POST-MIDDLE MIOCENE TUFFS OF BODIE HILLS AND MONO BASIN, CALIFORNIA: PALEOMAGNETIC REFERENCE DIRECTIONS AND VERTICAL AXIS ROTATION

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FRESNO STATE
Discovery. Diversity. Distinction.

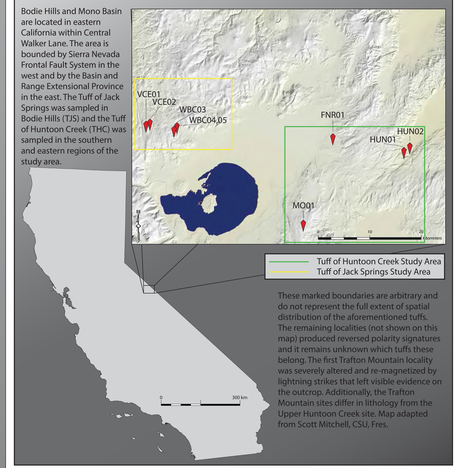
The relative motions of the Pacific and North American plates about the Sierra Nevada-North American Euler pole is accommodated by dextral slip along the San Andreas Fault System (~75%) and the Walker Lane-Eastern California Shear Zone system of faults, east of the Sierra Nevada microplate (~25%). The Bodie Hills and Mono Basin regions lie within the Walker Lane and partially accommodate deformation by vertical axis rotation of up to 60° rotation since ~9.4 Ma. This region experienced recurrent eruptive Events from mid to late Miocene, including John et al.'s (2012) ~12.05 Ma Tuff of Jack Springs (TJS) and Gilbert's (1968) 11.1 – 11.9 Ma "latite ignimbrite" east of Mono Lake. Both tuffs can be identified by phenocrysts of sanidine and biotite in hand specimens, with TJS composed of a light-grey matrix and the latite ignimbrite composed of a grey-black matrix. Our paleomagnetic results show these units to both be normal polarity, with the latite ignimbrite exhibiting a shallow inclination. TJS's normal polarity is consistent with emplacement during subchron C5 An. 1n (12.014 – 12.116 Ma). The X-ray fluorescence analyses of fiamme from TJS in Bodie Hills and the latite ignimbrite located east of Mono Lake reveal them both to be rhyolites with the latite ignimbrite sharing elevated K composition seen in the slightly younger Stanislaus Group (9.0 - 10.2 Ma).

We establish a paleomagnetic reference direction of **D** = 357.8° **I** = 39.6° α_{95} = 4.4° **n** = 5 sites (42 samples) for TJS in the Bodie Hills in a region hypothesized by Carlson (2012) to have experienced low rotation. Our reference for Gilbert's latite ignimbrite (at Cowtrack Mountain) is **D** = 352.9° **I** = 32.1° α_{95} = 4.7°. This reference locality is found on basement highland likely to have experienced less deformation then the nearby Mono Basin since ignimbrite emplacement. Paleomagnetic results from this latite ignimbrite suggests ~94.5° ± 6.5° of clockwise vertical axis rotation of parts of eastern Mono Basin since unit emplacement.

A welded 11.7 Ma (K-Ar; Drake, 1979) rhyolitic tuff near Trafton Mountain appears similar in composition to TJS. Drake's tuff exhibits a reversed polarity, consistent with reversed polarity subchron C5r.3r (11.614 – 12.014 Ma) and distinguishes this tuff from TJS and Gilbert's latite ignimbrite.

MAP OF STUDY AREA

Bodie Hills and Mono Basin are located in eastern California within Central Walker Lane. The area is bounded by Sierra Nevada Frontal Fault System in the west and by the Basin and Range Extensional Province in the east. The Tuff of Jack Springs was sampled in Bodie Hills (TJS) and the Tuff of Huntoon Creek (THC) was sampled in the southern and eastern regions of the study area.



These marked boundaries are arbitrary and do not represent the full extent of spatial distribution of the aforementioned tuffs. The remaining localities (not shown on this map) produced reversed polarity signatures and it remains unknown which tuffs these belong. The first Trafton Mountain locality was severely altered and re-magnetized by lightning strikes that left visible evidence on the outcrop. Additionally, the Trafton Mountain sites differ in lithology from the Upper Huntoon Creek site. Map adapted from Scott Mitchell, CSU, Fres.

TUFF OF JACK SPRINGS

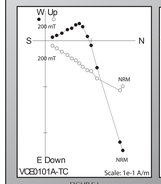


FIGURE 1

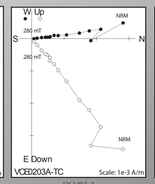


FIGURE 2

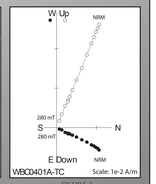


FIGURE 3

Figures 1-3: Typical zijderveld from TJS sites showed overprints likely from lightning strikes. Alternating field demagnetization typically removed the signatures at 15 -20 mT. All VCE01 samples demagnetized at steps 0, 2, 5, 10, 15, 20, 30, 45, 60, 80, 100, 130, 160, and 200 mT at CSU, Fresno Paleomagnetism Laboratory using a shielded single-axis 2G AF Demagnetizer. VCE02 and all WBC03, 04, 05 specimens were demagnetized at steps, 5, 10, 15, 20, 30, 40, 50, 60, 70, and 80 mT at the Paleomagnetics Laboratory at USGS, Menlo park using a multi-specimen fully automated cryogenic magnetometer and additional steps 100, 140, 200, and 280 mT were completed at CSU, Fresno Paleomagnetism Laboratory. All CSU, Fresno magnetic field measurements taken in an AGICO JR6 magnetometer.

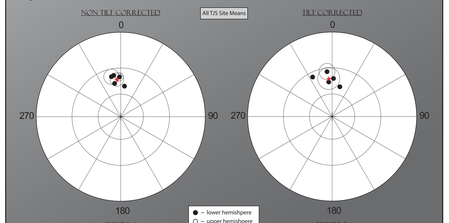


FIGURE 4 FIGURE 5


FIGURE 6

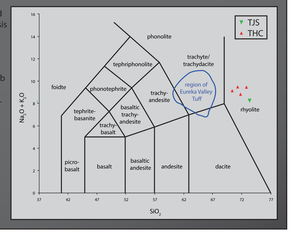
Figure 4: Characteristic remanent magnetizations (ChRM) of VCE01, VCE02, WBC03, WBC04, and WBC05 without tilt corrections. Red star indicates Fisher mean. **Figure 5:** ChRM of TJS sites with tilt corrections. For fig. 3 & 4, $\mathbf{D}_g$ = 353.5°, $\mathbf{I}_g$ = 42.5°, **α95** = 7.7°, $\mathbf{D}_s$ = 354.7°, and $\mathbf{I}_s$ = 41.8°. **Figure 6:** VCE01 outcrop. TJS can be identified in hand specimen by phenocrysts of sanidine and biotite. TJS has eutaxitic texture from which orientations were obtained. Chris for scale.

GEOCHEMISTRY OF TJS & THC

TABLE I

Result	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Cr_2O_3
WBC03	73.23	0.43	14.94	1.29	0.04	0.71	0.89	2.80	5.41	0.04	0.02
MO01	71.77	0.34	14.39	1.68	0.08	0.29	1.15	3.94	4.90	0.063	0.001
MO02	70.38	0.38	15.61	2.49	0.08	0.59	1.80	4.08	5.07	0.125	0.001
MO08	71.3	0.27	14.24	1.46	0.07	0.23	0.97	3.76	5.70	0.076	0.001
MO11	72.74	0.26	14.71	1.45	0.07	0.24	1.00	3.87	5.59	0.048	0.002

Table 1: Geochemistry of TJS obtained from fiamme at WBC03 locality. Analysis shows TJS is distinctly different from the THC (MO– specimens). Plotted on the LeBas diagram to the right, both tuffs are rhyolitic ignimbrites. Analysis preformed at CSU, Fresno Petrology lab by X-ray fluorescence. Geochemistry for Eureka Valley Tuff from King (2007).



TUFF OF HUNTOON CREEK

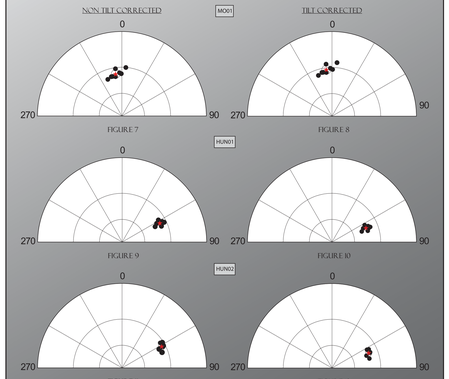


FIGURE 7 FIGURE 8 FIGURE 9 FIGURE 10 FIGURE 11 FIGURE 12

Figure 7: ChRM of MO01 without tilt corrected. **Figure 8:** ChRM of MO01 with tilt corrections. **Figure 9:** ChRM of HUN01 without tilt corrections. **Figure 10:** ChRM of HUN01 with tilt corrections. **Figure 11:** ChRM of HUN02 without tilt corrections. **Figure 12:** HUN02 with tilt corrections. Figures 9 -12 demagnetized at Caltech Paleomagnetism Laboratory from NRM to 90 mT. Red star indicates Fisher mean. **Figure 13:** ChRM of FN01 without tilt corrections. **Figure 14:** ChRM of FNR01 with tilt corrections. The outliers, indicated by blue in Figures 13 and 14, were lightning struck and loose before orientation (LBO), respectively, and were not included in the fisher mean statistics.

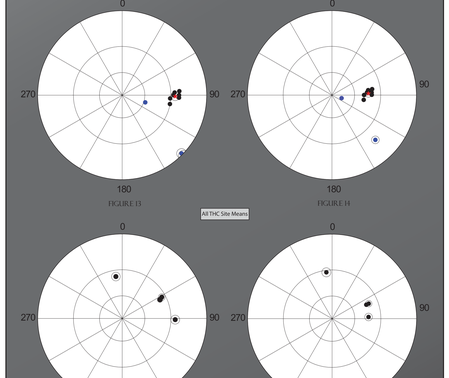


FIGURE 13 FIGURE 14 FIGURE 15 FIGURE 16

Figure 15: Means of THC ChRMs without tilt corrections. **Figure 16:** Means of THC ChRMs with tilt corrections.

Special thanks: AGICO JR6, Brandy Anglen, Sue Bratcher, Fresno Gem and Mineral Society, Shelby Fredrickson, Tommy Fredrickson, Jonathan Glen, David John, Shelby Jones, Bob Lindeman, Debbie Lindeman, Kevin Loeb, Scott Mitchell, Craig Poole, Keith Putirka, Belinda Rossette, Melissa Scruggs, Kelly Townsend, Brent Vanderburgh, John Wakabayashi

ROTATION AND FLATTENING

Locality	Declination (D_g)	Inclination (I_g)	Rotation	Flattening	Alpha 95	Declination (D_s)	Inclination (I_s)	Rotation	Flattening
MO01	351.4°	36.8°			4.7°	352.9°	32.1°		
HUN01	63.6°	37.0°	-72.2° ± 5.5	-0.2° ± 4.4	2.9°	67.8°	42.8°	-74.9° ± 5.5	-10.7° ± 4.4
HUN02	61.7°	33.9°	-70.3° ± 5.8	2.9° ± 4.7	3.6°	67.7°	39.8°	-74.8° ± 5.8	-7.7° ± 4.4
FNR01	91.3°	25.9°	-99.9° ± 6.1	10.9° ± 5.1	4.3°	87.4°	43.3°	-94.5° ± 6.5	-11.2° ± 5.1
VCE01	357.8°	39.6°			4.4°	333.7°	34.9°		
VCE02	6.4°	50.0°	-8.6° ± 5.7	-10.4° ± 4.1	2.7°	354.4°	45.3°	-380.7° ± 5.3	-10.4° ± 4.1
WBC03	349.7°	37.2°	-351.9° ± 5.2	2.4° ± 4.0	2.4°	14.5°	50.0°	-40.8° ± 5.2	-15.1° ± 4.0
WBC04	349.1°	46.3°	-351.3° ± 5.2	-6.7° ± 3.9	2.1°	2.1°	41.5°	-28.4° ± 4.8	-6.6° ± 3.9
WBC05	346.5°	38.1°	-348.7° ± 9.7	-1.5° ± 7.6	8.4°	353.5°	33.7°	-379.8° ± 9.2	1.2° ± 7.6

Table 2: Rotations for HUN01, HUN02, and FNR01 compared to MO01. MO01 at Cowtrack Mountain is considered stable because of its elevation and its granitic base makes it likely not to be rotated. Rotations for VCE02, WBC03, WBC04, WBC05 compared to VCE01 paleomagnetic reference directions established in this study.

THC DEMAGNETIZATION

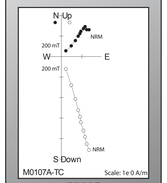


FIGURE 17

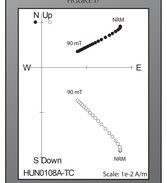


FIGURE 18

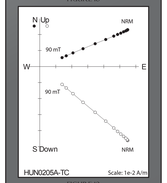


FIGURE 19

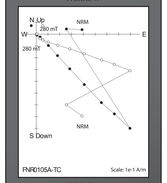


FIGURE 20

Figure 18 - 19: Demagnetized at Caltech Paleomagnetics Lab at NRM, 2, 4, 7, 10, 14, 18, 22, 26, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, and 90 mT.

OTHER SAMPLE SITES

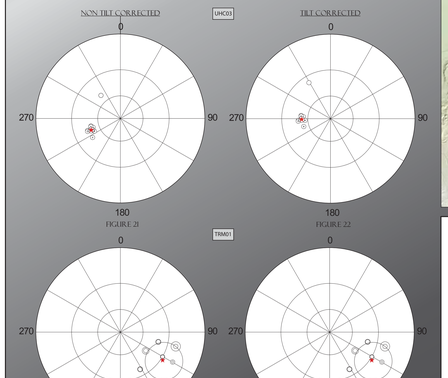


FIGURE 21 FIGURE 22 FIGURE 23 FIGURE 24 FIGURE 25 FIGURE 26

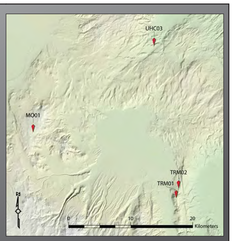


Figure 21: UHC03 with no tilt corrections. **Figure 22:** UHC03 with tilt corrections. **Figure 23:** TRM01 with no tilt corrections. **Figure 24:** TRM01 with tilt corrections. **Figure 25:** TRM02 with no tilt corrections **Figure 26:** TRM02 with tilt corrections. Figures 21 - 22 exhibits a reversed polarity and has a different lithology from fig 23 - 26. It is unkown to which tuffs these ignimbrite belongs. Figures 23 - 26 were originally hypothesized to be Drake's (1979) rhyolite ignimbrite. Map shows sample sites in relation to MO01.

GEOMAGNETIC POLARITY TIMESCALE

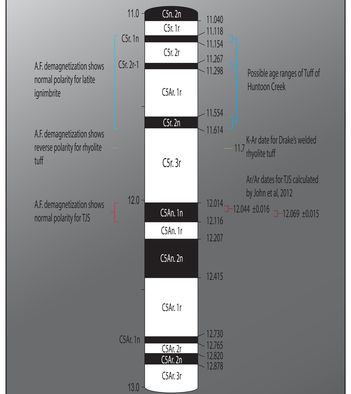
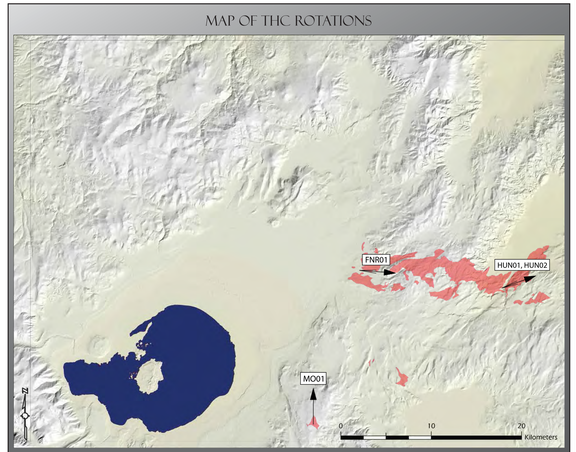


Figure 27: Paleomagnetic results for the Tuff of Huntoon Creek have further constrained the age dates fro the latite ignimbrite. Gilbert (1968) first age-dated the tuff ~11.12 - 11.50 Ma

MAP OF THC ROTATIONS



Map shows rotations of THC sites with errors. Based on elevation and granitoid baserock, it is likely that MO01 has occurred minimal rotation. Because of this, we tenatively establish this as our refeerence direction for THC. The areas in red are Tuff of Huntoon Creek originally mapped as latite ignimbrite by Gilbert (1968)

References

— Anderson, R.E., Berger, B.R., Miggins, D., 2012, Timing, magnitude, and style of Miocene deformation, west-central Walker Lane belt, Nevada: Lithosphere, v. 4, p. 187-208.
— Carlson, C.W., 2012, Changes in Central Walker Lane strain accommodation near Bridgeport, California, as told by the Stanislaus Group (M.S. thesis): California State University, Fresno.
— Gilbert, C.M., Christiansen, N.M., Al-Rawi, Y., and Lajoie, K.R., 1968, Structural and volcanic history of Mono Basin, California-Nevada: Mem. Geol. Soc. Am., 116, p. 275-329.
— King, N.M., Hillhouse, J.W., Gromme, S., Hauduin, B.P., and Plumlee, C.J., 2007, Stratigraphy, paleomagnetism, and anisotropy...: Geophysrs, v. 3, no5, p. 646-666.
— Kleinhampl, F.J., Davis, W.E., Silberman, M.L., Chesterman, C.W., Chapman, R.H., 1975, Aeromagnetic and Limited Gravity Studies and Generalized ...: USGS Bulletin 1384
— Oldow, J. S., Geissman, J. W. and Stockli, D. F., 2008, Evolution and Strain Reorganization within Late Neogene Structural Stepovers Linking the Central Walker Lane ...: International Geology Review, 50, 3, 270-290
— Stewart, J.H., Kleinhampl, F.J., Speed, R.C., Johannesen, D.C., 1984, Geologic map of the Little Huntoon Valley quadrangle, Mineral County, Nevada
— Unruh, J., Humphrey, J., Barron, A., 2003, Transtensional Model for the Sierra Nevada Frontal Fault System, Eastern California: Geology, v. 31, p. 327-330