Late Quaternary slip rates along the Sierra Nevada frontal fault zone, California: Evidence for slip partitioning across the western margin of the Eastern California Shear Zone/ Basin and Range Province

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ABSTRACT

New geologic mapping, tectonic geomorphology, and cosmogenic radionuclide (CRN) geochronology data provide the first quantitative rates on late Quaternary vertical slip and extension across the southern Sierra Nevada frontal fault zone, California. This fault zone exposes numerous NNW-striking, east-facing normal fault scarps that offset seven distinct Quaternary alluvial fan surfaces (Qf1, Qf2a and b, Qf3a,b and c, and Qf4 – oldest to youngest). Beryllium-10 CRN surface exposure dating of these surfaces provide surface abandonment ages of: 138 ± 35 ka for a Qf1 surface, 66 ± 16 ka for Qf2b, 23 ± 6 ka for Qf3a, 5 ± 1.2 ka for Qf3c, and 4 ± 1 ka for Qf4. These ages combined with measurements of vertical surface offset across fault scarps yield late Pleistocene vertical and horizontal slip rates of 0.2-0.4 ± 0.1 mm/yr and 0.1-0.3 ± 0.1 mm/yr, respectively, and Holocene vertical and horizontal slip rates of 1.4 ± 0.4 and 0.8 ± 0.2, respectively. These slip rate estimates are comparable to late Pleistocene vertical slip rate estimates across range front normal faults within the Basin and Range Province. The results, combined with data from the dextral Owens Valley fault, imply that the Sierra Nevada block is moving both perpendicular and parallel to Pacific-North America plate motion.

INTRODUCTION

The southwestern U.S. Cordillera is the world’s best place to examine the relative contributions of plate boundary forces and internal driving forces to intracontinental deformation kinematics. One of the most prominent geomorphic features within this region is the Sierra Nevada, a mountain range with a mean elevation of 2800 m above sea level and bounded along its east flank by a normal fault system, the Sierra Nevada frontal fault zone (SNFFZ). The SNFFZ defines the western boundary of both the Eastern California Shear Zone and Basin and Range Province, a region where NW-dextral shear has been superimposed on EW-extension (Fig. 1). There is a long history of research on the origin Sierra Nevada topography and role the SNFFZ plays in the evolution of this part of the Cordillera (e.g. Lindgren, 1911; Christensen, 1966). More recently, Flesch et al. (2000) used results from GPS, topographic, geoid, and Quaternary fault slip studies to hypothesize that NW-dextral shear and EW-extension within the ECSZ resulted from translation of the Sierra Nevada both parallel and perpendicular to the Pacific-North American plate boundary in consequence of plate tractions and gravitational potential

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energy, respectively. Data from a number of studies investigating deformation over time scales of ~3-8 Ma led Jones et al. (2004 and references therein) to suggest that removal of lithosphere beneath the Sierra Nevada at ~3.5 Ma initiated uplift and increased extensional strain rates. Their proposal, invoking a combination of locally derived internal forces (gravitational potential energy) and plate boundary forces to drive fault kinematics along the western boundary of the Eastern California Shear Zone and Basin and Range Province, is consistent with that of Flesch et al. (2000). In contrast to these hypotheses, the orientation of normal and strike-slip faults along the eastern margin of the Sierra Nevada relative to the small circles to the Sierra-Nevada-North America Euler pole, coupled with kinematic inversions of earthquake focal mechanisms, led Unruh et al., (2003) to hypothesize that normal faulting along the eastern flank of the Sierra Nevada is related to plate boundary driven NW-translation of this rigid block rather than to Sierra Nevada uplift or regional Basin and Range extension. These geodynamic hypotheses make different, testable predictions about the kinematics and rates of slip along the SNFFZ. Strain partitioning, with normal slip along the SNFFZ and dextral slip elsewhere, and an increase in slip rate along the SNFFZ since the late Miocene to early Pliocene would support deformation kinematics driven by a combination of internal and external forces. In contrast, oblique slip (normal and right lateral) along the SNFFZ would support NW-translation of the Sierra Nevada solely as a consequence of plate boundary forces.

In this paper, we describe the results of new detailed geologic mapping and cosmogenic radionuclide (CRN) geochronologic investigations along the southern part of the SNFFZ. Our data provide the first quantitative late Quaternary fault slip rates along this part of the SNFFZ that bear on the tectonic role of the Sierra Nevada during the late Quaternary.

GEOLOGIC SETTING

The Sierra Nevada is a large, west-tilted normal fault-block that defines the western margin of the Basin and Range Province in a region of active, intracontinental deformation where NW-dextral shear has been superimposed on EW-extension (Fig. 1). Today, this part of the margin is dominated by a complex array of NW-striking dextral faults, NE-striking connecting normal faults, and NW-striking range bounding normal faults that define the Eastern California Shear Zone (Dokka and Travis, 1990). This array of faults accommodates ~25% the relative motion between the Pacific and North American plates (e.g. Dixon et al., 2000; Gan et al., 2000).

The Sierra Nevada consists of Paleozoic and Mesozoic sedimentary and volcanic rocks intruded by Mesozoic granitic rocks overlain by Cenozoic volcanic and sedimentary deposits (e.g. Bateman and Wahrhaftig, 1966). The eastern piedmont of the southern Sierra Nevada comprises extensive Quaternary alluvial fan, glacial, rockslide, and lacustrine deposits that are cut by normal faults. The SNFFZ forms the eastern escarpment of the Sierra Nevada and extends ~300 km from just north of the Garlock fault to the Cascade Range.

SIERRA NEVADA FRONTAL FAULT ZONE

Alluvial Fan Surfaces

The southern part of the SNFFZ, between Oak and Lubkin creeks, offsets granite- and metamorphic-derived Quaternary coarse- to fine-grain alluvial fan, glacial, and rock slide deposits (Figs. 2 and 3). Seven Quaternary alluvial fan surfaces of distinct ages have been mapped based on alluvial fan surface morphology such as terrace height, presence or absence of
bar and swale morphology, degree of fan dissection, desert pavement development, inset geometry, and slope.

From oldest to youngest they are: Qf1—surface erosional remnants preserved as strongly dissected, high rounded mounds (30-100 m) with scarce, strongly weathered boulder clasts (Figs. 2 and 3). Qf2a—surfaces characterized by ridge and ravine morphology and inset into Qf1 surfaces. These are located a few meters to tens of meters above the modern channel. Qf2b—surfaces inset into Qf2a and relatively smooth to locally moderately dissected that contain large, moderately weathered, and embedded granitic boulders. Based on bar and swale morphology, together with inset geometry, the next youngest surface, Qf3, is divided into three subunits, Qf3a, b, and c. Qf3a—surfaces possess subdued bar and swale morphology, are moderately dissected, and contain scarce large, fresh granitic boulders embedded in a matrix of granitic pebbles and sand. Qf3b—surfaces characterized by muted bar and swale morphology, channel incision 1.0-2.5 m deep, and large granitic boulders. Qf3c—surfaces are exposed at the mouth of most creeks and canyons and extend ~2-4 km from the range front and preserve distinct bar and swale morphology containing boulder-lined channels and large (1-9 m) fresh granitic boulders. Qf4—the youngest surfaces are defined by channels that are active or have been abandoned for a short period of time. These surfaces are typically densely vegetated and contain unvarnished granitic clasts, debris flow deposits that include tree trunk clasts, and fresh boulder levee bars.

Cosmogenic Radionuclide (CRN) Dating Results

Twenty-eight quartz-rich granite samples were collected from the top of boulders for $^{10}$Be CRN surface exposure age determination of five of the alluvial fan surfaces: Qf1, Qf2b, Qf3a and c, and Qf4.

Model $^{10}$Be ages for boulder samples collected from an offset Qf1 surface, located just south of Bairs Creek (Fig. 2), and from Qf2b, Qf3a and c, and Qf4 surfaces in the Symmes-Shepherd creeks area (Fig. 3) yielded calculated surface abandonment ages of 138 ± 35.2 ka for Qf1, 66 ± 16.0 ka for Qf2b, 23 ± 5.9 ka for Qf3a, 5 ± 1.2 ka for Qf3c, and 4 ± 1.1 ka for Qf4. These ages were calculated with an erosion rate of 0.3 mm/yr of the boulder surface (Small et al., 1997). Ages in this study agree, within uncertainty, with published $^{10}$Be CRN surface abandonment ages elsewhere in the region (Bierman et al., 1995; Zehfuss et al., 2001). Results are summarized in Table 1, sample localities are shown in Figure 3, and dating procedures and sample descriptions are in data repository 2005####.

Fault Geometry, Magnitude of Offset, and Slip Rates

The ~35 km long stretch of the SNFFZ between Oak and Lubkin creeks is up to ~ 4 km wide and is comprised of NNW-striking, dominantly E-dipping, but also W-dipping normal fault scarps. These scarps cut and offset Qf1, Qf2, and Qf3 surfaces, rockslides, and moraines, but not Qf4 surfaces. Based on fault zone width, geometry, and location, this part of the SNFFZ defines four distinct, right-stepping geometric segments (Fig. 2). Faults that define each segment have an average strike of ~N026W, whereas faults that define the step-over between segments strike ~N010E. Segment A is a 4 km long and 4 km wide zone defined by six, sub-parallel, NW-striking, E-dipping normal faults. To the south of segment A, the locus of faulting steps ~1 km to the west to segment B which is a 7 km long and 5 km wide zone dominated by as many as seven, NNW-striking, E- and W-dipping, sub-parallel, W-stepping en echelon normal faults. Segment
C, located in the central part of the map area, is a ~10 km long and ~2 km wide zone of four sub-parallel, E-dipping en echelon normal faults. Faulting steps ~1 km westward to the south into segment D which is a ~12 km long and ~2 km wide zone of NNW-striking, E-dipping normal faults. Faults exposed in each segment exhibit normal, dip-slip motion; there is no geomorphic evidence for a lateral component of slip.

Kinematic GPS topographic profiling across normal fault scarps that cut and offset alluvial fan surfaces allow maximum vertical surface offsets to be determined (Table 1; Fig. 2). Combining data from \(^{10}\)Be CRN surface exposure dating with topographic profiling yields vertical slip rate estimates of 0.2-0.3 ± 0.1 mm/yr since ~138 ka, 0.2-0.3 ± 0.1 mm/yr since ~66 ka, 0.4 ± 0.1 since ~23 ka, and 1.4 ± 0.4 since ~5 ka (Table 1). Assuming a fault dip of 60° yields calculated horizontal extension rates for the late Pleistocene to Holocene that range from 0.1-0.3 ± 0.1 mm/yr to 0.8 ± 0.2 mm/yr (Table 1). Our calculated vertical and horizontal slip rates of 1.4 ± 0.3 mm/yr and 0.8 ± 0.2 mm/yr, respectively, for the late Holocene are four to seven times faster than our late Pleistocene estimates (Table 1). This indicates either that horizontal extension rates have increased over the last 5,000 years or that these calculated slip rates are maxima because these faults are early in the earthquake cycle. The latter is our preferred interpretation and we suggest that the late Pleistocene vertical slip rate of 0.2-0.4 mm/yr remains constant through the Holocene.

**DISCUSSION AND CONCLUSIONS**

Our new late Pleistocene and late Holocene vertical slip rate estimates of 0.2-0.4 ± 0.1 mm/yr and 1.4 ± 0.3 mm/yr, respectively, are the first based on numerical ages for offset geologic markers along the SNFFZ. Our late Pleistocene CRN slip rate determinations are the same, within uncertainty, as geologic slip rates based on qualitative estimates of the age of offset geologic markers for the southern and central parts of the SNFFZ (Clark, 1972; Gillespie, 1982; Berry, 1989; Clark and Gillespie, 1993). For the Lone Pine fault, exposed ~10 km east of the field area, offset measurements (Lubetkin and Clark, 1988; Beanland and Clark, 1994) and \(^{10}\)Be CRN model exposure ages on granitic boulders from the offset surface (Bierman et al., 1995) yield a Holocene vertical slip rate of 0.5 ± 0.2 mm/yr, the same as our late Pleistocene estimate. Likewise, for the Fish Springs fault, exposed to the NNE of our map area (Fig. 1), fault offset measurements and \(^{10}\)Be CRN model exposure ages on offset alluvial surfaces yielded a late Pleistocene vertical slip rate of ~0.2 mm/yr (Zehuss et al., 2001). Investigations of uplifted river channels and deposits, volcanic flows, tilted strata, and river incision rates along the western flank of the Sierra Nevada suggest ~1.5 to 2.5 km of uplift during the past 3-5 Ma (Huber, 1981; Unruh, 1991; Wakabayashi and Sawyer, 2001; Stock et al., 2004), implying a long-term vertical slip rate of ~0.3-0.8 mm/yr. This is the same, within error, as our late Pleistocene vertical slip rate estimate. Vertical slip rate estimates for the SNFFZ are also the same as those estimated for several range bounding normal faults within the Basin and Range Province to the east (e.g. Wesnousky et al., in press; USGS, 2004; Friedrich et al., 2004; Hayman et al., 2003; Machette et al., 1992). If we assume that the SNFFZ and the Lone Pine fault dip 60° and 75°, respectively, then summing their late Pleistocene horizontal extension rates yields an estimated horizontal extension rate of 0.6 ± 0.2 mm/yr across Owens Valley at the latitude of Lone Pine. Shallower dipping faults will result in a higher rate of extension, whereas more steeply dipping faults will result in a lower rate of extension.
The SNFFZ, the Lone Pine fault, and the active Owens Valley fault, located ~15 km to the east, form a normal-strike slip fault system with estimated normal and dextral slip rates of 0.6 ± 0.2 mm/yr and 2 ± 1 mm/yr to 3.1 ± 0.7 mm/yr, respectively (Lubetkin and Clark, 1988; Beanland and Clark, 1992; Lee et al., 2001). These subparallel faults strike clockwise with respect to the ~N047W-trending motion of the Sierra Nevada block relative to stable North America (Dixon et al., 2000), yet only the Lone Pine fault exhibits oblique slip (Lubetkin and Clark, 1988; Beanland and Clark, 1992; this study). These relations imply that motion of the Sierra Nevada block is partitioned into three components—dominant dextral slip along the Owens Valley fault, intermediate oblique slip along the Lone Pine fault, and subordinate normal slip along the SNFFZ. This kinematic framework is consistent with the hypothesis that NW-dextral shear and EW-extension resulted from translation of the Sierra Nevada both parallel and perpendicular, respectively, to the Pacific-North American plate boundary as a consequence of external and internal boundary forces (e.g. Hammond and Thatcher, 2004; Bennett et al., 2003; Flesch et al., 2000). This kinematic framework also indicates that plate boundary forces dominate. Our short term slip rate estimates along the SNFFZ are the same, within error, with longer term (Pliocene) estimates thus offering no support for an increase in extension rate since removal of lithosphere beneath the Sierra Nevada at ~3.5 Ma as proposed by Jones et al. (2004). We speculate that extension rates either increased immediately following removal of dense lithosphere, but soon thereafter slowed to rates similar to those observed across many normal faults in the Basin and Range Province or that rates remained slow and constant in response to removal of lithosphere. Variations in extensional strain rates, or lack thereof, along the SNFFZ have important implications for continental strength and viscosity of the asthenosphere.

ACKNOWLEDGMENTS
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REFERENCES CITED
Zehfuss, P.H., Bierman, P.R., Gillespie, A.R., Burke, R.A., and Caffee, M.C., 2001, Slip rates on the Fish Springs fault, Owens Valley, California, deduced from cosmogenic \(^{10}\)Be and \(^{26}\)Al and soil development on fan surfaces: Geological Society of America, v. 113, p. 241-255.

**Figure Captions**
**Figure 1.** Generalized map showing major Quaternary faults along the western boundary of the Basin and Range Province within the Eastern California Shear Zone. Solid circle is located on the hanging wall of normal faults and arrows indicate relative motion across strike-slip faults.
**Figure 2.** Shaded relief geologic map along the southern Sierra Nevada frontal fault zone showing major fault scarps cutting Quaternary alluvial fan surfaces. Location shown in Fig. 1.
**Figure 3.** Detailed geologic map of the Symmes and Shepherd creeks area showing normal fault scarps cutting Quaternary alluvial fan surfaces, cosmogenic radionuclide sample locations, and topographic profile locations. Boxes show calculated \(^{10}\)Be boulder age for each sample and age of abandonment for each surface; *indicates boulder sample age not calculated in the weighted mean. Location shown in Fig. 2.
**Figure 4.** Topographic profiles across fault scarps cutting Qf2a, Qf2b, and Qf3a alluvial fan surfaces showing magnitude of vertical offset. Vertical elevation is relative to an arbitrary datum. Location of profiles shown in Fig. 3.

**TABLE 1. SUMMARY OF SURFACE AGES, VERTICAL OFFSETS, AND SLIP RATES**

<table>
<thead>
<tr>
<th>Surface</th>
<th>Age ± error (ka)*</th>
<th>Vertical offset of dated surface (m)</th>
<th>Maximum measured vertical offset (m)</th>
<th>Vertical slip rate (mm/yr)</th>
<th>Horizontal slip rate† (mm/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qf1</td>
<td>138 ± 35.2</td>
<td>23.3 ± 4.7†</td>
<td>40.8 ± 8.2†</td>
<td>0.2-0.3 ± 0.1*</td>
<td>0.1-0.2 ± 0.1*</td>
</tr>
<tr>
<td>Qf2a</td>
<td>Qf1 &gt; Qf2a &gt; Qf2a</td>
<td>—</td>
<td>41.0 ± 8.2</td>
<td>0.3-0.6 ± 0.1</td>
<td>0.2-0.3 ± 0.1</td>
</tr>
<tr>
<td>Qf2b</td>
<td>66 ± 16.0</td>
<td>11.9 ± 2.4</td>
<td>21.9 ± 4.4</td>
<td>0.2-0.3 ± 0.1</td>
<td>0.1-0.2 ± 0.1</td>
</tr>
<tr>
<td>Qf3a</td>
<td>23 ± 5.9</td>
<td>10.2 ± 2.0</td>
<td>10.2 ± 2.0</td>
<td>0.4 ± 0.1</td>
<td>0.3 ± 0.1</td>
</tr>
<tr>
<td>Qf3c</td>
<td>5 ± 1.2</td>
<td>6.9 ± 1.4</td>
<td>—</td>
<td>1.4 ± 0.4</td>
<td>0.8 ± 0.2</td>
</tr>
</tbody>
</table>

*Age estimates are calculated using a boulder surface erosion rate of 0.3 mm/yr.
†Slip rates are calculated assuming a 60° fault dip.
‡Because the hanging wall surface is younger than the footwall surface, measured vertical offset is a minimum.
§Slip rate estimate is a minimum.
**Figure 1, Le et al.**

![Map of Nevada and California](image1)

**Explanation**
- Qf4, present day channels
- Qf3a, alluvial fan surface
- Qf3b, alluvial fan surface
- Bedrock, undifferentiated
- Fault scarp (hachures on relative downthrown side)
- Stratigraphic contact

**Table 1**

<table>
<thead>
<tr>
<th>Sample</th>
<th>*Be age ± error</th>
<th>Mean age ± error</th>
</tr>
</thead>
<tbody>
<tr>
<td>K3</td>
<td>40 ± 1</td>
<td>23 ± 6</td>
</tr>
<tr>
<td>K1</td>
<td>45 ± 1</td>
<td>23 ± 6</td>
</tr>
<tr>
<td>K1.5</td>
<td>32 ± 1</td>
<td>23 ± 6</td>
</tr>
<tr>
<td>K1.6</td>
<td>45 ± 1</td>
<td>23 ± 6</td>
</tr>
</tbody>
</table>

**Figure 2, Le et al.**

![Map of Nevada and California](image2)

**Explanation**
- Qf4, valley fill
- Qf4, present day channels
- Qf3, surface
- Qf2, surface
- Older bedrock, undifferentiated
- Fault scarp (hachures on relative downthrown side)
- Stratigraphic contact

**Figure 3, Le et al.**

![Map of Nevada and California](image3)

**Figure 4, Le et al.**

![Profile 1](image4)

**Profile 1**
- net vertical offset of Qf2b: 11.9 ± 2.4 m
- minimum vertical offset of Qf2a: 41.0 ± 12.3 m

![Profile 2](image5)

**Profile 2**
- net vertical offset of Qf3a: 10.2 ± 3.0 m

![Profile 3](image6)

vertically exaggerated by 1.5
Samples of approximately 300 to 1000 g were collected from the top 1 to 5 cm of each boulder using a rock hammer and chisel. Twenty-four quartz-rich granitic boulders were sampled from five different alluvial surfaces. Boulders were selected from locations where there was little or no apparent evidence of boulder exhumation. Sample sites were recorded on aerial photographs using a Garmin GPS to locate the position of each sample site to within ~10 m. Once collected, samples were crushed, ground, pulverized, and sieved to a grain size of 250 to 500 microns.

A leaching procedure was used to purify the quartz and to remove meteoric $^{10}$Be (Kohl and Nishiizumi, 1992). Beryllium carrier was then added to the sample as it was dissolved in HF and Be was separated by ion exchange chromatography (Kohl and Nishiizumi, 1992). Beryllium was then precipitated as the hydroxide and converted to beryllium oxide (Kohl and Nishiizumi, 1992; Gosse and Phillips, 2001) by ignition in quartz at 750°C. The oxide was mixed with niobium powder prior to determination of $^{10}$Be using the LLNL CAMS FN tandem van de Graaff accelerator mass spectrometer. Beryllium-10 was determined relative to standards prepared from an ICN $^{10}$Be solution by K. Nishiizumi, using a $^{10}$Be half-life of 1.5x10$^6$ y.

The measured isotope ratios were converted to radionuclide concentrations in quartz using the total Be in the samples and the sample weights (Table R1). Age determinations were calculated with a sea-level, high-latitude production rate of 5.16 at/g-quartz-y using scaling factors in Lal (1991) as modified by Stone (2000) with a SLHL production by muons accounting for 3% of the total. A correction for variation in the geomagnetic field was applied to determine the final age of each sample as described in Nishiizumi et al. (1989) using the SINT800 geomagnetic intensity assessment (Valet, private communication). The topographic and depth corrections were performed by numeric integration of the flux for the dip and topography corrected elevation at all azimuth directions.

References:
**TABLE R1: SUMMARY OF $^{10}$Be MODEL AGES WITH EROSION ESTIMATES FOR THE SOUTHERN SIERRA NEVADA FRONTAL FAULT ZONE**

<table>
<thead>
<tr>
<th>Sample name</th>
<th>Altitude (m)</th>
<th>Latitude (N)</th>
<th>Longitude (W)</th>
<th>Depth &amp; topography correction</th>
<th>Thickness layer (cm)</th>
<th>Long axis of sampled boulder (m)</th>
<th>Intermediate axis of boulder (m)</th>
<th>Short axis of boulder (m)</th>
<th>$^{10}$Be measured (10$^6$ atom g$^{-1}$)</th>
<th>No Erosion $^{10}$Be age (ka) ±</th>
<th>Error</th>
<th>Erosion $^{10}$Be age (ka) ±</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fan Surface, Qf1</strong></td>
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</tr>
<tr>
<td>K20</td>
<td>1887</td>
<td>36°41.629</td>
<td>118°14.777</td>
<td>0.96</td>
<td>5</td>
<td>1.3</td>
<td>1.1</td>
<td>0.9</td>
<td>0.62 ± 0.312</td>
<td>96.3</td>
<td>2.4</td>
<td>120.1</td>
<td>3.0</td>
</tr>
<tr>
<td>K21</td>
<td>1887</td>
<td>36°41.626</td>
<td>118°14.778</td>
<td>0.96</td>
<td>5</td>
<td>1.4</td>
<td>0.8</td>
<td>0.7</td>
<td>1.78 ± 0.044</td>
<td>118.4</td>
<td>2.9</td>
<td>164.6</td>
<td>4.1</td>
</tr>
<tr>
<td>K22</td>
<td>1890</td>
<td>36°41.630</td>
<td>118°14.763</td>
<td>0.99</td>
<td>1</td>
<td>1.6</td>
<td>1.5</td>
<td>0.8</td>
<td>2.20 ± 0.055</td>
<td>109.4</td>
<td>3.0</td>
<td>145.1</td>
<td>4.0</td>
</tr>
<tr>
<td>K23§</td>
<td>1893</td>
<td>36°41.607</td>
<td>118°14.792</td>
<td>0.96</td>
<td>5</td>
<td>0.7</td>
<td>0.6</td>
<td>0.5</td>
<td>2.10 ± 0.057</td>
<td>76.5</td>
<td>2.3</td>
<td>91.7</td>
<td>2.8</td>
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<tr>
<td>K24§</td>
<td>1884</td>
<td>36°41.627</td>
<td>118°14.776</td>
<td>0.97</td>
<td>4</td>
<td>0.8</td>
<td>0.6</td>
<td>0.4</td>
<td>1.43 ± 0.043</td>
<td>66.5</td>
<td>2.2</td>
<td>77.5</td>
<td>2.6</td>
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<tr>
<td>Arithmetic mean of sample ages ± error</td>
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<td></td>
<td></td>
<td>106.3 ± 27</td>
<td>138.2 ± 35</td>
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<tr>
<td><strong>Fan Surface, Qf2b</strong></td>
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</tr>
<tr>
<td>K2§</td>
<td>1869</td>
<td>36°43.848</td>
<td>118°16.482</td>
<td>0.97</td>
<td>2</td>
<td>3.5</td>
<td>2.5</td>
<td>2</td>
<td>1.53 ± 0.036</td>
<td>82.5</td>
<td>2.0</td>
<td>99.6</td>
<td>2.4</td>
</tr>
<tr>
<td>K3</td>
<td>1871</td>
<td>36°43.781</td>
<td>118°16.488</td>
<td>0.96</td>
<td>3</td>
<td>2.5</td>
<td>1.4</td>
<td>1.3</td>
<td>9.60 ± 0.031</td>
<td>51.7</td>
<td>1.7</td>
<td>58.6</td>
<td>1.9</td>
</tr>
<tr>
<td>K4§</td>
<td>1873</td>
<td>36°43.851</td>
<td>118°16.486</td>
<td>0.99</td>
<td>1</td>
<td>1.2</td>
<td>0.8</td>
<td>0.5</td>
<td>0.44 ± 0.017</td>
<td>23.9</td>
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**Arithmetic mean of sample ages ± error**

4.6 ± 1

### Fan Surface, Qf4

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**Arithmetic mean of sample ages ± error**

4.3 ± 1

### Landslide

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**Arithmetic mean of sample ages ± error**

16.5 ± 6

**Notes:**

-.§ Be model ages for the southern Sierra Nevada area.
- Error reported in the error column is analytical.
- *Boulder samples that are not used in the calculation of the arithmetic mean.
- “Be model exposure ages reported with errors in thousands of years.