PALEOMAGNETIC STRATIGRAPHY OF NORTH PACIFIC GIANT PISTON CORE LL44-GPC3

(30° 20'N, 157° 50'W; MPG-I STUDY AREA)

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July 1977

Prepared for

THE U.S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

UNDER CONTRACT NO. EY-76-S-02-2689.002

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ABSTRACT

Stable detrital remanent magnetization in North Pacific core GPC-3 (30° 19.9' N, 157° 49.9' W) allows the upper 4.5 m to be dated by correlation with the standard geomagnetic time scale. The sedimentation rate for this interval decreases from 2.5 mm/1000 yr. at the surface to 1.1 mm/1000 yr. at 2 m.y. Older sediments lack the consistently stable DRM required for similar dating, but stable DRM paleoinclination measurements at 2250 cm suggest deposition at a paleolatitude between 7.6 and 13.1° N. Based on current reconstructions of the absolute drift of the crust of the Pacific, this implies an age of deposition of 61 - 71 m.y. Such a range is consistent with P. Doyle's biostratigraphic estimates based on ichthyolith assemblages. Sedimentation at GPC-3 appears to have been continuous for the past 70 million years, with the rate increasing from less than 0.3 m/my at the base to 2.5 m/my at the sea floor.

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INTRODUCTION

Giant piston core LL44-GPC3 was collected in the Seabed Disposal Program's North Pacific study area MPG-I during cruise LL-44 of C/V Long Lines. The undisturbed portion of the core is 24.4 m long, and was collected at 30° 19.9' N, 157° 49.4' W in a water depth of 5705 m. The core was extruded on board. Pairs of samples for magnetic studies were taken in 5.79 cc cubic plastic boxes at 5 cm intervals down the core. Samples were refrigerated prior to analysis.

All magnetic measurements were made on a superconducting cryogenic magnetometer in Dr. N.D. Watkins laboratory at the Graduate School of Oceanography, U.R.I. Samples were demagnetized by spinning in a four-axis tumbler in an alternating field (a.f.) of controllable intensity.

NRM RESULTS

The natural remanent magnetization (NRM) of all samples was measured prior to demagnetization. The average of the mean intensities at all depths is 1.34×10^{-4} emu/cc, with a standard deviation of 0.625×10^{-4} emu/cc. The intensities of paired samples agree well; the mean difference is 0.168×10^{-4} emu/cc, with a standard deviation of 0.203×10^{-4} emu/cc, corresponding to 14.7 and 18.5 percent of the means, respectively. This agreement may be fortuitous, inasmuch as samples were taped together in the same orientation prior to analysis, so NRM changes due to extraneous fields during transport and storage would affect paired samples in the same way. Figure 1 shows the NRM intensity (average of paired samples) as a function of depth for GPC-3 sediments.

LL44-GPC3 NRM(EMU/CC) AVERAGED

3

Figure 1. Downcore profile of NRM intensity (average of paired samples) in core GPC-3. Samples taken for chemical analysis and sorption studies are shown at left (asterisks). The 25 samples chosen for stepwise demagnetization are identified at right (small dots) and their NRM values indicated by solid circles on the profile.

Further work on the character of the NRM properties and on their mineralogical implications is in progress and will be reported elsewhere.

DRM RESULTS

One half of the samples from the upper portion (0 - 775 cm) of the core were demagnetized at 75 oersted (oe) and then remeasured ("Set 1" of Fig. 2) to determine their remanent magnetization (DRM). The 75 oe value was chosen on the basis of unpublished work on Vema-32 cores from the MPG-I area by M. Kominz (written communication, 1976), which showed that 50 - 75 oe was the optimum a.f. intensity for "cleaning" the sediments by removing unstable secondary components of magnetization. This first set of GPC-3 samples was run without testing for the optimum a.f. value in order to determine how much of the upper part of the core preserved a stable paleomagnetic stratigraphy. Following this initial test, which showed a stratigraphy consistent with those of Kominz (written communication, 1976) and Kent and Lowrie (1974), 25 samples were selected down the core for detailed stepwise demagnetization. Samples were chosen to provide information on the major NRM (Fig. 1) and lithologic units, as well as on sediments selected for chemical analysis and sorption studies. All the lithologic units described in Hollister (1977) and most of the major NRM intensity peaks were sampled. These samples were demagnetized in 25 oe steps from 0 to 300 oe. Intensity and apparent pole position changes during these steps confirm that 75 oe is a reasonable value for "cleaning" the samples; a.f. intensities over 100 oe lead to erratic changes in magnetic properties. Samples taken above the color change between 390 and 470 cm have relatively stable magnetic inclinations (for example, #83 at 107 cm and #139 at 279 cm in the Brunhes and Matuyama magnetic epochs, respectively, Figs. 3

Figure 2. Normal (black) and reversed (white) polarity intervals of the upper 775cm of GPC-3. Sets 1 and 2 are paired samples taken at the same depths.

Figure 3. (a) Ratio of measured intensity of GPC-3 sample 83 (107 cm depth; Brunhes normal magnetic epoch) after demagnetization to NRM intensity vs. a.f. demagnetization intensity (25 oe steps). (b) Measured inclination as a function of stepwise demagnetization (25 oe steps). (c) Stereographic projection of magnetic vectors of sample after stepwise demagnetization.

and 4).

PRECISION OF THE MAGNETIC MEASUREMENTS

Repeated demagnetization of several samples at the same a.f. intensity provides a measure of the precision of the magnetic measurements. Figure 5 is a stereographic plot of the scatter of magnetic pole positions due to such repetitive measurements for 3 samples at 25 oe. In all cases, the scatter in inclination is less than 5° , but the declination varies over a range of 5 to 32° . The inclination is determined from the Z component of the raw measurement alone, whereas the declination is determined from the X and Y components, both of which were found to be noisier and less stable than the Z component when determined in the cryogenic magnetometer. Inasmuch as declination is meaningless for this core (sections were not oriented relative to one another) the poor precision of the declination measurements is not important for this study. It is clear, however, that scatter such as that in Figures 3c and 4c may be due as much to imprecision in the measurements as to real changes in the magnetic vector.

During the precision tests, the intensity of magnetization of all 3 samples decreased steadily, with a total decrease of 10 - 20% from first to last measurement. Such a decrease points to the presence of a time dependent viscous component which does not completely randomize over the short (1 minute) length of time used for a.f. demagnetizations.

MAGNETIC STRATIGRAPHY AND SEDIMENTATION RATES

The pairs of DRM values determined after 75 oe demagnetization were vector averaged to produce the DRM profiles of Figures 6 and 7. The average

Figure 4. Influence of stepwise a.f. demagnetization (25oe steps) of GPC-3 sample 139 (279cm depth; Matuyama reversed magnetic epoch) on: (a) Intensity of magnetization relative to NRM; (b) Inclination; and (c) Position of magnetic vector (stereographic projection).

REPETITIVE MEASUREMENTS
TO CHECK PRECISION

DRM inclination after demagnetization at 75 oe is shown in Figure 6. Also shown are the depth of each reversal boundary and its correlation (as far as the Matuyama-Gauss boundary) with the time scale of Cox (1969). Sedimentation rates for this upper part of the core decrease smoothly from 2.5mm/1000 yr. at the surface to 1.1mm/1000 yr. at 2 m.y. (Table 1; Fig. 7). The anomalously high rate from 0.69 to 0.8 m.y. probably results from the sample spacing and uncertainties in the ages of the magnetic boundaries. The Matuyama-Gauss magnetic boundary at 430 cm falls within the lithologic transition between 390 and 470 cm. A dramatic decrease in DRM intensity is associated with this lithologic transition (Fig. 6). Below this boundary the correlation between the observed polarity profile and the standard sequence of Cox (1969) breaks down. For an average sedimentation rate of 0.29 m/my for the rest of the core, based on the biostratigraphically dated base (see subsequent section on correlation with biostratigraphy), the observed reversal at 530 cm would correspond to 5.83 m.y. on the extended time scale of McDougall and others (1977), implying that eight reversed sequences are missing in the sampled record (line (A) of Fig. 7; Fig. 8). Alternatively, if it is assumed that the observed record sampled all reversals, correlation with the Cox time scale would require an erratic sedimentation rate with an average of 1.34 m/my for the period 2.24 - 4.48 m.y. (line (B) of Fig. 7). Figure 8 is an expansion of the core from 430 - 570 cm showing the measured polarity of individual sediment samples versus the predicted polarity for sedimentation rates of 0.29 and 0.22 m/my, respectively (see Fig. 9). Neither model fits the observed data well. For rates of 0.22 m/my or less, however, many of the events are not resolvable even with a 5 cm

AVERAGE DRM (75 OE)

Figure 6. Average of DRM values for paired samples after a.f. cleaning at 75oe. Average inclination values of sample pairs are shown, as well as a polarity log and its correlation with the time scale of Cox (1969). Ratio of magnetic intensity after 75oe a.f. treatment to NRM intensity (average of sample pairs) is shown at right.

Table 1. Magnetic stratigraphy of LL44-GPC3

Depth(cm)	Magnetic Boundary	Age(m.y.)*	Sedimentation Rate (mm/1000 yr)
0	-	0.0	2.51
173	Brunhes-Matuyama	0.69	1.85
210	Jaramillo	0.8	
228		0.95	3.00
305	?	-	1.65
337	Gilsa	1.61	1.17
358		1.79	
433	Matuyama-Gauss	2.43	1.17

*From Cox (1969)

Figure 7. Time scale ("age") of Cox (1969) vs. observed magnetic stratigraphy as a function of depth in GPC-3. Slope of line segments gives sedimentation rates. See text for discussion of alternatives (A) and (B).

Figure 8. Expanded portion of GPC-3 showing measured polarity of individual samples (drawn to scale) vs. expected magnetic stratigraphy for two model sedimentation rates. Predicted polarity sequence based on Cox (1969) and McDougall et al. (1977).

sample spacing. Thus, we do not feel that the paleomagnetic stratigraphy of GPC-3 can be extended back beyond 2.43 m.y. in the absence of an independent, high-resolution dating technique.

CORRELATION OF MAGNETIC STRATIGRAPHY WITH BIOSTRATIGRAPHY

Figure 9 is an interpretation of the preliminary ichthyolith biostratigraphy of GPC-3 described in a memo from P. Doyle to C.D. Hollister dated 3/14/77. Tertiary epochs have been converted to absolute ages (Table 2) using the time scale of Berggren and van Couvering (1974). The paleomagnetic stratigraphy down to 430 cm is indicated by the open circles and solid line. The dashed lines are possible alternative age-depth curves for the upper part of the core. Line (1), corresponding to 1.34 m/my, is from Figure 7. It is derived from the assumption that the observed NRM profile is complete and can be correlated with Cox's standard time scale. This curve is not consistent with the biostratigraphic data, nor with geochemical arguments that the sedimentation rate should have been much lower in pre-Pleistocene time when the site did not receive windblown periglacial debris from Asia. For these reasons and because of the low DRM intensities below 4 - 5 m, we do not favor this interpretation.

Curve (2) corresponds to a constant average sedimentation rate of 0.29 m/my for the period from 2 to 70 m.y. ago. This is the simplest age-depth model. It fails to intersect only 2 of the biostratigraphic age estimates, and only misses one of them (37.5 - 53.5 m.y. at 13 m) by more than a couple of million years. Curve (3) is the best fit to the biostratigraphic data. It requires a threefold variation in sedimentation rate; 0.22 m/my from 2.5 - 43 m.y., 0.67 m/my from 43 - 53 m.y., and 0.23 m/my from 53 - 77 m.y. The

Table 2. Ichthyolith biostratigraphy (after P. Doyle, written communication, 1977)

Depth (cm)	Tertiary Epoch	Age Range*
94 - 110	L. Miocene or younger	<10.5
394 - 408	L. Miocene or younger	<10.5
595 - 607	M. or L. (?) Miocene	5 - 14
694 - 706	Miocene	5 - 22.5
798 - 809	Miocene	5 - 22.5
894 - 906	M. Miocene - L. Oligocene	14 - 32
995 - 1006	Miocene - L. Eocene	5 - 32
1103 - 1114	M. Miocene - L. Eocene	14 - 43
1200 - 1215	Oligocene(?) - Eocene(?)	22.5 - 53.5
1288 - 1300	Eocene(?)	37.5 - 53.5
1394 - 1408	Oligocene(?) - Eocene(?)	22.5 - 53.5
1483 - 1498	L.(?) Eocene	37.5 - 43(53.5)
1591 - 1607	E. - M. Eocene	45 - 53.5
1691 - 1708	Eocene - L. Paleocene	37.5 - 57.5
1789 - 1811	Eocene(?)	37.5 - 5.5
1893 - 1912	Eocene - L. Paleocene	37.5 - 57.5
1995 - 2008	Eocene - L. Paleocene	37.5 - 57.5
2103 - 2166	Paleocene(?)	53.5 - 65
2195 - 2207	Paleocene - Cretaceous	>53.5
2290 - 2304	E. Paleocene - Cretaceous	>63
2390 - 2408	E. Paleocene - Cretaceous	>63

*From Berggren and van Couvering (1974)

uncertainties in biostratigraphic ages are too great to allow us to choose between models (2) and (3). We favor (2) for simplicity, but will reassess these alternatives when additional geochemical and magnetic studies are completed. Results to date show no evidence of better preserved DRM in 43 - 53 m.y. samples (using model 3), suggesting that magnetite has not been protected from oxidation to maghemite by faster burial in this interval (Kent and Lowrie, 1974). The principal features of the three curves are summarized in Table 3.

PALEOLATITUDE FROM INCLINATION AND PLATE MOTION

The inclination (I) measured at any spot on the earth is related to the latitude (L) by the formula:

$$\tan I = 2 \cot(90 - L).$$

In theory, if we know the path the core site has taken through time due to plate motion (and hence the paleolatitude as a function of time), and also the inclination of a sample in the core, we can estimate the age of the sample by computing the paleolatitude from the above equation, and then determining when the core site was at that latitude.

This method was applied to a pair of samples at 2250 cm (#900 and #901). Both these samples show reasonable magnetic stability under step-wise demagnetization at levels up to and including 100 oe (Fig. 10). The inclinations and demagnetization behavior are similar for the two samples, which are deep enough in the core to show paleoinclinations significantly shallower than those found today. Table 4 lists the predicted position of the core at 5 m.y. intervals from 75 m.y. ago to the present, and Figure 12 shows its paleolatitude as a function of age. The calculations are based on van Andel and others' (1975) history of the absolute rotation of the Pacific plate.

Table 3. Sedimentation rate models (see also Fig. 9).

Model	Depth Range (cm)	Age Range (m.y.)	Sedimentation Rate (cm/1000 yr)
1	433 - 528	2.43 - 2.80	2.57
	528 - 538	2.80 - 2.90	1.00
	538 - 543	2.90 - 2.94	1.25
	543 - 553	2.94 - 3.06	0.83
	553 - 608	3.06 - 3.32	2.12
	608 - 628	3.32 - 3.70	0.53
	628 - 673	3.70 - 3.92	2.05
	673 - 688	3.92 - 4.05	1.15
	688 - 723	4.05 - 4.25	1.75
	723 - 733	4.25 - 4.38	0.77
	733 - >775	4.38 - 4.50	>3.50
2	433 - 2400	2.43 - 70.0	0.29
3	433 - 1300	2.43 - 43.0	0.21
	1300 - 1970	43.0 - 53.0	0.67
	1970 - 2400	53.0 - 72.0	0.23

Figure 10. Influence of stepwise a.f. demagnetization (25 oe steps) of GPC-3 sample 900 (2250 cm depth) on: (a) Intensity of magnetization relative to NRM; (b) Inclination; and (c) Direction of magnetic vector.

Figure 12. Paleolatitude vs. age plot for the site of GPC-3, based on the absolute plate rotation model of van Andel, Heath and Moore (1975).

Figures 10b and 11b indicate that the paleoinclination lies between 15° and 25° (in contrast to the present inclination of 50°). This range corresponds to a paleolatitude of 7.6° to 13.1° N, which is equivalent to a depositional age of 61 to 71 m.y. (Table 4). Age-depth curves (2) and (3) in Figure 10, based on ichthyolith stratigraphy, both give an age of about 65 m.y. for 2250 cm. The agreement is probably fortuitously good, but the total independence of the methods lends credence to the age.

Following this initial test, all sample pairs between 2155 and 2345 cm were demagnetized at 25, 50 and 75 oe. The interval between 2230 and 2255 cm (Fig. 13) contains samples #900 and #901, as well as five other pairs which appear stable and indicate a similar inclination range. The remaining data do not show a clear pattern, although, as predicted by the plate rotation model, they generally have inclinations markedly lower than the present 50° . Below 2300 cm the scatter may be due to physical disturbance of the core, which is total below 2438 cm. Occasional disruption and faulting of layers are visible as far up the core as 1900 cm, but are minor above 2360 cm (shipboard description).

The sample pairs between 1215 and 1275 cm were also demagnetized at 50 and 75 oe in an attempt to determine an age which might distinguish between models (2) and (3) (Fig. 9). The inclination data are widely scattered, however, (Fig. 14) and show no trend suggestive of an inclination lower than the present 50° . (The inclination predicted by model (2) would be about 37° at a depth of 13 m in the core.) Little or no coherent detrital signal is preserved, rendering these samples unsuitable for paleoinclination studies.

Table 4. Paleopositions of GPC-3 based on poles and rates of notation from van Andel, Heath and Moore (1975).

Age (m.y. B.P.)	Latitude (N)	Longitude (W)	Rotation Rate (°/m.y.)	Rotation Pole
0	30° 20'	157° 49'	0.83	67°N 59°W
5	28° 44'	153° 53'		
10	27° 07'	150° 01'		
15	25° 30'	146° 13'		
20	23° 53'	142° 28'		
25	22° 17'	138° 45'	0.25	67°N 59°W
30	21° 48'	137° 37'		
35	21° 20'	136° 31'		
40	20° 51'	135° 24'		
45	20° 23'	134° 18'		
50	19° 54'	133° 12'	0.80	11°N 84°W
55	16° 57'	133° 20'		
60	13° 59'	133° 21'		
65	11° 02'	133° 13'		
70	8° 05'	132° 57'		
75	5° 08'	132° 33'

Figure 13. DRM inclination of individual GPC-3 samples in the interval from 2150 to 2350 cm after demagnetization at 50oe and 75oe. The six sample pairs indicated by filled circles cluster well and record an interval of stable magnetic inclination of 15° - 25°.

Figure 14. Inclination of individual GPC-3 samples in the interval from 1200 to 1280cm after demagnetization at 50oe (open circles) and 75oe (solid circles). The sample pairs do not cluster about a particular inclination, suggesting that they contain little stable DRM.

CONCLUSIONS

The DRM results for core LL44-GPC3 provide a detailed chronology for the upper 4.5 m, as well as an age at 22.5 m that is consistent with ichthyolith stratigraphy. Taken together, the magnetic and biostratigraphic data indicate that sedimentation has been continuous at the site of GPC-3 for the past 70 million years. The sedimentation rate has increased from less than 0.3 m/my at the base of the core, to 2.5 m/my at the sea floor.

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