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RESEARCH NOTE

Mono Lake Excursion in the Lahontan Basin, Nevada

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SUMMARY

In the Lahontan Basin of north-western Nevada, the Mono Lake Excursion is recorded in a wave-cut bank at Pelican Point on the west side of Pyramid Lake. The record is almost identical to one across the lake near Pyramid Island, 10 km away, and in the Carson Sink, 60 km further to the east. At each locality, the older half of the excursion is present only as a reduction in the relative field intensity, while the younger half shows the expected easterly declination and steep positive inclination that result in a small counterclockwise loop of the virtual geomagnetic poles. The younger half occurs during high relative field intensity, and the entire intensity pattern is similar to the one for the excursion in the Mono Basin, California, 250 km to the south.

The presence of only part of the Mono Lake Excursion in the Lahontan Basin might have resulted from the slow sedimentation rate in Pyramid Lake (estimated to be about 12 cm kyr^{-1}), with the field behaviour being more extensively integrated in the subsamples used. In an alternate explanation, the absence of the older part of the excursion can be attributed to overprinting when magnetic grains that were free to rotate in unconsolidated sediment were realigned during the high relative field intensity in the younger part of the excursion.

Key words: geomagnetic reversals, Lahontan Basin, magnetic polarity, Mono Lake Excursion.

INTRODUCTION

It has been shown that the Mono Lake Excursion is recorded in a large part of the Great Basin in western North America (Denham & Cox 1971; Liddicoat & Coe 1979; Negrini, Davis & Verosub 1984; Liddicoat 1992; Negrini & Davis 1992; Negrini 1994) and in the Gulf of California (Levi & Karlin 1989). Although those discoveries were slow in coming, they were advanced when a volcanic ash layer (Denham & Cox 1971; Liddicoat & Coe 1979; Liddicoat 1992) or a sequence of ash layers (Davis 1977, 1978; Verosub, Davis & Valastro 1980) was used to identify the stratigraphic interval in which the excursion might be present. The Wono Bed is one such ash layer, as is the Carson Sink Bed that is stratigraphically beneath it. Both ash layers were used in the search on the eastern shore of Pyramid Lake in the Lahontan Basin, Nevada (Verosub *et al.* 1980), and in the Carson Sink, 60 km to the east (Liddicoat, Lajoie & Sarna-Wojcicki 1982; Liddicoat 1992). The Carson Sink Bed is a particularly valuable marker horizon because it is chemically similar to the Wilson Creek Ash Bed 15 (Liddicoat *et al.* 1982; Sarna-Wojcicki *et al.* 1991) that is midway in the excursion in the Mono Basin, California (Liddicoat 1976; Liddicoat & Coe 1979).

Recently, another attempt was made to locate the Mono Lake Excursion in the Lahontan Basin using the Wono Bed as a marker horizon near Pelican Point on the western side of Pyramid Lake. The palaeomagnetic results, reported herein, supplement the data from near Pyramid Island on the opposite side of the lake, and are compared with the records from the Carson Sink (Liddicoat 1992) and the Mono Basin (Liddicoat & Coe 1979), where the recording process in the sediment has been investigated (Coe & Liddicoat 1994).

LOCALITY, STRATIGRAPHY, AND LABORATORY PROCEDURES

The late Pleistocene stratigraphy exposed along the eastern shore of Pyramid Lake where the Mono Lake Excursion was found previously (Liddicoat 1992) is described by Davis (1977, 1978) and Verosub *et al.* (1980) and is assigned to the Sehoo Alloformation by Morrison (1991). A similar section of clay, siltstone, and volcanic ash layers is exposed on the western side of the lake in a wave-cut bank at Pelican Point (Fig. 1).

The Trego Hot Springs Bed (age 21 800 years; Negrini & Davis 1992) is about 50 cm below the desert surface and is

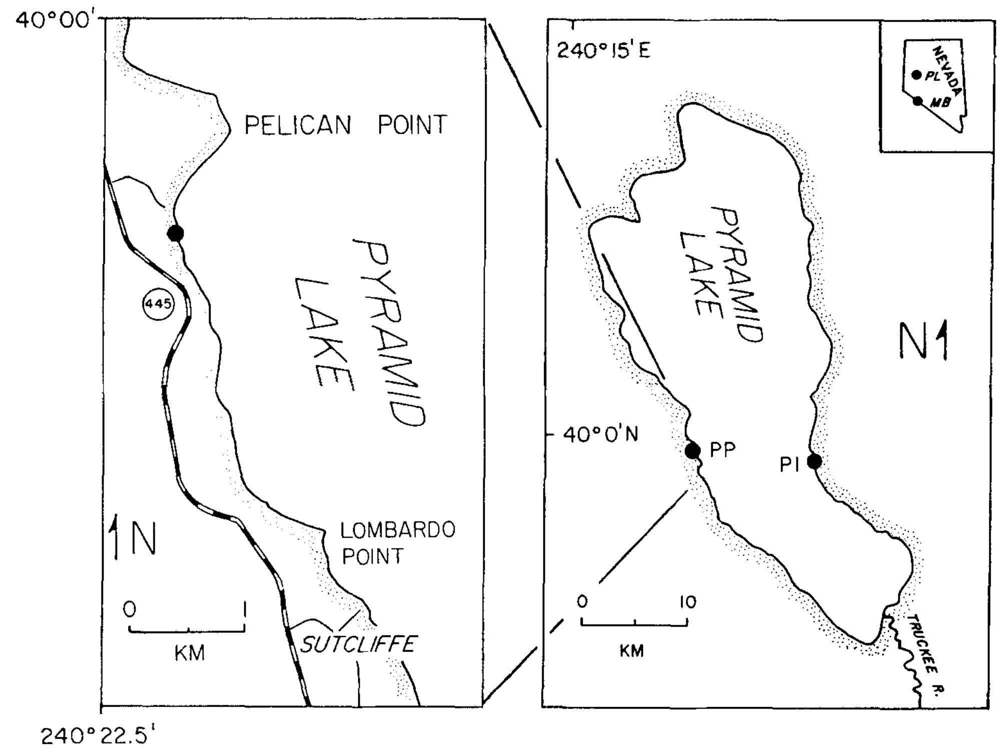

Figure 1. Map of localities (black circles) on the shores of Pyramid Lake (PI: Pyramid Island; PP: Pelican Point), 4 km north of Sutcliffe, Nevada. The sampling site at Pelican Point is 300 m south of the parking area for the boat launching ramp. The inset map shows the Mono Basin (MB), about 250 km south of Pyramid Lake (PL). Pyramid Lake is one degree of longitude west of Mono Lake, and that slightly upwind position might account for the thinness (< 1 mm) of the ash layer at Pelican Point. In the Carson Sink, 60 km downwind of Pyramid Lake and 20 minutes of longitude east of the Mono Craters (the source of the Carson Sink Bed), the ash layer is about 1 mm thick.

30 cm above the Wono Bed (age 24 800 years; Sarna-Wojcicki *et al.* 1991), which is 1.5 cm thick. 121 cm below the Wono Bed, there is a thin (< 1 mm) white volcanic ash in sediment that has dried into columnar blocks. These blocks are up to 15 cm long and have a horizontal separation of several centimetres. On the assumption that the white ash is the Carson Sink Bed (and therefore within the Mono Lake Excursion), oriented hand samples were collected from 22 cm above to 14 cm below the ash in an attempt to locate the excursion. Subsamples (cubes of side 2 cm) were then cut on a band saw and encased in polythyrene boxes for measurement in a 2G, three-channel cryogenic magnetometer. Although the sediment is fragile, which makes it difficult to maintain the orientation while preparing subsamples, as many as three subsamples could be made for many of the measured horizons, and especially for those close to the ash (Table 1). It is not known how much vertical rotation of the columnar blocks occurred as the sediment dried, but it is easy to envision rotation of 5°. The error in the horizontal and vertical orientation of subsamples prepared in the laboratory is estimated to be $\pm 2°$.

The spacing of the measured horizons is back-to-back, and the subsamples in polythyrene boxes were demagnetized stepwise in an alternating field (af) to 60 mT (Fig. 2). Other subsamples that were prepared for thermal demagnetization broke and lost their orientation at temperatures above 200 °C, which prevented further treatment. The af demagnetization was carried out using Schonstedt equipment, and the palaeomagnetic measurements were made in the shielded laboratory at the University of California, Santa Cruz. Measurement of the susceptibility was carried out using a Bartington MS 2 system.

DISCUSSION

The palaeomagnetic record of the Mono Lake Excursion that has been the most thoroughly studied is from the north-western, south-eastern, and eastern sides of Mono Lake, California (Liddicoat 1976; Liddicoat & Coe 1979; Liddicoat 1992; Coe & Liddicoat 1994). The excursion at those localities, some of which are 20 km apart, has two very different patterns of behaviour that bracket the Wilson Creek Ash Bed 15. The first (older) half shows a westerly declination towards about 300° when the inclination is negative (about −30°) and the relative field intensity is low. The second (younger) half has an easterly declination towards about 100° when inclination approaches positive 90° and the relative field intensity is high. During the excursion, the virtual geomagnetic pole (VGP) descends to about 20° North latitude, when a large clockwise loop is formed that is followed by a small counterclockwise loop (Liddicoat & Coe 1979). In Fig. 3 the palaeomagnetic directions at one locality (Wilson Creek) in the Mono Basin provide an example of the field behaviour described above.

The palaeomagnetic record in the Carson Sink and near Pyramid Island on the eastern side of Pyramid Lake does not contain the westerly declination and negative inclination that is recorded in the older half of the Mono Lake Excursion in the Mono Basin, but there is evidence of the reduced field intensity. One such record is for Carson Sink Site C (Liddicoat

Table 1. Palaeomagnetic data for the Mono Lake Excursion, Pelican Point, Nevada.

NO	POSIT	INCL	DECL	INT1	INT2	N	α95	PLAT	PLONG	χ	INT2/χ
17	99	40.8	327.2	3.18	1.18	1	-	57.8	129.2	-	-
16	101	36.4	334.1	3.13	1.13	1	-	60.3	116.3	-	-
15	103	35.6	333.3	2.92	1.04	1	-	59.4	116.7	-	-
14	105	38.5	341.2	2.95	.88	1	-	65.7	107.1	-	-
13	107	47.0	346.7	3.08	1.02	3	11.6	73.9	107.4	1.76	5.79
12	109	63.2	0.0	2.73	1.17	3	9.6	85.3	241.3	1.75	6.69
11	111	59.5	16.9	3.00	1.45	3	1.8	77.1	323.5	2.14	6.78
10	113	69.8	40.5	4.02	1.49	3	7.0	59.7	290.0	1.58	9.43
9	115	71.5	29.0	4.56	1.64	3	11.8	65.1	280.2	2.14	7.67
8	117	71.5	14.9	4.34	1.62	2	19.8	71.1	266.6	1.91	8.48
7	119	65.8	11.3	2.87	1.29	1	-	78.6	281.8	1.91	6.75
6	121	58.0	341.2	2.39	.82	3	19.0	75.4	151.2	1.43	5.73
5	123	62.4	350.7	3.56	1.20	3	28.1	82.1	181.7	1.81	6.62
4	127	59.1	0.5	1.72	.58	3	3.8	89.6	348.1	1.08	5.37
3	129	64.1	353.7	1.92	.60	3	23.0	82.6	204.2	1.13	5.31
2	131	69.7	343.4	2.20	.72	1	-	72.4	206.1	1.35	5.33
1	133	55.2	359.3	1.44	.43	1	-	85.7	68.0	1.01	4.26

NO: Number of the horizon; white bed is at horizon 6
POSIT: Centimetres below the Wono Bed
INCL: Mean inclination (degrees) after a.f. demagnetization at 40 mT
DECL: Mean declination (degrees) after a.f. demagnetization at 40 mT
INT1: Intensity ($\times 10^{-2}$ Am^{-1}) after a.f. demagnetization at 20 mT
INT2: Intensity ($\times 10^{-2}$ Am^{-1}) after a.f. demagnetization at 40 mT
N: Number of subsamples measured
α95: Alpha-95: semiangle (degrees) of cone at 95% level of confidence of palaeomagnetic directions
PLAT: North latitude of Virtual Geomagnetic Pole (VGP)
PLONG: East longitude of VGP
χ: Susceptibility (SI: $\times 10^{-2}$)
INT2/χ: Ratio of intensity following a.f. demagnetization at 40 mT (INT2) and susceptibility ($\times 10^{-1}$)

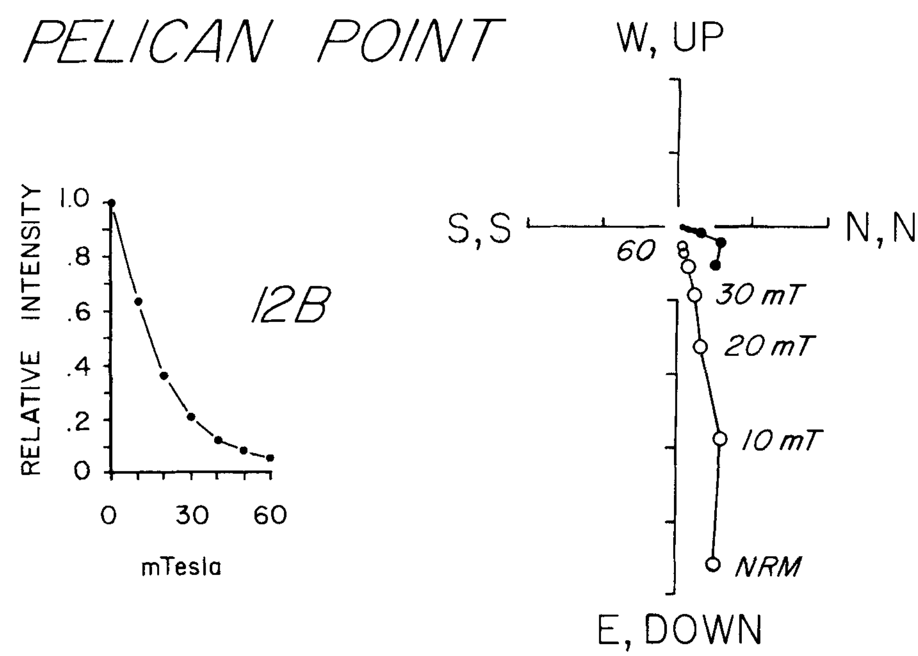

Figure 2. Vector component diagram and normalized intensity for a subsample of the Sehoo Alloformation at horizon 12 in Table 1 (12 cm above the white ash), which was subjected to progressive af demagnetization to 60 mT. Solid circles in the vector plot are projections on the NS–EW plane and open circles are projections on the EW–vertical plane; divisions on the axes are 2.5×10 Am^{-1}.

1992), which is shown in Fig. 3. Among the possible reasons for discovery of the partial record is integration of the palaeomagnetic field in the 2 cm thick subsamples that were used. [In the Carson Sink, the sedimentation rate is estimated to be 12.5 cm kyr^{-1}, or about three times slower than in the Mono Basin (Lund *et al.* 1988). The age in the Lahontan Basin is based on the distance—50 cm—between the Wono Bed and the Carson Sink Bed in the Carson Sink, and the time span—4000 years—using ^{14}C dates and extrapolation between the ash beds (Davis 1977; Liddicoat 1992).] Another reason may be that the magnetic grains were initially aligned parallel to the Earth's field, but that record (formed when the field intensity was reduced) was overprinted as the field intensity increased during the younger half of the excursion (Liddicoat

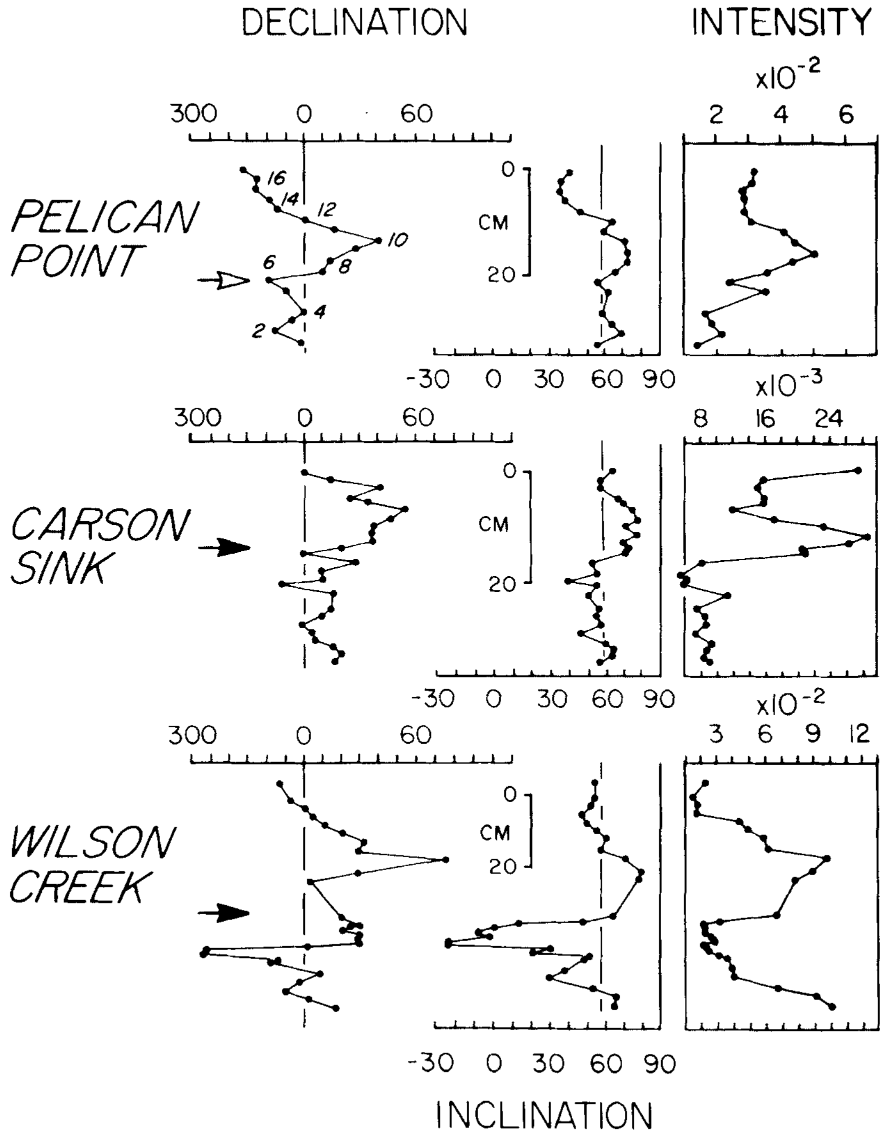

Figure 3. Palaeomagnetic curves for the Mono Lake Excursion at Pelican Point from 22 cm above to 14 cm below the white ash (open arrow), at Carson Sink Site C (Liddicoat 1992), and at Wilson Creek Site A in the Mono Basin (Liddicoat & Coe 1979); solid arrow is the position of the Carson Sink Bed (Wilson Creek Ash Bed 15). Plots are for 20 mT, except declination and inclination for Pelican Point, which is for 40 mT (Table 1). Note that the sedimentation rate is similar for Pelican Point and Carson Sink and it is less than that at Wilson Creek. Above the ash bed, easterly declination at both Pelican Point and Carson Sink occurs when inclination approaches a maximum positive, as it does at Wilson Creek; this is the younger half of the excursion that is recorded everywhere in the Mono Basin. The vertical line in each inclination plot is the inclination of an axial dipole field (59.2°). Intensity is in Am^{-1}, and numbers in the plot for Pelican Point correspond to the numbers in Table 1.

1992). Coe & Liddicoat (1994) examined that possibility for the palaeomagnetic record in wave-cut cliffs on the south-eastern side of Mono Lake, where the older half of the excursion is also partially present in three duplicate records from sites spread over 0.6 km. The proposed aligning mechanism is akin to the laboratory results of Lovlie (1993), who found that the ability of magnetic grains to rotate in a slowly drying epoxy is dependent on the relative field strength. The possibility that the older part of the excursion never occurred in the Lahontan Basin seems unlikely, because westerly declination and negative inclination were found during a restudy of the excursion in Lake Chewaucan sediments in southern Oregon (Negrini 1994), which is 300 km north of the Carson Sink and Pyramid Lake in a direction away from the Mono Basin.

An indication that the relative field intensity was reduced during the older half of the excursion is seen in the plot of normalized intensity, using the ratio of intensity after demagnetization at 40 mT (the alternating field that best defines the primary component of magnetization; Fig. 2), to susceptibility (Fig. 4). In Fig. 4, the relative intensity is reduced by almost a half in the lowermost four horizons (horizons 1 to 4; 6–14 cm below the white ash; Table 1). Above the two horizons of relatively high intensity (8 and 9) that define the younger half of the excursion, there are two horizons (10 and 11) of intermediate strength, and the overlying two horizons (12 and 13) have low relative intensity. This pattern is similar to the curves of unnormalized intensity for Carson Sink and Wilson Creek (Fig. 3) and of normalized intensity using the ratio of intensity to anhysteretic remanent magnetization for

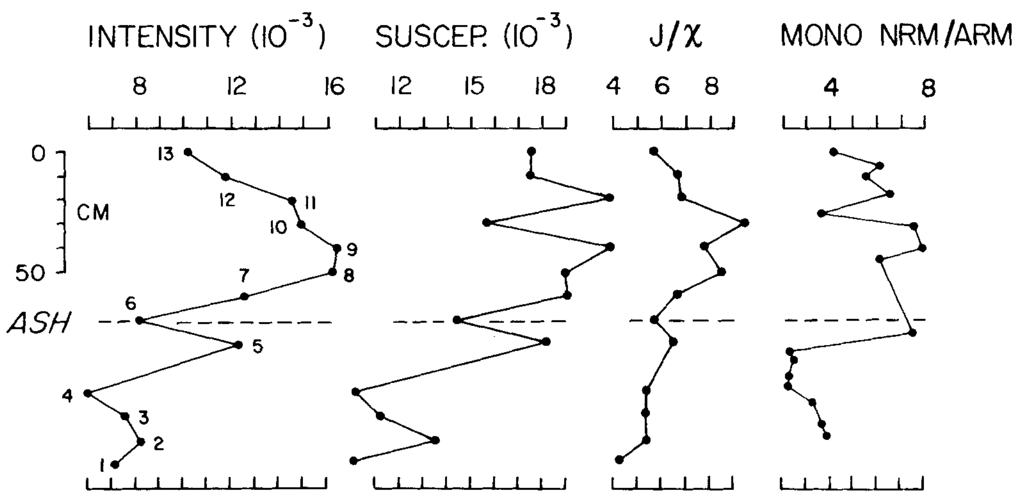

Figure 4. Intensity (Am^{-1}), susceptibility (SI), and ratio of intensity (J) to susceptibility (χ) through the Mono Lake Excursion for Pelican Point, and NRM/ARM for Wilson Creek Site A in the Mono Basin (Liddicoat & Coe 1979). Horizon numbers in the intensity plot are the same as in Fig. 3 and Table 1, and the dashed line is the position of the white ash; for the Mono Basin, the ash is Wilson Creek Ash Bed 15. For J/χ, the scale is $\times 10^{-1}$.

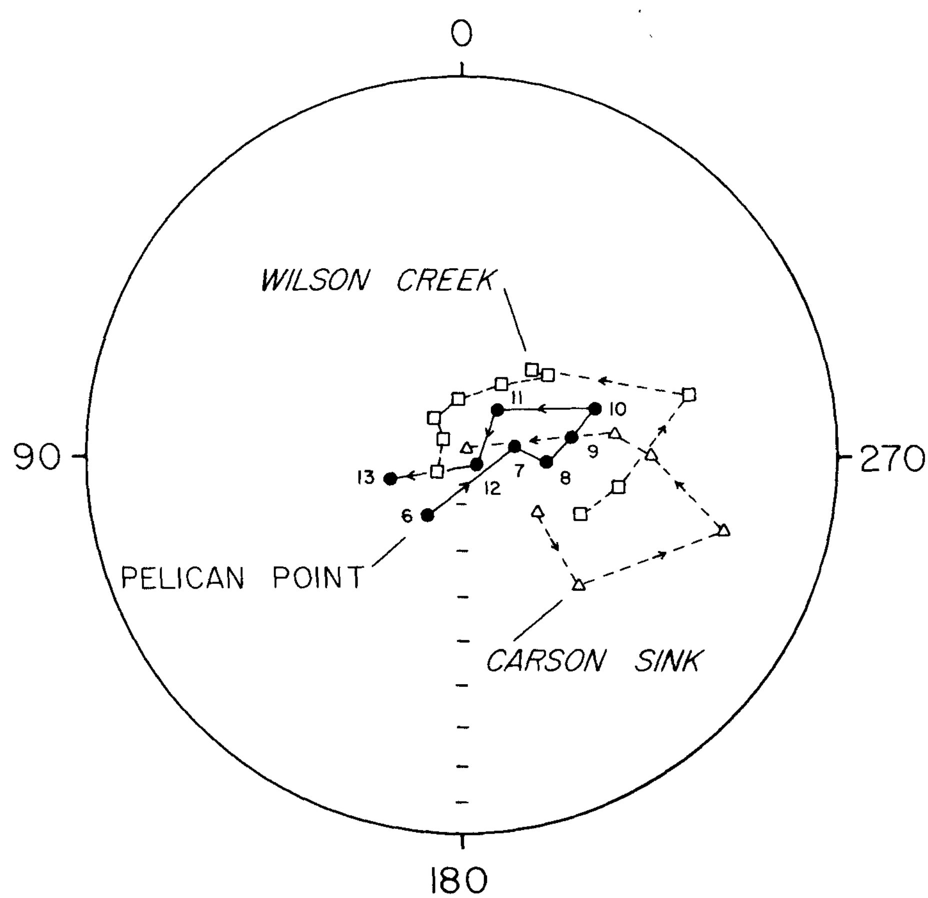

Figure 5. Equal-area plot of the VGPs for the portion of the Mono Lake Excursion above the ash layer (young half of the excursion) at Pelican Point (solid circles), Carson Sink Site A (open triangles; Liddicoat 1992), and Wilson Creek Site A (open squares; Liddicoat & Coe 1979). Numbering of the VGPs for Pelican Point is the same as in Fig. 3 and Table 1. Note that each plot forms a small counterclockwise loop when traced from old to young.

Wilson Creek Site A in the Mono Basin reported by Liddicoat & Coe (1979).

Besides the similarity in the intensity curves for Pelican Point and Carson Sink (Fig. 3), the inclination in each record reaches a maximum, which is almost 15° higher than the inclination of an axial dipole field (59.2°) about 10 cm above the white ash, when declination is most easterly (about 40°); this is the directional behaviour found everywhere in the Mono

Basin during the intensity high (Denham & Cox 1971; Denham 1974; Liddicoat 1976; Liddicoat & Coe 1979; Liddicoat 1992; Coe & Liddicoat 1994). This position in the section at Pelican Point is about 100 cm below the Wono Bed and compares favourably (within 10 cm) with the corresponding position of the steep inclination and easterly declination in the section near Pyramid Island on the opposite side of the lake (Liddicoat 1992). A further indication that the excursion is recorded at Pelican Point is that the VGPs for above the white ash, when traced from old to young, form a small counterclockwise loop that is similar to the one in the Carson Sink and at Wilson Creek in the Mono Basin (Fig. 5).

CONCLUSIONS

(1) The palaeomagnetic record of the Mono Lake Excursion at Pelican Point in the Lahontan Basin is incomplete, in that the older half is absent, except for reduced relative field intensity. The record resembles the excursion on the opposite side of Pyramid Lake near Pyramid Island, and the one in the Carson Sink 60 km to the east.

(2) Factors controlling the discovery or accurate recording of the Mono Lake Excursion in Lake Lahontan sediment may be the sedimentation rate (if too slow, the field directions are integrated in the subsamples) and the relative palaeomagnetic field intensity. If that intensity is reduced by a half or more, but recovers to the pre-reduction level before the aligned magnetic grains have been prevented from movement by a natural mechanism such as compaction, the original directional record may be partially or entirely eliminated.

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