PROCEEDINGS
OF THE
SEVENTH SYMPOSIUM
ON THE
GEOLOGY OF THE BAHAMAS

Edited by
Mark Boardman

Production Editor
Daniel R. Suchy

Bahamian Field Station, Ltd.
San Salvador, Bahamas
1995

Cover Photo: Outcrop showing Pleistocene soil profile,
caliche crust, and rhizocretions,
San Salvador, Bahamas.
Photo taken by Daniel R. Suchy.

Printed in USA by Don Heuer

ISBN 0-935909-55-9

NEW PALEOMAGNETIC STABILITY TESTS FOR PALEOSOLS ON SAN SALVADOR ISLAND, BAHAMAS

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ABSTRACT

The utility of paleomagnetic correlation on San Salvador Island has been problematic in as much as a stable primary magnetic remanence has not been conclusively demonstrated. Two new stability tests are here reported which greatly bolsters the confidence in the paleomagnetic data.

One conglomerate test performed on boulders at the base of The Bluff gives a positive test which implies stability on the order of decades to centuries. A second conglomerate test, from Gaulin Cay, likewise yields a positive statistical test. Since laminated paleosol clasts occur in a paleosol matrix directly overlying a laminated paleosol, which is texturally indistinguishable from the paleosol clasts, the Gaulin Cay paleosol is interpreted as an intraformational conglomerate. This indicates paleomagnetic stability dating back to the origin of the rock.

INTRODUCTION

San Salvador Island is located 620 km ESE of Ft. Lauderdale, Florida on an isolated carbonate bank. The modern stratigraphy of the island was established by Carew and Mylroie (1985). The oldest unit on San Salvador is the Owl's Hole Formation, consisting of bioclastic and peloidal eolianites. Overlying the Owl's Hole is the oolitic Grotto Beach Formation comprising various shallow marine facies, including coral reefs, as well as beach-dune facies. This unit was deposited during oxygen isotope stage 5e, 125 ka. Overlying the Grotto Beach units is the Rice Bay Formation, consisting of poorly-cemented Holocene bioclastic and peloidal eolian and beach deposits. The contact between each of these formations is marked by a paleosol.

It is not always possible to determine the stratigraphic assignment of a given outcrop, owing to the patchiness of deposition and locally extensive micritization. A specific paleosol marker horizon could help stratigraphic assignment considerably; however, there is no clear lithologic or mineralogic criteria that would allow stratigraphic recognition. Thus we examined the possibility that the paleomagetic signature of these paleosols might provide a criterion for stratigraphic assignment.

Efforts to establish a paleomagnetic correlation tool for paleosols on San Salvador Island have been ongoing for several years (Hudson and Panuska, 1990; Panuska et al., 1991). The validity of this technique requires that the paleosols are magnetically stable and that the paleomagnetic remanence dates to the time of formation of the paleosol. Confident usage of paleomagnetic correlation has been hampered by the lack of convincing paleomagnetic stability tests. Here we report the results of two new stability tests and provide additional data for a stability test previously reported (Panuska and Mylroie, 1993).

PALEOMAGNETIC STABILITY TESTS

The stability of paleomagnetic remanence can be assessed by employing field tests such as the fold test, reversal test, baked contact test and the conglomerate test. The fold test and baked contact test are precluded by the absence of both tectonic folds and igneous rocks. Only the reversal and conglomerate tests are potentially useful on San Salvador.

If rocks are remagnetized an entire section tends to be reset during a relatively short-lived event. Consequently, a single polarity (and single direction) are often observed. Since the earth's magnetic field reverses polarity periodically, the occurrence of stratigraphically controlled reversals in a given stratigraphic section provides strong evidence for magnetic stability. Unfortunately, the last major reversal occurred at about 783 Ka (Baksi et al., 1992) and there is no evidence that rocks on San Salvador are older than about 380 Ka at the oldest. Thus, the only standard paleomagnetic stability test applicable to San Salvador is the conglomerate test.

The conglomerate test evaluates the stability of a given unit by examining the paleomagnetic directions of clasts eroded from that unit. If the paleomagnetic remanence is stable, random directions should be observed in a suite of clasts because the magnetic alignment forces are dwarfed by the mechanical forces involved in clast transport. Ideally, the clasts in the conglomerate should be rounded and have undergone sufficient transport to produce complete reorientation of the clasts. However, if these conditions are not met the paleomagnetic directions from the clasts may display a preferred orientation, which may complicate the interpretation of stability.

PREVIOUS STABILITY TESTS

Circumstantial evidence for stability was presented by Hudson and Panuska (1990) and Panuska et al. (1991). These studies reported paleomagnetic directions for several paleosols. The fact that statistically distinct directions were observed for many of the paleosols was interpreted as a stable recording of secular variation of the geomagnetic field over some period of time.

The first conglomerate test attempted on San Salvador was performed by Panuska and Mylroie (1993). These workers reported a random orientation of mean directions for 11 clasts collected from a sloping beach rock surface along the shore of Fernandez Bay. Although these clast mean directions are random at 99% confidence, there was an apparent arc-like distribution of the directions. Panuska and Mylroie (1993) interpreted this distribution to be the result of preferred orientation of tabular clasts on the sloping surface. This interpretation was explained in detail and verified by Kirkova (1994).

While the Fernandez Bay conglomerate test is positive, it demonstrates short-term paleomagnetic stability and not necessarily long-term stability. The conglomerate test proves stability only for a duration dating to the deposition of the clasts. Since the Fernandez Bay clasts were eroded from a paleosol exposed at the present coastline and since the clasts were lying on a currently active beach rock slope, the time of clast deposition is likely to be on the order of perhaps decades, and centuries at most. The paleosol is likely to be tens of thousands years old: perhaps in excess of one hundred thousand years. Thus, there is an ample temporal window during which remagnetization could have occurred and still given a positive conglomerate test.

NEW STABILITY TESTS

The Bluff

The Bluff is an eolianite dune ridge, approximately 10 m high, located along the eastern shore of San Salvador Island. Multiple samples were collected from ten paleosol-bearing boulders at the base of this cliff for a conglomerate test. Seven of these boulders were 1.3 m or less in maximum dimension and occurred in the present swash zone. Thus, severe storm waves could reorient these clasts. Three boulders (8, 9 and 10) were distinctly tabular, measured from 2-5 m in length and were located about 2-4 m above present high tide.

Initial intensities of the samples was

fairly weak (10-7 to 10-9 emu/cm3). Three clasts (1, 4 and 5) were too weak to yield reliable results. The remaining samples generally showed well-defined remanence components. Secondary magnetic components comprised 60% or more of the initial signal and were removed by alternating field cleaning at peak fields of 125 to 150 Oe (Oersteds). The characteristic directions (Table 1) showed moderately tight to very tight within clast clustering (Fisher precision parameter, kappa, values of 17-283) and very poor clustering among clasts (kappa=2.8). This implies that the paleosol in the clasts is stably magnetized and became reoriented during erosion and transport from the in situ paleosol at the top of the cliff. The statistical evaluation of these data (Figure 1) shows a random distribution of directions at the 99% confidence level but a non-random distribution at the 95% confidence level. This suggests that the conglomerate test is equivocal; however this result is biased by tight directional clustering of boulders 8, 9 and 10. These are the largest boulders and the poles to bedding of internal paleosol laminations shows the least reorientation (Kirkova, 1994). If these three clasts are averaged and treated as one datum, on the basis that they were not sufficiently displaced from their initial orientations, then the conglomerate test is statistically significant at both the 95% and 99% confidence levels. However, it must be emphasized that since these boulders occur on a presently active geomorphic surface, paleomagnetic stability is shown for a time period of decades to centuries; longer term stability is not necessarily implied.

Gaulin Cay

Gaulin Cay is a small island, which lies approximately 2 km north of the Bahamian Field Station, in Graham's Harbour. A well-exposed paleosol breccia is exposed in an active beach rock outcrop along the eastern shore. The paleosol breccia consists of a massive, light reddish brown paleosol matrix containing angular, tabular, well-laminated paleosol clasts. The clasts range in size from 5 to 20 cm in maximum dimension and are approximately 1 cm thick. Immediately underlying this paleosol breccia is a well-laminated paleosol, which is indistinguishable from the paleosol clasts in the overlying breccia. The implication is that the breccia formed from the erosion of the well-laminated paleosol, producing angular clasts, and then modest transport of these clasts to a swale in the laminated paleosol surface. This outcrop is interpreted as an intraformational breccia; by this interpretation the breccia is penecontemporaneous with the underlying paleosol.

Four paleomagnetic cores were obtained from both the breccia matrix and the underlying laminated paleosol. In addition, 1 to 3 cores were collected from each of 11 paleosol clasts in the breccia.

The paleomagnetic specimens were subjected to stepwise alternating field demagnetization, in 25 Oe increments to remove potential secondary magnetic overprints. In general, the specimens yielded very well-defined characteristic directions, with only minor secondary components (Figure 2). With the exception of clast 9, all secondary components were removed by cleaning to 75-125 Oe.

The within clast clustering was quite high, with kappa values ranging from 44 to 245 (Table 2). However, the among clast clustering was rather low. The geographic (in situ) kappa value is 3.2. The stratigraphic directions, restored to their original horizontal directions by rotating along the present strike line of paleosol laminations, gave an even lower kappa (2.8). In contrast, the clustering of the intact underlying paleosols and the paleosol matrix of the paleosol breccia are very high (kappas of 131 and 1780 respectively, Table 3). Moreover, the directions for the lower paleosol and the breccia matrix are statistically identical.

The facts that the directional clustering of the paleosol is very poor and that the in situ parent paleosol and breccia matrix have tight clustering is strong evidence for a stable magnetic remanence (Figure 3). Unfortunately, the clast directions are not quite random. The lack of randomness, however, does not indicate a failure of the conglomerate test.

The paleosol clasts are distinctly tabular in nature and display a strong preferred (sub-horizontal) orientation; the kappa on the poles to bedding is 10.8. Given the preferred orientation of the clasts, a random orientation of clast vectors is not necessarily expected. Relative rotation of the

Table 1. Paleomagnetic directions for paleosol blocks at The Bluff, which exhibit randomization at 99% confidence level.

		Initial	Demag		Geographi		Stratigraphic		Mean geographic					Mean stratigraphic				
Block	Specime	Intensity	level	% NRM	Dec	Inc	Dec	Inc	Dec	Inc	Kappa	Alpha 95	N	Dec	Inc	Kappa	Alpha 95	N
2	87A	3.8E-07	100	26	32	47	119	51	37	48	282.0	14.9	2	120	48	265.6	15.4	2
	89A**	3.2E-07	100	34	42	48	120	44										
3	92A	4.9E-06	100	31	265	33	259	61	265	33			1	259	61			1
4	94A*	4.1E-08	200	12	125	1	123	-4										
	95A*	1.6E-08	125	36	155	46	173	11										
5	97A*	6.0E-09	300	21	170	32	163	-48										
	98A*	1.0E-08	500	10	103	-12	93	0										
	100A	2.3E-07	125	57	55	42	156	37										
	101A*	1.4E-08	150	41	47	1	99	57										
6	102A*	1.6E-08	300	22	135	13	108	34	147	20	18.3	62.2	2	107	47	19.4	60.2	2
	105A	3.3E-07	200	20	160	26	105	60										
7	106A	6.2E-06	125	16	32	35			30	30	72 5	10.9	4					
	107A	6.5E-06	150	20	25	19												
	108A	4.0E-06	125	21	33	39												
	109A	5.2E-06	125	29	29	26												
8	110A	2.2E-06	125	41	338	24	346	32	340	34	78.0	8.7	5	351	41	74 6	8.9	5
	111A	3.4E-06	175	26	330	39	342	49										
	112A**	1.1E-06	300	11	339	31	349	39										
	113A	1.7E-06	300	25	353	39	7	42										
	114A**	8.5E-07	175	26	341	35	352	42										
9	115A	3.4E-06	125	35	1	56	3	61	344	51	27.4	13.0	6	343	60	27.4	13.0	6
	116A	1.7E-06	150	27	337	75	334	80										
	117A	5.7E-06	250	21	345	38	345	43										
	118A	8 3E-06	175	29	347	36	347	41										
	119A	3.8E-06	100	47	338	51	338	56										
	120A	4.0E-06	175	28	331	47	329	52										
10	121A	1.8E-05	150	28	29	11	30	3	13	42	17.3	18.9	5	21	37	16.8	19.2	5
	122A	4.7E-06	175	5	2	47	13	43										
	124A	4.0E-06	125	38	15	43	23	37										
	125A	1.7E-06	175	35	360	54	14	51										
	126A	5.7E-06	175	15	10	51	21	46										
							Mean direction.		Dec	Inc	Kappa	Alpha 95	N	Dec	Inc	Kappa	Alpha 95	N
									5	58	2.8	44.5	7	30	71	4.0	38.7	6

Note: All specimen prefixes of "93-SS-" are omitted for clarity. "Geo" is geographic frame of reference, that is the present day (in situ) coordinates. "Strat" is stratigraphic frame of reference, that is a dip angle correction to ancient horizontal. "Dec" is declination, "Inc" is inclination. NRM (natural remanent magnetization) is used here as initial intensity. Kappa is Fisher's precision parameter. Alpha 95 is circle of 95% confidence. "N" is number of specimens/blocks. "*" refers to samples done entirely on cryogenic magnetometer, "**" refers to samples done partially on cryogenic magnetometer. Samples from block 7 have only geographic vector directions because an accurate attitude of bedding could not be observed.

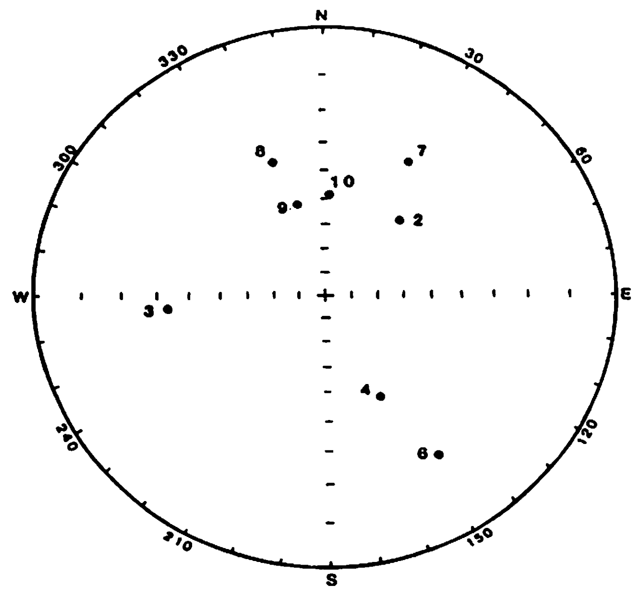

Figure 1. Paleomagnetic directions for The Bluff in geographic frame of reference. All directions are positive (downward). Numbers correspond to clast number.

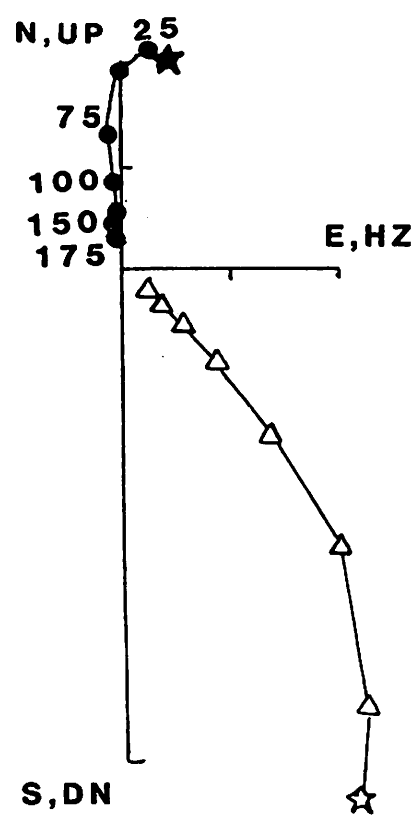

Figure 2. Vector diagram for a representative Gaulin Cay sample. Dots are declinations in N,E,S plane. Triangles are inclinations in vertical plane (HZ - horizontal, UP, DN - down). Demagnetization intensities are in Oersteds. Note that secondary components are removed by 75 Oersteds.

Table 2. Paleomagnetic directions for the paleosol clasts at Gaulin Cay.

Clast	Specimen	Initial Intensity	Demag level	% NRM	Geographic Dec	Geographic Inc	Stratigraphic Dec	Stratigraphic Inc	Mean geographic Dec	Mean geographic Inc	Mean geographic Kappa	Mean geographic Alpha 95	Mean geographic N		Mean stratigraphic Dec	Mean stratigraphic Inc	Mean stratigraphic Kappa	Mean stratigraphic Alpha 95	Mean stratigraphic N	
1	10A*	1.6E-08	175	9	32	14	26	9	32	14			1		26	9			1	
2	15A**	1.3E-07	175	22	45	68	50	30	53	73	245.2	7.9	3		53	34	244.4	7.9	3	
	16A*	1.5E-08	150	35	60	72	56	34												
	17A*	8.0E-09	200	30	57	77	54	39												
3	18A	1.8E-07	100	36	69	-25	74	-23	69	-25			1		74	-23			1	
4	19A*	4.3E-09	125	37	353	57	338	31	338	57	51.9	35.4	2		329	29	53.1	35.0	2	
	20A*	7.4E-09	250	22	324	56	321	26												
5	21A	4.9E-06	125	39	106	-38	124	-32	106	-38			1		124	-32			1	
6	22A**	1.6E-07	225	17	15	40	358	50	15	40			1		358	50			1	
7	23A*	2.7E-08	200	13	343	45	339	14	343	45			1		339	14			1	
8	26A*	2.0E-08	175	23	17	22	355	52	9	26	44.4	38.4	2		346	53	98.2	25.5	2	
	28A*	1.4E-08	150	29	360	30	336	54												
10	30A	1.6E-05	150	9	7	40	353	46	357	40	67.4	15.1	3		343	44	69.2	14.9	3	
	31A**	2.9E-07	175	22	1	37	348	42												
	32A*	8.5E-09	225	31	343	43	328	43												
11	33A**	6.0E-09	200	40	344	40	331	25	349	43	130.9	22.0	2		334	30	121.5	22.9	2	
	34A**	1.4E-07	225	28	355	46	337	34												
12	35A	1.1E-05	50	89	32	1	32	14	35	-1.5	215.5	17.1	2		35	12	220.6	16.9	2	
	36A	1.5E-06	150	12	38	-4	38	9												
							Mean direction		Dec	Inc	Kappa	Alpha 95	N	R	Dec	Inc	Kappa	Alpha 95	N	R
									23	31	3.2	30.3	11	7.905	15	28	2.8	33.8	11	7.410

Note: See Table 1 for abbrivations. Sample prefix is "93-SS-".

Table 3. Paleomagnetic directions for the lower paleosol and the paleosol matrix at Gaulin Cay, which show high degree of correlation.

Lower paleosol	Specimen	Initial Intensity	Demag level	% NRM	Geographic Dec	Inc				
	3A	1.2E-05	225	6	4	46				
	4A	2.0E-05	100	25	353	46				
	5A	4.6E-06	200	7	354	57				
	6A	6.0E-06	150	14	348	54				
			Mean direction:		Dec	Inc	Kappa	Alpha 95	N	R
					355	51	130.9	8.1	4	3.977

Paleosol matrix	Specimen	Initial Intensity	Demag level	% NRM	Geographic Dec	Inc				
	7A	4.6E-05	150	14	351	49				
	8A	5.8E-05	150	9	354	46				
	9A	2.5E-05	175	9	356	47				
	39A	3.8E-05	175	6	355	47				
			Mean direction:		Dec	Inc	Kappa	Alpha 95	N	R
					354	47	1779.5	2.2	4	3.998

Mean of all samples:	Dec	Inc	Kappa	Alpha 95	N	R
	355	49	234.5	3.6	8	7.971

Note: See Table 1 for abbrivations. Sample prefix is "93-SS-".

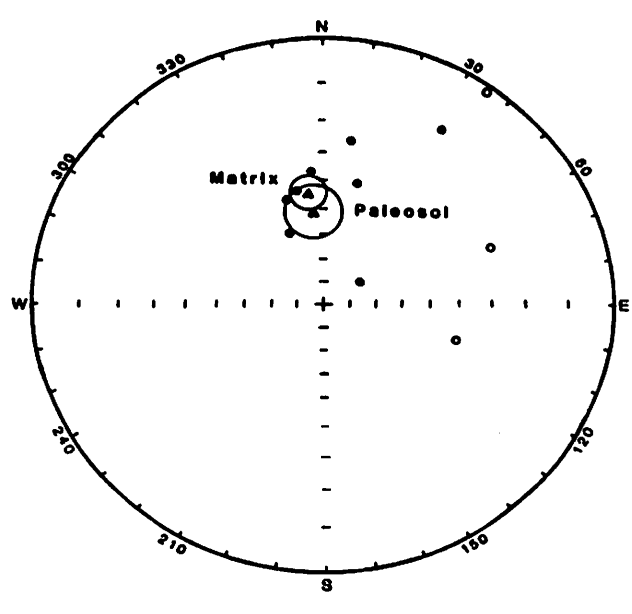

Figure 3. Paleomagnetic directions from paleosols and included paleosol clasts on Gaulin Cay. Dots are lower hemisphere (positive) clast directions; open circles are upper hemisphere (negative clast directions. Triangles are paleosol mean directions with associated circles of 95% confidence. The mean directions for the paleosol and the paleosol matrix are not statistically distinguishable.

clasts about the poles to bedding is suggested by the stratigraphic kappa being lower than the geographic kappa. Finally, the values of dispersion (kappa) of the in situ paleosols and the paleosol clasts are significantly different, which is predicted by the mechanical reorientation of clasts retaining a stable magnetic direction. Thus, the conglomerate test is positive.

The observation that the directions of the underlying in situ paleosol and the breccia matrix are the same strongly suggests that the two units are penecontemporaneous. This implies that the stability of remanence dates back to the origin of the paleosol. Therefore, the positive Gaulin Cay conglomerate test is a powerful test of magnetic directional stability.

CONCLUSIONS

Positive conglomerate tests from Fernandez Bay and The Bluff provide circumstantial evidence for stability. Since the age of deposition of these "conglomerate" (boulders and cobbles largely without matrix) clasts is likely to be only centuries at most, it is possible that the magnetization of the precursor paleosols were reset and then deposited. A positive conglomerate test under these circumstances although suggestive, is not a robust test of stability.

The paleosol breccia at Gaulin Cay satisfies the criteria for a positive conglomerate test. Because the age of deposition of the paleosol breccia is nearly the same as the parent paleosol, the paleomagnetic stability is virtually assured. If the observed stability at Gaulin Cay is characteristic of all of the paleosols on San Salvador, paleomagnetic directions may be confidently used as a stratigraphic correlation criterion.

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