Big Sur
Hellatite Camping Trip
April 18 – 20, 2003

Hellatite Mission Statement:
Our intention is to promote a self-motivated and cooperatively managed organization where anyone of any background can share expertise in a casual and non-discriminatory club dedicated to increasing knowledge of local areas, California geology, and natural awareness through direct field experience and mutual instruction.

Each participant understands the importance of individual responsibility and the desire to have fun while working together in an educational, non-academic environment.

Assemble at:
The entrance to Point Lobos State Reserve on Hwy 1, just south of Carmel , at 6:30pm on Friday, April 18. Be in possession of all gear, food, anything you will need for the weekend because there are no planned stops for provisions of any kind.

Field Trip Facilitators:
Greg Stock and Pete Adams, both doctoral students in Bob Anderson's geomorphology group. Be sure to let these guys know that you appreciate their efforts and insights.

Weekend Agenda:
Is up to us! Our facilitators, as well as other participants, have assembled many ideas of interesting and relevant places to see good geology and just plain good hiking. The path we take will be dictated by interest and whims of the group and facilitators, as well as the weather. All we know for sure at this point is that we will be camped Friday night at Andrew Molera State Park (has water and outhouses) and Saturday night at a dry camp on Forest Service land at Pruitt Ridge. Therefore,

This Field Trip Guide:
Is meant to be a jumping off point for discussion, questions, and exploration. This is not a stop-by-stop guide, but it should provide you with some interesting background knowledge on Big Sur geology, history, faulting, coastal and mountain morphology, climate, marine processes, mass wasting, and erosion. It is not all inclusive, and especially represents the interests of the people who put it together, so by all means, ask all the questions you want and let's help each other learn something.

Just the Rocks:

Take a look at the geologic maps of Big Sur included in this handout. All the faults make it look pretty crazy (Figure 1) but for our purposes we can basically break all the rocks down into two main groups: the Salinian Block and the Franciscan Formation (Figure 2).

Salinian Block:

AGE: Paleozoic (540-270 million years old) and Cretaceous (anywhere from 65 – 145 million years old)

WHAT THEY ARE: Metamorphosed Paleozoic marine sedimentary rocks (these are locally called the Sur Series) including schist, quartzite, granulite gneiss, granofels, and marble. The Sur Series was intruded during the Cretaceous by large volumes of granite magma, which closely resembles the granite of the Sierra Nevada. In many areas, younger sedimentary rocks form layers atop the Salinian basement.

MORE DETAILS: As implied above, the Sur Series formed in a marine basin but was uplifted, metamorphosed and added to the continent during the late Paleozoic or early Mesozoic, experiencing particularly high temperatures in the western region. About 120Ma, magma plutons first intruded the metamorphic rocks. This went on until about 75-80Ma. Composition of the plutons is mostly granitic but ranges to gabbroic in some areas.

Franciscan Formation:

AGE: Late Jurassic to Cretaceous (anywhere from 65 – 200 million years old)

WHAT THEY ARE: Mostly greywacke (AKA muddy sandstone) which collected in the deep ocean trench formed by an oceanic plate subducting under North America. Also contains other deep sea rocks like chert, greenstone (which is altered basalt), limestone, siltstone, and mudstone, as well as some very unusual metamorphic rocks like greenschist, blueschist, eclogite, and serpentinite.

MORE DETAILS: Most of the greywacke has been tectonically blended into a mixed-up "mélange", erasing stratigraphy and reorganizing the exotic metamorphic blocks. The blocks themselves are mysterious: in order to form their minerals, these rocks must have been buried very deeply, but now they're suspended in sediment which hasn't been changed and therefore couldn't have been buried. The serpentinite must have formed when ocean waters came into contact with minerals of the earth's mantle. The exotics contain some interesting minerals we'll hopefully see on this trip.

How did they get there?

Both the Salinian block and the Franciscan Formation owe their genesis to the long-lived subduction zone that was active at the western margin of North America for almost 200 million years, still active north and south of here, but ceasing in central California some 20-some odd million years ago.

Figure 3 is a cartoon of what we think California looked like when that subduction zone was active. The "Old Sialic Crust" consists of the metamorphic basement and intrusive igneous rocks that make up today's Sierra Nevada, and of which the Salinian block may be a part. A little farther seaward you can see the marine sediments that will later become the Franciscan. This is a very neat model with everything in its place, and it explains how these rock units formed. However, it didn't stay so neat.

If you take a look at Figure 2, the very simplified geologic map of the Coast Ranges, you can see that the Salinian block splits the Franciscan. It's not immediately obvious how a these metamorphic and igneous rocks could have ended up in the middle of those offshore sediments.

Fifty years ago, geologists noticed the strong similarities between the metamorphic and igneous rocks of the Salinian Block and those of the Sierra Nevada and proposed that the Salinian Block started as part of the southern Sierra which was torn off, moved west, and has since been scooting northward along the San Andreas Fault. This is pretty much the conventional wisdom on the topic today, and it makes pretty good sense if you look at the present day positions and motions of the Garlock and San Andreas Faults shown on Figure 2. They mapped all the major faults that are shown on Figure 4 or Figure 1. The argument got even stronger in the 1980's when other geologists tracked a line of granitic rocks of the right age stairstepping across the desert from the Sierra to the coast. However, the steepness and plant cover of the Coast Ranges make it possible to map pretty much *where* the faults are located, but not actually get a good grip on *what type* of faults they are. The original interpreters assumed that the faults they mapped were vertical strike-slip faults, like the San Andreas is today. However, there are other ways to interpret what we all agree is on the surface.

Figure 5 shows a cross section of modern geology across the same area. You can probably see that the Franciscan is shown underlying the Salinian block in the Big Sur area. In this case, the Sur-Nacimento Fault is interpreted to be a nearly flat thrust fault, a far cry from the prior ideas. This is shown on the map in Figure 4, as interpreted by Clarence Hall, a professor at UCLA, in 1991. Dr. Hall went a little crazy with font sizes, and turned a lot of heads by redefining the Salinian block as the Southern California allocthon. This would be an appropriate time to make a crack about how the universe revolves around UCLA, since those of us living on the allocthon don't exactly think of ourselves as southern Californian.

Complicating matters again, in the 1980's, paleomag data from some parts of Salinia suggested that the rocks may have formed at equatorial latitudes. No detailed model has been worked out for this yet, but there's no evidence against it, either.

Cone Peak stop:

Welcome to the summit of Cone Peak, at 1571 m (5152 feet) one of the highest summits in the Santa Lucia range. The coastal slope, from the peak down Limekiln Creek to the ocean is the steepest coastal slope anywhere in the continental United States. It also rivals many non-coastal slopes as well; the slope angle from here to the ocean is greater than that from the summit of Mount Whitney to the floor of the Owens Valley at Lone Pine. This peak is a central hub for several diverse drainages: the steep, marble-filled canyons of Limekiln Creek and Hare Canyon drain to the southwest, the deep gorge of Devil's Creek is incised into the peak's northwest shoulder, and the San Antonio river has its headwaters on the eastern flank. These rugged slopes contribute to a great diversity of habitats and a variety of unusual plants.

Nearly all of Cone Peak is composed of crystalline and metamorphic rocks of the Salinian Block. The summit area is composed of tonalite, while the majority of the western slope is composed of layered migmatitic gneiss. Masses of diorite and gabbro, and thin, contorted beds of marble, make up the remaining rocks in the immediate area. Less than 1 km inland of the coast is the Nacimiento Fault, a presumed thrust fault separating the crystalline and metamorphic rocks of the Salinian Block from the Franciscan rocks of the Nacimiento Block. To the east of Cone Peak are Cretaceous age sedimentary rocks whose origins range from submarine shelf deposits to subaerial channel conglomerates.

The views to the north and east reveal many important landmarks of the Santa Lucia range, including the Ventana Cones surrounding the Big Sur River watershed, and Junipero Serra Peak, the highest mountain in the range at 1787 m (5862 feet). Notice the approximate accordance of these summits, suggesting a large, flat-topped block that has been uplifted and subsequently sculpted by geomorphic processes. Such surfaces have long been used to infer uplift. Assuming that the surface was planed flat near base level (sea level), the amount of uplift can be simply calculated. If an age for the surface can be determined, an uplift rate can be deduced. Though this simple method works in some situations, it is probably more the exception than the rule. In fact, barring unique and rare geologic situations, determining rates of mountain uplift is damned difficult to do. Cone Peak may represent one of those unique and rare geologic situations, but before we discuss those data in detail, let's first deal with methods for deducing mountain uplift.

The Reader's Digest Version of Methods for Deducing Mountain Uplift

First, let's clarify what we mean by uplift. Geologists have recently tried to tighten up the term "uplift" by specifying two types: *rock* uplift and *surface* uplift. These terms deal with the competing forces of uplift and erosion. Rock uplift is simply the motion of a rock mass upward relative to a globally averaged surface, usually taken to be sea level. Surface uplift is how much the *surface* of that rock mass is moving upward relative to sea level. Depending on the climate and geomorphic processes acting in the region of rock uplift, there will be a certain amount of erosion of the surface during rock uplift. If range-wide erosion, sometimes called exhumation, cannot keep pace with rock uplift, then there is a net gain in elevation, i.e., it will experience surface uplift (example: modern Himalaya going up). If erosion is more rapid than rock uplift, then the mountain range will experience a net loss in elevation (example: Cenzoic-age Appalachians going down). If erosion and rock uplift are perfectly balanced, then there is no surface uplift, and the range is said to be in steady-state (example: Taiwan?).

Methods for deducing surface uplift of a mountain range are limited, and there are even fewer for deducing rock uplift. Among those used for determining rock uplift are studies of fault movement, isostatic calculations, and a variety of geochronological techniques that constrain when a particular mineral passed through a certain depth below the surface. These include complicated techniques such as fission-track dating and (U-Th)/(He) dating, discussed below. Methods of deducing surface uplift include dating of marine terraces, stratigraphic constraints, and offset or tilted markers such as volcanic flows. Methods used to measure erosion, such as river sediment fluxes and incision rates, basin fill rates, topographic reconstructions, and cosmogenic nuclide concentrations help constrain the amount of surface uplift. There is also a growing field of paleoaltimetry, which seeks to determine former heights of mountain ranges. Techniques here include paleoflora analyses, isotopic studies of sediments in mountain rainshadows, and using the vesicularity of basalt flows to estimate the atmospheric pressure and therefore altitude of the flow when erupted. Most of these studies are still in the development phase.

Back to the Santa Lucia's…

The Santa Lucia mountains are generally assumed to have experienced relatively recent (Plio-Pleistocene) rock uplift simply because of its steep, rugged character. However, until very recently no quantitative constraints existed to test this theory. Recent (U-Th)/(He) ages from a vertical transect down the western slope of Cone Peak were used to reconstruct a history of exhumation and rock uplift of the area, and nearby stratigraphic units were used to constrain the surface uplift.

(U-Th)/(He) dating works something like this: when a granitic rocks cools from magma, it forms minerals, among these apatite, that contain radioactive elements, such as U, that decay to other elements, such as Th, through ejection of He nuclei. The amount of these three elements could be used to date the formation of that mineral, expect for one thing: at temperatures above ~70°C, He is not retained in the mineral and therefore no date is possible. This frustrated geologists for a long time, until somebody turned the problem upside down and figured that, given normal geothermal gradients (the heat increase as you go down in the earth's crust), 70°C ought to be found about 2.5 km down. By dating the mineral, you are actually dating when the rock passed through that isotherm, and since the rock is now exposed on the surface, you know that about 2.5 km of material has been eroded, or exhumed, from above that spot since the age of the mineral.

The (U-Th)/(He) ages from the Cone Peak transect indicate exhumation rates of ~0.35 mm/yr between 6 and 2 million years ago, and then a substantial increase to ~0.9 mm/yr after 2 million years ago. At 4 million years ago, sedimentary rocks in the region record a shift from submarine to subaerial sedimentation, marking the time those rocks passed through sea level. The elevation of rocks that moved through the 70°C isotherm 4 million years ago is now 800 m. Therefore, a total of ~3440 m of rock uplift has occurred in this time, at a rate of ~0.86 mm/yr. Subtracting the amount of exhumation, determined from the cooling ages, from the amount of rock uplift yields a surface uplift rate of 0.2 mm/yr. So while surface uplift is far less than rock uplift, there has still been a net elevation gain of the Santa Lucia mountains in the last 4 million years.

A final note regarding the (U-Th)/(He) study at Cone Peak: exhumation rates of 0.9 mm/yr are awfully fast for any mountain range, and appear to be much faster than the rates at which modern rivers in the central California coast are downcutting. The authors therefore suggest that landsliding along the coastal slope is a major player in the geologic shaping of the range; in fact, they argue that it may be the dominant geomorphic processes. You have now had the opportunity to consider the effectiveness of coastal erosion, and to view landslide deposits along the western slope of the Santa Lucia's – what do *you* think?

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