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Front Cover: Close-up view of a patch-reef coral head in Grahams Harbor, north of Dump Reef. As shown here, Caribbean shallow-water reefs have declined since the mid-1980s and are now largely overgrown by fleshy green macroalgae and a variety of encrusting organisms. See Curran et al., “Shallow-water reefs in transition,” this volume, p. 13. Photograph by Ron Lewis.

Back Cover: Dr. A. Conrad Neumann, University of North Carolina, Chapel Hill, NC, Keynote Speaker for the 11th Symposium and author of “Cement loading: A carbonate retrospective,” this volume, p. xii. Photograph by Mark Boardman.

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PALEOMAGNETIC RECONNAISSANCE DATA FROM ELEUTHERA ISLAND, BAHAMAS

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ABSTRACT

Reconnaissance paleomagnetic data are reported for three paleosols on north Eleuthera Island, Bahamas. Although one set of transitional field directions is observed, the paleosols give well-defined mean directions. The paleosol directions are similar despite being obtained from three separate stratigraphic horizons. It is possible that directional similarity is the result of penecontemporaneous redeposition of paleosol sediment from higher topography; however, the depositional implications of the paleosols are poorly understood.

INTRODUCTION

Deposition in the Bahamian Archipelago is intimately linked to sea level position (e.g., Carew and Mylroie, 1995). During highstands, platforms are flooded and allow for marine carbonate production. During sea-level lowstands, shallow-water carbonate production is replaced by subaerial accumulation of terra rossa paleosols on the abandoned platforms. The similarity of sedimentary packages deposited during various sea level highstands tends to obscure the stratigraphic record. Where complete stratigraphic sections occur, the assignment of units to the proper sea-level highstand event is relatively straightforward. However, the patchy nature of the deposits and the lack of unique mineralogical compositions in the paleosols make correlation fairly difficult in practice (Carew and Mylroie, 1995; Boardman et al., 1995).

On San Salvador Island, recognition of stratigraphic units has been aided by paleomagnetic signatures of paleosols (Panuska et al., 1995, 1997). The two paleosols occurring above and below the late Pleistocene Grotto Beach Formation offer a useful tool for correlation. Unfortunately, their utility for inter-island correlation has not been established. Moreover, studies on San Salvador appear to indicate the presence of a third paleosol (Panuska et al., 1999), suggesting the possibility that the Owl's Hole Formation (occurring below the Grotto Beach Formation) may need to be subdivided into two members. If so, there are no current stratigraphic clues as to the order of the two pre-Grotto-Beach magnetotype directions. However, studies on Eleuthera Island may provide evidence regarding the stratigraphic order of magnetotype directions.

Eleuthera Island contains fossil coral-bearing units that are thought to correlate with the oxygen isotope stage 5e highstand, equivalent to the Grotto Beach rocks on San Salvador (Hearty, 1998). At least three stratigraphically distinct paleosols have been recognized on Eleuthera (Kindler and Hearty, 1995; Hearty, 1998). This suggests that it may be possible to establish the stratigraphic order of paleosol magnetotypes identified on San Salvador (Panuska et al., 1999). Therefore, as part of an examination of Eleuthera localities for a field trip guide (Panuska et al., 2002), a reconnaissance paleomagnetic study was conducted on 3 paleosols exposed at the Glass Window Bridge, which connects north and central Eleuthera Island.

SAMPLING AND DATA ACQUISITION

Eleuthera Island is located on the northeastern margin of the Great Bahama Bank, approximately 370 km east of Miami. Much of the work on Eleuthera to date has been conducted by Hearty and co-workers (Kindler and Hearty, 1995;

Hearty, 1997, 1998; Hearty et al., 1998, 1999; Kindler and Hearty, 2000). The stratigraphy of the island consists predominantly of eolianites with lesser subtidal and beach deposits. Some deposits contain significant corals, and perhaps as many as 4 paleosols can be observed (Hearty, 1998).

Three separate paleosols were sampled along the northeast coastline, approximately 100 meters north of the Glass Window Bridge (Figure 1). All paleosols occur within or on top of eolianite units. The lowermost paleosol occurs 15-20 meters above sea level; 12 samples were drilled at this site. The second paleosol lies approximately 6 meters above the lower paleosol (13 samples). The uppermost paleosol occurs in discontinuous epikarst pits along the currently exposed surface, about 2 meters stratigraphically above the middle paleosol. Two epikarst pits (about 3 meters apart) were drilled near the cliff edge, yielding 10 and 13 samples each.

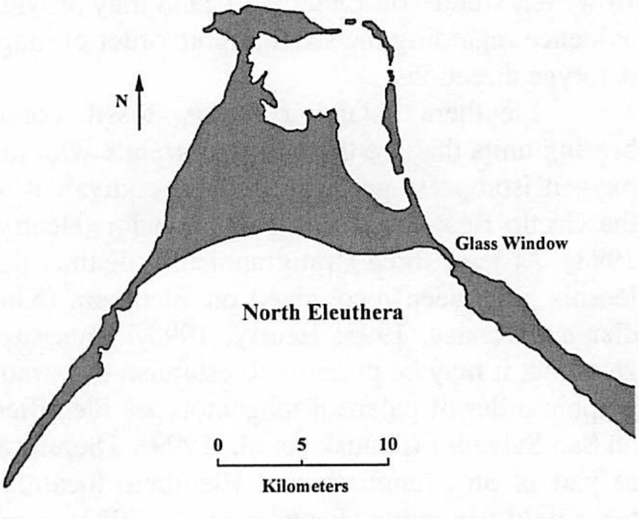

Figure 1. Map showing location of the Glass Window Bridge. Paleomagnetic samples were collected approximately 100m north of the bridge.

Magnetic remanence was measured using a Schonstedt SSM-1A spinner magnetometer. After each measurement, specimens were subjected to alternating field demagnetization, in 25 oersted increments, in order to define and remove secondary components of magnetization. Demagnetization experiments were run using a Molespin, 2-axis tumbling demagnetizer. The demagnetizer was used in both tumbling and static modes. Samples were demagnetized in two different orientations in order to monitor for the potentially obscuring effects of rotation remanent magnetization (RRM) or anhysteretic remanent magnetization (ARM). When RRM or ARM was suspected, both demagnetization orientations were measured and averaged together to remove spurious magnetic components. Characteristic directions of magnetization were determined as a decrease of intensity with little or no change in direction over successive demagnetization steps. Characteristic remanence directions were averaged, and standard statistical values were computed (Tables 1-3).

RESULTS AND DISCUSSION

All three paleosols gave similar mean directions, with circles of 95% confidence ranging from 2°-5°: lower paleosol, 359° declination, 42° inclination; middle paleosol, 3° declination, 45° inclination; pocket A upper paleosol, 355° declination, 42° inclination. Pocket A had one outlying datum (sample 38A), which was eliminated from the mean on the basis of the theta statistic (McFadden, 1980). However, pocket B from the upper paleosol yielded directions ranging from south and negative to north and nearly vertical. The distribution of these data is markedly elongate and precludes the use of simple averaging in the analysis (Figure 2).

The paleomagnetic directions of pocket B trend from a declination of 173°, -8° inclination to declination 15°, 85° inclination, forming a prominent pattern slightly eastward of a north-south vertical plane (Figure 2). The virtual geomagnetic poles (VGPs: the geographic location of the north magnetic pole that would produce a given paleomagnetic direction, in an axial geocentric dipolar field) likewise form a north-south trend from the Antarctic Circle to the North Carolina coast, along a South American longitude (Figure 3).

The trend of pocket B resembles a transitional field, which is sometimes observed during a geomagnetic reversal or during an aborted reversal (e.g., Herrero-Bervera et al., 1989; Tric et al., 1991a, 1991b). These directions are also similar to directions seen in paleosols on San Salvador Island (Panuska et al., 1991) and on Isla de Mona,

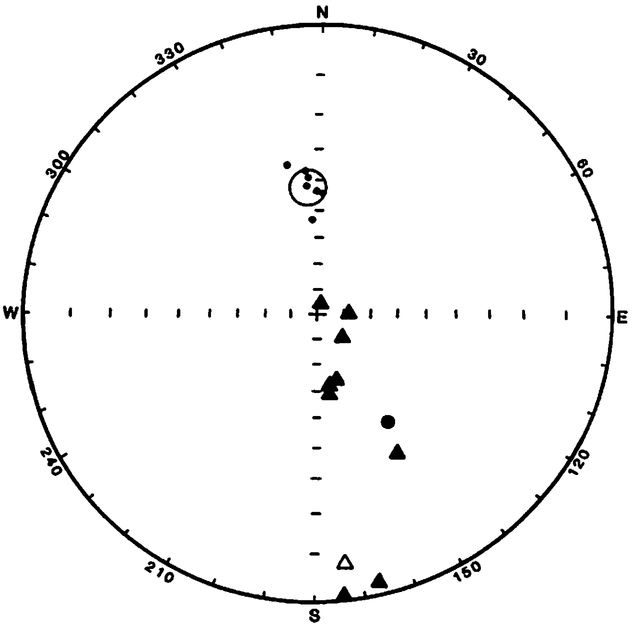

Figure 2. Stereographic plot showing characteristic paleomagnetic directions(triangles) measured from pocket B samples, upper paleosol. Note that the directions form an elongate distribution from south and negative to north and nearly vertical. Small dots represent directions from pocket A, with circle of 95% confidence. Large dot in the southeast quadrant is the anomalous direction from pocket A (omitted from the mean calculation). Notice the similarity of the pocket A anomalous direction and the pocket B trend. Open symbol indicates negative inclination.

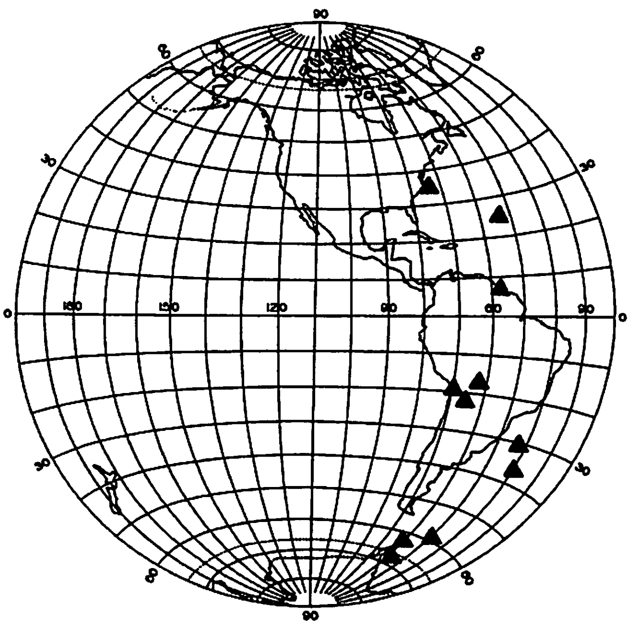

Figure 3. Virtual geomagnetic pole positions (VGPs) for pocket B, upper paleosol. VGPs form a great circle trend from the Antarctic Circle to the east coast of North America. Similar trends are observed during geomagnetic reversals and aborted reversals.

Puerto Rico (Panuska et al., 1993). Although similar directions have been observed in other paleosols, they can not be used to correlate them. Several short-lived reversals or aborted reversals have occurred during the last several hundred thousand years (Champion et al., 1988). Any one of these events could have produced anomalous directions, and the anomalous directions observed need not have been produced by a specific event.

Pocket A of the upper paleosol displays a well-defined set of directions, with the exception of one anomalous datum, sample 38A. This sample contains a southeast, positive characteristic direction. The direction yields a VGP located on the east coast of South America, very much along the trend of the samples from pocket B (Figures 2 and 3). Thus, the striking agreement of the anomalous datum and the directional trend observed in pocket B provides sound justification for the rejection of sample 38A.

The lower and middle paleosols at the Glass Window locality show tight clustering of directions and small circles of confidence (Figure 4). Statistical comparison of the Glass Window directions yields somewhat surprising results. The lower and middle as well as the lower and upper paleosols are statistically the same at 95% confidence, using the test of McFadden and Lowes (1981). However, the middle and upper paleosols are different, albeit marginally. (These two directions are the same at 90% confidence but different at 95% confidence.) The Fisher precision parameters (k) are statistically different, suggesting that there may be a problem with incomplete sampling or an incompletely removed secondary component. Nevertheless, the data can not be regarded as being able to demonstrate directional distinctness; therefore, they do not allow stratigraphic differentiation of the paleosols.

This finding is rather unexpected. On San Salvador, stratigraphically separate paleosols, at a

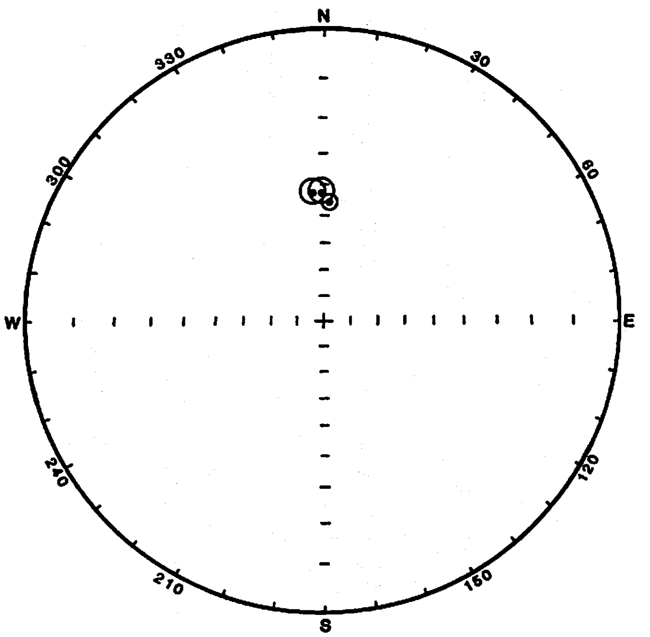

Figure 4. Mean directions and circles of 95% confidence for all three Eleuthera paleosols.

given locality, invariably yield distinct directions. There are several possible explanations accounting for the similarity of directions on Eleuthera: (1) the samples have been remagnetized, (2) secondary magnetic components have not been adequately removed by AF demagnetization, (3) there are insufficient data points to allow statistical discrimination, (4) the three paleosols were deposited within a short period of time.

Remagnetized samples tend to show much better agreement of directions than shown in the samples collected. Additionally, the dispersions (k, the Fisher precision parameter) would also be similar and rather high. Therefore, it is unlikely that the samples have been remagnetized.

There is no evidence from the demagnetization behavior that there are unresolved secondary components. Most specimens displayed straight-line demagnetization towards the origin after removal of modest secondary magnetizations. The coercivity spectra of these samples are quite similar to the samples from San Salvador Island, which are stable and have proved to be useful correlation criteria.

It is possible that there are insufficient data from each paleosol to provide reliable statistical correlation. Obid (2000) has shown that low sample density from paleomagnetic localities can produce false positive correlations. However, this was found to be the case for localities having only 4 or 5 samples. Although Obid (2000) suggested that 8 samples was the minimum number necessary to make statistical correlations, he found that a sample number of 6 or 7 did give the "correct" correlation in numerical simulations. Given that the Eleuthera paleosol localities have 6 or 7 samples for each mean direction, it is not likely that false positive correlations were obtained. Additional sampling is needed to establish this point.

The most reasonable explanation accounting for the similarity of paleomagnetic directions among the three paleosols is rapid emplacement. If the three paleosols are penecontemporaneous, there would be too little time for secular variation to vary the local magnetic field direction. Rapid deposition of eolian sand dunes is certainly possible; however, it is not clear that there would be sufficient time to accumulate several decimeters of wind blown suspension load (paleosol), before secular variation would produce divergent paleomagnetic directions. It could be that rapid dune migration was coupled with rapid soil redeposition during storm events. Paleosol strata can be observed to merge and diverge over distances of tens to hundreds of meters, with considerable change in elevation (Panuska et al., 2002). This implies a substantial paleo-topographic relief, allowing for soil wash-in from higher elevations.

Alternatively, the paleosols might be remobilized soil sediment collecting in dissolution conduits. Panuska et al. (2002) and Boardman et al. (2002) have described tower karst features on Eleuthera, where caves are preferentially formed in dune swales. A well-cemented former surface horizon diverts groundwater to the buried axes of swales in older dune deposits. This produces a sequence of caves occurring at various elevations, following the now exhumed swale. These swale-linked caves could be filled with remobilized soil, as washed-in deposits. This sort of scenario was invoked to explain a lenticular paleosol breccia deposit occurring in an apparent swale in the paleo-topography near Whale Point, approximately 4 km northwest of the Glass Window Bridge (Panuska et al., 2002; Boardman et al., 2002).

Although the Glass Window paleosols do not display a lenticular pattern, the general process remains valid. It is possible that a more detailed examination of the outcrops will identify evidence for dissolutional channeling along well-cemented horizons. However, the paleosol horizons can be traced for considerable distances in the sea cliff exposures. Cave in-fill sediments would necessarily produce laterally discontinuous deposits, suggesting that piping of sediments into karst conduits is not a likely mechanism.

From the preceding discussion, it is clear that this reconnaissance study raises more questions than it answers. Additional field work will be necessary to give a proper characterization of the paleosols on Eleuthera Island. Specifically, it will be important to establish whether similarity of paleosol paleomagnetic directions is the rule or the exception. If field criteria can not be identified to ascertain when penecontemporaneous paleosol formation is likely, then paleomagnetic correlation of paleosols on Eleuthera would be of questionable utility.

CONCLUSIONS

A reconnaissance paleomagnetic study of Eleuthera Island was conducted in order to determine whether paleomagnetic stratigraphic correlation is feasible. Three separate paleosol horizons were sampled near the Glass Window Bridge, north Eleuthera. Most samples responded well to alternating field demagnetization experiments, yielding well-defined mean characteristic directions. One paleosol-filled epikarst pit produced anomalous (transitional field?) directions.

Unexpectedly, the mean directions are very similar. This suggests that all three paleosols were formed penecontemporaneously, by some, as yet, poorly understood mechanism. Alternatively, the finding of similarity may indicate severe limitations of the paleomagnetic technique for Eleuthera Island.

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REFERENCES

Boardman, M.R., McCartney, R.F., and Eaton, M.R., 1995, Bahamian paleosols: Origin, relation to paleoclimate, and stratigraphic significance, *in* Curran, H. A., and White, B., (eds.), Terrestrial and Shallow Marine Geology of the Bahamas and Bermuda: Geological Society of America Special Paper 300, p. 33-49.

Boardman, M.R., Carew, J.L., Mylroie, J.M., Panuska, B.C., Sealey, N.E., and Voegeli, V.J., 2002, The geology of Eleuthera Island Bahamas: Reinterpretation of megaboulder and oxygen isotope substage 5a deposits: Geological Society of America, Abstracts with Programs, v. 34, p. 14.

Carew, J.L., and Mylroie, J.E., 1995, Depositional model and stratigraphy for the Quaternary geology of the Bahama Islands, *in* Curran, H.A. and White, B., eds., Terrestrial and shallow marine geology of the Bahamas and Bermuda: Geological Society of America Special Paper 300, p. 5-32.

Champion, D.E., Lanphere, M.A., and Kuntz, M.A., 1988, Evidence for a new geomagnetic reversal from lava flows in Idaho: Discussion of short polarity reversals in the Brunhes and late Matuyama polarity chrons: Journal of Geophysical Research, v. 93, p.11667-11680.

Hearty, P.J., 1997, Boulder deposits from large waves during the last interglaciation on north Eleuthera Island, Bahamas: Quaternary Research, v. 48, p. 326-338.

Hearty, P.J., 1998, The geology of Eleuthera Island, Bahamas: A Rosetta Stone of Quaternary stratigraphy and sea-level history: Quaternary Science Reviews, v. 17, p. 323-355.

Hearty, P.J., Kindler, P., Cheng, H., and Edwards, R.I., 1999, A +20m middle Pleistocene sea-level highstand (Bermuda and the Bahamas) due to the partial collapse of Antarctic ice: Geology, v. 27, p. 375-378.

Hearty, P.J., Neumann, A.C., and Kaufman, D.S., 1998, Chevron ridges and runup deposits in the Bahamas from storms late in oxygen-isotope substage 5e: Quaternary Research, v. 50, p. 309-322.

Herrero-Bervera, E., Helsley, C.E., Hammond, S.R., and Chitwood, L.A., 1989, A possible lacustrine palaeomagnetic record of the Blake episode from Pringle Falls, Oregon, U.S.A.: Physics of the Earth and Planetary Interiors, v. 56, p. 112.

Kindler, P., and Hearty, P.J., 1995, Pre-Sangamonian eolianites in the Bahamas? New evidence from Eleuthera Island: Marine Geology, v. 127, p. 73-86.

Kindler, P., and Hearty, P.J., 2000, Elevated marine terraces from Eleuthera (Bahamas) and Bermuda: Sedimentological, petrographic and geochronological evidence for important deglaciation events during the middle Pleistocene: Global and Planetary Change, v. 24, p. 41-58.

McFadden, P.L., 1980, Determination of the angle in a Fisher distribution which will be exceeded with a given probability: Geophysical Journal of the Royal Astronomical Society, v. 60, p. 391-396.

McFadden, P.L., and Lowes, F.J., 1981, The discrimination of mean directions drawn from Fisher distributions: Geophysical Journal of the Royal Astronomical Society, v. 67, p. 19-33.

Obid, J.A., 2000, Paleomagnetic Correlations of Paleosols on San Salvador Island, Bahamas, [M.S. thesis]: Mississippi State University, Starkville, MS, 76 p.

Panuska, B.C., Carew, J.L., and Mylroie, J.E., 1991, Paleomagnetic directions of paleosols on San Salvador Island, Bahamas: Prospects for a stratigraphic correlation, *in* Bain, R.J., ed., Proceedings of the 5th Symposium on the Geology of the Bahamas: San Salvador, Bahamian Field Station, p. 193-202.

Panuska, B.C., Carew, J.L., Taggart, B.E., and Mylroie, J.E., 1993, Anomalous paleomagnetic directions from paleosols on Isla de Mona, Puerto Rico: Geological Society of America, Abstracts with Programs, v. 25, p. A-199.

Panuska, B.C., Kirkova, J.T., Mylroie, J.E., and Carew, J.L., 1995, New paleomagnetic stability tests for paleosols on San Salvador Island, Bahamas, *in* Boardman, M., ed., Proceedings of the 7th Symposium on the Geology of the Bahamas: San Salvador, Bahamian Field Station, p. 89-96.

Panuska, B.C., Mylroie, J.E., and Carew, J.L., 1997, Stratigraphic tests of paleomagnetic secular variation correlation of paleosols, San Salvador Island, Bahamas, *in* Carew, J.L., ed., Proceedings of the 8th Symposium on the Geology of the Bahamas and Other Carbonate Regions: San Salvador, Bahamian Field Station, p. 148-157.

Panuska, B.C., Mylroie, J.E., and Carew, J.L., 1999, Paleomagnetic evidence for three Pleistocene paleosols on San Salvador Island, Bahamas, *in* Curran, H.A., and Mylroie, J.E., eds., Proceedings of the 9th Symposium on the Geology of the Bahamas and Other Carbonate Regions, San

Salvador, Bahamian Field Station, p. 93-100.

Panuska, B.C., Boardman, M.R., Carew, J.L., Mylroie, J.E., Sealy, N.E., and Voegeli, V., 2002, Eleuthera Island Field Trip Guide, 11th Symposium on the Geology of the Bahamas and Other Carbonate Regions: San Salvador, Gerace Research Center.

Tric, E., Laj, C., Jehanno, C., Valet, J.-P., Kissel, C., Mazaud, A., and Iaccarino, S., 1991a, High resolution of the upper Olduvai transition from Po Valley (Italy) sediments: Support for dipolar transition geometry? Physics of the Earth and Planetary Interiors, v. 65, p. 319-336.

Tric, E., Laj, C., Valet, J.-P., Tucholka, P., Paterne, M., and Guichard, F., 1991b, The Blake geomagnetic event: Transition geometry, dynamical characteristics and geomagnetic significance: Earth and Planetary Science Letters, v. 102, p. 1-13.

SAMPLE	DEMAG	PERCENT NRM	NRM INTENSITY	GEOGRAPHIC		VGP	
				DEC	INC	LAT	LONG
1A	150	44	2.4E-6	359	44	89	210
2A	125	23	2.5E-6	359	36	84	115
4A	150	28	2.2E-6	1	42	88	79
9A	175	20	2.9E-6	0	41	88	124
10A	175	23	3.0E-6	354	42	85	179
12A	175	32	5.2E-6	358	49	85	263
MEAN				359	42	88	159
				k = 311.3		k = 427.2	
				A95 = 3.8°		A95 = 3.2°	
				R = 5.984		R = 5.988	
				N = 6		N = 6	

Table 1. Lower Paleosol; k is the Fisher precision parameter, A95 is the 95% statistical confidence limit, and N is the number of samples.

SAMPLE	DEMAG	PERCENT NRM	NRM INTENSITY	GEOGRAPHIC		VGP	
				DEC	INC	LAT	LONG
13A	125	29	2.8E-6	360	48	87	280
15A	175	30	3.1E-6	5	43	85	20
16A	125	48	3.3E-6	3	42	87	43
18A	100	58	4.4E-6	4	42	86	32
19A	125	21	3.1E-6	4	48	85	327
21A	175	21	2.5E-6	3	45	87	356
24A	125	28	2.7E-6	358	45	88	218
MEAN				3	45	88	356
				k = 675.5		k = 676.2	
				A95 = 2.3°		A95 = 2.3°	
				R = 6.991		R = 6.991	
				N = 7		N = 7	

Table 2. Middle Paleosol.

SAMPLE	DEMAG	PERCENT NRM	NRM INTENSITY	GEOGRAPHIC		VGP	
				DEC	INC	LAT	LONG
26A	100	17	1.7E-5	355	37	83	144
27A	150	28	8.1E-6	359	43	89	183
29A	100	24	7.0E-6	355	39	84	159
30A	150	30	5.0E-6	348	34	77	165
36A	200	17	5.7E-6	353	42	84	181
37A	150	16	8.9E-6	356	53	82	260
38A*	125	18	2.3E-5	147	42*	-31	318*
39A	150	13	2.4E-5	2	44	89	350
MEAN				355	42	86	177
				k = 133.9		k = 182.4	
				A95 = 5.2°		A95 = 4.5°	
				R = 6.955		R = 6.967	
				N = 7		N = 7	

*Table 3. Upper paleosol, pocket A. * Sample 38A was rejected by theta-95 statisic.*

SAMPLE	DEMAG	PERCENT NRM	NRM INTENSITY	GEOGRAPHIC		VGP	
				DEC	INC	LAT	LONG
40A	175	10	5.6E-4	173	-8	-68	301
41A	100	37	2.2E-4	174	1	-64	298
42A	150	19	6.2E-4	167	3	-60	310
43A	100	22	1.1E-4	150	32	-38	321
44A	175	3	4.7E-5	86	79	25	307
45A	125	5	1.6E-5	15	85	34	286
46A	125	11	2.3E-4	135	77	6	301
47A	125	25	5.6E-4	163	64	-18	296
48A	75	58	6.2E-4	171	63	-20	290
49A	100	34	3.5E-4	168	61	-22	293

Table 4. Upper paleosol, pocket B.