Paleomagnetic Investigation of the Bonneville Alloformation, Lake Bonneville, Utah

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Received February 25, 1998

Paleomagnetic secular variation in a portion of the Bonneville Alloformation is compared with secular variation in lacustrine sediments in the Mono Basin, California, and with secular variation in Lake Lahontan sediments in the northwestern Great Basin. The comparison places an age of about 18,000 yr B.P., and a span of 1000 to 3000 yr, on part of a transgressive stage of Lake Bonneville near Delta, Utah, that is coeval with a wet period in the Lahontan Basin. © 1998 University of Washington.

Key Words: Lake Bonneville; Mono Basin; Lake Lahontan; Pleistocene; paleomagnetism; secular variation; geochronology; Utah; California; Nevada.

INTRODUCTION

For more than a century following the classic report by Gilbert (1890), Lake Bonneville in the northeastern Great Basin (Fig. 1) has been one of the most thoroughly studied Pleistocene lakes in the world (Scott et al., 1983; Morrison, 1991; Oviatt et al., 1994). Among the academic interests in the lake is a record of paleoclimatic changes preserved in the lacustrine deposits (Morrison, 1991; Oviatt, 1997). A chronology for this record is based on radiocarbon and U-series dates (Broecker and Kaufman, 1965; Kaufman and Broecker, 1965; Thompson et al., 1990; Oviatt et al., 1992) and aminostratigraphy (Oviatt et al., 1994). The paleomagnetic data we report correspond to a transgressive phase of Lake Bonneville in the latest Pleistocene by comparing long-term paleoclimatic changes (secular variation) of the paleomagnetic field in a portion of the Bonneville Alloformation near Delta, Utah, with secular variation in lake sediments in the Mono Basin, California (Lund et al., 1988), and Lahontan Basin, Nevada (Liddicoat and Coe, 1997).

HISTORICAL BACKGROUND

When we began this investigation in the early 1970s, we sampled Lake Bonneville sediments in the Delta area because radiometric dates (Broecker and Kaufman, 1965; Kaufman and Broecker, 1965) indicated that the sediments were deposited when an anomalous feature of the paleomagnetic field we were trying to locate—the Mono Lake Excursion (Denham and Cox, 1971)—was believed to have occurred. During the investigation, we did not find the excursion, which was assigned a radiocarbon age of about 24,000 yr B.P. (Denham and Cox, 1971). Moreover, knowledge about the secular variation in the Mono Basin was not sufficiently detailed that a confident match could be made to our curves of declination and inclination in the Bonneville Basin. Since then, the record of secular variation for the latest Pleistocene has been refined not only in the Mono Basin (Liddicoat and Coe, 1979; Lund et al., 1988; Liddicoat, 1992, 1996; Coe and Liddicoat, 1994) but elsewhere in the western United States (Verosub et al., 1980; Doh and Steele, 1983; Nebrini and Davis, 1992; Liddicoat and Coe, 1997; Glen and Coe, 1997). These studies prompted us to reexamine the record of secular variation in the Bonneville Alloformation as a chronologic tool.

The paleomagnetic secular variation for the Mono Basin is recorded in sediments from Pleistocene Lake Russell (of which Mono Lake is the remnant) in a combined section from wave-cut cliffs on the southeastern side of Mono Lake (Lund et al., 1988; Coe and Liddicoat, 1994) and from the bank of Wilson Creek on the northwestern side of the lake (Denham and Cox, 1971; Liddicoat and Coe, 1979; Lund et al., 1988). Radiocarbon dating and paleomagnetic secular variation correlations between the record at Wilson Creek and radiocarbon-dated marine sediments indicate that the top of the section in the wave-cut cliffs is about 13,000 yr old and the base of the
exposure at Wilson Creek is no younger than about 36,000 yr (Lund et al., 1988; Benson et al., 1998).

The secular variation in Lake Russell sediments in the Mono Basin has been used in the Lahontan Basin as a means of correlating portions of the lacustrine stratigraphy and lake histories in the two basins. On the basis of that correlation, a high stand of Lake Lahontan (Benson et al., 1995) filled the valley of the Truckee River south of Pyramid Lake from about 19,000 to 16,000 yr B.P. (Liddicoat and Coe, 1997).

LOCALITY, STRATIGRAPHY, AND FIELD AND LABORATORY PROCEDURES

Lake Bonneville sediment is exposed in natural and excavated outcrops at many localities in the Bonneville Basin. In the Sevier Delta, the deposits are assigned to two major cycles of Lake Bonneville (Oviatt et al., 1994). The paleomagnetic sampling was in a portion of the Bonneville Alloformation

FIG. 1. Map of western United States showing Lake Bonneville (stippled) and paleomagnetic localities (filled circles).

FIG. 2. Map of Delta, Utah, area. The 10-m unit of the Bonneville Alloformation was sampled about 2 km east of Lynndyl at Locality D62 (filled circle).

FIG. 3. Stroeg field magnetization versus temperature heating and cooling curves for a magnetic separate from the sampled unit of the Bonneville Alloformation. Upper diagram, heating in air; lower diagram, heating in vacuum. Experiments were done in the Rock Magnetic Laboratory, U.S. Geological Survey, Menlo Park, CA.
exposed in a gully eroded into the west side of a large flat area above the left (eastern) bank of the Sevier River several kilometers east of Lynndyl, Utah (NE 1/4 and NW 1/4 of the SW 1/4, sec. 18, TSS, R4W, Millard County; 39°30.92'N latitude, 112°20.93'W longitude; altitude 1449.7–1460.4 m (4755–4790 ft)) (Fig. 2). The locality is identified as D62 on the generalized geologic section and is within the silt and clay facies of the Taylor Flat subunit of Unit A in the report by Varnes and Van Horn (1991). According to Oviatt et al. (1994), their locality L20 is the same as D62 and lies within the transgressive-phase underflow fan unit of the Bonneville Alloformation. Henceforth, the section used for paleomagnetism will be referred to as the “unit.”

The unit is about 10 m thick and is siltstone of uniform lithology and horizontal bedding. It overlies another 10-m-thick unit of interbedded siltstone and fine- to medium-grain unconsolidated sand. Gastropods collected from the sand yielded 14C ages in the range of 19,500 to 20,500 yr. Gastropods also were taken for amino acid epimerization (Oviatt et al. 1994).

FIG. 5. Paleomagnetic curves for the sampled unit of the Bonneville Alloformation for a.f. demagnetization at 10 mT. Vertical line in the plot of inclination is the inclination of an axial dipole field (59°). Intensity is Am⁻¹.

FIG. 6. Equal area plot of mean paleomagnetic directions for 10 mT a.f. demagnetization for seven sites at locality D62 on the same bed along a lateral distance of 375 cm.
TABLE 1
Consistency Test of Paleomagnetic Directions at One Horizon in the Sampled Unit of the Bonneville Alloformation

<table>
<thead>
<tr>
<th>Site number</th>
<th>Separation*</th>
<th>Inclination*</th>
<th>Declination*</th>
<th>N</th>
<th>(\alpha_{95})*</th>
</tr>
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<tbody>
<tr>
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<td>0</td>
<td>53.9</td>
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<td>6</td>
<td>2.9</td>
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<tr>
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<td>353.2</td>
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</tr>
<tr>
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<td>353.7</td>
<td>6</td>
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</tr>
<tr>
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<td>375</td>
<td>51.3</td>
<td>353.0</td>
<td>6</td>
<td>2.9</td>
</tr>
</tbody>
</table>

* Lateral separation (cm) of sites from Site 1.
* Mean inclination (degrees) after a.f. demagnetization at 10 mT.
* Mean declination (degrees) after a.f. demagnetization at 10 mT.
* Alpha-95, radius (degrees) of circle of 95% confidence about mean paleomagnetic direction.

al., 1994). A disconformable contact with pre-Lake Bonneville sediments exposed to the south along the Sevier River marks the base of the lacustrine sequence.

Examined in polished thin sections, the siltstone is well sorted and contains rounded grains of detrital quartz and feldspar ≤80 μm in diameter. Also present are hematite and unidentified opaque angular grains that have a diameter of 20–30 μm. The matrix consists mostly of fine-grained calcite. Portions of many nonopaque grains have been altered and replaced by calcite.

Although some hematite is present in the polished thin sections, X-ray diffraction and thermomagnetic analysis of a magnetic separate identified only magnetite or titanomagnetite as carriers of the magnetization (Fig. 3). The presence of magnetite is consistent with the behavior of subsamples that were thermally demagnetized to an unblocking temperature of 585°C (Fig. 4).

Before preparing an oriented hand sample, ca. 30 cm of the outcrop surface was removed to expose unweathered sediment. In the laboratory, subsamples (cubes 1.5 cm on a side) were cut using a band saw and encased in plastic boxes for measurement in a slow-spin, fluxgate magnetometer. At some horizons, pairs of subsamples were treated by thermal or alternating field (a.f.) demagnetization to either 590°C or 100 millitesla (mT), respectively. The treatment showed that the stable paleomagnetic direction can be isolated by either method of demagnetization (Fig. 4). The accuracy of the horizontal and vertical orientation of field samples and subsamples prepared in the laboratory is estimated to be ±2°.

RESULTS AND INTERPRETATION

Bonneville Alloformation

The sampled horizons are spaced vertically about every 10 cm (Fig. 5) and contain six subsamples each. Within each horizon, the grouping of paleomagnetic directions after a.f. demagnetization at 10 mT does not exceed 7.0° and averages about 4.0° (Liddicoat, 1976). To help determine the quality of the record, a field experiment at one horizon was carried out in which the paleomagnetic directions were measured at seven sites spread laterally over 375 cm on a bedding plane. For each site, six subsamples were demagnetized in a field of 10 mT. Reproduction of the record is excellent (Fig. 6), with the mean paleomagnetic directions overlapping at the 95% confidence level (Liddicoat, 1976; Table 1).

In the field experiment, the 3.9° range in the paleomagnetic directions for inclination, being larger than the 2.2° range for declination, probably is not the result of errors in sample orientation, because the vertical orientation was referred to the bedding plane, which is within 1° of horizontal. A more likely reason for the spread in inclination is variable amounts of inclination error [the difference between the recorded inclination and the inclination of an axial dipole field (King, 1955)] and the mean inclination of 50.6° (compared to 59° of an axial dipole field) for the entire unit also is an indication of possible inclination error.

An inclination error might occur if the magnetization process were detrital remanent magnetization (DRM) that caused magnetic grains settling in the water column to rotate toward the horizontal upon contact with the lake bottom. A magnetization process such as chemical remanent magnetization (CRM), resulting from the growth of a secondary magnetic

![Correlation of curves of inclination and declination for the sampled unit of the Bonneville Alloformation and lake deposits in the Mono Basin (Lund et al., 1988). Black arrows identify the crossover from west to east declination in each record, and white arrows show where declination returned to north at about 16,500 yr B.P. Correlation shown by dashed lines is the alternate correlation discussed in the text. The preferred correlation is shown by solid lines. Vertical line in the plots of inclination is the inclination of an axial dipole field (59°).](image-url)

FIG. 7. Correlation of curves of inclination and declination for the sampled unit of the Bonneville Alloformation and lake deposits in the Mono Basin (Lund et al., 1988). Black arrows identify the crossover from west to east declination in each record, and white arrows show where declination returned to north at about 16,500 yr B.P. Correlation shown by dashed lines is the alternate correlation discussed in the text. The preferred correlation is shown by solid lines. Vertical line in the plots of inclination is the inclination of an axial dipole field (59°).
FIG. 8. Correlation of curves of inclination and declination for the Bonneville Alloformation, Mono Basin (Lund et al., 1988), and Lahontan Basin (Liddicoat and Coe 1997). Black arrows identify the crossover from west to east declination in each record.

mineral, would not produce an inclination error, nor would postdepositional remanent magnetization (PDRM) when magnetic grains in pore spaces are aligned parallel to the ambient magnetic field before compaction of the sediment (Tarling, 1983). On the assumption that the magnetization process is DRM, the paleomagnetic directions—allowing for a systematic inclination error—and fluctuations in the record represent the true behavior of the paleomagnetic field.

Figure 5 shows that the inclination in the lower 2 m of the unit is close to the inclination of an axial dipole field. In the central part of the unit, the inclination shallows to about 40° before averaging about 45° in the upper half of the record. The mean declination in the lower half of the unit remains about 10° west of north and is to the east by a similar amount in the upper half; the declination changes from west to east when the inclination approaches 40°. The mean relative intensity for the entire unit is about $1 \times 10^{-2}$ Am$^{-1}$, and at several horizons in the lower half of the record, the intensity decreases to about $5 \times 10^{-3}$ Am$^{-1}$.

Comparison of Secular Variation Recorded in the Bonneville Alloformation, Mono Basin, and Lahontan Basin

When the paleomagnetic record for the Bonneville Alloformation is compared with the secular variation in the Mono Basin (Lund et al., 1988) (Fig. 7), two possible matches can be found. One is about 18,000 yr B.P. for the center of the unit, with an overall time span of about 1000 yr. The age is based on matching the inclination low in the center of the unit with a similar reduction in the Mono Basin and also on the change in declination from west to east at about the same position in each record.

For the second possibility, the time span is 3000 years, from 19,000 to 16,000 yr B.P. This is based on the return to a north declination (identified by an open arrow in Fig. 7) from near 20° declination in both records, and also on the overall north-northwesterly declination present in the older (lower) half of the records. However, in the Bonneville record 5 m of north-northwest declination precedes 4 m of north-northeast declination, whereas in the Mono Basin no more than 2 m of north-northwest declination precedes 2.5 m of north-northeast declination. For the relative thickness of the two portions of the records to be in reverse order requires differing rates of deposition at the two localities. More difficult to explain is the steepening of inclination near the center of the Mono Basin record (at about 17,000 yr B.P.), a feature not present in the Lake Bonneville record. Once the Bonneville record reaches its low mean inclination of about 45°, there is only a gradual return to steeper inclination in the upper (younger) half of the curve.
FIG. 9. Lake Bonneville and Lake Lahontan chronology inferred from data in Oviatt (1997) and Benson et al. (1995), respectively. Time span shown by hatchure pattern (19,000 to 16,000 yr B.P.) is for the alternate age interpretation for deposition of the sampled Bonneville Alloformation. Modified after Benson et al. (1995, Fig. 9) and Oviatt (1997, Fig. 2).

Depending on which chronology is used, the average sedimentation rate during deposition of the Lake Bonneville unit was about 0.3 or 1 cm yr\(^{-1}\). Although the rate of sedimentation for the Bonneville Alloformation is 10 to 30 times higher than the rate in the Mono Basin (Lund et al., 1988), such a rate seems possible for the Sevier River delta that had a plentiful supply of sediment (Oviatt et al., 1994).

In Figure 8, the secular variation in Lake Lahontan sediment on the western bank of the Truckee River north of Wadsworth, Nevada, is compared with the secular variation in the Mono Basin (Liddicoat and Coe, 1997) and Bonneville Alloformation. The deposition of Lake Lahontan sediment occurred during a high lake stand that inundated the Truckee River valley between Pyramid Lake and Wadsworth from about 19,000 to 13,000 yr B.P. (Benson et al., 1995, 1998; Liddicoat and Coe, 1997) (Fig. 9).

Although the Mono Basin and Lake Lahontan paleomagnetic records match best for inclination, the more prominent changes of declination can be correlated in a general way. For example, from the top of the Lake Lahontan record down to about 16,000 yr B.P., there is a gradual change in declination from east to west. The preceding 2000 yr (18,000–16,000 yr B.P.) are entirely easterly in declination. At about 18,000 yr B.P., declination returns to the west. Inclination is relatively steep at about 14,000 yr B.P., but is preceded by shallowing that followed an earlier inclination high at about 16,000 yr B.P. The high was itself preceded by steepening that began at about 17,000 yr B.P. At the base of the record are 2000 years of shallowing inclination (viewed from old to young). The pattern in the sampled unit of the Bonneville Alloformation is somewhat similar to the record in the Lake Lahontan sediment in that there is overall shallown inclination at about 18,000 yr B.P. and the change from west to east declination occurs near that time.

CONCLUSIONS

Paleomagnetic secular variation in a 10-m-thick unit of the Bonneville Alloformation near Delta, Utah, compared with secular variation in the Mono Basin, California, suggests that the unit was deposited either (1) about 18,000 yr ago over a span of 1000 yr at a rate of 1 cm yr\(^{-1}\), or (2) between 19,000 and 16,000 yr B.P. at a rate of 0.3 cm yr\(^{-1}\). The deposition occurred during a transgressive stage of Lake Bonneville (Oviatt et al., 1994) and coincided with a wet period in the Lahontan Basin (Benson et al., 1995).

ACKNOWLEDGMENTS

We thank S. Liddicoat, D. Varnes, R. Van Horn, R. Morrison, A. Cox, S. Gromme, E. Mankinen, and R. Gordon for assistance in the investigation, and L. Benson for suggesting the longer time span for the sampled Bonneville deposits. Revisions to the manuscript suggested by L. Benson, R. Morrison, and D. Varnes were especially helpful, as was a thoughtful review by W. E. Scott. The use of the paleomagnetism laboratories at Stanford University and the U.S. Geological Survey, Menlo Park, CA, made the investigation possible. Funding was from a GSA Sigma Xi grant (J.C.L.), NSF-NRC Research Associateship at the U.S. Geological Survey (J.C.L.), and NSF Grant GA-36037 (R.S.C.).

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