# 23. ROCK- AND PALEOMAGNETISM OF BASALTS FROM SITE 396B, LEG 46

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## ABSTRACT

Paleomagnetic and rock magnetic properties of 112 samples of basalt from Hole 396B, Leg 46, were measured.

Four magnetic polarity zones or magnetic units, defined by the inclination of stable remanent magnetization, could be distinguished. Stable magnetic inclination values are remarkably constant within the individual magnetic units. Owing to the changing polarity of natural remanence of the rocks, the intensity of magnetization integrated over the whole length of the drill hole is much too low to explain the amplitude of the marine magnetic anomaly observed at the drill site. The remanent magnetization of the investigated rock samples is carried by fine grains of titanomagnetite. As is typical for deep ocean weathering, the titanomagnetite grains have been altered by low temperature oxidation. No high temperature deuteric oxidation of titanomagnetite was observed.

## INTRODUCTION

Paleomagnetic and rock magnetic properties were analyzed for 112 samples from Hole 396B, Leg 46 (Mid-Atlantic Ocean). These measurements were complemented by ore microscopic observation.

The rock samples were oriented with respect to vertical; consequently, only the inclination of the natural remanent magnetization can be given in absolute values.

The main aims of this investigation were (1) measurement of the magneto-stratigraphy, and (2) identification of the ferromagnetic mineral phases.

## PALEOMAGNETIC MEASUREMENTS

### Methods

The remanent magnetization of the rocks was measured partly with a Schonstedt spinner magnetometer (shipboard measurements) and partly with a Digico spinner magnetometer (shore-based measurements). Stepwise alternating field demagnetization using fields of 25, 50, 75, 100, 150, 200, 300, 400, 500, and 1000 Oe in an earth-field-compensated space was carried out in order to determine the "stable direction" of magnetization.

Volume susceptibility was measured with a Bison magnetic susceptibility bridge. The Königsberger Q-ratio was determined from these values. Magnetic stability of the rocks was characterized by three different measured properties: (1) medium destructive field (MDF) which is the alternating field during a.c. demagnetization necessary to erase half of the natural remanent magnetization (NRM); (2) the coercivity ($H_c$); and (3) the coercivity of remanence ($H_{cr}$).

$H_c$ and $H_{cr}$ were determined by stepwise reduction of an isothermal saturation remanent magnetization ($J_{sr}$, produced in a $10^4$ oe magnetic d.c. field) by magnetic d.c. fields applied in opposite directions.

### Results

The results are summarized in Tables 1 and 2 and Figure 1. The most prominent result is the occurence of different polarity groups defined by the stable magnetic inclination values. Four polarity groups or magnetic units can be distinguished. Within the individual magnetic units, the stable magnetic inclination values are remarkably consistent (apart from magnetic Unit IV). Most of the samples have high magnetic stability and low susceptibility; this is also reflected in the high values of the Königsberger Q-factor. Only the center part of lithologic Unit 3 (the basalt flow or sill, Core 15) and Core 22 in lithologic Unit 4 have higher susceptibility values and correspondingly lower magnetic stabilities.

In Figure 1, the theoretical central dipole value for the inclination of the earth's magnetic field at the latitude of drilling (40.30) has been included for comparison. Apart from magnetic Unit II, the measured magnetic inclinations of the rocks are distinctly shallower, with mean values of +20.8° and -60° for magneitc Units I and III, respectively (Table 2). This may be a result of tectonic tilting.

The intensity of NRM shows relatively little scatter in lithologic Units 1 and 2 as compared with Units 3 and 4.

## ROCK MAGNETIC MEASUREMENTS

### Methods

Curie temperature ($T_c$) and specific saturation magnetization ($I_s$) were determined by measuring the temperature dependence of the strong field magnetization using a magnetic balance (the

**TABLE 1**
**Compilation of Different Magnetic and Mineralogic Parameters of all Measured Samples From Site 396B**

| Sample (Interval in cm) | Depth Below Basement[a] (m) | NRM Intensity $10^{-3}$ Gauss | NRM Incl. (°) | Stable Incl.[b] (°) | Suscept. $10^{-4}$ Gauss/oe | Q Factor[c] | Magnetic Stability[d] MDF (oe) | $H_c$ (oe) | $H_{cr}$ (oe) | $J_{rs}$[e] (Gauss) | $I_s$[f] ($10^{-2}$ Gauss · cm$^3$/g) | $J_{rs}/J_s$[g] | TiM Grain Size[h] (µm) | $T_c$[i] (°C) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4-1, 22-24, 2 | 0.62 | 0.0175 | | | | | >1000 | | | | 11.5 | | | 330 |
| 4-1, 103-105, 9 | 2.76 | 1.34 | +14.2 | +15.5 | | | 490 | | | | | | <1 | |
| 4-2, 57-59, 9 | 5.52 | 0.168 | +11.9 | +11 | | | 430 | | | | 7.5 | | <1 | 380 |
| 4-2, 62-64, 9 | 5.65 | 1.26 | +14.5 | +11 | | | 680 | | | | 12.5 | | | 270 |
| 5-1, 14-16, 1B | 6.98 | 0.756 | +19.7 | +20 | 1.83 | 11 | 900 | 392 | 602 | 0.180 | 13.5 | 0.48 | | 330 |
| 5-1, 86-88, 9 | 9.26 | 1.49 | +17.8 | +17.5 | | | 860 | | | | | | <1 | |
| 5-2, 9-11, 2 | 11.57 | 1.08 | +26.1 | +25.5 | | | 820 | | | | 7.7 | | | 325 |
| 5-2, 12-14, 2 | 11.98 | 0.0383 | +26.7 | +21.5 | | | 530 | | | | 12.5 | | | 365 |
| 5-2, 51-53,6 | 12.90 | 1.78 | +22.5 | +21.5 | | | 520 | | | | | | 1 | |
| 6-1, 36-38 | 18.41 | 1.04 | +28.6 | +28 | | | 500 | | | | 23.0 | | | 310 |
| 6-1, 55-57, 7 | 19.65 | 0.95 | +42.5 | +22 | | | 460 | | | | | | 2 | |
| 6-1, 109-111, 14 | 23.17 | 0.0642 | | | | | 900 | | | | 8.0 | | | 330 |
| 7-1, 53-55, 7 | 25.05 | 1.10 | +20.3 | +19.5 | | | 760 | | | | | | 1.5 | |
| 7-1, 100-102, 9B | 26.41 | 0.697 | +23.7 | +23 | 1.91 | 9 | 410 | 300 | 360 | 0.347 | 18.0 | 0.69 | | 250 |
| 7-1, 132-134, 11B | 27.33 | 0.91 | +37.8 | +20.5 | | | 430 | | | | | | 3 | |
| 7-1, 142-144, 12 | 27.62 | 0.356 | +32.9 | +30 | | | 520 | | | | 14.0 | | | 275 |
| 7-1, 145-147, 12 | 27.70 | 1.72 | +24.0 | +16 | | | 420 | | | | 19.0 | | | 263 |
| 7-2, 34-36, 4 | 28.83 | 0.187 | +29.0 | +27 | | | 330 | | | | 7.3 | | | 385 |
| 7-2, 47-49, 5 | 29.20 | 0.443 | +29.4 | +20 | | | 1020 | | | | 9.0 | | | 310 |
| 7-2, 48-50, 5 | 29.23 | 0.952 | +19.2 | +18 | | | 880 | | | | 7.5 | | | 280 |
| 7-2, 96-98, 9 | 30.61 | 0.75 | +23.6 | +21 | | | 690 | | | | | | <1 | |
| 7-3, 13-15, 1B | 32.54 | 1.27 | +23.5 | +21.5 | | | 490 | | | | | | 3 | |
| 8-1, 21-23, 3 | 33.89 | 1.137 | +19.3 | +17 | | | 550 | | | | 13.0 | | | 285 |
| 8-1, 62-64, 8A | 35.55 | 0.67 | +29.2 | +16 | | | 520 | | | | | | 3 | |
| 8-2, 17-19, 2 | 39.79 | 1.363 | +22.9 | +20 | | | 650 | | | | 19.0 | | | 321 |
| 8-2, 60-62, 6A | 41.53 | 0.445 | +32.5 | +30 | | | 190 | | | | | | 3 | |
| 9-1, 67-69, 9 | 44.37 | 0.802 | +28.3 | +28 | 1.04 | 20 | 710 | 420 | 548 | 0.194 | 14.0 | 0.49 | | 280 |
| 9-1, 108-110, 14 | 45.50 | 0.032 | | | 0.95 | 1 | | 372 | 564 | 0.078 | 10.0 | 0.28 | | 325 |
| 9-1, 120-122, 15B | 45.83 | 1.21 | +22.1 | +20 | | | 500 | | | | | | | |
| 9-2, 19-21, 2 | 47.18 | 1.13 | +23.8 | +20 | 1.09 | 27 | 570 | 440 | 592 | 0.278 | 15.0 | 0.66 | 2 | 285 |
| 9-2, 23-25, 2 | 47.29 | 0.230 | +32.6 | +30 | 1.64 | 4 | 430 | 336 | 476 | 0.168 | 10.5 | 0.57 | | 320 |
| 10-1, 51-53, 9A | 54.06 | 1.69 | +23.2 | +21 | | | 780 | | | | | | <1 | |
| 10-2, 21-23, 4 | 58.81 | 0.401 | +22.2 | +19 | | | 630 | | | | | | <1 | |
| 11-1, 56-58, 6 | 62.18 | 1.25 | + 6.3 | + 5 | | | 710 | | | | | | | |
| 11-2, 5-7, 1 | 63.36 | 1.02 | +23.2 | +11 | | | 420 | | | | | | 5 | |
| 12-1, 9-11,1 | 64.11 | 0.939 | +22.8 | +17.5 | | | 530 | 420 | 572 | 0.251 | 13.5 | 0.66 | | 305 |
| 12-1, 27-29, 3 | 64.31 | 0.148 | +20.6 | +17.5 | | | 200 | 488 | 768 | 0.110 | 8.0 | 0.49 | | 270 |
| 12-1, 127-129, 8 | 65.42 | 1.27 | +19.5 | +14 | | | 430 | | | | | | 3 | |
| 13-1, 45-47, 4 | 66.80 | 1.38 | +14.4 | +12.5 | | | 600 | | | | | | 1 | |
| 13-1, 136-138, 13 | 69.39 | 0.520 | + 9.0 | + 9 | 0.65 | 20 | 1000 | 652 | >800 | 0.105 | 7.5 | 0.50 | | 290 |
| 13-2, 8-10, 2A | 70.01 | 0.0015 | -16.0 | -35 | | | | | | | | | | |
| 13-2, 46-48, 5A | 71.09 | 0.784 | +17.0 | +13 | 0.91 | 22 | 620 | 436 | 600 | 0.239 | 13.5 | 0.63 | | 300 |
| 13-2, 49-51, 5A | 71.17 | 0.540 | +18.1 | +15 | | | 375 | | | | | | | |
| 13-2, 99-101, 11A | 72.59 | 1.81 | +17.4 | +14 | 1.39 | 33 | 430 | 388 | 492 | 0.320 | 18.0 | 0.63 | | 270 |
| 13-2, 107-109, 11B | 72.82 | 0.881 | +15.3 | +14 | 1.78 | 18 | 540 | 660 | 780 | 0.241 | 15.0 | 0.57 | | 290 |
| 13-2, 129-131, 12 | 73.44 | 0.789 | +23.5 | +23 | 1.18 | 17 | 860 | 528 | >800 | 0.169 | 9.5 | 0.64 | | 310 |
| 13-3, 4-6, 1 | 74.15 | 1.29 | +65.3 | +55 | | | 510 | | | | | | 5 | |
| 13-3, 10-12, 1 | 74.32 | 1.02 | +50.8 | +51.5 | 1.20 | 22 | 530 | 368 | 460 | 0.314 | 18.0 | 0.62 | | 240 |
| 14-1, 17-19, 3 | 75.43 | 0.792 | +19.5 | +21 | 0.80 | 25 | 600 | 572 | >800 | 0.189 | 8.5 | 0.79 | | 305 |
| 14-1, 81-83, 6c | 76.95 | 1.482 | -79.0 | -80 | 0.97 | 39 | 570 | 448 | 604 | 0.212 | 11.5 | 0.66 | | 270 |
| 14-1, 140-142, 10 | 78.35 | 1.077 | -78.0 | -80 | 1.03 | 27 | 550 | 492 | 640 | 0.220 | 10.5 | 0.75 | | 285 |
| 14-2, 17-19, 2 | 78.99 | 1.40 | -76.9 | -77 | | | 680 | | | | | | 2 | |
| 14-2, 95-97, 10A | 80.84 | 1.280 | -70.9 | -75 | 1.33 | 25 | 570 | 292 | 356 | 0.302 | 18.0 | 0.60 | | 247 |
| 14-3, 5-7, 1A | 82.27 | 1.448 | -75.6 | - | 1.13 | 33 | 580 | 440 | 540 | 0.278 | 15.0 | 0.66 | | 235 |
| 14-3, 66-68, 5B | 83.72 | 1.79 | -69.3 | -73 | 1.32 | 35 | 550 | 328 | 392 | 0.298 | 16.0 | 0.67 | 5 | 260 |
| 15-1, 85-87, 11 | 85.65 | 1.17 | -59.1 | -58 | | | 610 | | | | | | 3 | |
| 15-2, 19-21, 1B | 86.77 | 0.786 | - 1.0 | -70 | 2.49 | 8 | 550 | 138 | 148 | 0.468 | 30.0 | 0.56 | | 240 |
| 15-2, 28-30, 1D | 86.90 | 1.103 | -14.5 | -68 | 2.71 | 10 | 450 | 122 | 140 | 01436 | 33.0 | 0.47 | | 245 |
| 15-2, 120-122, 2c | 88.13 | 1.584 | -23.8 | -61 | 16.41 | 2 | 220 | 44 | 112 | 0.254 | 65.0 | 0.14 | | 185 |
| 15-2, 129-131, 2c | 88.25 | 2.57 | -54.3 | -65 | | | 180 | | | | | | 20 | |
| 15-3, 16-18, 2B | 88.74 | 3.49 | -47.2 | -64.5 | | | 315 | | | | | | 15 | |
| 15-3, 79-81, 3A | 89.58 | 1.48 | -54.3 | -63.5 | 1.41 | 27 | 500 | 216 | 448 | 0.373 | 20.0 | 0.67 | 10 | 250 |
| 15-3, 140-142, 7 | 90.40 | 3.005 | -49.6 | -68 | 3.10 | 25 | 240 | 136 | 156 | 0.443 | 35.0 | 0.45 | | 250 |
| 15-4, 59-61, 3 | 91.32 | 1.281 | -46.5 | -62 | 1.95 | 17 | 590 | 145 | 156 | 0.421 | 33.5 | 0.45 | | 233 |
| 15-4, 76-78, 4 | 91.55 | 2.06 | +22.1 | -66 | | | 170 | | | | | | 15 | |
| 15-4, 135-137, 4B | 92.33 | 2.135 | -42.0 | -70 | 2.01 | 27 | 510 | 156 | 172 | 0.441 | 31.5 | 0.50 | | 270 |
| 15-5, 70-72, 9 | 93.48 | 5.00 | -68.1 | -69 | | | 470 | | | | | | | |
| 16-1, 83-85, 10D | 95.08 | 3.41 | - 7.3 | -10 | | | 610 | | | | | | 3 | |
| 16-2, 40-42, 4A | 96.45 | 1.77 | -10.5 | -14 | | | 630 | | | | | | 1 | |
| 16-3, 37-39, 4B | 98.36 | 1.206 | - 3.7 | - 3 | 1.00 | 31 | 810 | 368 | 112 | 0.172 | 10.0 | 0.61 | | 270 |
| 16-3, 109-111, 12 | 99.26 | 3.68 | - 6.6 | -11 | 0.59 | 160 | 500 | 376 | 452 | 0.261 | 12.5 | 0.75 | | 255 |
| 16-3, 144-146, 1B | 99.71 | 1.002 | - 4.7 | - 7 | 0.98 | 26 | 510 | 380 | 580 | 0.129 | 9.0 | 0.51 | | 300 |
| 16-4, 20-22, 2 | 100.05 | 2.83 | - 6.2 | - 7 | | | 700 | | | | | | 3 | |
| 16-4, 41-43, 5 | 100.32 | 0.713 | - 7.0 | - 8 | 0.80 | 23 | 800 | 468 | 712 | 0.113 | 7.5 | 0.54 | | 300 |
| 16-5, 96-98, 11 | 102.95 | 2.78 | -10.6 | -10.5 | | | 600 | | | | | | | |
| 17-1, 132-134, 11B | 118.35 | 2.11 | - 2.6 | - 7 | | | 620 | | | | | | 3 | |
| 17-3, 33-35, 2B | 120.40 | 2.78 | - 3.1 | - 7.5 | 1.40 | 51 | 460 | 288 | 380 | 0.207 | 14.0 | 0.53 | 2 | 275 |
| 18-1, 18-20, 2 | 122.79 | 2.460 | - 6.4 | - 7 | 0.77 | 82 | 830 | 500 | 760 | 0.141 | 7.5 | 0.67 | | 305 |
| 18-1, 117-119, 7D | 124.28 | 3.38 | + 4.7 | 0 | | | 600 | | | | | | 5 | |
| 18-2, 22-24, 1B | 125.11 | 4.17 | - 2.7 | - 4 | 1.32 | 81 | 530 | 340 | 440 | 0.197 | 12.0 | 0.59 | | 290 |
| 18-2, 97-99, 5 | 126.24 | 3.021 | - 4.4 | - 5 | 1.19 | 65 | 650 | 372 | 480 | 0.174 | 13.5 | 0.46 | | 270 |
| 19-1, 4-6, 1 | 131.25 | 5.02 | -14.9 | -16.5 | | | 690 | | | | | | | |

**TABLE 1** –*Continued*

| Sample (Interval in cm) | Depth Below Basement[a] (m) | Intensity $10^{-3}$ Gauss | Incl. (°) | Stable Incl. (°) | Suscept. $10^{-4}$ Gauss/0e | $Q$ Factor[c] | Magnetic Stability[d] MDF (0e) | $H_c$ (0e) | $J_{rs}$ (0e) | $I_s$[f] ($10^{-2}$ (Gauss) | Gauss · cm$^3$/g) | $J_{rs}/J_s$[g] | TiM Grain Size[h] (μm) | $T_c$[i] (°) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20-1, 15-17, 1B | 136.19 | 2.346 | - 5.3 | - 6 | 0.86 | 70 | 850 | 532 | >800 | 0.124 | 8.0 | 0.55 | | 350 |
| 20-1, 24-26, 2 | 136.30 | 1.009 | - 9.2 | -10 | 1.90 | 14 | 800 | 260 | 408 | 0.090 | 7.0 | 0.46 | | 400 |
| 20-1, 53-55, 4B | 136.64 | 3.51 | - 9.4 | -10.5 | | | 585 | | | | | | | |
| 20-2, 50-52, 5A | 138.37 | 3.15 | | | | | | | | | | | | |
| 20-2, 50-52, 5A | 138.37 | 3.15 | +0.1 | -0.5 | 0.95 | 85 | 590 | 428 | 576 | 0.211 | 10.0 | 0.75 | | 280 |
| 20-2, 87-89, 8 | 138.81 | 1.962 | -6.9 | -5 | 1.29 | 39 | 720 | 352 | 512 | 0.135 | 9.5 | 0.51 | | 340 |
| 20-2, 94-96, 9A | 138.89 | 0.637 | -6.3 | -6 | | | 570 | | | | 10.5 | | | 410 |
| 20-3, 33-35, 4 | 139.94 | 2.67 | -2.4 | -5 | | | 640 | | | | | | | |
| 20-3, 133-135, 16A | 141.12 | 0.985 | -6.4 | -6 | 1.20 | 21 | 540 | 336 | 510 | 0.118 | 10.0 | 0.42 | | 325 |
| 20-4, 71-73, 11A | 142.16 | 2.19 | -2.2 | -1.5 | 1.11 | 51 | 720 | 368 | 520 | 0.148 | 10.0 | 0.53 | 1.5 | 305 |
| 20-4, 117-119, 12F | 142.70 | 3.556 | -0.8 | -2.5 | 1.16 | 79 | 610 | 336 | 412 | 0.202 | 12.0 | 0.60 | | 310 |
| 20-6, 16-18, 2 | 145.05 | 1.893 | -4.8 | -5 | 0.71 | 68 | 880 | 572 | >800 | 0.118 | 7.0 | 0.60 | 2 | 335 |
| 21-1, 4-6, 1 | 145.78 | 1.806 | -4.2 | -7 | 0.94 | 49 | 710 | 404 | 640 | 0.102 | 6.5 | 0.56 | | 350 |
| 21-1, 107-109, 12A | 151.54 | 2.61 | -4.7 | -8.5 | | | 620 | | | | | | | |
| 21-2, 24-26, 2 | 153.60 | 3.79 | -3.8 | -5 | | | 610 | | | | | | 2 | |
| 22-1, 93-96, 11 | 156.68 | 3.78 | -1.9 | -2.5 | | | 760 | | | | | | 1.5 | |
| 22-2, 63-65, 3c | 158.84 | 1.923 | +1.9 | -1 | 1.11 | 44 | 650 | 320 | 432 | 0.198 | 12.0 | 0.59 | | 290 |
| 22-2, 124-126, 7B | 159.93 | 0.570 | -12.7 | -1 | 1.71 | 8 | 200 | 144 | 164 | 0.327 | 33.0 | 0.35 | | 195 |
| 22-2, 134-136, 7D | 160.11 | 10.09 | +5.4 | -4.5 | 3.34 | 77 | 140 | | | 0.372 | 37.0 | 0.36 | | 165 |
| 22-3, 12-14, 1A | 160.61 | 4.075 | -2.6 | -3.5 | 0.87 | 120 | 550 | 344 | 416 | 0.207 | 11.5 | 0.64 | | 260 |
| 22-3, 50-52, 3A | 161.29 | 3.16 | -3.2 | -5 | | | 750 | | | | | | | |
| 22-4, 75-77, 8 | 164.43 | 1.031 | 0 | -4 | 0.99 | 27 | 840 | 384 | 564 | 0.118 | 7.0 | 0.60 | | 310 |
| 23-1, 14-16, 3 | 165.45 | 2.568 | | | | | 140 | | | | 25.1 | | | 365 |
| 23-1, 80-82, 12B | 170.42 | 2.27 | +55.4 | +54 | | | 710 | | | | | | 1.5 | |
| 24-1, 55-57, 9 | 179.32 | 2.435 | +17.2 | +17 | 0.90 | 69 | 770 | 684 | >800 | 0.165 | 8.5 | 0.69 | | 300 |
| 24-1, 94-96, 15A | 183.03 | 2.17 | +17.2 | +16 | | | 685 | | | | | | 1 | |
| 26-1, 7-10, 1 | 200.06 | 1.10 | +20.7 | +22 | | | 880 | | | | | | <1 | |
| 28-1, 10-12, 2 | 214.47 | 2.46 | -10.0 | -6.5 | | | 220 | | | | | | 3 | |
| 30-1, 25-27 | | | | | | | | | | | 20.0 | | | 310 |
| | | | | | | | | | | | | | | 560 |
| 32-1, 69-71, 10 | 242.33 | 2.59 | +45.0 | +43 | | | 470 | | | | | | 2.5 | |
| 32-1, 85-87, 12 | 243.78 | 3.15 | -11.0 | -14 | | | 600 | | | | | | | |

[a]Depth has been calculated by assuming proportional distribution of the recovered core material over the whole respective core length.

[b]Inclination of natural remanent magnetization after partial alternating field demagnetization.

[c]Natural remanent magnetization/magnetization induced by the present earth's magnetic field.

[d]MDF (medium destructive field) is the magnetic field necessary to erase half of the natural remanent magnetization by alternating field demagnetization.

[e]Saturation remanence acquired in a magnetic field of 10,000 oe.

[f]Strong field specific magnetization measured in 1800 oe at room temperature.

[g]$J_s = I_s \times \rho$, where $\rho$ is the density of the rock sample.

[h]Mean grain diameter of the titanomagnetites.

[i]Curie temperature.

**TABLE 2**
**Mean Values With Standard Deviation**

| | Stable Incl. (°) | NRM Intensity ($10^{-3}$ Gauss) | Susceptibility ($10^{-4}$ Gauss/oe) | $I_s$ ($10^{-2}$ Gauss·cm$^3$/g) | Curie Temperature (°) |
|---|---|---|---|---|---|
| Magnetic Unit | | | | | |
| I | +20.8 ±9.3 | 0.86 ±0.50 | | | |
| II | - 69.3 ±6.5 | 1.90 ±1.05 | | | |
| III | - 6.0 ±3.7 | 2.70 ±1.70 | | | |
| IV | +27.2 ±18.0 | 2.11 ±0.58 | | | |
| Lithologic Unit | | | | | |
| 1 | | 0.85 ±0.51 | 1.30 ±0.49 | 12.2 ±4.4 | 308 ±36 |
| 2 | | 1.17 ±0.38 | 1.19 ±0.27 | 13.9 ±3.5 | 274 ±26 |
| 3 | | 2.30 ±1.27 | 4.30 ±5.37 | 35.4 ±13.9 | 239 ±26 |
| 4 | | 2.70 ±1.70 | 2.99 ±4.28 | 12.0 ±7.6 | 300 ±55 |
| 5 | | 2.11 ±0.58 | | 16.8 ±11.7 | 332 ±46 |

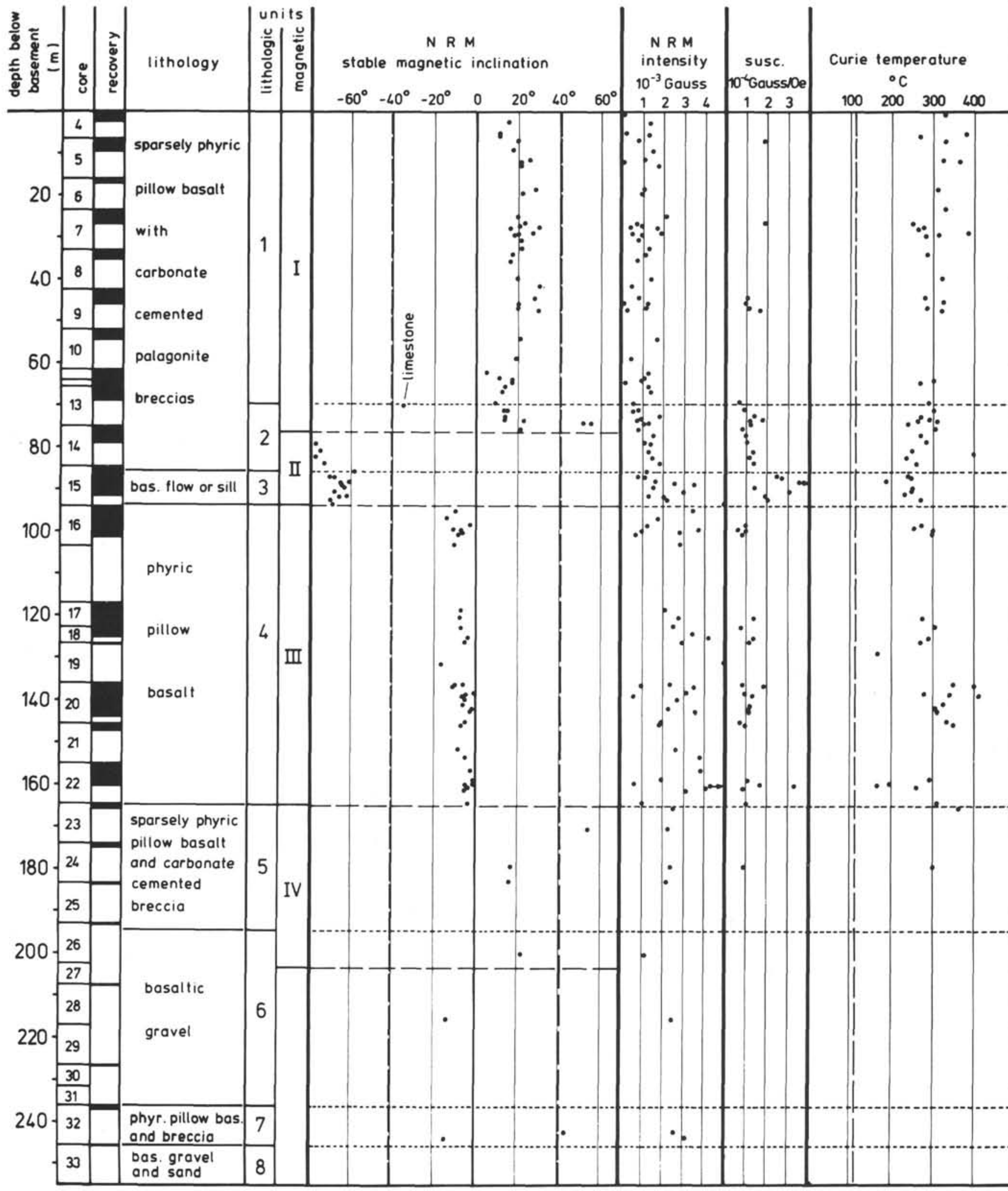


Figure 1. *Downhole plot of stable magnetic inclination, NRM-intensity, susceptibility, and Curie temperature of basalt samples from Hole 396B, Leg 46. The depth of the individual samples has been calculated by assuming proportional distribution of the recovered core material over the whole respective core length. For comparison the theoretical inclination value to be expected at the drill site has been included (dashed vertical lines in the stable magnetic inclination field). The dashed vertical line in the Curie temperature field represents the Curie temperature of the unaltered, primary magnetic mineral component. Note that the boundary of lithologic Units 2 and 3 cuts right through the missle of magnetic Unit II.*

measurements were carried out in air, with an applied magnetic field of 1800 oe).

The ratio of saturation remanent magnetization and saturation magnetization ($J_{rs}/J_s$) were used to estimate the magnetic domain state (single or multidomain) of the ferromagnetic mineral component.

Rock magnetic measurements were complemented by ore microscopic observations in polished section. Magnetic colloid was used to aid in the identification of the magnetic minerals.

**Results**

The results are summarized in Tables 1 and 2 and Figure 1. The dominant ore phase in all investigated samples is titanomagnetite, mostly in skeletal form. Tiny spherules of sulfides are also present in most of the samples, but in much smaller quantities than titanomagnetite. Only the basalt flow or sill (lithologic Unit 3) contains ilmenite, which is present as separate grains.

All titanomagnetite grains show signs of low temperature oxidation (pale color and volume change cracks in larger grains, features similar to those described by Ade-Hall et al., 1976, for Leg 34 basalts); they are probably titanomaghemites. In general, the smaller the titanomagnetite grains, the higher the oxidation state. In extremely altered samples (20-1, 24-26 cm, for example), where titanomagnetite is no longer visible, bright yellow spots show where the oxides were located and the surrounding silicates are stained yellow-brown. In pillow basalts, the titanomagnetite grains are extremely small, from 5$\mu$m down to the limit of visibility. In the center part of the basalt flow or sill (lithologic Unit 3), grain size of the titanomagnetites increases to about 20 $\mu$m.

The ore microscope observations are well supported by the Curie temperature measurements. Curie temperatures between 200° and 400°C are typical for low-temperature oxidized titanomagnetites in oceanic basalts (Johnson and Merrill, 1973; Ozima et al., 1974; Ade-Hall et al., 1976; Bleil and Petersen, 1977). The Curie temperature of the original unaltered titanomagnetite must have been much lower. Comparative measurements on synthetic unoxidized titanomagnetites having a composition corresponding to the average composition of titanomagnetites in tholeiitic basalts (Petersen, 1976), give original Curie temperature of 110°C (Petersen and Eisenach, unpublished results) This value has been included with the measured Curie temperatures in Figure 1 (dashed vertical line). From this comparison it is concluded that none of the samples has retained its original titanomagnetite composition. It is difficult to say when this low temperature alteration of titanomagnetite took place, but there are arguments that most of the process happened relatively shortly after the emplacement of the rock (Honnorez and Petersen, this volume).

The high $J_{rs}J_s$ ratio (saturation remanence/saturation magnetization) of 0.6 for most of the samples suggests single domain particles (Dunlop, 1969); this is in agreement with the optical grain size measurements (see Table 1). According to Soffel (1971), the transition from multidomain to singledomain titanomagnetite particles is close to 1 $\mu$m.

## SUMMARY AND CONCLUSIONS

The remanent magnetization of the investigated samples is carried by fine grains of titanomagnetite. There may also be a very small contribution from sulfides. Titanomagnetite grains have been altered by low temperature oxidation as is typical in deep ocean weathering (halmyrolysis). No sign of high temperature oxidation of titanomagnetites was detected. In contrast to subaerial basalts, high-temperature oxidation of titanomagnetites seems to be rare in ocean floor basalts (Ade-Hall et al., 1976) and may only occur in the center of massive flows (Watkins and Haggerty, 1967; Grommé et al., 1969).

Four magnetic polarity groups or magnetic units, defined by the stable magnetic inclination, can be distinguished in the section from Hole 396B. Within the individual magnetic units the stable magnetic inclination values are remarkably constant. Lithologic and magnetic unit boundaries do not always coincide.

Owing to changes in polarity of natural remanence in the rocks, the intensity of of magnetization integrated over the whole length of the drill hole is much too low to explain the amplitude of the marine magnetic anomaly observed at the drill site. This is similar to the occurrence of different magnetic polarity units within a single drill hole observed in the deep holes of the Atlantic Legs 37 (Hall and Ryall, 1977) and 45 (Johnson, 1977). This is in contrast to what would be expected from the simple block model of the Vine and Matthews sea-floor-spreading hypothesis. It has been argued that these drill holes accidentally hit the boundary region between two neighboring magnetic polarity zones, but this explanation can be excluded for Hole 369B which is precisely in the center of positive marine magnetic anomaly 5.

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## REFERENCES

Ade-Hall, J. M., Fink, L. K., and Johnson, H.P., 1976. Petrography of opaque minerals, Leg 34. *In* Hart, S. R., Yeats, R. S., et al., *Initial Reports of the Deep Sea Drilling Project*, Volume 34: Washington (U.S. Government Printing Office), p. 349-362.

Bleil, U. and Petersen, N., 1977. Magnetic properties of basement rocks, Leg 37, Site 332. *In* Aumento, F. Melson, W. G., et al., *Initial Reports of the Deep Sea Drilling Project*, Volume 37: Washington (U. S. Government Printing Office), p. 446-456.

Dunlop, D. J., 1969. Hysteretic properties of synthetic and natural monodomain grains: *Phil. Mag.*, v. 9, p. 329-338.

Grommé, C. S., Wright, T. L., and Peck, D. L., 1969. Magnetic properties and oxidation of iron-titanium oxide minerals in Alae and Makaopuhi lava lakes, Hawaii: J. Geophys. Res., v. 74, p. 5277-5293.

Hall, J. M. and Ryall, P. J. C., 1977. Paleomagnetism of basement rocks, Leg 37. *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. 489-502.

Johnson, H. P., in press. Paleomagnetism of oceanic crustal rocks, DSDP, Leg 45. *In* Melson, W. G. Rabinowitz, P. D., et al., *Initial Reports of the Deep Sea Drilling Project*, v. 45: Washington (U.S. Government Printing Office).

Johnson, H. P. and Merrill, R. T., 1973. Low temperature oxidation of a titanomagnetite and the implications for paleomagnetism: *J. Geophys. Res.*, v. 78, p. 4938.

Ozima, M., Joshima, M., and Kinoshita, H., 1974. Magnetic properties of submarine basalts and the implications on the structure of the oceanic crust: *J. Geomag. Geoelectr.*, v. 26, p. 335-354.

Petersen, N., 1976. Notes on the variation of magnetization within basalt lava flows and dikes: *Pageoph*, v. 14, p. 177-193.

Soffel, H., 1971. The single domain-multidomain transition in natural intermediate titanomagnetites: *Z. Geophys.*, v. 37, p. 451-470.

Watkins, N. D. and Haggerty, S. E., 1967. Primary oxidation variation and petrogenesis in a single lava: *Contrib. Min. Petrol.*, v. 15, p. 251-271.