Age and correlation of a paleomagnetic episode in the western United States by \(^{40}\text{Ar}^{39}\text{Ar}\) dating and tephrachronology: The Jamaica, Blake, or a new polarity episode?

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Abstract. High-resolution paleomagnetic records from two sites near Pringle Falls, Oregon, are compared with similar records from Summer Lake, Oregon, \(\sim 170\) km to the southeast: Paoha Island, in Mono Lake, \(\sim 600\) km to the southeast and Benton Crossing, in Long Valley, approximately \(700\) km to the southeast, in east-central California. The sequences at Pringle Falls contain a distinctive coarse pumice-lapilli tephra layer which we have dated as \(218\pm 10\) ka by \(^{40}\text{Ar}^{39}\text{Ar}\) step-heating of plagioclase feldspar. Stratigraphically, this tephra is closely associated with a suite of several other tephra layers that bracket the interval studied paleomagnetically. Each tephra layer is distinguished by the unique chemical composition of its volcanic glass shards. The pumice layer dated at Pringle Falls is correlated with layers at three of the other localities. Using all the tephra layers, we can correlate the lake stratigraphic sequences and associated paleomagnetic records among the four distant localities. Additional age control is obtained from a fifth locality at Tulelake in northern California, where the stratigraphic interval of interest is bracketed between \(171\pm 43\) and approximately \(140\) ka. Characteristics of the paleomagnetic records indicate virtually identical paleofield variation, particularly the geometry of a normal to normal (N-N) geomagnetic polarity episode. The observed paleofield behavior resembles the Blake geomagnetic polarity episode, but is significantly older than the generally accepted age of the Blake episode. Either the age of the Blake episode is significantly underestimated, or the polarity episode documented here is older, perhaps the Jamaica episode, or is an as yet unreported episode. A corollary of the latter option is that paleomagnetic polarity episodes of different ages may have similar transition polar paths, a conclusion implying that a common mechanism is involved.

Introduction

One of the main difficulties in interpreting the paleofield behavior from the sedimentary record is age control [e.g. Verosub and Banerjee, 1977; Negrini et al., 1987; 1988; Verosub, 1988; Sarna and Davis, 1992; Berger, 1991]. Sediments ranging from 40 ka to 200 ka

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magnetic record at Pringle Falls is registered in time by the $^{40}\text{Ar}/^{39}\text{Ar}$ age of one tephra layer (layer D) and by an additional age from Tulelake, California, that can be correlated to the Pringle Falls, Oregon area [Rieck et al., 1992]. The stratigraphy at Pringle Falls and the inferred position of layer D relative to the other tephra layers and sediments is shown in Figure 2.

$^{40}\text{Ar}/^{39}\text{Ar}$ Age

Plagioclase phenocrysts were separated from the Pringle Falls D ash. We then loaded 169.6 mg of purified plagioclase grains in a 99.99+% pure Cu foil packet and irradiated the sample for 1 hour in the central thimble of the U.S. Geological Survey (USGS) TRIGA reactor in Denver, Colorado, at a 1 MW power level. The neutron flux was monitored using sandstone from the Taylor Creek rhyolite (27.92 Ma). Irradiation and analytical procedures at Stanford followed those of Pringle et al. [1992]. Analytical data, neutron flux, and reactor corrections are given in Table 1.

After preheating the sample to 700°C to purge largely nonradiogenic Ar and other contaminating gases, Ar was extracted from the sample in seven steps from 900°C to 1500°C. Five of the seven steps yielded a well-defined plateau age of 218 ± 10 ka (1σ) for over 92% of the total $^{39}\text{Ar}$ released (Figure 3).

An isotope correlation plot shows that the composition of trapped nonradiogenic Ar in these five steps is indistinguishable from atmospheric Ar (298 ± 7) with an associated inverse isochron age of 195 ± 59 ka (1σ). The isochron age and the plateau age are not significantly different, but the isochron age has a large relative uncertainty resulting from the low radiogenic yield (<10% for any step). We take the plateau age of 218 ± 10 ka (1σ) to be the best estimate of the age of the Pringle Falls D ash layer.

Pumice clasts were separated from the andesite tuff of Medicine Lake by hand. The pumice clasts were then crushed, sieved, and washed. Approximately 640 mg of sample was encapsulated in 99.99+% Cu-foil packages and arranged in a vertical column along with mineral...
standards in a controlled geometry [Fish Canyon sanidine, 27.84 Ma, [Cebula et al., 1986]; MMhb-1, 520.4 Ma, [Samson and Alexander, 1987]; and an internal laboratory sanidine standard]. The sample package was then placed in a 3 cm diameter aluminum tube and irradiated with fast neutrons in the Central thimble of the core of the USGS TRIGA reactor for 1.5 hours at 1 MW as was the case of the plagioclase phenocrysts described above.

The \(^{40}\)Ar/\(^{39}\)Ar analyses of Medicine Lake andesite tuff were done at the Institute of Human Origins, Geochronology Center, Berkeley, California, using a fully automated microextration-mass spectrometer system. The system employs a 1.5-kW double-vacuum resistance furnace for sample heating and is in line with a Mass Analyzer Productus MAP 215 50 90° sector extended-geometry mass spectrometer. The mass spectrometer uses a Nier ion source and has an effective radius of 21.5 cm and a mass resolution of 600. The detection limit of the MAP 215 series mass spectrometer is of the order of 1.1 x 10\(^{-14}\) cm\(^3\) STP (approximately 5 x 10\(^{-16}\) mol). M/e60(\(^{40}\)Ar) backgrounds at 1600°C for 10 min for the furnace system are typically between 1 x 10\(^{-9}\) and 6 x 10\(^{-10}\) cm\(^3\) STP (7.0 x 10\(^{-14}\) to 2.7 x 10\(^{-14}\) mol). M/e39(\(^{39}\)Ar) and M/e36(\(^{38}\)Ar) backgrounds are less than 1 x 10\(^{11}\) cm\(^3\) STP (5 x 10\(^{16}\) mol) and 9 x 10\(^{12}\) cm\(^3\) STP (9 x 10\(^{17}\) mol), respectively.

Incremental heating of the sample was induced by a 1.5-kW vacuum resistance furnace. The released gases were scrubbed of reactive gases such as H\(_2\), CO\(_2\), CO and N\(_2\) by exposure to a Zr-Fe-V and Zr-Al alloy getter [see Turrin et al., 1991]. The remaining inert gases, principally Ar, were then admitted to the mass spectrometer and the argon-isotopic ratios were determined. Ages were calculated from the \(^{40}\)Ar/\(^{39}\)Ar ratio after correcting for contamination by atmospheric Ar and for interfering neutron reactions with Ca and K [Brerceton, 1970; Dalrymple et al., 1981]. The estimated analytical precision (± 1\(\sigma\)) of all data presented is calculated using standard methods of propagation errors [Taylor, 1982].

The sample was incrementally heated from 700°C to fusion in eight roughly equal steps. All eight of the steps from 700°C to fusion yield a plateau of 171±43 ka and contain 100 percent of the total \(^{39}\)Ar released (Figure 3). The eight steps combine to give an integrated total fusion age of 180±150 ka.

Inverse isochron and isochron plots for the eight steps that define the plateau age indicate an initial \(^{40}\)Ar/\(^{38}\)Ar ratio of atmosphere (295.7±0.9) and an age of 149±95
Table 1. Analytical Data, Neutron Flux and Reactor Correction Factors for $^{40}$Ar/$^{39}$Ar ages for (a) Pringle Falls D Ash, and (b) Pumice Clasts from the Andesite Tuff of Medicine Lake

(a) $T \, ^\circ C$ | $^{40}$Ar, mol | $^{40}$Ar/$^{39}$Ar | $^{37}$Ar/$^{39}$Ar | $^{36}$Ar/$^{39}$Ar | $\Sigma$ $^{39}$Ar | $^{40}$Ar* | Age, ka ± 1σ
---|---|---|---|---|---|---|---
900 | 1.70 E-14 | 0.2957 | 1.7646 | 0.0351 | 0.084 | 0.028 | 130 ± 44
1000 | 1.50 E-14 | 0.5697 | 2.5348 | 0.0238 | 0.189 | 0.077 | 250 ± 33
1100 | 2.30 E-14 | 0.4450 | 4.2915 | 0.0213 | 0.371 | 0.070 | 195 ± 22
1200 | 2.90 E-14 | 0.5094 | 7.6892 | 0.0288 | 0.550 | 0.060 | 273 ± 24
1300 | 2.40 E-14 | 0.4805 | 10.7343 | 0.0257 | 0.720 | 0.066 | 211 ± 24
1400 | 1.80 E-14 | 0.5052 | 11.4658 | 0.0196 | 0.887 | 0.093 | 221 ± 23
1500 | 1.40 E-14 | 0.5329 | 11.5005 | 0.0232 | 1.000 | 0.082 | 234 ± 33

(b) $T \, ^\circ C$ | $^{40}$Ar, mol | $^{40}$Ar/$^{39}$Ar | $^{37}$Ar/$^{39}$Ar | $^{36}$Ar/$^{39}$Ar | $\Sigma$ $^{39}$Ar | $^{40}$Ar* | Age, ka ± 1σ
---|---|---|---|---|---|---|---
700 | 2.00 E-12 | 153.1 | 0.47758 | 0.5170 | 0.039 | 0.002 | 224 ± 415
750 | 8.31 E-13 | 38.01 | 0.55438 | 0.1284 | 0.104 | 0.005 | 127 ± 105
800 | 2.31 E-12 | 55.05 | 0.71077 | 0.1855 | 0.228 | 0.015 | 178 ± 107
850 | 3.58 E-12 | 73.30 | 0.87681 | 0.2477 | 0.373 | 0.002 | 107 ± 143
900 | 2.60 E-12 | 44.28 | 0.88835 | 0.1490 | 0.551 | 0.007 | 198 ± 95
950 | 7.76 E-12 | 47.28 | 0.88111 | 0.1593 | 0.723 | 0.006 | 172 ± 88
1000 | 4.07 E-12 | 70.08 | 0.93223 | 0.2362 | 0.895 | 0.005 | 228 ± 141
1050 | 7.54 E-12 | 211.0 | 0.99050 | 0.7129 | 1.000 | 0.002 | 236 ± 394

Pringle Falls D Ash:
J = 0.0002430 ± 0.000010, total fusion age 212 ± 10 ka, weighted mean plateau age 218 ± 10 ka (92% $^{39}$Ar).
Inverse isochron age 195 ± 59 ka, MSWD 0.6, $^{40}$Ar/$^{39}$Ar 298 ± 7. Reactor correction factors: $^{39}$Ar/$^{37}$Ar$^\text{C}_4$: 6.73 E-4, $^{36}$Ar/$^{39}$Ar$^\text{C}_4$: 2.64 E-4, $^{40}$Ar/$^{39}$Ar$^\text{C}_4$: 1.1 E-3.

Andesite Tuff of Medicine Lake:
J = 0.0003389 ± 0.000006, total fusion age 180 ± 50 ka, weighted mean plateau age 171 ± 43 ka (100% $^{39}$Ar).
Inverse isochron age 149 ± 95 ka, MSWD 0.1, $^{40}$Ar/$^{39}$Ar 296 ± 1. Reactor correction factors: $^{39}$Ar/$^{37}$Ar$^\text{C}_4$: 6.73 E-4, $^{36}$Ar/$^{39}$Ar$^\text{C}_4$: 2.59 E-4, $^{40}$Ar/$^{39}$Ar$^\text{C}_4$: 8.6 E-3.

and 149±110 ka, respectively, with a Mean Square Weight Deviate (MSWD) of 0.1. The isochron ages are not statistically different from the plateau age at the 95% confidence level; thus the preferred age is the plateau age (171±43 ka).

Tephrochronology

We measured and described the stratigraphy and sampled tephra layers at the above mentioned sites except for Summer Lake, Oregon, which was studied by Davis, [1985] and Negri et al., [this issue]. Volcanic glass shards were separated from the tephra samples and analyzed by electron-microprobe for SiO$_2$, Al$_2$O$_3$, FeO$_3$, MgO, MnO, CaO, TiO$_2$, Na$_2$O and K$_2$O using methods described by Sarna-Wojcicki et al., [1984]. Glass chemical analyses, including those of Davis [1985], were compared with the existing data base of about 3100 samples of the Tephrochronology Project at Menlo Park, California, [see Sarna-Wojcicki et al., 1984], and the best chemical matches were identified (Table 2). These data were combined with information on petrographic characteristics, stratigraphic position, and available age data to correlate tephra.

At Pringle Falls, tephra layer D is within the lower third of the stratigraphic section studied for paleomagnetism (Figure 4). Tephra layers in the two sections at Pringle Falls can be correlated to other localities (Figure 2 and Table 2). These layers are layer S, which correlates to layer I at Summer Lake; layer D, which correlates to layer G at Summer Lake and to Pl-OH at Paoha Island in Mono Lake; layer E, which correlates to layer PAOH-3 at Paoha Island and to layer M7810 at Benton Crossing, Long Valley; layer H, which correlates to layer EE at Summer Lake; and layer K, which correlates to layer DD at Summer Lake.

Tephra layers V, JJ, and KK present at Summer Lake have not been found at Pringle Falls. Layer V is higher in the section at Summer Lake than the other above mentioned layers, while JJ and KK are near the base and closely underlie layer II (Figure 2). Layer V correlates with layer T 1103 at Tulelake, California (Figure 1). Layer JJ contains silicic and basaltic shards and may correlate with layer PAOH-1 at Paoha Island. It has also been found in a sediment core from Walker Lake, Nevada (Figure 1, layer WL5 42A; approximately 141.8 m). Layer KK correlates with layer T-2123 at Tulelake and with another layer at Walker Lake (layer WL4-57; 145.4 m) (Figure 2, Table 2).
These correlations are consistent among all the studied sites with respect to relative stratigraphic position and available age control. In addition to the 218 ka age on layer D, estimates of the age of two other layers have been made at Tulelake. Rieck et al. [1992] estimated the age of T-1193 to be approximately 140 ka and that of T-2023 to be 160±25 ka based on tephra correlations and magnetostratigraphy. New 40Ar/39Ar step-heating data presented here on the age of an andesitic tuff that was previously correlated with T-2023 by Rieck et al. [1992] revise the age of this layer to 171±43 ka (see Table 1 and Figure 3). Although the mean ages for GG and KK are reversed from their stratigraphic positions (GG, 218 ka and KK, 171 ka), they are the same within the analytical uncertainty. At Summer Lake, layers CC and KK are separated by only ~1.5 m. Another broadly constraining age was obtained from the Walker Lake core, where a U disequilibrium (J. Rosoll, as cited by Benson, 1988) age of approximately 130 ka was obtained on organic material at 95 m in the core, about 37 m stratigraphically above the Walker Lake tephra layer 5-42A (Figure 2).

The age of the paleomagnetic episode documented for the Paoha Island and the Benton Crossing sites in east-central California was estimated by Liddicoat and Bailey [1989] and Liddicoat, [1990] to be approximately 280-290 ka, based on earlier tephrochronologic data from Tulelake, California, supplied to them by A.M. Sarria-Wojcicki. This age was based on a straight-line interpolation of layer KK between two stratigraphic horizons spaced far apart in the Tulelake core. This episode was thus proposed to be the Levantine episode [Ryan, 1972] by Liddicoat and Bailey [1989]. Subsequent isotopic dating in the Tulelake area of an andesitic ash layer, correlated with layer KK, yielded an age of 160±25 ka and thus revised the age of this part of the section [Sarria-Wojcicki et al., 1991]. We revise the age of layer KK here to 171±43 ka based on correlation of layer KK to the dated andesitic ash layer. This is slightly older than our previous estimate for the andesitic ash bed and Tulelake tephra layer T-2023 (and by correlation, Summer Lake layer JJ and PAOH-1, etc., Figure 2), but within the estimated errors for both.

**Paleomagnetism**

In this section we compare detailed records of a geomagnetic excursion from three localities containing correlative tephra layers at Pringle Falls and Summer Lake, Oregon and at Long Valley, California. Paleomagnetic records of excursions from each of the above localities have been published previously [Negrini et al., 1988, this issue; Herrero-Bervera et al., 1989; Liddicoat and Bailey, 1989; Liddicoat, 1990, Herrero-Bervera and Helley, 1993] but here for the first time we recognize them as the same excursion. A record of the excursion from a fourth locality, Paoha Island in Mono Lake, California, has also been documented [Liddicoat and Bailey, 1989]. Because the large sample interval of this Paoha Island record inhibits comparisons with the other records, we will not include it as part of this paper.
Table 2. Chemical Analyses of Volcanic Glass Shards From Tephra Layers Stratigraphically Associated With Magnetic Event at Pringle Falls, Oregon and Several Other Localities

<table>
<thead>
<tr>
<th>Ash Bed Name</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>Fe₂O₃</th>
<th>MgO</th>
<th>MnO</th>
<th>CaO</th>
<th>TiO₂</th>
<th>Na₂O</th>
<th>K₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer Lake V</td>
<td>72.84</td>
<td>14.23</td>
<td>2.68</td>
<td>0.17</td>
<td>0.06</td>
<td>1.07</td>
<td>0.23</td>
<td>5.21</td>
<td>3.51</td>
</tr>
<tr>
<td>Tulelake T-1193</td>
<td>73.34</td>
<td>14.22</td>
<td>2.61</td>
<td>0.15</td>
<td>0.07</td>
<td>1.11</td>
<td>0.22</td>
<td>4.82</td>
<td>3.47</td>
</tr>
<tr>
<td>Pringle Falls K</td>
<td>69.76</td>
<td>15.33</td>
<td>3.64</td>
<td>0.58</td>
<td>0.10</td>
<td>1.91</td>
<td>0.51</td>
<td>5.81</td>
<td>2.35</td>
</tr>
<tr>
<td>Summer Lake DD</td>
<td>69.40</td>
<td>15.55</td>
<td>3.41</td>
<td>0.62</td>
<td>0.11</td>
<td>1.89</td>
<td>0.60</td>
<td>6.12</td>
<td>2.31</td>
</tr>
<tr>
<td>Pringle Falls H</td>
<td>70.53</td>
<td>15.04</td>
<td>3.28</td>
<td>0.49</td>
<td>0.10</td>
<td>1.68</td>
<td>0.51</td>
<td>5.95</td>
<td>2.41</td>
</tr>
<tr>
<td>Summer Lake EE</td>
<td>70.37</td>
<td>15.46</td>
<td>3.05</td>
<td>0.46</td>
<td>0.09</td>
<td>1.54</td>
<td>0.50</td>
<td>6.12</td>
<td>2.41</td>
</tr>
<tr>
<td>Pringle Falls E (1)</td>
<td>73.65</td>
<td>14.46</td>
<td>2.13</td>
<td>0.42</td>
<td>0.04</td>
<td>2.00</td>
<td>0.26</td>
<td>4.03</td>
<td>3.02</td>
</tr>
<tr>
<td>Pringle Falls E (2)</td>
<td>73.41</td>
<td>14.61</td>
<td>2.14</td>
<td>0.43</td>
<td>0.04</td>
<td>2.06</td>
<td>0.26</td>
<td>3.95</td>
<td>3.10</td>
</tr>
<tr>
<td>Paoha Is. PAOH-3 (1)</td>
<td>73.84</td>
<td>13.96</td>
<td>2.26</td>
<td>0.45</td>
<td>0.04</td>
<td>2.10</td>
<td>0.28</td>
<td>3.89</td>
<td>3.19</td>
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<tr>
<td>Paoha Is. PAOH-3 (2)</td>
<td>72.80</td>
<td>14.98</td>
<td>2.20</td>
<td>0.40</td>
<td>0.03</td>
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<td>0.27</td>
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<tr>
<td>Benton Crossing KRL10779A</td>
<td>73.31</td>
<td>14.49</td>
<td>2.27</td>
<td>0.43</td>
<td>0.04</td>
<td>2.11</td>
<td>0.30</td>
<td>4.06</td>
<td>3.00</td>
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<td>Benton Crossing M7810</td>
<td>73.36</td>
<td>14.56</td>
<td>2.19</td>
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<td>3.05</td>
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<tr>
<td>Pringle Falls D (1)</td>
<td>70.09</td>
<td>15.22</td>
<td>3.61</td>
<td>0.51</td>
<td>0.12</td>
<td>1.76</td>
<td>0.51</td>
<td>5.71</td>
<td>2.47</td>
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<tr>
<td>Pringle Falls D (2)</td>
<td>69.96</td>
<td>15.61</td>
<td>3.62</td>
<td>0.50</td>
<td>0.10</td>
<td>1.80</td>
<td>0.47</td>
<td>5.49</td>
<td>2.45</td>
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<td>Summer Lake GG</td>
<td>69.30</td>
<td>15.37</td>
<td>3.68</td>
<td>0.55</td>
<td>0.11</td>
<td>1.86</td>
<td>0.59</td>
<td>6.13</td>
<td>2.41</td>
</tr>
<tr>
<td>Paoha Is. Pt-OR</td>
<td>70.39</td>
<td>14.85</td>
<td>3.65</td>
<td>0.55</td>
<td>0.13</td>
<td>1.79</td>
<td>0.53</td>
<td>5.65</td>
<td>2.47</td>
</tr>
<tr>
<td>Pringle Falls S</td>
<td>72.16</td>
<td>14.66</td>
<td>3.12</td>
<td>0.26</td>
<td>0.09</td>
<td>1.25</td>
<td>0.33</td>
<td>5.40</td>
<td>2.83</td>
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<td>Summer Lake II</td>
<td>71.68</td>
<td>14.61</td>
<td>3.02</td>
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<td>0.08</td>
<td>1.22</td>
<td>0.35</td>
<td>5.92</td>
<td>2.81</td>
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<tr>
<td>Summer Lake JJ (basaltic)</td>
<td>57.52</td>
<td>16.29</td>
<td>9.22</td>
<td>3.04</td>
<td>0.15</td>
<td>6.15</td>
<td>1.59</td>
<td>4.53</td>
<td>1.51</td>
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<td>Summer Lake JJ (silicic)</td>
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<td>14.42</td>
<td>2.27</td>
<td>0.16</td>
<td>0.05</td>
<td>0.96</td>
<td>0.20</td>
<td>5.62</td>
<td>3.01</td>
</tr>
<tr>
<td>Walker Lake 5-42A</td>
<td>73.46</td>
<td>14.29</td>
<td>2.30</td>
<td>0.17</td>
<td>0.06</td>
<td>0.98</td>
<td>0.17</td>
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<td>3.04</td>
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<td>Paoha Is. PAOH-1</td>
<td>72.87</td>
<td>14.91</td>
<td>2.28</td>
<td>0.15</td>
<td>0.07</td>
<td>1.00</td>
<td>0.19</td>
<td>5.56</td>
<td>2.97</td>
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<td>Paoha Is. Pt-GBW-B</td>
<td>74.19</td>
<td>13.95</td>
<td>2.29</td>
<td>0.18</td>
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<td>0.99</td>
<td>0.22</td>
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<tr>
<td>Paoha Is. Pt-GBW-Q</td>
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<td>13.90</td>
<td>2.31</td>
<td>0.17</td>
<td>0.09</td>
<td>0.99</td>
<td>0.19</td>
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<tr>
<td>Paoha Is. Pt-GBW-W</td>
<td>74.09</td>
<td>14.06</td>
<td>2.33</td>
<td>0.17</td>
<td>0.08</td>
<td>1.00</td>
<td>0.18</td>
<td>5.08</td>
<td>3.02</td>
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<tr>
<td>Summer Lake KK (polymodal ash)</td>
<td>67.79</td>
<td>16.78</td>
<td>6.19</td>
<td>1.98</td>
<td>0.11</td>
<td>4.73</td>
<td>0.98</td>
<td>4.82</td>
<td>2.11</td>
</tr>
<tr>
<td>Tulelake (T-1228; 53.13 m)</td>
<td>62.57</td>
<td>16.40</td>
<td>6.16</td>
<td>2.35</td>
<td>0.14</td>
<td>4.94</td>
<td>0.97</td>
<td>4.40</td>
<td>2.08</td>
</tr>
<tr>
<td>Tulelake (T-20238; 53.07 m)</td>
<td>63.60</td>
<td>16.31</td>
<td>5.88</td>
<td>1.99</td>
<td>0.09</td>
<td>4.44</td>
<td>0.96</td>
<td>4.55</td>
<td>2.17</td>
</tr>
<tr>
<td>Tulelake (T-2023; 53.07 m)</td>
<td>63.30</td>
<td>16.03</td>
<td>3.07</td>
<td>2.02</td>
<td>0.10</td>
<td>4.61</td>
<td>0.98</td>
<td>4.70</td>
<td>2.09</td>
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<tr>
<td>Tulelake (T-2019a; 53.12 m)</td>
<td>64.33</td>
<td>16.17</td>
<td>5.48</td>
<td>1.76</td>
<td>0.09</td>
<td>4.26</td>
<td>0.95</td>
<td>4.55</td>
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<tr>
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<td>64.43</td>
<td>16.13</td>
<td>5.43</td>
<td>1.76</td>
<td>0.10</td>
<td>4.24</td>
<td>0.94</td>
<td>4.57</td>
<td>2.39</td>
</tr>
<tr>
<td>Medicine L. Andes Tuff (194Ma)</td>
<td>64.56</td>
<td>16.00</td>
<td>5.37</td>
<td>1.60</td>
<td>0.08</td>
<td>4.08</td>
<td>0.89</td>
<td>4.88</td>
<td>2.45</td>
</tr>
<tr>
<td>Walker Lake 4-57 (145.4 m)</td>
<td>64.20</td>
<td>15.88</td>
<td>5.51</td>
<td>1.77</td>
<td>0.10</td>
<td>4.54</td>
<td>0.86</td>
<td>4.96</td>
<td>2.18</td>
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<tr>
<td>Tulelake (T-2019c; 53.12 m)</td>
<td>66.35</td>
<td>15.82</td>
<td>4.67</td>
<td>1.38</td>
<td>0.08</td>
<td>3.59</td>
<td>0.84</td>
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</tr>
<tr>
<td>Medicine L. Andes Tuff (194Mb)</td>
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<td>4.68</td>
<td>1.31</td>
<td>0.07</td>
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<tr>
<td>Medicine L. Andes Tuff (194Mc)</td>
<td>67.03</td>
<td>15.34</td>
<td>4.42</td>
<td>1.20</td>
<td>0.06</td>
<td>3.36</td>
<td>0.84</td>
<td>4.84</td>
<td>2.92</td>
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<table>
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<tr>
<th>RLS (glass standard); n=18</th>
<th>±1 standard deviation</th>
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<tbody>
<tr>
<td>75.40</td>
<td>11.30</td>
</tr>
<tr>
<td>0.10</td>
<td>0.20</td>
</tr>
</tbody>
</table>

Concentrations are in oxide weight percent recalculated to 100 percent. Replicate analyses of an external glass standard, RLS 132, are given at the bottom of the table. The standard deviation of these is a close approximation of analytical error for these analyses.

*Iron for the standard is reported as FeO rather than Fe₂O₃.

Representative Records from Each Locality

We first chose a representative paleomagnetic record or two from each of the three localities, starting with the Long Valley locality. Four paleomagnetic records of a polarity episode from Long Valley were presented and compared in earlier publications [Liddicoat and Bailey, 1989; Liddicoat, 1990]. One sample set was taken from each of three vertical columns with a total separation of no more than 15 m. The VGP paths corresponding to an alternating field demagnetization (AFD) level of 30 mT were found to be quite similar for each sample set. Furthermore, a second subset was sampled from the vertical column of section A. This subset was subjected
Figure 4. Inclination records of the two Pringle Falls sites. Features A, B, and C are correlated. The distance between the two records is approximately 1.5 km. Notice the radiometrically dated pumice layer D.

to thermal demagnetization (TD) at 400°C and subsequently compared with its companion subset treated with AFD. The paleomagnetic directions corresponding to the two different magnetic cleaning methods were also similar, further demonstrating the intrabasin reproducibility of this excursion record. We chose the TD record from the Long Valley A section for extrabasinal comparison because it is the most detailed (smallest sample interval).

A highly detailed record of a middle-to-late Pleistocene excursion was obtained from diatomaceous lacustrine silt near Pringle Falls, Oregon [Herrero-Bervera et al., 1989]. Using a correlation based on tephra layer D, a second record of the excursion was recovered from the same sequence exposed 1.5 km from the original locality [Herrero-Bervera and Helsley, 1993]. These two records bear striking similarities that strongly argue for the intrabasin reproducibility of this excursion (Figure 4). The paleomagnetic samples for each record were treated at AFD levels of 15-17.5 mT. Isothermal remanent magnetization (IRM) and anhysteretic remanent magnetization (ARM) acquisition experiments were conducted on all samples. The magnetic susceptibility of each sample was also measured. These rock magnetic measurements indicated the presence of magnetite as the principal, and perhaps the only magnetic carrier. None of the parameters varied significantly with stratigraphic depth. Hence we chose these two records to represent the Pringle Falls localities. These two inclination records shown in Figure 4 demonstrate the reproducibility of the paleosignal over an approximate distance of 1.5 km.

The originally published middle-to-late Pleistocene excursion record from Summer Lake, Oregon, is based on one sample per horizon and is from section C along the banks of the Ana River [Negrini et al., 1988]. Since then two more records of this excursion have been obtained based on three samples per horizon [Negrini et al., this issue]. One of the new records is also from section C and the other is from section D, 200 m downstream. The correlation of the three records is facilitated by several correlated tephras layers (including tephra layer CG) found at both sections within the excursion interval. The paleomagnetic signatures of the three records are virtually identical [Negrini, et al., this issue]. The samples for each record were treated at AFD levels of 15-25 mT. A wide variety of rock magnetic parameters including measurements of susceptibility to ARM acquisition y ARM, calculations of the ratio of volume susceptibility to induced magnetization (x), and determination of various hysteresis parameters all indicate a mineralogy dominated by magnetite and that the magnetic grain sizes of all samples fall within the PSD range of 1-15 μm (for magnetite grains). Extrabasinal comparisons between paleomagnetic directions for water-lain volcanic ashes at section C and paleomagnetic directions for correlated welded tuffs were used to establish the sediments at section C as accurate recorders of the Earth’s magnetic field [Negrini et al., 1988, this issue]. For this reason, and because it is based on three samples per horizon, we chose the newly obtained paleomagnetic record, AR-C, as the representative of the excursion recorded at Summer Lake [Negrini et al., this issue].

Comparison of Representative Records

The thermal demagnetization record from Long Valley, one record from Pringle Falls (the two records shown in Figure 4 are virtually identical), and record AR-C from Summer Lake are plotted in Figure 5 along with the stratigraphic position of all tephra layers correlated between the three localities. A comparison of the ‘wave forms’ of the declination records in Figure 5 suggests that the same excursion is recorded at all three localities. In all three cases, correlative tephra layers occupy the same position relative to the paleomagnetic record. In particular, ash M7810 at Long Valley occupies the same relative position in the excursion as does its correlative (PF-E) at Pringle Falls. Tephra layers PF-D/SL-GG, PF-S/SL-II, PF-H/SL-EE and PF-K/SL-DD also appear to occupy almost the
same respective positions in the declination records of the excursion from Pringle Falls and Summer Lake.

The paleomagnetic correlations are not perfect, however. For example, the entire Summer Lake inclination record and the latter part of the declination record appear to be severely attenuated. One explanation could be due to the different sedimentation rates among the three localities. The section thickness which expresses the polarity episode for Long Valley is about 100 cm, for Summer Lake it is about 50 cm and for Pringle Falls it is about 700 cm (see Figures 4 and 5). These three different resolutions of the records indicate three different sedimentation rates for the three sections sampled. Thus, the VGP's shown in Figure 6a-6c attest for the varying degrees of resolution of the field at these localities. As an alternative explanation one can say that the apparent discrepancy in the fidelity of the inclination and declination record is probably the result of limitations in the presentation of vector data as scalar components and is not a manifestation of varying fidelities in the acquisition of declination versus inclination. This is shown in plots of VGP's for the first part of the excursion for each locality (Figure 6d). Note that the attenuated VGP path for the Summer Lake record remains approximately equidistant from the site locality (Figure 6d), thus demonstrating the featureless nature of the inclination record. Such attenuation also occurs for the Mono Lake Excursion record in the Summer Lake sediments [Negrini et al., 1984]. In contrast, secular variations of normal amplitude are recorded very accurately at Summer Lake [Negrini et al., 1984, 1988]. The discrepancy in the accuracy of excursion versus non-excision records at Summer Lake is explained by Negrini et al. [this issue] as due to the abnormally low paleointensities observed during the excursion intervals. Despite the problem with the Summer Lake record, similar morphologies demonstrated by the three excursion records and the correlation control provided by the tephra layers are evidence that true magnetic field behavior has been recorded.

Figure 5. Correlation of the declination and inclination "waveform" records from Long Valley site A, Pringle Falls and Summer Lake section C. Shaded areas show tephra layers and their probable correlation.
Figure 6. (a) Virtual geomagnetic pole (VGP) path of site 1 at Pringle Falls, Oregon. (b) VGP path of site 2 at Pringle Falls. The distance between sites is approximately 1.5 km. (c) VGP path of the Long Valley site A record located approximately 700 km from the Pringle Falls sites. (d) VGP path of the Summer Lake, Oregon record. Arrows show sequence from oldest to youngest. The solid triangle represents the location of the sampling site(s).

The declination and inclination data can be converted to VGP plots representing the apparent motion of the pole during this geomagnetic polarity episode (Figure 6). The directional data obtained at Pringle Falls (from two sites 1.5 km apart), are very detailed with a great number of transitional directions, from which we have calculated successive VGP positions. Figure 4 depicts the inclination records from the two localities and Figures 6a and b show the intermediate inclinations and VGPs respectively. It can be seen that the transitional directions that make up the polarity episode are represented from the bottom to the top of the inclination records in both cases.

The descriptive characteristics of Pringle Falls and Long Valley Site A VGPs have been discussed elsewhere [Herrero-Bervera et al., 1989; Herrero-Bervera and Helley, 1993; Liddicoat and Bailey, 1989; Liddicoat 1990], but the characteristics of the last portion (between Brazil and the central equatorial Pacific continuing on to Kamchatka Peninsula area) of the VGP
path of the Pringle Falls records represent the antipodal behavior of the path. In summary, Figures 6a and 6b show the preferred behavior of the VGP path over the Americas and over Asia [see Laj et al., 1991; 1992; 1993]. Figures 6a and 6b also depict periods of rapid directional changes and slower periods or stand-still intervals. These major loops are intrinsic characteristics of the polarity episode discussed here. It is unlikely that the brief stable periods represent fluctuations in sedimentation rate since bulk magnetic property variations do not correlate with these stability periods as would be expected if the supply of magnetic material was variable [e.g. Herrero-Bervera et al., 1989; Herrero-Bervera and Khan, 1992; Herrero-Bervera and Helsley, 1983; Tric et al., 1991a,b]. Large loops in the most detailed volcanic and sedimentary records (including this one) are due perhaps to a diminished strength of the main dipolar field, which would lead to a larger ratio of the nondipole field to the dipole field. It is conceivable that the very large loops in the Pringle Falls records are much more reminiscent of the second phase of the Steens transition and probably reflect characteristics of the reversing geodynamo (E. Mankinen, written communication, 1993). The VGP loop in Figures 6a and 6b suggests that this excursion may represent an aborted reversal [Hoffman 1981; Verosub 1982], because the data include directions
that are virtually antipodal to the present field. If the Pringle Falls polarity episode is an aborted reversal, the behavior noted certainly rules out reversal models that favor an axysymmetric transitional field.

Figure 6c shows the composite figure corresponding to Long Valley site A. There is a striking similarity between the Pringle Falls and Long Valley records in the highest amplitude segment of the path from South America to the Northwest Pacific (Figure 6). Both VGP paths occupy nearly the same position during this principal part of the excursion. Both records also appear to cluster at the same position due east of New Zealand.

**Geomagnetic Implications**

**A New Middle to Late Pleistocene Excursion?**

Taphrochronology and striking similarities in the paleomagnetic records from three widely spaced localities confirm the Pringle Falls/Summer Lake/Long Valley excursion as a regional phenomenon, and an important chronostratigraphic marker horizon for middle to late Pleistocene stratigraphy of western North America.

Correlation of this excursion on a global scale is more problematic. The paleomagnetic signature of this excursion is quite similar to that of the 115-120 ka Blake polarity episode [Herrero-Berera et al., 1989; Tric et al., 1991a; Herrero-Berera and Holsen, 1993]. However, new age constraints described in this paper place the age of the polarity episode between 180 and 218 ka, which is older than the Blake polarity episode. Thus, either the age of the Blake episode has been underestimated by at least 50 percent or the Pringle Falls/Summer Lake/Long Valley is a separate excursion. We prefer the latter interpretation because many lines of evidence (e.g., radiometric age determinations, characteristic inclination (see Figure 4) and declination (see Figure 5) as well as similarity of the VGP paths among the records) point to an isotope stage 6 deposition (~130 to 190 ka) of the western North American sediments described in this study [Sarna-Wojcicki et al., 1991; Negrini et al., 1993]. In contrast, the marine sediments containing the Blake episode were most certainly deposited during stage 5 (~86-130 ka) [e.g., Emiliani and Milliman, 1966; Tric et al., 1991a].

A better choice for a possible correlatable on a global scale might be the Jamaica episode [Wollin et al., 1971; Ryan, 1972]. However, sufficiently detailed records of the Jamaica episode do not exist, and we cannot test this hypothesis. Along these lines, that in keeping with the practice of naming geomagnetic polarity episodes after locations where they were unambiguously described we propose here to naming the Pringle Falls records the Pringle Falls geomagnetic polarity episode. The reasons are the following: it is certainly well expressed magnetically and has an excellent, closely associated radiometric age determination to locate it in time. We would like to point out that we realize that the Jamaica episode named by Ryan [1972] has an age that is estimated to be similar to the one we report here. However, we have seen many examples where episodes found in a particular core could be in a different stratigraphic order, and have a considerably different estimated age. In a few cases a reported episode has been proven to be nonexistent. Also, if we were to call our Pringle Falls episode the “Jamaica”, we may find in the future that they could not represent this episode. Thus, as we have stated above, global possible correlatives are the Jamaica and Biwa I.

**The Relationship between Excursions and Polarity Transitions**

The overall VGP path for the main part of the excursion, as seen for both the Pringle Falls and Long Valley records (Figures 6a and 6b), roughly falls in the range of longitudes previously suggested as the preferred path for late Tertiary polarity transitions and for the Blake episode [Laj et al., 1991; 1992; 1993; Herrero-Berera and Khan, 1992; Herrero Berera and Holsen, 1993]. Also, the distinct clustering observed in both the Pringle Falls and Long Valley VGP paths east of New Zealand (Figures 6a and 6b) is a confirmed phenomenon similar to clusters in the VGP path typical of (1) the two-stage dynamic reversal behavior of Huffman, [1991; 1992], (2) the “loitering” in the empirical reversal models of Kaiser and Verosub [1985], and (3) the “stop-and-go” described for the Steens Mountain reversal [Prenat et al., 1985]. Thus our findings further support the contention that at least some excursions behave like polarity transitions and might be, in fact, aborted reversals.

**Summary and Conclusions**

The paleomagnetic records, correlation, chronostratigraphy, geochronology and tephrochronology documented for the two sites at Pringle Falls, and for the Summer Lake, Paoha Island, and Benton Crossing localities demonstrate that details of the paleofield can be correlated over distances as great as 700 km. The intrinsic characteristics of the records presented in Figures 4, 5 and 6 indicate the existence of a geomagnetic polarity episode at about 180 to 218 ka. We suggest that the geometric characteristics of the episode manifested in the VGP, particularly in the traverse of the paths between the western part of South America and the central equatorial Pacific, are evidence of a long-distance correlation of the geomagnetic polarity episode. Also, within the limits of our resolution, the VGP results indicate that at least for the Pringle Falls profiles, reversed directions were recorded during the ~228 to ~186 ka time period. These ages are upper limits between the determined radiometric dates for the Pringle Falls site taken as 218+10 ka and the minimum age determined for the Tulalake site of 169+17 ka (see Figure 2). We can correlate palcomagnetic signals from at least three distant localities, each with entirely different lithologies and sedimentation rates. Figure 5 shows the correlation among the records and the relative location of the tephra layers that allow us to correlate the paleomagnetic behavior of the field. We argue that the paleofield
characteristics of the records, such as the preferred VGP longitudinal bands over the Americas and Asia, reflect the actual movement of the geomagnetic pole during a continuous dipolar transition process and not the effect of bias imposed on the magnetization of sediments [Weeks et al., 1992].

New radiometric and correlated age data, combined with the paleomagnetic record, indicate an age of 218 ± 10 ka for the geomagnetic polarity episode recorded here. This age is considerably older than the Blake episode. The Blake episode has a similar virtual pole wandering path to that presented here, and thus we must infer that either: 1) The age of the Blake episode [e.g., Tucholska, 1987; Tric et al., 1991a] has been underestimated or, 2) The paleomagnetic episode documented here is different than the Blake episode, and is perhaps the Pringle Falls-Jamaica [e.g., Ryan, 1972; Champion et al., 1988] or another previously unreported episode. In the latter case, a corollary conclusion would be that paleomagnetic episodes of different ages can have similar VGP paths [Tric et al., 1991b; Herrera-Bervera and Helseb, 1993].

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