Paleomagnetic and tephra evidence for tens of Missoula floods in southern Washington

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ABSTRACT

Paleomagnetic secular variation and a hiatus defined by two tephra layers confirm that tens of floods from Glacial Lake Missoula, Montana, entered Washington's Yakima and Walla Walla Valleys during the last glaciation. In these valleys, the field evidence for hiatuses between floods is commonly subtle. However, paleomagnetic remanence directions from waterlaid silt beds in three sections of rhythmically bedded flood deposits at Zillah, Touchet, and Burlingame Canyon display consistent secular variation that correlates serially both within and between sections. The secular variation may further correlate with paleomagnetic data from Fish Lake, Oregon, and Mono Lake, California, for the interval 12,000–17,000 ^{14}C yr B.P. Deposits of two successive floods are separated by two tephras derived from Mount St. Helens, Washington. The tephras differ in age by decades, indicating that a period at least this long separated two successive floods. The beds produced by these two floods are similar to all of the 40 beds in the slack-water sediment sequence, suggesting that the sequence is a product of tens of floods spanning a period of perhaps a few thousand years.

Keywords: Glacial Lake Missoula, jökulhlaups, tephra, paleomagnetic secular variation.

INTRODUCTION

In the 1920s, J. Harlan Bretz (1925, 1928, 1929) proposed an ''outrageous hypothesis''; i.e., cataclysmic floods had coursed across the Columbia Plateau of eastern Washington, carving what he termed the ''Channeled Scabland'' (Fig. 1). Although the evidence Bretz presented for the floods is unassailable, his hypothesis was rudely dismissed, in part because it was catastrophic, but mainly because no source of water for such a vast flood could be imagined (Allison, 1933; Flint, 1938; Hodge, 1938). Pardee (1942) later identified a source for the floodwaters, namely Glacial Lake Missoula, which was impounded by the Purcell Trench lobe of the Cordilleran ice sheet during latest Pleistocene time. Shortly after Pardee published his Lake Missoula paper, opinion on the origin of the Channeled Scabland began to shift, and by the 1950s, Bretz was vindicated (Bretz et al., 1956; Bretz, 1969).

The Missoula floods and the Channeled Scabland, however, have continued to be subjects of controversy. Bretz argued that the Scabland was eroded by a few floods, but other geologists (Waitt, 1980, 1984, 1985; Atwater, 1984, 1986; Smith, 1993) have found evidence for more than 40 great floods from Glacial Lake Missoula at the end of the last glaciation, referred to locally as the Fraser Glaciation. Each of these floods has been ascribed to a glacier outburst, or jökulhlaup, that emptied Lake Missoula and lasted days to weeks. Successive floods were separated by intervals of decades, during which Lake Missoula refilled against the reformed ice dam.

The main evidence for scores of floods comes from valleys in Idaho, Washington, and Oregon that were inundated by the floodwaters. Beds of gravel and sand, interpreted to be Missoula flood deposits, are separated by varved glacial lake silts in the Priest River valley in northern Idaho and in the Sanpoil River and Latah Creek valleys in northeastern Washington (Fig. 1; Waitt, 1980, 1984, 1985; Atwater, 1984, 1986, 1987). Farther south, and more distant from the source of the floods, are thick sequences of rhythmically bedded silt-sand beds, informally termed the ''Touchet beds'' by Flint (1938). These sediments are slack-water flood deposits found mainly in valleys tributary to the Columbia River in southeastern Washington. The slack-water deposits comprise more than 40 couplets, each of which grades from medium to very coarse sand at the base to silt or very fine sand at the top. The sediments are particularly well exposed in the Yakima and Walla Walla Valleys of southern Washington (Fig. 1).

Proponents of the many-flood hypothesis argue that each couplet in the slack-water sequence records one flood. They cite evidence for subaerial exposure between deposition of

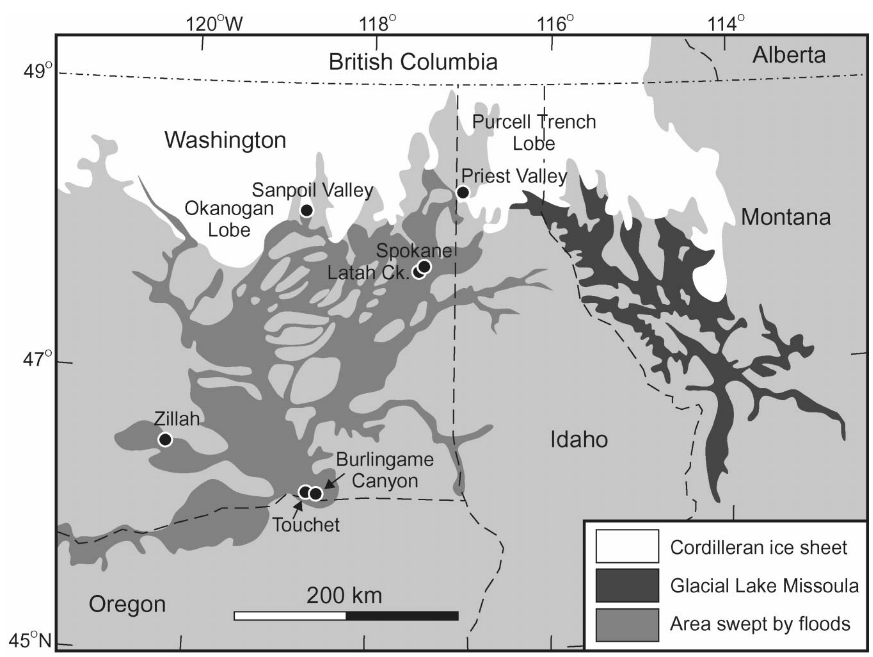

Figure. 1. Map showing Channeled Scabland, Glacial Lake Missoula, southern margin of Cordilleran ice sheet at its maximum extent during Fraser Glaciation, and three study sites (Burlingame Canyon, Touchet, and Zillah). Modified from Waitt (1985, their Fig. 1).

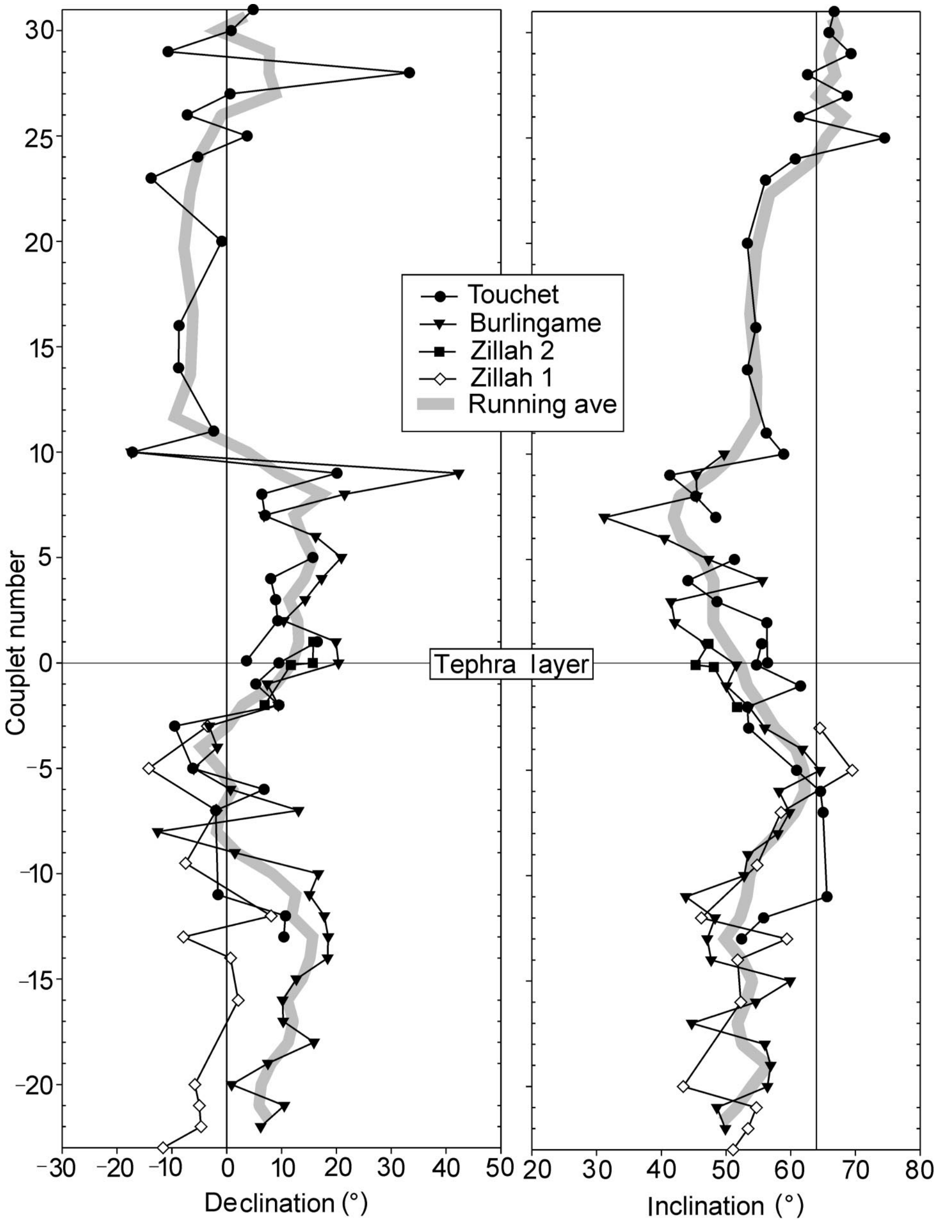

Figure 2. Magnetic declination and inclination plotted as function of couplet number at three study sites. Tephras provide datum for intersite correlation of couplets. Lower couplets at Zillah can only be placed approximately. Gray curve is three-point running average of average data from three sections.

successive couplets, including loess, rodent burrows, a tephra bed, channels infilled with slopewash, and rip-up clasts of silt and shells within sand beds (Waitt, 1980). Other workers have concluded that the slack-water deposits record only one, or at most a few, floods (e.g., Baker, 1973, 1978, 1983; Patton et al., 1979; Bunker, 1982; Baker and Bunker, 1985; Shaw et al., 1999). They attribute the rhythmic bedding to hydraulic surging during a single long-lived flood that inundated the Yakima and Walla Walla valleys.

Here we report new evidence that the Yakima and Walla Walla Valleys were backflooded at least 40 times at the close of the Fraser Glaciation. We present paleomagnetic data that indicate the slack-water sequence spans thousands of years rather than the one year or less required by a single flood. We also report two geochemically distinct tephras between two couplets in these valleys. The tephras indicate that two adjacent couplets in the slack-water sequence were separated by a period of at least several decades.

PALEOMAGNETISM

Earth's geomagnetic field varies over periods of hundreds to thousands of years with swings and loops of tens of degrees that can be recognized over regions of continental extent. This secular variation provides a critical test to differentiate between the one-flood and many-flood hypotheses. If the entire Touchet sequence accumulated during one flood, the paleomagnetic directions recorded by the beds would not be significantly different from top to bottom. If, however, the sequence is the product of tens of floods spanning hundreds or thousands of years, the paleomagnetic directions of the sediments would follow serially correlated swings that could be observed at different localities.

Steele (1991) used this approach on lacustrine sediments interbedded with coarse-grained Missoula flood deposits in the Sanpoil River valley in northeastern Washington. He found secular variation in the short sequences he analyzed (6 to 13 beds), and concluded that many Missoula floods had entered the valley.

Methods

We collected oriented samples from the waterlaid, silty, upper horizons of couplets at Zillah in the Yakima Valley, and Touchet and Burlingame Canyon in the Walla Walla Valley (Fig. 1). Between 4 and 10 plastic cylinders (2.5 cm diameter, 2.2 cm deep), oriented by compass, were extracted from each bed to produce a reliable average. We sampled as many couplets as possible at each site; some beds were not measured because they could not be accessed on steep outcrops or because they were disrupted along the line of the profile by clastic dikes or soft-sediment deformation. At Zillah and Touchet, we were forced to shift the line of profile laterally to access as many beds in the upper parts of the exposures as possible. Two tephras provided time-equivalent marker horizons for correlating couplets among the three sites (except for the lower 12 couplets sampled at Zillah).

Remanence measurements were made at the Paleomagnetism Laboratory of the Geological Survey of Canada–Pacific on an AGICO JR5-A spinner magnetometer. Stepwise alternating field demagnetization was carried out using a Schonstedt GSD-5 with tumbler in peak fields up to 80 mT, typically at steps of 10 mT. All specimens were perfectly monocomponent, with strong magnetization (0.1–0.7 A/m) and a median destructive field of 20 mT. The mean magnetic orientation of each bed was calculated from these data and plotted as a function of couplet number, with the tephras as the zero level (Appendix Table DR1[1]).

Results

The three records display serially correlated swings characteristic of secular variation (Fig. 2). Within-couplet dispersions are low, with Fisher precision factors, k, as high as 1100. The median value of k is 121, corresponding

[1]GSA Data Repository item 2003023, paleomagnetic and tephra major element data, is available on request from Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301-9140, USA, editing@geosociety.org, or at www.geosociety.org/pubs/ft2003.htm.

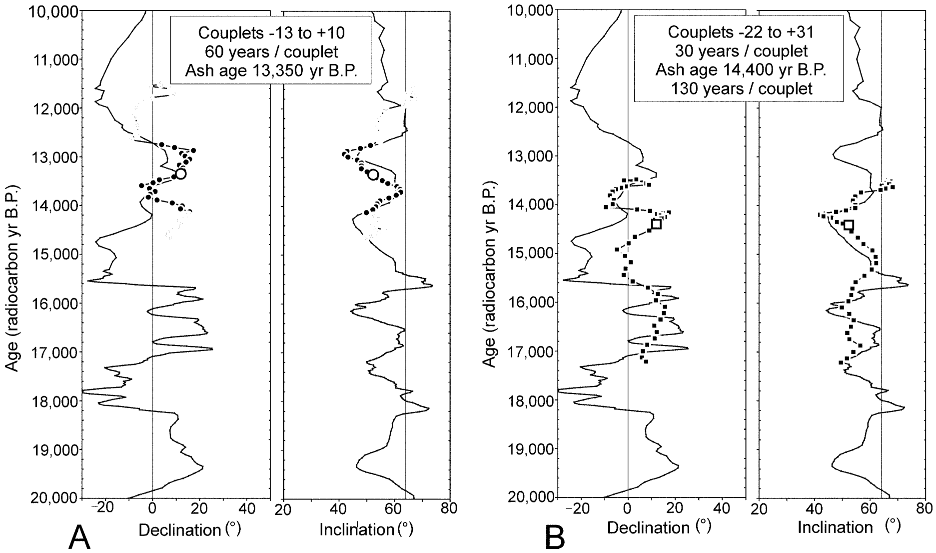

Figure 3. Possible correlation of mean magnetic curve and combined, smoothed Mono Lake–Fish Lake paleosecular varation curve (see text for details). Both correlations are based on minimum spherical mismatch between curves.

to a circular standard deviation (CSD) of 7.4°. Similarly, the median change between neighboring couplets is 7.6°. In contrast, the CSD of the entire collection is larger, 10.2°. More important, the same trends are seen in the three sections. For example, there is a consistent increase in declination and decrease in inclination in the five couplets up to the tephra layer.

These data are incompatible with the one-flood hypothesis, which must therefore be rejected. Rather, they are the expected data for a sequence laid down over a few thousand years. The noise (dispersion) is higher than we had hoped, but these sediments were deposited in a relatively high energy, transient environment, unlike silt and clay deposited from suspension in a stable lake.

In an attempt to date the sequence by correlating it to a reference secular variation record, we averaged the remanence directions from the three sections, couplet by couplet, and then filtered the record with a three point running average (Figs. 2 and 3). The mean curve shows three swings of as much as ~30°.

For a reference curve, we pieced together the Fish Lake, Oregon (Verosub et al., 1986), and the Mono Lake, California (Lund et al., 1988), records, which are the best dated and closest to our study sites and span the interval of interest. Corrections to study site locations in southern Washington State were made via virtual geomagnetic poles (Noel and Batt, 1990) (Fig. 3). The two reference records were averaged where they overlap (13,100 to 12,300 ^{14}C yr B.P.), and the same three-point running average was applied.

Variations in the length of time separating Missoula floods, and differences in the way in which the Touchet beds and the Mono Lake and Fish Lake sediments acquired magnetic remanence, make it difficult to correlate the patterns seen in Figure 3.

We propose two correlations of our record to the reference curve. In Figure 3A, we fit only the directions from couplets with two or more results, and we assume that intervals between couplets are constant. For each pair of tephra age and couplet duration, we calculate the total spherical angular difference between the combined Touchet curve and the reference curve. The statistical best fit between the two curves corresponds to a tephra age of 13,350 ^{14}C yr B.P. and an interval of 60 yr between couplets. Varve counts from the Lake Missoula basin, Sanpoil River, and Latah Creek (Waitt, 1984; Atwater, 1986) suggest an interval of 30–40 yr between flood events, but do not preclude a 60 yr interval. The thin, uppermost Touchet couplets do not correlate well under this scenario, but they may have been laid down in rapid succession with shorter intervening intervals just before 12,000 ^{14}C yr B.P.

A second correlation (Fig. 3B) is based on the entire sequence, but assumes different intervals between couplets before and after tephra deposition in order to model an increase in the frequency of floods through time. In this case, the best-fit age for the tephra is 14,400 ^{14}C yr B.P., and the sequence spans the period 17,000–13,000 ^{14}C yr B.P. Both correlations are consistent with available geological data (Mullineaux et al., 1975, 1978; Waitt, 1980, 1984, 1985).

TEPHRAS

Two thin (<1 cm) layers of white dacitic volcanic ash occur in many outcrops of the slack-water sequence. The two layers serve as important stratigraphic markers (Mullineaux et al., 1975) and provide strong evidence that decades separated deposition of at least two of the couplets. Further, because the couplet directly above the two ash layers and the couplet just below them are not fundamentally different from any two other couplets in the se-

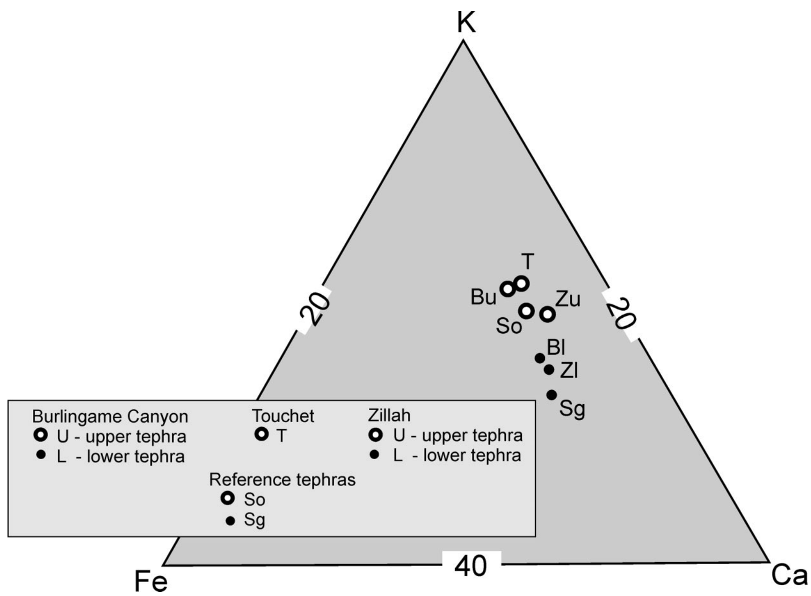

Figure 4. K-Fe-Ca ternary diagram showing compositions of Burlingame, Touchet, and Zillah tephras, and Mount St. Helens So and Sg reference tephras. Upper tephras at Burlingame Canyon and Zillah and single tephra at Touchet are Mount St. Helens So. Lower tephras at Burlingame Canyon and Zillah are Mount St. Helens Sg. Compositions of Glacier Peak B, Mazama O, and Mount St. Helens Jy tephras are shown for comparison. Circle around each average tephra composition represents one sigma of observed compositional variation.

quence, it is reasonable to conclude that each of the more than 40 couplets represents a single flood (Waitt, 1980).

The two ash layers are found in the middle part of the Touchet sequence and are separated by as much as 10 cm of nonvolcanic silt. The lower layer is the finer of the two, consisting mainly of fine silt. The upper layer grades upward from fine sand to silt.

In many outcrops, the two tephra layers contain little nonvolcanic or lithic material. This local pureness argues for deposition on a subaerial surface rather than in water (Waitt, 1980).

We analyzed ~20 glass shards from each of the tephras from the three study sites. Glass compositions were determined with a Cameca Camebax electron microprobe using an acceleration voltage of 15 kV, a beam diameter of 6 mm, and a beam current of 10 nA. Analyses were performed for Si, Al, Fe, Ti, Na, K, Mg, Ca, and Cl, and the shard chemistry was compared with that of known tephras of similar age in Washington (Fig. 4; Appendix Table DR2; see footnote 1).

The tephras at the three sites correlate with each other and, more important, record two separate eruptions—the lower is Mount St. Helens Sg and the upper is Mount St. Helens So. Set S tephras record a lengthy phase of explosive volcanic activity at Mount St. Helens that extended from ca. 18,000 to 12,000 ^{14}C yr B.P. (Mullineaux et al., 1975). The ages of individual set S tephras, however, are poorly known. So and Sg tephras are thought to be ca. 13,000 C^{14} yr B.P. based on limited radiocarbon dating (Mullineaux et al., 1978), but they may be as much as 1000 yr younger or several thousand years older.

So and Sg probably differ in age by many tens of years. Two thin (<1 cm) beds of Sg tephra are separated by 7 mm of diatomaceous clayey silt in a core taken from Little Boulder Lake on Mount Hood in Oregon. Radiocarbon ages from the Little Boulder Lake core indicate that the sediment between the two Sg tephras accumulated in ~40 yr. It is likely that the compositionally different So and Sg eruptions were separated by at least this amount of time.

CONCLUSION

New paleomagnetic data indicate that late Pleistocene slack-water flood deposits in the Yakima and Walla Walla Valleys, Washington, were produced by tens of Missoula floods rather than one or a few floods, as has been argued by some researchers. The paleomagnetic data show secular variation spanning a few thousand years. Two Mount St. Helens set S tephras occur between deposits of two of the floods at our study sites. The two tephras are probably decades different in age. They are marker beds that allowed us to correlate the slack-water couplets and the magnetic data among our study sites. Provisional correlations of our magnetic record with a reference secular variation record provide estimates of the age of the tephras of 13,350 and 14,400 ^{14}C yr B.P. The correlations are compatible with independent estimates of the age of the Fraser Glaciation maximum, during which Glacial Lake Missoula existed.

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