29. PALEOMAGNETISM OF SEDIMENTS, LEG 37

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ABSTRACT

A study of 94 semioriented sediment samples from DSDP Sites 332, 333, 334, and 335 is described. Of these samples 91 were obtained from sediment above the first basalt layer of oceanic basement and 3 from sediment intercalated among the basement basalts. Sediment NRM intensity varies widely from 3×10^{-8} to 2×10^{-4} emu/cm^3. Reliable stable inclinations, obtained by alternating-field cleaning of NRMs, were generally evident only where NRM intensity exceeded 1×10^{-6} emu/cm^3. Stable NRM inclinations show that many geomagnetic polarity epochs are represented in the sediment columns. Average sediment stable NRM inclinations are closer to ideal dipole inclinations of $\pm 56°$ than are stable NRM inclinations for the underlying basalts. However, site average values are generally a little shallow, even when corrected for the effect of a northwards offset geomagnetic source dipole. It is thought that differences between measured and expected inclinations are the result of the inclusion of transition inclinations, together with a degree of tectonic rotation of the sediment section at Site 333, rather than absolute plate motion.

INTRODUCTION

The paleomagnetic study of the sediments lying above oceanic volcanic basement has several aims. The sediments carry a magnetic record of value in its own right, which incorporates parts of the history of geomagnetic reversals and, in principle, information that may be used to determine absolute plate motion. In addition, comparison of the paleomagnetic record of the sediments and the underlying basalts may help to understand the many anomalous NRM inclinations recorded by the basalts (Hall and Ryall, this volume).

SAMPLING AND MEASUREMENT

Ninety-four samples were taken from the working half of the main core in the manner used during DSDP Leg 34 (Ade-Hall and Johnson, 1976). Of these, 91 were from sediment lying above the uppermost basement basalts and 3 were from sediments intercalated within the basalts. Sample volumes average 6.7 cm^3, with average mass close to 10 g. A large recovery of basalt precluded the shipboard measurement of sediment samples. The NRM of the latter were measured at Dalhousie University using a Schonstedt DSM 1 digital spinner magnetometer. Where justified, alternating-field partial demagnetization was carried out to isolate stable NRM inclinations.

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RESULTS

A wide range of NRM intensities was encountered, spanning the interval from 3.3×10^{-8} emu/cm^3 to 2.09×10^{-4} emu/cm^3 (Table 1). Reliable paleomagnetic information could not be obtained for 27 of the 35 samples with intensities of less than 1×10^{-6} emu/cm^3. This was partly due to sample magnetic moment approaching specimen holder magnetic moment. While the computer associated with the magnetometer can be programmed to remove the sample holder moment from the measured moment, variations of the sample holder moment with time do not allow confidence in this operation. In addition, relatively low moments are sometimes associated with low magnetic stability, suggesting that strong and weak samples may contain different types as well as amounts of magnetic phases.

Alternating field demagnetization indicated that a wide range of NRM stabilities occurs. Of 57 samples that yielded satisfactory stable NRM inclinations, 41 (72%) showed a difference between NRM and stable inclination of more than 5°. The widespread occurrence of large soft components supports the need for systematic remanence cleaning of sediment NRMs. Stable directions were usually but not always closer to the ideal dipole inclinations ($\pm 56°$) for the sites than were NRM inclinations.

The distribution of satisfactory stable NRM inclinations reflects the distribution of NRM intensities (Tables 1, 2, Figure 1). Thus Holes 332A and 333, with 60% and 70% of samples, respectively, with NRM values of less than 1×10^{-6} emu/cm^3, yielded few stable inclinations. Sites 334 and 335, on the other hand, gave

TABLE 1
Paleomagnetic Properties of Sediments at Leg 37 Sites

Sample (Interval in cm)	Depth[a]	J_o[b]	I_o[c]	STABLI[d]	n[e]	Remarks
Hole 332A						
1-1, 144-146	8.45	1.88	-30.5	-46.6	4	
2-3, 116-118	68.17	0.403	–	–	–	
2-4, 109-111	69.60	0.038	–	–	–	
2-5, 078-080	70.79	0.976	–	–	–	
2-5, 115-117	71.16	0.033	–	–	–	
3-4, 032-034	78.33	0.078	–	–	–	
3-4, 127-129	79.28	0.137	–	–	–	
4-5, 094-096	89.95	209.3	-45.8	-46.0	4	
4-5, 128-130	90.29	62.2	-49.1	-59.5	4	
5-5, 117-119	99.68	0.349	–	–	–	
5-6, 081-083	100.82	0.106	–	–	–	
5-6, 087-089	100.88	0.158	–	–	–	
6-1, 087-089	102.88	1.68	+08.1	-61.8	3	
6-2, 040-042	103.91	2.48	-76.6	-47.9	4	
6-2, 084-086	104.35	3.62	+35.9	+46.5	3	
22-1, 037-040	245.38	6.30	+56.0	+61.6	5	Intercalated in basement
22-1, 090-092	245.91	3.80	+33.0	+34.1	5	
Hole 332B						
6-2, 20-23	286.21	3.55	-42.2	-46.3	4	Intercalated in basement
Hole 333						
1-2, 107-109	1.68	1.27	+27.9	+56.3	4	
1-2, 113-115	1.72	7.65	+45.8	+46.0	2	
1-2, 131-133	2.82	3.01	+55.8	+52.0	5	
2-1, 057-059	146.08	0.049	–	–	–	
2-2, 014-016	147.15	0.058	–	–	–	
2-3, 132-134	149.83	0.170	–	–	–	
2-4, 028-030	150.29	0.045	–	–	–	
2-5, 041-043	151.92	0.140	–	–	–	
2-6, 067-069	153.68	0.065	–	–	–	
3-4, 088-090	169.89	0.056	–	–	–	
3-5, 093-095	171.44	0.073	–	–	–	
3-6, 019-021	172.20	0.063	–	–	–	
4-1, 082-084	184.33	0.350	–	–	–	
4-2, 117-119	186.18	0.500	–	–	–	
4-3, 082-084	187.33	0.473	–	–	–	
4-4, 105-107	189.06	0.324	–	–	–	
4-5, 108-110	190.59	0.263	–	–	–	
5-2, 120-122	195.71	2.88	-01.5	–	–	Very soft NRM, MDF ≈ 10 oe
5-3, 102-104	197.03	0.061	–	–	–	
5-4, 058-060	198.09	0.563	–	–	–	
5-5, 140-142	200.41	1.43	+14.1	–	–	Scattered values, shallow N or N
6-1, 121-123	203.72	1.78	-32.4	-36.2	2	
6-2, 059-061	204.60	3.62	-20.0	-46.6	2	
7-2, 030-032	213.81	10.34	+32.3	+34.0	6	
7-2, 141-143	214.92	3.16	+44.7	+27.6	4	
Hole 333A						
1-1, 135-137	218.36	0.069	–	–	–	
1-1, 145-147	218.46	0.084	–	–	–	
1-2, 037-039	218.88	0.111	–	–	–	
Site 334						
1-2, 106-108	2.57	2.79	-11.1	+17.3	5	
2-1, 092-094	130.93	0.582	+32.0	+64.7	4	
2-2, 096-098	131.97	8.55	+25.5	+42.3	7	
2-3, 120-122	133.71	4.85	+16.1	+38.2	6	
2-4, 117-119	135.18	4.17	-23.1	-03.8	3	Definitely disturbed, omitted from mean
2-5, 009-011	135.60	3.15	+34.2	+17.5	2	
2-5, 055-057	136.06	2.73	+56.1	+49.3	6	
2-5, 109-111	136.60	2.82	-34.0	R	–	Very soft, MDF ≈ 40 taken as -47>I>-55
2-6, 132-134	138.33	3.94	-46.1	-64.6	3	
3-1, 118-120	140.19	3.77	+68.9	+11.0	3	
3-2, 107-109	141.58	10.3	-49.3	-54.8	6	
4-1, 043-045	148.94	26.5	+69.7	+70.8		

TABLE 1 – *Continued*

Sample (Interval in cm)	Depth[a]	J_o[b]	I_o[c]	STABLI[d]	n[e]	Remarks
5-3, 083-085	161.84	7.31	+60.0	+67.6	3	
5-4, 076-078	163.27	27.0	+38.9	+49.4	5	
5-4, 137-139	163.88	8.23	+27.9	+46.0	5	
6-1, 034-036	167.85	28.1	+52.5	+47.8	3	
6-2, 056-058	169.57	14.3	+37.4	+36.1	5	
7-1, 132-134	178.33	7.14	+28.2	+37.0	5	
7-2, 137-140	179.88	5.19	+56.7	+43.3	4	
7-3, 146-148	181.47	2.99	+48.1	+54.2	5	
7-4, 060-062	182.11	10.8	+31.4	+45.3	4	
7-5, 057-059	183.58	17.4	+37.4	+49.2	4	
7-6, 143-145	185.94	25.4	+48.2	+67.8	2	
8-2, 106-108	189.07	8.34	-59.0	-67.1	5	
9-2, 107-109	197.08	2.66	-16.2	-24.3	2	
9-3, 085-087	198.36	1.60	+19.7	-75.4	3	
9-4, 099-101	200.00	1.90	-44.1	-09.8	4	
10-3, 135-137	209.56	2.42	+30.5	+19.4	2	
10-4, 121-123	211.22	1.60	-34.6	-41.9	4	
11-2, 124-126	217.75	9.30	-24.9	-21.8	7	
11-3, 054-056	218.57	1.38	-45.4	-54.9	9	
11-4, 128-130	220.89	5.16	+65.0	+64.9	6	
12-4, 085-07	229.86	5.21	+58.5	+63.6	5	
13-4, 089-091	219.90	2.68	+68.0	+79.2	2	
13-5, 107-109	214.08	3.01	+60.1	–	–	Very soft, MDF ≈ 65, probably N
13-6, 139-141	242.90	0.720	+49.3	–	–	N
13-6, 145-147	242.96	2.81	-34.9	-58.5	3	
14-1, 134-136	244.85	6.95	-37.8	–	–	Very soft, MDF ≈ 30
Site 335						
1-3, 047-049	90.48	1.90	+43.8	–	–	Shallow R or R
1-4, 070-072	92.21	0.103	-57.4	-64.3	3	Very stable, MDF >200
2-2, 056-058	127.07	0.189	–	–	–	
2-5, 137-139	132.38	0.994	+03.1	–	–	Shallow R or R
3-1, 054-056	220.55	3.39	+72.0	+74.3	3	
3-1, 121-123	221.22	1.92	-49.5	-46.7	4	
4-2, 123- 25	317.74	0.174	-41.6	-52.9	2	
4-3, 111-113	319.12	38.2	-62.6	-54.4	5	
5-1, 080-082	448.83	10.9	+42.0	+41.3	6	
5-1, 094-096	448.95	10.4	+34.2	+33.8	2	

[a]Depth subbottom.

[b]NRM intensity before demagnetization $\times 10^6$ emu/cm^3.

[c]NRM inclination before demagnetization (°).

[d]Inclination of stable remanence (°).

[e]Number of values contributing to STABLI.

stable inclinations for almost every sample, including all but one of the few samples with NRM of less than 1 $\times$ 10^{-6} emu/cm^3.

At all sites the profiles of stable NRM with depth show that a number of geomagnetic reversals are recorded in the sediment column (Figure 2). This is to be expected for the young Neogene, when field reversal was a frequent occurrence (Heirtzler et al., 1968). While the episodic nature of basalt eruption (Hall and Ryall, this volume) provides only a fragmentary record of the geomagnetic field, the sediments, which are continuously deposited nanno-foram oozes, probably contain a more complete record of the geomagnetic field.

We have attempted to match the polarity sequences of the sediment sections with the time-geomagnetic polarity zones of Talwani et al. (1971), modified after Blakely (1974) for t >7.3 m.y. The matching of observed and standard profiles is valuable in confirming the sediment ages now rather broadly confined by paleontological work, and in recognizing the changes in sedimentation rate at each site. Presently the density of the paleomagnetic data alone is everywhere insufficient for a unique match with standard profiles. The sediment record at Site 334, where coring was continuous from 130 meters subbottom to basement at 259 meters subbottom, with reliable stable inclinations available for almost every sample, is most promising for a match.

A combination of paleomagnetic polarity and paleontological data has been used by Howe and Miles (this volume) to estimate the age of the Site 334 sediment section. Their best estimate for the age of the basal sediment at this site is 11.6 m.y., which conflicts with the apparent location of the site within crust of anomaly 5 (8.9 to 10.0 m.y.) age. According to the paleontological-paleomagnetic match anomaly 5 time at this site is represented by the sediments of Cores 4 to 7 inclusive, at 148.5 to 186.5 meters subbottom (Figure 2), rather than the basement basalts at 260 meters subbottom. *Regardless of the difficulty in matching ages at*

TABLE 2
Site-Average Sediment Paleomagnetic Properties and Selected Site-Average Basalt Properties for Comparison

Site/Hole	NRM Intensity ($\times 10^6$ emu/cm^3) Arithmetic Av.	Logarithm[c]Av.	Sediment Av. Stable NRM inclination (Basalt Value) (°)	Apparent Paleo-latitude (°N) (Basalt Value)	Apparent Paleolatitude Corrected for Offset Dipole (Basalt Value) (°N)
332A	20.0 ±147[a]	0.74 ±3.29[a]	56.2 ±5.0[a]	36.8 ±5.3	41.1 ±5.8
			(37.7 ±6.0)	(21.1 ±4.4)	(24.0 ±4.7)
332B	–	–	–	–	–
			(27.5 ±3.7)	(14.6 ±2.3)	(17.0 ±2.3)
333 } 333A }	1.38 ±0.46	0.35 ±1.06	42.7 ±3.9	24.8 ±3.0	27.9 ±2.7
			(15.5 ±3.0)	(7.9 ±1.6)	(10.0 ±1.6)
334	7.46 ±3/24	4.83 ±0.42	45.8 ±3.5	27.2 ±2.5	30.6 ±3.0
			(53.1 ±3.1)	(33.7 ±3.0)	(37.7 ±3.2)
335	6.82 ±3.71	1.68 ±2.28	46.4 ±7.6	27.8 ±7.1	31.1 ±7.0
			(-63.5 ±1.1)	(45.1 ±1.4)	(50.4 ±1.5)
All sites	7.32 ±2.37[b]	1.46 ±0.74[b]	47.8 ±2.9[c]	29.2 ±2.6[c]	32.7 ±2.9[c]
			(39.5 ±8.6)	(24.5 ±6.7)	(27.8 ±7.3)

Note: Present Latitude of Sites: 36°N to 37°N – Ideal Dipole Inclination: ±56 to 57°
[a]RMS scatter about average value.
[b]Average for all samples giving unit weight to each sample.
[c]Average for all sites giving unit weight to each site.

this site the high quality of the sediment paleomagnetic data would make it worthwhile to core completely the sediment section when the site is reoccupied to extend penetration of the basement mélange.

Sediment stable NRM inclinations bear on two further problems, the questions of absolute plate motion and the explanation of the many shallow basement stable NRMs at Sites 332 and 333.

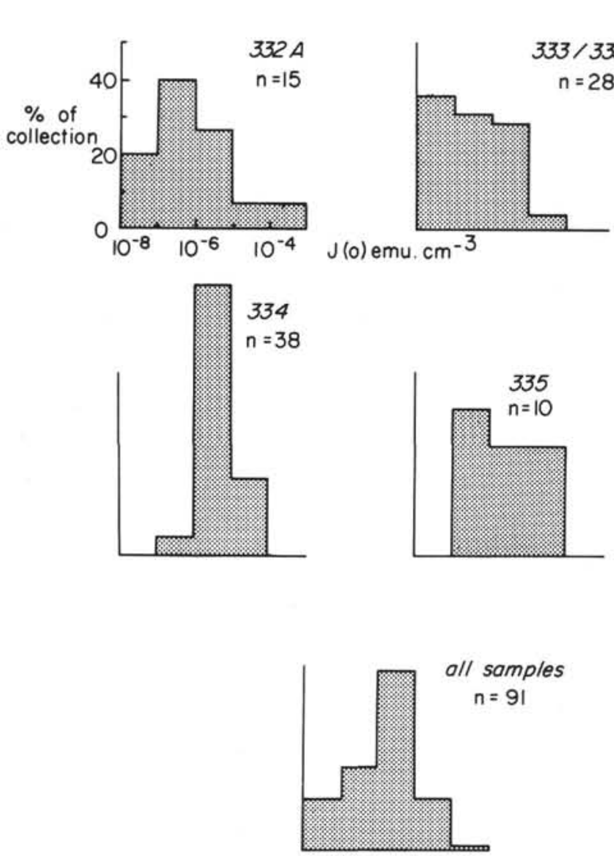

Figure 1. *Histograms showing distributions of sediment NRM intensities by site and for the collection as a whole.*

With average sedimentation rates ranging from 2.9 cm/1000 yr to 6.2 cm/1000 yr, the 2-cm diameter sediment samples each represent on the average paleomagnetic inclinations for from 300 yr to 700 yr. These time intervals comprise at least large fractions of the duration of observed secular variation quasicycles. For this reason the sediment paleomagnetic data will give a very much better representation of the average paleomagnetic field than will the underlying basalts, and with this, a much improved opportunity to obtain a reliable estimate of absolute plate motion. The more representative nature of the sediment stable NRM inclinations is evident in Figure 3, where inclinations are clustered about the ideal dipole inclination, in contrast with the basalt values (Table 2, and Hall and Ryall, this volume). However, the distributions of Figure 3 are generally not simple, with several peaks and tails to low values. The complicated form of the distributions raises the question of which part of the data represents a largely axial dipole field, and should be averaged to obtain absolute plate motion. The shallow values, some of which probably mark transitions of the geomagnetic field, and therefore should be excluded from averages, cannot be excluded from the data of the distributions on present knowledge. This follows since Wilson et al. (1972) have shown that the stable dipole states of geomagnetic field can include some shallow directions. Table 2 gives values of apparent absolute plate motion for all the sites. We note that a simple treatment of the sediment paleomagnetic data gives paleolatitudes that are closer to the present site latitudes than do the underlying basalts, but which are, on the average, still displaced by a large angle for the small times involved. Thus, the average sediment-based site paleolatitude is 29.2 ±2.6°N against an average present site latitude of 36.5°N. If this difference is interpreted in terms of plate motion, 810 km northwards motion over ~5 m.y., at an average rate of 17 cm/yr is implied. This is probably unrealistically high. Wilson (1970, 1971) has shown that during the Neogene the geomagnetic dipole has been offset from the earth's center towards the North Pole

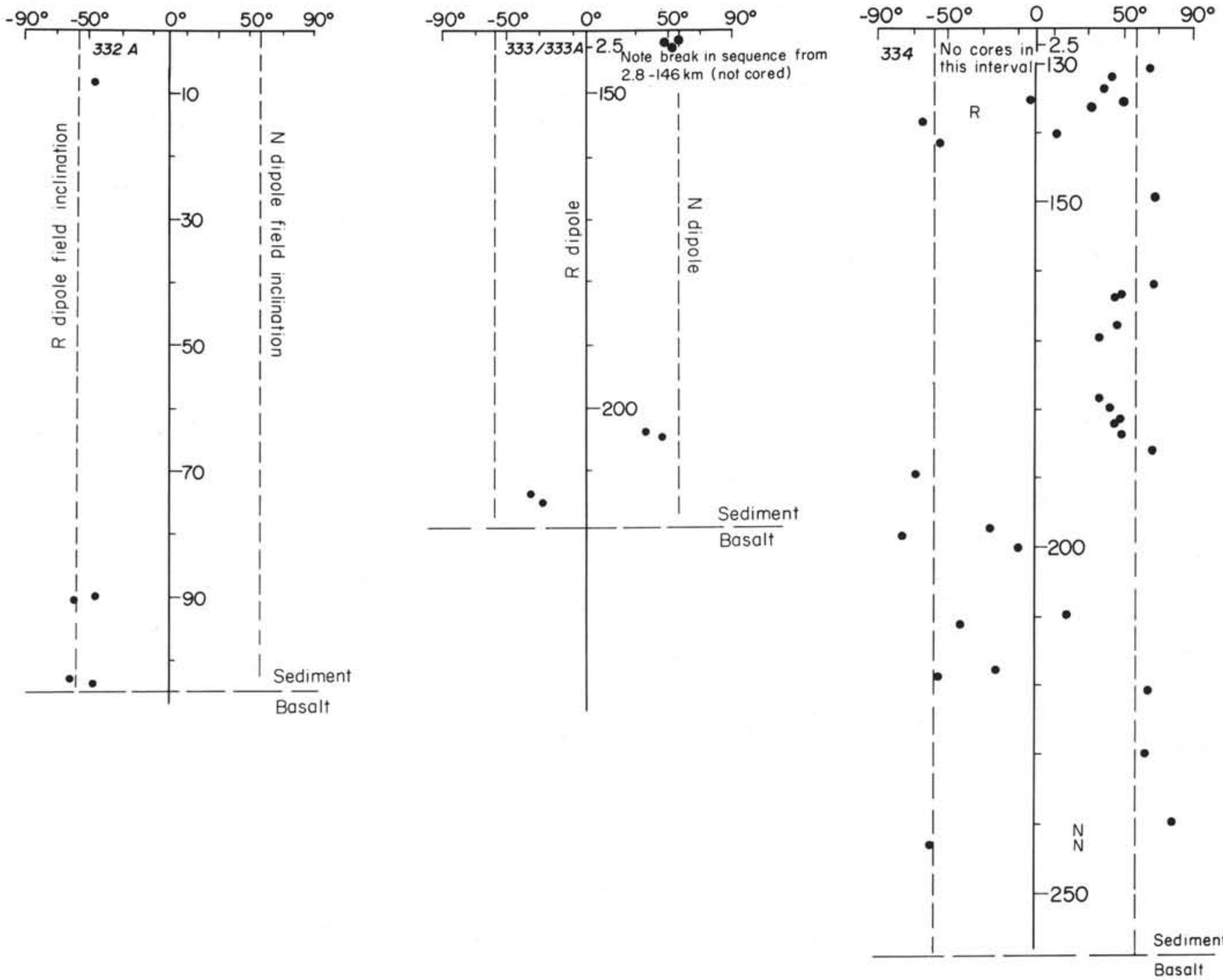

Figure 2. *Distribution with depth of stable sediment NRM inclinations. Site 335 data are not shown as the few cores are very widely spaced.*

by 285 km on the time average. The effect of this offset at the latitude of the Leg 37 sites is that dipole inclinations will average close to 4° shallower than for a corresponding centered axial dipole source. Since our paleomagnetic data are biased in this sense it seems sensible to correct the apparent plate motion for an offset dipole effect. We see from the right-hand column of Table 2 that correction for an offset dipole brings the sediment (and basalt) paleolatitudes closer but not exactly to the present site latitudes. Average apparent absolute plate motion for the sediments is now reduced to 4° of latitude in ~5 m.y., or an average northwards velocity of 9 cm/yr. This figure is still high and unremoved bias from two sources may be expected. One is the presence of a number of geomagnetic transition inclinations, which should be removed from the average inclinations for the reason described above. The other is the possibility that tectonic rotation of one or more sediment columns has biased inclinations away from dipole and towards shallow values. The situation at Site 333 is particularly intriguing in this respect. Here the topmost sediments are magnetized with dipole inclinations. However, four samples from close to the base of the sediment section (2 of N polarity and 2 of R polarity) all have rather shallow inclinations. This would be consistent with a rotation of at least the lowermost 20 meters of sediments by 20° about an east-west axis, the dip now being towards the south.

While this is not a unique interpretation of the shallow sediment NRM inclinations, it would fit conveniently in a model of basement rotation in the same sense of some 40°, which would be responsible for the typically shallow basement stable NRM inclinations at this site. If both sediment and basement shallow inclinations are the result of tectonic rotation it is implied that 20° of rotation occurred before sedimentation started and the remaining 20° while sedimentation was in progress, with rotation terminating before the topmost sediments were deposited. This model, if correct, provides a unique means of following the tectonic history of a basement segment to the present day. It would be desirable to extend sampl-

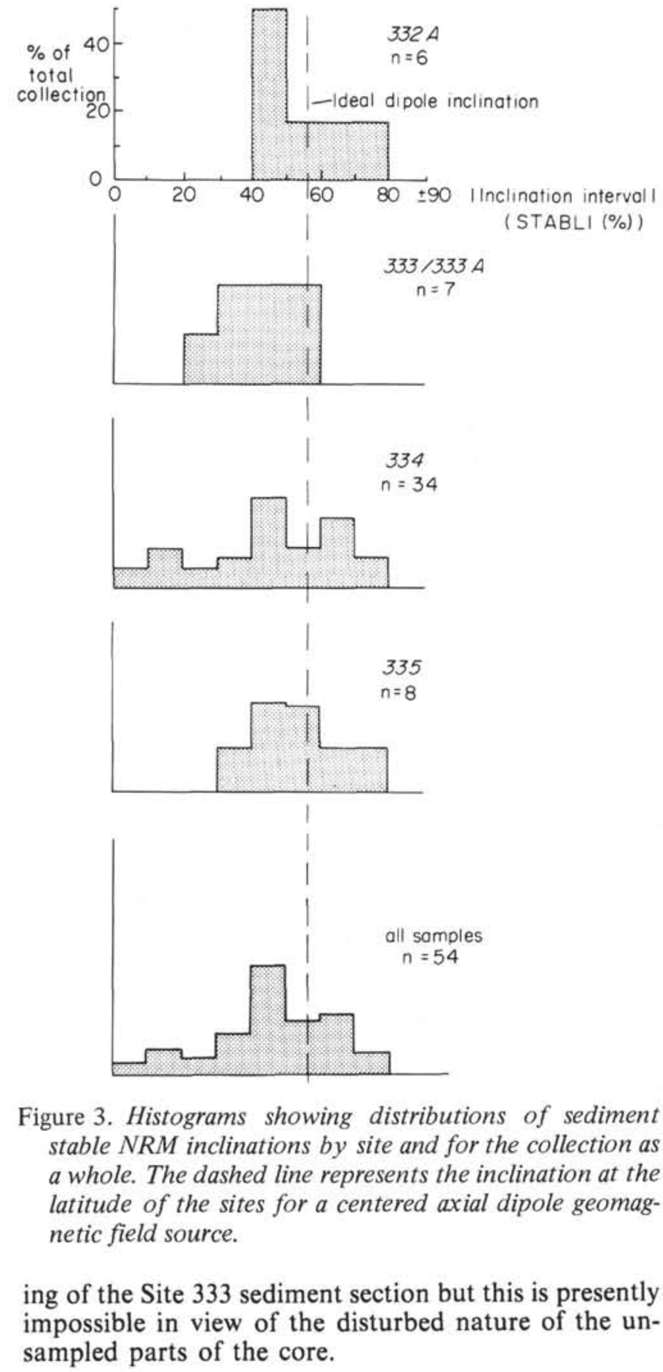

Figure 3. *Histograms showing distributions of sediment stable NRM inclinations by site and for the collection as a whole. The dashed line represents the inclination at the latitude of the sites for a centered axial dipole geomagnetic field source.*

ing of the Site 333 sediment section but this is presently impossible in view of the disturbed nature of the unsampled parts of the core.

SUMMARY AND CONCLUSIONS

The main results of the Leg 37 sediment paleomagnetism study are in the record of time—geomagnetic polarity zoning, the better agreement of sediment stable NRM inclinations than basalt inclinations with ideal dipole field inclinations, and the hint of evidence for tectonic rotation of both sediment and basement sequences at Site 333. The results obtained so far are sufficiently interesting to encourage further sampling of the Leg 37 sediment sections during an IPOD leg.

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