Sierra Nevada Earthquake History From Lichens on Rockfall Blocks

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Part 1--A Recent Rockfall Splash

Abstract

Strong seismic shaking from nearby and distant earthquakes causes rocks to shift downhill and fall from cliffs. Lichens colonize bare rock and largest lichen sizes date times when blocks fell. Lichen-size measurements cluster in peaks that record earthquake-induced and nonseismic landslides. Same-age lichen-size peaks throughout the Sierra Nevada record regional seismic shaking events. Peak sizes are larger nearer earthquake epicenters, so are used to make maps describing seismic shaking intensity for historic and prehistoric earthquakes, and to study sensitivity of landforms to earthquakes.

Introduction

It was a gorgeous Sierra Nevada morning in the South Fork. I looked up at the cliffs towering above the Roaring River parking lot, massive cliffs that rival those of the fabled Yosemite. Rather monotonous gray lichens coat the surface of the jointed, granitic rocks. Then I noticed several small light gray to whitish patches on the cliff face (Fig. 1). Could these be where rock, weakened by expanding joints and fractures had fallen away from the cliff so recently that the rock surface had yet to be re-colonized by the gray lichens?

Luckily, I had the right tools to discern if a rockfall type of landslide had occurred recently. I had digital calipers, and I know how fast several genera of crustose lichens grow. Careful measurements of lichen sizes, with digital calipers

Figure 1. View of north-facng cliffs above the talus slope next to the Roaring River parking lot, South Fork Kings River. Whitish splotches on granitic outcrop are where masses of rock detached along exfoliation joints, in one or several events, and fell to add another increment(s) to the talus accumulating at the edge of the valley floor. The rest of the cliff has been stable for sufficiently long to become coated with gray lichens that like the cool, wet microclimate.

that read to 0.01 mm, can provide insight about when the surfaces of fallen rock-fall blocks were first exposed to be colonized anew by lichens.

Different lichens start to grow on rock-fall blocks after they arrive on the sunny, dry talus slope at the base of the cliffs. I know how fast bright yellow, brown, and speckled yellow-green lichens grow, which allows me to estimate their ages to within just a few years. Using calipers, I go from block to block, and for each block I have the same question; "when did you come tumbling down the hill". I prefer nearly circular lichens with clearly defined margins growing as a symbiotic algae-fungi crust on smooth rock surfaces. I measure the longest axis of the largest lichen on each rockfall block, assuming that this single measurement records the time when the first lichen colonized the freshly exposed rock surface of this block after a landslide. I don't trust a single lichen-size measurement. It is better to measure many lichens because one does not know how far a single lichen size might vary from the norm. I collect enough measurements to define the range of lichen sizes for a specific rockfall event—we call this a lichen-size peak. The big piles of rocks in the Sierra Nevada are the result of many small rockfalls and larger landslides too.

Although different lichens grow at different rates, all crustose lichens pass through three stages of growth. First is the time it takes the first lichen to colonize a freshly exposed rock surface. This varies from about 8 to 40 years for my three lichen genera. Colonization is followed by rapid growth that gradually becomes slower. This great-growth phase may continue for more than 60 years. Then uniform growth begins at about the time that lichen fruiting structures form. Constant expansion of lichen size continues for many centuries for the crustose

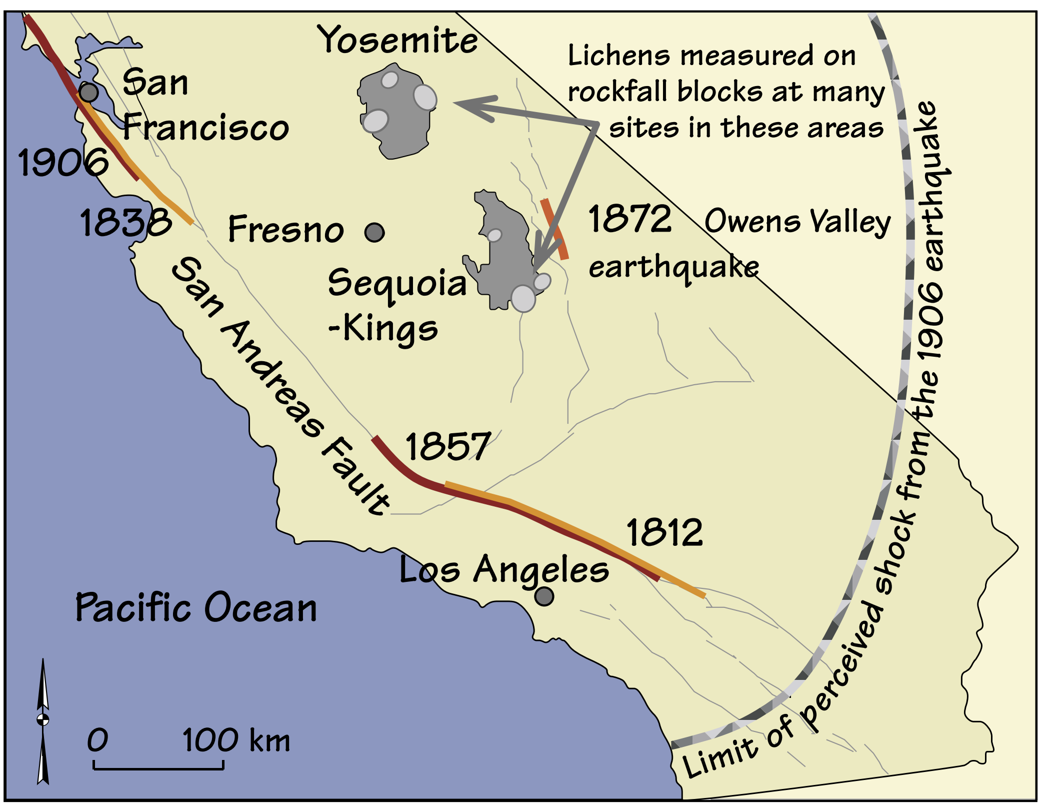

Figure 2. California location map showing locations of groups of lichenometry sites in the Sierra Nevada. Extents of historic magnitude Mw ~7.5 San Andreas fault earthquakes are shown by orange and reddish brown lines and the Owens Valley Mw 7.6 earthquake of 1872 with a red line. Limit of 1906 perceived shock is from Ellsworth (1990). Figure 1 from Bull (2003a).

lichens growing on the rocks of the Sierra Nevada. Some lichens at the Roaring River site are more than 1,000 years old.

So geologists with digital calipers can assess the history of landslides in the Sierra Nevada in order to answer several questions. How often do landslides occur? What causes them? Are they a hazard to visitors in the National Parks or hikers in the back country? The author is a tectonic geomorphologist and paleoseismologist so you can expect him to focus on landslides caused by earthquakes. I will conclude that the Sierra Nevada landscape records seismic shaking from distant earthquakes, including those noted in Figure 2.

Purpose and Scope

The purpose of this note is to see how distant or local earthquakes cause landslides in the Sierra Nevada and how we can use lichens to study such co-seismic landslides. The theme is that regional seismic shaking causes a regional rockfall event with larger and more abundant landslides closer to the earthquake epicenter. These mass movements range from a trickle of small rocks to huge, smothering rock avalanches. It is the intermediate size, very common, rockfall event that is most useful for my purposes. The glaciated valley sides make the Sierra Nevada a nice sounding board for earthquakes, even those generated by slip on the distant San Andreas fault. I test the idea that more rocks are shaken loose nearer an earthquake epicenter by mapping areal variations in the abundance of rockfalls for historic and prehistoric earthquakes. Such studies provide clues as to the sensitivity of different landforms and rock types to seismic shaking. Comparison of Sierra Nevada regional rockfall events with known ages of the much studied prehistorical San Andreas fault earthquakes is a good way to assess the validity of lichenometric dating of earthquakes and to find out how far back in time the method can be used. I use metric units of measurement, in part to get us Americans familiar with the way the rest of the world describes sizes.

Recent Rockfall Splash on Roaring River Talus Slope

I had a particular interest in trying to estimate the time, or times, of apparent recent cliff failure above the Roaring River parking lot. I was in the final stages of setting up a field-trip stop for a large group of geologists known as the 'Friends of the Pleistocene'. Yes, they are especially keen to learn more about Sierra Nevada geology of the past 2 million years. Surely they would be curious as to when and why parts of the cliff failed. It would be better if I could be specific rather than make some shallow comment such as "a coating of gray lichens shows that these cliffs are fairly stable, but white patches suggest a recent rockfall event; most likely caused by the nearby Mw magnitude 7.6 earthquake of 1872".

Having only 45 minutes before meeting a Park Ranger, I measured only a dozen lichens for each of the three genera for which I know rates of growth. I didn't have time to measure hundreds of lichens—my preferred approach would require two or three long days work because large as well as small lichens would be measured. So I took a chance that 42 lichen-size measurements might reveal a consistent story about recent cliff failure, and that different genera would

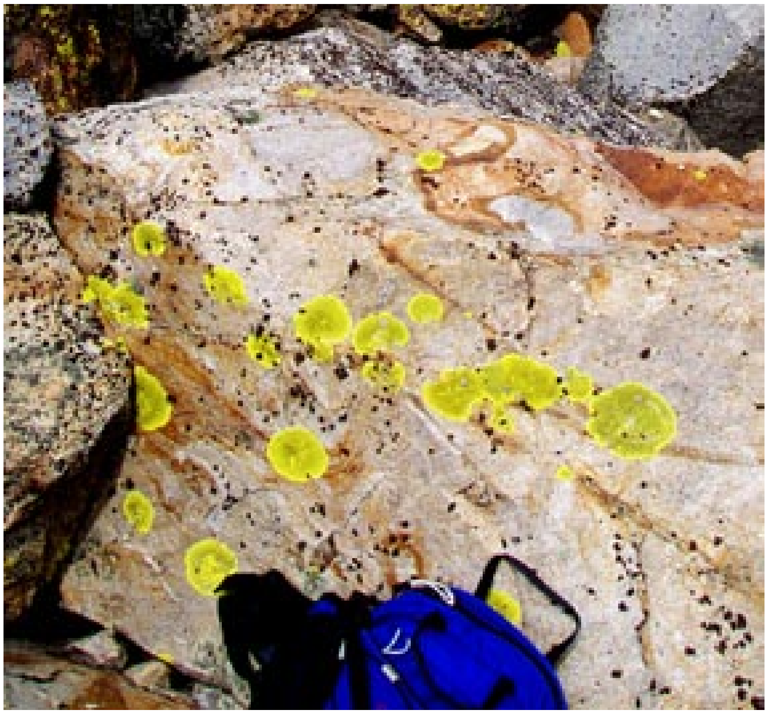

Figure 3 *Acarospora chlorophana* on Kings Canyon talus block. We examine each block for a potential largest lichen maximum diameter scrutinizing the largest thallus to see if it is indeed a single, not merged, thallus. Then determine if the two measuring points for the longest axis are sharp and well preserved. If in doubt, do not measure; just move on to the next block.

confirm a common story. Would there be a pattern of a few blocks breaking loose from the cliff face each frosty winter? (lichen sizes would be evenly spread out in such a graph). Would all the lichen sizes clump together in one peak on a graph summarizing the results? (indicating that the cliff failed at only one time and was completely stable the rest of the time). The bright yellow crustose lichen, *Acarospora chlorophana* (Fig. 3), is one of my favorite lichens so I measured it at the start of my transect across that part of the talus slope where damaged oak trees also told me of recent rockfalls.

I use a histogram to see if my lichen sizes cluster, or are scattered. This simple graph consists of simply stacking one lichen size on top of another of the same size to see if peaks appear in the overall distribution of sizes. Two peaks are apparent even with only 14 measurements (Fig. 4A). This suggests that rocks have fallen from the cliff face as discrete events rather than as an annual trickle. Virtually nothing happens between the times of discrete rockfall events. Having a lichen-growth-calibration equation ready to use (Bull, 1996), I estimate the times of these two rockfall events to be approximately 1811 and 1741 A. D. I say approximately because lichenometry is not as precise as historical records, or tree-ring dating of landslides. But lichenometry is much better than the radiocarbon method for dating trees buried by a landslide. Importantly, it dates the event instead of wood that grew some time before the landslide event. Precision is excellent and the accuracy of lichenometric dating commonly is about 2 years from the true age. I recognize possible uncertainties of my calendric age estimates by adding a generous ± 10 years to the lichenometry dates of rockfall events.

Both *Acarospora chlorophana* age estimates suggest rockfalls during times of regional seismic shaking, because they are within 10 years of the known times of earthquakes. A big southern California earthquake occurred on the San Andreas fault in 1812, and tree ring dating suggests that the Honey Lake

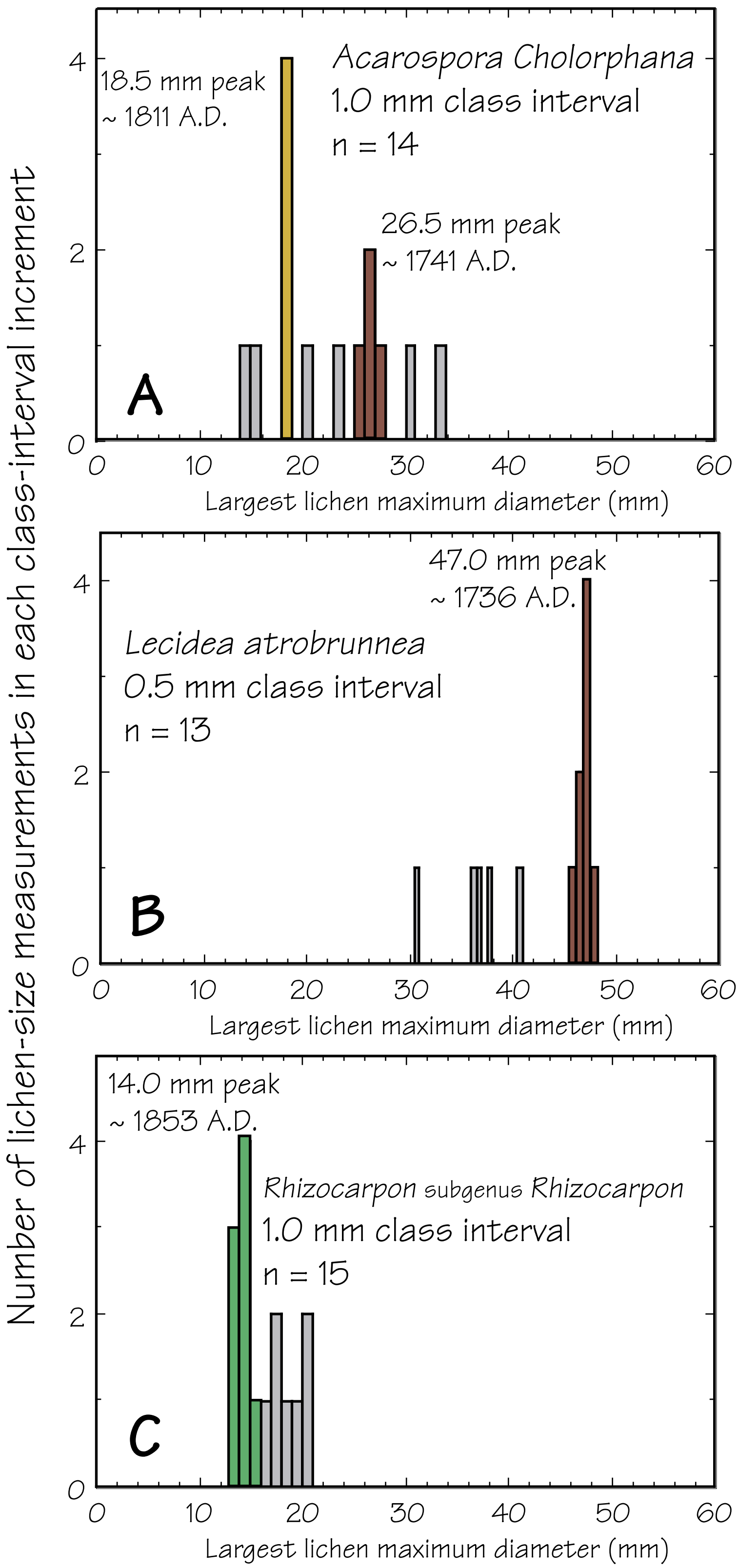

Figure 4 Simple histogram graphs for three common crustose lichens reveal clustering of lichen sizes. These lichen-size peaks date the times of the most recent rockfall events that splashed blocks and rock fragments onto a pre-existing talus slope at the Roaring River parking lot site, South Fork Kings River.
A. *Acarospora chlorophana*
B. *Lecidea atrobrunnea*
C. *Rhizocarpon subgenus Rhizocarpon*

fault zone north-northwest of Reno, Nevada might be the source of earthquake-triggered regional seismic shaking during the winter of 1739-1740 A. D..

Surprise! This cliff failed not once but twice, apparently from earthquakes whose epicenters were 300 km away. Both times are quite a bit older than I would have guessed by looking at the cliff. I say “apparently” to allow for the remote possibility that prolonged rain or snowmelt, or wedging by tree roots,

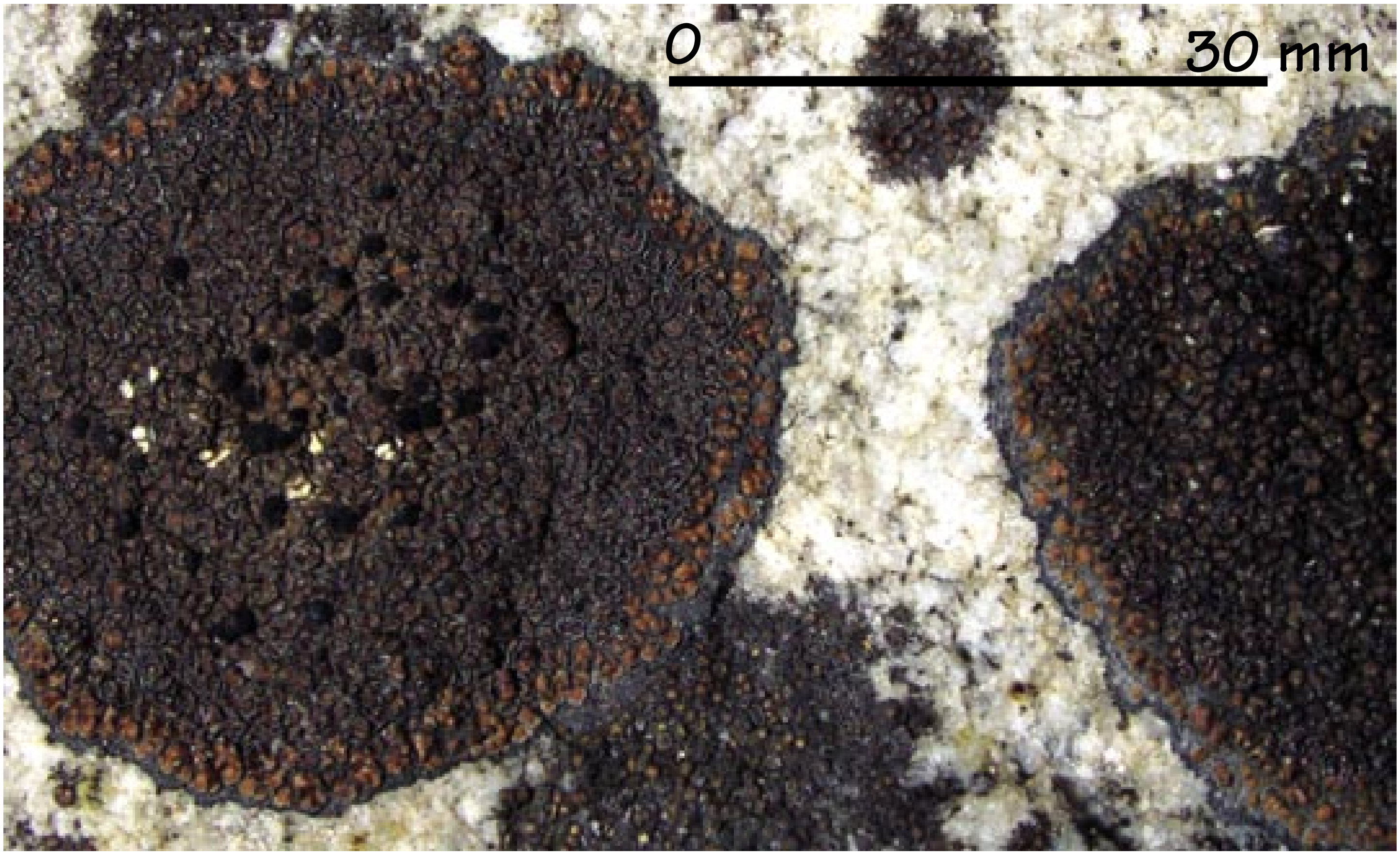

Figure 5 *Lecidea atrobrunnea* with typical large black apothecia and algal thallus rim. Broken areoles reveal whitish interior color.

might have caused rockfalls that just happened to coincide with the times of two earthquakes. I try to be careful, realizing that no one actually witnessed either cliff collapse. A good test of the earthquake hypothesis is to see if the same time of this rockfall event also occurs at high and low altitude lichenometry sites throughout the Sierra Nevada. Then, we can label the event as being regional instead of just being an unimportant local event. Yes, I'll do this for both the 1812 and 1739 events later on in this note. Fortunately, I know how fast two other lichen genera grow. What story do they have to tell me?

My initial results were crosschecked by graphing the sizes of another lichen genus in about the same part of the talus slope. This histogram is for the faster growing brown lichen *Lecidea atrobrunnea* (Fig. 5). Its uniform phase rate of growth is 23.1 mm each century as compared to 11.4 mm per century for *Acarospora chlorophana*. So, it is no surprise that the largest lichen on each rockfall block is bigger. This time, there is just one clumping of lichen sizes. It forms a single tall, symmetrical lichen-size peak (Fig. 4B) that dates to about 1736 A. D. Once again this is quite close to the known age of the regional seismic shaking event of 1739-1740 A. D..

The one remaining plot is that for the yellow-green *Rhizocarpon* subgenus *Rhizocarpon* (Fig. 6), and it is still different. This is slow-growing lichen, has a uniform-phase growth rate of only 9.5 mm per century. Most of my few lichen-size measurements form a large peak at about 14 mm (Fig. 4C), which dates to

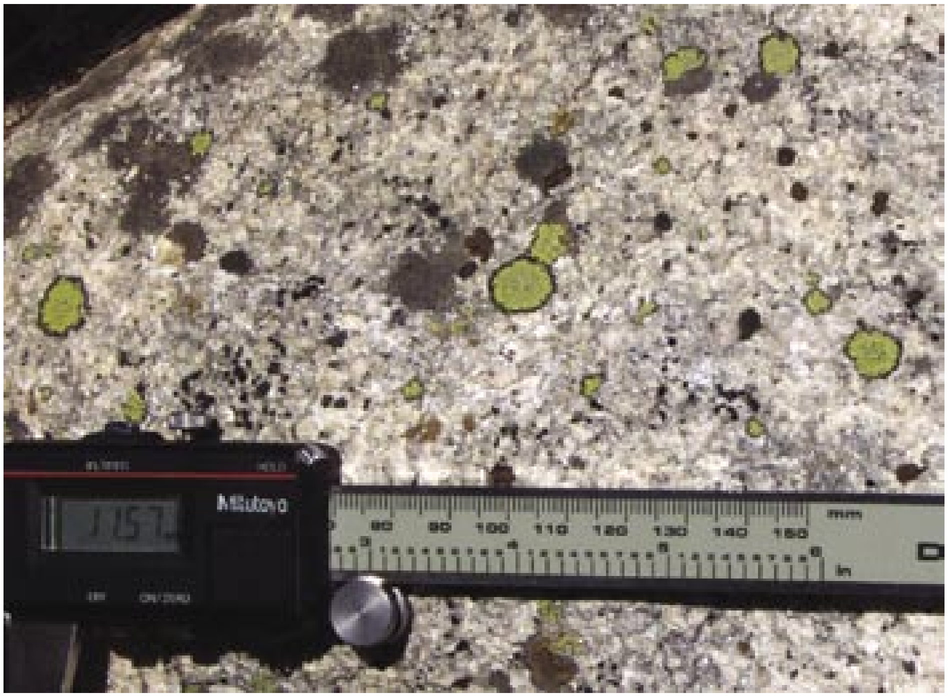

Figure 6 Small thalli of *Rhizocarpon* subgenus *Rhizocarpon*. A progression of lichen sizes that approach the favored largest lichen maximum diameter is much better than having only a single lichen to measure on a rock-fall block.

about 1853 A. D. This result is clearly different than indicated by the other two lichen genera, but it too seems to have been earthquake generated. A major earthquake occurred on the southern San Andreas fault in 1857 A. D.. These yellow rhizocarpon measurements were collected at the end of my traverse, and the results clearly show that I had moved off of the 1739-1812 A. D. part of the rockfall accumulation into an area where the surface had been splashed more recently with chunks of rock during the 1857 A. D. earthquake.

So, measuring a few lichens changed my initial overall impression that the talus slope had been splashed by a single and fairly recent collapse of a small part of the overlying cliffs. Three earthquakes are recorded, and their epicenters lie either far to the north or to the south of the valley of the South Fork.

Where are the rockfalls that I expected from the Mw magnitude 7.6 Owens Valley earthquake of 1872 (Fig. 2) whose epicenter was only 50 km away to the east? Apparently the orientations of the joints and the overall east-west trend of the valley did not favor many blocks being shaken loose by seismic waves coming from the east. The east-west orientation of the joints in the cliff-face granitic rocks appears to be more conducive to blocks being pried loose by seismic waves coming in from the north or south. A given cliff face does not respond in the same manner to different earthquakes.

Of course not all cliffs disintegrate during an earthquake, only those parts that have reached the stage where a small amount of disruptive energy moves them across a stability threshold. The rest of the cliffy landscape remains unchanged by the seismic shaking. We can think of each hillslope, cliff, rubbly glacial moraine, steep talus slope as having its own sensitivity to seismic shaking.

Measuring lichens sizes as a way to study earthquakes strikes me as being a protective way of doing science in Yosemite or Sequoia-Kings Canyon National Parks. Nothing was dug up or sampled. I left with only photographs and lichen-size measurements. Best of all, you, or another tectonic geomorphologist can walk up to the same pile of rocks and collect a replicate set of measurements to check out my story. The Figure 4 story may strike you as being reasonable, but many geologists are skeptical. The precision of this new way of studying earthquakes just seems too good to be true. Besides they just might prefer to continue to study earthquakes using older methods that they feel more comfortable with.

End of Part 1--A Recent Rockfall Splash

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