STOP 3.

Chris Wills, California Division of Mines and Geology, San Francisco CA 94107, cwills@consrv.ca.gov

We have driven down from Beckwourth Pass into the Honey Lake basin, passing below the shoreline of Lake Lahontan. Because we are on the lake bed, we can be sure all of the landscape features around us (channels, terraces, fault scarps, etc.) post-date the lake. That is: we are looking at an almost exclusively Holocene landscape.

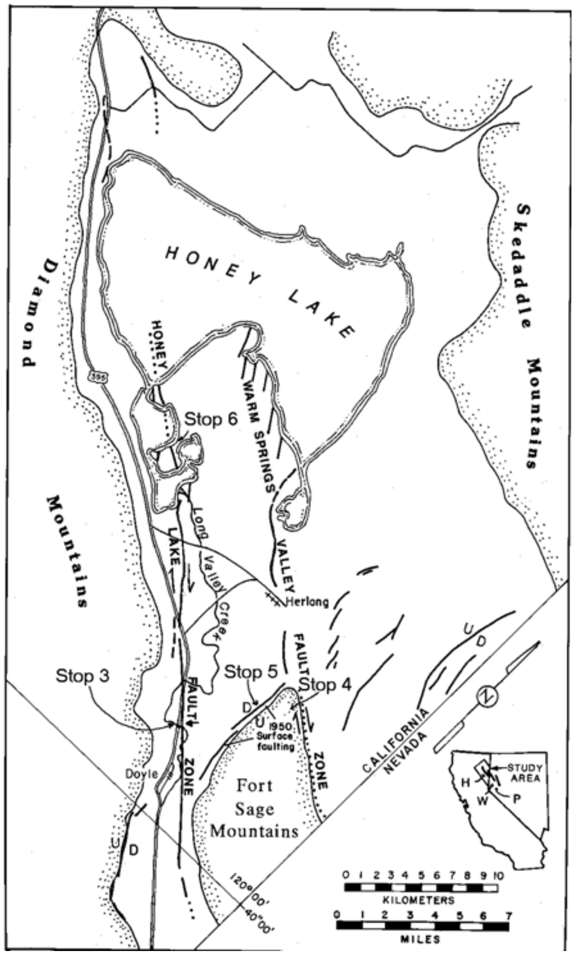


Fig. 3-1. Map of the Honey Lake basin showing major faults and stops for the 2001 FOP field trip. Modified from Wills and Borchardt (1993).

The features we are here to see are the Honey Lake fault zone and the channel and deposits of Long Valley Creek. At this site Wills and Borchardt (1993) used the right-lateral offset of the channel margin to calculate a slip rate of about 2 mm/yr. They logged the stream bank, cut in Holocene deposits in the inset terrace, and concluded that there had been at least 4 major ground rupturing earthquakes in the past 8000 years.

There have been extensive changes to this site since Wills and Borchardt did their work in 1989 and 1990. Most importantly, floods in 1998 filled much of the incised channel of Long Valley Creek and eroded the bank. According to Cindy Judd, who owns the property, the flood eroded up to 15 feet of the inset terrace. This means two things: 1) the stream bank logged by Wills and Borchardt is gone, and 2) the current exposure, which is steeper and possibly slightly higher has never been logged. Your intrepid field trip leaders spent almost an hour poking at the current exposure, enough to convince them that strands of the Honey Lake fault zone can still be observed cutting the Holocene sediments.

At this stop, then, one can observe a near-vertical 3+ meter high stream bank exposure of well-bedded Holocene sediments. The Mazama ash (Tsoyawata ash of J.O. Davis) is about a meter above the level of the creek bed. Many layers in the exposure are irregular and lens shaped, and show quite a bit of cross-bedding. We found one fault strand that appeared to cut layers up to near the surface, but did not have the time to clean or log much of the exposure.

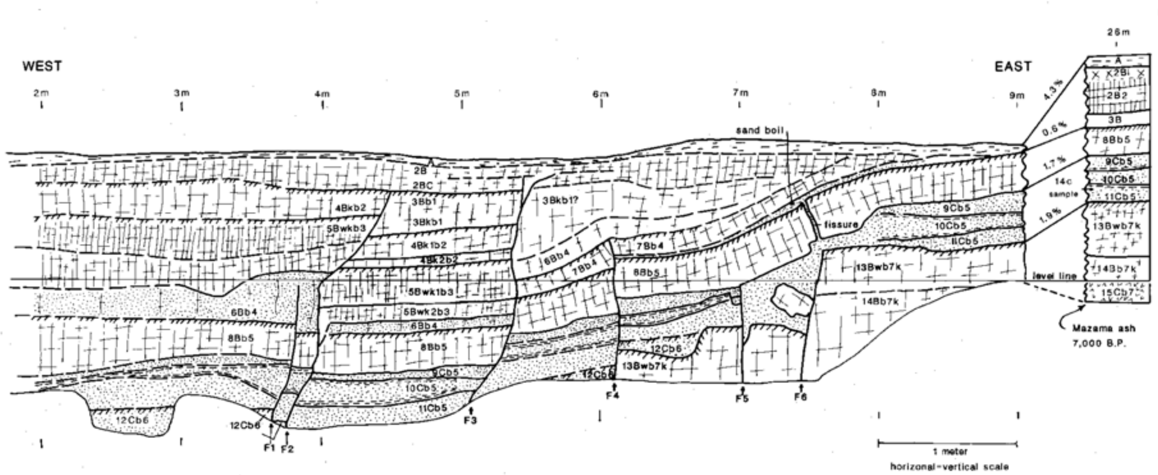


Fig. 3-2. Log of the bank of Long Valley Creek as it appeared in 1990. Note that Mazama ash was not observed in the fault zone itself, but several strands of the fault were logged cutting to different levels within the Holocene sediments. From Wills and Borchardt (1993)

The new exposures of the Holocene sediments in the channel of Long Valley Creek are similar to those described by Wills and Borchardt (1993), but it is not known if the current exposures would show evidence for more, or fewer, earthquakes or if additional datable material could constrain the ages of paleo-earthquakes. FOPers are encouraged to help scrape some of the slough off of the exposure and see how many strands of the fault can be observed, and how far up through the Holocene sediments they extend.

The second part of the Honey Lake fault story at this stop is the right-lateral offset of the top of the riser between the inset terrace and the surrounding lake bed. This has not changed since it was described by Wills and Borchardt, but is worth walking out. Briefly, this offset results in a slip rate because the top of the terrace riser can be traced on both sides of the fault and 16 m offset can be measured. The age of the terrace river must be younger than Lake Lahontan (it represents a channel cut into the floor of the lake). This riser was an active channel margin at least until the inset terrace material was deposited, protecting the riser from further erosion. Mazama ash in the inset terrace deposits was used to constrain the date of those deposits. If the inset terrace deposits, with Mazama Ash at the base, represent a relatively passive filling of the old channel, then the deposition of the inset terrace marks the abandonment of the old channel margin. The result is a feature with an age of between 8 and 14 ka is offset 16±2 m, giving a slip rate between 1.1 and 2.6 m, rounded to 2.0 mm/yr.

(**Fig. 3-3** on next page)

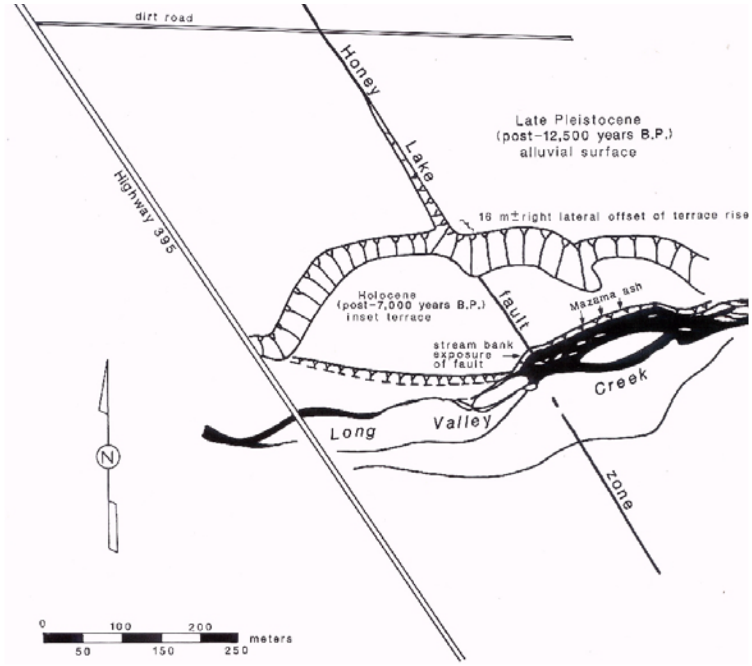


Fig. 3-3. Sketch map of Stop 3 showing inset terrace and offset of terrace riser from which Wills and Borchardt derived a slip rate estimate of 2 mm/yr. From Wills and Borchardt (1993)

Stop 4.

Clifford Riebe[1] and Darryl Granger[2]
[1]*Dept. Earth and Planetary Science, University of California, Berkeley*
[2]*Dept. Earth and Atmospheric Sciences, Purdue University*

Description of Stop 4 (Also see the introduction under Stop 1 for an overview.)

This is a flat-topped ridge on the fault scarp of the northeastern Fort Sage Mountains. The watersheds on either side of this ridge were the subject of the erosion rate study of Granger et al. (1996). Alluvial fans at the mouths of these catchments have been collecting their erosional debris since Lake Lahontan retreated from the scarp base, 16,000 years ago (Benson, 1993). The fan boundaries could once be distinguished by differences in vegetation (see Fig. 4-2), but the vegetation was consumed in a recent fire, and the fans are no longer obvious from this overlook. In the catchments, steeper slopes expose only slightly more boulders and bare rock than their gentler counterparts, in contrast to what was seen at Stop 1, where the steeper slopes are much more densely mantled by boulders and bare rock.

Cosmogenic nuclide measurements have come into wide use as chronometers for surface exposure and processes. It has been proposed that streams may mix eroding sediment such that the average cosmogenic nuclide concentrations in stream sediment samples should reflect the long-term erosion rates of the sediment contributing areas (Fig. 4-1; Brown et al., 1995; Bierman and Steig, 1996; Granger et al., 1996). The two Fort Sage Mountains catchments visible from Stop 4 provide an ideal setting for testing whether cosmogenic nuclides in sediment can be used to measure basin-wide erosion rates, because erosion rates inferred from cosmogenic nuclides can be compared with erosion rates recorded by accumulation in the alluvial fans (Fig. 4-2, after Granger et al., 1996). For both catchments, the two different techniques for measuring erosion rates are averaged over similar timescales and agree to within 30% (Table 4-1, after Granger et al., 1996).

Erosion rates at Fort Sage have a strong dependence on hillslope gradient, increasing exponentially with gradients up to 0.63, and with proximity to the fault scarp face, which is apparently a source of locally rapid baselevel forcing (Fig. 4-3). These results lie in stark contrast to the relatively uniform erosion rates of the Diamond Mountains over an even broader range of hillslope gradients. This disparity may be explained by the lack of boulder armoring at the Fort Sage study area. Boulder abundance at both of the Fort Sage catchments is uniformly low, never exceeding 20% even on steep slopes (Fig. 4-4; Granger et al., 2001). The Fort Sage Mountains, then, provide a counterproof to the boulder-armoring hypothesis by showing that steep slopes in the absence of boulder cover erode much more rapidly than gentle slopes in a granitic bedrock very similar to that of the Diamond Mountains.

We have also developed a new technique for measuring long-term chemical weathering rates, based on cosmogenic nuclide measurements and geochemical mass balance (Riebe et al., 2001b). The technique requires that, in addition to measuring cosmogenic erosion rates, we also have to measure representative concentrations of immobile elements in catchment rock and soil (Fig. 4-5). We did so across the subcatchments of Fort Sage watershed A (Fig. 4-6). Chemical depletions (which reflect the degree to which insoluble elements are enriched in catchment soils) are roughly uniform across the wide range of denudation rates at Fort Sage, while rates of chemical weathering and total denudation are tightly correlated, possibly because chemical weathering rates are regulated by rates of fresh mineral supply by physical erosion of rock (Fig. 4-7). This result implies that tectonic uplift rates may regulate chemical weathering rates.

We also used cosmogenic nuclides to measure long-term rates of erosion and weathering at five other Sierra Nevada granitic sites, including the two Diamond Mountain sites (Riebe et al., 2001b; Fig. 4-8; Table 4-2). Our sites span 22-145 cm/yr in average precipitation and 4-15 C in mean annual temperature. At our Fall River site (northern Sierra foothills), as is the case at Fort Sage, chemical depletions are roughly uniform across a wide range of denudation rates, while rates of chemical weathering and total denudation are tightly correlated (Fig. 4-9). Note that Fall River is much wetter than Fort Sage, yet chemical depletions and the ranges of chemical weathering and denudation rates are very similar at the two sites (compare Figs. 4-7 and 4-9). The results shown in Fig. 4-9 lend further support to the notion that chemical weathering rates are regulated by rates of fresh mineral supply by physical erosion of rock. These results also strengthen the argument for strong tectonic control of chemical weathering rates. Across the suite of Sierra Nevada sites, differences in chemical weathering rates are strongly associated with differences in denudation rates across each individual site, and obscure any clear correlation of chemical weathering with average precipitation or temperature (Fig. 4-10). This implies that chemical weathering rates are more tightly coupled to erosion rates than they are to climate, at least across these sites.

References:

Benson, L., Factors affecting ^{14}C ages of lacustrine carbonates: Timing and duration of the last highstand Lake in the Lahontan Basin, *Quaternary Research*, **39**, 163 (1993).

Bierman, P., and E. J. Steig, Estimating rates of denudation using cosmogenic isotope abundances in sediment, *Earth Surface Processes and Landforms*, **21**, 125 (1996).

Brown, E. T., R. F. Stallard, M. C. Larsen, G. M. Raisbeck, and F. Yiou, Denudation rates determined from the accumulation of in situ-produced ^{10}Be in the Luquillo Experimental Forest, Puerto Rico, *Earth and Planetary Science Letters*, **129**, 193 (1995).

Granger, D. E., *Landscape erosion and river downcutting rates from cosmogenic nuclides in sediment* (Ph.D. Thesis, University of California, Berkeley, 1996) 118 p.

Granger, D. E., J. W. Kirchner, and R. Finkel, Spatially averaged long-term erosion rates measured from in situ-produced cosmogenic nuclides in alluvial sediment, *Journal of Geology*, **104**, 249 (1996).

Granger, D.E., C. S. Riebe, J. W. Kirchner, and R. C. Finkel, Modulation of erosion on steep granitic slopes by boulder armoring, as revealed by cosmogenic ^{26}Al and ^{10}Be, *Earth and Planetary Science Letters* **186**, 269 (2001).

Riebe, C. S., J. W. Kirchner, D. E. Granger, and R. C. Finkel, Erosional equilibrium and disequilibrium in the Sierra Nevada, inferred from cosmogenic ^{26}Al and ^{10}Be in alluvial sediment, *Geology*, **28**, 803 (2000).

Riebe, C. S., Tectonic and climatic control of physical erosion rates and chemical weathering rates in the Sierra Nevada, California, inferred from cosmogenic nuclides and geochemical mass balance (Ph.D. Thesis. University of California, Berkeley, 2000) 212 p.

Riebe, C. S., J. W. Kirchner, D. E. Granger, and R. C. Finkel, Strong tectonic and weak climatic control of long-term chemical weathering rates, *Geology* **29**, 511 (2001b).

A PRIMER ON DENUDATION RATES FROM COSMOGENIC NUCLIDES

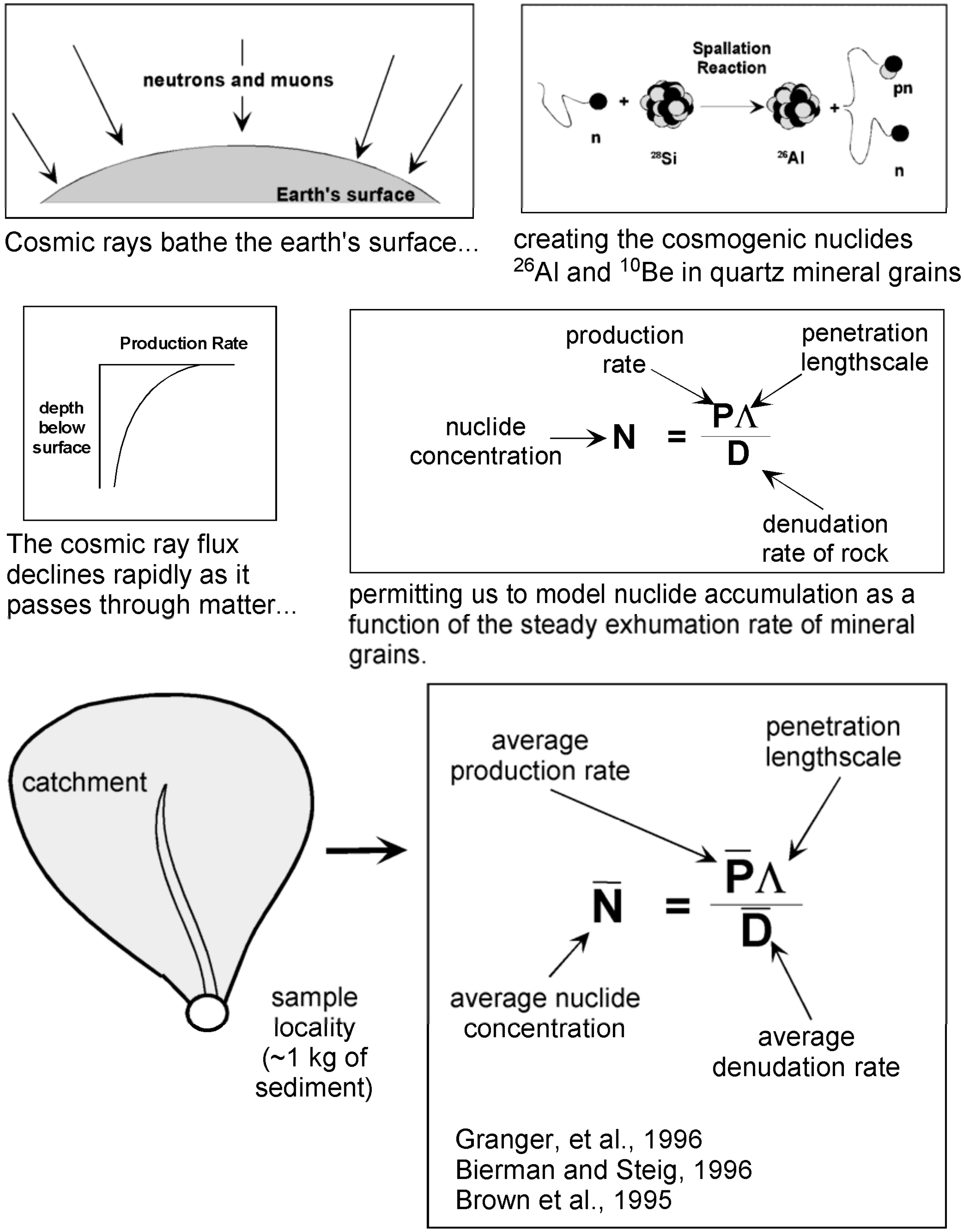


Fig. 4-1.

Fig. 4-2. Taken from Granger et al., 1996. Oblique aerial photo of the Fort Sage Mountains fault scarp, showing catchment boundaries (solid lines), subcatchment boundaries (dotted lines) and alluvial fan thickness contours (in m, from depths to beach sands below). The fans have accumulated each catchment's erosional debris since Lake Lahontan retreated from the scarp base ~16 ky ago. Thus the fans record long-term erosion rates of the contributing areas.

Table 4-1. Comparison of cosmogenic- and fan-based denudation rates. Adapted from Granger et al., 1996. The two techniques average denudation over similar timescales, so the agreement between the cosmogenic- and fan-based estimates within each catchment indicates that the cosmogenic nuclide method can be used to accurately measure long-term, catchment-wide denudation rates. Moreover, the denudation rates of the two catchments are notably different from one another, indicating that the cosmogenic nuclide technique can be used to quantify how denudation rates vary across landscapes.

	Catchment A	Catchment B
Fan volume (10^3 m^3)	188±34	310±52
Volume of eroded rock (10^3 m^3)[a]	111±29	178±45
Total volume of rock removed by denudation (10^3 m^3)[b]	133±43	212±67
Contributing area (10^3 m^2)[c]	132±20	408±12
Denudation rate from fan volume (mm/kyr)[d]	**63±19**	**33±9**
Denudation rate from cosmogenic nuclides (mm/kyr)	**70±8**	**44±5**

[a] To obtain volume of eroded rock, fan volumes were corrected for bulk density change from bedrock (2.7 g/cm^3) to soil (1.6±0.3 g/cm^3).
[b] To obtain total volume of eroded rock removed by denudation, I use equations reported in Riebe (2000) with the zirconium enrichment factor of catchment A (1.18±0.03) to adjust the volumes of both fans. Because post-depositional weathering and erosion of the fan itself cannot be ruled out, the weathering losses, and thus fan-based denudation rates, are minimum estimates.
[c] Contributing areas are as reported by Granger (1996).
[d] Fan age is 16.0±0.4 kyr (Granger, 1996, after radiocarbon dates for Lake Lahonton retreat reported by Benson, 1993).

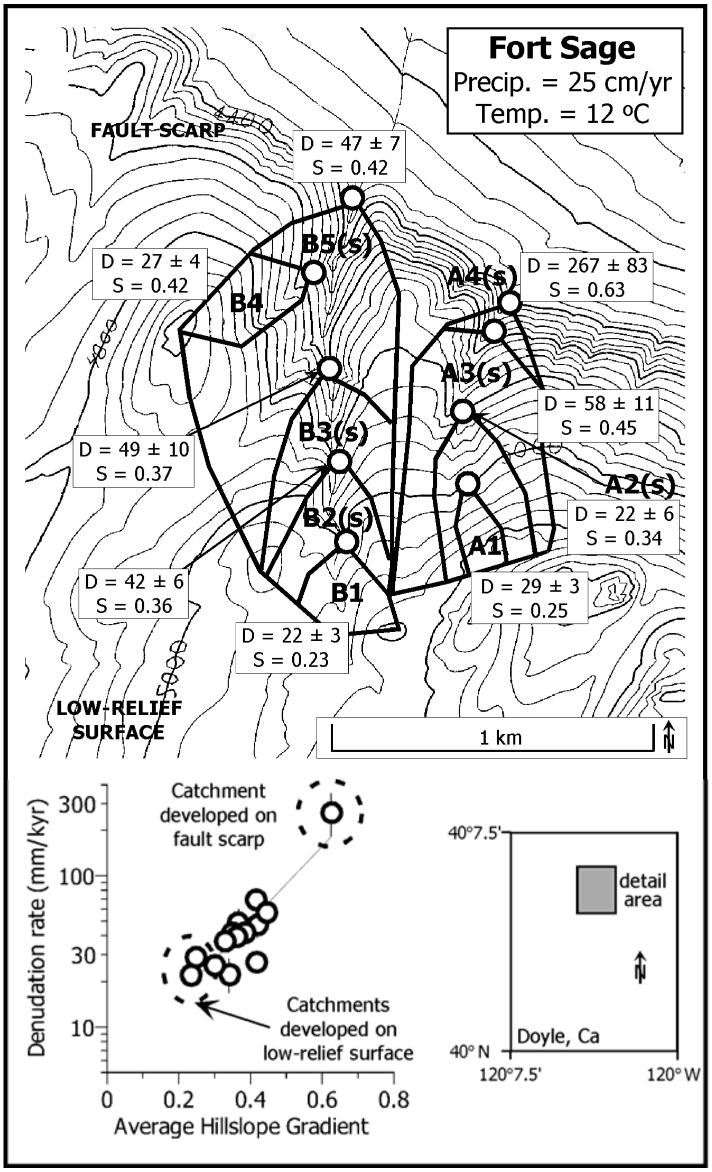


Fig. 4-3. Adapted from Riebe et al., 2000. Map of Fort Sage showing catchment boundaries, names, denudation rates ("D", equivalent to "Erosion rates" of Fig. 2), average hillslope gradients ("S" in m/m), and sampling localities (open circles). The map is excerpted from the USGS 7.5' topographic quadrangle Doyle, CA (shown as an index in the panel corner). Contour interval = 40 ft. Denudation rates increase with hillslope gradients and proximity to the fault scarp face, which is apparently a source of locally rapid baselevel forcing.

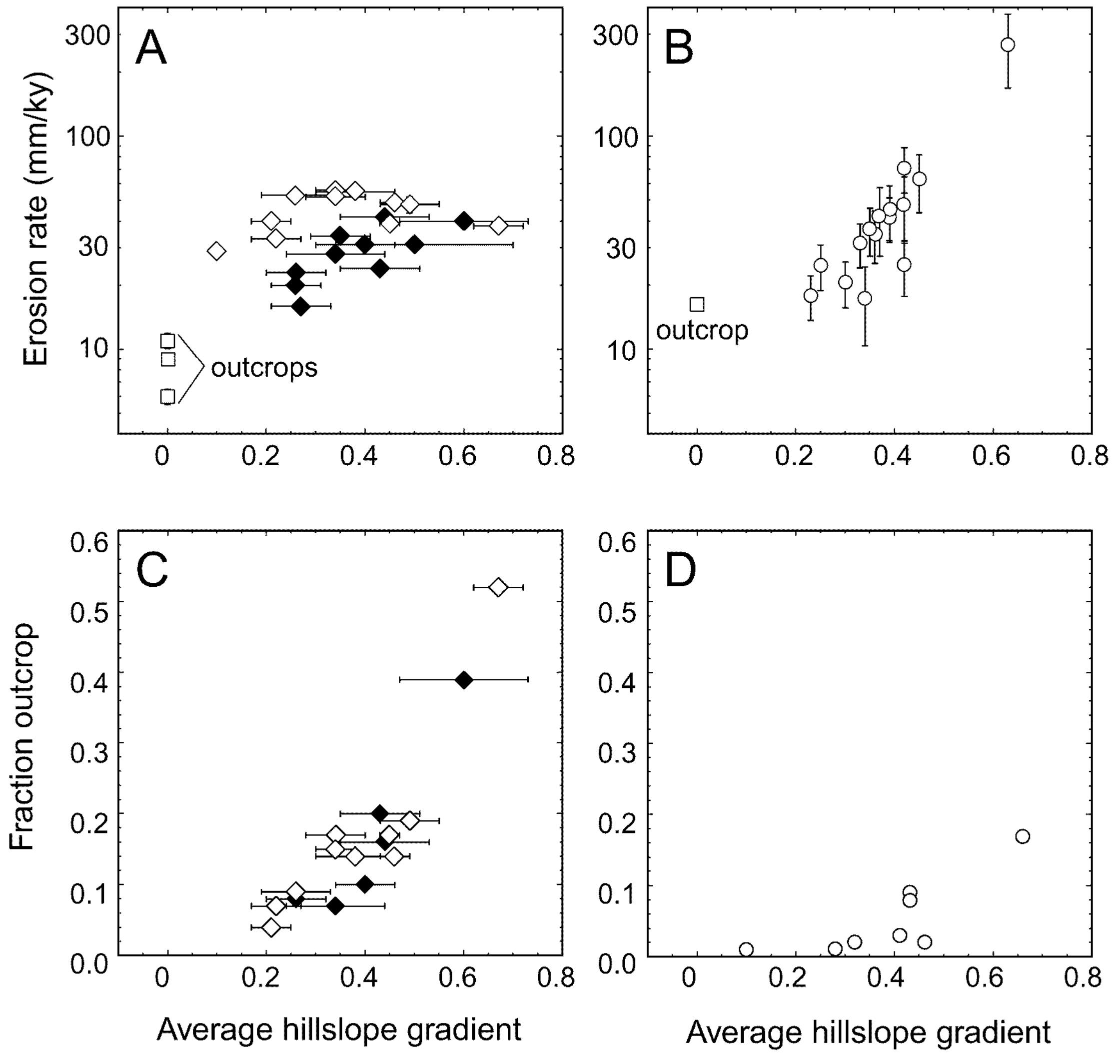
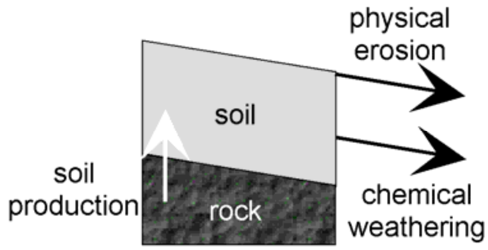


Fig. 4-4. Taken from Granger et al., 2001. Catchment erosion rates (A and C) and fraction outcrop (B and D) plotted against average hillslope gradient for catchments at the Diamond Mountain sites (A and C, with open diamonds from Adams Peak and closed diamonds from Antelope Lake) and at Fort Sage (B and D open circles). Erosion rates at Fort Sage have a strong dependence on hillslope gradient, increasing exponentially at gradients up to 0.63. These results lie in stark contrast to the relatively uniform erosion rates of the Diamond Mountains over an even broader range of hillslope gradients. This disparity may be explained by the lack of boulder armoring at the Fort Sage study area. Boulder abundance at both of the Fort Sage catchments remains uniformly low, never exceeding 20% even on steep slopes. The Fort Sage Mountains, then, provide a counterproof to the boulder-armoring hypothesis by showing that steep slopes in the absence of boulder cover erode much more rapidly than gentle slopes in a granitic bedrock very similar to that of the Diamond Mountains.

Mass balance 1: soluble elements

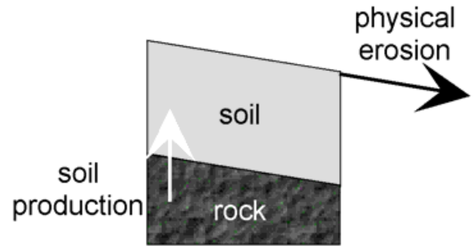


soil production rate = physical erosion rate + chemical weathering rate

eolian fluxes are small

depth = constant

Mass balance 2: insoluble elements



soil production rate = physical erosion rate

dissolution of other elements leads to enrichment of insoluble elements

chemical weathering rate = total denudation rate x chemical depletion fraction

$$W = \underbrace{\rho_{rock} \times D}_{\text{total denudation rate}} \times C$$

and

$$C = 1 - \frac{Zr_{rock}}{Zr_{soil}}$$

To estimate long-term chemical weathering rates for our catchments all we need are:

1) cosmogenic estimates of denudation rates
2) representative [Zr] from rock and soil

Fig. 4-5. Measuring long-term chemical weathering rates from cosmogenic nuclides and geochemical mass balance.

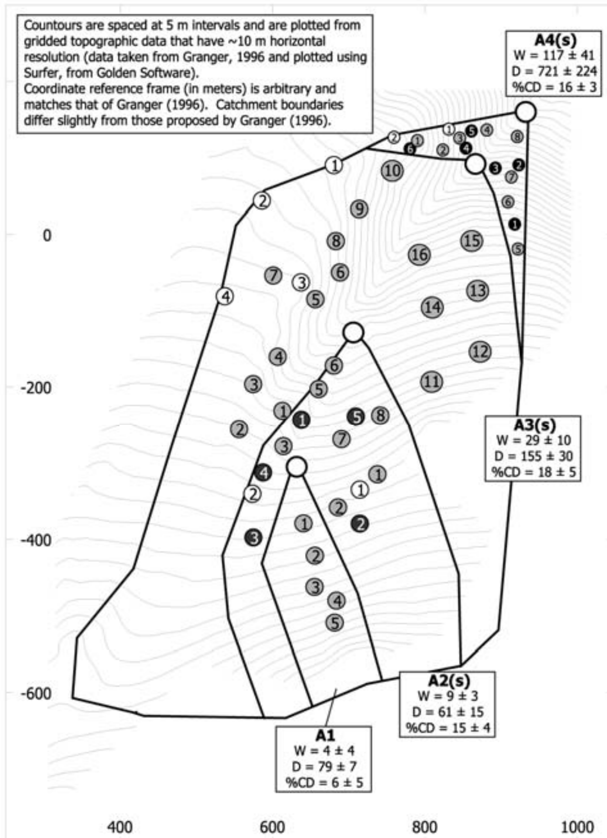


Fig. 4-6. Taken from Riebe 2000. Map of Fort Sage catchment A showing locations of soil pit (black circles), soil surface (gray circles), and bedrock (open circles) samples. These samples were analyzed for major and trace element concentrations by XRF. Large open circles are cosmogenic nuclide sampling localities. Labels include chemical weathering rates "W" in t km^{-2} yr^{-1}, denudation rates "D" in t km^{-2} yr^{-1}, and percent chemical depletion "%CD".

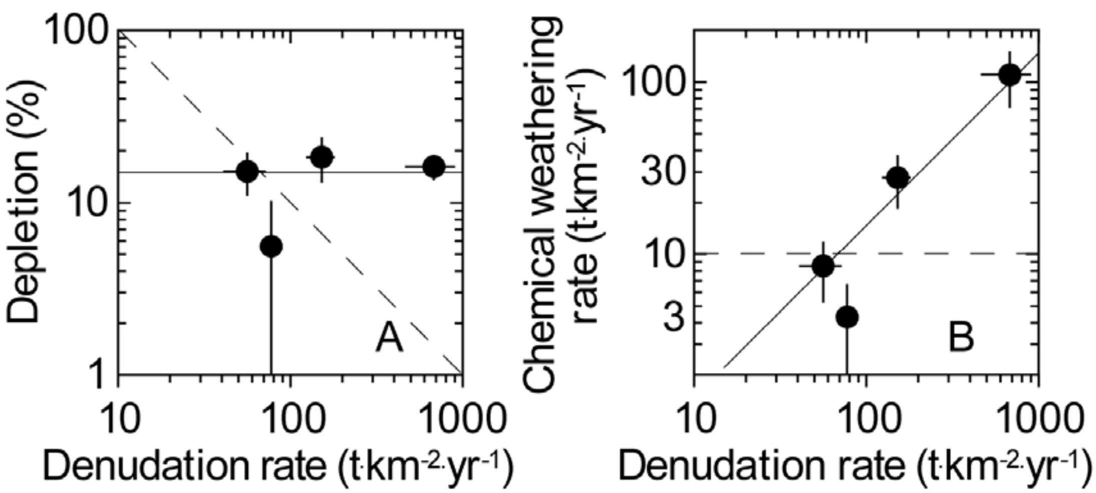


Fig. 4-7. Adapted from Riebe et al., 2001b. Plots of chemical depletions (A) and chemical weathering rates (B) versus total denudation rates for the Fort Sage site. Chemical depletions are roughly uniform across a wide range of denudation rates, while rates of chemical weathering and total denudation are tightly correlated, possibly because chemical weathering rates are regulated by rates of fresh mineral supply by physical erosion of rock. This result implies that tectonic uplift rates may regulate chemical weathering rates.

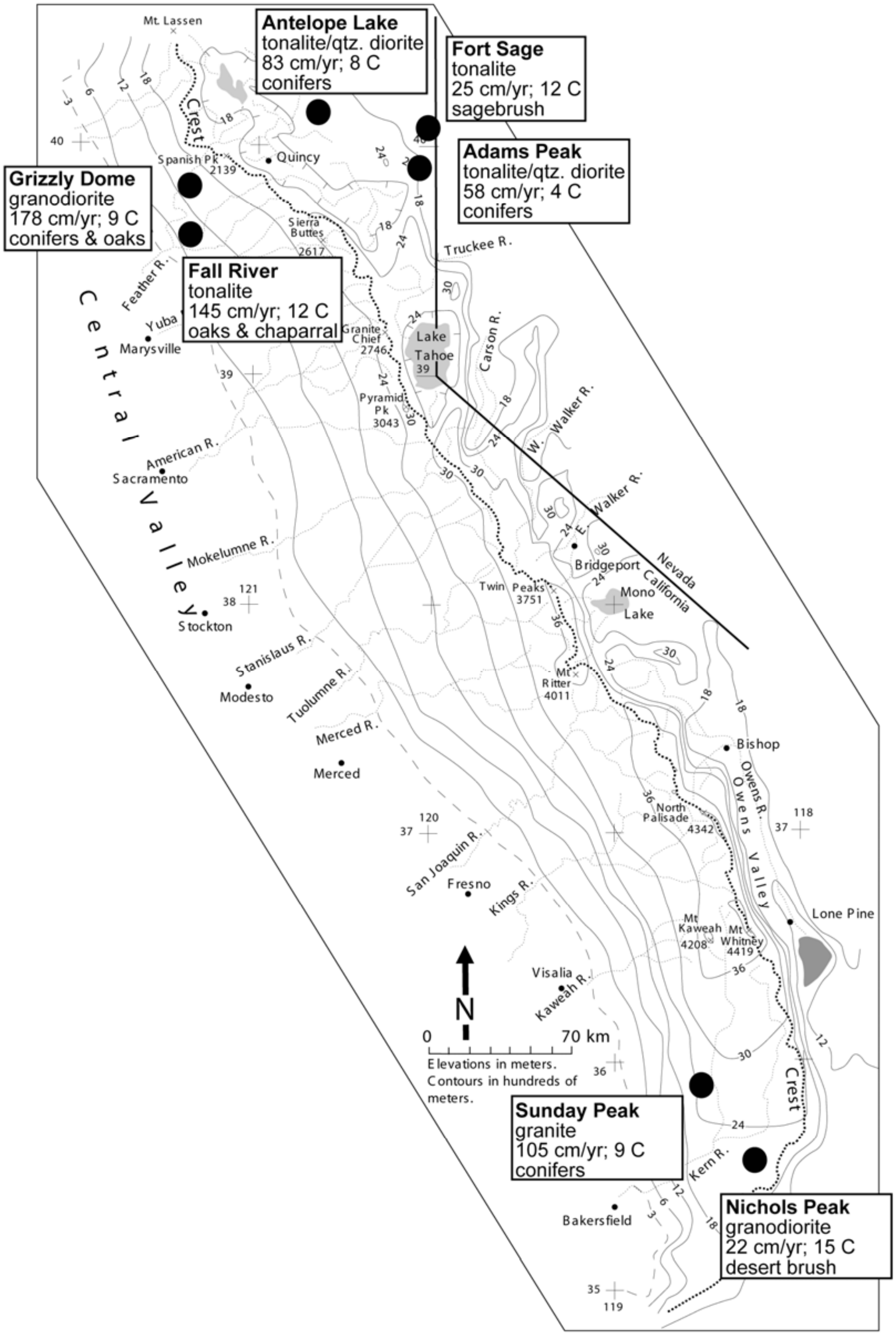


Fig. 4-8. Generalized topographic map of the Sierra Nevada (drafted by John Wakabayashi) showing locations, lithologies, annual averages of precipitation, mean annual temperatures and dominant vegetation types of sites where we have measured rates of erosion and weathering using cosmogenic nuclides.

Table 4-2. Denudation rates, [Zr], chemical depletion fractions, and weathering rates

Basin	Denudation rate (t km^{-2} yr^{-1})	$[Zr]_{saprolite}$ (ppm)	$[Zr]_{outcrop}$ (ppm)	$[Zr]_{rock}$ (ppm)	$[Zr]_{soil}$ (ppm)	Chemical depletion fraction (%)	Weathering rate W_{Si} (t km^{-2} yr^{-1})	Weathering rate W (t km^{-2} yr^{-1})
Fort Sage (granodiorite; 25±3 cm/yr; 12.2±0.6 °C; average depletion = 15±3 %)								
A1	79±7	N.D.	112±3 (2)	112±3	118±5 (5)	6±5	0±1	4±4
A2(s)	61±15	120±4 (5)	112±3 (2)	118±3	139±5 (19)	15±4	3±1	9±3
A3(s)	155±30	N.D.	113±4 (4)	113±4	139±7 (16)	18±5	9±3	29±10
A4(s)	721±224	118±4 (4)	122±3 (2)	119±3	142±3 (22)	16±3	38±13	117±41
Fall River (tonalite; 145±5 cm/yr; 11.9±0.6 °C; average depletion = 19±2 %)								
FR-2	400±79	94±9 (12)	85±6 (3)	92±7	109±6 (13)	15±8	19±12	61±34
FR-5	325±48	121±5 (7)	114±3 (4)	119±3	150±5 (25)	21±3	23±5	68±15
FR-6	100±22	N.D.	83±5 (3)	83±5	102±3 (9)	19±5	7±2	19±7
FR-8	39±4	N.D.	87±1 (3)	87±1	106±3 (9)	18±3	2±1	7±1
Adams Peak (tonalite; 58±7 cm/yr; 4.2±0.5 °C; average depletion = 14±2 %)								
AP-3	127±13	111±4 (5)	112±1 (3)	111±2	135±3 (20)	17±2	6±1	22±4
AP-4	85±9	N.D.	108±1 (3)	108±1	115±4 (9)	6±4	1±1	5±3
AP-5	154±15	N.D.	112±3 (4)	112±3	129±7 (9)	12±6	5±3	19±9
AP-11	94±12	N.D.	109±6 (2)	109±6	129±5 (4)	15±6	4±2	14±6
AP-13	123±12	N.D.	112±5 (2)	112±5	131±3 (4)	14±4	5±2	18±6
Antelope Lake (tonalite; 83±6 cm/yr; 7.8±0.4 °C; average depletion = 18±5 %)								
AL-4	70±8	N.D.	166±15 (4)	166±15	227±8 (9)	27±7	6±2	19±5
AL-5	81±10	N.D.	165±48 (2)	165±48	211±10 (7)	22±23	5±6	18±19
AL-9	104±11	N.D.	211±25 (3)	211±25	271±18 (8)	22±11	6±3	23±11
AL-10	85±8	182±11 (8)	192±7 (2)	183±9	212±6 (26)	14±5	3±1	12±4
Sunday Peak (granite; 105±5 cm/yr; 9.4±0.4 °C; average depletion = 10±4 %)								
SP-1	111±12	228±16 (8)	214±7 (3)	225±12	252±7 (23)	11±6	4±2	12±6
SP-3	89±10	N.D.	238±12 (3)	238±12	245±16 (9)	3±8	1±2	3±7
SP-8	85±8	N.D.	244±13 (4)	244±13	278±7 (8)	12±5	3±2	11±5
Nichols Peak (granodiorite; 22±3 cm/yr; 15.4±0.5 °C; average depletion = 25±6 %)								
NP-1	119±12	119±8 (5)	140±4 (2)	125±7	160±10 (19)	22±6	8±3	26±8
NP-18	85±8	197±3 (4)	229 (1)	203±19	285±15 (14)	29±8	6±2	24±7

Site descriptions (underlined) include mapped lithology, average precipitation (in cm/yr), mean annual temperature (in °C), and average chemical depletion fraction (in %, weighted by inverse variance).

N.D. = not determined.

Denudation rates are inferred from cosmogenic nuclide concentrations in the quartz fraction of stream sediment draining from the catchments. For further details, see Riebe (2000).

Zr concentrations are measured by X-Ray Fluorescence (see Riebe, 2000, for further details) and reported as averages ± standard errors for *n* samples (in parentheses).

$[Zr]_{rock}$ is averaged from the combined pool of saprolite and outcrop samples (see Riebe, 2000, for further details).

Chemical depletion fraction = W/D = $(1-[Zr]_{rock}/[Zr]_{soil})$.

Weathering rates are inferred from equation 3, using chemical depletion fractions and denudation rates measured from cosmogenic nuclides.

See Riebe (2000) for explanation of W_{Si} is measured.

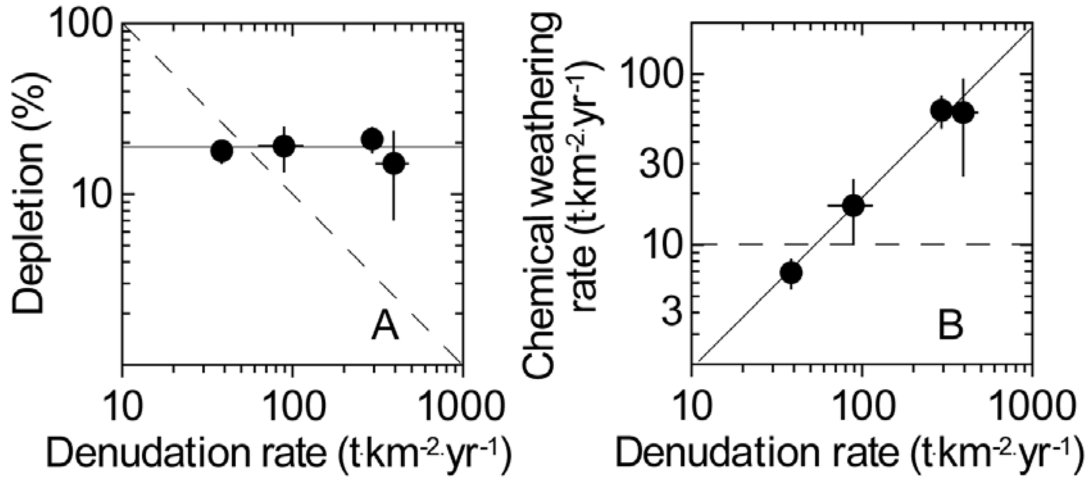


Fig. 4-9. Adapted from Riebe et al., 2001b. Plots of chemical depletions (A) and chemical weathering rates (B) versus total denudation rates for the Fall River site. As is the case at Fort Sage, chemical depletions are roughly uniform across a wide range of denudation rates, while rates of chemical weathering and total denudation are tightly correlated. Note that Fall River is much wetter than Fort Sage, yet chemical depletions and the ranges of both chemical weathering and denudation rates are very similar at the two sites (compare Figs. 4-7 and 4-9). The results shown here lend further support to the notion that chemical weathering rates are regulated by rates of fresh mineral supply by physical erosion of rock. These results also strengthen the argument for strong tectonic control of chemical weathering rates.

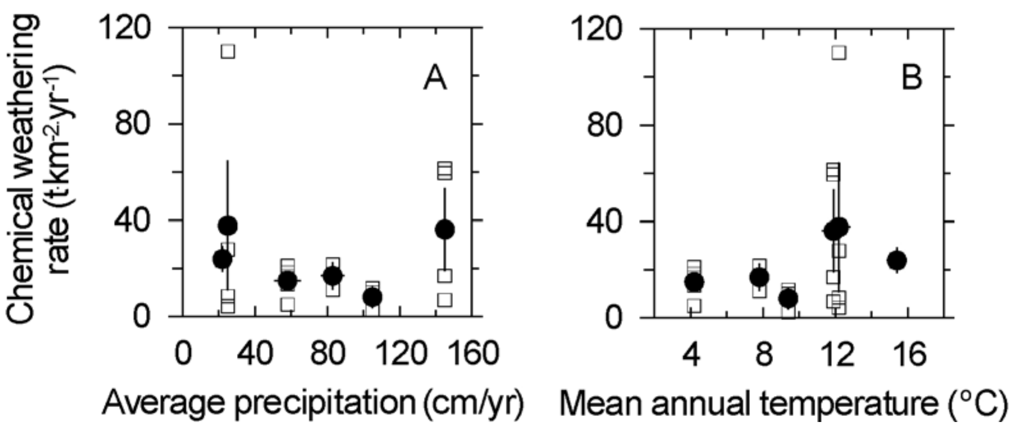


Fig. 4-10. Adapted from Riebe et al., 2001b. Chemical weathering rates plotted against average annual precipitation (A) and mean annual temperature (B) both for site wide averages (solid circles) and the individual catchments (open squares). Differences in chemical weathering rates are strongly associated with differences in denudation rates across each individual site, and obscure any clear relationship between chemical weathering and average precipitation or temperature. This implies that chemical weathering rates are more tightly coupled to erosion rates than they are to climate, at least across these sites.

FORT SAGE MOUNTAINS SUPPLEMENTAL STOP

William B. Bull, Dept. Geosciences, University of Arizona, Tucson, AZ

Reconnaissance for Lichenometry Sites in the Sierra Nevada of California

The 2001 Pacific Cell Friends of the Pleistocene field trip emphasizes paleoseismology and new tools for studying landscape evolution. To that great mix of topics I would like to add a few thoughts regarding the potential of lichenometry for dating and understanding geomorphic processes. Unfortunately, recent events did not allow me to fly back to the United States in time to participate in the dry run of this year's field trip. So, like the rest of you, I find myself in the position of making a reconnaissance for useful lichenometry sites. Selection of lichenometry sites has a crucial influence on precision of age estimates and resolution of closely spaced events.

The main purpose of this note is to outline features that we should look for while driving through, or walking across, the Sierra Nevada of northeastern California. With luck we might find an outcrop or a debris slope that is sensitive to seismic shaking. The FOP trip format virtually eliminates hands-on instruction, so I propose a 2002 lichenometry short course.

Searching for a Useful Site

One nice aspect of the new approach to lichenometry is that regional rockfall events caused by earthquakes should be represented by lichen-size peaks within your study area. Some times of abundant rockfalls are historical events, but the prehistorical events generally require independent confirmation of their times and locations. Once established, this basic catalog of lichen-size peaks caused by regional rockfall events is useful basis for assessing the quality and departures from the norm of your next lichenometry site. I refer you to 1998 article by myself and Mark Brandon for the details about a lichenometry method that provides precise, accurate age estimates for geomorphic events of the past 500 to 1,000 years. My 1996 article uses this method farther South in the Sierra Nevada, but the growth rate equations for four genera of lichens should be applicable in the northern Sierra Nevada.

Factors to consider in site selection include diversity and frequency of geomorphic processes, lichen species and abundance, quality of thalli, substrate smoothness, sizes of rockfall blocks, and ability to recognize old, stabilized block fields where lichen communities are not related to the times of substrate exposure because the first generation of lichens has died and has been replaced.

Much of the Sierra Nevada consists of soil -mantled hillslopes with scattered blocks of granitic rock. Are these useful sites to measure lichen sizes for dating purposes? Unfortunately, blocks on such stable slopes have lichen populations that do not reflect the times at which these rocks moved down the hill to their present locations. I mention this at the beginning because we do not want to waste time measuring the third or fourth generation of lichens growing on either an outcrop a joint face or a ridgecrest corestone if those lichen sizes do not provide information about a geomorphic event. I gather that Stop 1 has examples of such cruddy lichens.

Such undesirable sites are pretty obvious. Masses of lichens have grown together to the extent that circular or elliptical thalli are no longer present. Old stabilized block fields, on which several generations of lichens have grown and died, generally have minimal geochronologic information. Blocks may have weathered surfaces or may be largely buried by fine detritus. Such sites typically have slopes that are much less than the angle of repose for talus. Blocks whose oldest lichens colonized long after the time of initial substrate exposure typically have large thalli with highly irregular margins, or the lichens may have grown together to form a mosaic of thalli margins. Some block fields accumulate slowly and may have a mixture of datable and undatable blocks.

So, we seek nearly circular, isolated lichens that are suggestive of a first-generation lichen community. Our measurements consist of the largest lichen maximum diameters for each rock-fall block on a hillslope, or joint faces on the outcrops that are the source of blocks. The ideal Sierra Nevada rockfall lichenometry site is sensitive to both nearby and distant earthquakes. Such a site would have:

Unstable cliffs of fine-grained, strongly jointed rock.
Pervasive joints that parallel the cliff face.

Abundant blocks with smooth planar surfaces.

A limited size range for most blocks (such as 0.5 to 2 m).

A large repository of blocks close to the angle of repose.

Extensive, thick deposits of blocks devoid of plants, which might shade lichens or provide fuel for fires.

A local microclimate that favors the species of lichen being measured and that lacks persistent snow cover, or fierce winds, which can kill lichens.

Trip Stop 4 has some intriguing possibilities. The tonalite corestones on the soil-mantled slopes have black, irregularly shaped lichens according to Darryl Granger--probably another example of useless lichens. But, there is a volcanic neck that is only an easy 1/2 mile walk from the Stop 4 campsite. Darryl notes that it is 50% covered by yellow, circular lichens. Sounds like first generation Acarospora chlorophana to me. This is the best lichen for our purposes in the drier parts of the Sierra Nevada; tis easy to measure with digital calipers, is very slow growing, and has already been used to date earthquakes as old as 700 A. D.. There should also be rock-fall blocks at bases of the volcanic outcrops (the blocks produced at time of exposure of the outcrop joint faces). A data set here has potential of dating the very recent prehistorical earthquake that produced the fault scarp at nearby Trip Stop 3.

<u>Lichenometry Short Course</u>

I have run short courses for persons interested in lichenometry for the past three years, but these introductions to the subject have been in New Zealand.

A good short course site in the western United States is in the canyon of the South Fork of the Kings River in the Sierra Nevada a couple of miles up the valley from hamlet of Cedar Grove. The glaciated valley upstream from Cedar Grove ranges in altitude from 4600 feet to about 5000 feet. Rocky debris is being shed off the towering cliffs. The south-facing side of the valley has few usable lichens on it but the cooler north-facing side has several usable lichenometry sites.

The most convenient site is just downvalley from Roaring River bridge. Here jointing parallel to the hillslope, accentuated by some vertical fractures allows the formation of a debris cone. Off to one side is an area of sheet talus. Just upstream from the Roaring Fork waterfall is another cliffy area that has a sheet-like accumulation of talus. Both of these appear to be excellent sites for measuring sizes of lichens.

Advantages include:

1) Right by the road, so no long hikes are needed.

2) All four genera of the lichens for which we have growth rates are present,

3) A wide range of sizes should allow tying into the recent historical earthquake record, including the nearby 1872 earthquake in the Owens Valley.

4) Should be some old blocks (600 to 1000 years old)

5) Lack of fire on coarse blocky talus slopes makes for a more complete record of rockfall events.

I would expect the quality of lichen thalli to vary with microenvironment, plus the usual poorer quality for the big lichens. The chief disadvantage from a paleoseismology viewpoint is that one has to pick a measurement area fairly carefully or we are going to have a considerable signal from avalanches as well as seismically-generated rockfalls. This means that we will make a viorous reconnaissance, which could turn out to be an advantage from a short course instructional view.

Logistics appear good, there being both campgrounds and a store in Cedar Grove. Participants could fly into Fresno. Driving in takes several hours because of slow mountain roads. When working under NSF support, I had to get a permit from Sequoia-Kings National Park, mainly to collect samples of tree rings and of lichens. We may not need a permit for a short course if the activities of several people are restricted to walking, taking photos, and measuring sizes of lichens.

Timing. I live in New Zealand half of each year and expect to leave for my second home in late February or early March. Still snow on the ground in the Sierra Nevada then, so the only time for a California lichenometry Short course would be from late September to November. Not ideal because of shorter daylight hours, but cooler and much better chance of getting into a campground. Just send an e-mail to Bill@ActiveTectonics.com if you would like to join us for a day or two.

STOP 5.
James N. Brune, Seismological Laboratory, University of Nevada, Reno

This stop is along Fort Sage mountains road 1-2 miles SW of the north end of Turtle mountain (the northernmost extension of Fort Sage Mountains into Honey Lake Basin). From the road walk a few hundred yards East across the Lahontan shoreline and then across a young alluvial fault scarp about 1-2 meters high., representing recent slip on the western bounding normal fault of the Fort Sage Mountains horst. Although the scarp looks quite young, it is not observed extending into the sediments of the Honey Lake Basin. This suggests the slip occurred before the most recent high stand of Lake Lahontan. Alternatively the slip may be confined to the bounding horst faults and not extend into the basin. Other sections of the fault are confused by shorelines of high stands.

The 1950 M=7.2 Fort Sage Mountains earthquake produce small scarps (about 10 cm) along this fault, but no obvious remnants remain.

East of the alluvial scarp proceed East upslope about 1 km to spectacular balanced rocs which constrain the ground motion which could have occurred in the last few thousand years. In particular these rocks constrain the ground motion which could have occurred during the Fort Sage mountains earthquake, or any other recent earthquakes on the Fort Sage Mountains fault, and also constrain ground motion which could have occurred during earthquakes suggested for the Honey Lake fault during the last several thousand years by Wills and Borcherdt (1993).

We discuss the implications of the precarious rocks for earthquake hazard from the Honey Lake strike-slip fault, the Fort Sage Mountains normal fault, and for earthquake hazard in the broader Walker Lane and the Basin and Range in General.

The following are excerpts from a recently submitted paper

Precarious rock evidence for low near-source accelerations for trans-tensional strike-slip earthquakes

James N. Brune

Abstract

This paper describes precarious rock evidence for low ground motions associated with extensional sections of strike-slip faults. Recent evidence from physical and numerical models and data regressions has indicated that ground motion for extensional strike-slip regions may be lower than for strike-slip faults with a large fault-normal tectonic stress component, and for thrust faults in general. Data from compressional strike-slip and thrust earthquakes dominates the database used in most regression curves for ground acceleration, and in the calculation of current probabilistic seismic hazard maps. Therefore, estimates of ground accelerations on these seismic hazard maps may be too high for sites near extensional sections of strike-slip faults. This paper discusses precariously balanced rock data from three areas near extensional sections of strike-slip faulting: (1) the region of the Honey fault, California, with an active Holocene fault, (2) the Red Rock Canyon region of the Garlock fault, near a dilatational step-over, and (3) the region just south of Beaumont, California, near the Hemet dilatational step-over in the San Jacinto fault. These are all active strike-slip faults, with at least a few large earthquakes in the Holocene, and, in the case of the San Jacinto example, historic large earthquakes (M~7). Thus the precarious rocks at these sites are evidence of relatively low ground motions associated with extensional strike-slip faulting. The results of this study could be very important in developing more detailed seismic hazard maps in the future.

Precarious Rock Evidence from the Honey Lake Strike-slip Fault

A spectacular zone of precarious rocks exists in the Fort Sage Mountains near (2-7 km distance) the strike-slip Honey Lake Fault Zone, California (Figures 5-1 and 5-2). This fault has been interpreted to be the locus of a total of 16 m of offset in Holocene time, a result of a few to several major earthquakes, with at least one major event in the last several hundred years (Wills and Borcherdt, 1993). The adjacent Honey Lake Basin is a major extensional feature. The rocks are thus strong evidence for low ground accelerations from this major strike-slip fault zone in an extending region. The appearance and geomorphic conditions of the rocks indicates they have been in precarious positions for thousands of years. The examples shown in Figure 5-2 are a selection from more than 50 such rocks in a relatively small region. Some of the rocks are only one or two kilometers from the trace of the fault. Preliminary estimates of toppling accelerations are about 0.3 g. Based on current attenuation curves it would appear that these rocks would be shaken down by ground motion from either an M=6.5 event on the Honey Lake fault (or an M =6 on the Fort Sage Mountains normal fault). The USGS-CDMG hazard maps for this region indicate a very high hazard, with 2500-year recurrence accelerations (2% in 50 yr probabilities) of over 0.8 g (Intensity X). The rocks suggest upper limit constraints on ground motion that is inconsistent with these maps.

The nearby Fort Sage Mountains normal fault was site of the 1950 M=5.6 Fort Sage Mountain normal faulting earthquake. Thus these rocks also provide support for low ground motions on the footwall of normal faults, further complementing the results of Brune (2000).

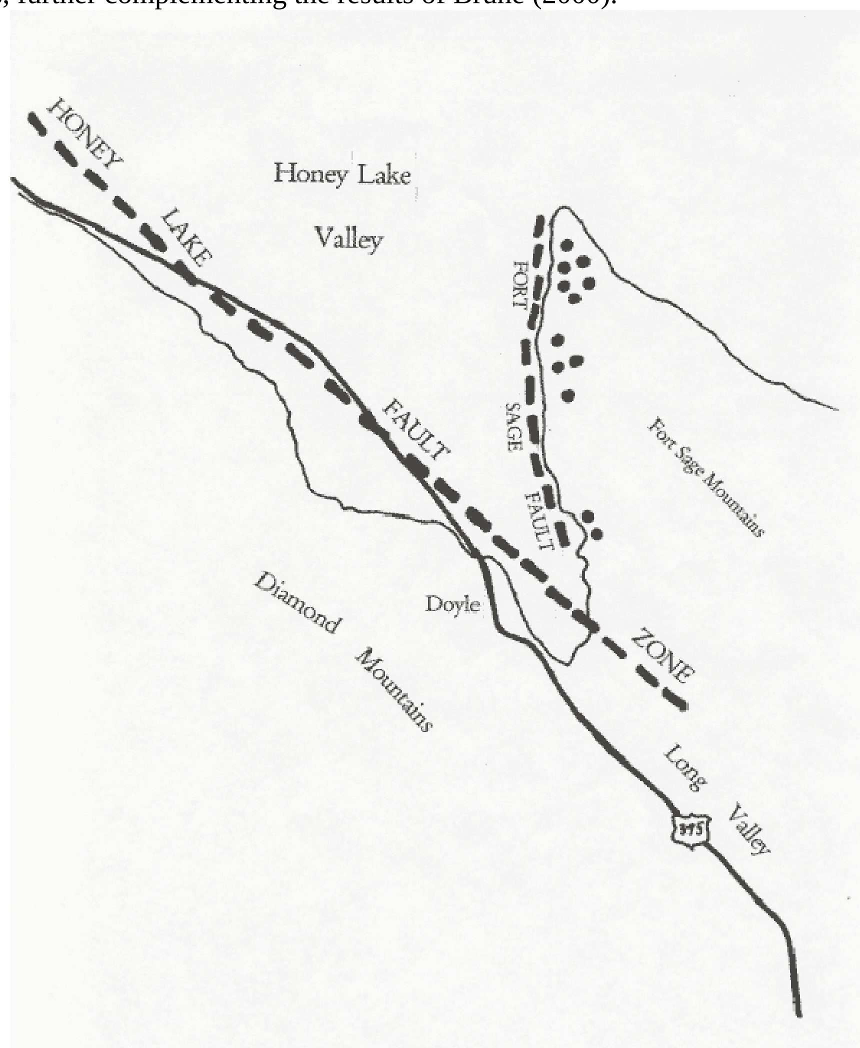


Fig. 5-1.

Fig. 5-2.

Conclusions

This paper has presented precarious rock evidence for low ground motions associated with three extensional sections of strike-slip faults. The results support recent evidence from physical and numerical models, and data regressions, indicating that ground motion for extensional strike-slip regions may be lower than for strike-slip faults with a large fault-normal tectonic stress component. Estimates of ground accelerations on some current seismic hazard maps may be too high for sites near extensional sections of strike-slip faults. The results of this study could be very important in developing more detailed seismic hazard maps in the future.

References

Brune, J.N., 2000. Precarious rock evidence for low ground shaking on the footwall of major normal faults. Bulletin Seismological Society of America 90, 1107-1112.

Wills, C.J., and Borchardt, G., 1993. Holocene slip rate and earthquake recurrence on the Honey Lake Fault Zone, Northeastern California. Geology 21, 853-856.

STOP 6.

Chris Wills, California Division of Mines and Geology, San Francisco CA 94107, cwills@consrv.ca.gov

At this stop we return to the Honey Lake fault zone. Several geologists working in the area, either mapping the geology or the fault itself, have visited this locality over the past 10 years or so, but no one has done any detailed work here as far as we know. There is a wealth of geologic features here and we expect the group will spread out along the shore of Honey Lake and several smaller groups will form focusing on some of the more spectacular features. While at this locality, don't spend too long looking at the exposures near the fault, though those are the first we come to. Be sure to walk out along the bluffs to the south and take time to look at the range of features exposed here.

The main features include the scarp of the Honey Lake fault zone that crosses this peninsula in Honey Lake. The 2-3 m high east-facing scarp is visible from the point that the dirt road reaches the shore of the lake, but you may want to walk back northeast away from the scarp to see more of it. Once again this scarp is developed in the bed of Lake Lahontan, so is essentially a Holocene feature.

The scarp projects into the bluffs and the fault can be easily found in the bluff exposures. The 'rocks' here are Pliocene or Pleistocene (?) lake (?) beds mostly of very light gray siltstone and claystone, the fault forms the boundary between the near-vertical beds found where we can first see these rocks and the much more gently dipping rocks that make up most of the bluffs. The fault also clearly offsets the Lake Lahontan deposits which overlie the older lake beds. Adjacent to the fault, the angular unconformity between the Plio-Pleistocene (?) lake beds and the Lake Lahontan deposits is marked by a gravel layer and overlain by grayish brown deposits including abundant tufa. That contact is offset vertically at least 3 m. Also visible at the fault zone, within the lake beds, is an area of dark brownish gray friable sand. We suspect this sand was injected into the lake beds by liquefaction.

Southward from the main fault exposures there are numerous minor faults, most of which do not cut the Lake Lahontan deposits that overlie the lake beds. There is also abundant evidence for soft-sediment deformation and/or slumping within the lake beds.

The most spectacular exposures of structural geology, including fairly tight folding and thrust faulting in the lake beds are just around the "nose" of the bluffs. Just south of that area, the lake beds contain numerous clean, white ash beds. A couple of these beds were sampled by Wills and Borchardt in 1989 and sent to Andrei Sarna for analysis. He reported that they were somewhat altered and not clearly correlated with any known ash deposits, but most closely resembled Pliocene ashes.

There are numerous questions to be asked here, beginning with the age and depositional environment of the "lake" beds, correlation of the ash layers, origin of the "plastic" appearing deformation of the lake beds by soft sediment deformation or slumping (or is some of it tectonic?), how much of the folding and low angle faulting is due to interactions with the current strike slip fault (or is some of it soft-sediment slumping?), development of the different strands of the fault over time, development of the broad warp in the former bed of Lake Lahontan and relation of that to faulting. You will no doubt come up with many more questions. Don't come to your field trip leaders for answers, we will be happy to speculate and wave our arms, but by the time we leave this stop you will have spent nearly as much time at these outcrops as anyone.