GEOLOGY 25 - <u>LECTURE 5A</u>

National Parks of the Sierra Nevada

[Textbook Chs. 17 & 1 (p, 16-17)]

Sierra Nevada Geologic Province

The Sierra Nevada form the backbone of the state, extending northwest-southeast for 600 km (400 mi) along the eastern flank of California.

The highest peak in the Sierra, Mt. Whitney, is 14,495’ high and is the highest in the contiguous 48 states - it is located in Sequoia NP. The “High Sierra” include the highest part of the range and extend from north of Yosemite to south of Mt. Whitney. 12 peaks are > 14,000’ high. The range is lowest in the north toward the Feather River where the highest elevations are around 6500’.

- three national parks: Yosemite, Kings Canyon and Sequoia

Topography and Structure of the <u>Modern</u> Sierra Nevada . . . .

The Sierra form a wedge-shaped block, with gradual western slopes rising upward before dropping off as a steep eastern escarpment. (the crest of the Sierra is located just above the eastern escarpment, not in the middle of the range as you might expect)

- western slopes catch most of the moisture from storm fronts and are much greener than the eastern slopes in the “rain shadow”
- numerous rivers drain the western slope, spilling into Sacramento and San Joaquin Rivers of the Central Valley – they eventually converge in ‘the Delta’ then flow seaward toward the Golden Gate

How were the modern Sierra Nevada uplifted to become a mountain range?

An extensive **fault system** runs along the base of the eastern escarpment

- a **fault** is simply a planar fracture within rock along which displacement has occurred. The rock on one side of the fault has shifted relative to rock on the other side of the fault. This commonly happens suddenly during an earthquake, with **offset** (aka **displacement**) of maybe less than a meter to as much as 5 or more meters per earthquake.

(A fault plane is different than a joint plane because the rocks on either side of a fault plane have moved relative to one another. The rocks on either side of a joint are stationary – i.e., a joint is just a crack or fracture.)

- a “**fault line**” is the orientation of a fault along the surface; it marks the location on the landscape where the fault plane intersects the surface. (fault lines are what you see on maps)
- a **fault system** is a network of related faults, usually trending in the same orientation
- through time, hundreds or thousands of earthquakes can produce hundreds to thousands of meters of **uplift** (balanced by ongoing erosion)

There are several types of faults (e.g., reverse, thrust, strike-slip), but the faults that bound the eastern margin of the Sierra Nevada are called “normal faults”

A **normal fault** forms when a mass of rock is pulled apart by continent-scale tectonic forces (more on this later) – the block of rock on one side of the *normal fault plane* slides downward relative to the block of rock on the other side.
- the block on the downthrown side commonly forms a valley or basin, whereas the block on the upthrown side forms a high elevation area like a plateau or mountain range
- by the way, these are not "plates" on either side of the fault; they are just large blocks of rock called 'fault blocks.' Faults can happen just about anywhere because tectonic forces along plate boundaries can be translated into the interior of plates.

Uplift of the Sierra Nevada occurred by faulting that created the westward tilt
- uplift of the **modern Sierra** began only about **5 m.y.a.** - very young mountain range. Faulting and uplift were accompanied by a long series of earthquakes that continue to today
- with each earthquake, the rocks of the crust to the east of the fault system were dropped downward while the rocks of the Sierran crustal block jerked upward and tilted westward.
- mountain ranges formed by normal faulting like this are called **tilted fault block mountains** (the Sierra Nevada are the largest tilted fault block mountains in North America)
- GPS (global positioning system) measurements show that the modern Sierra are rising at an average rate of 1-2 mm/yr (1-2 meters/thousand years, 10-20 meters per 10,000 years, & 1-2 km per million years). Erosion (by running water, glaciers, and landslides) continually grinds away at the rising mountains.
- visit the eastern escarpment and be amazed at how rugged and steep it is by driving along Route 395, one of the most scenic roads in California. You've driven it if you've ever been to Mammoth Lakes to ski or hike.

Where did the rocks composing the modern Sierra Nevada come from?
Granitic Roots of the Sierra Nevada

Recall from earlier in the course that the rocks had to have formed first, then were later uplifted to form mountains. The last event is weathering and erosion that forms the modern landscape.

Rocks that form by crystallization from a molten magma or lava are called **igneous rocks**. Solidification of igneous rocks may occur either inside the earth in a magma chamber or on the surface of the earth along the flanks of a volcano.

The main mass of the Sierra is composed of rocks that solidified from molten magma deep within the ground (i.e., magma becomes granitic rock). These types of igneous rocks occur in the **intrusive** realm (since they intrude the **country rock** that was there previously).

Igneous rocks that cool slowly in a magma chamber are called **plutonic** igneous rocks. (As opposed to **extrusive volcanic** rocks that solidify as lava or pyroclastic debris on the surface, like in the Cascades).
- country rock can be any type of rock: sedimentary, metamorphic, or even older igneous rock
- (lava and magma are the same thing, only that magma is what molten rock is called when it's beneath the surface whereas molten rock above the surface is called lava)

Rocks are composed of aggregates of **minerals**, which in turn are composed of mixtures of **elements**.

- the magma is composed of a thick mixture of elements in the form of a hot, molten fluid. The magma consists of countless atoms of O, Si, Mg, Na, Al, Ca, and many other elements of the periodic table).
- as the molten liquid gives off its heat to the surrounding country rock, the magma cools. As the magma cools, solid mineral crystals form from the liquid, but not all at once. Each mineral has a specific temperature at which it crystallizes.
- with time and more cooling, more mineral crystals grow from the liquid until all the liquid solidifies and what's left is an interlocking mosaic of crystals of different minerals.
- because cooling and crystallization occurs slowly (maybe over several hundreds of thousands of years), the growing mineral crystals can grow to large sizes visible to the naked eye
- coarse-grained, intrusive igneous rocks of the Sierra are broadly called **granite**

When a magma chamber cools, it solidifies into a large mass of plutonic igneous rock called a **pluton**. Each pluton was once an individual magma chamber with a distinctive chemistry.
- the granites of Yosemite NP originally formed about 3-15 km beneath the surface in massive magma chambers at temperatures of ~1000°C (~1800°F).
- the dimensions of a magma chamber and the resulting pluton may be several tens of kilometers in diameter and 10-20 km in depth

In the Sierra, over a hundred individual overlapping plutons combine to form a larger mass of granite called the **Sierran batholith**.
- these intrusive igneous rocks crystallized over a time span ranging from 210 to 80 m.y., with about 90% crystallizing between **120-80 m.y.a.** (Mesozoic age)
- the granites of the Sierran batholith form the backbone of the Sierra Nevada and are by far the dominant rock of the range

What was the tectonic origin of the granite?
Tectonic origin of the Sierran batholith and the Ancestral Sierra Nevada

It would be wise to refer back to the section in the Cascades notes on plate tectonics to see the similarities and other details with the tectonic story below.

A convergent, **Andes-style subduction zone** dominated the entire margin of western North America during the Mesozoic. (The Andes Mountains of South America that we discussed back in the Cascades section is a modern analog for the ancestral Sierra Nevada during the Mesozoic.)
- at its maximum extent, the volcanic mountain chain that included the ancestral Sierra Nevada extended from Baja Calif. to British Columbia (see the paleogeographic map from 92 Ma)

It is generally understood that granitic batholiths form along **subduction zones** where oceanic lithosphere descends beneath continental lithosphere.
- magma generated along the subduction zone rose upward where it formed chambers in the crust. Those magma chambers fed a chain of volcanoes that marked the crest of the **ancestral Sierra Nevada** - the ancestral Sierra Nevada looked like the modern Andes Mountains, or the modern Cascades chain of volcanoes.

- the magma chambers eventually cooled to become granitic plutons, which collectively form the Sierran batholith, which in turn formed the roots of an Andean-style mountain chain during the Mesozoic in California (i.e., the ancestral Sierra Nevada).
- convergent tectonics not only causes the intrusion of granitic magma and a crown of volcanoes, but also compresses and deforms older rocks along the continental margin, squeezing and uplifting them to create a high mountain chain (this is another one of the ways that "uplift" occurs)
- over Cenozoic time, the volcanoes that once topped the ancestral Sierra Nevada were worn away by weathering and erosion.
- this should all be familiar to you since we discussed the same tectonic setting in the parks of the Cascades Range (be sure to refer back to those notes)

The Mesozoic subduction-generated granite batholith can be seen in the Sierra Nevada, of course, but also in **Joshua Tree National Park** in southern California, and many other mountain ranges in western North America

The oceanic plate that was subducting beneath western North America during the Mesozoic is called the **Farallon plate**. Remnants of this plate in today's world include the Juan de Fuca plate off the Pacific Northwest and the Cocos plate off Central America.
- the reason for knowing about the Farallon plate is that it figures prominently in the geologic origin and evolution of the entire American West, which we'll get to eventually in the course
- long before there was the San Andreas plate boundary in California there was a subduction zone that originated about 200 m.y. ago during the Mesozoic

In sum, there are two phases of the Sierra Nevada: a Mesozoic phase when the granitic plutons were formed within the **ancestral Sierra Nevada** and a late Cenozoic phase when the **modern Sierra Nevada** was uplifted, beginning the creation of the landscape we see today.

The Sierra Nevada are still rising today as the normal faults along the eastern flank episodically rupture, causing earthquakes. For example, in 1872 a normal fault along the base of the east side of the Sierra Nevada ruptured, triggering a M7.8 earthquake near the small town of Lone Pine. The Sierra Nevada in the region rose ~2 meters during the minute or two of violent shaking.

The actual composition and structure of the Sierra Nevada is more complex than just the Mesozoic batholith and its granitic rocks, but these are the dominant rocks in the three national parks of the Sierra.

If the above ideas seem incomprehensible and overly complex to you, read the notes in conjunction with the images in the lecture videos. Relate the words directly to an image and learn to think visually. The notes will make much more sense if you can associate them with a graphic. And the book explains all of this in more detail.