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# Ion microprobe U-Pb analytical data of zircons and trace and major element chemistry of obsidian

**To accompany Stateline fault system: A new component of the Miocene-Quaternary Eastern California shear zone**

**Bernard Guest**
**Nathan Niemi**
**Brian Wernicke**
*Division of Geological and Planetary Sciences, California Institute of Technology, 1200 East California Boulevard, Pasadena, California 91125, USA*

## CUMULATIVE FAULT OFFSETS OF CENOZOIC FAULTS IN THE EASTERN CALIFORNIA SHEAR ZONE

Cumulative offsets of geologic markers along major faults in the Eastern California shear zone were compiled from the literature and plotted on a map of western United States faults (Figure1A). Compiled offset data are tabulated with references in Table DR1.

## TRACE AND MAJOR ELEMENT CHEMISTRY OF OBSIDIAN

Samples of obsidian were collected from the Devil Peak rhyolite dome and from an obsidian block at Black Butte (Table DR2). Blocks of volcanic glass from each locality were sent to Activation Laboratories for trace and major element lithogeochemistry analysis. Samples were fused with lithium metaborate/tetraborate and analyzed by inductively coupled plasma mass spectrometry. Results of trace element (Table DR3) and major element (Table DR4) analyses are presented, along with detection limits of elements analyzed using this methodology. Selected trace element analyses of obsidian samples from Black Butte and Devil Peak are compared with analyses of other obsidian glasses from the western United States (Table DR5).

## ION MICROPROBE U-PB ANALYTICAL PROCEDURES

U-Pb apparent ages for 5 zircon samples were determined using the UCLA Cameca IMS 1270 ion microprobe, following established procedures (Table DR6; Quidelleur et al., 1997). A 3–8 nA $O^-$ primary beam focused to a spot diameter of ~20 mm was used for analysis. The sample was flooded with $O2^-$ at a pressure of ~$3 \times 10^{-5}$ torr to achieve secondary ionization of $Pb^+$. Differentiation of the $^{204}Pb$ peak from $^{176}Hf\ ^{28}Si^+$, the primary molecular interference in zircon analysis, was accomplished with a mass resolving power of ~6000 (Compston et al., 1984). A 3.5 or 5 eV offset was used to measure the $^{238}U^+$ peak. Approximately 4 zircons, on average, were analyzed per sample. Each zircon was typically subject to a single spot analysis. Analysis of zircon standard AS3 yielded weighted mean ages within error of the age estimate of the standard as determined using thermal ionization mass spectrometry (Paces and Miller, 1993).

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TABLE DR1. FAULT OFFSET DATA FOR THE EASTERN CALIFORNIA SHEAR ZONE

| Fault Name | Offset No.* | Offset (km) | Offset Marker | Separation | Initiation | Reference |
|---|---|---|---|---|---|---|
| Blackwater | 1 | 0.3 – 1.8 | Late Miocene dacite lava flows | Dextral | Post 7.23 Ma | Oskin and Iriondo (2004) |
| | 2 | 1.8 | Pliocene basalt lava flows | Dextral | Post 3.77 Ma | Oskin and Iriondo (2004) |
| Calico | 1 | 8.2 | Early Miocene detachment zone | Dextral | Post 17 Ma | Dibblee (1961); Glazner et al. (2000) |
| | 2 | 9.6 | Middle Miocene Barstow Fm. and normal fault | Dextral | Post 13 Ma | Garfunkel (1974); Oskin et al. (2007) |
| Camp Rock | | 1.6 – 4 | Early Miocene detachment zone | Dextral | Post 17 Ma | Dokka (1983) |
| Death Valley – Furnace Creek | | 45 – 50 | Jurassic quartz monzonite | Dextral | Post Jurassic | McKee (1968); Reheis and Sawyer (1997) |
| – Fish Lake Valley | | ~104 | | Dextral | Post 11.6 Ma | Niemi et al. (2001) |
| | | ~68 | Mesozoic faults and folds | Dextral | Post-Cretaceous | Snow and Wernicke (1989) |
| Garlock | 1 | 64 | Late Jurassic Independence dike swarm | Sinistral | Post Jurassic | Smith (1962) |
| | 2 | 64 | Mesozoic thrust faults and folds | Sinistral | Post Cretaceous | Smith et al. (1968) |
| | 3 | 64 | Precambrian and Early Paleozoic facies boundaries | Sinistral | Post Paleozoic | Smith and Ketner (1970) |
| | 4 | 64 | Mid-Miocene Eagle Crag and Cudahy Camp volcanics | Sinistral | Post ~15 Ma | Monastero et al. (1997) |
| Hunter Mountain | | 8 – 10 | Jurassic Hunter Mtn Batholith and Pliocene basalt | Dextral | Post 4 Ma | Burchfiel et al. (1987) |
| Lenwood | | 1.5 – 3 | Early Miocene detachment zone | Dextral | Post 17 Ma | Dokka (1983); Strane (2007) |
| Owens Valley | | ~65 | Cretaceous Golden Bear and Coso dikes | Dextral | Post Cretaceous | Kylander-Clark et al. (2005) |
| Pinto Mountain | | ~16 | Triassic pluton and dikes | Sinistral | Post Triassic | Dibblee (1992); Barth and Wooden (2006) |
| Rodman and Pisgah | | 6.4 – 14.4† | Early Miocene detachment zone | Dextral | Post 17 Ma | Dokka (1983) |
| San Andreas | 1 | ~213 | Late Miocene strata | Dextral | ~21 Ma | Huffman (1972) |
| | 2 | ~350 | Eocene strata | Dextral | ~21 Ma | Clarke and Nilsen (1973) |
| | 3 | ~350 | Cretacous mafic conglomerate | Dextral | ~21 Ma | Ross et al. (1973) |
| | 4 | ~350 | Early Miocene Neenach – Pinnacles volcanic field | Dextral | ~21 Ma | Matthews (1976) |
| | 5 | ~240 | Late Miocene Caliente and Mint Canyon Fms. | Dextral | ~21 Ma | Ehlig et al. (1975) |
| | 6 | 320 – 330 | Oligo-Miocene San Joaquin – La Honda basins | Dextral | ~21 Ma | Stanley (1987) |
| San Gregorio | | ~115 | Sandstone dike intrusion into the Monterey Fm. | Dextral | ~21 Ma | Stanley and Lillis (2000) |
| San Jacinto | | ~25 | Eastern Peninsular Ranges mylonite zone | Dextral | 1.1 Ma | Matti and Morton (1993); Morton and Matti (1993); Kirby et al. (2007) |
| Southern Death Valley | | ~35 | Miocene Confidence Hills alluvial fan gravels | Dextral | Post 10 Ma | Butler et al. (1988) |
| | | ~55 | Late Miocene to Pliocene Amargosa Chaos basin | Dextral | Post 7.8 Ma | Topping (1993) |
| Stateline | 1 | 3 | Mesozoic faults and folds | Dextral | Post Cretaceous | Walker et al. (1995) |
| | 2 | ~30 | ~12.6 Ma volcanic and rock avalanche deposits | Dextral | Post middle Miocene | This paper |
| | 3 | 10 – 20 | Correlated pre-Cenozoic faults and facies trends | Dextral | Post Cretaceous | Burchfiel et al. (1983); R. L. Christiansen, personal communication in Stewart at al. (1968) |
| Whittier - Elsinore | | 8 – 9 | Paleogene basin axis | Dextral | Neogene | McCulloh et al. (2000) |

*Numbers shown next to arrows on Figure 1A.

†The validity of this offset has been questioned by Glazner et al. (2002).

TABLE DR2. SAMPLE LOCATIONS AND DESCRIPTIONS

| Sample Number | Sample Coordinates (°N) | Sample Coordinates (°W) | Sample Notes |
|---|---|---|---|
| Black Butte Rhyolite Ash | | | |
| 11-33-1 | 35.88452 | 115.71788 | Sample of biotite ash from road cut along road that ascends the east flank of Black Butte. |
| 11-33-2 | 35.88452 | 115.71788 | Sample of biotite ash from road cut along road that ascends the east flank of Black Butte. |
| 11-30-1 | 35.88452 | 115.71788 | Sample of biotite ash from outcrop in gulley ~20m below road that ascends the east flank of Black Butte |
| Devil Peak Rhyolite Ash | | | |
| 11-50-2 | 35.69790 | 115.48465 | Sample from outcrop along the access road to the Umpire Perlite Mine, northwest of Devil Peak. |
| Devil Peak Stony Rhyolite | | | |
| 11-51-2 | 35.70010 | 115.46582 | Sample of rhyolite from cliff face north of Picture Rock Mine, northwest of Devil Peak. |
| Black Butte Obsidian | | | |
| 11-43-1 | 35.88452 | 115.71788 | Sample of obsidian block from rock avalanche deposit ~20m below the road that ascends the east flank of Black Butte. |
| Devil Peak Obsidian | | | |
| 11-51-1 | 35.69790 | 115.48465 | Sample from outcrop along the access road to the Umpire Perlite Mine, northwest of Devil Peak. |

TABLE DR3. TRACE ELEMENT ANALYSES OF OBSIDIAN GLASS FROM THE STATELINE FAULT REGION

| Element | Detection Limit (ppm) | Sample 11-43-1 (ppm) | Sample 11-51-1 (ppm) |
|---|---|---|---|
| Sc | 1 | 4 | 4 |
| Be | 1 | 3 | 3 |
| V | 5 | 14 | — |
| Cr | 20 | 70 | 100 |
| Co | 1 | 2 | — |
| Ni | 20 | — | — |
| Cu | 10 | 10 | — |
| Zn | 30 | 60 | 40 |
| Ga | 1 | 21 | 19 |
| Ge | 0.5 | 1.5 | 1.4 |
| As | 5 | — | — |
| Rb | 1 | 193 | 166 |
| Sr | 2 | 235 | 214 |
| Y | 0.5 | 28 | 25 |
| Zr | 4 | 229 | 126 |
| Nb | 0.2 | 21.8 | 20 |
| Mo | 2 | 2 | 4 |
| Ag | 0.5 | 0.5 | — |
| In | 0.1 | — | — |
| Sn | 1 | — | — |
| Sb | 0.2 | 1.4 | 1.8 |
| Cs | 0.1 | 4.7 | 3.6 |
| Ba | 3 | 929 | 592 |
| La | 0.05 | 80.8 | 56.2 |
| Ce | 0.05 | 151 | 111 |
| Pr | 0.01 | 17.3 | 12.8 |
| Nd | 0.05 | 53.9 | 40.4 |
| Sm | 0.01 | 8.6 | 7.42 |
| Eu | 0.005 | 1.37 | 1.16 |
| Gd | 0.01 | 5.99 | 5.44 |
| Tb | 0.01 | 0.83 | 0.79 |
| Dy | 0.01 | 4.31 | 4.12 |
| Ho | 0.01 | 0.82 | 0.79 |
| Er | 0.01 | 2.47 | 2.37 |
| Tm | 0.005 | 0.378 | 0.357 |
| Yb | 0.01 | 2.43 | 2.34 |
| Lu | 0.002 | 0.365 | 0.324 |
| Hf | 0.1 | 6.1 | 4.1 |
| Ta | 0.01 | 1.44 | 1.46 |
| W | 0.5 | 1.2 | 1.7 |
| Tl | 0.05 | 1.38 | 0.77 |
| Pb | 5 | 30 | 33 |
| Bi | 0.1 | — | 0.2 |
| Th | 0.05 | 21.8 | 23 |
| U | 0.01 | 4.91 | 5.68 |

*Note:* Trace element concentrations below the detection limit are indicated by —.

TABLE DR4. MAJOR ELEMENT ANALYSES OF OBSIDIAN GLASS FROM THE STATELINE FAULT REGION

| Element | Detection Limit (%) | Sample 11-43-1 (%) | Sample 11-51-1 (%) |
|---|---|---|---|
| $SiO_2$ | 0.01 | 68.54 | 73.30 |
| $Al_2O_3$ | 0.01 | 13.65 | 13.81 |
| $Fe_2O_3$ | 0.01 | 1.67 | 1.18 |
| MgO | 0.01 | 0.53 | 0.16 |
| CaO | 0.01 | 1.11 | 1.15 |
| $Na_2O$ | 0.01 | 2.76 | 3.62 |
| $K_2O$ | 0.01 | 6.03 | 5.21 |
| $TiO_2$ | 0.001 | 0.211 | 0.125 |
| $P_2O_5$ | 0.01 | 0.07 | 0.03 |
| LOI* | 0.01 | 0.068 | 0.073 |

*Loss on ignition.

TABLE DR5. COMPARISON OF TRACE ELEMENT DATA FOR OBSIDIAN SAMPLES FROM BLACK BUTTE AND DEVIL PEAK WITH OTHER OBSIDIAN SOURCES FROM THE WESTERN UNITED STATES

| Element | Sample | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Black Butte 11-43-1*** | **Devil Peak 11-51-1*** | Devil Peak West Side† | Devil Peak East Side† | Big Pine§ | Little Glass Mountain§ | Panum Dome§ | Clear Lake§ |
| Sc | **4** | **4** | | | 3.3 | 4.3 | 1.9 | 4.6 |
| Be | **3** | **3** | | | 7.3 | 2.6 | 3.8 | 2.3 |
| Cr | **70** | **100** | | | 1.6 | 5 | 4 | 2.3 |
| Co | **2** | **0.5** | | | 0.3 | 1.9 | 0.2 | 1.4 |
| Zn | **60** | **40** | | | 38 | 32 | 41 | 24 |
| Rb | **193** | **166** | 177.3 | 204.1 | 208 | 155 | 178 | 201 |
| Sr | **235** | **214** | 251.3 | 108.1 | 8 | 115 | 8 | 73 |
| Y | **28** | **25** | 25.8 | 28.6 | 40 | 25 | 26 | 33 |
| Zr | **229** | **126** | 156 | 107.4 | 73 | 208 | 105 | 136 |
| Nb | **21.8** | **20** | 22.5 | 25.2 | 40 | 9.6 | 22 | 14 |
| Mo | **2** | **4** | | | 5.3 | 2.9 | 2.6 | 0.75 |
| Sn | **0.5** | **0.5** | | | 3 | 3 | 3.1 | 5.7 |
| Sb | **1.4** | **1.8** | | | 1.4 | 0.6 | 0.9 | 1.2 |
| Cs | **4.7** | **3.6** | | | 4.4 | 10.1 | 5.3 | 14.8 |
| Ba | **929** | **592** | 869.9 | 342.5 | 12 | 850 | 50 | 655 |
| La | **80.8** | **56.2** | 86.6 | 59.6 | 11 | 24 | 24 | 31 |
| Ce | **151** | **111** | 163.5 | 113.2 | 28 | 46 | 52 | 64 |
| Nd | **53.9** | **40.4** | | | 13 | 17 | 19 | 25 |
| Sm | **8.6** | **7.42** | | | 4 | 4.5 | 4.4 | 5.2 |
| Eu | **1.37** | **1.16** | | | 0.31 | 0.57 | 0.13 | 0.33 |
| Gd | **5.99** | **5.44** | | | 4 | 3.8 | 4.9 | 5 |
| Tb | **0.83** | **0.79** | | | 0.71 | 0.68 | 0.75 | 0.96 |
| Tm | **0.378** | **0.357** | | | 0.39 | 0.4 | 0.45 | 0.56 |
| Yb | **2.43** | **2.34** | | | 3.1 | 2.5 | 2.8 | 3.5 |
| Lu | **0.365** | **0.324** | | | 0.46 | 0.39 | 0.39 | 0.46 |
| Hf | **6.1** | **4.1** | | | 4.2 | 5.6 | 4.3 | 5.5 |
| Ta | **1.44** | **1.46** | | | 3.8 | 1.1 | 1.97 | 1.31 |
| W | **1.2** | **1.7** | | | 2.4 | 1.4 | 2.2 | 3.5 |
| Pb | **30** | **33** | 40.7 | 42.4 | 30 | 18 | 21 | 21 |
| Th | **21.8** | **23** | | | 21.8 | 14.9 | 18.9 | 21.7 |
| U | **4.91** | **5.68** | | | 7.2 | 6.7 | 5.2 | 6.8 |

***This study**
**†Schackley (1994) Reported values are averages of 10 analyses from each sample locality.**
§McDonald et al. (1992)

TABLE DR6. ION MICROPROBE U-PB ANALYTICAL RESULTS FOR ZIRCONS FROM BLACK BUTTE AND DEVIL PEAK

| Analysis* | $^{206}Pb/^{238}U$ Age† (Ma) | $^{206}Pb^{*}$§ (%) | $^{206}Pb^{*}/^{238}U$ | $^{207}Pb^{*}/^{235}U$ | $^{207}Pb^{*}/^{206}Pb^{*}$ | CC# | U (ppm) | Th (ppm) |
|---|---|---|---|---|---|---|---|---|
| Sample 11-51-2 | | | | | | | | |
| g1 s1 | 14.85 ± 1.13 | 90.6 | 0.0025 ± 0.0002 | 0.0422 ± 0.0079 | 0.1201 ± 0.0234 | 0.042 | 125 | 87 |
| g2 s1 | 13.98 ± 1.04 | 91.3 | 0.0024 ± 0.0001 | 0.0376 ± 0.0080 | 0.1145 ± 0.0220 | 0.450 | 141 | 168 |
| g3 s1 | 13.40 ± 0.65 | 96.8 | 0.0021 ± 0.0001 | 0.0211 ± 0.0020 | 0.0711 ± 0.0063 | 0.426 | 379 | 298 |
| g4 s1 | 13.38 ± 0.73 | 98.7 | 0.0021 ± 0.0001 | 0.0163 ± 0.0016 | 0.0563 ± 0.0059 | 0.096 | 438 | 502 |
| g5 s1 | 12.25 ± 0.71 | 98.9 | 0.0019 ± 0.0001 | 0.0146 ± 0.0018 | 0.0550 ± 0.0070 | 0.204 | 610 | 601 |
| Sample 11-33-1 | | | | | | | | |
| g1 s1 | 13.35 ± 0.98 | 92.9 | 0.0022 ± 0.0001 | 0.0312 ± 0.0050 | 0.1014 ± 0.0171 | 0.072 | 168 | 207 |
| g2 s1 | 12.37 ± 0.67 | 94.7 | 0.0020 ± 0.0001 | 0.0245 ± 0.0032 | 0.0876 ± 0.0106 | 0.396 | 308 | 351 |
| g3 s1 | 12.96 ± 0.73 | 93.7 | 0.0021 ± 0.0001 | 0.0283 ± 0.0039 | 0.0955 ± 0.0120 | 0.392 | 176 | 198 |
| g4 s1 | 12.00 ± 0.75 | 93.5 | 0.0020 ± 0.0001 | 0.0267 ± 0.0039 | 0.0970 ± 0.0143 | 0.175 | 184 | 204 |
| g4 s1 | 11.91 ± 0.87 | 89.0 | 0.0021 ± 0.0001 | 0.0380 ± 0.0050 | 0.1326 ± 0.0182 | 0.133 | 105 | 123 |
| Sample 11-33-2 | | | | | | | | |
| g1 s1 | 13.92 ± 0.80 | 98.2 | 0.0022 ± 0.0001 | 0.0184 ± 0.0024 | 0.0607 ± 0.0071 | 0.458 | 336 | 288 |
| g2 s1 | 12.17 ± 0.75 | 92.6 | 0.0020 ± 0.0001 | 0.0293 ± 0.0056 | 0.1041 ± 0.0206 | -0.022 | 130 | 157 |
| g3 s1 | 14.07 ± 0.96 | 95.2 | 0.0023 ± 0.0001 | 0.0266 ± 0.0030 | 0.0840 ± 0.0099 | 0.225 | 271 | 303 |
| g4 s1 | 12.67 ± 0.70 | 97.7 | 0.0020 ± 0.0001 | 0.0180 ± 0.0026 | 0.0646 ± 0.0093 | 0.222 | 322 | 509 |
| g5 s1 | 13.82 ± 1.71 | 93.2 | 0.0023 ± 0.0003 | 0.0315 ± 0.0089 | 0.0991 ± 0.0279 | 0.199 | 125 | 154 |
| Sample 11-30-1 | | | | | | | | |
| g2 s1 | 14.12 ± 0.74 | 99.0 | 0.0022 ± 0.0001 | 0.0166 ± 0.0021 | 0.0543 ± 0.0064 | 0.389 | 645 | 357 |
| g3 s1 | 12.38 ± 0.61 | 99.2 | 0.0019 ± 0.0001 | 0.0141 ± 0.0012 | 0.0527 ± 0.0040 | 0.486 | 729 | 723 |
| Sample 11-50-2 | | | | | | | | |
| g1 s1 | 13.65 ± 1.37 | 80.1 | 0.0026 ± 0.0002 | 0.0736 ± 0.0141 | 0.2018 ± 0.0319 | 0.643 | 305 | 354 |
| g2 s1 | 13.55 ± 0.77 | 96.7 | 0.0022 ± 0.0001 | 0.0218 ± 0.0032 | 0.0725 ± 0.0095 | 0.464 | 313 | 491 |
| g3 s1 | 13.12 ± 2.65 | 38.0 | 0.0054 ± 0.0003 | 0.3925 ± 0.0301 | 0.5311 ± 0.0221 | 0.844 | 540 | 606 |
| g4 s1 | 13.59 ± 0.66 | 96.7 | 0.0022 ± 0.0001 | 0.0218 ± 0.0019 | 0.0723 ± 0.0057 | 0.464 | 561 | 572 |

*g, grain number; s, spot number.

†All samples were corrected for common Pb using $^{206}Pb/^{204}Pb$ = 18.911; $^{207}Pb/^{204}Pb$ = 15.70; and $^{208}Pb/^{204}Pb$ = 38.526.

§% $^{206}Pb^{*}$, percent radiogenic $^{206}Pb$.

#Correlation coefficient between $^{206}Pb/^{238}U$ and $^{207}Pb/^{235}U$.