24. EXPERIMENTAL EMPLACEMENT MODE DETERMINATION OF BASALT IN HOLE 396B

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ABSTRACT

The anisotropy of magnetic susceptibility (AMS) and remanent magnetism of 32 basaltic samples from Hole 396B have been measured.

Using criteria developed in our earlier studies of DSDP basaltic rocks, the AMS data suggest a definite extrusive origin for all samples except those in the 235 to 244 meter depth interval, where an intrusive body may have been sampled.

We have now measured the AMS of 246 basaltic samples taken from the first 46 legs of DSDP. One-third of these have been diagnosed as intrusive. Shallower parts of Layer 2 appear to have a higher intrusive fraction than is the case for ophiolite complexes.

INTRODUCTION

Kidd (1976) and Kidd and Vine (1976) have recently emphasized the importance of emplacement mode determinations of igneous samples in defining the structure of the oceanic crust. Without such control, the direct testing of their new linear magnetic anomaly formation models would be perhaps impossible. Ellwood and Watkins (1976) have shown that emplacement mode analyses of DSDP samples is possible if a sufficiently large data set is available. During the earliest phases of DSDP, it became clear that conventional means of distinguishing between intrusive and extrusive igneous rocks would, for a range of reasons, not be feasible to any consistent extent. For this reason we initiated experimental attempts to solve the problem (Ellwood and Watkins, 1973). The principle which we have employed is based on the suspicion that pressure fields present during emplacement would be more systematic for intrusive rocks, so that net preferred elongation of crystals can be expected to be higher in intrusives. We have used anisotropy of magnetic susceptibility (AMS) measurements to measure variations in the net preferred elongation of ferrimagnetic crystals in unaltered DSDP basaltic rocks.

Magnetic susceptibility (K) is a proportionality constant relating the intensity of magnetization which is induced in a sample by placing it in a given magnetic field. It is a tensor of the second rank and is usually characterized by a representation quadric whose maximum, intermediate, and minimum orthogonal axial magnitudes are K_a, K_b, and K_c, respectively. For most materials the axial magnitudes are similar (the material is nearly isotropic). When basalts contain crystals with a slight degree of preferred alignment, the axes are unequal, and such anisotropy can be measured. The triaxial ellipsoid which can be derived from AMS measurements describes the directions and magnitudes of each axis. Ellwood (1975) observed that various functions of AMS differed between samples because of contrasts in the measured K. He therefore suggested the use of an emplacement mode indicator F, where

$$F = \frac{Ka'}{(Kb' \times Kc')^{1/2}}$$

and K_a', K_b', and K_c' are tensor magnitudes recalculated for a standard volume susceptibility of 1.0×10^{-3} cgs. units. F emphasizes long axis alignments and is independent of K. Ellwood (1975) measured 312 specimens from known intrusive and extrusive units and showed that a value of $F = 1.04$ divides, with 80 per cent confidence, intrusives from extrusives.

While believing that directions of remanent magnetism in DSDP basalts are of limited value, we also measure the remanent magnetic properties for use in inferring titanomagnetite oxidation state, crystal size, and stability (Watkins and Haggerty, 1967). Although not invariably true, magnetic stability tends to be higher in extrusives, because of faster cooling rates and higher oxidation states, which produce smaller effective titanomagnetite crystal size.

We have measured (Ellwood and Watkins, 1975) a large collection of DSDP igneous rocks, and showed that emplacement mode is between 20 and 40 per cent intrusive. This paper is part of a series in which we continue to add to the data, which we ultimately hope to use for characterizing the rate of increase of intrusive fraction with depth in the ocean crust.

METHODS

A total of 32 samples of 2.5-cm diameter were drilled normal to the vertical axis of the basaltic core recovered at Hole 396B on DSDP Leg 46. Sample depth in the core ranged from 157 to 359 meters below the sea floor. Samples were sliced into cores of 2.2-cm length. AMS was measured on a low-field torque meter similar to that described by Stone (1963). K was measured using a 300 Hz susceptibility bridge (Collinson et al., 1963). Precision limits have been described by Ellwood (1975).

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RESULTS

The AMS results for all samples are given in Table 1. The ratio of the intensity of magnetization before and after demagnetization in peak alternating fields of 100 and 200 Oe is included in the table.

DISCUSSION

Emplacement Mode in Hole 396B

The last column of Table 1 indicates the emplacement mode inferred from the measured F values. It can be seen that F for all except one sample is well below 1.04, consistent with a nearly isotropic net crystal arrangement. At 237.7 meters depth below the mudline, one sample occurs with a slightly anisotropic quality: conceivably, then, an intrusive body has been sampled.

Functions of stability of the remanent magnetism (J_{100}/J_0 and J_{200}/J_0, where J = intensity of magnetization and the suffixes refer to the peak demagnetizing field in Oe, with o = the undemagnetized specimen) show that almost all samples retained more than 70 per cent of their original J after demagnetization at 200 Oe. The lowest J retained after demagnetization is 23 per cent, and occurs at a depth of 237.7 meters. Therefore, the sample at this depth has two properties which are consistent with an intrusive origin.

Emplacement Mode for All DSDP Igneous Rocks

It is appropriate to review all our results to date. Figure 1 illustrates F values determined for all 246 DSDP samples which we have measured. The samples are from Holes 10, 57, 63, 66, 105, 146, 163, 165A, 304, 317A, 319A, 321, 332B, 334, 335, and 396B. The depths in each hole are given in Table 2.

In Figure 2 we illustrate a comparison of the F value emplacement mode determinations with determinations made by conventional means during the respective cruises, as reported in the Initial Reports volumes. The results are also summarized in Table 2. Total disagreement between the independent emplacement mode determinations occurs only for Hole 63. Such a disagreement could be of substantial significance. For example, the age of the sea-level magnetic anomaly above the hole may be inferred from micropaleontological analysis of the oldest sediment in the hole. If the hole were terminated in a sill within Layer 1, then the age of basement could be much younger than the age of the material causing the anomaly.

The overall extrusive to intrusive ratio in the shallower portions of Layers 1 and 2 of the oceanic crust is illustrated in Figure 3 and suggests that extrusives dominate over intrusives by a 2 to 1 ratio. The high percentage of intrusives is similar to results reported for 180 DSDP samples by Ellwood and Watkins (1976), who have pointed out that such high intrusive percentages are not found in the shallower parts of ophiolite sequences. Intrusions into Layer 1 sediments could in part account for this observation, but it is now appearing that the sea floor may be characterized by intrusive fractions which are higher than expected.

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TABLE 1
Anisotropy of Magnetic Susceptibility Data for Basaltic Samples From Hole 396B, DSDP Leg 46

Sample (Interval in cm)	Depth (m)	$K \times 10^{-4}$	J_{100}/J_{nrm}	J_{200}/J_{nrm}	$K_a \times 10^{-4}$	$K_b \times 10^{-4}$	$K_c \times 10^{-4}$	D_{max}	I_{max}	D_{int}	I_{int}	D_{min}	I_{min}	% An	F	"Emplacement"
5-1, 34	157.34	1.423	0.903	0.796	1.432	1.421	1.417	208.3	-21.7	104.5	-30.9	327.5	-50.7	1.063	1.001	E
5-1, 60	157.60	1.981	0.823	0.625	1.995	1.987	1.961	327.8	-0.7	237.2	-42.1	58.6	-44.9	1.718	1.002	E
5-2, 54	159.04	1.105	0.935	0.791	1.117	1.103	1.094	163.8	-9.1	286.8	-73.5	71.6	-13.6	2.100	1.002	E
7-1, 65	174.65	1.200	0.838	0.681	1.211	1.203	1.187	356.7	-14.4	260.3	-23.5	114.4	-61.9	1.947	1.002	E
8-1, 69	184.19	1.013	0.907	0.677	1.034	1.012	0.992	289.7	-36.5	179.2	-25.3	63.1	-42.9	4.135	1.003	E
9-1, 88	193.88	1.232	0.760	0.531	1.239	1.235	1.223	217.0	-29.5	114.9	-20.6	354.8	-53.0	1.334	1.001	E
9-2, 127	195.77	0.519	0.935	0.910	0.522	0.520	0.515	277.6	-24.2	12.9	-11.4	126.1	-62.9	1.324	1.000	E
10-2, 30	204.30	0.559	0.969	0.823	0.567	0.558	0.553	109.1	-46.7	293.9	-43.2	201.7	-2.4	2.380	1.001	E
11-1, 134	213.34	1.010	0.893	0.766	1.026	1.005	1.000	173.6	-42.4	168.2	-5.1	3.7	-47.2	2.675	1.002	E
12-1, 61	215.11	1.165	0.801	0.632	1.179	1.171	1.147	136.9	-12.6	235.2	-32.7	28.8	-54.3	2.799	1.002	E
13-1, 63	217.13	1.232	0.844	0.626	1.265	1.219	1.212	256.1	-41.7	21.4	-38.5	132.4	-24.3	4.360	1.005	E
14-2, 42	226.40	0.833	0.974	0.797	0.873	0.842	0.785	344.4	-52.1	169.9	-37.8	77.8	-2.7	10.481	1.006	E
14-2, 42	227.42	0.691	0.979	0.823	0.702	0.697	0.673	162.6	-8.5	252.6	-0.5	345.6	-81.4	4.173	1.002	E
15-1, 100	236.00	9.877	1.225	0.903	0.902	0.864	0.863	221.9	-69.6	61.9	-19.3	329.6	-6.5	4.550	1.004	E
15-2, 124	237.74	16.340	0.668	0.232	16.702	16.268	16.056	36.1	-61.8	207.3	-27.9	299.3	-3.7	3.975	1.067	I
16-1, 76	245.26	0.721	0.983	0.861	0.732	0.722	0.709	183.3	-10.0	291.9	-61.1	88.2	-26.8	3.204	1.002	E
16-5, 104	251.54	0.486	1.009	0.964	0.488	0.485	0.483	178.8	-25.6	20.8	-62.7	273.1	-8.9	0.997	1.000	E
17-2, 86	269.86	0.926	0.840	0.753	0.943	0.923	0.913	211.4	-27.9	10.7	-60.5	115.7	-8.8	3.191	1.002	E
17-3, 28	270.78	0.914	1.007	0.777	0.949	0.909	0.885	319.5	-20.8	198.4	-53.7	61.3	-28.3	7.050	1.005	E
18-1, 108	274.08	1.390	0.786	0.523	1.434	1.410	1.324	331.1	-50.1	192.3	-32.3	88.4	-20.9	7.797	1.007	E
18-2, 53	275.03	0.672	0.994	0.924	0.683	0.668	0.666	169.4	-26.8	358.4	-62.9	261.2	-3.6	2.504	1.002	E
20-2, 25	287.25	0.859	0.946	0.823	0.868	0.860	0.840	209.4	-13.6	115.7	-14.8	340.2	-69.6	2.120	1.001	E
20-3, 142	290.92	0.707	0.924	0.889	0.721	0.704	0.695	327.2	-4.6	236.9	-2.7	116.3	-84.7	3.675	1.002	E
20-4, 52	291.52	0.852	0.944	0.845	0.869	0.847	0.841	112.3	-11.0	024.4	-10.7	337.5	-75.6	3.322	1.003	E
20-6, 45	294.45	0.821	0.890	0.794	0.834	0.820	0.811	211.7	-1.6	121.1	-23.1	305.5	-66.8	2.823	1.002	E
21-1, 34	296.34	1.178	0.933	0.689	1.233	1.154	1.147	228.5	-20.5	122.9	-35.7	342.2	-47.1	7.412	1.008	E
22-1, 136	306.86	0.985	0.957	0.910	1.035	0.969	0.950	352.6	-0.6	262.4	-15.5	84.7	-74.5	8.714	1.007	E
22-2, 48	307.48	0.953	0.960	0.933	0.979	0.965	0.915	186.5	-2.9	276.8	-4.3	62.8	-84.8	6.675	1.004	E
22-3, 133	309.83	1.075	0.983	0.800	1.093	1.067	1.065	335.6	-49.5	174.7	-38.9	76.9	-9.5	2.683	1.003	E
22-4, 13	310.13	0.680	0.895	0.816	0.696	0.679	0.664	199.1	-9.1	107.1	-11.8	326.8	-75.0	4.637	1.002	E
23-1, 81	315.81	1.197	0.972	0.956	1.219	1.200	1.173	103.9	-8.9	237.4	-77.2	12.4	-9.2	3.804	1.003	E
28-1, 9	358.09	2.460	0.289	1.043	2.541	2.426	2.412	298.7	-47.8	99.8	-40.6	198.1	-9.5	6.332	1.012	E

Note: K = volume susceptibility in cgs units; K_a, K_b, K_c = magnitudes in cgs units of (A) maximum, (B) intermediate, and (C) minimum susceptibility; corresponding directions given by D and I max., int., and min., where D = declination in degrees east of an arbitrary zero azimuth; I = inclination, %An = percent anisotropy = $(K_a - K_c)K_b \times 100.0$; F = emplacement number, see text for definition. "Emplacement": E = extrusive; I = intrusive. J_{100}/J_{nrm} and J_{200}/J_{nrm} are simple ratios illustrating intensity of magnetization decrease with demagnetization treatment, where J_{nrm}, J_{100}, and J_{200} are the intensities of magnetization for natural remanent magnetization and after 100 and 200 Oe demagnetization treatments, respectively.

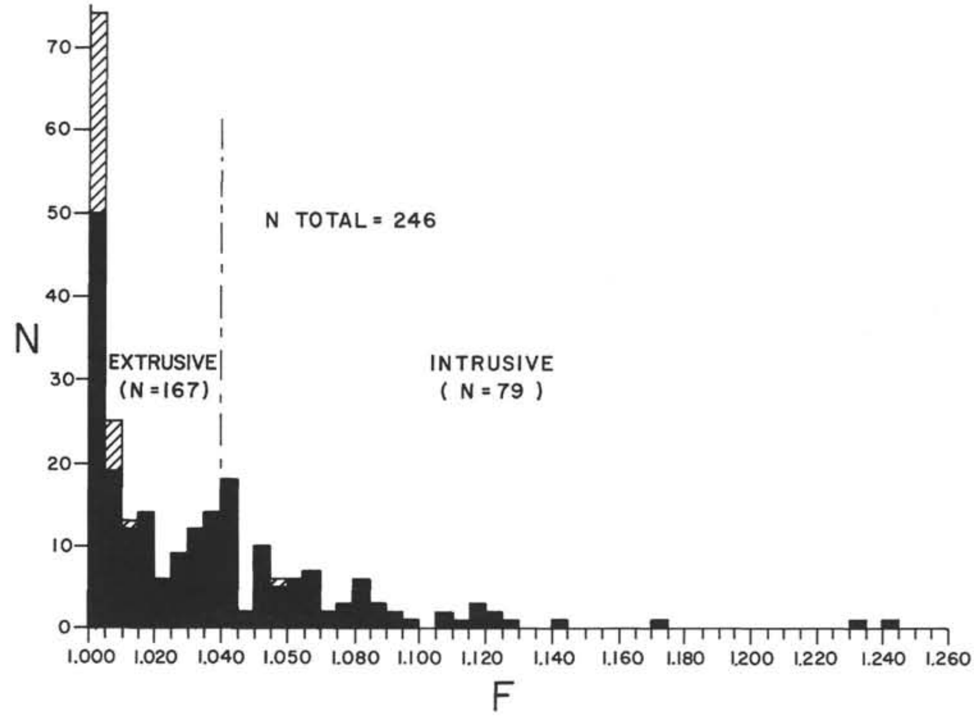

Figure 1. *Histogram of* F *values in 246 DSDP igneous samples. The dashed line divides "intrusives"* (F > *1.040) from "extrusives"* (F < *1.040) according to Ellwood (1975). Hatched symbols are from current analyses on Hole 396B. Blackened values are from Holes 10, 57, 63, 66, 105, 146, 163, 165A, 304, 317A, 319A, 321, 332B, 334, and 335, and represent* F *results for all DSDP samples which we have analyzed.*

TABLE 2
Comparison of DSDP Basaltic Emplacement Mode Analyses Using Anisotropy of Magnetic Susceptibility and Conclusions Reached in the Initial Reports

Leg No.	Hole No.	Depth Range (cm)	N	AMS Emplacement Mode	Initial Reports Emplacement Mode	Initial Report Page No.	Remarks from Initial Report
2	10	459.9-461.1	7	E	E	211, 218	Volcanic assumed to mean extrusive
6	57	328.9-331.4	9	I	E, I	496	
7	63	564.2-565.8	6	I	E	328, 329	Basalt contains xenoliths of baked calcareous sediment
7	66	192.0-193.0	2	E	E	730	
11	105	625.3-632.9	28	E	E	227	
15	146	749.5-758.7	28	I	I	17, 22, 24, 26, 33	
16	163	276.2-293.8	24	E	E	411, 413, 416, 418	
17	165A	452.3-489.9	12	E	E	47, 59, 60, 64	Interbedded basalts and sediments
32	304	335.9-344.1	11	I	E, I	49, 55	
33	317A	915.2-943.5	7	E	E	162, 163, 170, 171, 186	Interbedded basalts and sediments
34	319A	98.4-120.7	17	E	E, I	28, 34	Possibly shallow sills
34	319A	121.1-123.7	5	I	E, I	28, 34	Possibly shallow sills
34	319A	123.9-148.0	11	E	E, I	28, 34	Possibly shallow sills
34	321	125.5-129.9	10	I	E, I	118, 123, 124	Possibly shallow sills
37	332B	156.0-677.0	25	E	E	26	
37	334	292.5-319.5	2	E	E	63	
37	334	321.5-321.9	2	I	I	63	Not basaltic samples
37	335	467.0-516.0	8	E	E	74	
46	396B	157.3-358.1	32	E	E	1-14	Discussion is in the Igneous and Metamorphic rocks section of report

Note: Depth range below the mudline. n = number of samples within each depth range. E = extrusive and I = intrusive, refers to the dominant emplacement mode within each depth range. Page numbers are taken from the Site Report portions of the Initial Report for the leg involved. Leg No. = Initial Report Volume No. (Note: at the time of writing, Initial Reports for Legs 37 and 46 had not been published, so page references are from the preliminary green book and orange book, respectively.)

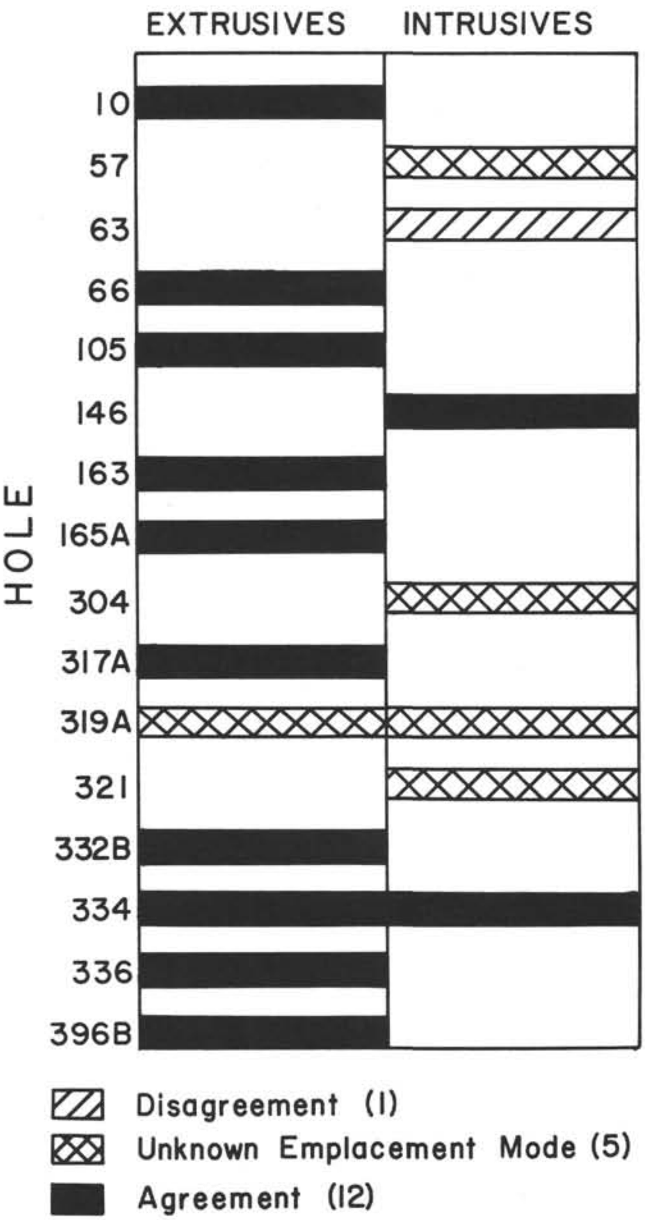

Figure 2. *Comparison of mode of emplacement of DSDP igneous rocks using anistropy of magnetic susceptibility measurements and conventional analyses, as given in the respective* Initial Reports *volumes for the hole indicated. Black solid bars represent agreement of AMS analyses with* Initital Reports. *Cross-hatched bars indicate that emplacement mode conclusions in the* Initial Reports *for the hole represented are in doubt (conclusions for Hole 321, for example, suggest the basalt may be a shallow sill or a flow). Hatched bars show disagreement of AMS data with conclusions made in the* Initial Reports *volume. See Table 2 for further details.*

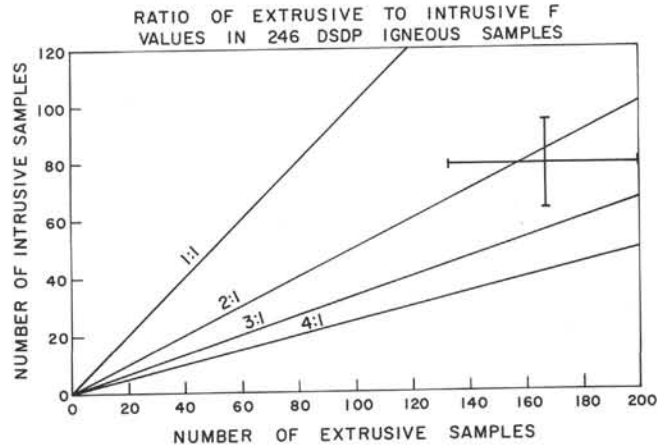

Figure 3. *Comparison of intrusive to extrusive samples from DSDP basaltic cores collected during cruises through Leg 46, as determined using anisotropy of magnetic susceptibility measurements. Twenty per cent confidence limits added.*