, with periods of rapid (10^2 years or less) extrusion followed by periods of quiescence (10^3 to 10^4 years).

The inclinations of the Hole 396 samples are scattered and low. Intensities of magnetization are also low. Johnson (this volume, Chapter 15) suggests that they were erupted during a major transition between normal and reversed polarity. Alternatively, they could have been disturbed by faulting.

On the basis of inversion techniques, both Sites 395 and 396 appear to be centrally located on magnetized blocks (see plate in back pocket; Purdy and Rabinowitz). Sediment ages just above basement at Site 395 are consistent with formation of upper Layer 2 within the axial rift during magnetic anomaly 4 about 7 million years ago (Krasheninnikov, this volume; Bukry, this volume). Sediments at Site 396, however, are older than that expected from the magnetic anomaly identification, suggesting Layer 2 formation more than 13 million years ago during magnetic anomaly 5B, rather than 10 million years ago during anomaly 5.

Gabbro and serpentinized peridotite cobbles were recovered in the sediments of Hole 395, as well as between two of the major basalt units of both Holes 395 and 395A. Their occurrence does not appear to be related to even a small fracture zone. Instead, we infer that they represent talus or debris shed from a nearby scarp. This scarp appears to have been exposed in the axial rift before eruption of the last aphyric basalt unit, which buried some of the ultramafic boulders.

Modification of the Crust During and After Cooling

Cooling of the oceanic lithosphere is thought to occur both by conductive heat loss and by hydrothermal circulation of sea water in the cooling basalts. The circulating hydrothermal solutions may provide the major agent of alteration and metamorphism of sea floor basalts. A study of basalt alteration and metamorphism was begun on Leg 45. The work integrates geochemical and mineralogical studies and modification of the physical and magnetic properties of the lavas as determined by shipboard measurements. By and large, the central feature of alteration of the Site 395 basalts is that it occurred at low temperature, less than 2°C (Lawrence et al., this volume). The only evidence for even slightly elevated temperatures is in the interiors of the thickest flow or intrusive units, a consequence of their slower cooling. A zone of hydrothermal alteration occurs adjacent to intrusive dolerites cored deep in Hole 395A, as evidenced by both alteration of magnetic minerals (Johnson and Melson, this volume) and somewhat higher formation temperatures of secondary minerals in adjacent rocks, indicated by oxygen isotopes (Lawrence et al., this volume).

Iron- and manganese-rich and red-clay-enriched sediments were recovered a few meters above basement in both Holes 395 and 396. Although these are similar to basal metal-enriched sediments commonly found near active spreading centers, they do not in this case appear to be related to hydrothermal leaching of immediately subjacent basalts.

Shore-Based Studies

All participating shipboard scientists took samples on-board ship for analysis in shore labs by themselves and their collaborators. American, British, French, German, and Soviet laboratories contributed the following studies to this volume.

1) Petrography, including fabric analysis.
2) Major-, minor-, and trace-element geochemistry.
3) Mineralogy, using optical X-ray diffraction, electron microprobe, and scanning electron microscope techniques.
4) High-pressure experimental petrology.
5) Isotopic studies of argon, carbon, oxygen, and strontium.
6) Paleomagnetism, rock magnetism, and opaque mineralogy.
7) Seismic velocities and their anisotropy at atmospheric and elevated temperatures and pressures.
8) Studies of secondary minerals and geochemical fluxes in basalts.
9) Age determinations by paleontologic and isotopic techniques.

The results of these investigations are reported in Chapters 9 through 41 of this volume.

ANALYTICAL PROCEDURES

This section gives information about analytical procedures used for major elements determined on Leg 45 igneous samples. Certain trace elements were analyzed for the first time on board during Leg 45; the procedure used is described below.

X-Ray Fluorescence

These investigations were performed by H. Bougault and M. Rhodes with the help of A. Gilbert (DSDP technician), using the CNEXO X-ray fluorescence van aboard the *Challenger*.

During Leg 45, the following major elements were analyzed: SiO_2, Al_2O_3, Fe_2O_3, MgO, CaO, TiO_2, and K_2O. In addition, four trace elements were measured: Cr, Ni, Sr, and Zr.

Major Elements

Leg 45 shipboard major-element chemical analyses using the XRF unit introduced no significant procedural differences with respect to procedures used on Leg 37. The methods were discussed in detail in Bougault (1977), to which the reader is referred.

Minor differences concern the use of OPR crucibles and the derivation of calibration curves from standards.

OPR crucibles: These crucibles, made of an alloy of platinum, gold, and rhodium, allow the liquid to cool inside the crucibles without sticking, thus ensuring easy removal of the glass discs formed from the crucibles. During Leg 37, the bottoms of the crucibles were bent, and we had to grind the glass discs to get a flat surface for analysis. During Leg 45 we had new, thicker, OPR crucibles which did not bend with use, and grinding was not necessary. The OPR crucibles have been further improved since Leg 45, allowing long-term use without deformation of the bottoms.

Calibration curves: Instead of drafting the calibration line and obtaining the concentration of unknown samples from this calibration line, the slope and intercept were calculated using a least-square method with a Hewlett-Packard 65 programmable calculator. These parameters—together with a reference standard intensity to take into account possible daily variations caused by the instrument drift—were stored. This reference standard was measured every day, together with at least two other standards; the concentrations of unknown samples were obtained from their intensities through these parameters, using the Hewlett-Packard 65 calculator.

Precision of results is probably within 1 per cent relative for all major elements, as can be observed by looking at data from homogeneous basalt units where several samples were analyzed (Table 2).

Trace Elements

Four trace elements were chosen to improve the discrimination of different magmatic units: two of them (Cr and Ni) with high crystal/liquid partition coef-

TABLE 2
Precision of XRF Data
Determined on Board Ship

	$\overline{x}$	σx	$\sigma\overline{x}$
SiO_2	49.71	.18	0.05
Al_2O_3	15.14	.22	0.06
Fe_2O_3	11.20	.19	0.05
MgO	7.63	.27	0.07
CaO	11.30	0.10	0.03
TiO_2	1.72	0.02	0.01
Ni (ppm)	117	4.4	1.1
Sr (ppm)	131	2	0.5
Zr (ppm)	125	4.8	1.2

Note: Unit A_3; 15 analyzed samples. Average: $\overline{x}$; standard deviation: σx; standard deviation for average $\overline{x}$: $\sigma\overline{x}$. K_2O is not given, since it is a variable element even within a homogeneous unit, σ values integrate both analytical precision and possible variation within the unit; those σ values were used as a criterion to distinguish one sample from another, in order to discriminate among different chemical units.

ficients, and two others (Zr and Sr) with low partition coefficients. In addition to the recognition of chemical units, these data can provide additional information, especially in aphyric units, about partial melting and fractional crystallization.

Shipboard measurements of trace elements were made from powder pellets; they were prepared by mixing two grams of rock powder and 0.2 grams of wax. After pressing, the pellet was put on a hot plate at a temperature higher than the melting point of wax. The wax melts and, when cool, ensures a durable pellet.

Precise determination of trace elements using such a method requires the solution of two problems, following the procedure of Bougault et al. (1977).

1) Background determination: more exactly, determination of possible interferences caused by components of the instrument (holder, tube impurities, etc.) and occurring within the peak intensities of the element to be determined.
2) Matrix effect correction ($\Sigma\alpha_i C_i$).

Calculation to get sample concentrations from measurements was made in three steps, using a Hewlett-Packard 65 programmable calculator:

1) Calculation of matrix effect for standards and corrected intensities, taking into account instrumental interferences.
2) Calculation of the straight-line calibration curve (corrected intensities versus concentrations of standards) through a least-squares method.
3) For unknown samples, calculation of matrix effects (from major-oxide concentrations and their mass absorption coefficients), corrected intensities, and deduction of concentrations from parameters previously determined.

All measurements were made using a gold tube. Counting time was 80 sec on the peak and 40 sec for each background for Cr, Ni, and Sr, and 200 sec on the peak, with 100 sec for each background for Zr. Cr, Ni, and Sr were measured on their K_α line. The K_β line was used for Zr in order to avoid interference of the Sr Zr K_β line with the K_α line. The orders of magnitude of measured counts for intensities are as follows: Cr (300 ppm) 21,000; Ni (100 ppm) 35,000; Sr (100 ppm) 27,000; Zr (130 ppm) 30,000.

Calibration curves for Ni, Sr, and Zr are presented in Figure 6. Table 2 indicates the values found for standards from calculated parameters. No figure is shown for Cr. The reproducibility of intensity measurements for Cr is as good as for the other elements, but there are problems associated with V interference (VK_β) and with the exact determination of Cr absorption coefficients (Cr is a light element, compared with Ni, Sr, and Zr). Consequently, the concentrations obtained for Cr are only derived from intensity measurements, without any matrix correction or V interference correction, and are not as accurate as Ni, Sr, and Zr determinations.

For Zr, it can be seen that standards DRN and BR are slightly off the curve; in fact, two other standards, W1 and G2, are on this calibration curve (shore-based study), but were not available on board.

The precision and accuracy can be estimated from standard measurements (Table 3) or from the results obtained for different samples of a single homogeneous basaltic layer (Table 2): these precisions and accuracies are confirmed by shorebased studies (Bougault et al., this volume). The determination of these four trace elements proved to be very helpful for discrimination of the different chemical types.

Paleomagnetism: Equipment and Procedures

In order to study the paleomagnetic directions and intensities of both the sediment and igneous rock cores sampled during Leg 45, a spinner magnetometer and alternating field demagnetizing unit were installed on board at Norfolk, Virginia. The equipment was on loan to DSDP from Prof. J. M. Hall, of Dalhousie University, for use during Legs 45 and 46. The magnetometer was a Schönstedt digital spinner magnetometer, model DSM-1. This is a conventional spinner magnetometer similar to that used on shipboard for Legs 34 and 37, but modified so that the output of the fluxgate sensor was fed to a PDP 11/05 computer, where the signal was then processed to yield total sample magnetization intensity and the inclination and relative declination of the magnetic vector directly. The demagnetization unit was a Schönstedt AC Geophysical Specimen Demagnetizer, model GSD-1. This is a single-axis, non-tumbling, alternating-field demagnetizer with a peak obtainable field of 1000 oersteds. The recovery of coarse-grained magnetically unstable samples from Site 395 required a modification of the ordinary single-axis demagnetization procedures, described in Chapter 6, this volume.

Where continuous sediment cores were obtained, we originally planned to sample at 1-meter intervals to determine the paleomagnetic stratigraphy of the sedimentary column. The sediments at both Sites 395 and 396 were sufficiently disturbed, however, that no meaningful results could be obtained. For igneous rock cores, we tried to sample each different lithologic unit recovered, in order to identify "magnetic units" (rock

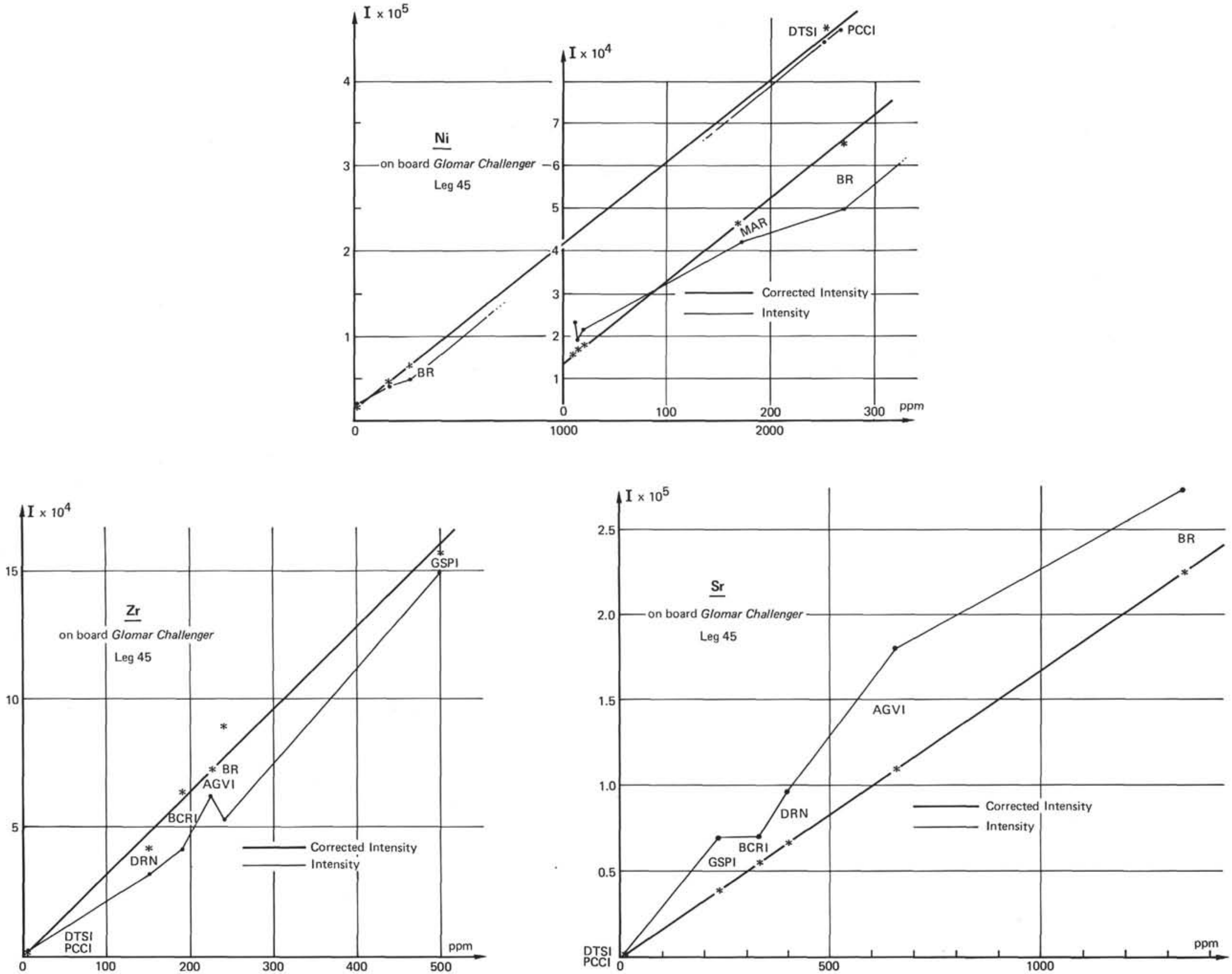

Figure 6. *Calibration curves for Ni, Sr, and Zr determined on board ship during Leg 45.*

TABLE 3
Reproducibility of Trace-Element Data for Standard Samples

	Zr				Sr				Ni			
	Recom-mended Values	18 Dec	29 Dec	10 Jan	Recom-mended Values	17 Dec	30 Dec	10 Jan	Recom-mended Values	16 Dec	29 Dec	1 Jan
PCC1	<10	3.5			0.41	.7			2339	2305	2306	2305
BA	240	266	270	267	1350	1351	1352	1354	270	266	265	
DAN	150	131			400	399			20	22.6	25	21
BCR1	190	201	197	191	330	328	332	332	15	14	15	13
DTS1	<5	13			0.35	2			2269	2304		2312
GSP1	500	496	497	495	233	233	233		12	11.6		
AGY1	225	228			657	658	659	656				
MAR	70	71	70	71		108	110	109	170	171	171	170
GAST	115	115				125				156		
KNIPPA	297	293			1004	1008						

units that were extruded or intruded in a short period of time and have very similar magnetic inclination values). For shipboard work, NRM direction and intensity, stable inclination, and median demagnetizing field (MDF) were determined for each sample. These are listed on the basement description sheets at the end of Chapters 7 and 8 (this volume). In order to aid in the interpretation of these data, shore-based studies of the opaque mineralogy, weak-field susceptibility measurements, viscous remanent magnetization studies, X-ray diffraction, scanning electron microscope, and thermomagnetic analyses are reported in the chapters by Johnson (this volume), Johnson and Melson (this volume), and Eisenach (this volume).

EXPLANATORY NOTES

Organization of the Volume

This volume is divided into an introductory chapter (Part I), site survey reports and a regional geophysical synthesis (Part II), site chapters (Part III), sedimentological and paleontological studies (Part IV), rock magnetics and physical properties studies (Part V), and petrological and geochemical studies (Part VI).

The site chapters (Part III) are detailed summaries of the geological data obtained at each site. The presentation is brief; most information is given on the core summary forms at the ends of the site chapters, and in data tables. The core summary forms contain prime data provided by shipboard investigators, revised with some shore-based data. The site reports are organized as follows:

Site Data
Summary
Operations
Sediments
- a) lithology
- b) petrography
- c) biostratigraphy

Igneous and Metamorphic Rocks
- a) lithology
- b) petrography
- c) alteration
- d) geochemistry
- e) paleomagnetism
- f) physical properties

Background for the two sites has been given in this chapter. Extensive interpretations of the data are given by individual contributors to the volume (Parts IV through VI).

The site reports are co-authored by the entire scientific party. In general, operations was written by P. Rabinowitz, sediments by J. Natland, J. Lawrence, and A. Kaneps, igneous and metamorphic rocks by W. Melson, H. Bougault, J. M. Rhodes, A. Graham, B. Zolotarev, T. Fujii, E. Prosser, and J. Natland (lithology, petrography, and geochemistry), J. Lawrence (alteration), H. P. Johnson (paleomagnetism), and P. Rabinowitz (physical properties).

Numbering of Sites, Holes, Cores, Samples

Drill site numbers run consecutively from the first site drilled by *Glomar Challenger* in 1968; the site number is thus unique. Sites are drilled in site survey areas, designated by a mnemonic letter code and a number. On Leg 45, Atlantic Transect areas AT-5 and AT-6 were drilled. Specific targets within these areas are designated by an additional letter. Target Pond A in area AT-5 is therefore AT-5A.

The first (or only) hole drilled at a site takes the site number. Additional holes at the same site are further distinguished by a letter suffix. The first hole has only the site number; the second has the site number with suffix A; the third has the site number with suffix B; and so forth. It is important, for sampling purposes, to distinguish the holes drilled at a site, since recovered sediments or rocks usually do not come from equivalent positions in the stratigraphic column at different holes.

Cores are numbered sequentially from the top down. In the ideal case, they consist of 9 meters of sediment or rock in a plastic liner of 6.6 cm diameter. In addition, a short sample is obtained from the core catcher (a multifingered device at the bottom of the core barrel which prevents cored materials from sliding out during core-barrel recovery). This usually amounts to about 20 cm of sediment or rock. During Leg 45, the core-catcher sample was split, described, and stored along with the rest of the core, if at all possible, taking care to maintain its proper vertical orientation. This sample represents the lowest stratum recovered in a particular cored interval. The core-catcher sample is designated by CC (e.g., 395-4, CC is the core-catcher sample of the fourth core taken at Hole 395).

The cored interval is the interval in meters below the sea floor, measured from the point at which coring for a particular core was started to the point at which it was terminated. This interval is generally about 9.5 meters (nominal length of a core barrel), but may be shorter if conditions dictate. Each core was measured on Leg 45. All coring was continuous (no intervals were uncored).

When a core is brought aboard the *Glomar Challenger,* it is labeled and the plastic liner and core cut into 1.5-meter sections. A full, 9-meter core would thus consist of six sections, numbered from the top down, 1 to 6. (The discrepancy between the 9-m core and 9.5-m cored interval is discussed below.) Generally, something less than 9 meters is recovered. In this case, the sections are still numbered starting with one at the top, but the number of sections is the number of 1.5-meter intervals needed to accommodate the length of core recovered; this is shown on Figure 7. Thus, as shown, recovery of 3.6 meters would result in a core with 3 sections, with a void of 0.9 meter at the top of the first section. By convention, and for convenience in routine data handling at the Deep Sea Drilling Project, if a core contains a length of material less than the length of the cored interval, the recovered material is measured from the bottom of the core catcher sample, with the top of Section 1—rather than the top of the sediment—equal to the top of the cored interval. This is shown on Figure 8 for the core in the example above. Thus, the depth below the sea floor of the top of the sediment or volcanic rock of this hypothetical core would lie at 150.9 meters (not 150.0 m) and the bottom at 154.5 meters.

It was noted above that a discrepancy exists between the usual coring interval of 9.5 meters and the 9-meter length of core recovered. The core liners used are actually 9.28 meters in length, and the core catcher accounts for another 0.2 meter. In cases where the core liner is recovered full to the top, the core is still cut into six 1.5-meter sections, measured from the bottom of the liner, and the extra 0.28-meter section at the top is designated Section 0, or the "zero section." On Leg 45, all zero sections were split and described. In the case of cores with zero sections, depth below sea floor is calculated by placing the top of Section 0 at the top of the cored interval.

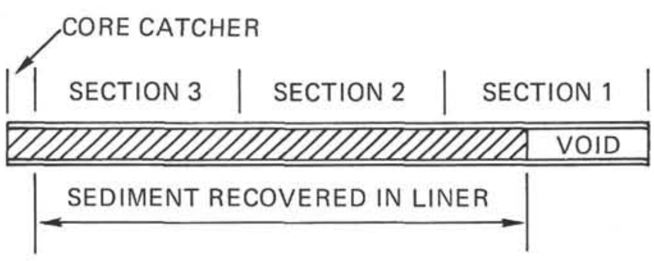

Figure 7. *Diagram illustrating convention for placement of sections in a core, and identification of the top of a core.*

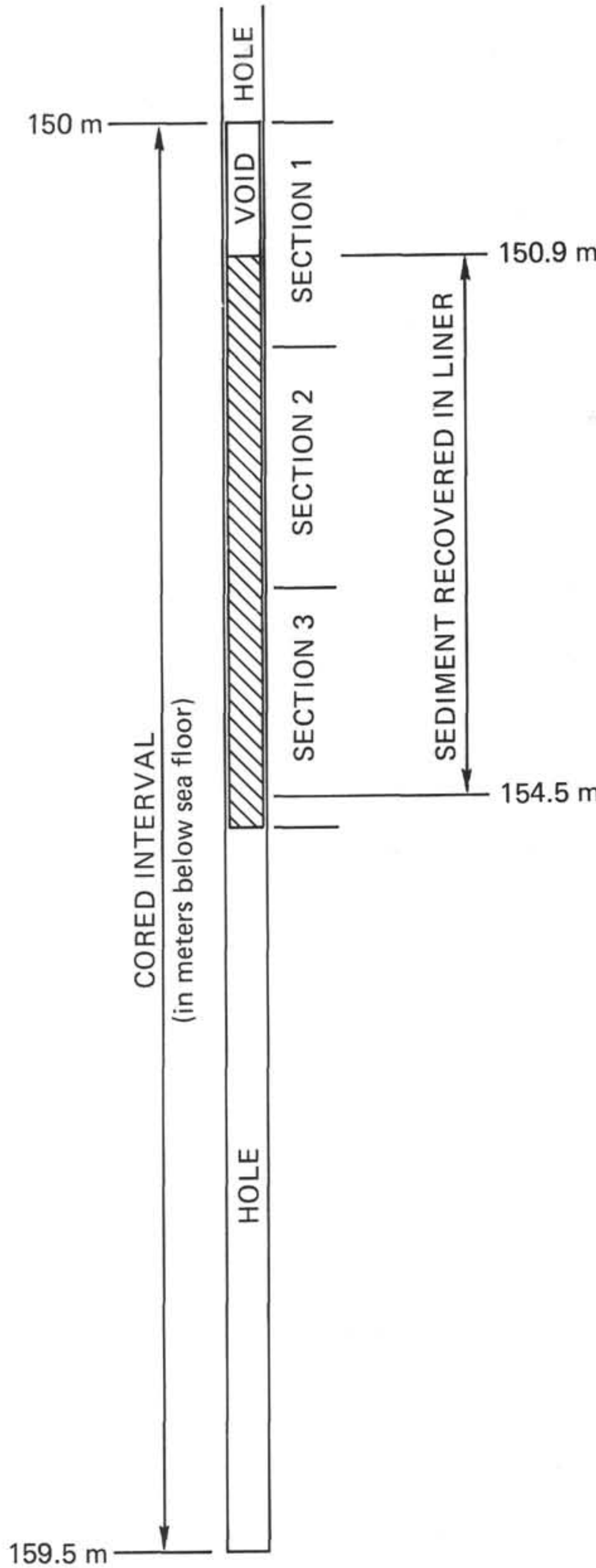

Figure 8. *Diagram illustrating convention used on Leg 45 for placement of sections within a 9.5-meter interval.*

In the core laboratory on the *Glomar Challenger,* after routine processing, the 1.5-meter sections of cored material and liner are split in half lengthwise. One half is designated the "archive" half, which is photographed; and the other is the "working" half, which is sampled by the shipboard scientists for further shipboard and shore-based analysis.

Samples taken from core sections are designated by the interval in centimeters from the top of the core section from which the sample was extracted; the sample size, in cubic centimeters, is also given. Thus, a full sample designation would consist of the following information:

Leg (Optional)
Site (Hole, if other than first hole)
Core Number
Section Number
Interval in centimeters from top of section

Sample 395A-1-3, 122-124 cm ($10 cm^3$) designates a 10 cubic-centimeter sample taken from Section 3 of Core 1 from the second hole drilled at Site 395, Hole A (mud-line core). The depth below the sea floor for this sample would then be the depth to the top of the cored interval (0 m for a mud-line core) plus 3 meters for Sections 1 and 2, plus 122 cm (depth below the top of Section 3), or 4.2 meters. Note, however, that subsequent sample requests should refer to a specific interval within a core section (in centimeters) rather than depth in meters below the sea floor.

Sediment Description Conventions

Core Disturbance

Sediment descriptions are given on sediment core description sheets; conventions and symbols for descriptions are discussed below.

Unconsolidated sediments are often quite disturbed by the rotary drilling/coring technique, and there is a complete gradation of disturbance style with increasing sediment induration. An assessment of degree and style of drilling deformation is made on board ship for all cored material, and shown graphically on the core description sheets. The following symbols are used:

- - - - Slightly deformed; bedding contacts slight bent.
– – – – Moderately deformed; bedding contacts have undergone extreme bowing.
~~~~ Highly deformed; bedding completely disturbed, often showing symmetrical diapir-like structures.
OOO Soupy, or drilling breccia; water-saturated intervals that have lost all aspects of original bedding and sediment cohesiveness.

Consolidated sediments and rocks seldom show much internal deformation, but are usually broken by drilling into cylindrical pieces of varying length. There is frequently no indication whether adjacent pieces in the core liner are actually contiguous or whether intervening sediment has been lost during drilling. The symbol (-o-o-o) was used for cylindrical pieces of core separated by intervals of drilling breccia or injected (remolded) softer sediment.

Smear Slides

The lithologic classification of sediments is based on visual estimates of texture and composition in smear slides made on-board ship. These estimates are of areal abundances on the slide and may differ somewhat from the more accurate laboratory analyses of grain size, carbonate content, and mineralogy. Experience has shown that distinctive minor components can be accurately estimated (± 1 or 2%), but that an accuracy of ± 10 per cent for major constituents is rarely attained. Carbonate content is especially difficult to estimate in smear slides, as is the amount of clay present. Smear-slide analyses at selected levels, as well as averaged analyses for intervals of uniform lithology, are given on the core description sheets. For carbonate content, reference should be made to shipboard carbonate bomb analyses and shore-based analyses (also shown).

Carbonate and Grain Size Data

During Leg 45, the carbonate bomb device was used as an aid in sediment classification. This device is basically a cylindrical vessel with pressure gage, in which a sediment sample of known weight is reacted with acid. The pressure of CO_2 generated is measured and converted to per cent carbonate. Accuracy to within ± 5 per cent total carbonate has been quoted for the device. Shipboard carbonate bomb data are listed in a separate column on the core description sheet.

Samples were taken for DSDP shore-based carbon-carbonate analysis using the Leco 70-second Analyzer. These are also listed on the core description sheet in the sequence total carbon, organic carbon and $CaCO_3$. Grain size data are listed in the sequence sand, silt, and clay.

Sediment Induration

The determination of induration is highly subjective, but field geologists have successfully made similar distinctions for many years. The criteria of Moberly and Heath (1971) are used for calcareous deposits; subjective estimate or behavior in core cutting is used for others.

a) Calcareous sediments
   Soft: Oozes have little strength and are readily deformed under the finger or the broad blade of a spatula.
   Firm: Chalks are partly indurated oozes; they are friable limestones that are readily deformed under the fingernail or the edge of a spatula blade.
   Hard: Cemented rocks are termed limestones.
b) The following criteria are used for other sediments.
   If the material is soft enough that the core can be split with a wire cutter, the sediment name only is used (e.g., silty clay; sand).
~~~~

If the core must be cut on the band saw or diamond saw, the suffix "stone" is used (e.g., silty claystone; sandstone).

Sediment Classification

The sediment classification scheme used on Leg 45 is basically that devised by the JOIDES Panel on Sedimentary Petrology and Physical Properties and adopted for use by the JOIDES Planning Committee in March 1974, with minor modifications. The classification is outlined below. Only those portions pertinent to Leg 45 are listed. A compilation of symbols is given in Figure 9.

I. General rules for class limits and order of components in a sediment name.
   A. Sediment assumes the names of those components present only in quantities greater than 15 per cent.
   B. Where more than one component is present, the component in greatest abundance is listed farthest to the right, and other components are listed progressively to the left in order of decreasing abundance.
   C. The class limits are based on percentage intervals given below for various sediment types.

II. Pelagic Biogenic Calcareous Sediments
   $>30\%$ $CaCO_3$
   $<30\%$ terrigenous components
   $<30\%$ siliceous microfossils

   Principal components are nannofossils and foraminifers; qualifiers are used as follows:
   Foraminifers,

%	Name
<10	nannofossil ooze (chalk, limestone)
10-25	foraminiferal-nannofossil ooze
25-50	nannofossil-foraminiferal ooze
>50	foraminiferal ooze

   Calcareous sediments containing 10 to 30 per cent siliceous fossils carry the qualifier radiolarian, diatomaceous, or siliceous, depending upon the identification.

III. Transitional Biogenic Calcareous Sediments
   $>30\%$ $CaCO_3$
   $>30\%$ terrigenous components or pelagic clay
   $<30\%$ siliceous microfossils

   If $CaCO_3$ 30 to 60%, marly is used as a qualifier:
   soft: marly calcareous (or nannofossil, etc.) ooze
   firm: marly chalk (or marly nannofossil chalk, etc.)
   hard: marly limestone (or marly nannofossil limestone, etc.)

   If $CaCO_3$ $>60\%$:
   soft: calcareous (or nannofossil, etc.) ooze
   firm: chalk (or nannofossil chalk, etc.)
   hard: limestone (or nannofossil limestone, etc.)

   NOTE: Sediments containing 10 to 30 per cent $CaCO_3$ fall in other classes, where they are denoted with the adjective "calcareous," "nannofossil," etc.

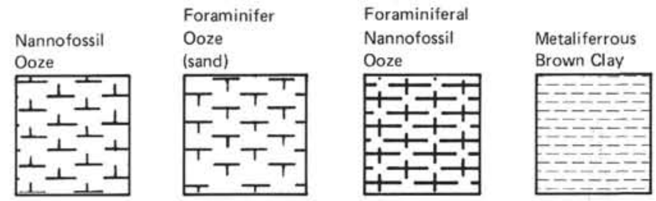

Figure 9. *Symbols used for sediments on core description sheets, Leg 45.*

IV. Special Sediment Types
   A. At Sites 395 and 396, brown to yellow-brown clays were recovered near volcanic basement. These appear similar to iron- and manganese-rich clays near basement at other DSDP sites which are not normal pelagic clays. Rather, they may relate to basement hydrothermal activity. These clays are therefore modified by color only. The term "pelagic" is avoided.

Biostratigraphy

Age boundaries shown on the core forms are based on foraminifer studies by A. Kaneps (DSDP) and nannofossil studies by D. Bukry (USGS).

Basement Description Conventions

Core Forms

Initial core description forms for igneous and metamorphic rocks are not the same as those used for sediments. The sediment barrel sheets are substantially those published in previous *Initial Reports.* Igneous rock representation on barrel sheets is too compressed to provide adequate information for potential sampling. Consequently, Visual Core Description forms, modified from those used on-board ship, were used for more complete graphic representation. All shipboard data per 1.5-meter section of core are listed on the modified forms, together with summary hand-specimen and thin-section descriptions.

To provide a uniform basis for future descriptions, a series of symbols and a number of format conventions for igneous and metamorphic rocks have been adopted. The symbols are presented on Figure 10. It is expected that this will increase and be amended on future cruises.

All basalts on Leg 45 were split into archive and working halves, using a rock saw with a diamond blade. The working halves were described and sampled on board ship. On a typical basalt description form, the left column is a visual representation of the working half, using the symbols of Figure 10. Two closely spaced horizontal lines in this column indicate the location of styrofoam spacers taped between basalt pieces inside the liner. Each piece is numbered sequentially from the top of each section, beginning with the number 1. Pieces are labeled on the rounded, not the sawed surface. Pieces which could be fit together before splitting are given the same number, but are separately and consecutively lettered: 1A, 1B, 2C, etc. Spacers were placed between pieces with different numbers, but not between those with different letters and the same number. In general,

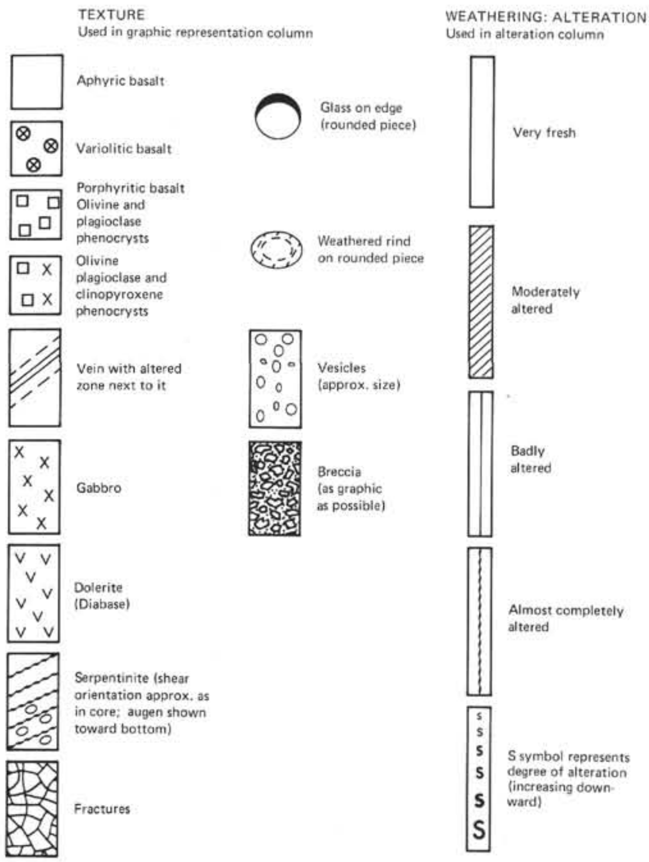

Figure 10. *Symbols for igneous rocks, Leg 45.*

addition of spacers represents a drilling gap (no recovery). In cores where recovery was high, however, it was impractical to use spacers. In these cases, drilling gaps are indicated only by a change in numbers. Basalt rocks in the deeper cores of Hole 395A are so highly fractured that no attempt was made to move them from the liners for numbering. They were split in the liner with a special diamond rock saw fitted to a movable track. Each section was allowed to dry, then intervals and core and section number were marked on the sawed surfaces of pieces at least every 10 cm, and at closer intervals for small pieces. All pieces greater in longest diameter than about 1 cm were marked. All pieces, whether labeled on the rounded drilled surfaces, or, in the case of shattered rock, on sawed surfaces, have orientation arrows pointing to the top of the section, both on archive and working halves, provided the original unsplit piece was cylindrical in the liner and of greater length than the diameter of the liner. Special procedures were adopted to ensure that orientation was preserved through every step of the sawing and labeling process. All pieces suitable for sampling requiring knowledge of top from bottom are indicated by upward-pointing arrows to the left of the piece numbers on the description forms. Since the pieces were rotated during drilling it is not possible to sample for declination studies.

Samples were taken for various measurements on board ship. The type of measurement and approximate location are indicated in the column headed "Sample," using the following notation:

X = X-ray fluorescence analysis
M = magnetics measurements
S = sonic velocity measurements
T = thin section
D = density measurements
P = porosity measurements

Igneous and Metamorphic Rock Classification

Basalts, gabbros, and serpentinites were recovered on Leg 45. Classification was based mainly on mineralogy of minerals visible in hand specimens, and secondarily on texture. Thin-section work in general added no new information to the hand-specimen classification.

Basalts were termed aphyric, sparsely phyric, moderately phyric, or phyric depending on the proportion of phenocrysts visible with the binocular microscope (~12×). Aphyric basalts were so called if phenocrysts were absent. In a practical sense, this meant that if one piece of basalt was found with a phenocryst or two in a section with all other pieces lacking phenocrysts, and no other criteria such as grain size or texture distinguished this basalt from the others, then it too was described as aphyric. A note of the rare phenocrysts, however, was included in the general description. This was done in order to restrict the number of lithologic units to those with clearly distinctive and persistent visual differences.

Sparsely phyric basalts are those with 1 to 2 per cent phenocrysts present in almost every piece of a given core of section. Clearly contiguous pieces without phenocrysts were included in this category, again with the lack of phenocrysts noted in the general description.

Moderately phyric basalts contain 2 to 10 per cent phenocrysts. Aphyric basalts within a group of moderately phyric basalts are separately termed aphyric basalts.

Phyric basalts contain more than 10 per cent phenocrysts. No separate designation is made for basalts with more than 20 per cent phenocrysts; the proportion indicated in the core forms should be sufficient to guide the reader.

The basalts are further classified by phenocryst type, preceding the terms phyric, sparsely phyric, etc. A plagioclase-olivine moderately phyric basalt contains 2 to 10 per cent phenocrysts, most of them plagioclase, but with some olivine.

Intrusive basalts cored in Hole 395A are termed dolerite rather than diabase.

Plutonic rocks recovered on Leg 45 are also described by mineralogy, except where separate rock names based on the mineralogy are in common usage. Thus, lherzolite and harzburgite are olivine-orthopyroxene-clinopyroxene peridotite and olivine-orthopyroxene peridotite, respectively, following the classification of Jackson (1968). These rocks are 20 to 40 per cent serpentinized, and are therefore described as serpentinized lherzolite or harzburgite, respectively. Peridotites whose original mineralogy is substantially (~ >70 per cent) obliterated are called serpentinites. Gabbros with metamorphic textures recovered on Leg 45 are called recrystallized gabbros, again with appropriate mineralogic modifiers, because their specific metamorphic association—e.g., hornfels versus granulite—was not possible to determine.

No petrochemical or normative classification schemes are used on the core forms. The reader is referred to the site summaries and the interpretive chapters on geochemistry and petrology by individual contributors or groups for information pertinent to this aspect of Leg 45 igneous rock classification.

REFERENCES

Aumento, F., Loncarevic, B. D., and Ross, D. I., 1971. Hudson Geotraverse: Geology of the Mid-Atlantic Ridge at 45°N, *Phil. Trans. Roy. Soc. London,* Ser. A, v. 268, p. 623-650.

Bougault, H., 1977. Major elements, analytical chemistry on board and preliminary results. *In* Aumento, F., Melson, W. G., et al., *Initial Reports of the Deep Sea Drilling Project,* v. 37: Washington (U.S. Government Printing Office), p. 643-657.

Bougault, H., Cambon, P., and Toulhoat, H., 1977. X-ray spec trometric analysis of trace elements in rocks; correction for instrumental interferences, *X-Ray Spectrometry,* v. 6, no. 2, p. 66-72.

Hart, S. and Schilling, J.-G., 1973. The geochemistry of basalts from Iceland and the Reykjanes Ridge, *Carnegie Institute Washington Yearbook,* v. 72, p. 259-261.

Jackson, E. D., 1968. The characteristics of the lower crust and upper mantle beneath the Hawaiian Islands, *Int. Geol. Congr. 23rd, Prague, 1968, Proc.,* v. 1., p. 135-150.

Moberly, R., Jr. and Heath, G. R., 1971. Carbonate sedimentary rocks from the Western Pacific: Leg 7, Deep Sea Drilling Project. *In* Winterer, E. L., Riedel, W. R., et al., *Initial Reports of the Deep Sea Drilling Project,* v. 7, Part 2: Washington (U.S. Government Printing Office), p. 977-985.

Morgan, W. J., 1971. Convection plumes in the lower mantle, *Nature,* v. 230, p. 42-43.

_______, 1972. Deep mantle convection plumes and plate motion, *Am. Assoc. Petrol. Geol. Bull.,* v. 56, p. 203-213.