Magneto stratigraphy of Plio-Pleistocene Lake Sediments in the Confidence Hills of southern Death Valley, California

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ABSTRACT

Over 200 meters of continuous playa and lacustrine sediments and volcanic ashes are exposed in the Confidence Hills of southern Death Valley. Oriented samples from two stream canyons which cut through the sediments possess stable characteristic components of Natural Remanent Magnetization (NRM). Progressive demagnetization experiments yield several normal and reversed polarity zones which are stratigraphically distinct, and the characteristic components pass the reversal test. The presence of the Huckleberry Ridge volcanic ash (c.a. 2 Ma) in one of the reversed polarity zones provides a dated stratigraphic marker for correlation of the magnetos tratigraphy to the magnetic polarity timescale. The correlation indicates that deposition began before the Reunion magnetic event (2.14-2.15 Ma) in the early Matuyama reversed chron (late Pliocene), and continued through the Olduvai normal subchron (c.a., 1.79 Ma) into the early Pleistocene. Deposition rates for the portion of the formation studied average about 26 cm/ky. Despite the close proximity of the sequence to strands of the Death Valley Fault, no net vertical-axis tectonic rotation could be detected.

INTRODUCTION

During the last several million years, many topographic basins in southern California contained fresh and/or hypersaline lakes. Among these are Owens Valley, Searles Valley, Panamint Valley, Manix Basin, Tecopa Basin, and Death Valley. Lacustrine and playa deposits are sensitive recorders of climate variations; consequently, a local climatic record related to fluctuating depositional environments can be pieced together if suitable age constraints are obtained.

In the Confidence Hills of southern Death Valley, late Pliocene to early Pleistocene sediments have been folded between two branches of the Southern Death Valley fault during at least two episodes of deformation (Troxel & Butler 1986; Gomez et. al. 1992, this volume). These playa and/or lacustrine sediments, informally named the 'Confidence Hills Formation' (Beratan et al., 1992, this volume), have then been eroded by streams (approximately perpendicular to the fold axes) which drain east to west from the Owlshead Mountains, to the Amorgosa River. Stratigraphically highest are alluvial fan deposits which form a broad anticline and unconformably overlie the lacustrine sediments.

Sedimentary rocks in the Confidence Hills consist mainly of claystones to sandstones with interbedded evaporites and volcanic ashes (Beratan et al., 1992, this volume). Of the 15 ashes within the part of the section studied, three have previously been identified by chemical fingerprinting using electron microprobe analyses (Troxel et. al., 1986). In the field, only the Huckleberry Ridge ash could be identified reliably because of its thickness and distinctive gray color.

The magnetostratigraphic section is along a major canyon identified by Troxel et al. (19$6), located in the southern part of the area mapped by Gomez et al. (1992, this volume) and informally designated as 'Confusion Canyon'. Nearly perfect, bed-by-bed exposures of sediments within the sequence crop out on the northeast limb of a major anticline, where beds dip steeply at nearly 90° with a regional strike of about N40W. Beratan et al. (1992, this volume) provide evidence in the form of ripple marks, cut and fill features, etc., that these beds are in fact overturned. The section is continuous, undisturbed by faulting or tight folding (Gomez et. al. this volume). Similar work is in progress in canyon N2 of Gomez et al. (1992, this volume), in which the sediments dip approximately 30o to the SW; together these should provide good structural control for a paleomagnetic fold test.

METHODS

Oriented samples of the playa and lacustrine sediments were collected by drilling with a gasolinepowered diamond-tipped bit cooled with compressed air. Samples were collected in stratigraphic succession from the steep walls of two canyons in order to minimize the effects of weathering. A continuous composite of these

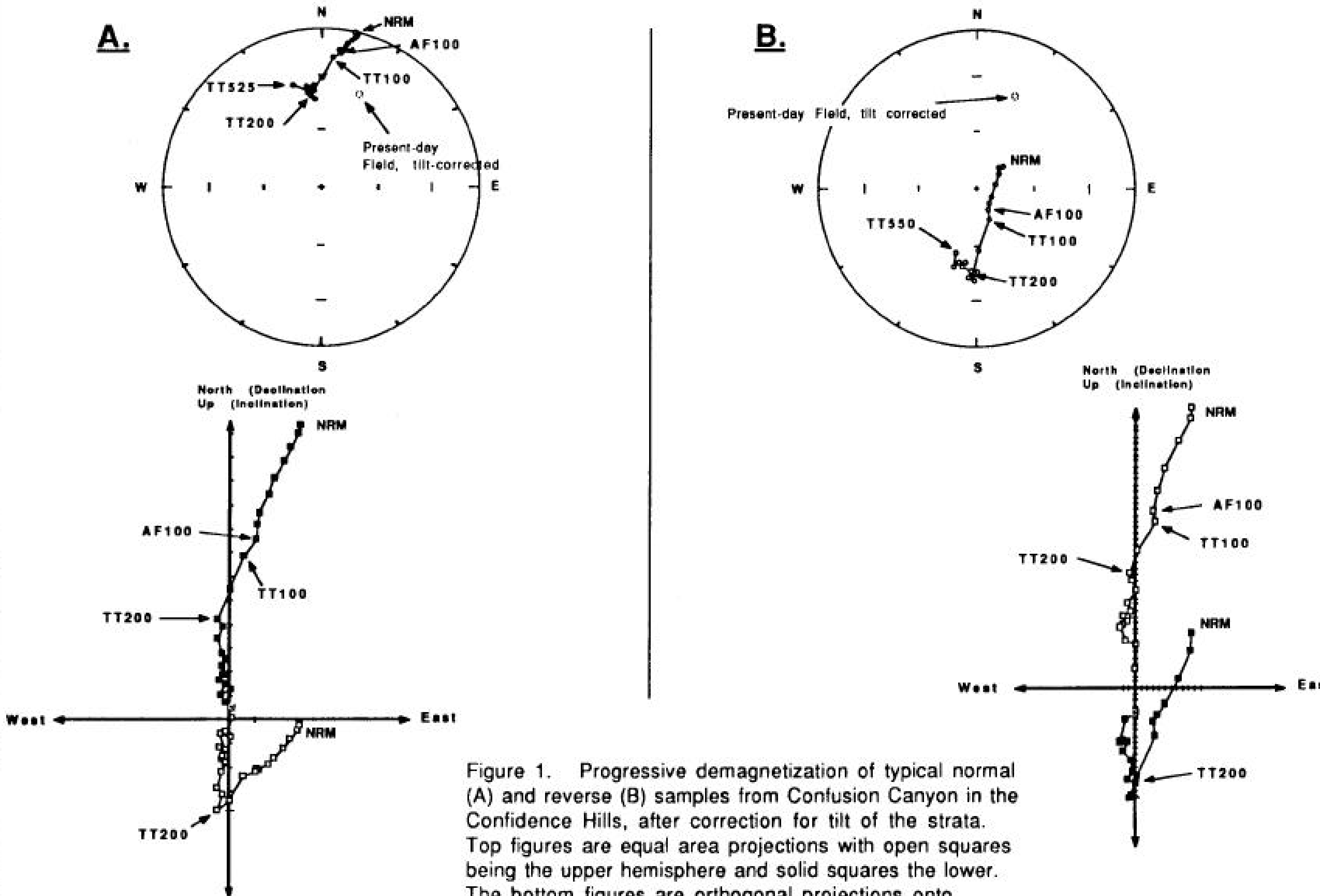


Figure 1. Progressive demagnetization of typical normal (A) and reverse (B) samples from Confusion Canyon in the Confidence Hills, after correction for tilt of the strata. Top figures are equal area projections with open squares being the upper hemisphere and solid squares the lower. The bottom figures are orthogonal projections onto horizontal and vertical planes, the declination (solid squares) being depicted in the horizontal and the inclination (open squares) projected onto the vertical.

was assembled using marker beds for stratigraphic control. Any fractured samples were consolidated in the laboratory using ceramic cement.

Measurements were made using a computer-controlled SQUID (superconducting quantum interference device) magnetometer with a background noise level of 5 x 10-12 Am'. Progressive demagnetization experiments were performed in order to isolate characteristic components of the NRM. The demagnetization consisted of 3-axis alternating field (AF) demagnetization in several steps up to 15 millitesla (mT). This technique removes magnetically viscous components that probably result from large multi-domain grains of magnetite. This was then followed by progressive thermal demagnetization, stepping from 1500 to 500oC at 50o intervals. This technique preferentially removes the magnetic components caused by weathering products such as maghemite, goethite, and fine grained hematite relative to that of detrital magnetite.

In an attempt to place constraints on the mineralogy and magnetic granulometry of the material which pr- - preserves the magnetic remanence, small amounts (approximately 0.1 g) of material were removed from representative fine-grained samples and subjected to a battery of rock-magnetic analyses. These sub-samples were disaggregated by gentle crushing, placed in a 1 ml plastic epindorph tube, sealed with a small volume of parafin, and loaded into the fully computer-controlled SQUID magnetometer system housed in the Caltech biomagnetics clean laboratory. Standard rock-magnetic experiments included, in order, (1) an acquisition of Anhysteretic Remanent Magnetization (ARM) in a 100 mT alternating field, with progressively stronger background biasing fields between 0 and 2 mT as done by Cisowski (1981), (2) the progressive AF demagnetization of the ARM after the 2 mT ARM step, (3) the progressive AF demagnetization of a 100mT Isothermal Remanent Magnetization (IRM), and (4) an IRM acquisition experiment in pulsed fields up to 800 mT.

RESULTS

Demagnetization Analysis

Figure 1 shows demagnetization results of typical normally and reversely magnetized samples from the Confusion Canyon section. The intensity of the NRM was exceedingly strong for sediments, usually about 1 x 10-3 Am2/Kg. This is probably due to the incorporation into the sediments of detrital magnetite derived from nearby crystalline rocks of the Owlshead Mountains. Most of the samples measured contain a magnetic component parallel to the present geomagnetic field direction which could be removed by low-intensity alternating fields (< 15 mT) and by thermal demagnetization below 250oC. These components are probably due to large crystals of multi-domain magnetite, which the AF demagnetization can remove, and magnetic weathering products such as ilmenite and maghemite, which can be removed in the progressive thermal demagnetization experiments.

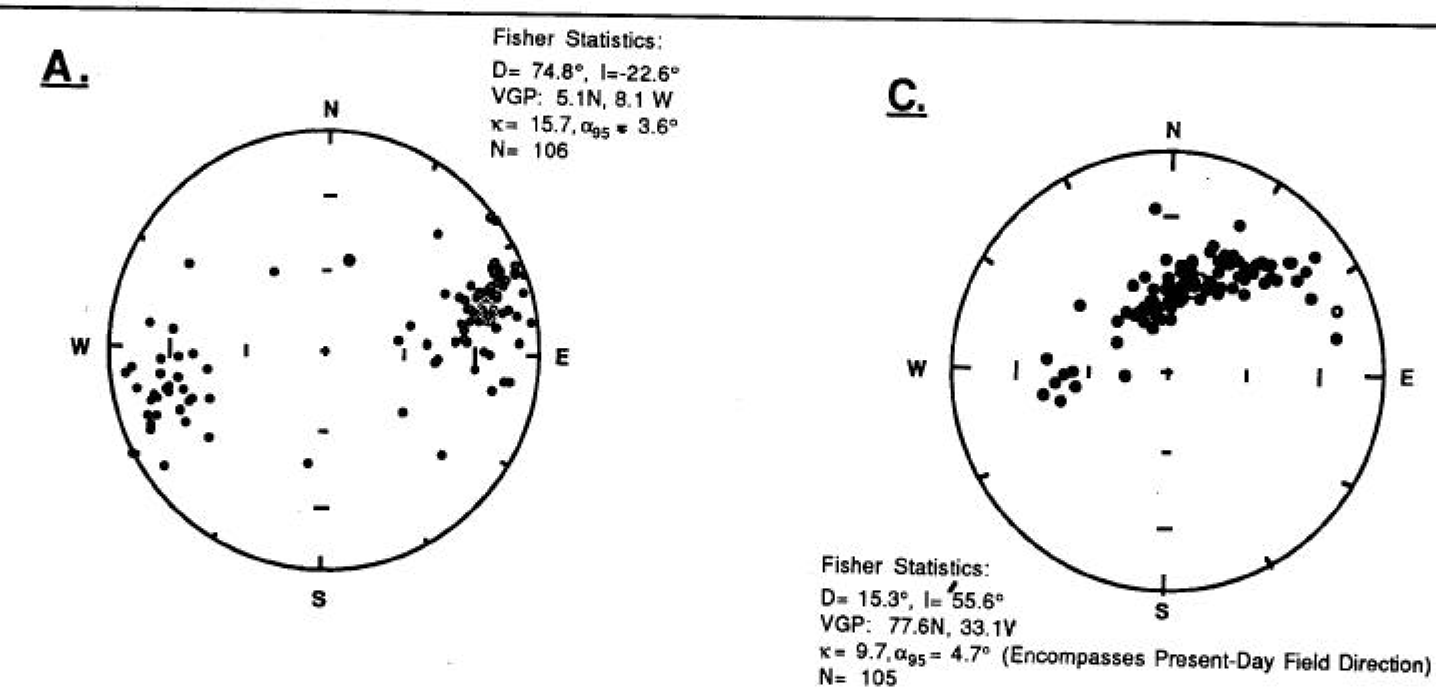
Due to the large dip of the beds in Confusion Canyon, the magnetic overprint associated with the present geomagnetic field is nearly perpendicular to, and hence readily distinguished from, the primary normal and reverse directions of magnetization. (This is a rather rare situation in such young rocks). Thus the overprint is clearly recognizable in standard orthogonal projections of the demagnetization data for each sample. The characteristic (depositional) components are then separated with standard Principal Component Analysis (Kirschvink, 1980). Figure 2 shows the normal and reversely magnetized characteristic components, before and after correction for dip of the beds.

Field Stability Tests and Tectonic Rotation

A reversal test, which compares the mean directions of the normally and reversely magnetized strata to test for antiparallel orientation, was performed on data from the Confusion Canyon section. The Fisher test for common mean directions (e.g., Fisher et al., 1987) and the data of Figure 2 indicates that the directions are indeed antiparallel with a high degree of confidence (e.g., the null hypothesis that the directions are antiparallel cannot be rejected at any standard level of significance). These results along with the excellent match of the polarity zones in Confusion Canyon to the standard geomagnetic reversal time scale (discussed below), and the simple twocomponent demagnetization paths, provide further support for the interpretation that the stable magnetic remanence was acquired at the time of deposition of the sediments, or shortly thereafter. The mean directions from the characteristic components of Figure 2 also indicate that the sediments in Confusion Canyon have not been subjected to net tectonic rotation, in contrast to sediments of this age in other areas of the Mojave desert (e.g., Pluhar et al., 1991).

Rock Magnetic Analysis

Figure 3 shows a representative coercivity spectrum measured from a sample of the Confidence Hills formation in Confusion Canyon. For the IRM acquisition data, roughly 90% of the intensity is acquired after exposure to peak fields of less than 300 mT. This suggests that the mineral magnetite dominates the magnetic materials present in the sediments. However, the fact that these samples continue to acquire a small amount of magnetic remanence in higher fields suggests that minerals like fine-grained hematite or goethite are also present. These are probably responsible for the secondary component of magnetization produced by weathering as noted earlier in the demagnetization analysis. Finally, for virtually all of these samples the demagnetization of the ARM is magnetically more difficult than for the lItM, confirming that the main carriers of the magnetic remanence are probably within the single-domain or



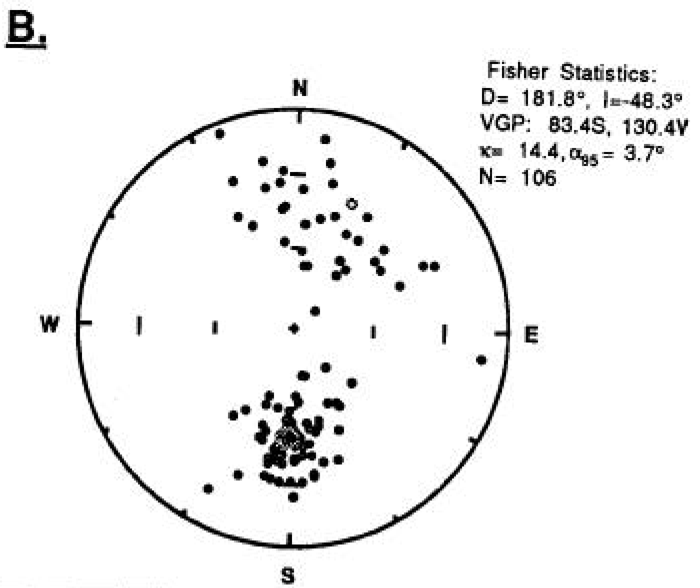


Figure 2. Equal-area projections of the characteristic directions as isolated by least-squares analysis before and after correction for tilt of the strata.
(A) shows all samples before correction for tilt,
(B) shows all samples after correction for tilt, and
(C) shows the secondary overprints (tilt-corrected) which cluster around the present-day magnetic field.

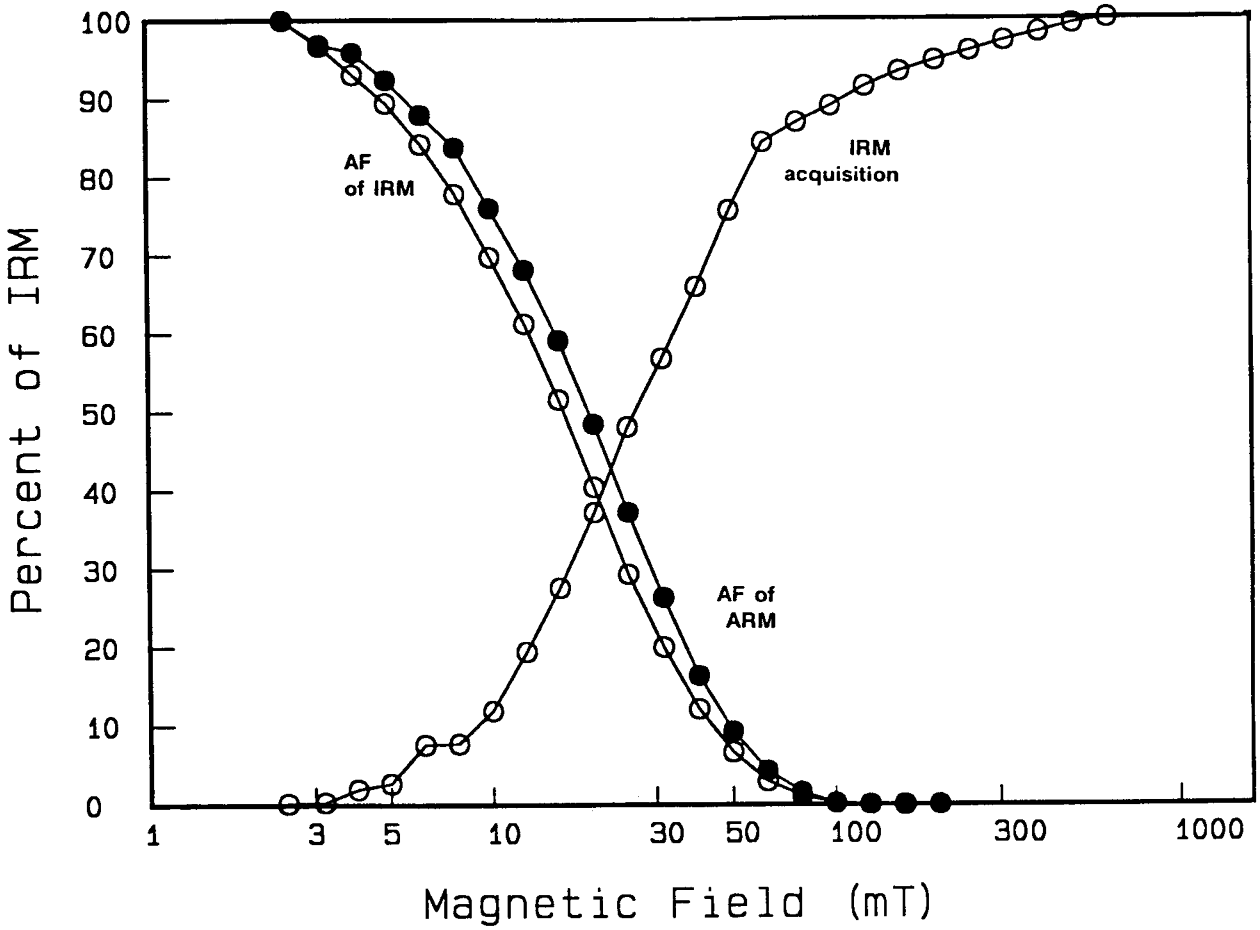


Figure 3. A typical coercivity distribution for a sample from the Confidence Hills formation. Data for the IRM acquisition and AF demagnetization are shown with open circles, whereas the solid circles show the AF demagnetization of the ARM acquired in a 2 mT direct current biasing field and a 100 mT alternating field.

pseudo single-domain size range (e.g., a positive ARM Lowrie-Fuller Test as described by Johnson et al., 1985). Hence, these properties are consistent with an early acquisition of remanence through the deposition of finegrained magnetite.

Magnetostratigraphy and Deposition Rates

Virtual Geomagnetic Pole (VGP) latitudes calculated from the least-squares directions of all samples are plotted in Figure 4 with respect to stratigraphic position within the section. Note that some of the directions (below 80m and above185m) are preliminary since the samples from these sections have not been completely demagnetized. The stratigraphic column adapted from Beratan and Murray (this volume) is presented alongside for reference. The .fact that the VGP latitudes are grouped stratigraphically into bounded normal and reversed zones strongly supports the interpretation that the primary magnetic directions were acquired at the time of or soon after deposition of the beds.

The magnetostratigraphic section contains three reversed polarity zones (two of them are unbounded in one direction) separated by two normal polarity zones. The middle reversed zone contains the c.a.. 2 Ma Huckleberry Ridge ash as correlated by Troxel et. al. (1986). The normal zone stratigraphically above this marker bed is interpreted to be the Olduvai normal subchron. The normal zone below it records the relatively short Reunion event.

Average deposition rates for the Confidence Hills formation are best calculated using the stratigraphic positions of astronomically-calibrated magnetic reversal horizons since many of the K/Ar techniques used in past studies have been shown recently to be in error by as much as 5 to 7% (Shackleton et al., 1990; Walter et al., 1991). Numerical dates for the magnetic reversals used here are those proposed by Shackleton et al. (1990), Hilgen (1991), and Zijderveld et al., (1991), and are based on calibrations from deep sea sediments which preserve

Figure 4. Paleomagnetic record in the Confusion Canyon of the Confidence Hills. The polarity timetable was adapted from that of Harland et al., (1989), with the revised ages of Hilgen (1991), Zijderveld et al. (1991), and Shackleton et al., (1990). Sedimentary column adapted from Beratan and Murray (this volume). Data below 80m is preliminary, due to incomplete sample demagnetization.

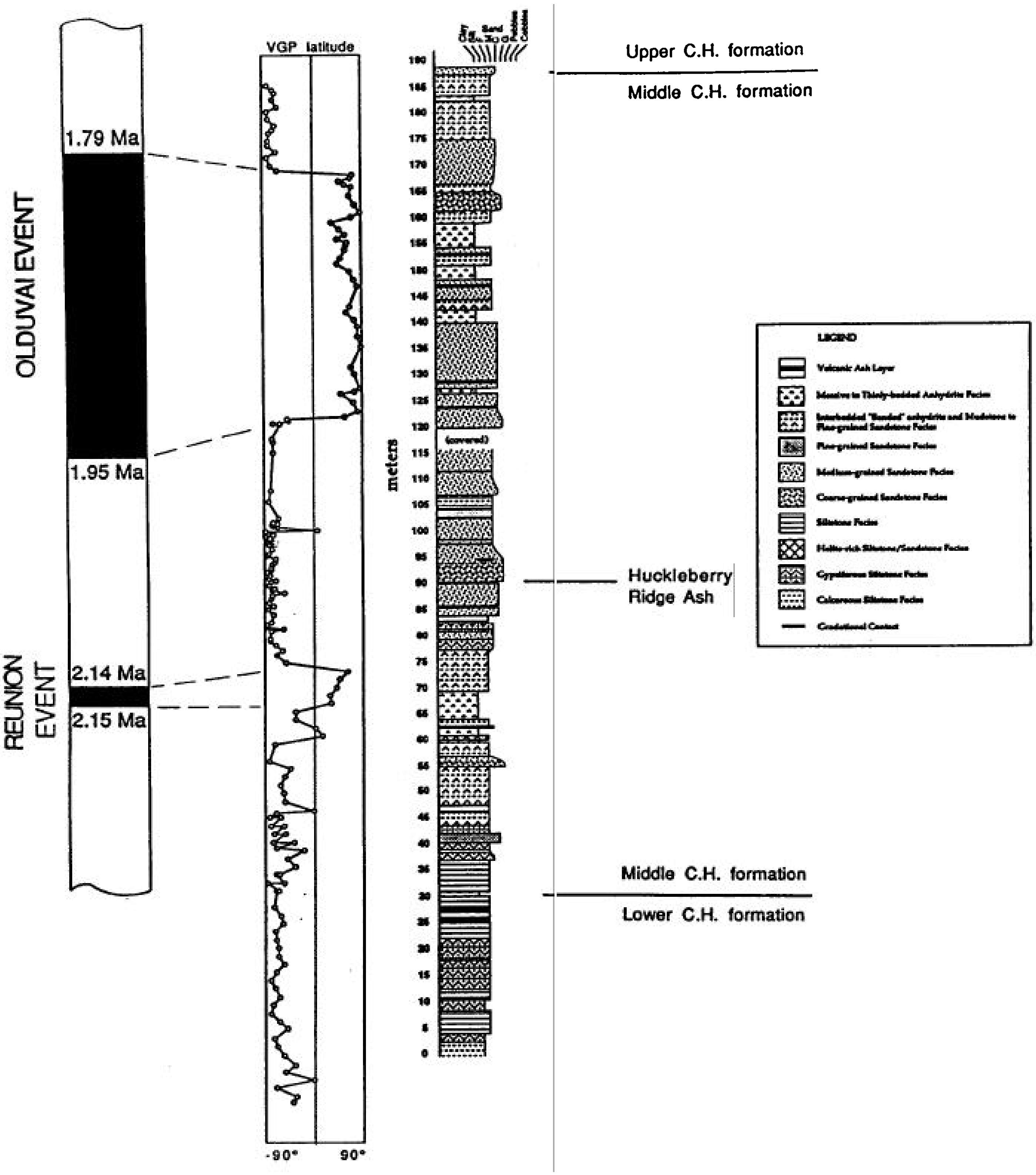


Table 1. Paleomagnetic control points for sedimentation rate determination and ash beds located In Beratan and Murray (1992) with interpolated ages.

A. Control Points

Magnetic Reversal	Position in Section (m)	Age (Ma)*	Reference
Olduvai Top	168.0	1.79	Hilgen, 1991
Olduvai Bottom	122.5	1.95	Hilgen, 1991
Reunion Top	77.0	2.14	Hilgen, 1991
Reunion Bottom	72 (approx.)	2.15	Hilgen, 1991

Average Sedimentation Rate (cm/kyr)
Olduvai Top to Olduvai Bottom: 28.4
Olduvai Bottom to Reunion Top: 23.9
average: 26.2

B. Ash units with interpolated ages

Ash Unit	Position in Section (m) (approximate)	Thickness (cm)	Interpolated Age (Ma)	Brief Description
15	161.3	3	1 .81	white, lens
14	154.5	3	1.84	white, lens
1 3	153.3	1 5	1.84	lower 6cm very white
12	147.4	1 0	1 .86	white
11	147.0	15	1.86	white, upper 11cm reworked
1 0	128.5	8	1 .93	white
9	128.0	1 0	1 .93	white
8	124.0	3	1 .94	white
7	104.0	9	2.03	white
6	102.5	45	2.03	white, upper 25cm reworked
5	98.5	1 0	2.05	white
4	98.0	7	2.05	white
3	94.8	2	2.07	grey
2	90.0	40	2.09	grey with white (Huckleberry Ridge Ash)**
1	85.5	25	2.10	white, upper 17cm reworked

* Errors on the dates for the Olduvai and Reunion events are unknown. See Hilgen (1991) for a discussion of these dates.
**Huckleberry Ridge Ash is dated at approximately 2.0 Ma (Izett, 1981). Much uncertainty surrounds this date, although exact errors are not given.

the climatic records of orbital perturbations (Milankovitch cycles). These ages are shown in Table 1, along with the position of each reversal in the lithostratigraphic column of Beratan and Murray (1992, this volume). As the base of the Reunion event in this section is partially obscured by slumping, only the top o f this event is used for estimates of deposition rates. Hence, the 45.5 meters of sediment between the top of the Reunion event and base of the Olduvai yields a rate of 23.9 cm/ky, and the 45.5 meters of sediment between the base and top of the Olduvai subchron implies a rate of 28.4 cm/ky. An additional temporal constraint is the absence of normal polarity rocks at the base of this section. This indicates that they are younger than the Gauss chron which ended at 2.59 Ma. Hence, the total 79.5 meters of section between the top of the Olduvai subchron and the top of the Reunion event exhibit a minimum deposition rate of 17.7 cm/ky.

It is important to note that such consistently high deposition rates make the Confidence Hills an excellent location to study the characteristics of geomagnetic field reversals (e.g. Holt et al., 1991).

DISCUSSION

The almost 200 meter thick section of playa and lacustrine sediments in Confusion Canyon yields a highly detailed magnetos tratigraphic record. Identification of the Huckleberry Ridge ash within the section provides a dated stratigraphic marker which permits correlation of the lithostratigraphic section with the magnetic polarity time scale. Deposition of the Confidence Hills formation began substantially before the Reunion event (2.14 - 2.15 Ma), during the late Pliocene, continued through the Reunion event and the Olduvai subchron, and ended substantially after the end of the Olduvai subchron (1.79 Ma) during the Quaternary. Deposition rates averaged about 26 cm/ky.

Many volcanic events are recorded in the sediments (including the eruption of the Huckleberry Ridge ash). Based on deposition rates and stratigraphic position relative to the dated magnetic reversal horizons, an extrapolated age can be assigned to each ash. Table 1 gives these interpolated values for the ages of the 15 ashes recognized in the Confusion Canyon section.

ACKNOWLEDGEMENTS

Supported by NSF grant EAR-9019289 to JLK and by a California Institute of Technology Summer Undergraduate Research Fellowship (SURF) to CJP.

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