Open-file Report 98-752 (Paleomagnetism of Pleistocene Sediments from Drill Hole OL-92, Owens Lake, California – Reevaluation of Magnetic Excursions Using Anisotropy of Magnetic Susceptibility) contains new anisotropy of magnetic susceptibility (AMS) data for selected samples from drill hole OL-92. The data were obtained from depth intervals that in earlier publications were interpreted to span several paleomagnetic excursions. Preliminary interpretation of the AMS results indicates that the high dispersion of the paleomagnetic directions within these intervals is due to core deformation rather than to rapid, high amplitude changes in the past geomagnetic field.

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Paleomagnetism of Pleistocene Sediments From Drill Hole OL-92, Owens Lake, California—Reevaluation of Magnetic Excursions Using Anisotropy of Magnetic Susceptibility

by

Joseph Rosenbaum[1], Richard Reynolds[1], and Robert Meyer[2]

[1]U.S. Geological Survey, Denver, Colorado 80225

[2]University of California, Santa Barbara, California 93106

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Introduction

Core OL-92 from Owens Lake, California, was obtained using rotary-core drilling into 323 m of lacustrine sediments, estimated to represent the past 800,000 years (Smith and Bischoff, 1997). Because deposition was rapid and was probably nearly continuous during this period, the core potentially contains a detailed record of geomagnetic field behavior for the late Quaternary. Glen and Coe (1997) presented paleomagnetic results that documented the Matuyama/Brunhes (M/B) polarity boundary near the bottom of the core. In addition, they interpreted the results to record detailed field behavior during the M/B transition as well as numerous (about 16) magnetic excursions during the Brunhes Chron. Although these paleomagnetic results were considered tentative, pending efforts to assess the validity of the record, many of the features were interpreted to correlate with magnetic excursions reported in the literature. These correlations were used to corroborate the depth/age model for the OL-92 core that was based on mass accumulation rates (Bischoff and others, 1997b). If the paleomagnetic record from core OL-92 is shown to record excursions, then this record will be important for age control of the sedimentary section as well as for a remarkable archive of geomagnetic field behavior through the Brunhes Chron.

Use of a paleomagnetic record such as that from OL-92 to provide age control requires (1) that the measured characteristic directions of remanent magnetization are accurate enough representations of the ancient geomagnetic field that features of interest (reversals, excursions, or wave-forms due to secular variation) can be discerned, and (2) that features of interest can be unambiguously correlated with corresponding features from well-established, dated paleomagnetic records. Many factors can affect the quality of a sedimentary magnetic record, including sediment grain size, depositional environment, natural and coring-induced deformation, as well as authigenic growth and/or destruction of magnetic minerals. Perhaps the best way to evaluate the quality of sedimentary paleomagnetic records is to compare multiple records from a given sedimentary sequence. This approach is prohibitively expensive for the entire middle and late Quaternary sequence from Owens Lake sampled in OL-92. Nevertheless, there are a number of ways by which one may assess the effects of deformation, the destruction of detrital magnetic minerals, and the formation of authigenic magnetic phases. Here we present the results of several such tests that were performed on a relatively small subset of the samples used by Glen and Coe (1997). These tests include the identification of remanence carrying magnetic minerals and the use of anisotropy of magnetic susceptibility (AMS) to assess the likelihood of significant deformation. The results of these tests cast grave doubt on previous interpretations of the OL-92 magnetic record.

Methods

Samples were obtained from four depth intervals, 119.7 – 115.5 m, 103.6 - 99.6 m, 85.1 - 78.1 m, and 27.4 - 12.9 m. As interpreted by Glen and Coe (1997), these depth intervals span the Pringle Falls, Jamaica-Biwa I, Blake, and Mono Lake excursions, respectively. Twenty-three specimens from the lower part (27.4 - 20.7 m) of the uppermost interval lie outside of an interpreted excursion. Although the paleomagnetic specimens had been placed in plastic boxes, orientation of some samples could not be maintained due to desiccation during the several years following the paleomagnetic investigation of Glen and Coe (1997). After elimination of such specimens, a total of 122 samples were deemed suitable for measurement of isothermal remanent magnetization (IRM) and AMS. The reliability of the paleomagnetic data can be first evaluated in view of detailed core descriptions of the sedimentary structures and features from Smoot (1998).

Combined magnetic and petrographic methods were used to examine the distributions and origins of different magnetic minerals that might elucidate AMS results and assess paleomagnetic reliability. The identification of magnetic particles was primarily done using reflected-light microscopy of polished mounts containing magnetic grains isolated from the bulk sediment in a magnetic separator similar to that described by Petersen and others (1986). Magnetic susceptibility (MS) was used as a measure of all magnetic material but mainly reflects ferrimagnetic minerals such as magnetite or greigite when they are present. MS was determined in a 0.1 milliTesla induction at a frequency of 600 Hz. A measure of the quantity of ferrimagnetic grains sufficiently large (greater than about 30 ηm for magnetite) to carry remanent magnetization is provided by IRM, the magnetization acquired by a sample after exposure to a strong magnetic field (Thompson and Oldfield, 1986). In this study, laboratory induced remanent magnetizations were measured using a 90-Hz spinner magnetometer with a sensitivity of about 10^{-5} Am^{-1}. In some settings, the parameter IRM/MS is a useful indicator for the presence and amount of greigite, an authigenic magnetic iron sulfide mineral (Fe_3S_4), when it coexists with magnetite (Snowball and Thompson, 1990; Reynolds and others, 1994; Roberts, 1995; Roberts and others, 1996). High ratio values suggest the presence of greigite, because it usually occurs in much smaller magnetic grain sizes than detrital Fe-Ti oxides, thus increasing IRM, with little addition to MS. We screened for greigite, because it had been reported in the Owens Lake sediments by S. Lund (personal comm., 1994) and Benson and others (1996). IRM/MS values may not be diagnostic for greigite, however, in some sediments having certain igneous rock fragments that contain fine grained iron oxides.

AMS is defined by differences in length and orientations of the principal axes of the magnetic susceptibility ellipsoid (Collinson, 1983). The AMS of typical detrital magnetic grains is controlled by grain shape, with higher susceptibility corresponding to larger grain dimensions (Dunlop and Ozdemir, 1997). For sediment deposited in quiet water, the longer grain axes tend to be randomly distributed in the horizontal plane thereby producing a sedimentary foliation. In such sediments, AMS defines a planar fabric with the maximum (K1) and intermediate (K2) axes of the ellipsoid nearly equal in magnitude and subhorizontal, and the minimum axis (K3) subvertical. AMS was measured using a KLY-3 Kappa Bridge.

Comparison of AMS data to that expected for a sedimentary fabric provides a means of screening paleomagnetic data derived from sediments. Deformation of the sediment will rotate and/or deform the AMS ellipsoid resulting typically in a deflection of K3 axes toward shallower inclinations. In addition, growth of authigenic magnetic mineral grains, whose orientations are not controlled by gravitational settling, may modify the AMS ellipsoid. A thorough study of AMS data would involve analysis of both the orientations and shapes of the samples' ellipsoids. Such a detailed analysis is not needed here. A simple examination of the orientations of the K3 axes provides an adequate means of screening groups of samples for possible disruption of the expected fabric. At the sample level, not all deformation or alteration will produce significant deflection of the K3 axis. Therefore, a steep K3 axis does not guarantee that the sample possesses an undisturbed paleomagnetic direction. K3 axes that are significantly shallower than those derived from undisturbed sediment, however, provide strong reasons to question the integrity of samples and the associated paleomagnetic data.

Sediment magnetic and AMS data for individual samples are listed in appendix 1.

Sedimentary Structures and Features in Interpreted Excursion Intervals

Detailed core descriptions, completed to a depth 82.65 m, indicate severe deformation and disruption of core OL-92 within the intervals of the interpreted Mono Lake (Smith, 1993; Smoot, 1998) and Blake excursions (Smoot, 1998). Within the interpreted Mono Lake interval, sediment from about 16.6 to 14 m and from 17. 6 to 17.1 m is described as "fluidized"; core was not recovered between about 19 and 20.2 m in the drill hole (Smoot, 1998). Within most of the interpreted Blake interval (80 to 77.2 m and 82.5 to 81 m), the sediment is broken by a dense network of shear planes that offset and disrupt layers (Smoot, 1998).

We did not undertake AMS studies for three other interpreted geomagnetic excursions (Glen and Coe, 1997) in the upper 82 m of the core examined in detail for sedimentary features. Nevertheless, we note that two of these intervals (interpreted as the Laschamps, and Norwegian and Greenland Sea excursions) are spatially associated with documented sediment disruption along with large amounts of missing core, whereas the third interval (interpreted as the Fram Strait excursion) contains growth faults and closely spaced laminations of coarse sand (Smoot, 1998).

Magnetic Mineralogy

Knowledge about the distribution and origins of magnetic minerals is essential for meaningful paleomagnetic and paleoenvironmental interpretations. We examined magnetic minerals from intervals in the interpreted magnetic excursions: three samples from the Mono Lake interval; five from the Blake interval; and two each from the Jamaica-Biwa I and Pringle Falls intervals. The stratigraphic locations of the samples are indicated on the depth plots of IRM/MS (Figure 1).

Magnetic property and petrographic studies of Owens Lake sediment reveal large variations in the types, textures (grain size and shape), and amounts of magnetic minerals (Reynolds, and others, 1998). Detrital iron-titanium oxide minerals and greigite are present. Moreover, nonmagnetic pyrite (FeS_2) is also present in the some intervals, where it commonly replaces detrital magnetite. We also found earlier that, in the interval of the inferred Fram excursion near 65 m depth, the dominant magnetic mineral is very fine-grained iron oxide (< 1 μm) magnetite in large (coarse silt) volcanic rock fragments (Reynolds and others, 1998). These sketchy results provide useful information when viewed in the context of more detailed magnetic and petrographic studies on the 83 to 32-m interval in the core (Reynolds and others, 1998).

Samples from the interpreted Mono Lake interval contain varied magnetic mineral populations. The sample from 14.2 m depth contains dominantly angular, silt-sized, optically homogeneous magnetite, of the type elsewhere inferred to be derived from glacial flour (Reynolds and others , 1998). Other Fe-Ti oxides, such as composite grains of magnetite and ilmenite, are also present. Aggregates of pyrite and greigite are subordinate in abundance. The sample has an IRM/MS value of nearly 4 kA/m (Figure 1). A sample from 15.75 m contains sparse greigite as the dominant magnetic mineral and has an elevated IRM/MS value (17.4 kA/m) that reflects a high content of greigite relative to Fe-Ti oxide minerals. For comparison, IRM/MS values of samples from other parts of the core that contain abundant greigite typically exceed 30 kA/m (Reynolds and others, 1998). The sample from 18.93 m (IRM/MS=7.3 kA/m) mainly contains rare magnetite, magnetic varieties of ilmenite, rock fragments with magnetite, and titanomagnetite altered by dissolution and sulfidization. A sample from 26.12 m depth

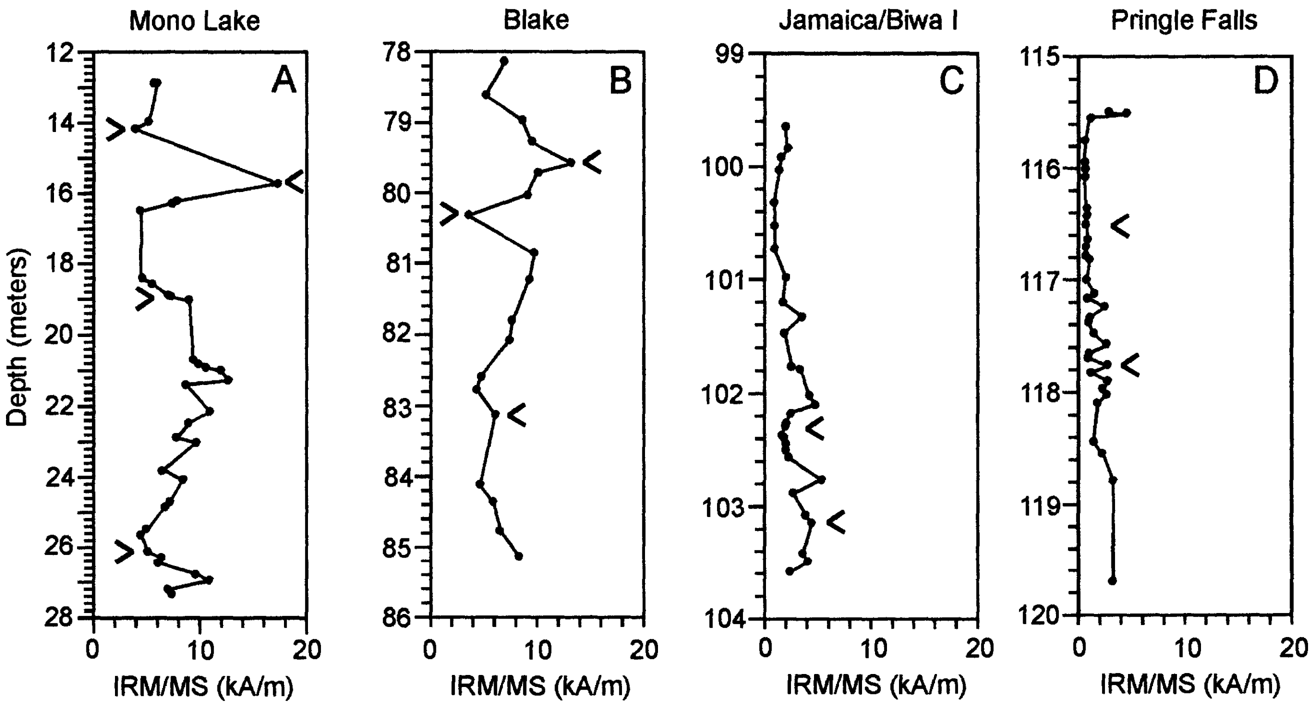

Figure 1. IRM/MS vs. depth plots for the four intervals of inferred geomagnetic excursions. A, Mono Lake excursion from 12.9-20.5 m and an underlying interval outside the excursion; B, Blake excursion; C, Jamaica-Biwa I excursion; D, Pringle Falls excursion. Arrow heads denote samples examined petrographically for magnetic minerals.

(IRM/MS=5.1 kA/m) contains dominantly magnetite in rock fragments and forms of ilmenite, with minor amounts of fine-grained sulfide, perhaps greigite. From these observations and more detailed work deeper in the core (Reynolds and others, 1998), we infer that samples in the disrupted interval, interpreted to represent the Mono Lake excursion, contain dominantly either greigite or detrital Fe-Ti oxides. The same can be inferred for the underlying, nondisrupted interval from 27.4 to 20.2 m, on the basis of IRM/MS ratios that indicate relatively high values from about 23 to 19 m and about 27 to 26.7 m, perhaps reflecting a relatively high content of greigite, and lower values elsewhere (about 26 to 23.8 m; 27.4 to27 m), likely indicating dominant Fe-Ti oxide detrital carriers.

Petrographically examined samples from the interpreted Blake-excursion interval, which were deposited during the penultimate glaciation (Bischoff and others, 1997a; Bischoff and others, 1997b; Smith and others, 1997), contain a nearly uniform magnetic mineral population of angular, silt-sized, optically homogeneous magnetite, interpreted to be derived from glacial-flour (Reynolds and others, 1998). IRM/MS values in this interval range from 3.6 to 13.2 kA/m.

Magnetic minerals in the inferred Jamaica-Biwa I and Pringle Falls excursion intervals are similar and consist mainly of large (sand size) titanomagnetite that has been extensively replaced by pyrite. In a sample from 117.76 m depth, even much of the magnetite within rock fragments has been sulfidized. Samples from this interval have very low IRM/MS ratios, in the range of 0.5-5.4 kA/m.

AMS Results and Discussion

The approach taken here is to define the AMS that occurs in undeformed sediments and in sediments known to be badly deformed as bases for comparison. The best available estimate of the AMS to be expected from a depositional fabric in these sediments is provided by 23 samples in the interval 27.4 – 20.7 m (Figure 2). The dispersion of paleomagnetic directions in this interval is low as compared to intervals interpreted by Glen and Coe (1997) to record excursions, and core disturbance is not recognized from macroscopic inspection (Smoot, 1998). In this interval, K3 inclinations are steep, averaging 84° (Table 1). Only one sample in this interval yielded a K3 axis with inclination less than 70°, and more than 90% of the samples yielded K3 axes with inclinations greater than 80°.

In contrast, samples from between 19.1 and 12.9 m (Figure 2) illustrate the effects of severe core deformation on both the paleomagnetic and AMS data. Highly variable paleomagnetic directions in this interval were interpreted by Glen and Coe (1997) as a record of the Mono Lake excursion, but many of the samples were taken from core that has been described as "fluidized" (Smoot, 1998) or "cuttings" (Smith, 1993). Thus, paleomagnetic directions in this interval cannot be attributed to geomagnetic field behavior. The K3 axes in this interval are also much more highly dispersed than those in the underlying, apparently undisturbed sediments described above. Inclinations of K3 axes in this interval average 66.5°, and 38% are less than 70° (Table 1). Only about half of the samples have K3 inclinations greater than 80°.

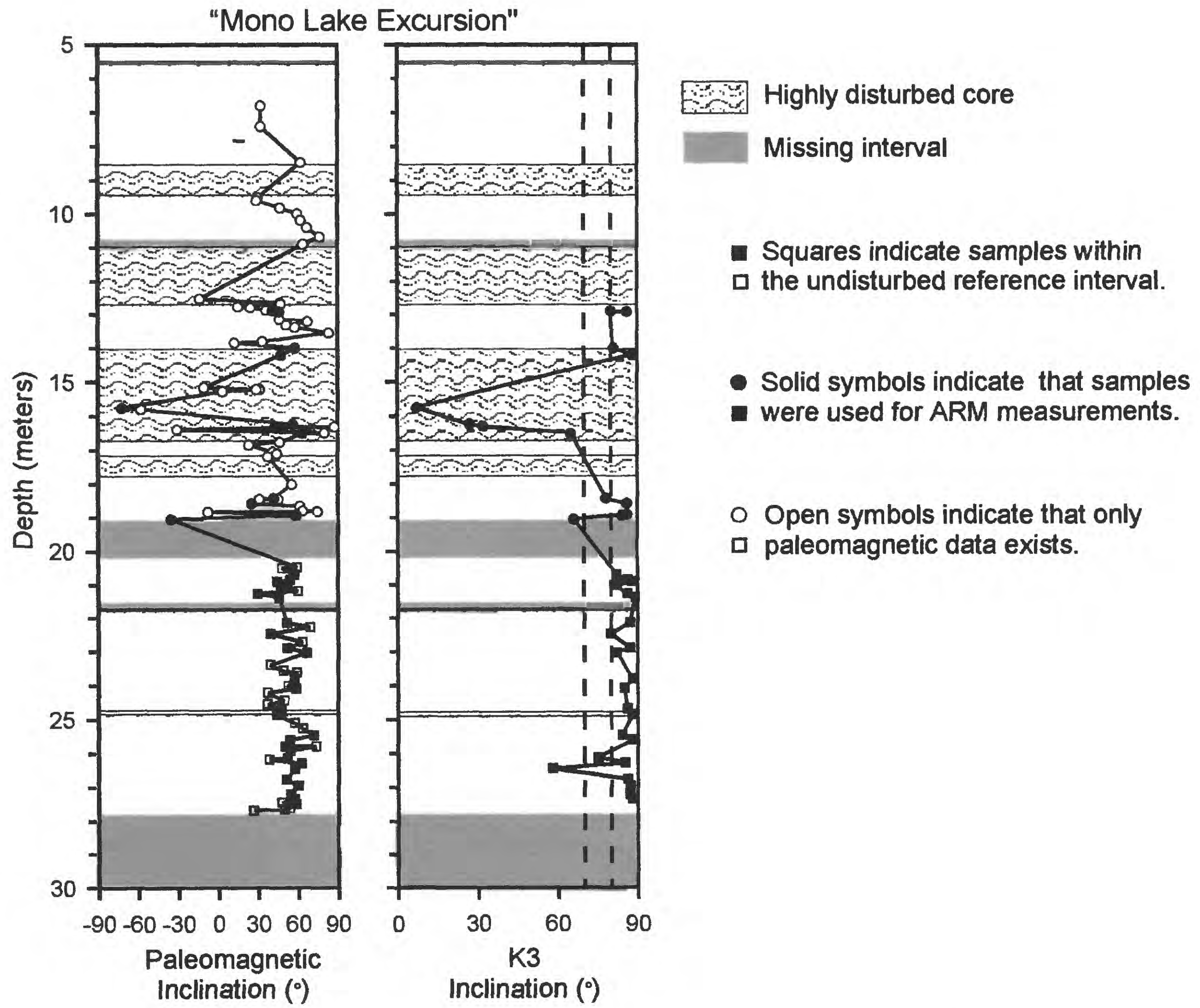

Figure 2. Depth plots of paleomagnetic inclination and inclination of the minimum anisotropy of magnetic susceptibility axis (K3) for the interval interpreted to represent the Mono Lake excursion (Glen and Coe, 1997) and the underlying undeformed reference interval.

TABLE 1. Average Inclinations and Dispersions of Paleomagnetic Vectors and K3 Axes

Depth (m)	* N/N	* Average Paleomagnetic Inclination	Standard Deviation of Paleomagnetic Inclination	Average Inclination of K3	Standard Deviation of Inclination of K3	N>85	N>80	80>N>70	N<70	Interpreted Excursion (Glen and Coe, 1997)
12.9 - 27.3	48/13	35.1/33.2	33.8/39.0	66.5	25.9	4	7	1	5	Mono Lake
20.7-27.3	47/23	52.2/52.7	9.8/8.7	84	6.4	16	21	1	1	none
78.1 - 85.1	28/19	35.1/36.6	23.7/21.8	69	24.3	0	5	8	6	Blake
99.6 - 103.6	42/31	46.2/52.8	23.9/14.4	81	6.1	10	19	9	3	Jamaica/Biwa 1
115.5 - 119.7	45/36	44.2/45.4	15.7/14.9	76	13.7	12	21	10	5	Pringle Falls

*First number for all paleomagnetic samples, second number for AMS samples.

AMS results of sediments from the interval corresponding to the interpreted Blake excursion (85.1 to 78.1 m depth) are similar to those for the "fluidized" interval, 19.1 to 12.9 m of the interpreted Mono Lake excursion (Figure 3 and Table 1). Sediments within the interpreted Blake interval are severely disrupted by shear planes due to core rotation and spin-out (Smoot, 1998). The average inclination of K3 axes is 69°. Only about a quarter of the samples yield K3 axes steeper than 80°, and more than 30% yield K3 axes with inclinations less than 70°.

AMS results from the 103.6 to 99.6 m (interpreted Jamaica/Biwa I) and 119.7 to 115.5 m (interpreted Pringle Falls) depth intervals are intermediate between those expected for an undisturbed depositional fabric and those from a highly deformed zone (Figure 4, Table 1). For the two intervals, average inclinations of K3 are 81° and 76°, respectively. In both intervals, about 60% of K3 axes are steeper than 80°, and 9 to 14 % have inclinations less than 70°.

The magnetic excursions interpreted by Glen and Coe (1997) in core OL-92 are characterized by zones of relatively high dispersion of paleomagnetic directions. If the highly dispersed directions are representative of geomagnetic field behavior, then there is no reason to expect a relation between the dispersion of paleomagnetic data and the orientations of AMS ellipsoids. On the other hand, steeply inclined K3 axes, such as those expected for a sedimentary fabric, will generally be deflected to lower inclinations if the fabric is deformed or rotated. Paleomagnetic vectors and K3 axes are not usually parallel; therefore, deformation or authigenic mineral growth need not produce a one-to-one correspondence between low inclinations of the paleomagnetic vectors and the K3 axes. Nevertheless, groups of samples in which the sedimentary fabric has been disrupted should have more dispersed K3 axes with lower average inclination than samples with an intact depositional fabric.

The AMS results for the five intervals described above have a strong relation to the dispersion of paleomagnetic directions (Table 1 and Figure 5). K3 axes in the 103.6 to 99.6-m depth interval (interpreted to correspond to the Jamaica/Biwa I excursion) have about the same dispersion and only a slightly shallower average inclination than that expected for an undeformed depositional fabric. It should be noted, however, that the AMS samples did not fully sample the paleomagnetic dispersion in this interval (Table 1, Figures 4 and 5). In general, greater dispersion of paleomagnetic directions is associated with greater dispersion of K3 axes and lower average K3 inclinations. This is precisely what is expected if the paleomagnetic dispersion is produced by disruption of the sedimentary fabric.

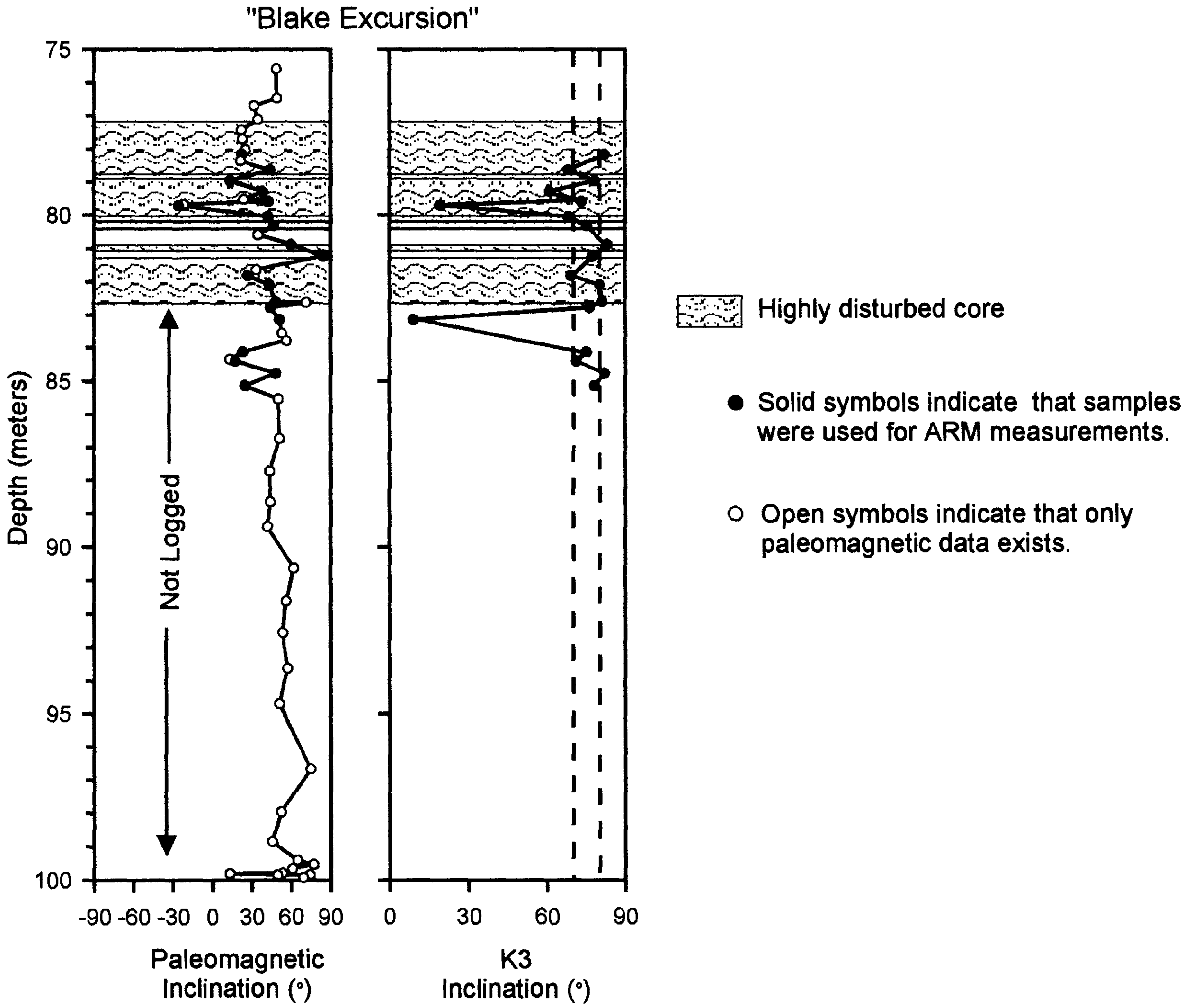

Figure 3. Depth plots of paleomagnetic inclination and inclination of the minimum anisotropy of magnetic susceptibility axis (K3) for the interval interpreted to represent the Blake excursion (Glen and Coe, 1997).

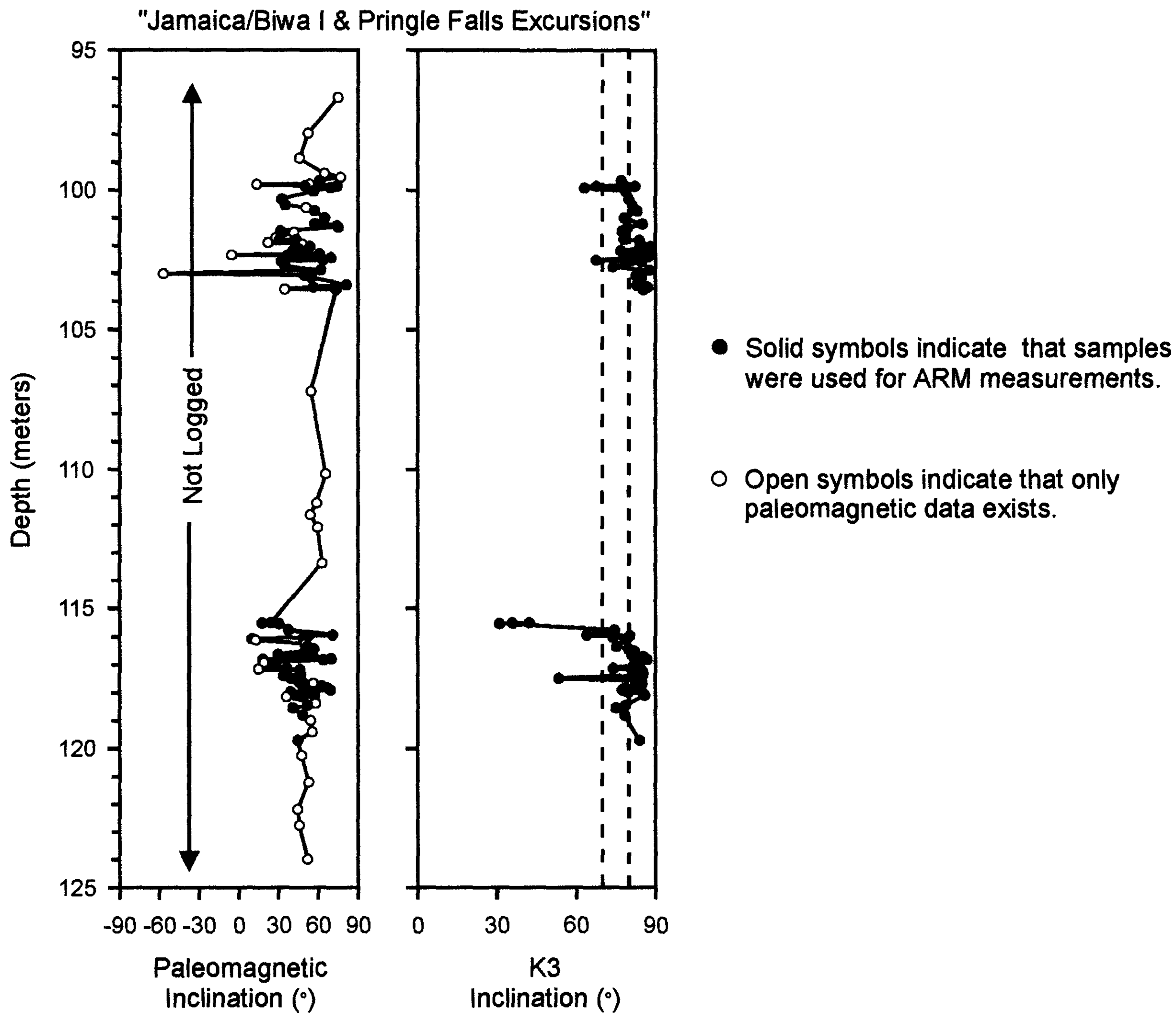

Figure 4. Depth plots of paleomagnetic inclination and inclination of the minimum anisotropy of magnetic susceptibility axis (K3) for the interval interpreted to represent the Jamaica-Biwa I and Pringle Falls excursions (Glen and Coe, 1997).

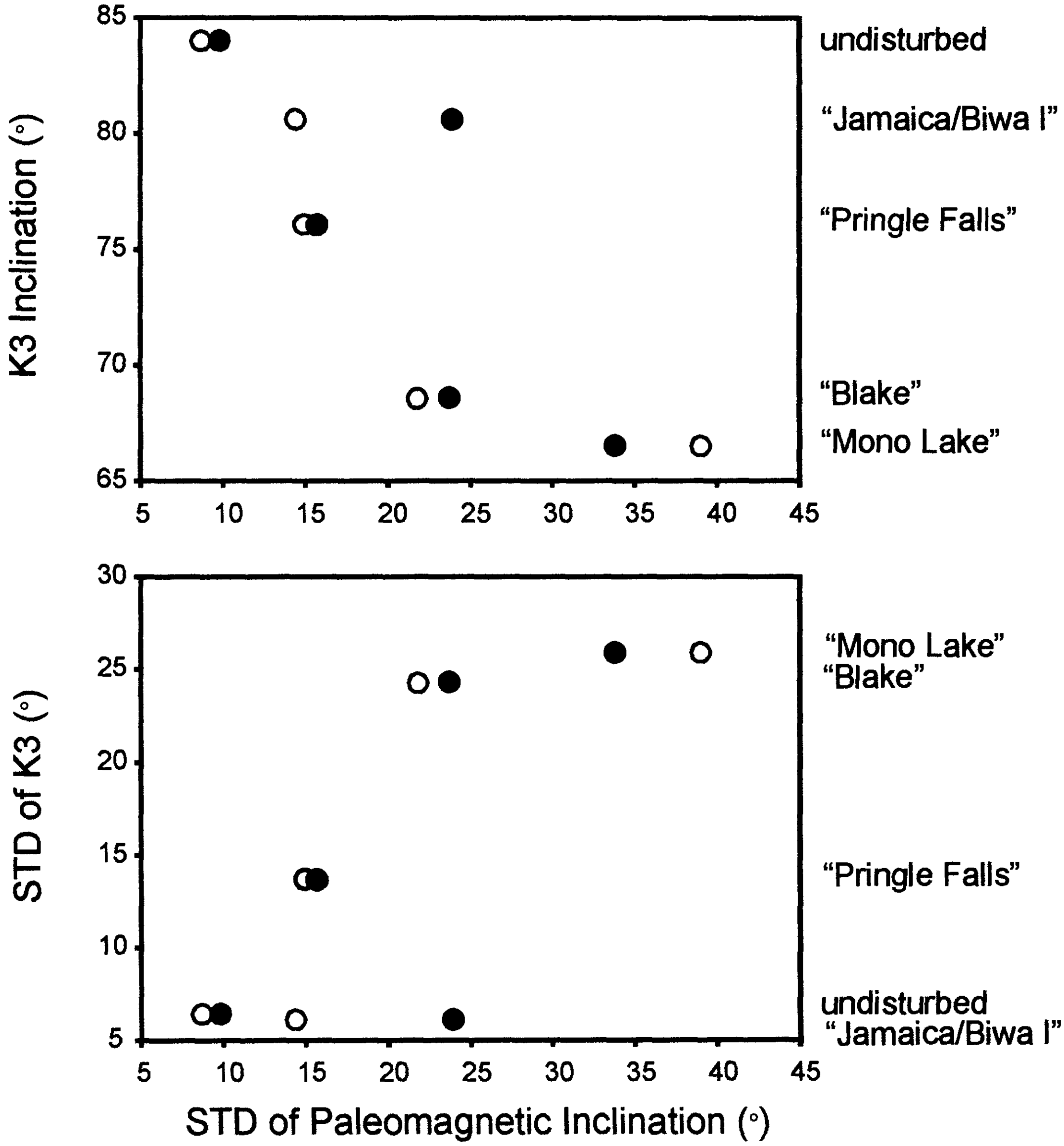

Figure 5. Plots of the standard deviation of paleomagnetic inclination against the K3 inclination and against the standard deviation of K3 inclination. As paleomagnetic inclination dispersion increases, the average inclination of K3 decreases and the dispersion of K3 inclination increases as expected for deformation of a sedimentary fabric. For each interval, standard deviation of paleomagnetic inclinationis was claculated for all samples in interval (closed symbols) and for samples used for AMS measurements (open symbols).

Conclusions

Anisotropy of magnetic susceptibility results are consistent with sediment deformation as the cause of dispersions of paleomagnetic inclinations in four intervals in Owens Lake core OL-92. The paleomagnetic inclinations in these four intervals were previously interpreted to represent geomagnetic field excursions (Glen and Coe 1997). Two of these intervals, correlated with the Mono Lake and Blake excursions, are characterized by visible core deformation (Smoot, 1998). The other two, stratigraphically deeper intervals, have not been examined in detail for sedimentary features and structures. There is no evidence to associate any of the low inclination-angle paleomagnetic directions in the examined core, which were used to infer excursions, with geomagnetic field behavior. Given the evidence that the interpreted excursions in the studied intervals are the result of core deformation, other interpreted excursions must be considered highly suspect.

Remanent magnetization of the Owens Lake sediments is carried by many different magnetic minerals of different origins. At this point, though, we lack sufficient data to assess systematically the possible relations among magnetic mineral types, associated textures, and AMS results. To our knowledge, such an analysis has not been done for any sedimentary setting, and it remains a potentially rewarding exercise. It is likely that different textural properties arising from different magnetic mineral populations would affect AMS parameters in sediments. For example, we expect that small, strongly elongate and angular homogenous magnetite derived from Sierran granites via glacial erosion would differ in AMS properties from large, rounded titanomagnetite from volcanic sources, and perhaps also from magnetic varieties in the ilmenite-hematite solid-solution mineral series that tend to dominate where sulfidization removes more easily altered magnetite. Diagenetic products, such as greigite formation and preferential pyrite replacement of detrital magnetite, may further impart particular AMS characteristics. At the very least, such differences in magnetic mineralogy should be considered for paleomagnetic and paleoenvironmental interpretations of the Owens Lake core.

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APPENDIX 1

Table explanation:

Depth interval 12.9-20.49 m corresponds to interpreted Mono Lake excursion (Glen and Coe, 1997); interval 20.7-27.4 m lies below the zone containing the interpreted Mono Lake excursion; interval 78.1-85.1 m corresponds to interpreted the Blake excursion (Glen and Coe, 1997); interval 99.6-103.6 m corresponds to the interpreted Jamaica-Biwa I excursion (Glen and Coe, 1997); and interval 115.5-119.7 corresponds to the interpreted Pringle Falls excursion (Glen and Coe, 1997). Sample number and paleomagnetic inclination from Glen and others (1993). SIRM, saturation remanent magnetization. K1, maximum axis of AMS ellipsoid. K3, minimum axis of AMS ellipsoid. L, K1/K2, magnetic lineation. F, K2/K3, magnetic foliation, where K2 is the intermediate axis of AMS ellipsoid. P, K1/K3, degree of anisotropy. P', another measure of degree of anisotropy (see Hrouda, 1982). T and Q are different measures of the shape of the susceptibility ellipsoid (see Hrouda, 1982).

Sample	Depth (meters)	Paleomagnetic Inclination (degrees)	Mass (g)	Magnetic Susceptibility (m3/kg)	SIRM (Am^2/kg)	SIRM/MS (A/m)	L	F	P	P'	T	Q	K1 Declination (degrees)	K1 Inclination (degrees)	K3 Declination (degrees)	K3 Inclination (degrees)
	6.80	32.2														
	7.40	32.3														
	8.47	62.2														
	9.50	29.6														
	9.59	28.9														
	9.81	46.8														
	9.99	59.7														
	10.18	62.1														
	10.40	66.8														
	10.67	76.4														
	10.89	63.9														
	12.52	-13.6														
	12.65	46.9														
	12.67	47.3														
	12.76	15.1														
	12.79	24.5														
	12.87	36.0														
F46	12.89	41.0	5.966	7.34E-08	4.24E-04	5774	1.003	1.017	1.020	1.022	0.706	0.2	269.7	9.7	108.1	79.8
F47	12.91	45.9	6.100	7.44E-08	4.54E-04	6107	1.002	1.022	1.023	1.026	0.854	0.1	351.9	4.0	155.6	85.8
	13.14	46.1														
	13.21	67.2														
	13.28	57.5														
	13.31	51.3														
	13.38	57.9														
	13.54	83.4														
	13.80	33.4														
	13.84	12.5														
F55	13.99	57.9	6.262	7.74E-08	4.08E-04	5271	1.007	1.027	1.034	1.036	0.595	0.2	356.0	2.2	99.3	80.5
F56	14.20	47.4	6.443	3.39E-07	1.36E-03	3998	1.028	1.099	1.130	1.136	0.548	0.3	235.0	0.3	132.6	88.4
	15.16	-10.5														
	15.21	28.8														
	15.21	31.3														
	15.27	3.5														
F43	15.75	-72.0	6.835	5.31E-08	9.25E-04	17411	1.003	1.010	1.013	1.014	0.560	0.2	202.9	27.9	109.0	7.3
	15.79	-57.6														
F32	16.23	56.4	2.404	3.54E-08	2.81E-04	7922	1.001	1.028	1.030	1.034	0.902	0.1	350.8	14.1	88.1	26.6
F31	16.29	43.3	3.732	5.12E-08	3.78E-04	7394	1.005	1.025	1.030	1.033	0.686	0.2	328.3	50.6	189.6	31.7
	16.31	87.3														
	16.39	-30.7														
	16.48	80.0														
F35	16.51	63.5	4.931	8.91E-08	4.00E-04	4488	1.009	1.010	1.019	1.019	0.058	0.6	7.7	22.2	157.1	64.6

Sample	Depth (meters)	Paleomagnetic Inclination (degrees)	Mass (g)	Magnetic Susceptibility (m3/kg)	SIRM (Am^2/kg)	SIRM/MS (A/m)	L	F	P	P'	T	Q	K1 Declination (degrees)	K1 Inclination (degrees)	K3 Declination (degrees)	K3 Inclination (degrees)
	16.76	46.3														
	16.84	22.9														
	17.05	41.1														
	17.10	44.2														
	17.19	37.7														
	18.00	55.2														
	18.42	41.2														
F22A	18.42	41.9	4.731	7.84E-08	3.63E-04	4622	1.008	1.108	1.117	1.131	0.848	0.1	182.2	8.3	50.1	77.7
	18.44	45.3														
	18.44	31.1														
F24	18.57	25.1	4.281	6.31E-08	3.52E-04	5573	1.002	1.068	1.070	1.080	0.952	0.0	95.7	1.2	349.3	85.8
	18.65	61.5														
	18.79	63.5														
	18.81	74.6														
	18.82	-7.7														
F28	18.90	58.4	3.669	4.13E-08	2.90E-04	7029	1.008	1.044	1.052	1.056	0.674	0.2	146.6	4.3	326.2	85.7
F29	18.93	58.4	3.852	4.13E-08	3.04E-04	7356	1.005	1.040	1.045	1.050	0.767	0.1	205.3	5.8	4.9	83.8
F30	19.04	-35.4	2.808	2.66E-08	2.40E-04	9021	1.009	1.014	1.023	1.023	0.198	0.5	182.7	21.9	338.7	66.2
	20.47	59.1														
	20.49	47.7														
F15	20.70	57.3	3.399	2.30E-08	2.17E-04	9412	1.008	1.075	1.084	1.093	0.798	0.1	31.6	7.8	191.2	81.7
F16	20.84	53.8	2.984	1.81E-08	1.78E-04	9874	1.016	1.055	1.072	1.075	0.554	0.3	218.8	1.2	110.5	86.1
F17	20.90	44.3	3.062	1.85E-08	1.97E-04	10632	1.004	1.054	1.058	1.065	0.865	0.1	154.8	1.5	11.9	88.1
F18	21.01	47.5	3.122	1.49E-08	1.79E-04	12001	1.018	1.047	1.066	1.068	0.443	0.3	108.7	7.5	264.8	81.8
	21.02	51.5														
	21.17	60.0														
F20	21.26	29.7	2.945	1.66E-08	2.12E-04	12771	1.008	1.055	1.063	1.069	0.740	0.1	190.3	4.2	2.5	85.8
F21	21.38	45.9	3.639	2.80E-08	2.45E-04	8737	1.004	1.045	1.050	1.055	0.823	0.1	220.3	1.4	18.5	88.5
E53	22.14	51.5	3.236	1.86E-08	2.05E-04	11037	1.014	1.060	1.075	1.080	0.605	0.2	13.5	2.7	224.7	86.9
	22.27	68.8														
E55	22.47	39.3	2.982	2.05E-08	1.84E-04	8965	1.011	1.046	1.058	1.061	0.595	0.2	14.8	5.1	255.8	79.5
	22.71	63.2														
E57	22.89	51.6	3.472	3.37E-08	2.64E-04	7822	1.006	1.044	1.050	1.055	0.769	0.1	350.9	0.1	258.9	87.3
E58	23.03	66.5	3.559	2.98E-08	2.88E-04	9663	1.008	1.053	1.061	1.066	0.740	0.1	171.8	0.9	268.2	81.6
	23.39	39.0														
	23.56	48.6														
	23.61	58.9														
E39	23.81	57.5	3.854	3.64E-08	2.39E-04	6573	1.003	1.053	1.056	1.064	0.883	0.1	279.9	0.5	174.6	88.3
	23.99	52.4														
E41	24.08	57.9	3.957	3.70E-08	3.13E-04	8447	1.007	1.050	1.057	1.062	0.751	0.1	146.7	3.2	277.8	85.1
	24.21	36.9														
	24.43	49.5														

Sample	Depth (meters)	Paleomagnetic Inclination (degrees)	Mass (g)	Magnetic Susceptibility (m3/kg)	SIRM (Am^2/kg)	SIRM/MS (A/m)	L	F	P	P'	T	Q	K1 Declination (degrees)	K1 Inclination (degrees)	K3 Declination (degrees)	K3 Inclination (degrees)
	24.54	37.1														
E44	24.69	47.5	4.360	5.60E-08	4.05E-04	7244	1.003	1.050	1.053	1.059	0.899	0.1	232.1	3.6	30.9	86.1
E45	24.85	43.8	4.113	4.43E-08	2.96E-04	6692	1.009	1.056	1.065	1.071	0.731	0.1	344.4	1.7	204.9	87.7
	25.09	57.1														
	25.25	63.0														
E48	25.46	71.4	4.411	4.60E-08	2.32E-04	5056	1.010	1.050	1.060	1.065	0.669	0.2	347.4	5.5	151.3	84.3
E49	25.60	53.4	5.081	5.71E-08	2.53E-04	4436	1.004	1.047	1.051	1.057	0.844	0.1	99.3	1.5	326.2	87.7
	25.78	50.0														
	25.78	73.4														
	25.92	53.8														
E52	26.12	51.8	5.877	9.08E-08	4.72E-04	5202	1.030	1.053	1.085	1.086	0.268	0.5	227.3	13.2	17.5	74.9
	26.17	38.1														
F1	26.28	62.2	4.424	4.02E-08	2.63E-04	6545	1.010	1.056	1.066	1.071	0.701	0.2	130.9	0.9	31.2	84.6
F2	26.44	57.1	4.176	5.39E-08	3.25E-04	6034	1.041	1.092	1.137	1.140	0.369	0.4	221.8	0.1	311.9	58.0
F3	26.75	50.8	4.515	4.12E-08	4.01E-04	9727	1.028	1.043	1.072	1.073	0.211	0.5	15.8	3.0	157.1	86.1
F4	26.94	59.9	4.103	4.25E-08	4.68E-04	11014	1.009	1.054	1.064	1.069	0.704	0.2	175.8	2.0	40.1	87.3
F5	27.20	54.3	4.151	5.14E-08	3.63E-04	7056	1.006	1.049	1.055	1.061	0.787	0.1	350.3	1.0	99.9	87.0
F6	27.34	56.9	4.665	5.18E-08	3.85E-04	7421	1.010	1.101	1.111	1.124	0.821	0.1	5.3	0.5	262.1	87.8
	27.44	47.6														
	27.46	57.8														
	27.60	53.3														
	27.64	49.3														
	27.67	26.3														
	75.58	48.6														
	76.46	49.2														
	76.69	31.7														
	77.09	34.8														
	77.42	22.2														
	77.69	22.9														
	78.02	25.3														
C30	78.15	22.5	6.636	8.45E-07	5.91E-03	6992	1.026	1.107	1.135	1.144	0.600	0.2	116.3	3.2	228.4	81.6
	78.35	21.6														
C31	78.62	44.0	6.843	3.48E-07	1.81E-03	5217	1.007	1.133	1.142	1.161	0.889	0.1	260.6	20.9	59.4	67.8
C32	78.96	13.4	8.010	3.94E-07	3.40E-03	8628	1.022	1.100	1.125	1.133	0.624	0.2	339.7	2.6	237.4	78.1
C33	79.28	38.3	8.028	5.26E-07	5.00E-03	9508	1.038	1.069	1.110	1.111	0.286	0.5	253.9	12.4	140.2	61.2
	79.52	24.1														
C34	79.58	42.7	7.626	5.21E-07	6.90E-03	13240	1.017	1.124	1.144	1.158	0.743	0.1	175.5	9.5	51.9	73.1
	79.67	-21.8														
C35	79.71	-25.7	8.364	4.74E-07	4.72E-03	9963	1.036	1.066	1.104	1.106	0.282	0.5	69.5	4.6	161.1	18.7
C36	80.04	42.4	7.889	9.20E-07	8.33E-03	9054	1.028	1.088	1.118	1.123	0.511	0.3	280.2	13.4	154.9	67.5
C37	80.32	46.8	8.057	2.89E-07	1.04E-03	3592	1.041	1.054	1.097	1.097	0.137	0.6	208.2	1.0	114.3	75.1

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	80.58	35.0														
C38	80.87	59.9	8.073	6.79E-07	6.62E-03	9741	1.020	1.026	1.047	1.047	0.128	0.6	220.4	6.7	39.5	83.3
C39	81.23	84.2	7.538	6.54E-07	6.03E-03	9219	1.004	1.104	1.108	1.124	0.929	0.0	277.9	3.4	23.0	77.0
	81.63	33.5														
C40	81.81	26.8	8.520	1.64E-06	1.26E-02	7663	1.034	1.188	1.228	1.247	0.674	0.2	155.8	12.0	33.0	68.6
C41	82.08	43.3	7.311	4.87E-07	3.59E-03	7360	1.006	1.088	1.094	1.106	0.866	0.1	121.8	6.5	354.0	79.5
C42	82.59	48.0	7.204	5.00E-07	2.36E-03	4718	1.011	1.107	1.119	1.132	0.798	0.1	49.2	6.9	270.0	80.9
	82.61	71.2														
C43	82.77	44.2	8.134	4.02E-07	1.76E-03	4362	1.007	1.073	1.080	1.089	0.830	0.1	357.8	13.5	190.4	76.2
C44	83.13	51.0	7.893	4.90E-07	3.01E-03	6136	1.028	1.055	1.085	1.086	0.314	0.4	71.9	12.6	339.9	8.8
	83.54	52.8														
	83.78	56.5														
C46	84.12	23.2	7.403	4.74E-07	2.23E-03	4701	1.011	1.109	1.121	1.134	0.809	0.1	65.4	1.6	161.2	74.9
	84.35	13.3														
C47	84.40	17.5	7.524	5.20E-07	3.06E-03	5892	1.013	1.113	1.128	1.141	0.789	0.1	142.7	13.6	277.6	71.1
C48	84.77	48.3	7.374	6.36E-07	4.19E-03	6584	1.003	1.178	1.182	1.211	0.966	0.0	162.1	7.9	338.0	82.1
C49	85.13	24.9	7.088	5.35E-07	4.47E-03	8357	1.014	1.165	1.181	1.203	0.838	0.1	289.6	2.1	29.3	77.7
	85.53	50.2														
	86.72	51.0														
	87.71	43.7														
	88.64	44.1														
	89.38	42.0														
	90.62	62.0														
	91.60	56.0														
	92.55	53.5														
	93.61	57.2														
	94.68	51.0														
	96.67	74.8														
	97.95	52.3														
	98.85	45.7														
	99.40	64.6														
	99.53	76.8														
	99.65	60.8														
	99.78	53.3														
	99.80	13.3														
	99.84	49.5														
	99.84	74.1														
	99.92	69.2														
	96.67	74.8														
	97.95	52.3														
	98.85	45.7														

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	99.40	64.6														
	99.53	76.8														
D3	99.65	60.8	5.345	6.88E-08	1.42E-04	2070	1.001	1.023	1.024	1.027	0.917	0.0	84.2	2.3	344.4	77.0
	99.78	53.3														
	99.80	13.3														
D5A	99.84	49.5	6.340	7.31E-08	1.54E-04	2111	1.003	1.022	1.025	1.027	0.722	0.2	273.9	6.9	65.7	82.2
D5B	99.84	74.1	6.340	7.17E-08	1.60E-04	2230	1.002	1.023	1.026	1.028	0.821	0.1	232.5	22.1	40.3	67.5
D6	99.92	69.2	6.355	7.36E-08	1.14E-04	1542	1.003	1.016	1.019	1.020	0.700	0.2	188.1	27.0	14.2	62.9
D7	100.03	56.3	6.797	7.34E-08	9.86E-05	1344	1.005	1.021	1.026	1.028	0.629	0.2	223.6	10.2	16.4	78.6
D8	100.32	32.3	8.693	7.45E-08	7.21E-05	968	1.004	1.020	1.024	1.026	0.646	0.2	53.8	5.9	287.6	80.0
D9	100.53	35.0	8.353	7.39E-08	7.79E-05	1054	1.010	1.019	1.030	1.030	0.291	0.4	199.5	4.4	319.5	81.3
	100.62	50.7														
D10	100.73	57.1	8.014	6.98E-08	7.28E-05	1043	1.001	1.021	1.022	1.025	0.903	0.1	267.3	5.9	119.6	83.1
D12	100.99	64.7	7.856	6.51E-08	1.35E-04	2073	1.006	1.024	1.030	1.032	0.598	0.2	102.0	7.2	335.4	78.1
D13	101.20	57.2	8.298	6.79E-08	1.15E-04	1686	1.008	1.020	1.029	1.030	0.416	0.3	216.0	3.0	342.5	85.0
	101.27	74.0														
D14	101.33	74.8	8.749	5.82E-08	2.07E-04	3561	1.007	1.029	1.036	1.038	0.618	0.2	227.3	9.3	77.8	79.3
C50	101.47	31.3	8.124	5.75E-08	1.09E-04	1899	1.003	1.044	1.048	1.053	0.862	0.1	163.9	2.2	64.3	77.3
	101.52	41.4														
	101.71	27.8														
D17	101.76	30.7	8.800	4.93E-08	1.28E-04	2598	1.005	1.038	1.043	1.047	0.781	0.1	138.1	11.2	298.0	78.1
C51	101.79	43.5	7.559	4.73E-08	1.64E-04	3477	1.003	1.037	1.040	1.044	0.837	0.1	160.1	5.8	322.2	83.9
	101.88	22.0														
	101.94	48.0														
C52	102.02	53.8	7.559	7.50E-08	3.22E-04	4293	1.009	1.030	1.039	1.041	0.543	0.3	99.5	0.7	210.3	88.2
D20	102.09	44.9	6.338	6.55E-08	3.17E-04	4838	1.007	1.041	1.048	1.052	0.702	0.2	148.4	0.3	55.9	83.8
D21	102.17	40.8	7.743	7.49E-08	1.83E-04	2448	1.009	1.031	1.040	1.042	0.556	0.3	111.8	12.8	280.9	76.9
D22	102.26	47.5	7.505	6.01E-08	1.22E-04	2029	1.000	1.046	1.047	1.054	0.982	0.0	177.8	2.2	31.4	87.3
C53	102.29	60.7	7.507	6.89E-08	1.35E-04	1966	1.004	1.043	1.048	1.053	0.824	0.1	171.4	2.3	274.3	79.9
	102.33	-5.6														
D23	102.36	36.5	7.740	6.36E-08	1.05E-04	1651	1.004	1.048	1.052	1.058	0.858	0.1	160.2	1.6	289.3	87.5
C54	102.39	41.9	7.311	5.90E-08	1.10E-04	1866	1.002	1.056	1.058	1.066	0.913	0.0	160.3	1.9	25.4	87.2
E1	102.44	69.5	7.038	5.79E-08	1.20E-04	2082	1.005	1.048	1.053	1.058	0.817	0.1	178.2	5.0	293.3	78.5
E2	102.51	63.4	7.501	6.20E-08	1.27E-04	2053	1.003	1.044	1.048	1.053	0.854	0.1	154.8	17.2	292.9	67.4
C55	102.56	31.8	7.575	5.81E-08	1.38E-04	2375	1.002	1.046	1.048	1.054	0.907	0.0	102.9	0.3	196.3	84.6
C56	102.76	34.9	5.689	4.40E-08	2.37E-04	5394	1.003	1.035	1.038	1.042	0.849	0.1	92.0	16.1	274.0	73.9
E3	102.88	61.7	7.583	4.92E-08	1.34E-04	2727	1.005	1.034	1.039	1.042	0.733	0.1	256.4	1.9	41.1	87.7
	103.01	-56.9														
E4	103.07	49.6	9.005	4.75E-08	1.87E-04	3940	1.003	1.039	1.042	1.047	0.844	0.1	304.0	4.3	70.4	82.7
E5	103.14	54.6	7.225	3.95E-08	1.79E-04	4535	1.001	1.040	1.042	1.048	0.932	0.0	192.7	2.8	314.6	84.7
E6	103.41	81.0	6.700	4.55E-08	1.65E-04	3638	1.002	1.042	1.044	1.050	0.908	0.0	156.7	6.8	323.7	83.0
E7	103.49	56.1	8.180	4.64E-08	1.91E-04	4128	1.002	1.041	1.044	1.050	0.885	0.1	199.2	0.3	294.9	87.0

Sample	Depth (meters)	Paleomagnetic Inclination (degrees)	Mass (g)	Magnetic Susceptibility (m3/kg)	SIRM (Am^2/kg)	SIRM/MS (A/m)	L	F	P	P'	T	Q	K1 Declination (degrees)	K1 Inclination (degrees)	K3 Declination (degrees)	K3 Inclination (degrees)
	103.57	34.5														
E8	103.58	73.1	7.955	4.71E-08	1.17E-04	2471	1.003	1.038	1.041	1.046	0.858	0.1	209.1	3.1	340.5	85.4
	107.20	54.5														
	110.15	65.5														
	111.20	58.7														
	111.62	53.7														
	112.08	59.4														
	113.38	62.7														
E9	115.50	24.1	7.944	6.62E-08	1.92E-04	2902	1.004	1.026	1.031	1.033	0.711	0.2	352.9	16.3	247.6	42.1
C57	115.52	17.5	7.979	6.78E-08	3.11E-04	4595	1.005	1.030	1.034	1.037	0.724	0.2	111.1	37.3	234.4	35.7
E10	115.54	30.1	7.153	6.47E-08	7.22E-05	1116	1.010	1.013	1.023	1.023	0.148	0.5	242.4	17.9	141.2	30.8
C58	115.76	37.2	8.648	6.85E-08	5.11E-05	746	1.014	1.017	1.031	1.031	0.102	0.6	261.5	2.5	0.5	74.4
E11	115.94	70.8	9.746	6.98E-08	4.29E-05	615	1.012	1.016	1.028	1.028	0.149	0.5	38.4	4.2	136.9	63.8
C59	115.96	52.6	9.179	6.75E-08	3.99E-05	592	1.004	1.028	1.032	1.035	0.735	0.1	101.1	3.8	213.7	80.3
E12	116.02	48.7	9.102	6.54E-08	5.50E-05	841	1.005	1.029	1.034	1.037	0.729	0.1	271.2	14.9	69.1	74.0
C60	116.08	9.7	8.236	6.68E-08	4.26E-05	638	1.002	1.033	1.035	1.040	0.911	0.0	241.3	7.2	110.5	79.0
	116.12	12.8														
	116.26	49.9														
E13	116.35	51.8	7.610	6.79E-08	5.18E-05	763	1.004	1.033	1.037	1.041	0.785	0.1	62.2	5.4	310.9	75.3
E14	116.43	56.5	8.754	6.41E-08	5.90E-05	920	1.002	1.027	1.029	1.033	0.842	0.1	199.4	8.0	341.1	79.9
C61	116.51	50.6	9.032	6.87E-08	5.63E-05	820	1.005	1.033	1.038	1.041	0.746	0.1	182.7	7.4	342.1	82.1
E15	116.64	29.6	9.209	6.49E-08	6.21E-05	957	1.003	1.038	1.041	1.046	0.860	0.1	242.2	7.4	27.3	81.0
E16	116.71	55.7	8.739	6.74E-08	5.37E-05	796	1.001	1.037	1.038	1.043	0.921	0.0	70.2	1.6	319.8	85.4
E17	116.79	69.7	9.354	6.33E-08	5.02E-05	792	1.002	1.036	1.038	1.043	0.906	0.0	134.5	7.2	287.2	82.0
C62	116.81	18.0	9.347	6.85E-08	5.82E-05	850	1.001	1.041	1.042	1.048	0.959	0.0	139.8	3.2	320.4	86.8
E18	116.83	63.8	8.762	6.30E-08	7.02E-05	1114	1.002	1.042	1.044	1.050	0.894	0.1	138.8	4.7	360.0	83.8
	116.92	18.8														
E20	117.00	27.4	6.320	6.15E-08	5.24E-05	852	1.004	1.051	1.055	1.062	0.859	0.1	156.7	0.8	252.0	81.8
C63	117.13	36.1	8.354	6.11E-08	9.77E-05	1601	1.007	1.027	1.034	1.036	0.601	0.2	177.5	3.1	278.4	74.0
	117.15	14.7														
E21	117.17	45.9	8.284	6.73E-08	5.95E-05	884	1.001	1.051	1.052	1.060	0.965	0.0	279.1	1.7	26.6	84.5
E22	117.24	46.1	8.426	6.07E-08	1.57E-04	2585	1.002	1.041	1.043	1.049	0.889	0.1	84.7	3.2	315.3	85.0
E23	117.34	46.7	9.266	6.38E-08	7.11E-05	1114	1.001	1.048	1.049	1.056	0.970	0.0	49.0	4.4	208.6	85.3
C64	117.39	33.7	9.518	6.88E-08	7.46E-05	1084	1.007	1.012	1.020	1.020	0.258	0.5	304.4	8.3	100.6	81.0
E24	117.48	38.9	8.543	7.07E-08	1.05E-04	1482	1.008	1.007	1.016	1.016	-0.064	0.7	292.0	5.8	194.2	53.3
E25	117.58	45.0	8.193	6.35E-08	1.72E-04	2715	1.005	1.029	1.034	1.037	0.687	0.2	351.1	1.5	244.9	84.7
E26A	117.66	48.9	8.037	6.63E-08	7.21E-05	1089	1.008	1.029	1.037	1.040	0.580	0.2	359.7	4.4	208.8	85.0
	117.66	56.1														
C65	117.70	47.4	7.958	6.82E-08	6.44E-05	945	1.003	1.032	1.035	1.039	0.845	0.1	27.5	4.7	172.8	84.3
E27	117.76	62.4	9.007	6.03E-08	1.70E-04	2816	1.003	1.034	1.038	1.042	0.840	0.1	313.2	0.5	46.9	82.4
E28	117.83	66.9	8.567	6.19E-08	7.64E-05	1234	1.004	1.032	1.036	1.039	0.778	0.1	285.8	11.3	115.3	78.6
E29	117.90	69.2	9.281	5.83E-08	1.66E-04	2842	1.008	1.041	1.049	1.053	0.666	0.2	275.4	12.2	81.5	77.4

Sample	Depth (meters)	Paleomagnetic Inclination (degrees)	Mass (g)	Magnetic Susceptibility (m3/kg)	SIRM (Am^2/kg)	SIRM/MS (A/m)	L	F	P	P'	T	Q	K1 Declination (degrees)	K1 Inclination (degrees)	K3 Declination (degrees)	K3 Inclination (degrees)
E30	117.97	39.2	9.462	5.39E-08	1.29E-04	2395	1.003	1.045	1.048	1.054	0.891	0.1	256.9	10.3	73.7	79.6
E32	118.02	51.3	9.193	5.16E-08	1.42E-04	2745	1.003	1.049	1.052	1.059	0.871	0.1	114.2	0.8	14.0	85.3
E31	118.09	57.0	8.856	5.38E-08	9.93E-05	1845	1.001	1.049	1.050	1.058	0.953	0.0	335.0	0.6	73.7	85.9
	118.15	35.7														
	118.37	57.6														
E34	118.45	51.6	7.615	4.89E-08	7.30E-05	1492	1.004	1.045	1.050	1.055	0.836	0.1	226.9	9.7	78.8	78.6
E35	118.54	40.6	7.954	5.09E-08	1.19E-04	2347	1.003	1.042	1.045	1.051	0.850	0.1	233.7	14.8	44.0	75.0
E36	118.80	48.5	9.662	4.90E-08	1.62E-04	3314	1.006	1.038	1.044	1.048	0.743	0.1	171.3	11.3	336.8	78.4
	118.99	54.2														
	119.40	55.3														
E37	119.70	44.3	9.353	4.98E-08	1.64E-04	3300	1.006	1.030	1.036	1.039	0.667	0.2	120.2	5.7	319.6	84.0
	119.70	44.3														
	120.25	47.5														
	121.21	52.7														
	122.18	44.2														
	122.75	45.8														
	123.98	51.9														