# Earth Science Field Trips in Southern California

**Hidden Valley, Joshua Tree National Park**

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## Acknowledgements

This project would not be possible if it were not for the support of Cerritos College, which has allowed me to pursue an academic endeavor that I feel serves to benefit our students as well as the students and instructors at other institutions of learning. Writing this manuscript has also allowed me an opportunity to deepen my knowledge of California geology, which in turn will help me better communicate content in my courses and in turn be a better teacher.

Thank you to my colleagues in the Earth Science Department, Dan DeKraker, Ryan Goode, Olivia Hinton, and Raymond Villalba who encouraged me to undertake the project and provided valuable input. Thank you to Bob "DK" Kreger, who helped me develop the concept of writing a "how to" field trip guidebook and for providing astute observations and editing to the introductory chapters. Thank you to Dee Trent, whose suggestions on the Joshua Tree chapter provided invaluable guidance at the start of my writing. Thank you to Nate Onderdonk, who invited me to join his students on field trips and through doing so, provided me with fresh insights. Huge thanks to Glenda Greene, grammar queen, for her editing prowess and for providing valuable suggestions about adding content to enhance clarity. Finally, thank you to my wife Hilda for being completely supportive throughout this entire process.

I would also like to thank the authors of guidebooks from which I've learned a tremendous amount, resulting in the addition of meaningful and instructive content to this document: Art Sylvester and Libby Gans and their *Roadside Geology of Southern California* and Edward Sharp and Alan Glanzer, whom authored *Geology Underfoot in Southern California* and *Geology Underfoot in Death Valley and Owens Valley*.

## Preface

This guidebook is written primarily for educators of earth science-related subjects but should be interesting and useful to anyone that has ever wondered about the "why", the "how", or the "when" behind some of the unique and beautiful and natural areas of southern California.

At the risk of oversimplifying content, there has been an attempt to strike a balance with the presentation of the material so it will be comprehensible to advanced high school students and college students in introductory-level courses, while at the same time "meaty" enough that it could be used to supplement curriculum in earth science courses.

Included is a section on "how to plan field trip" for educators and other group leaders that may be inexperienced in planning field trips and managing large groups of students in the field. If you feel confident in coordinating field trips then feel free to just skim this section or skip it altogether, while keeping in mind the old adage, "prepare for the worst and hope for the best".

The links to videos and animations may or may not be accessible while in the field depending on availability of cellular data or type of phone service. Downloading this content ahead of time to electronic devices is encouraged so instructors can use these instructional tools when a lack of cell service prevents access.

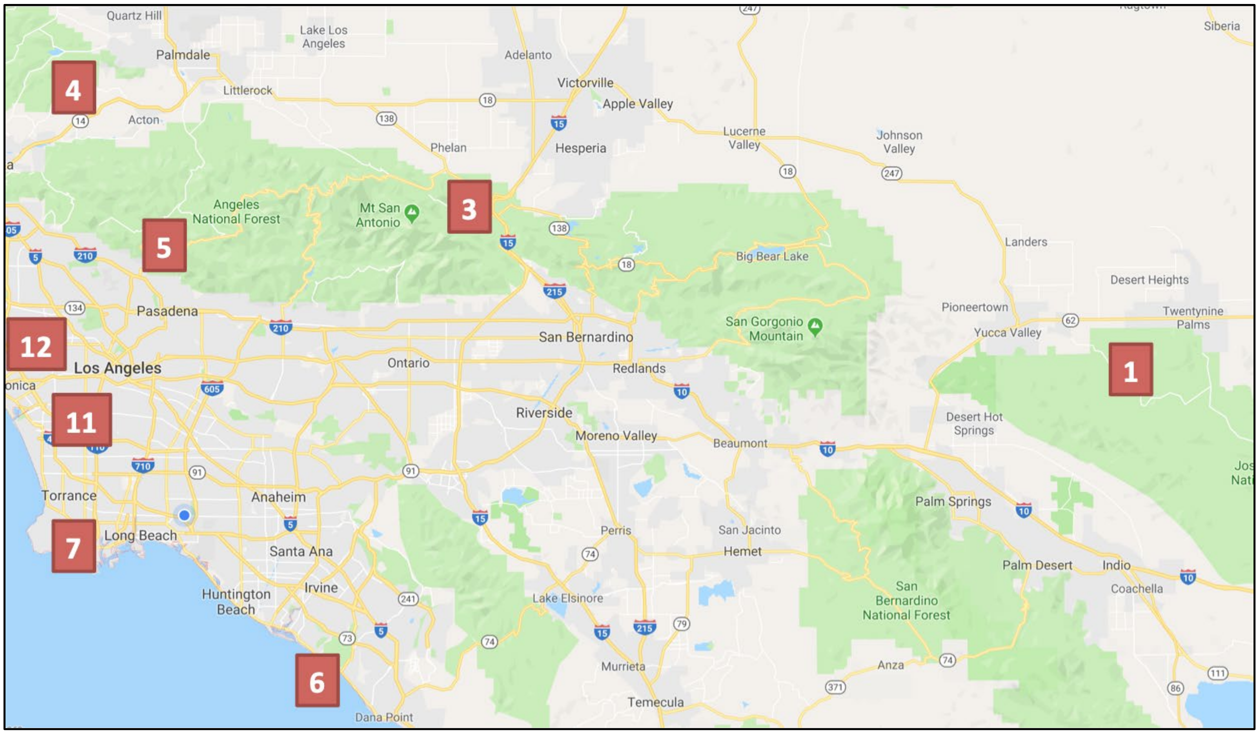
Each field trip locality includes a pre field trip assignment that could be used to help students prepare for the field trip curriculum. Suggested "Learning Objectives", also called student-learning outcomes (SLOs), are included to help provide a framework for instruction, while in-field activities and follow-up/post-field trip questions and assignments are offered to help students master the learning outcomes. You may want to require students to carry a "field book" in order to complete these exercises. Composition books, notepads, or even a stapled stack of papers on clipboard would all make for fine field books. Before embarking on a field trip, consider "copying-and-pasting" the learning objectives for that trip and distributing these to the participants ahead of time. Require your group to monitor your teaching to make sure you've addressed each one. I'm pretty sure your students will be motivated to police you ☺.

Each chapter includes most everything needed for an educational and fun half-day to multiday trip. However, the reader is encouraged to pick-and-choose from different itineraries to create a field trip experience best suited for them from a logistical standpoint and considering the academic background of their group.

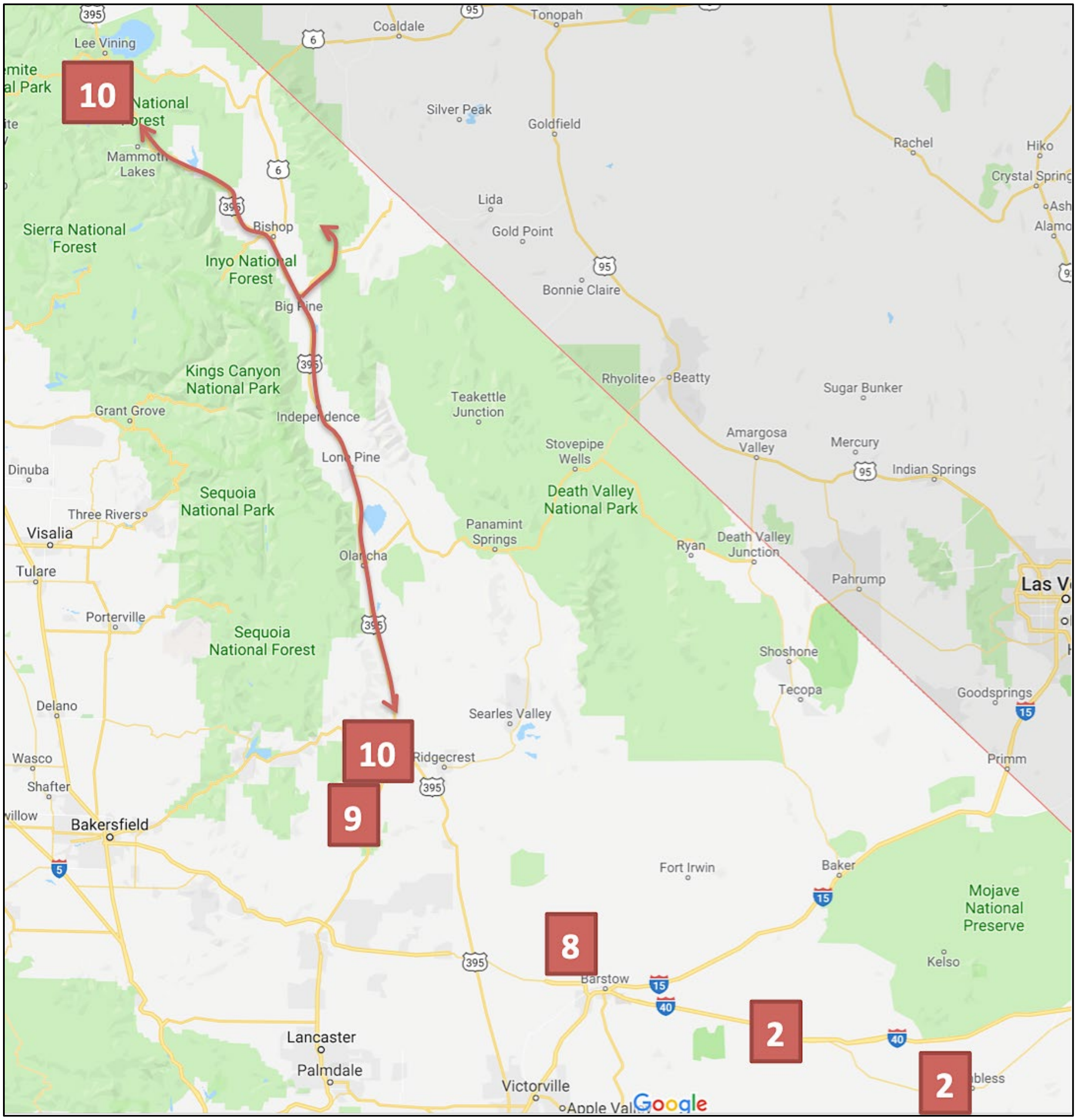
Accompanying the field trip destinations outside the greater LA area are suggested "en route talking points" that should serve to broaden the field trip experience by making use of some of "downtime" that comes with road trips. Note that these are written from the viewpoint of the author, departing from Cerritos College, which is located at the junction between CA-91 and I-605 in southeastern Los Angeles County. Consequently, it may be that some of the talking points will not relate to your route and/or you may have other places or stories that you wish to point out. In any case, southern California has a varied and fascinating geography with a complex and interesting human history that can be shared with students to make for a more intriguing and educational outing.

# Maps

See maps 1 and 2 for approximate locations.  Numbers on maps correspond to field trip chapters.




Field trip locations, map 1. – Modified Google Map.




Field trip locations, map 2.  Modified Google Map.

## Planning a Field Trip

To conduct an educational field trip consideration should be given to one or more of the following:

1. **Request**: You'll almost have to request your field trip, even if field trips are a required part of the course curriculum. The request should be a straightforward statement clarifying to the administration how the field trip experience will supplement instruction and help students better conceptualize or appreciate the curriculum. This paperwork will likely go to the intermediary between you and the academic Dean or Principal, such as an administrative secretary; you'll need to determine the standard practice at your particular institution. In either instance, the best approach is to submit field trip request paperwork early in the academic semester.
2. **Legal Paperwork**: You and the institution you represent must be legally protected in the unlikely event that a student is seriously injured, lost, or decides to take legal action for something that happened during a field trip. Consequently, your managing institution may legally require additional paperwork, such as a class roster, medical consent and hold harmless indemnification forms, and transportation requests if charter buses are needed. If students are driving themselves, additional documents may be necessary. Before departing, ensure all forms are submitted, and you've made copies to take with you on your trip.
3. **Academic Fee Waivers**: You may be able to apply for an academic fee waiver if your field trip destination requires an entrance fee, Joshua Tree National Park, for example. While meeting these requirements means a little extra work for you, it can result in significant cost savings for students and your academic institution. For example, the current fee at Joshua Tree National Park for a charter bus is $12 per person. That computes to $600 for a full bus! Always check ahead to determine if entrance costs can be reduced or eliminated. By doing so you are reducing costs, making it more likely that funding requests for transportation will be approved in the future. In any case, when visiting someplace for the first time, it's always wise to check their website and/or make some calls.
4. **Transportation**: Field trip localities will typically be accessed via personal vehicles or institution-supported transportation, like school vans or charter buses. The destination and logistics of the trip should dictate your choice; some pros and cons are discussed below.
    a. Personal vehicles. In this case, students are providing their own transportation. Ahead of the field trip, students should be arranged into carpooling groups and given clear instructions about logistics: departure time, driving directions, arrival time at destination, parking, parking fees, etc. This option won't cost your institution anything unless reimbursing students and may require less instructor paperwork. On the other hand, the costs are being transferred to students in the form of gas and mileage and possible parking fees. You're also asking students to drive themselves to an unfamiliar location, to which they may get lost along the way. Finally, campuses may not allow students to transport themselves, especially if the itinerary includes multiple stops. Check ahead of time and ensure your students complete the appropriate liability forms required by your institution.

b. School vans. Some colleges provide passenger vans or large SUVs to be used by the academic departments that utilize field trips for instruction. This efficient option consolidates students into a single vehicle, encouraging classmates bonding. Vans and SUVs also typically allow better access to hard-to-reach destinations, places that smaller cars and busses can't reach. However, it is paramount that responsible drivers are behind the wheels of each van, as the most significant hazard to and from any field trip will be safely navigating the sea of automobiles on our roadways. Again, check ahead of time and be sure to have your students complete the appropriate liability forms required by your school. Also, consider designating a student to be "on call" so communication can happen among vans.

c. Charter buses. Charter buses have two advantages in that everyone rides together, and the instructor is freed from the responsibility of driving. Consequently, the instructor can communicate with everyone in person, providing students with instructions, pre/post field lectures, and narration of exciting and noteworthy landmarks, "en route talking points" as the bus rolls along. The big drawback of the bus is its size, which can limit access to the places you want to take your group. All field trips outlined in this field trip guidebook are accessible by charter bus, except for Rainbow Basin. Hiring a bus should not be the responsibility of the instructor, so be sure to leave this process to the staff charged to do so. If you are tasked with hiring the bus, contact a local charter bus directly. In my experience, I've found charter bus companies to be relatively easy to work with and eager for your business. In any case, always make your expectations for the bus and drivers as straightforward as possible, including the following:
   - A working microphone – they frequently do not!
   - A working DVD player or wifi – media that compliments the field trip curriculum can help constructively fill up time for longer drives.
   - A request that the driver has food and water for the day – try to avoid, if at all possible, stops for food and water, as they are typically a huge time sink.
   - Finally, consider that your bus driver's skill can impact the quality of your field trip experience; some drivers are extraordinarily skilled, professional, and safe, while others may need help with directions, parking, and other logistics. Always be sure you know where you are going and what you will likely encounter along the way if your help is needed to get you and your students there and back again safely. I keep a log of my "favorite" drivers and request them by name.

5. **Logistics**: Executing safe, educational, and fun field trip experiences are more likely if planned from start to finish. This entails physically visiting the sites ahead of time, thinking about what your students will do before, during, and after the field trip, and, most importantly, identifying safety considerations. Throughout this guidebook, based on past experiences, I've addressed the most significant logistical and safety issues. Nevertheless, I strongly encourage a "walk-through" ahead of your first visit to any field trip destination, especially if you plan to reach the site via charter bus, to prepare yourself and the driver for any obstacles. Fortunately, many excellent destinations are reachable by a large charter bus. Unfortunately, some drivers may feel uncomfortable navigating a

tight parking lot or driving a rutted road. Still, your assurance that the destination is accessible can be a big boost to a driver's confidence.

6. **Safety and equipment**: Safety is critical for any field trip. Even a minor injury or illness can spoil the day, and students should be treated to a fun and educational experience. Hence, it is essential that they are made aware of potential hazards and that you monitor student behavior throughout the trip. As stated above, all drivers must consider safety first and may require your assistance so they may focus on transporting passengers safely. Always consider traffic when exiting vehicles, whether on a seemingly empty backcountry road or a parking lot. In my experience, students tend to exit buses as if stepping onto a deserted stretch of the Sahara, without any thoughts of traffic. Likewise, having students exit onto the shoulder of a roadway to examine the geology, biology, etc. will necessitate a reminder to stay out of the road – students tend to "float" out into the street, feeling perhaps an unrealistic "safety in numbers". Once you're safely in the field trip area, you are presented with a new host of hazards, including slip and fall, rattlesnakes, horseplay, dehydration, and exposure. To help mitigate these and other dangers, communicate with your students before, en route, and in the field. I always instruct students to bring at least a ½ gallon of water into the field and more if it's an extended visit. Be explicit! "Lots" of water to someone inexperienced with hiking is a 16 oz bottle of Arrowhead water. You will also find that many students really want to climb and explore: fantastic, but not on your field trip. Too many things can go wrong if you allow students to start "exploring", from a twisted ankle to getting lost or worse. I keep everyone together and limit climbing and exploring to what complements the learning objectives of the trip. I also try to keep my large groups as "small" as possible in order to reduce our physical imposition on others. I remind my students to walk single-file on trails and ask them to "gather round" as tightly as possible when at a lecture stop. This has the added benefit of making it easier for them to hear you and, in turn, be more engaged with the discussion. To help illustrate concepts and new vocabulary, bring a large drawing pad and markers of different colors. Finally, include a first-aid kit to treat minor injuries.
7. **Rules of Conduct**. Student safety must always be paramount regardless of the nature of a field trip. Making it clear beforehand, and again in the field, that reckless behaviors that are unacceptable will help ensure a safe trip and, at the same time, help students better focus on the main objective of the trip: learning curriculum in the field. Keep in mind that an academic field trip is just that, academic. You are conducting class outdoors, and you are in charge, period. Any student behavior that endangers themselves or others or negatively impacts the learning environment is unacceptable. Adopting this mentality will minimize misbehavior. When lecturing, I consider the field like an outdoor classroom: I wait until I have the attention of everyone before talking, then use classroom management strategies if there are disruptions during the lecture or learning activities. When walking from stop to stop, it's essential to keep everyone together and move reasonably briskly to minimize "tardies" at the next lecture stop. Similarly, I've also learned to become more tolerant and considerate of the fitness of my students. Frequently, there are a few students that genuinely have a difficult time keeping up with the group because of their lack of physical fitness. In these cases, I praise the students for making their efforts and encourage them to do their best but not to overdo it. Again, safety. Heat exhaustion (or worse) is a real possibility in southern California. While you

want your students to meet the learning objectives of the field trip, you also want them to remember the field trip as a positive experience.

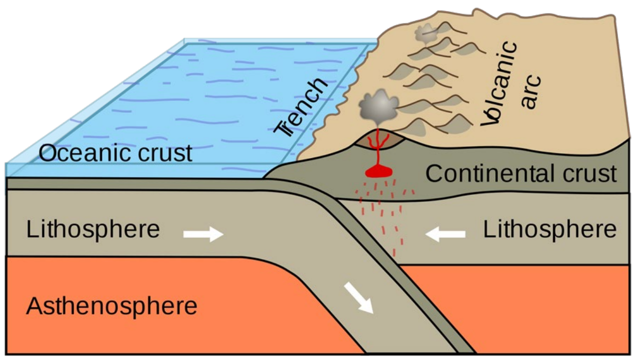
8. **Considering Accessibility**. Some students may have accessibility issues, such as being hearing impaired or having limited mobility. As their instructor, it is your responsibility to do all you can to help all students experience and meet the learning objectives of the field trip. I think a good practice is communicating with students with accessibility issues ahead of time to determine what they need and then doing all that is reasonable to accommodate their needs. For example, if they are hearing impaired, be sure to invite their sign language interpreters or if a student is in a wheelchair, consider how you can modify the field trip so that they may learn and enjoy along with their classmates. In my experience, so long as you try to get on the same page as the student(s) and make them feel that you are doing all you can for them, they will appreciate the efforts and have a positive experience.

## The Big Picture: Overview of the Geology of Southern California

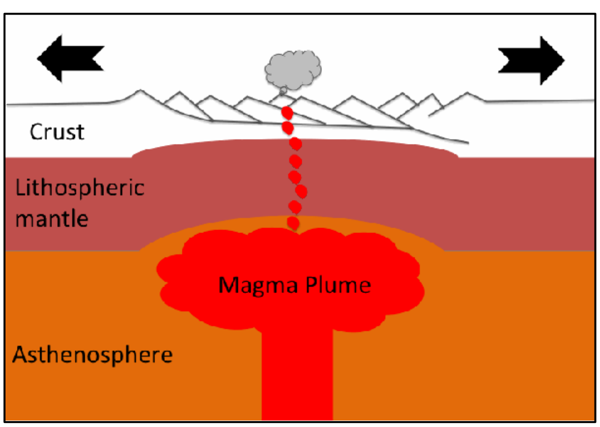
The landscape of southern California represents one of the most geologically diverse places on Earth. The varied terrain of prominent mountains, wide basins, rolling hills, deserts, and coastal plains results from a complex geologic history spanning nearly 2 billion years. Constructive geologic processes like plate tectonics have built tall mountain ranges and generated volcanic activity. In contrast, destructive geologic processes like mass wasting and erosion from rivers, wind, and waves have acted to wear down and shape the landscape.

### Very Brief Geology Lesson

The process of plate tectonics drives constructive geologic processes. The Theory of Plate Tectonics describes how Earth's outermost layer of rock, the lithosphere, is broken into individual slabs called plates. Ocean crust, continental crust, or a combination of both makes up the upper portion of a plate. The plates are slowly moving and interacting with one another along plate boundaries, resulting in constructive geologic processes, such as volcanism and mountain building. The compressional stresses crumple the crust, like pushing a rug into a wall, causing the folding and faulting of the crust, and building up mountains. Subduction occurs when one, or both, of the colliding plates, is capped by ocean crust. During this process, the oceanic plate sinks into the mantle, destroying the ocean crust while at the same time producing magma that rises to Earth's surface to construct volcanoes, ultimately making new rock and landforms.



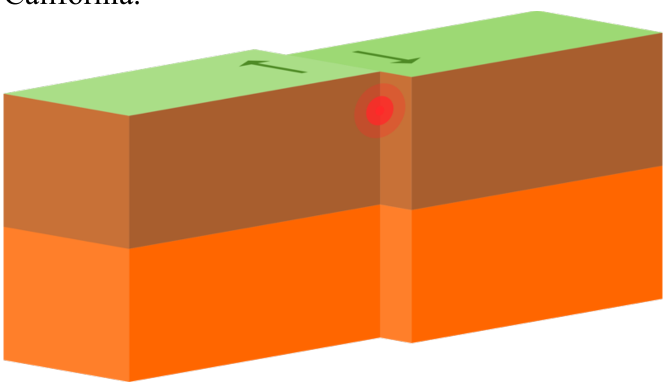
Convergent plate boundary between an oceanic plate and continental plate. From Creative Commons (CC).



Tensional stresses initiating a divergent boundary within continental crust.

Constructive geologic processes can also happen where tensional stresses pull plates apart along divergent plate boundaries. On the ocean floor, divergent boundaries generate magma that rises to the ocean floor, creating volcanoes and solidifying into new rock, making new ocean crust. When tensional stresses stretch the continental crust, it fractures through continental rifting. Blocks of crust slide down along fractures (faults) making valleys, while blocks of crust on the opposite side of faults move upward to produce mountains.

Plates can also slide horizontally past each other along a transform plate boundary, causing shearing stresses that fracture the crust, creating earthquake faults, like the San Andreas fault, in California.



**Transform plate boundary. –CC**

Destructive geologic processes oppose the constructive geologic processes; Earth's destructive geologic processes, weathering, mass wasting, and erosion act to weaken rock and wear-down landforms. For example, the erosive action of the Colorado River removing rock at a rate of about 1.5 inches per 100 years over the past four million years has resulted in carving out a canyon over a mile deep and up to 15 miles wide, the Grand Canyon. The "look" or topography of the landscape in any given place is a consequence of constructive vs. destructive geologic processes.

## A Similarly Brief Geologic History of Southern California

Southern California is home to the oldest rocks in California, about 1.8 billion years old (Norris, R., Webb, R. 1990). These are in the San Gabriel and San Bernardino mountains and the Mojave desert. While the origin of these rocks isn't certain due to their highly altered state, they probably represent part of the ancient core of the North American continent or are chunks of crust plastered onto the continent's side by plate tectonic activity. From about a billion years to around 200 million years ago, the western margin of North America was very much like the geologically passive margin along today's east coast. The continental shelf (shallow sea) stretched far out to the west from a shoreline that today would be situated in the Midwest. From the continental highlands to the east, sediment was eroded and deposited onto the continental margin, where it accumulated as stratigraphic layers tens of thousands of feet thick. The best display of this long-term cycle of erosion and deposition are strata (layers of sedimentary rock) making up the walls of the Grand Canyon. In southern California, these rocks have altered into metamorphic rocks.

Starting around 200 million years ago, the long slumbering western half of North America geologically woke up when the ocean crust along the western margin of the continent began to

subduct beneath the continent. This event made a new plate boundary between the subducting, oceanic Farallon Plate and the overriding, continental North American Plate.
Subduction continued for about 150 million years, generating magma that rose to Earth's surface to build up a line of volcanoes running south to north through California, just like the modern-day Cascade Range that starts in northern California and extends northward through Oregon and Washington. The magma that solidified within the crust is today exposed as granite and granite-like rocks that make up the core of California's major mountain ranges: the Sierra Nevada Mountains, the Transverse Ranges, and the Peninsular Ranges.

Subduction in southern California ended about 23 million years ago when the plate boundary between the ocean and continental crust began to change from a convergent to a transform plate boundary (Sylvester and Gans, 2016), now known as the San Andreas fault. As the type of plate boundary changed, so did the geologic processes shaping the crust. Magma stopped being generated, so volcanoes went extinct. The crust was twisted and fractured. Blocks of crust rotated and uplifted as shear stresses deformed the crust, resulting in the squeezing up of blocks to make mountains and hills, while in other places, the crust has dropped down to form basins (broad valleys).

Starting 16 million years ago, western North America was subjected to continental rifting as tensional stresses significantly stretched the crust, making normal faults along which blocks of crust slid to form deep basins bracketed by tall mountains. This region of stretched crust extends from the eastern front of the Sierra Nevada Mountains in California, to western Utah, and includes mountains over 13,000 feet tall and deep basins, including the lowest spot in the western hemisphere, Death Valley in southern California. Concurrently, the northward movement of the Pacific Plate peeled a block of crust away from the North American plate, eventually causing it to rotate about 110o clockwise (Sylvester and Gans, 2016). Today, this "captured" block of crust is known as the Western Transverse (crosswise) Ranges. It includes the Santa Ynez in the Santa Barbara region and the Santa Monica Mountains west of Hollywood. See this excellent animation by Tanya Atwater for a video summary of this extraordinary event. Tensional stresses related to the rotation caused subsidence of crust as well, creating what is now the Los Angeles Basin.

In the early stages of the rotation event, lava rose along faults to fill gaps caused by the extension; some of this lava is today exposed in the greater Los Angeles area as volcanic rocks. As the rotation of the Transverse Ranges continued, they were also moving northward with the Pacific Plate, leading to more stretching and subsidence. Around 5 million years ago, the plate boundary, the San Andreas fault, jumped eastward. With this new orientation, movement along the fault resulted in localized compressional stresses, causing the uplift of the modern-day Transverse Ranges, including the San Gabriel and San Bernardino mountains. Sediment eroded from the growing mountains filled the Los Angeles Basin, which was deep under seawater then. In just the past 1 million years, the basin has filled to above sea level; this geologically mighty feat required a massive volume of sediment, as estimates put the bottom of the pile at 30,000 feet deep in some places.

## Geologic Time Scale

The Geologic Time Scale the widely accepted system used to arrange the significant geologic and biologic events of Earth. Terms from the Geologic Time Scale are used throughout this guidebook.

| Eon | Era | Period | Epoch | MYA |
|---|---|---|---|---|
| Phanerozoic | Cenozoic | Quaternary | Holocene | 0.01 |
| | | | Pleistocene | 2.6 |
| | | Tertiary – Neogene | Pliocene | 5.3 |
| | | | Miocene | 23.0 |
| | | Tertiary – Paleogene | Oligocene | 33.9 |
| | | | Eocene | 56.0 |
| | | | Paleocene | 66.0 |
| | Mesozoic | Cretaceous | | 145.0 |
| | | Jurassic | | 201.3 |
| | | Triassic | | 252.2 |
| | Paleozoic | Permian | | 298.9 |
| | | Pennsylvanian | | 323.2 |
| | | Mississippian | | 358.9 |
| | | Devonian | | 419.2 |
| | | Silurian | | 443.4 |
| | | Ordovician | | 485.4 |
| | | Cambrian | | 541.0 |
| Proterozoic | Precambrian | | | 2500 |
| Archean | | | | 4000 |
| Hadean | | | | 4600 |

**Geologic Time Scale. –CC**

# Chapter 1 – Joshua Tree National Park

## Introduction


Joshua Tree

Joshua Tree National Park (JTree) is situated within the Little San Bernardino Mountains at the easternmost extent of the Transverse Mountain Range. Lying in the rain shadow of the San Jacinto and San Bernardino Mountains, JTree contains parts of two deserts, the Mojave and Colorado. *Yucca brevifolia*, a.k.a. Joshua tree, roughly delineates the Mojave Desert in the northern part of the park from the Colorado Desert to the south. It is an excellent destination for observing intrusive igneous rocks, like granite, common rock-forming minerals, metamorphic rock (gneiss), the effects of weathering on rock, intrusive structures like veins, the San Andreas fault, common desert landforms, including inselbergs and alluvial fans, desert ecology, and historic mining operations. It's also unlike any landscape most students have seen; this eye-opening experience is reason enough to expose young minds to Los Angeles's closest National Park.

When planning your trip consider the season and weather. It can be dangerously warm during the summer, early fall, and late spring, and can be surprisingly cold during the winter. Plan your visit for the late fall, winter, or early spring months to enjoy comfortable temperatures and blue skies. However, this is also the peak season for visitors, so arrive early if you visit on a weekend.

## Human History

JTree was first inhabited by Native Americans 7000-5000 years ago, based on artifacts found in the Pinto Basin area. More recently, ancestors of the Cahuilla, Chemehuevi, and Serrano people occupied other parts of the park, including the Oasis of Mara, which later became a popular stopover for miners working in the area due to the freshwater source. Mining operations in the park have produced millions of dollars in gold and silver. Coincident with mining was cattle raising due to the relative abundance of grassy meadows found in the park when the region was more relaxed and wetter just 150 years ago. In the early part of the 20th Century, the park's natural beauty drew in visitors, many of whom found the warm, dry air therapeutic. However, with more people came a more significant impact on the environment, prompting the protection efforts that led to the establishment of Joshua Tree National Monument in 1936 and then JTree in 1994.

## Geology

Two rock types constitute most of the JTree landscape, granite and gneiss. Technically, the "granite" in JTree does not fully meet the chemical criteria for granite, which is quite specific. Nevertheless, it will be called granite for the sake of simplicity. The granite is comparable to the rock of the Sierra Nevada and Peninsular mountain ranges, having formed through subduction of

the Farallon plate as the North American continent broke free of Pangea and moved westward. The Pacific plate is now situated where the Farallon plate once was.
In contrast, the distribution of the gneiss is not as widespread and is more local to the JTree region. It is the byproduct of the metamorphism of ancient sediments through the collision of ancient continents some 1.7 billion years ago.

The granite that provides the backdrop for many of the points of interest in the park is an assemblage of several separate masses of solidified magma, known as **batholiths**. Each batholith formed at different times with different chemistries; therefore, each has distinctive mineral compositions and weathering characteristics. Consequently, these distinct granitic bodies vary in appearance and are given different names, including Palms granite, White Tank monzogranite, Twentynine Palms quartz monzonite, and Queen Mountain monzogranite. At a distance, these granitic bodies appear buff to tan to brown as they weather into **inselbergs** and boulder piles. With some training, the eye can distinguish between the different batholiths. Upon closer inspection, one can observe the mineral crystals of quartz, plagioclase and orthoclase feldspar, and biotite and muscovite mica that constitute granite. In Rattlesnake Canyon, at the southeast end of the Indian Cove campground, the granite contains impressive "megacrysts" of feldspar: blocky crystals several inches across. Visiting this area is not part of this chapter's itinerary but is a worthwhile side trip if you have enough time in your day.

## Spheroidal Weathering

Weathering is the action of rock physically and chemically weakening and breaking down at or near Earth's surface. One of the main reasons millions visit JTree each year is its uniquely beautiful landscape, one that contains numerous isolated rounded hills that are surrounded by boulders of granite. Many of these hills qualify as **inselbergs**, the bedrock remnants of mountains, which have been weathered and eroded down to resistant, boulder-mantled knobs rising above the desert plain; aptly been described as "highly eroded mountains drowning in their own debris".

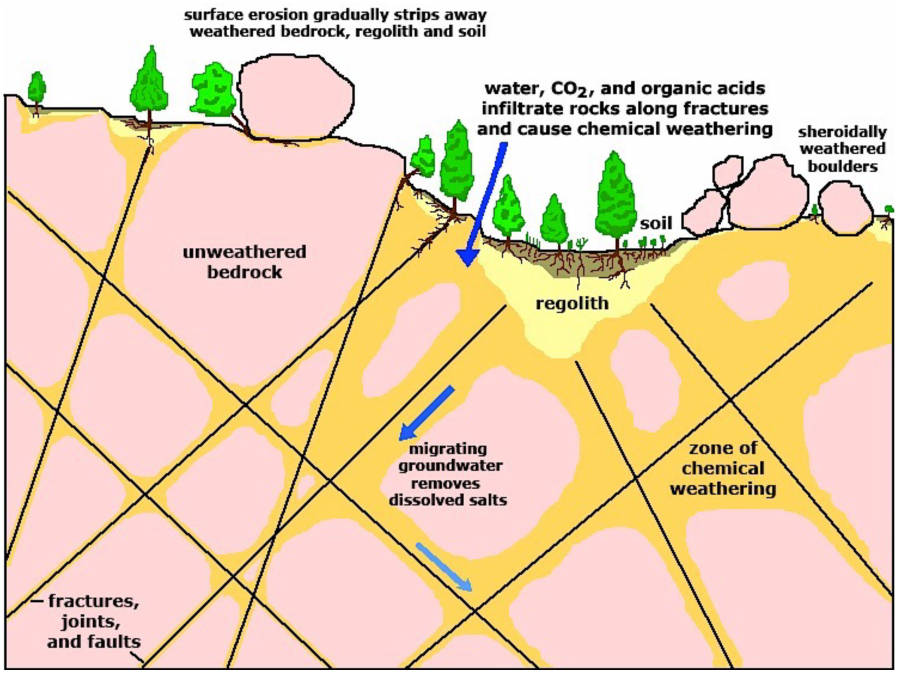
Inselberg.

### *Forming Inselbergs*

1. Before reaching Earth's surface, stresses acting on a batholith cause joints or sets of roughly parallel fractures oriented in different planes. These intersecting fractures can disect the body of rock into cubic blocks.
2. The granite is brought close to Earth's surface through tectonic uplift and erosion.
3. Acidic water infiltrating from Earth's surface flows down and along with the

Joints in granite. – CC.

fractures, chemically reacting with feldspar in the granite, changing it into clay.



Rock undergoing spheroidal weathering. –CC

4. Because the fracture pattern created cube-like blocks of granite, the corners of the cubes are preferentially w Because the fracture pattern created cube-like blocks of granite, the corners of the cubes are preferentially weathered faster than the rest of the block – just like sucking on an ice cube will result in the cube becoming rounded – and the cubes of granite become more spherical.
5. Once erosion exposes granite on Earth's surface, the clay is easily washed away, leaving behind rounded hills and cliffs of granite. The stripping away of clay and loose mineral grains is particularly effective when warming and drying climates reduce the density of vegetation, leaving soil and weathered rock more prone to water erosion.


Cliffs of rounded and fractured granite bedrock.

## Learning Objectives

Through participation in this field trip students should be able to:

1. Name the type, and the specific name of the plate boundary crossed to get to JTree
2. Identify phaneritic (coarse-grained) igneous rock texture in the field
3. Identify granite in the field
4. Identify common igneous minerals in rock samples in the field
5. Describe the role played by subduction in forming granite
6. Identify foliation and metamorphic rocks in the field
7. Distinguish between igneous and metamorphic rocks in the field
8. Identify spheroidal weathering in the field
9. Explain the process of spheroidal weathering and how it contributes to the look of the JTree landscape
10. Identify veins and explain how and when they form
11. Use linear landforms, such as the Indio Hills, to locate faults, like the San Andreas
12. Identify a roof pendent and explain or illustrate the structural relationship to the batholith
13. Identify common desert landforms, including *inselbergs*, *alluvial fans*, and *pediments*
14. Describe the climate and geography of JTree and briefly discuss how the climate has changed over time
15. Identify a "soil notch" in the field and briefly explain its significance

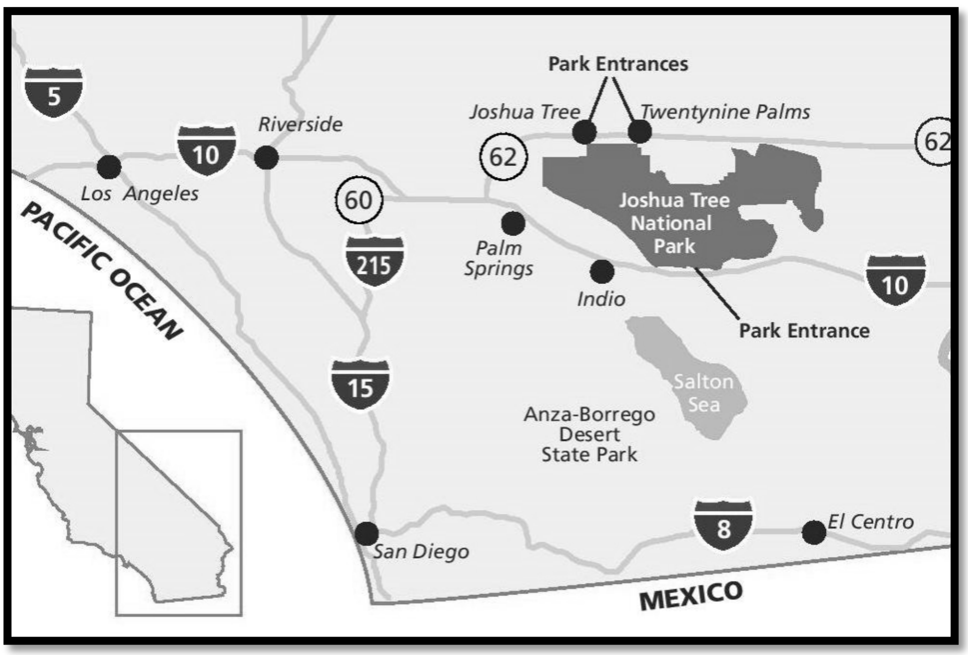
## Key Vocabulary

- **Alluvial Fan** – a fan-shaped pile of sediment that was deposited intermittently by flash floods/debris flows at the mouth of a mountain canyon
- **Batholith** – a very large mass of crystalized magma; often granitic
- **Bedrock** – solid rock of the crust that makes up the geologic foundation of most landforms
- **Gneiss** – metamorphic rock with dinstinctive wavy bands of lighter and darker minerals
- **Granite** – intrusive igneous rock, rich in silica and potassium, light-colored
- **Inselberg** – "rock islands" that are bedrock remnants of prehistoric mountains
- **Joints** – sets of fractures in the bedrock
- **Pediment** – gently sloping surfaces of bedrock leading up to the base of desert mountains or inselbergs
- **Pinto Gneiss** – metamorphic rock unit representing the oldest rock exposed in the park
- **Roof Pendent** – a geologically older bedrock body of rock "capping" a relatively younger intrusive igneous rock unit
- **Soil Notch** – eroded "dents" or "hollows" in granite outcrops
- **Spheroidal Weathering** – chemical weathering process that develops in the subsurface along joints, resulting in creating spherical boulders that are later exposed on Earth's surface
- **Vein** – relatively thin, tabular bodies of minerals cutting across masses of bedrock
- **Palms Granite/White Tank Monzogranite** – granitic unit that makes up the most easily observable landscape of JTree

## Pre Field Trip Questions

1. Click on the following link then answer the questions after watching the video. Note that the video has no audio: geology overview of JTree.
    a. What plate tectonic process was needed to make the rocks of JTree?
    b. What type of rock makes up the landscape of JTree (igneous/sedimentary/metamorphic)?
2. Read the article found through the following link and answer the questions below: discussion about deserts.
    a. Describe why JTree is situated in a desert. What type of desert is this?
3. Read the section on "Fracturing" found through the following link then answer the question below: textbook description about fracturing and faulting.
    a. Define what a joint in rock is and describe, in your own words, how joints form.

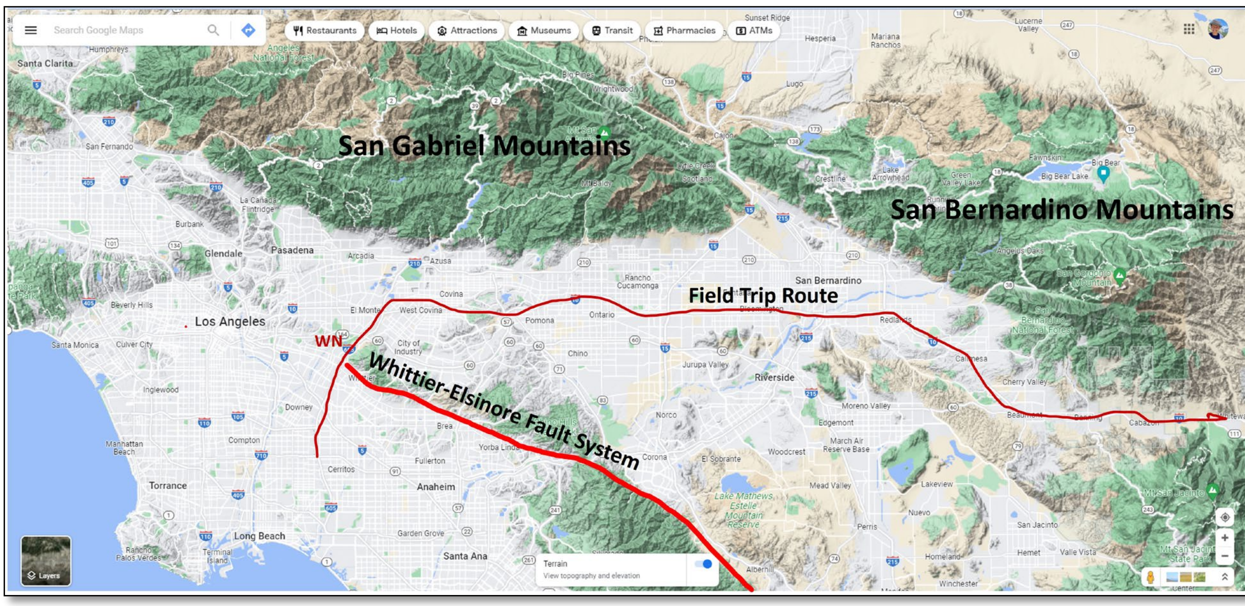
## En Route Talking Points: Cerritos College, I-605 north, I-10 east, CA-62




**Location of Joshua Tree National Park. –CC**

- I-605 north
    - The 605 trends north-south across the eastern Los Angeles Basin. This incredibly deep basin formed from roughly 16 million to about 1 million years ago as tectonic forces slowly peeled the Transverse Ranges away from the Peninsular Ranges, rifting open a series of basins. The sea flooded these pits as they slowly opened, meaning what is today the metropolis of Los Angeles and Orange counties were once at the bottom of the Pacific Ocean. All the while, sediment being eroded from the continental highlands filled these depressions with silt, sand, and gravel, up to 6 miles in thickness.
    - San Gabriel River
        - The San Gabriel River Freeway (formal name for I-605)
            - Follows a path of least resistance from river erosion
            - River erosion creates natural pathways

        - Pathways become footpaths
        - Footpaths become horse trails
        - Horse trails become thoroughfares
        - Thoroughfares become highways
    - The San Gabriel River transports sediment from the San Gabriel mountains to its base level, the Pacific Ocean
- Whittier Narrows water gap (WN). The San Gabriel River and Rio Hondo River, just to the west, have created the Whittier Narrows by eroding faster downward than the hills have been uplifted, resulting in carving a topographic saddle, a "water gap", 2 miles wide and 800 feet deep, bisecting the Puente Hills into 2 parts: the Montebello Hills to the west and Whittier Hills to the east. For a more detailed description read the excellent discussion in *Geology Underfoot in Southern California,* "Vignette 9 – A Boon to Communication, The Whittier Narrows"
    - Similarly, Santa Ana River erosion has created water gaps through hills that are now occupied by the 91 and 57 freeways



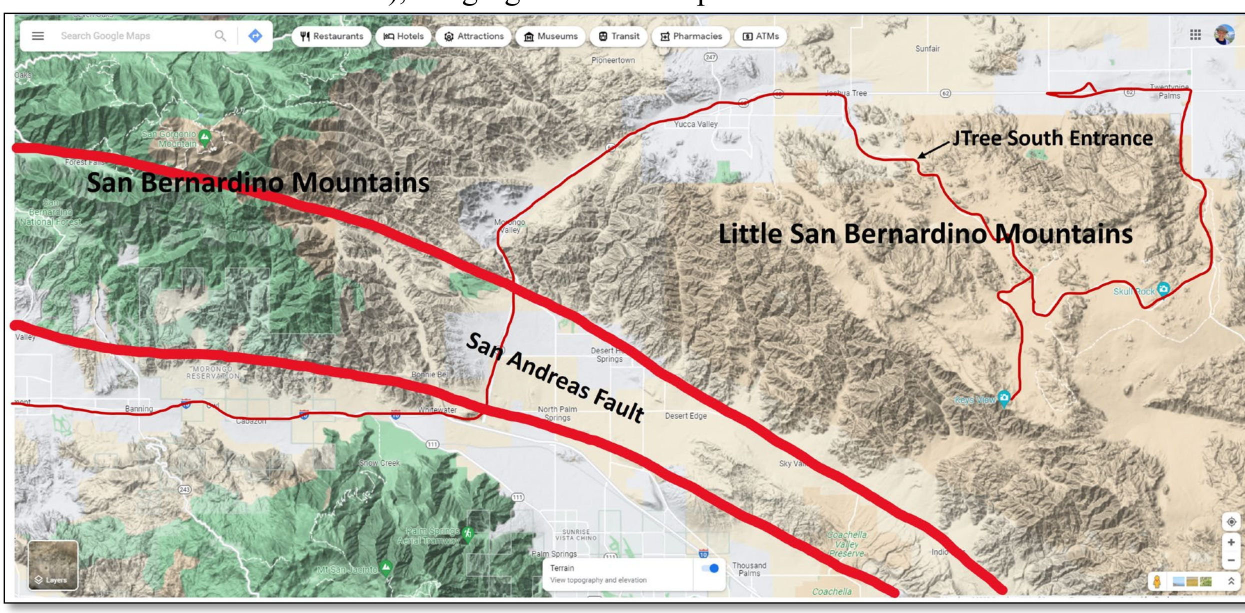

**Route Map and Landmarks**

- Whittier and Puente Hills (east of the 605) are being actively uplifted along the Whittier fault. It runs along the southern base of the hills and is part of the Elsinore fault system. It is very much active, as evidenced by the recent Whittier (1987, M 5.9), Chino Hills (2008, M 5.5), and La Habra (2014, M 5.1) earthquakes.
- Montebello (Repetto) Hills (west of the 605)
    - Western extension of Puente Hills
    - Like Puente Hills, the Montebello Hills are made up of steeply tilted, south-dipping sedimentary rock that is typical of sediment in the LA Basin: mudstone, siltstone, sandstone, and conglomerate
- On a clear day point out the San Gabriel Mountains making up the northern skyline and its highest peak, the 10,064 feet tall Mt San Antonio, a.k.a. Mt Baldy.

- Eastbound on I-10
  - "The 10" takes advantage of the San Gorgonio Pass, 1 of 3 topographic passes through the mountains surrounding the greater Los Angeles area, the other two being the Tejon and Cajon passes, utilized by I-5 and I-15, respectively.
  - Just east of Azuza Ave. the hills (San Jose Hills) buttressing the north side of I-10 are partly composed of lava flows know as the "Glendora volcanics"
    - ~16 million years old
    - Volcanic eruptions were triggered by the rifting that formed the Los Angeles Basin
    - Exposed as olive brown rock, as opposed to buff-orange rock exposed in preceding hills
  - Slover Mountain, approximately 2 miles west of the 91 interchange was originally a 700 feet high mountain of marble that has been quarried for cement
    - Colton Cement quarry, now known as CalPortland at base of Slover Mountain is the oldest cement works west of the Rocky Mountains has provided the cement needed to make such structures as Los Angeles City Hall, the Memorial Coliseum, the Bonaventure Hotel in downtown LA, and the Hoover Dam.
  - Santa Ana River at I-10/215 interchange
    - Largest river in Los Angeles region
    - Tributaries bring water from San Gabriel, San Bernardino, San Jacinto, and Santa Ana mountains
    - Mouth of the river divides Huntington Beach from Newport Beach
  - I-10/CA-111 junction – look south for alluvial fans along the base of San Jacintos
  - San Gorgonio Pass
    - Whitewater rest stop (just after I-10/CA-111)
      - Bathroom break
      - Overview of the Transverse Mountain Ranges
        - Whitewater is situated at the base of the San Bernardino Mountains, near the eastern end of the Transverse Mountains
        - A unique mountain range in that they are one of the only east-west oriented mountain ranges in the western hemisphere, going against the grain of the other mountain ranges in California, which all trend roughly north-south
        - Joshua Tree National Park contains the easternmost extent of this prominent mountain range, the Little San Bernardino Mountains
        - The San Bernardino and Little San Bernardino Mountains have been growing intermittently for about 9 million years, with recent earthquakes indicating that they continue to be uplifted along local faults
        - The San Andreas fault delineates the southern margin of the mountains
  - San Gorgonio Pass – from Cabazon (Morongo Casino) to North Palm Springs

- This valley between the two tallest mountains in southern California, San Gorgonio (11,503 feet) to the north and San Jacinto (10,834 feet) to the south, is one of three passes through the mountains surrounding the greater L.A. area, the other two being the Cajon and Tejon, for the 15 and 5 freeways, respectively.
- This topographic passageway also creates a wind tunnel for air rushing in from the Pacific to fill in an area of atmospheric low pressure that develop over the desert. As this air squeezes through the pass, it speeds up, resulting in one of the windiest places in California. Consequently, this area was chosen for the San Gorgonio Pass Wind Farm. Note wind turbines as you continue your journey to CA-62 north.

- CA-62, Twentynine Palms Highway
    - Leaving I-10, you'll proceed nearly 7 miles across the alluvial deposits from the San Bernardino Mountains before reaching the base of the Little San Bernardino Mountains. Over this stretch of the 62 you cross the plate boundary between the Pacific and North American plates, as defined by two branches of the San Andreas fault, the Banning fault and Mission Creek fault, crossed at mile markers PM 1.6 and PM 6.6, respectively. CA-62 ascends steeply through a deep gash in the mountain front where foliated, dark to light colored rock frame the highway on either side. This rock is Proterozoic migmatite (Trent, personal communication), a high-grade metamorphic rock.




**Route Map and Field Trip Location**

- The Morongo Canyon Preserve, about 11 miles after leaving the I-10, offers a nice opportunity to mix some biology into your field trip. Desert plants, birds, and mammal tracks can be studied via a well-designed and thoughtfully shady boardwalk trail system. There are also instructional displays, maps, and handouts to enhance the learning experience.

- Descending into the community of Yucca Valley, consider that the highway runs roughly parallel to the Pinto Mountain Fault. This left-lateral fault facilitates some of the uplift of the Little San Bernardino Mountains and Joshua Tree NP.

## Directions into JTree

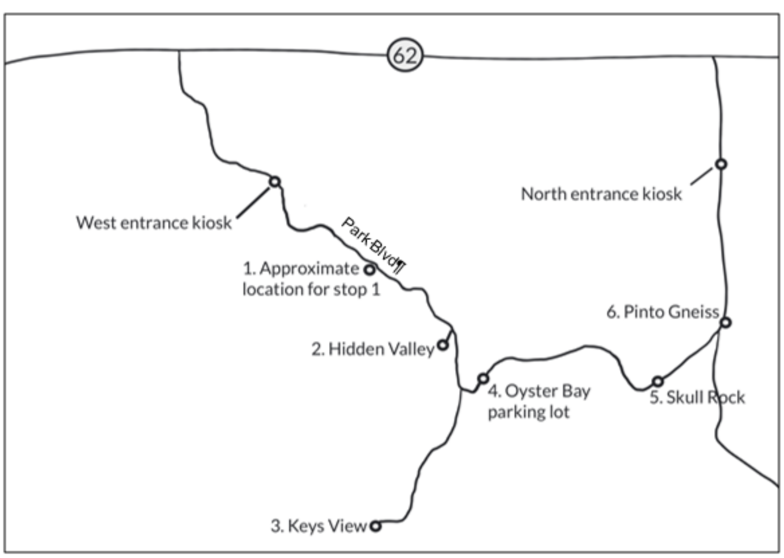
The park can be accessed from CA-62 using the West entrance, by turning south on Park Blvd from the arty community of Joshua Tree, or via the North entrance, from Twentynine Palms, by turning south onto Utah Trail road, which is 16 miles east of Park Blvd. While the west entry is more picturesque, the northern entrance will likely be less crowded and has a larger visitor center with more restrooms. In either case, arrive as early as possible and be prepared for a line of cars at the entrance kiosk, especially on the weekends. You will need to present your academic fee waiver for free entrance and be sure to request park brochures to help you and your students navigate. Alternatively, one can access JTree from the south by exiting I-10 at Cottonwood Springs Road/Box Canyon Road and driving north to the South entrance. This route is not recommended because it demands the longest drive time (from the greater LA area) and is furthest from the stops outlined in this chapter.

## Field Trip Stops

All stops listed in this chapter are accessible by large charter bus, van, or 2-wheel drive car, and written as if entering the park from the West entrance.  "Zero" odometer at West entrance Kiosk, to use mileages listed (note, some mileages may refer to other starting points).

*Activity 1: As you wait to enter the park at the West entrance kiosk, instruct students to interpret the landscape as you wind your way through the park. Specifically, you may ask them to identify the different rock types making up the landscape (granites and gneiss) and desert landforms, like inselbergs.*

*Activity 2: Help students develop map skills by having them locate and label each field trip stop on a JTree National Park map, #1, #2, etc. (Maps can be requested at Kiosk, visitors center, or through the NPS website: [Joshua Tree brochure map]()*




**Cartoon map of Joshua Tree National Park. Numbered stops shown.**

## Stop 1 – Inselberg and Introduction to JTree

Addresses learning objectives:
13. Identify common desert landforms, including *inselbergs*, *alluvial fans*, and *pediment*
14. Describe the climate and geography of JTree and briefly discuss how the climate has changed over time

Roughly 3.5 miles from the West entrance kiosk, park on the road shoulder where it is safe to observe an excellent example of an inselberg off to the right (west). Note how loose boulders rest on the flanks and around the base, earning these landforms the nickname, *boulder pile mountains*. Behind the inselberg, off in the distance, you may notice the darker rock making up the relatively smoother slopes of the mountains. The lighter rock of the inselberg and slopes across the road are made of the 75 million-year-old Palms granite, while the darker rock is *just a bit* older: 1.7 billion years old Pinot Gneiss *(Trent, et. al., 2015)*. These are some of the oldest rocks in the western United States.

If you couldn't park at 3.5 miles in, look for parking at other road-shoulder pullouts or the Quail Springs picnic area, Boy Scout Trailhead, or Hemmingway parking lots. In any event, try to find a good spot to "set the scene" for the day, where you can also discuss:

- The geographic location of JTree
- Explanation of the rain shadow effect
- The human history of JTree
- Timing of protecting this area as a National Monument and National Park; *why* protection is needed
- Define and discuss the formation of inselbergs

## Stop 2 - Hidden Valley

Addresses learning objectives:
2. Identify phaneritic (coarse-grained) igneous rock texture in the field
3. Identify granite in the field
4. Identify common igneous minerals in rock samples in the field
5. Describe the role subduction plays in forming granite

Some logistical considerations:

- Commit 1-1.5 hours.
- There may not be space for the bus (if you've arrived by charter bus) to park. If so, ask the driver to drop off the group then return at a designated time (cell phone service may not work).
- Remind students to bring the necessary gear (water, note-taking materials, etc.) and to watch for cars while exiting the bus and crossing parking lot.
- Direct students to a meeting point – I recommend the 3rd picnic table, about 200 feet south of the Hidden Valley trailhead. This area makes for a convenient natural classroom, where one can conduct an in-field lecture and student activity.
- There are 2 bathrooms – ones just north of the trailhead and another south of the picnic table classroom mentioned above.

*Activity 3 – Organize students into 2-3 person field teams and ask them to sketch a small, maybe 6"x 6" inch section of one of the boulder outcrops (I use this area, ~100 yards south of the trailhead) and to label the common granite forming minerals: quartz, feldspar(s), and biotite mica. If possible, bring along some hand lenses or magnifying glasses – 1 per team works well.*

Once the lecture and field exercise is complete, collect the magnifiers and head up the trail into the hidden "valley". If you wish to add a little cultural flavor to the hike, discuss how this area came to earn its name:

- When white men first settled in the region of JTree, it was wetter and cooler than today and grassy meadows blanketed the valleys, making them well-suited for grazing livestock. In fact, the grass was described by an Army officer in 1852 as being "belly-high to a horse". Along with the livestock came cattle rustlers who discovered that the cliffs surrounding what is now the Hidden Valley trail offered an excellent hiding place for their stolen livestock, and so it came to be known as the "hidden valley".

For a virtual field trip experience, watch this video, from 1:37 to 4:33, shot by The Table along the Hidden Valley loop trail.
Once up the short switchback section and into Hidden Valley proper, head left and clockwise around the trail. Depending on your time constraints and depth of curriculum, there are many talking points along the trail, but two are particularly beneficial for teaching about spheroidal weathering. The first is about ¼ mile along the trail, just before the first moderately steep downhill section and just after a section bracketed by two cliffs; here, located around 34°00'51.3"N 116°10'21.6"W, one can observe a partially "sphered" block of granite. The second recommended lecture stop could be somewhere along the northern section of the trail (where it begins to climb gently uphill); the south-facing cliffs of granite exhibit the jointing needed for spheroidal weathering to happen**.**

Partially sphered block of granite.

I find that just the walk alone, allowing students to soak up their surroundings, is enough to have them buzzing and talking about coming back with their family, significant others, etc. To tailor the walk to your students, I'd encourage you to visit before your first field trip and note spots that would best enhance your course curriculum.

### Stop 3 – Keys View and the San Andreas Fault

Addresses learning objectives:
1. Name the type and specific name of the plate boundary crossed to get to JTree
11. Use linear landforms, like the Indio Hills to locate faults, like the San Andreas

Logistical notes:

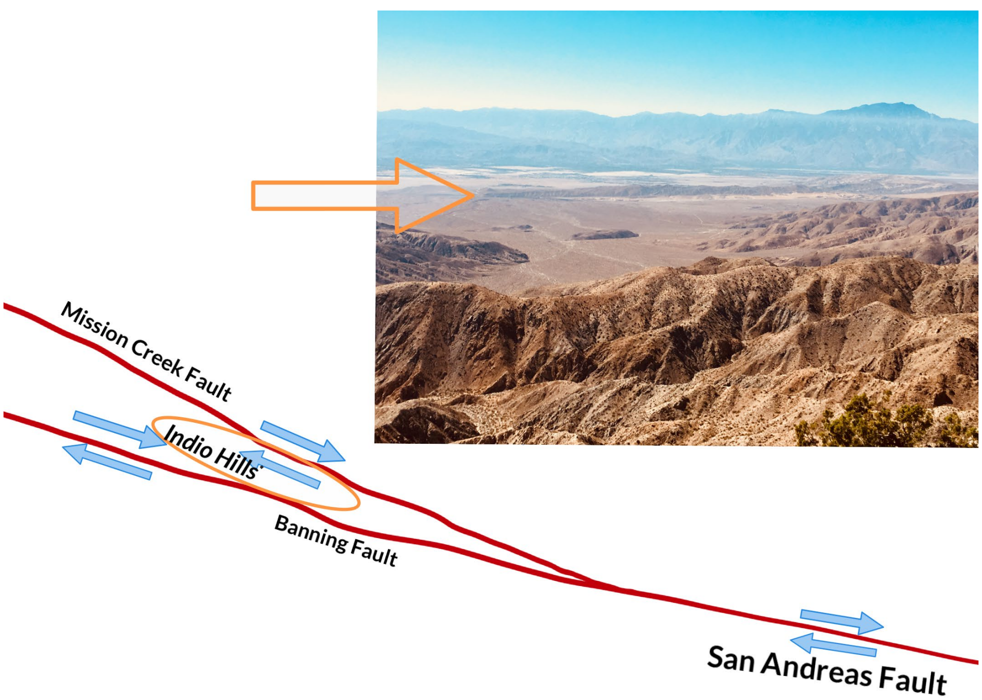
- Accessible by any vehicle, with parking typically available
- There is a bathroom at the bottom of the parking lot

- Remind students to not leave any trash behind and to look both ways when exiting vehicles

Although it lacks designated picnic areas, Key's View makes an excellent lunch spot at the end of Key's View Road. Even with larger groups, there is plenty of room to spread out and enjoy the impressive vistas while enjoying lunch. After lunch, students can be directed to meet at the top of the hill along the south side of the parking lot, this is Key's View. From Key's View, the Salton Sea and Salton Trough can be observed and discussed, the Peninsular Ranges and Mt. San Jacinto, and the Indio Hills and the San Andreas fault.

The Salton trough is a pull-apart basin, a product of the same tensional forces peeling Baja California away from mainland Mexico and forming the Gulf of California. The Salton Sea is California's largest lake at about 35 miles long and 10 miles wide, but it's been as long as 100 miles long and 35 miles wide during its 2.5-million-year history (Sylvester and Gans, 2016). The water currently occupying California's second lowest landscape was put there by an accidental flooding of the Colorado River, when engineers were diverting water for agriculture.

The Indio Hills are the low, straight hills to the south of the Keys View, between the Little San Bernardino Mountains and Palm Springs at the base of the San Jacinto Mountains. They are a squeeze-up structure or a "squeeze block" caused by compressional forces, created where the San Andreas fault diverges into two branches, the Banning and Mission Creek faults.




**Indio Hills and the San Andreas fault. Animated version of the illustration. .**

Linear features like the Indio Hills are atypical in nature – nature typically doesn't like straight – and is therefore a good indicator of a fault-controlled structure. Keys View offers one of the best places to clearly the topographic expression of the San Andreas fault.

*Activity 4 – Have students sketch the Indio Hills and the San Andreas fault splitting into 2 branches, the Mission Creek fault and the Banning fault. Sketches could include arrows indicating the relative movement of the crust on south and north sides of the fault and the names of the tectonic plates on either side, the Pacific Plate and North American Plate, respectively.*

### Stop 4 – Roof Pendent from Oyster Bay parking lot

Addresses learning objective:

12. Identify a roof pendant and explain/illustrate the structural relationship to the batholith

This quick, 10-minute stop is useful for observing and discussing a *roof pendant*. From the parking lot observe that Ryan Mountain, immediately east, is composed of lighter rock, Palms granite (also referred to as White Tank monzogranite), and darker rock, the Pinto Gneiss. From this perspective, we see the Palms granite is topographically lower than the Pinto Gneiss. To create this juxtaposition, we need to go back to about 75 million years ago, when magma rose through the crust, intruding into the overlying host rock. The host rock and ancient "roof" to this body magma is the 1.7 billion years old Pinto Gneiss. Thanks to erosion, we can see the relationship between these two rock bodies, which has exposed a cross-sectional perspective of the Pinto Gneiss, the *roof pendant*, capping the Palms granite. *Note: this is a better stop in the afternoon than in the morning when the sun is illuminating the mountainside*.

**Ryan Mountain roof pendent.**

*Activity 5 – Ask students to sketch the mountainside and label the White Tank monzogranite, Pinto Gneiss, and the roof pendent. Additionally, you could have students draw step by step: (1) the magma being made through subduction; (2) the magma rising up into the Pinto Gneiss; and (3) the magma solidifying into granite.*

### Stop 5 – Veins near Skull Rock

Addresses learning objective:

10. Identify veins and explain their emplacement

Parking for this stop can be found on the road shoulder just after the "Reduce Speed" sign, about a 15-minute drive from the Oyster Bar parking lot. The *Reduce Speed* sign is ~1/8 mile east of the entrance to the Jumbo Rocks Campground. If parking is not available, which is quite possible considering the proximity to the very popular Skull Rock, proceed another mile to "Plan B", the Live Oak picnic area. The Live Oak picnic area will likely have ample parking and a bathroom, although fewer examples of veins.

If you did find parking, exit vehicles and proceed about 200 feet south up the slope to the granite outcrops. Here is an offering of excellent, easy-to-see examples of veins cutting through the White Tank Monzogranite.

Veins like these probably formed as the pluton cooled, solidified, and contracted, then cracked in response to tensional stresses. Residual, mineral-rich fluids filled the cracks, where minerals like quartz and feldspars crystallized. After completing Activity 6 (see below), you may wish to join the madness at the very popular photo-op spot, Skull Rock.

"Plan C" could be, instead of going to Live Oak, to the Split Rock trail, opposite the Live Oak access road. From the west side of the parking lot, walk about ¼ mile west along the trail. Eventually, you'll notice abundant veins cutting across the granite.

*Activity 6 – Have students sketch a section of the granite containing a vein and label the relative age of each unit.*

After returning to vehicles, continue in the same eastward direction to complete the loop of the park. If time permits, make a last, quick stop to observe the Pinto Gneiss firsthand.

### Stop 6 – Pinto Gneiss

Addresses learning objectives:
6. Identify foliation and metamorphic rocks in the field
7. Distinguish between igneous and metamorphic rocks in the field

An easily accessible outcrop of Pinto Gneiss is just northeast of the junction with Pinto Basin Road that leads to Pinto Basin, Cottonwood, and I-10. Proceed towards 29 Palms about 500 feet and park in the turnout. Exit the vehicles and proceed a few tens of feet onto the small knob of black Pinto Gneiss, pointing out the foliation to students, which helps to identify this rock as metamorphic. From the turnout, head north to the northern park kiosk to exit the park. Be prepared to show your fee waiver to a park ranger once again at the kiosk as you leave.

Pinto Gneiss

## Follow-up Questions

1. What type of rock makes up the inselbergs (small-boulder pile hills) throughout the park?
    a. What are 3 minerals contained in this rock?
    b. Considering plate tectonics, what process was initially needed to make the magma that crystallized to form this rock? About how long ago did this happen?
2. What type and what is the name of oldest rock observed in JTree ?
3. What process makes the outcrops of granite so rounded?
    a. Describe or illustrate, step by step, how this type of weathering gives the rock its "bouldery" appearance.
4. What is a *roof pendant*? How old is the rock that makes up the roof pendant? Illustrate the relationship between the roof pendant and the rock that intruded into it with a simple, labeled diagram.
5. What type of climate exits in Joshua Tree?
    a. Was the climate of JTree wetter or dryer in the past?

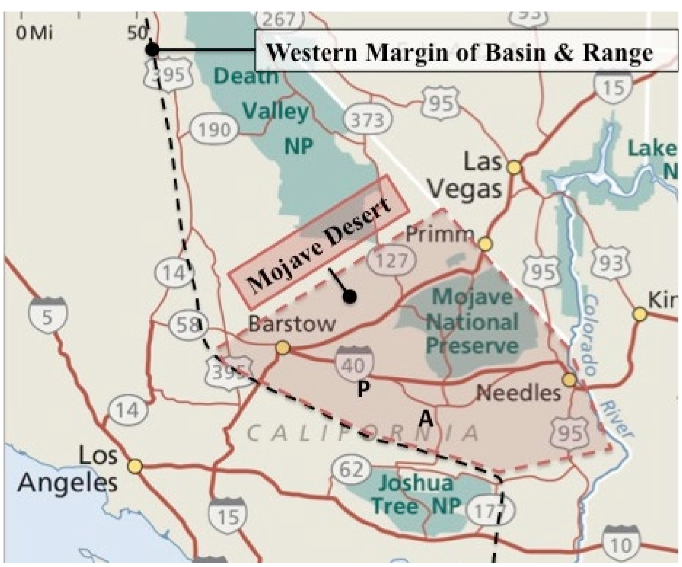
# Chapter 2 – Pisgah Crater and Amboy Crater

**Panoramic view from the top of Amboy Crater.**

## Introduction

This field trip will take you to the closest volcanoes to Los Angeles and will provide an opportunity to observe firsthand cinder cone volcanoes as well as other volcanic features, such as lava flows, a crater and **vent**, lava tubes, and more.

Pisgah and Amboy craters are two of four volcanoes in the Cima Volcanic Field and constitute just a couple of the approximately 40 young cinder cone volcanoes in the Mojave Desert and greater Basin and Range Geologic province. The Basin and Range is a region of **continental rifting**, extending from the eastern front of the Sierra Nevada Mountains to western Utah and as far south as Mexico. The following video, courtesy of Robert McMillian, provides a nice visual overview of some volcanoes in the Mojave Desert: drone video of volcanoes in the Mojave Desert. Both volcanoes are on the North American Plate, with Pisgah Crater being about a half-hour closer to Los Angeles than Amboy Crater, making it the more practical destination of the two. On the other hand, Amboy Crater has been developed for visitors, having recently been designated a Natural Landmark; it has a paved road and parking area, restrooms, and a picnic area. It also has retained a nearly perfect conical shape, while the configuration of Pisgah Crater has been degraded by mining operations.




**Map of Mojave Desert, Basin and Range, Pisgah Crater (P) and Amboy Crater (A). –Modified image from CC.**

### Special Safety considerations at Pisgah and Amboy craters

- Rattlesnakes. Rattlesnakes have been observed during a past field trip so exercise extra caution if your students walk off of the road or trails.
- Gloves. If you opt to explore the lava tubes then encourage students bring gloves for some hand protection.
- Water. As for any field trip, students should bring plenty of water, but visiting either of these volcanoes will require walking a few miles, meaning several hours away from vehicles, under potentially very hot and dry conditions.
- Weather. It can be dangerously warm during the summer and early fall. Visits should be made during the late fall, winter or early spring months.

## Geology

Cinder cones are small, steep-sided, cone-shaped piles of **cinders** - small blobs of lava that erupted from a central vent to build up a volcano. Cinder cone eruptions are not explosive, but can be spectacular to behold, with lava fountaining out of the vent 100s of feet into the air. To get sense of such an eruption access the following video, where lava is being ejected from a vent near Kilauea, resulting in constructing a cinder cone: volcanic eruption.

From the time a cinder cone starts erupting, it will continue to do so regularly for months to decades, building its cone through the accumulation of lapilli-sized pyroclasts, (cinders). These are ejected from the vent as pea to golf ball-sized blobs of lava that quickly solidify into rocks of **basalt** (cinders) after landing. Eventually, the volcano may emit basaltic lava flows from its base. This may signal that the eruptive cycle is coming to an end; for once the lava flows stop, these volcanoes typically go extinct and never erupt again.

Cinder cones usually form over hot spots or within continental rift zones, like the Basin and Range. They can also form near convergent boundaries, in instances where the magma is **mafic** in composition.

When Pisgah Crater and Amboy Crater last erupted is not known for certain. Lava flows interbedded with lake bed sediments constrain a maximum age of about 100,000 years (Sharp and Glazner, 1993), but most studies hypothesize an age for these two cones in the range of 20,000 to 5,000 years old; perhaps even younger. Certainly, the flows and Amboy Crater look quite young. Pisgah crater may look older, but this is because mining operations have degraded the shape of the cone. Pisgah and Amboy craters rise 300 and 250 feet high above the surrounding plain, respectively, and were built from basaltic pyroclastic material called cinders. Each has extensive basaltic lava flows emanating from their base. Geographically they roughly align with other volcanic features in the area, suggesting that they may have formed along a fault (Sylvester and Gans, 2016). Certainly, earthquake faults exist in the area, as evidenced by the 1999, magnitude 7.1 Hector Mine earthquake.

The Cady and Bristol mountains that make up the skyline north of Pisgah and Amboy craters are composed of rock that provides a notable contrast to the very young basalt flows associated with these volcanoes. While these mountains are also made up igneous rock, it is significantly older and of more felsic in composition. There is intrusive, Mesozoic-age granitic rock, and Tertiary (~ 20 million years) lava and pyroclastic flows. The Bristol Mountains also contain Proterozoic metamorphic rocks.

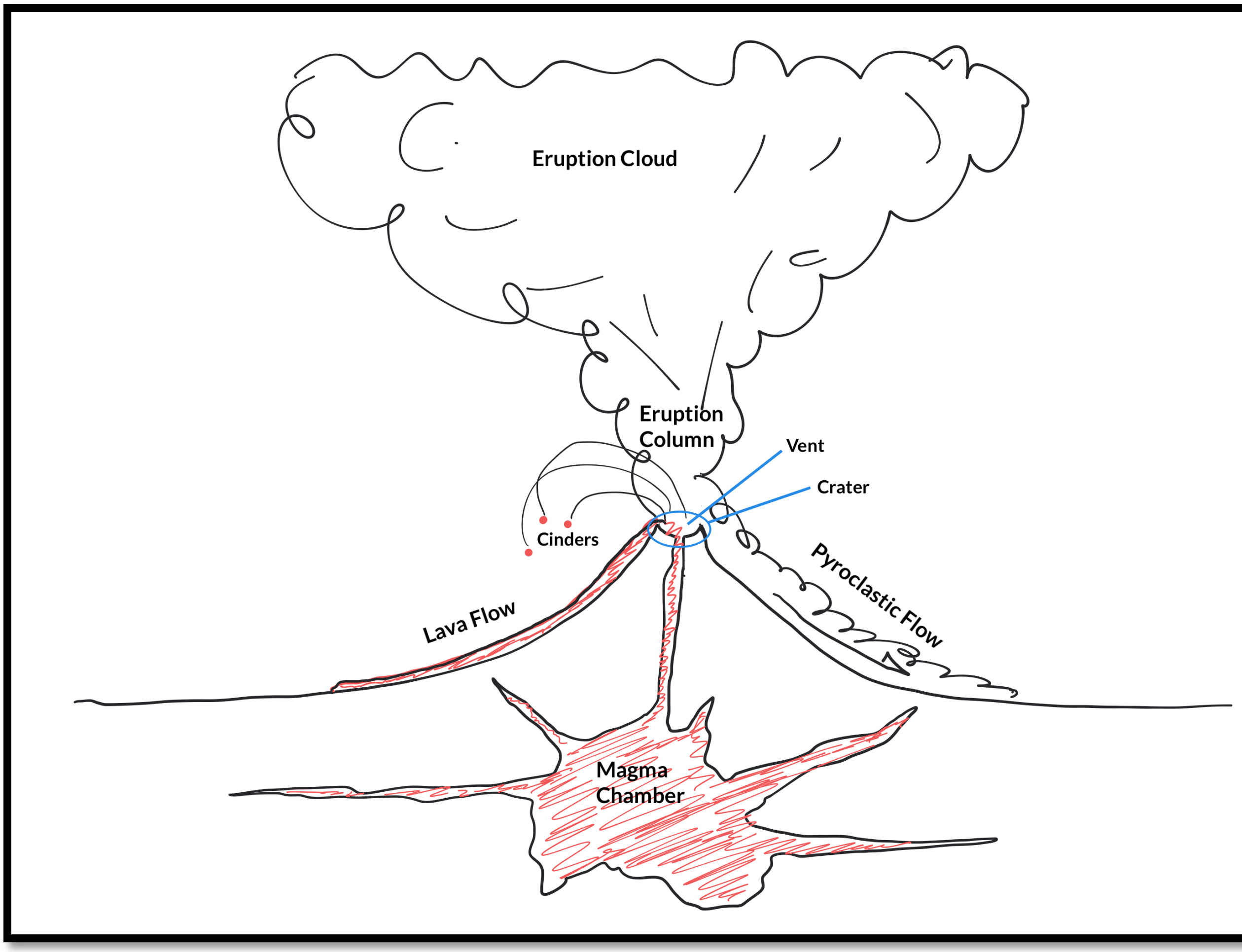
## Learning Objectives

Through participation in this field trip students should be able to:

1. Name the type and the specific name of the plate boundary that was crossed in order to get to Pisgah/Amboy Crater
2. Identify aphanitic (fine-grained) igneous rock texture
3. Identify basalt, 2 types of lava flows, pahoehoe or aa lava, and lava flow features such as pressure ridges and squeeze-ups
4. Describe the evolution and life cycle of cinder cone volcanoes
5. Identify different components of a volcano, such as the crater and central vent
6. Describe why volcanoes have formed in the Mojave Desert

## Key Vocabulary

- **Aa** – basaltic lava flows with a jagged surface, representing more viscous part of flow
- **Basalt** – Most common volcanic rock; mafic in composition
- **Cinders** – small, basaltic pyroclastic material ejected during the eruption of cinder cones that solidify into small, pea to golf ball-sized rocks
- **Continental rifting –** stretching of continental crust by tectonic forces; could be in the initial stages of making a divergent plate boundary
- **Crater –** closed depression at the summit of volcano
- **Decompression melting –** melting of rock in the upper asthenosphere triggered by a release of pressure through sea-floor spreading or continental rifting
- **Mafic** – Term used to describe the composition of igneous rocks that contain abundant Iron and Magnesium and lower amounts of silica, ~ 50%
- **Pahoehoe** – fluid basaltic lava flows with a smooth, "ropy" surface
- **Pressure ridge** – an elongated, uplifted portion of a solidified lava flow, formed while the lava was flowing
- **San Andreas fault** – Major right-lateral strike-slip fault and transform plate boundary between the Pacific and North American plates
- **Squeeze-up** – small extrusion of solidified lava from a fracture in a lava flow
- **Vent –** an opening or fissure at the bottom of the crater, or a fracture on or near the volcanic cone from which the volcano releases gas, pyroclastic material, and lava




The anatomy of a volcano.

## Pre Field Trip Questions

1. Can a volcano form anywhere?
2. Why do volcanoes form where they do?
3. What is needed to make a volcano?
4. Can magma be made anywhere?
5. Compare and contrast a cinder cone to a shield volcano and composite cone volcano. Answer as a short essay or illustratively, using labeled sketches of each of volcano or by constructing a Venn Diagram.
6. Describe how the color of mafic rocks would be different than the color of intermediate or felsic igneous rocks.
7. Quickly sketch or describe in words the difference in texture between an aphanitic and phaneritic igneous rock.

## En Route Talking Points: I-605 north, I-10 east, I-15 north, I-40 east

- I-605 north
  - The 605 takes us across part of the Los Angeles Basin. This incredibly deep basin formed from roughly 16 million to about 1 million years ago as tectonic forces slowly peeled the Transverse Ranges away from the Peninsular Ranges, rifting

open a series of basins. The sea flooded these pits as they slowly opened, meaning what is today the metropolis of Los Angeles and Orange counties were once at the bottom of the Pacific Ocean. All the while, sediment being eroded from the continental highlands filled these depressions with silt, sand, and gravel, up to 6 miles in thickness.

- San Gabriel River
  - The San Gabriel River Freeway (formal name for I-605)
    - Follows a path of least resistance from river erosion
    - River erosion creates natural pathways
    - Pathways become footpaths
    - Footpaths become horse trails
    - Horse trails become thoroughfares
    - Thoroughfares become highways
  - River transports sediment from the San Gabriel mountains to its base level, the Pacific Ocean
  - Whittier Narrows water gap. The San Gabriel River and Rio Hondo River, just to the west, have created the Whittier Narrows by eroding faster downward than the hills have been uplifted, resulting in carving a topographic saddle, a "water gap", 2 miles wide and 800 feet deep, bisecting the Puente Hills into 2 parts: the Montebello Hills to the west and Whittier Hills to the east. For a more detailed description read the excellent discussion in *Geology Underfoot in Southern California,* "Vignette 9 – A Boon to Communication, The Whittier Narrows"
  - Similarly, Santa Ana River erosion has created water gaps through hills that are now occupied by the 91 and 57 freeways
- Whittier and Puente Hills (east of the 605) are being actively uplifted along the Whittier fault, which runs along the base of these hills; this fault is active as evidenced by the recent Whittier (1987, M 5.9), Chino Hills (2008, M 5.5), and La Habra (2014, M 5.1) earthquakes.
- Montebello (Repetto) Hills (west of the 605)
  - Western extension of Puente Hills
  - Like Puente Hills, the Montebello Hills are made up of steeply tilted, south-dipping sedimentary rock that is typical of sediment in the LA Basin: mudstone, siltstone, sandstone, and conglomerate
- On a clear day point out the San Gabriel Mountains making up the northern skyline and its highest peak, the 10,064 feet tall Mt San Antonio, a.k.a. Mt Baldy.

- Eastbound on I-10
  - "The 10" takes advantage of the San Gorgonio Pass, 1 of 3 topographic passes through the mountains surrounding the greater Los Angeles area, the other two being the Tejon and Cajon passes, utilized by I-5 and I-15, respectively.
  - Just east of Azuza Ave. the hills (San Jose Hills) buttressing the north side of I-10 are partly composed of lava flows know as the "Glendora volcanics"
    - ~16 million years old
    - Volcanic eruptions were triggered by the rifting that formed the Los Angeles Basin

        - Exposed as olive brown rock, as opposed to buff-orange rock exposed in preceding hills
- Northbound on the I-15
    - The 15 freeway takes advantage of the Cajon Pass, one of three topographic passes through the mountains surrounding the greater Los Angeles area, the other two being the Tejon pass, utilized by I-5 and the San Gorgonio Pass, over which the I-10 stretches to Arizona and beyond.
    - San Gabriel and San Bernardino Mountains
        - Represent part of the Transverse Ranges, a block of crust that was peeled away from the Peninsular Ranges and rotated 110º to its current position (for a more thorough discussion see the Introduction in *Roadside Geology of Southern California*, Sylvester and Gans, 2016)
        - Stream erosion along the **San Andreas fault** Zone has created the Cajon Pass, which divides the Transverse into 2 geographically distinct mountain ranges, the "San Gabriels" and the "San Bernardinos"
        - Compressional tectonic forces have uplifted the mountains, over the past 5 million years at a rate as fast as 70 feet per 1000 years (Sylvester and Gans, 2016)
            - San Gabriels could be growing as fast as the Himalayan Mountains (Prothero, 2011)
            - Rapid uplift evidenced by very deep, steep-sided canyons and triangulated ridges
        - Contains metamorphic rock as old as 1.7 billion years, as well as Proterozoic plutonic rocks; these were intruded by magma of diorite to granite composition that was generated by subduction of the Farallon Plate during the Mesozoic time
    - The I-15 crosses over Lytle and Cajon creeks, at 5 and 7.5 miles north of I-210 interchange. These two major tributaries of the Santa Ana River contain abundant cobble and boulder-sized clasts of bedrock from the adjacent mountains.
    - The San Andreas fault and the plate boundary
        - About 2.5 miles after passing Kenwood Ave, just after I-15 curves due north, you cross over the San Andreas fault, the plate boundary between the Pacific and North American plates
- I-15 to the I-40 interchange
    - The 15 climbs up the Cajon Pass then descends onto the southern margin of the Mojave Desert
- I-40 Desert Oasis rest stop 28 miles east of I-15/I-40 interchange
    - Restroom stop for students
    - Instruct to students to begin to looking for lava flows and volcanoes after leaving rest stop

## Directions to Pisgah Crater

- Continue on I-40 eastbound for just over 3.5 miles to Hector Road. Exit freeway and turn right and immediately left on National Trails Highway (CA-66); procede about 4.5 miles and turn right onto the Pisgah Road (look for beat-up sign).

## Pisgah and Amboy Crater Field Trip Stops

All stops listed in this chapter are accessible by large charter bus, van, or 2-wheel drive car. However, some charter bus drivers may be reluctant to drive the charter bus on the unimproved Pisgah Road. It would be wise to inform the charter bus representative ahead of the field trip of the road condition and to give the bus driver a heads-up upon loading the bus at the start of the trip. If the driver chooses not to drive the road upon arrival to Pisgah Crater then the Plan B would be to continue on to Amboy Crater, which has a paved road and parking area, but, as mentioned in the introduction, it is about a half hour beyond Pisgah Crater. The paved parking lot and observation veranda at Amboy Crater may also make it preferable for students that use a wheelchair for mobility.

Pisgah Crater and Pisgah Road

## Pisgah Crater

### *Stop 1 – Observe aa lava flows*

Addresses learning objective:
3. Identify basalt, and pahoehoe and aa lava flows in the field.

- Drive up to gate and park, exit and inspect lava flow just past gate on east side of road to observe a good example of **aa** basalt flows

*Activity 1: Ask students to describe the surface of the aa flow as smooth or jagged.*

### *Stop 2 – Observe pahoehoe flows and discuss the geology of Pisgah Crater and cinder cone volcanoes*

Addresses learning objectives:
2. Identify aphanitic (fine-grained) igneous rock texture in the field
3. Identify basalt, and pahoehoe and aa lava flows in the field
4. Describe the evolution and life cycle of cinder cone volcanoes
6. Describe why volcanoes have formed in the Mojave Desert

Hike (if the gate is locked shut) or drive up haul road to the wide, flat abandoned mining operations area on western flank of volcano. Park on the western side. Exit vehicles and assemble along the top of the western edge, so you're atop the slope looking down upon the extensive pahoehoe basalt flows.

Panoehoe flows.

*Activity 2: Ask students to describe the surface of the aa flow as smooth or jagged. Do these flows exhibit aa or pahoehoe characteristics?*

- Discuss the presence of cinder cones in the Mojave Desert
  - About 40 young cinder cone volcanoes and extensive lava flows are found in the Mojave Desert
  - Age of oldest lava flows indicate the volcanic activity started about 7.5 million years ago
  - Considering the timing and geographic location, it is feasible that the concentration of young volcanoes in Mojave is a consequence of **decompression melting** in the upper mantle, caused by crustal extension from the continental rifting of the Basin and Range.
  - Cinder Cone volcanoes
    - Typically erupt cinders over the course of months, years, or decades building up their cone
    - Lava flows often signal the end of the eruptive cycle and break through the base or side of volcano, as the loose pile of cinders are not strong enough to contain the lava all the way from the magma chamber up to the crater
    - They have effusive, quiet eruptions – throwing out small, fragmented basaltic lava that hardens into small rocks (cinders) that pile up around a central vent, building up the cone over time
    - Once the eruptive cycle has completed they go extinct

*Activity 3: Ask students to inspect lava flows and cinders, noting in particular the texture and composition. If these rocks were felsic in compostion and formed intrusively, how would the color and texture be different?*

### *Stop 3 – Inside crater*

Addresses learning objective:
5. Identify different components of a volcano, such as the crater and central vent

Walk up the road and around the south flank of volcano to a trail leading into the crater on east side of the cone.

- Once everyone is inside the crater, which is about where the trail levels-off, explain that you're now *inside* the crater
- Point out the central **vent**, which should be visible in the low point of the crater depression

*Activity 4: Ask students to answer the question: Considering what is typical of cinder cone volcanoes, how likley is it that Pisgah Crater will erupt while we are visiting it today? How about during out lifetime? If Basin and Range extension is still happening in the Mojave Desert region, is possible that another cinder cone volcano could form nearby in our lifetime?*

- From here you can head down to the bottom of the crater and into the vent, which forms a cave-like feature that can fit a few students at a time – students love caves!

- Additionally, you can take the trail to the top of the volcano, which provides outstanding views of the surrounding landscape – again, remind students to be careful as they walk up and down trail. Even a small stumble could result in significant skin loss on hands and knees from the sharp basalt.

### *Stop 4 – Lava Tubes*

Addresses learning objective:
3. Identify basalt, 2 types of lava flows, pahoehoe or aa lava, and lava flow features such as pressure ridges and squeeze-ups
5. Identify different components of a volcano, such as the crater and central vent

**Amboy Crater behind some aspiring geologists.**

- If you feel comfortable with your student's ability to manage their own safety, you might want to explore one or more of the lava tubes. Lava tubes form when the top of a fluid lava flow that is contained in a channel solidifies, making a roof over the rest of the flow. This happens because the flow below is insulated; while the top of the flow loses heat the fastest. Eventually, the lava empties out of the "roofed" channel, leaving behind a tunnel or lava tube. There are dozens of lava tubes in the lava fields around Pisgah, many with collapsed roofs; several can be found near the base of the eastern side of the volcano. If you choose to venture out into the lava field, exercise caution. The ground is uneven, unstable, and sharp. Watch for rattlesnakes. Be sure to have a safety chat with the students before allowing any of them to explore. If students are uncomfortable then propose that they just observe from the edge of the "parking area" on the eastern flank of the cone.

## Directions to Amboy Crater

- From Barstow head east on I-40 for 52 miles to Ludlow. Turn right (south) from the off-ramp then immediately left (east) and continue about 26 miles to the road leading to Amboy Crater National Natural Landmark and park in the parking lot.

### Amboy Crater

### *Stop 1 – Overview*

Addresses learning objectives:
2. Identify aphanitic (fine-grained) igneous rock texture in the field
3. Identify basalt, and pahoehoe and aa lava flows in the field
4. Describe the evolution and life cycle of cinder cone volcanoes
6. Describe why volcanoes have formed in the Mojave Desert

From the parking lot walk up to the gazeebo-type observation area to provide students with a geologic overview:

- Cinder cones in the Mojave Desert
    - Pisgah and Amboy craters are two of four volcanoes in the Cima Volcanic Field and constitute just a couple of the approximately 40 young cinder cone volcanoes in the greater Mojave Desert region.

- About 40 young cinder cone volcanoes and extensive lava flows are found in the Mojave Desert
- Age of the oldest lava flows indicate the volcanic activity started about 7.5 million years ago
- Considering the timing and geographic location, it is feasible that the concentration of young volcanoes in Mojave are a consequence of decompression melting in the upper mantle, caused by crustal extension from continental rifting of the Basin and Range.

*Activity 1: Ask students to answer the question: Considering what is typical of cinder cone volcanoes, how likley is it that Amboy Crater will erupt while we are visiting it today? How about during out lifetime? If Basin and Range extension is still happening in the Mojave Desert region, is possible that another cinder cone volcano could form nearby in our lifetime?*

- Cinder Cone volcanoes
  - Typically erupt cinders over the course of months, years, or decades building up their cone
  - Lava flows often signal the end of the eruptive cycle and break through the base or side of volcano, as the loose pile of cinders are not strong enough to contain the lava all the way from the magma chamber up to the crater
  - They have effusive, quiet eruptions – throwing out small, fragmented basaltic lava that hardens into small rocks (cinders) that pile up around a central vent, building up the cone over time
  - Once the eruptive cycle has completed they go extinct

### *Stop 2 – anywhere along the trail to the volcano*

Addresses learning objectives:
2. Identify aphanitic (fine-grained) igneous rock texture in the field
3. Identify basalt, and pahoehoe and aa lava flows in the field
4. Describe the evolution and life cycle of cinder cone volcanoes

- It's best to use the trail to access the volcano, as opposed to going overland and running the risk of twisted ankles, snake encounters, or losing students. Along the way there are many opportunities to discuss lava features, such as pahoehoe vs. aa lava, **pressure ridges**, and **squeeze ups**. One could also discuss the gradient or slope of the flank of the volcano and relate this to interpreting topographic maps.

Pressure ridge. – CC.

*Activity 2: Ask students to inspect lava flows and cinders, noting in particular the texture and composition. If these rocks were felsic in compostion and formed intrusively, how would the color and texture be different?*

*Activity 3: Ask students to visually identify and draw pressure ridges and squeeze-ups.*

### *Stop 3 – Inside crater*

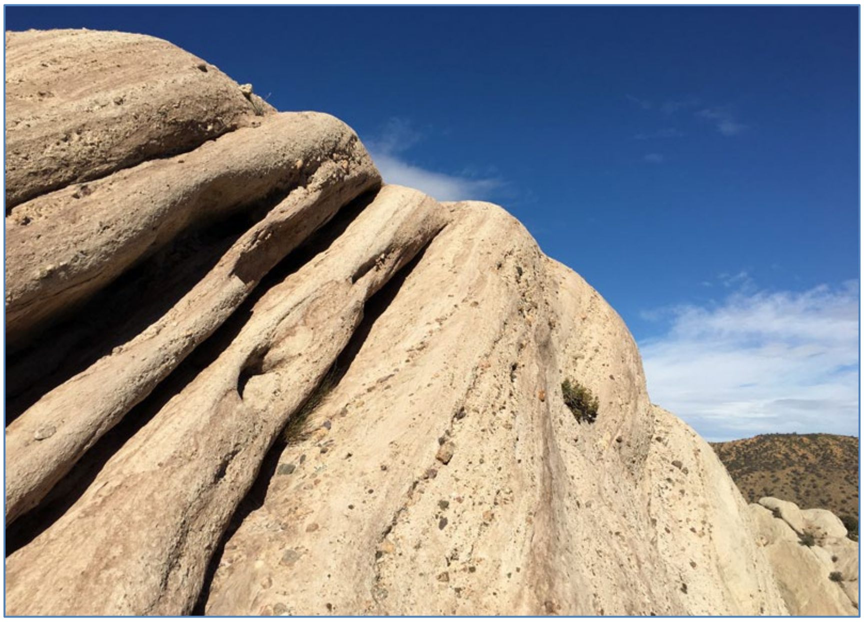
Addresses learning objectives:
5. Identify different components of a volcano, such as the crater and central vent

- Walk counterclockwise around to the west side of the volcano and ascend the step trail up into the crater through a breach in the side of the volcano. It's likely that this side of the volcano was carried away by a lava flow bursting through the base of the cone and flowing off towards the south.
- Once inside, you'll notice (especially if you walk up onto the rim of the crater) that there are two small roughly shaped "rings" of cinders that represent two subsequent eruptions that happened after the principal, volcano building eruption.
- Climbing up on the rim offers excellent views of the Bristol Mountains off to the north and the Marine Corps Base off to the south.

## Follow-up Activities and Questions

1. Ask students to reflect on and write about how observing a cinder cone volcano first-hand was different and the same as their expectations.
2. Have student summarize the eruptive history of Pisgah or Amboy crater, including why the volcanoes exist in the Mojave Desert, the timing of the eruptions, and chemistry of the lava flows.
3. What is a "water gap" (like the Whittier Narrows that contains the 605 freeway) and how does one form?
4. Should scientists be surprised if Pisgah/Amboy crater were to erupt again? Explain.
5. Considering that the Mojave Desert lies within the Basin and Range, should we expect more volcanoes to form in the Mojave in the future? Explain.

## Chapter 3 – The San Andreas Fault, Mormon Rocks, and Devil's Punchbowl Natural Area



**Tilted strata of the Punchbowl Formation at Devil's Punchbowl Natural Area.**

### Introduction

This field trip includes stops at the San Andreas fault, Mormon Rocks, and Devil's Punchbowl Natural Area; at these locations students can observe and study the effects of crustal deformation, faulting, and tectonic uplift. It also provides an opportunity to observe and discuss sedimentary rocks and depositional envirnoments, and make connections between plate tectonic stresses and plate boundaries.

Devil's Punchbowl has an attractive picnic area and small, but interesting nature center that includes at least 2 owls – look for these in the outdoor cages. Considering weather, it's best to conduct this trip during late fall, late winter, or early spring.

### Geology

At 750 miles long the **San Andreas fault** is the most important tectonic structure in California. This right-lateral strike-slip fault, along with its subsidiary faults make up the San Andreas fault zone; this represents the plate boundary between the Pacific and North Ameican Plates, which accommodates about one inch of plate motion per year. Relative movement between these plates happens mainly as intermittent slipage along the San Andreas fault, resulting in major earthquakes, such as the magnitude 7.9 San Francisco earthquake in 1906 and the 1857 Fort Tejon in southern California. Careful analysis of **strata** that was offset by past earthquakes, shows that major earthquakes happen along the San Andreas fault at a averaged rate of one every 150 years. Major earthquakes typically disturb the ground surface, making ground cracks and fault scarps; with the later being the result of one block of crust being uplifted relative to the crust on the other side of the fault.

Since 1857, disruptions to the ground surface, such as scarps and ground cracks have been mostly erased by erosion and urban development, making the trace of the fault difficult to locate on the Earth's surface. Instead, we can use topographic and indirect geologic evidence, such as stream offsets, sag ponds, eroded scarps, and juxtoposition of distinct rock units to locate a fault's position. The first stop, the Blue Cut area, immediately south of the San Andreas fault provides some of the aforementioned geologic and topographic evidence that can be used to locate the San Andreas fault.

Mormon Rocks offers a striking example of how tectonic forces can uplift and tilt strata and an opportunity to discuss the formation, texture, and depositional setting for sedimentary rocks.

Devil's Punchbowl provides an opportunity to build upon the first two stops. Here, students will observe a sedimentary rock formation that is deceptively similar to the rock found at Mormon Rocks and have also been deformed by the tectonic forces active along the Pacific-North American plate boundary.

## Learning Objectives

Through participation in this field trip students should be able to:

1. Name the type and specific name of plate boundary crossed en route to Devil's Punchbowl
2. Use stratigraphy and texture to identify rocks as sedimentary
3. Identify clastic/detrital texture in rocks
4. Identify stream terraces and unconformities
5. Use indirect evidence, such as the juxtapositon of rock units or topographic features to locate faults
6. Describe the geologic significance of the "inface bluffs"
7. Describe how the orientation of the strata of the Cajon Formation and the Punchbowl Formation violates the Law of Original Horizontality and explain why this has happened
8. Identify and draw a syncline
9. Explain why the Cajon and Punchbowl formations are not the same body of rock despite having very similar lithology

## Key Vocabulary

- **Alluvial fan** – fan-shaped pile of sediment that was deposited intermittently by flash floods/debris flows at the mouth of a mountain canyon
- **Detrital** – texture of sedimentary rock composed of clasts or grains of rocks and minerals
- **Law of Original Horizontality** – sediment is always deposited as strata that is horizontal or very nearly horizontal
- **Plunging syncline** – a syncline with a fold axis that is inclined or has a "plunge"
- **San Andreas fault** – Major right-lateral strike-slip fault and transform plate boundary between the Pacific and North American plates
- **Strata** – a vertical sequence of layers of sediment and is considered the definitive characteristic for sedimentary rocks
- **Stream terrace** – topographically flat surface elevated above the active stream channel representing the past position of the stream bed or flood plain for the stream
- **Syncline** – a "U"-shaped structure typically caused by the compressing and tilting of strata around an imaginary axis (fold axis)

- **Syncline (plunging**) – a syncline where the fold axis has been tilted from horizontal, resulting in the tilting of the syncline structure
- **Unconformity** – contact between older rock below and significantly younger rock above, representing a gap in geologic time caused by prolonged erosion and/or lack of deposition

## Pre Field Trip Questions

1. What characteristic of sedimentary rocks makes them easily recognizable in the field?
2. If inspecting a **detrital** sedimentary rock what would you see that makes it "detrital"?
3. Examine a few pictures of alluvial fans: Google images of alluvial fans.
4. Access this link: geology Devil's Punchbowl Natural Area. Analyze each illustration and read the accompanying text. Starting with the third illustration, summarize the geologic history of the Punchbowl Formation (abbreviated as "Mp").
5. Watch this short video, The San Andreas Fault then answer this question, "How likely do you think it is that we could experience the *Big One*, a major earthquake on the San Andreas fault, while we are on our field trip?" Explain.
6. If a major earthquake happens on the San Andreas fault every 150 years and the last major earthquake was in 1857, when should the next one happen? Considering your answer, what does this mean?

## En Route Talking Points: I-605 north, I-10 east, I-15 north

- I-605 north
  - The 605 takes us across part of the Los Angeles Basin. This incredibly deep basin formed from roughly 16 million to about 1 million years ago as tectonic forces slowly peeled the Transverse Ranges away from the Peninsular Ranges, rifting open a series of basins. The sea flooded these pits as they slowly opened, meaning what is today the metropolis of Los Angeles and Orange counties were once at the bottom of the Pacific Ocean. All the while, sediment being eroded from the continental highlands filled these depressions with silt, sand, and gravel, up to 6 miles in thickness.
  - San Gabriel River
    - The San Gabriel River Freeway (formal name for I-605)
      - Follows a path of least resistance from river erosion
      - River erosion creates natural pathways
      - Pathways become footpaths
      - Footpaths become horse trails
      - Horse trails become thoroughfares
      - Thoroughfares become highways
    - River transports sediment from the San Gabriel mountains to its base level, the Pacific Ocean
    - Whittier Narrows water gap. The San Gabriel River and Rio Hondo River, just to the west, have created the Whittier Narrows by eroding faster downward than the hills have been uplifted, resulting in carving a topographic saddle, a "water gap", 2 miles wide and 800 feet deep, bisecting the Puente Hills into 2 parts: the Montebello Hills to the west and Whittier Hills to the east. For a more detailed description read the

        - excellent discussion in *Geology Underfoot in Southern California,* "Vignette 9 – A Boon to Communication, The Whittier Narrows"
        - Similarly, Santa Ana River erosion has created water gaps through hills that are now occupied by the 91 and 57 freeways
    - Whittier and Puente Hills (east of the 605) are being actively uplifted along the Whittier fault, which runs along the base of these hills; this fault is active as evidenced by the recent Whittier (1987, M 5.9), Chino Hills (2008, M 5.5), and La Habra (2014, M 5.1) earthquakes.
    - Montebello (Repetto) Hills (west of the 605)
        - Western extension of Puente Hills
        - Like Puente Hills, the Montebello Hills are made up of steeply tilted, south-dipping sedimentary rock that is typical of sediment in the LA Basin: mudstone, siltstone, sandstone, and conglomerate
    - On a clear day point out the San Gabriel Mountains making up the northern skyline and its highest peak, the 10,064 feet tall Mt San Antonio, a.k.a. Mt Baldy.
- Eastbound on I-10
    - "The 10" takes advantage of the San Gorgonio Pass, 1 of 3 topographic passes through the mountains surrounding the greater Los Angeles area, the other two being the Tejon and Cajon passes, utilized by I-5 and I-15, respectively.
    - Just east of Azuza Ave. the hills (San Jose Hills) buttressing the north side of I-10 are partly composed of lava flows know as the "Glendora volcanics"
        - ~16 million years old
        - Volcanic eruptions were triggered by the rifting that formed the Los Angeles Basin
        - Exposed as olive brown rock, as opposed to buff-orange rock exposed in preceding hills
    - Slover Mountain, approximately 2 miles west of the 91 interchange was originally a 700 feet high mountain of marble that has been quarried for cement
        - Colton Cement quarry, now known as CalPortland at base of Slover Mountain is the oldest cement works west of the Rocky Mountains has provided the cement needed to make such structures as Los Angeles City Hall, the Memorial Coliseum, the Bonaventure Hotel in downtown LA, and the Hoover Dam.
- Northbound on the I-15
    - The 15 freeway takes advantage of the Cajon Pass, one of three topographic passes through the mountains surrounding the greater Los Angeles area, the other two being the Tejon pass, utilized by I-5 and the San Gorgonio Pass, over which the I-10 stretches to Arizona and beyond.
    - Cucamonga Fault
        - Eastern extension of the Sierra Madre Fault
        - Wraps around southeast foot of San Gabriel Mountains

Southern California fault map.

- Fault intersects I-15 just before the I-215 interchange
- The Sierra Madre Fault-Cucamonga (bold and red on fault map) fault zone has accommodated as much as 10,000 feet of vertical uplift of the crust, which today is expressed as the San Gabriel Mountains

- San Jacinto Fault
  - Trends from San Gabriel Mountains southeast into the city of San Bernardino
  - Takes up most of the motion along the Pacific-North American plate boundary in southern California
  - Intersects the Cucamonga fault just south of the I-15/I-215 interchange
  - Very active in 20$^{th}$ century – at least 8 magnitude 6+ earthquakes, except the segment through San Bernardino, which has not slipped in historic time and is therefore of major concern to the city

- San Gabriel and San Bernardino Mountains
  - Represents part of the Transverse Ranges, a block of crust that was peeled away from the Peninsular Ranges and rotated 110$^{o}$ to its current position (for a more thorough discussion see the Introduction in *Roadside Geology of Southern California*, Sylvester and Gans, 2016)
  - Stream erosion along the San Andreas fault zone has created the Cajon Pass, which divides the Transverse into 2 geographically distinct mountain ranges, the "San Gabriels" and the "San Bernardinos"
  - Compressional tectonic forces have uplifted the mountains, over the past 5 million years at a rate as fast as 70 feet per 1000 years (Sylvester and Gans, 2016)
    - San Gabriels could be growing as fast as the Himalayan Mountains (Prothero, 2011)
    - Rapid uplift evidenced by very deep, steep-sided canyons and triangulated ridges
  - Contains metamorphic rock as old as 1.7 billion years, as well as Proterozoic plutonic rocks; these were intruded by magma of diorite to granite composition that was generated by subduction of the Farallon Plate during the Mesozoic time
- The I-15 crosses over Lytle and Cajon creeks, at 5 and 7.5 miles north of I-210 interchange. These two major tributaries of the Santa Ana River contain abundant cobble and boulder-sized clasts of bedrock from the adjacent mountains.

## Field Trip Stops

All stops listed in this chapter are accessible by large charter bus, van, or 2-wheel drive car.

### Stop 1 – San Andreas Fault and the Blue Cut

Addresses learning objectives:
1. Name the type and name of plate boundary crossed en route to Devil's Punchbowl
4. Identify stream terraces and unconformities
5. Use indirect evidence, such as the juxtapositon of rock units or topographic features to locate faults

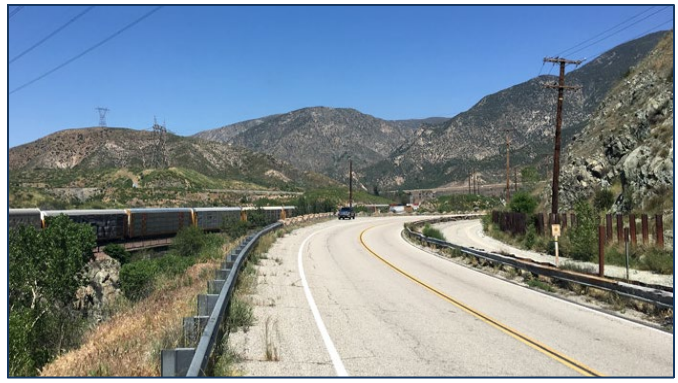
From I-15 exit Kenwood Road (exit 124) and turn left, passing under the freeway then turning right when the road ends onto old Route 66, Cajon Boulevard. Proceed 3.7 miles to where the road curves to the northeast then pull over onto the northern shoulder, just along side the old, stone wall.

- This area is named the Blue Cut because of exposures of the Pelona Schist, which conveys a bluish hue. This geologically signicantly rock unit represents marine sediments that were deposited atop the oceanic Farallon Plate then metamorphosed into schist (metamorphic rock). Tectonically speaking, the Pelona Schist represents the top part of the Farallon Plate, which subducted under the North American plate from approximately 200-25 million years ago. Consequently, the Pelona Schist is referred to as a "lower plate" rock unit, because it was subducted under, or beneath the North American Plate. Today it is only sporadically exposed on Earth's surface, where uplift and erosion has revealed the lower plate as "tectonic windows". The Blue Cut area represents one of the these rare tectonic windows.
- Cajon Creek has eroded this valley containing the Blue Cut and Route 66. It also separates the San Gabriel Mountains from the San Bernardino Mountains, which if we face north, are off to our left and right, repsectively.
- Across Cajon Creek note the 8000 year old **stream terrace** that supports the train tracks; this feature formed through erosion of the Pelona Schist bedrock. One can also observe an **unconformity** (nonconformity) between the 75 million year old Pelona Schist and light-colored Quaternary gravels.

**Unconformity between Cretaceous age Pelona Schist (gray) and Quaternary age gravels (pinkish).**

- The hill on the southeast side of the road is made up of Pelona Schist – in afternoon light the schist takes on a blueish hue, giving this area its name
- Note the landslide catch fences – the Pelona Schist is susceptible to mass wasting
- At this location, the Pelona Schist has been made weaker due to the Punchbowl fault that cuts through the hill and merging with the San Andreas fault some miles to the east of this location
- Note the dramatic bend in Cajon
  Creek caused by right-lateral movement along the San Andreas fault

Exposure of Pelona Schist.

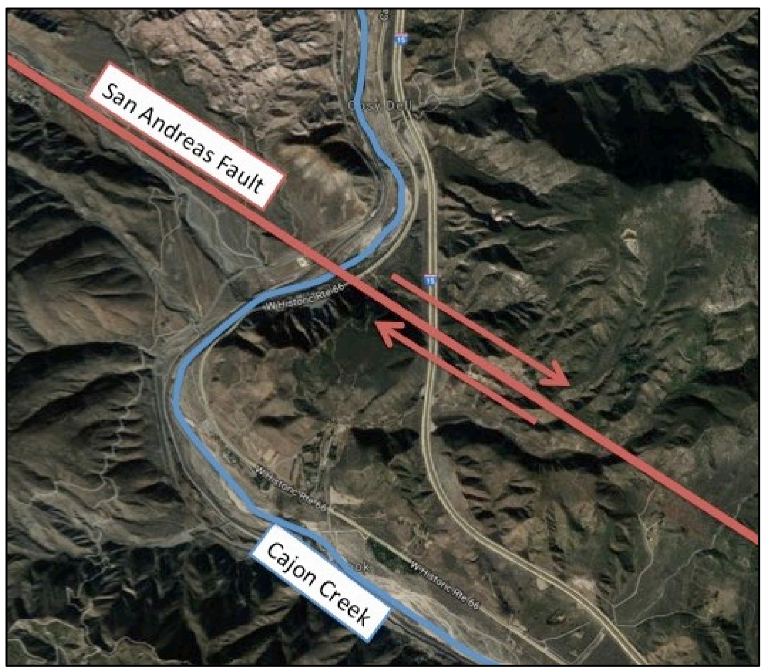


Looking north along old route 66 bend in road reflects fault-controlled bend in Cajon Creek.

*Activity 1: Make a map view drawing showing the path of Cajon Creek* <u>*without*</u> *offset from San Andreas fault.*

The Blue Cut area is situated on the very edge of the Pacific Plate. In order to cross the plate boundary, the San Andreas fault and to get to the North American Plate, return to your vehicles and drive about ½ mile further north on Route 66. Just as you reach the end of the hills on the right, the same ones that contain the Blue Cut, pull off onto the road shoulder. Here, you are on the San Andreas fault zone.

- Point out that rock making up the hills off to the left, on the far side of Cajon Creek, are on the North American Plate and are significantly younger (~ 50 million year old sedimentary rock) than the rock supporting the hills on the Pacific Plate side of the fault (75 million year old Pelona schist). The juxtaposition of these different rock bodies is due to the San Andreas fault moving them to their present positions.




Map view of Cajon Creek with estimated location of the San Andreas fault. - Google Earth

- The San Andreas Fault is a right-lateral strike slip fault
  - The San Andreas fault and its subsidiary branches comprise the San Andreas fault zone, which altogether have accommodated approximately 350 miles (USGS) of plate movement between the Pacific and North American plates

*Activity 2: Research indicates that this segment of the fault should be moving about 1 inch per year, but friction has prevented this part of the fault from moving since before the year 1700. If the fault were to slip today, how many feet would you expect the road on the other side of fault to shift? Show your work as you convert from inches to feet per year. Start by subtracting 1700 from the current year. In what direction would the ground on the other side of the fault move relative to us (right or left)?*

*Activity 3: Make a map view drawing of the San Andreas Fault that shows how Route 66 would be offset by movement along the fault.*

### Stop 2 – Mormon Rocks

Addresses learning objectives:
2. Use stratigraphy and texture to identify rocks as sedimentary
3. Distinguish clastic/detrital texture in rock
6. Describe the geologic significance of the "inface bluffs"
7. Describe how the orientation of the strata of Cajon Formation and the Punchbowl Formation violates the Law of Original Horizontality and explain why this has happened
9. Explain why the Cajon and Punchbowl formations are not the same body of rock despite having very similar lithology

Continue on Cajon Blvd (Route 66) towards the I-15. As you drive onto the North American Plate ask students what type of rock make up the hills off to the left.

Take I-15 north to the next exit, CA-138, turn left and go 1.5 miles to the Mormon Rocks; park in the paved parking area immediately off the right side (north) of CA-138 and just past Lone Pine Canyon Road. From the parking area, walk across the desert scrub brush mantled floodplain towards Mormon Rocks then down into the Cajon Creek wash. From here take a moment to observe the outcrops of the Cajon Formation or Cajon Valley Formation (Kenney, M.) that make up Mormon Rocks.

*Activity 4: Ask, Does the strata making up the Cajon Formation agree with the **Law of Original Horizontality**? –* No*. Why not? –* It isn't horizontal. *What happened to the strata since it was deposited and why? –* It has been tilted so it now juts out of the ground.

Walk up to the outcrops.

*Activity 5: Instruct students to make a sketch representative of an approximate 1 foot by 1 foot section of the Cajon Formation so the drawing shows stratification and a few of the clasts or grains. Students should also note the color and texture of the grains, because they will be asked to campare these to the pebbles and cobbles contained in the Punchbowl Formation later on this field trip. If students are more advanced they could also be asked to identify the specific type of rock that make up the grains in their drawings.*

*Ask, "What was the depositional environment where this sediment was deposted?" –* energetic streams/braided streams

- Cajon Formation

  - Sandstone and conglomerate
  - Represent braided stream deposits; horse and camel fossils indicate that the sediments were deposited 15-18 million years ago (Prothero, 2011)
  - Tectonic stresses have tilted the strata up to about 45º
  - Holes in strata could be the result of larger grains being "weathered-out" then wind erosion enlarging the hole over time <u>OR</u> are from a different weathering process called tafoni:
    - Tafoni are common weathering phenomena in semiarid regions (Trent, personal communication) where rock outcrops intersect the soil horizon. Alternating wetting and drying results in chemical weathering of the rock at ground level, along the soil horizon, making the holes in the rock. Erosion of the older soil horizon leaves the holes suspended above the current ground level.

Return to vechicle(s) and continue west on CA-138 for 3.9 miles, where you'll pull over on the shoulder of the highway at Mt. Shadow Manor Lane (or anywhere you can safely do so before or after Mt. Shadow Manor Lane). If you feel that you'll have enough space to safely assemble your group on the side of the bus opposite the road, then you could exit vehcile(s) for a discussion about the inface bluffs (see below). Alternatively, discuss from within your vehicle.

- Inface bluffs
  - The inface bluffs are a cross-sectional view of the interior of several **alluvial fans** that were disconnected from the San Gabriel mountain front from which they were receiving their sediment. This happened because of the headward (upstream) erosion of Cajon Creek. Streams, like Cajon Creek will flow and erode a path of least resistance. In this case, that path is along the San Andreas fault, where the rock has been ground-up, making it weaker and more easily erodeble, by movement along the fault. Relative to us, movement of the North American plate has shifted these alluvial fans to our right, with their interiors now exposed see "C" in illustration below (Sylvester and Gans, 2016).

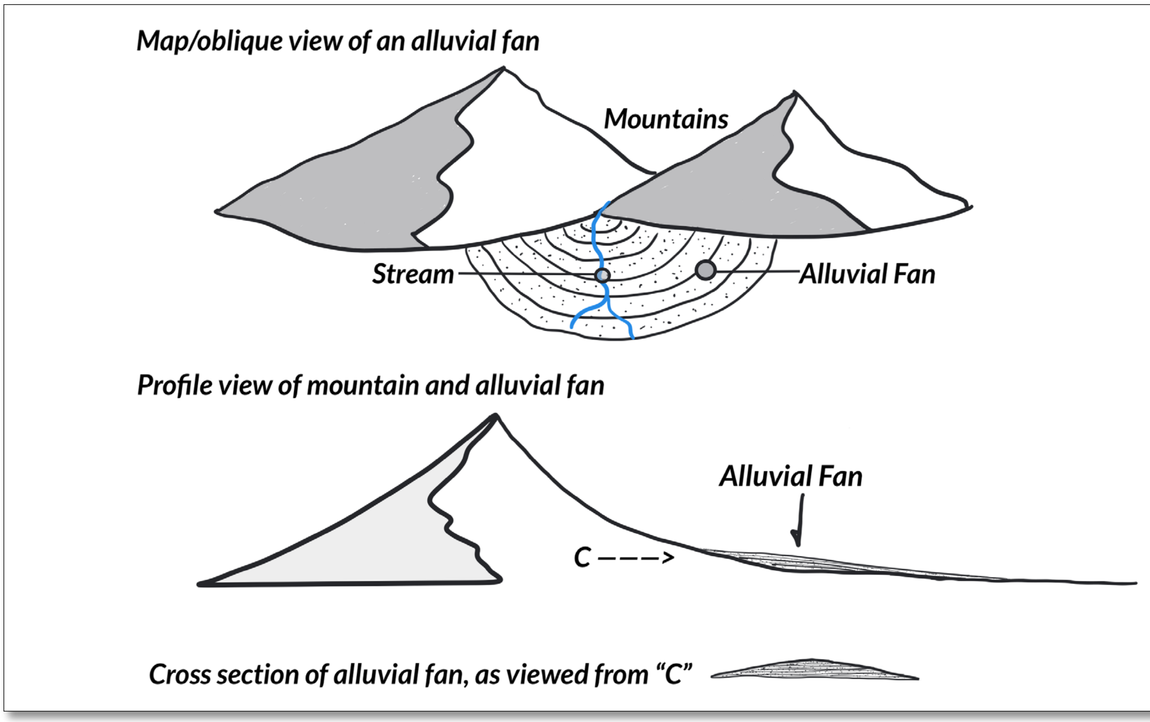



Diagram of an alluvial fan from different perspectives.

Continue west on CA-138 for about 24.5 miles to 131st/Longview Road (N6); turn left (south) and continue for about 2.2 miles to Fort Tejon Road, where you turn left then make a quick right onto the next street, 131st/Longview Road (N6). Proceed about 2.3 miles to Tumbleweed Road (look for signs for Devil's Punchbowl) and turn left. Drive until the road ends at the parking lot for Devil's Punchbowl; note: Tumbleweed Road turns into Devils Punchbowl Road. The parking lot is often full so expect to park along the road just before the parking lot. If arriving by charter bus, ask the driver to enter the parking lot (the driver should be able to turn the bus around in the parking lot) to unload the group then park where space is available in the parking lot or along the road.

Before leaving vehicles, remind students to take everything with them, as you'll be away from the bus for 1.5-2.5 hours. Assuming you start your visit with a lunch break, direct students to the picnic area, about 50 yards beyond the far right corner (southeast) of the parking lot. You may want to point out the port-a-potty in the parking lot and the other restrooms, which are to the left of the visitor's center. Finally, it's probably a good idea to designate a meeting place and time for your lecture, to prevent students from wandering too far off. The "punchbowl overlook" (see below) is great spot to discuss the geology that makes this a special place.

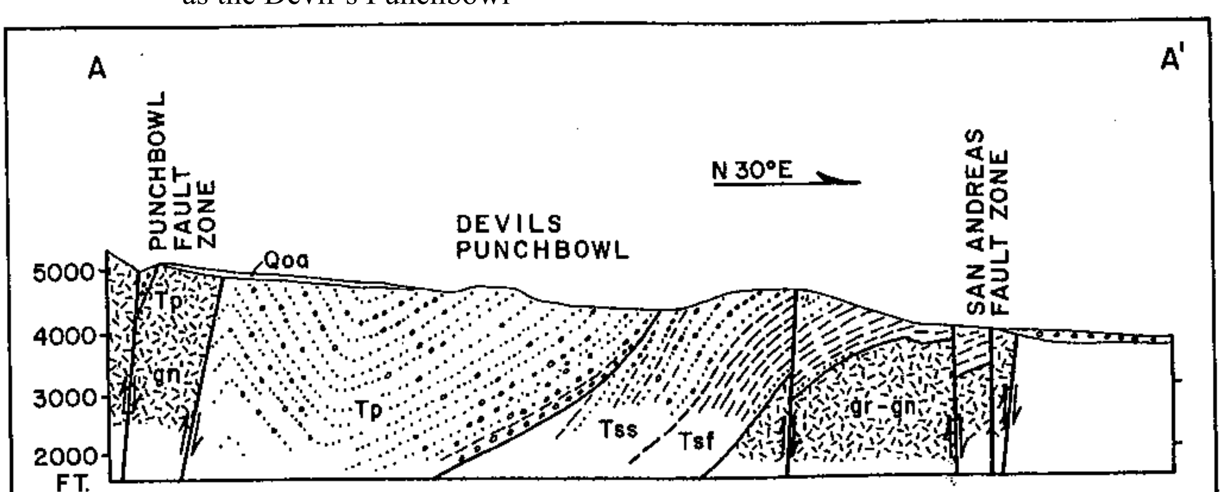
### Stop 3 –Devil's Punchbowl Natural Area

Addresses learning objectives:
2. Identify sedimentary rocks and strata
3. Distinguish clastic/detrital texture in rock
7. Describe how the orientation of the strata of Cajon Formation and the Punchbowl Formation violates the Law of Original Horizontality and explain why this has happened
8. Identify and draw a syncline

9. Explain why the Cajon and Punchbowl formations are not one and the same despite appearing very similar

Punchbowl overlook - just to the left (north) of the building opposite the visitor's center, the one with owl cages outside, there is an overlook that offers excellent views of the **plunging syncline** that gives this place its name and good spot to give a lecture on the geology. Note, you may wish to withhold some of the information below from your students until after they have completed the Activity 8, in order to not give away answers to the suggested questions.

- Punchbowl Formation
  - Conglomerate and sandstone beds represent braided river and alluvial fan deposits from 7-10 million years ago (as opposed to 15-18 million years old for the Cajon Formation)
  - Boulders larger than 2 feet across indicate they were deposited during flash flood events
  - Granitic and gneissic cobble to boulder-sized clasts do not match the bedrock of the adjacent and upstream San Gabriel Mountains, nor do the generally smaller grains of porphyritic andesite
    - The source area for the porphyritic andesite is the Sidewinder Volcanic field, nearly 60 miles to the northeast… How did it get here???
    - The fact that the lithology of the sediment within the Punchbowl Formation do not match the lithology of the local source area (San Gabriel Mountains) indicate this formation is exotic to this area and was therefore moved here from its place of formation, its depositional environment, by lateral movement along the San Andreas fault Zone
      - Sediment containing Sidewinder volcanic rock was transported across the San Andreas fault and deposited on the Pacific Plate
  - The Punchbowl Formation is situated on the Pacific Plate, between the San Andreas fault to the north and the Punchbowl Fault to the south, which has caused the strata to be squeezed by compressive stresses into the **syncline** now exposed as the Devil's Punchbowl




Cross-section of Syncline at Devil's Punchbowl; Tp = Tertiary Punchbowl Formation. – Dibblee, 1987.

*Activity 6: Ask, What type of rock (igneous, sedimentary, metamorphic) is the Punchbowl Formation? Has the orientation of the strata changed from its original position? Does this agree with the Law of Original Horizontality?*

*Activity 7: Instruct students to show the orientation or dip of the strata to their left (north) vs. to their right (south) using an outstretched hand. Ask students to discuss why there is a difference.*

Leaving the Punchbowl Overlook you'll walk down the trail to the right (immediately to the north of the overlook) and begin the "Loop Trail" (not the Pinyon Pathway trail). Walk down the Loop Trail a few hundred feet to the first hairpin right turn, step over the dead tree trunk and walk past the "Trail →" sign post. Your next stop are the outcrops of the Punchbowl Formation just in front of you.

The first, smallest outcrop immediately left of the pinyon pine and about 10 feet north of Loop Trail contains a large, nearly black clast of Sidewinder volcanic field. Continue north (away from the Loop Trail) to the taller, more prominent and instructive outcrops, but be careful to avoid the top of cliff to your right. Alternatively, you could walk back towards the Loop Trail, turning right (west) just before reaching the Loop Trail to access roughly-defined trail that takes you down and past the first small outcrop, along a wash, and about 100 feet to the dip slope side of the tall, prominent outcrops (see photograph of outcrops).

**Outcrops of the Cajon Formation.**

*Activity 8: Ask students to closely inspect Punchbowl Formation then make a sketch of the Cajon Formation – like the sketch of the Cajon beds at Mormon Rock. Once they've finished, ask them if this rock, is the same as the Cajon Formation at Mormon Rocks.*

- For "yes" answers, ask: *What makes you think they are the same? And, How did these rocks end up here?*
- For the correct answer, "no" ask: *How do we know they are not the same*? Evidence for the answer to this question lies in the grains that make up some pebbles within the strata. In particular, the black to reddish clasts are volcanic sediments from the Sidewinder Volcanic field in the Mojave Desert, northeast of Victorville, about 60 miles away. Also, the other grains in the Punchbowl Formation do not match the rock that makes up the San Gabriel Mountains next to us. This means that this sediment was not originally deposited here, but instead must have been moved to this location. *How could this happen?*

After discussion and study of outcrops you may wish to complete the Loop Trail. This moderately strenuous hike takes one down through outcrops of the Punchbowl formation, which provide opportunities for further study, to a small creek at the bottom of Devil's Punchbowl then back out again. Allow about an hour to complete. NOTE: If you choose to hike the entire loop trail you should be prepared that some students may struggle walking back out of the punchbowl; on a few occasions I've been sincerely worried about the health of some students. As a result, before descending to the bottom I now announce to my group that the hike is strenuous and therefore optional, and that it is perfectly okay if they want to wait in the visitor's center or immediately around the picnic area for the group to return.

With enough time, examine the stream channel at the bottom of the punchbowl. There, you can discuss stream channels – this one provides an excellent example of a "bedrock channel" – and point and discuss the lithology of the cobbles and boulders within channel.

*Activity 9: Ask students to identify the lithology of the cobbles and boulders within the channel.*

Point out to students the stream sediment, alluvium, has been eroded from the San Gabriel Mountains upstream and are different than the grains within the Punchbowl Formation. You could also point out some of the rock sliding that's happening just above the channel. Go back to the trail and hike to your left, in order to complete the Loop Trail.

Load up the vehicles and head to home. I'd recommend checking Google Maps for the fastest route back. Depending on your origin and traffic the best route could be west on CA-138 to CA-14 south or CA-138 east, back to the I-15 south.

## Follow-up Questions

1. Explain how the shape of Cajon Creek and the juxtaposition of rock units near the Blue Cut area provide evidence for recent movement along the San Andreas fault.
2. What type of rock is found at Mormon Rocks? What is the specific name and age of the geologic formation? What was the depositional environment for the sediments that make up the Cajon beds at Mormon Rocks?
3. What is the geologic significance of the inface bluffs as discussed at Mormon Rocks.
4. On what tectonic plate is Devil's Punchbowl State Park found?
5. What type of rock is found at Devils Punchbowl? What is the specific name and age of the geologic formation? Under what geologic conditions were these sediments deposited?
6. How do we know that sediment included in the Punchbowl Formation was deposited in a different geographic position than they are today?
7. Explain why the Cajon and Punchbowl formations are not the same rock unit despite being very similar in apperance?
8. What type of geologic structure gives Devil's Punchbowl its name? How does such a structure form?

# Chapter 4 – Vasquez Rocks Natural Area

## Introduction

Vasquez Rocks Natural Area Park (Vasquez Rocks) is a local geologic gem in that it offers perhaps the best continuous sequence of early Miocene terrestrial sedimentary rock in southern California – vividly colored, spectacularly tilting out of the ground, and all this within an hour from wherever you are! Because of its geology, Vasquez Rocks has been used as the backdrop for countless movies, television shows, and commercials, including: *The Lone Ranger, Bonanza, Maverick, Blazing Saddles, several Star Trek movies, and TV episodes, Cars, Holes*, *Mighty Morphin Power Rangers, John Carter Westworld,* the *Flintstones,* and most importantly, *Bill and Ted's Bogus Journey*. Recently, Jeep was running a commercial where rock climbers appeared to be repelling down from the upturned **strata** into the parking area... Nothing bogus about that!

**Cerritos College students in front of the "Star Trek" outcrop.**

Long before Vasquez Rocks was discovered by Hollywood, though, this area was settled by Native Americans. Archeological evidence indicates that people lived here as far back as 2300 BCE, perhaps even earlier. While little is known about the earliest occupants of Vasquez Rocks, more is known about its most recent inhabitants, the Native American Tataviam people. Tataviam, or "people facing the sun", settled in this sunny region now known as Vasquez Rocks about 2000 years ago. They subsisted mostly by hunting and gathering. They made their homes by assembling cottonwood and Juniper branches around deeper sections of overhanging strata and then covering the framework with native grasses. The Tataviam are grouped with native peoples in the Uto-Aztecan language family, although their language was difficult to understand. Spanish missionaries arrived in this area in the 1700s, pressuring the Tataviam to adopt the Spanish language and culture. The last full-blooded and native-speaking Tataviam died in 1916.

A more notorious dweller at Vasquez Rocks was Tiburcio Vasquez, an infamous bandito who utilized the complicated topography for his hideouts. Legend has it that he was Mexican Robin Hood, stealing money and livestock from the well-off and giving to needy Mexican families. His hideout was eventually discovered, and he was chased out of his Vasquez Rocks refuge, tracked down, captured then tried and executed.

This field trip could be done in a half-day or paired with other field trip itineraries covered in this book: Devil's Punchbowl Natural Area, the San Andreas fault, or Red Rock Canyon State Park.

A video introduction:

## Geographic Setting

Vasquez Rocks is located on the northern side of the central Transverse Ranges at the eastern end of the Soledad Basin (a.k.a. Soledad Canyon). The Santa Clara River separates this hilly area from the San Gabriel Mountains to the southeast. Being shadowed by the San Gabriels, Pacific Ocean-borne moisture has a difficult time reaching this region, making the climate dry, resulting in vegetation typical of arid terrains of southern California like yuccas, California juniper, scattered scrub oak, and manzanita.

## Geology

The Vasquez Formation, which is principally exposed at Vasquez Rocks, is an exceptionally thick sequence of **sandstone**, **conglomerate,** and **breccia,** that were deposited within a relatively short period of time, 20-23 million years ago. The size, angularity, and sorting of the grains represent **braided stream**, **alluvial fan**, and debris flow deposits. The Santa Clara River, which is crossed en route to Vasquez Rocks, is a braided stream. Comparisons can be made between the sediment in its channel and the texture of the grains in the Vasquez Formation.

The Vasquez Formation represents the lower portion of about 25,000 feet of sediment that accumulated in the Soledad Basin. The Soledad Basin was one of many basins forming about 23 million years ago when the plate boundary in southern California began changing from a convergent to a transform plate boundary. Consequently, tensional stresses started stretching the crust, resulting in blocks of crust rapidly down-dropping along faults, forming deep basins (structural depressions) like the Soledad basin. This basin was filled with sediment eroded from the ancestral San Gabriel mountains, an earlier version of the San Gabriel mountains that have since eroded. We know this because the clasts of anorthosite, gabbro, and the Lowe Granodiorite that make up some of the grains in the Vasquez Formation match the bedrock of the San Gabriel Mountains. Oxidation of ferromagnesium minerals, biotite and hornblende from these clasts gives the Vasquez Formation its vibrant red-brown hue. During the past 5 million years, this stratigraphic sequence has been deformed by compressional stress into a wide **syncline**, uplifted, and **differentially weathered**. The northern limb of this east-west trending syncline is now exposed as the **hogback ridges** that make up the skyline and backdrop for the aforementioned television commercials, programs, and movies at Vasquez Rocks.

## Supplementary materials

- Compasses
- Vasquez Rocks USGS 7.5 minute topographic map (2 scanned and modified sections of this map are included in this chapter, one with locations corresponding to suggested learning activities)
- Free digital topo maps can be accessed using US Topo: Maps for America

## Learning Objectives

Through participation in this field trip students should be able to:

1. Identify sedimentary rocks and strata
2. Identify clastic/detrital texture in rocks
3. Explain how and why the orientation of the strata of the Vasquez Formation violates the Law of Original Horizontality
4. Locate positions and interpret topography using a topographic map
5. Recognize braided stream channels
6. Identify channel bars within a braided stream channel
7. Discuss some of the human history associated with field trip stops

## Key Vocabulary

- **Alluvial Fan** – fan-shaped pile of sediment that was deposited intermittently by flash floods/debris flows at the mouth of a mountain canyon
- **Braided stream** – a stream channel made up of several interlacing individual channels, separated from each other by channel bars (piles of alluvium)
- **Breccia** – detrital sedimentary rock composed of angular cobble to boulder sized grains
- **Conglomerate** – detrital sedimentary rock composed of rounded cobble-sized grains
- **Detrital** – texture of sedimentary rock composed of clasts or grains of rocks and minerals
- **Differential Weathering** – different rates of weathering for different types of rock, based on variations in texture, composition, and structure
- **Hogback ridges** – adjective used to describe a landscape with beds of tilted strata separated by gaps where the rock was more easily weathered
- **Law of Original Horizontality** – sediment is always deposited as strata that is horizontal or very nearly horizontal
- **Megacycle** – an unofficial term referring to a repeating succession of similar textures in strata
- **Strata** – a vertical sequence of layers of sediment and is considered the definitive characteristic of sedimentary rocks

- **Sandstone** – detrital sedimentary rock composed of sand-sized grains
- **Syncline** – a "U"-shaped structure caused typically caused by compressing of strata

## Pre Field Trip Questions

1. What physical characteristics make sedimentary rocks easily recognizable in the field?
2. If inspecting a **detrital (clastic)** sedimentary rock, what would you see that makes it "detrital"?
3. Using this video: forming sedimentary rocks, answer the following questions (note, you need only watch up to the 3:36 mark in the video):
4. What is meant by a *clastic* sedimentary rock? Describe the relationship between detrital and clastic sedimentary rocks.
5. Where can clastic sedimentary rocks form?
6. About how old are the rocks that make up the Vasquez Rocks landscape?
7. Where did the clasts found in the strata at Vasquez Rocks come from?
8. What caused the strata at Vasquez Rocks to be tilted?

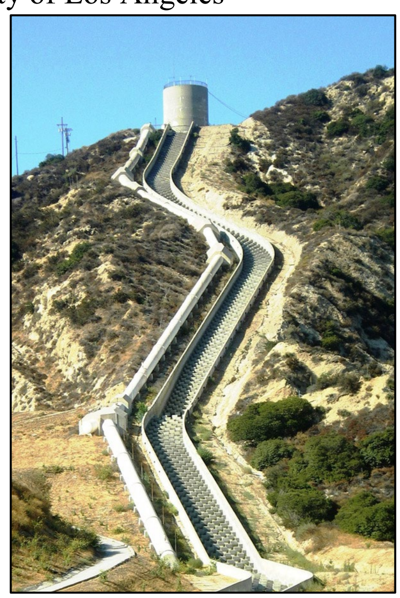
## En Route Talking Points: I-605 north, I-210 west, CA-14 north

- I-605 north
  - The 605 takes us across part of the Los Angeles Basin. This incredibly deep basin formed from roughly 16 million to about 1 million years ago as tectonic forces slowly peeled the Transverse Ranges away from the Peninsular Ranges, rifting open a series of basins. The sea flooded these pits as they slowly opened, meaning what is today the metropolis of Los Angeles and Orange counties were once at the bottom of the Pacific Ocean. All the while, sediment being eroded from the continental highlands filled these depressions with silt, sand, and gravel, up to 6 miles in thickness.
  - San Gabriel River
    - The San Gabriel River Freeway (formal name for I-605)
      - Follows a path of least resistance from river erosion
      - River erosion creates natural pathways
      - Pathways become footpaths
      - Footpaths become horse trails
      - Horse trails become thoroughfares
      - Thoroughfares become highways
    - River transports sediment from the San Gabriel mountains to its base level, the Pacific Ocean
    - Whittier Narrows water gap. The San Gabriel River and Rio Hondo River, just to the west, have created the Whittier Narrows by eroding faster downward than the hills have been uplifted, resulting in carving a topographic saddle, a "water gap", 2 miles wide and 800 feet deep, bisecting the Puente Hills into 2 parts: the Montebello Hills to the west and Whittier Hills to the east. For a more detailed description read the excellent discussion in *Geology Underfoot in Southern California,* "Vignette 9 – A Boon to Communication, The Whittier Narrows"

    - Similarly, Santa Ana River erosion has created water gaps through hills that are now occupied by the 91 and 57 freeways
- Whittier and Puente Hills (east of the 605) are being actively uplifted along the Whittier fault. It runs along the southern base of the hills and is part of the Elsinore fault system. It is very much active, as evidenced by the recent Whittier (1987, M 5.9), Chino Hills (2008, M 5.5), and La Habra (2014, M 5.1) earthquakes.
- Montebello (Repetto) Hills (west of the 605)
    - Western extension of Puente Hills
    - Like Puente Hills, the Montebello Hills are made up of steeply tilted, south-dipping sedimentary rock that is typical of sediment in the LA Basin: mudstone, siltstone, sandstone, and conglomerate
    - On a clear day point out the San Gabriel Mountains making up the northern skyline and its highest peak, the 10,064 feet tall Mt San Antonio, a.k.a. Mt Baldy.
- San Gabriel Mountains
    - Mountains at northern end of the 605 freeway
        - Part of the Transverse Mountain Range, which also includes the Santa Susana, Santa Monica, and Santa Ynez Mountains, the Northern Channel Islands to the west, and the San Bernardino Mountains and Little San Bernardino Mountain, including Joshua Tree National Park, to the east
    - Compressional tectonic forces have rapidly uplifted the San Gabriel Mountains past 5 million years
    - Could be growing as fast or faster than the Himalayan Mountains (Prothero, 2011), at a rate as fast as 70 feet per 1000 years (Sylvester and Gans, 2016)
        - Rapid uplift evidenced by very deep, steep canyons, like Arroyo Seco or Big Tujunga Canyon and triangulated ridges
    - Mountain range is being uplifted along 2 faults, the San Andreas fault along the north side and the Sierra Madre-Cucamonga fault zone (SMCFZ) along the south side
        - SMCFZ Runs along the foot of mountains and has facilitated as much as 10,000 feet of vertical uplift of the San Gabriel Mountains
        - Associated the San Fernando fault that produced the 1971 Sylmar earthquake
    - Contains metamorphic rock as old as 1.7 billion years, Proterozoic plutonic rocks that were intruded by magma of diorite to granite composition generated by subduction of the Farallon Plate during the Mesozoic time
- After passing the I-10 and shortly before arriving at the I-210 interchange watch for deep pits on either side of the freeway
    - Gravel pits are mines for alluvium being shed off the San Gabriel Mountains
    - Gravel used for concrete and roadways

    - Water in a pit means it is deeper than the water table (depth to groundwater)

- I -210 west
  - The foothills are a series of coalesced alluvial fans that formed as the San Gabriel Mountains were uplifted, weathered, and eroded by streams; when the streams flow out of narrow mountain canyons, they slow and lose their ability to transport their sediment load, resulting in deposition and the formation of alluvial fans
  - Many of these stream channels are dammed where canyons open up, creating “catch flow basins” that trap or at least slow the dangerous boulder-sized clasts contained in inevitable debris flows
- Continuing on the I-210 west at the CA-134 interchange, look for “benched” road cuts, a common practice used to increase slope stability
- Driving through Sylmar takes one past the epicenter of the 1971 magnitude 6.5 Sylmar earthquake that caused over a billion dollars in damage and 65 deaths, mostly from the collapse of the Olive View Hospital
- Los Angeles Aqueduct
  - As the 210 mergers with I-5, look ahead, and you should notice a long pipe-like feature coming down the hillside just to the right of the freeway freeway
    - This is a chute for carrying water, baffled for aerating
  - One of three aqueduct systems that brings water to the greater Los Angeles area, the other two being the California Aqueduct which delivers water from the western Sierra Nevadas, and the Colorado River Aqueduct brings water from the Colorado River
  - Desgined by self-taught engineer William Mulholland to divert water from the Owens River and its tributaries to the burgeoning city of Los Angeles
    - Water would be used to boost land values and profits for developers
  - Remarkable engineering feat considering it was desinged and built over 100 years ago, so water flows downhill over its entire length, requiring no pumps and only gravity to transport water from its source 235 miles to L.A.



**Los Angeles Aqueduct - CC**

  - Building the aquaduct necessitated some shady business dealings, violence, and even deaths
    - Residents of Owens Valley had plans to use the water from the Owens River to develop agriculture and livestock

- Fred Eaton, a former mayor of Los Angeles and politically well-connected, used a contact in Owens Valley to, through deception, buy up land in Owens Valley and with it water rights to the Owens River
- Mullholland and Eaton were also working behind the scences with a collection of friends and business partners to buy up cheap land in the San Fernando Valley, which would be made drastically more valuable once it was provided with a reliable water source

William Mulholland. – CC.

- This story serves as part of the plot for the critically acclaimed 1974 movie *Chinatown*, starring Jack Nickolson: [movie clip from Chinatown]

- While completed ahead of schedule and under budget, the completion of the aqueduct consumed machines, mules, and men, with several construction-related deaths
- Owens Valley residents rebelled upon learning that all the water of "their river" was being diverted to Los Angeles
  - In 1924 seventy armed Owens Valley men took control of an aqueduct gate and shut off the flow of water
  - In 1927 a 45-foot section was blown up
  - The uprisings were permantly qualched when Mulholland sent out machine gun armed horseback patrols with orders to shoot to kill anyone disturbing the aqueduct

- I-5/I-14 interchange
  - Some of the overpasses here collapsed during both the 1994 and 1971 earthquakes
- CA-14 north to Stop 1

## Field Trip Stops

All stops listed in this chapter are accessible by large charter bus, van, or 2-wheel drive car.

### Stop 1 – Placerita Canyon

Addresses learning objective:
7. Discuss some of the human history associated with field trip stops

Exit Placerita Canyon Road (exit 3) from CA-14, turn right onto Placerita Canyon Road and drive east for about 1.5 miles to Placerita Canyon Nature Center. Here you'll find restrooms, a vulture, hawk, and raven (at the time of this writing) in outdoor cages, interesting information about the local nature, and trail system that includes a trail to the Oak of the Golden Dream.

Placerita Canyon earned its name and fame for the placer deposits discovered here in 1842, six years before the Gold Rush began in the western Sierra Nevada Mountains. As the story goes, Francisco Lopez found gold flakes in the soil while digging up wild onions. Gold deposited as sediment by rivers is called *placer gold*, hence the canyon's name. Look for signage for the Oak of the Golden Dream, the tree under which Francisco found the gold. Rumor has it that one can still find flakes of gold in the streambed after heavy rains have turned over boulders (Prothero, 2011).

Return to vehicles and continue northbound in CA-14.

### Stop 2 – Santa Clara River

Addresses learning objectives:
5. Recognize braided stream channels
6. Identify channel bars within a braided stream channel

Exit Sand Canyon Road; turn right onto Sand Canyon and drive over the bridge. Make a right on the first street after the bridge, Lost Canyon Road, and immediately park on the road shoulder opposite the education center (GLC SB/SC). Exit vehicles and backtrack over the west side of the bridge (be sure to remind students to stay on sidewalk) to about 2/3 of the way across for the best views of the Santa Clara River.

#### *Santa Clara River*

- Longest undammed river in southern California (Prothero, 2011) and significant in that its channel hasn't been modified by human construction
- Braided stream, common in the foothills of mountains
- Multiple intertwining channels, weaving around channel bars
- Ephemeral stream channel in that it is dry unless it has just rained
- The dry channel is deceiving, because water is flowing in the subsurface as groundwater, which will eventually be utilized by communities downstream (Sylvester and Gans, 2016)

**Santa Clara River.**

Return to CA-14 north and proceed 2 exits to Agua Dulce Canyon Road.

### Stop 3 – Vasquez Rocks

Addresses learning objectives:
1. Identify sedimentary rocks and strata
2. Identify clastic/detrital texture in rocks
3. Describe how the orientation of the strata of the Vasquez Formation violates the Law of Original Horizontality and explain why this has happened
4. Locate position and interpret topography using a topographic map

Exit Agua Dulce Canyon Road from CA-14, turn left at bottom of the off-ramp onto Agua Dulce Road and drive a little over 2 miles to the entrance, marked by the sign "Vasquez Rocks Natural Area". If traveling by charter bus, alert the driver that they will need to make a hairpin turn. Proceed past the visitor's center, veering left towards the hogback ridges and onto the unpaved road.  Take the road all the way down to the “bottom”, which is a huge parking area where any type of vehicle can easily turn around.   I recommend parking along the eastern margin.  There are three port-o-potties at the south end of the parking area that some students may need to visit before embarking on field trip.

Note: the visitor’s center has interesting historical information and a little about the local biology and geology, but perhaps not enough content to make it educationally worthwhile for an earth science field trip.

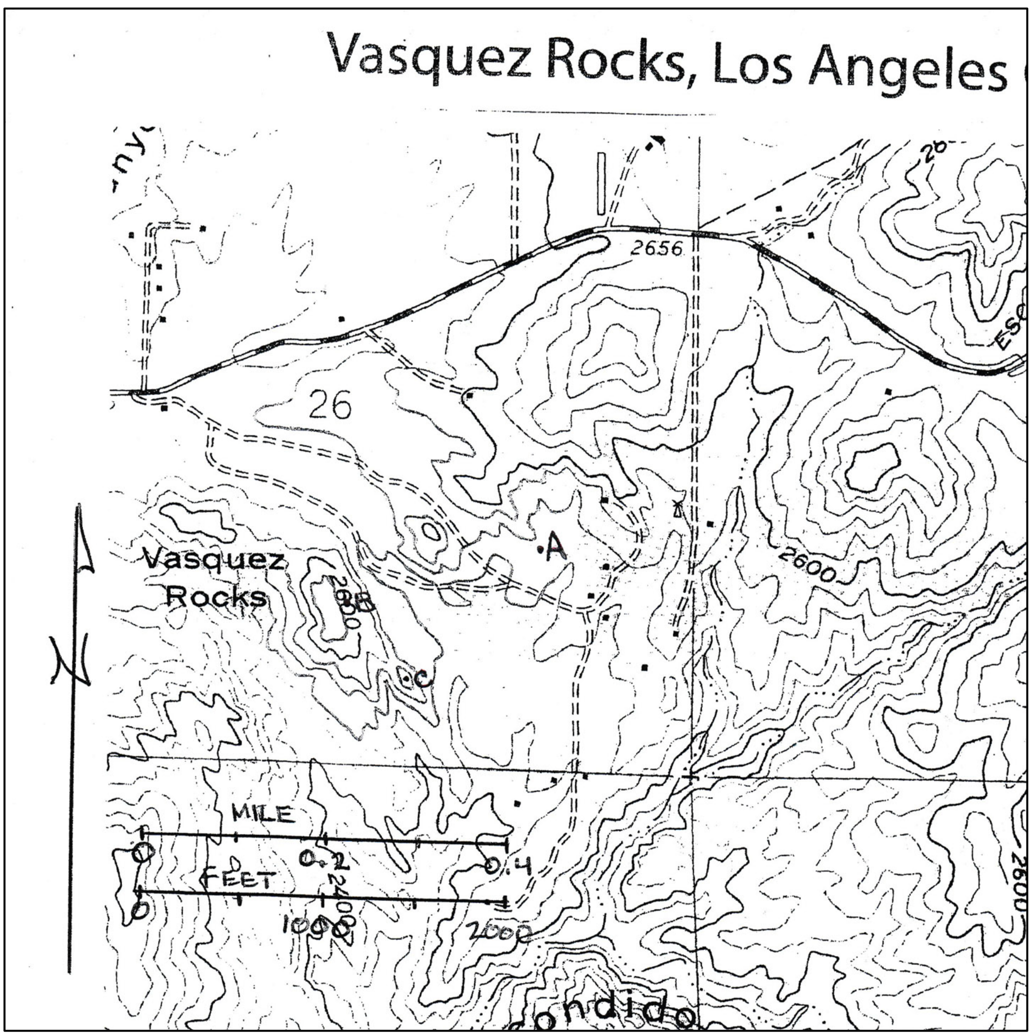
**Rock slide blocks resting on the dip slope of a hogback ridge behind a hiker at Vasquez Rocks.**

From the eastern margin of the parking area, you could start by pointing out some of the nice examples of rockslides on the south-facing slopes a few hundred feet to the north. After doing so, walk east up onto the outcrops (opposite the tallest tilted strata upon which people are probably climbing, hereafter referred to as the *Star Trek* outcrop) and across the “hogbacks” of tilted strata for about 100 yards until you reach a ledge that cannot by navigated without climbing.  You should be standing on very course **breccia** bed, which is at approximately point “A” on the map (following pages).  Look back westward over the stratigraphic sequence between you and the parking area.

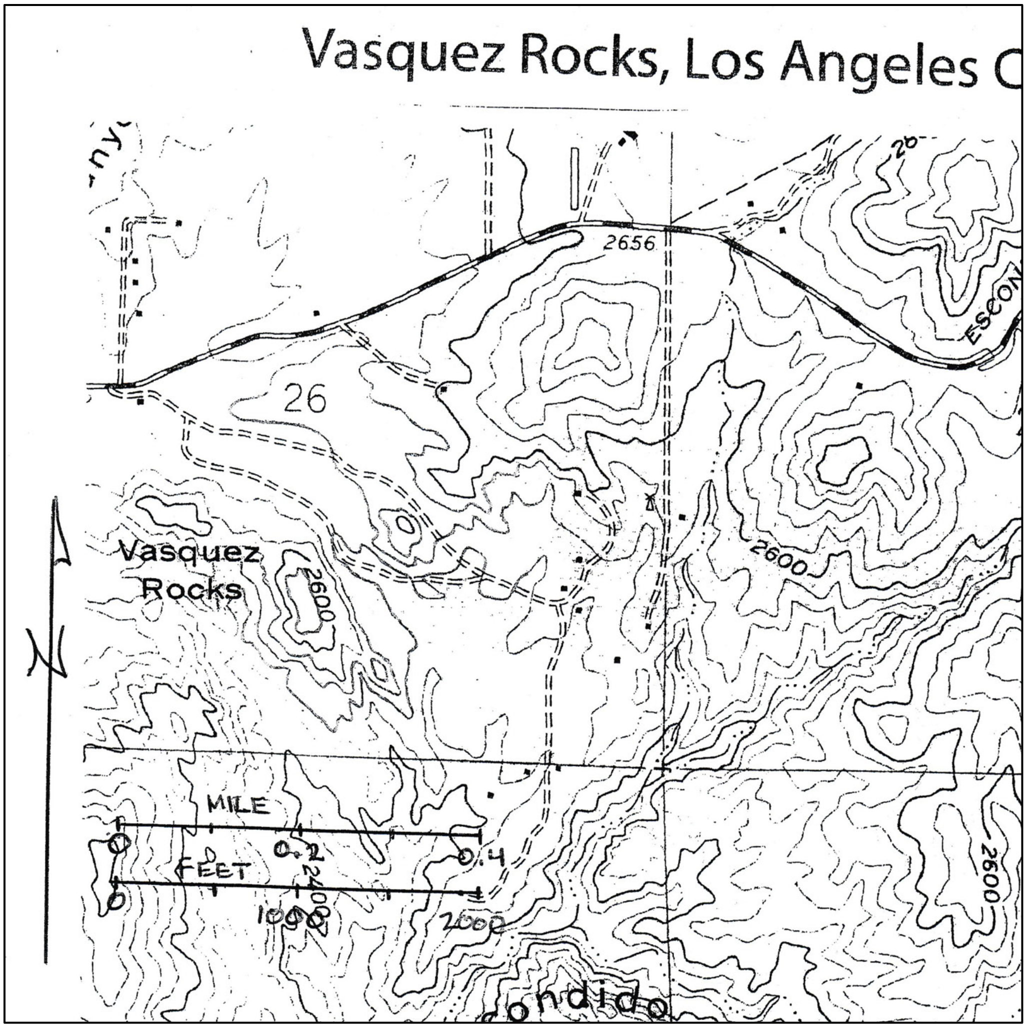
Once you have your group comfortably within earshot, you could give them a geologic description of the Vasquez Formation (see *Geology* section at the start of this chapter).  Point out the sizes, shapes, and compositions of the grains contained in the strata here.  These strata exemplify detrital sedimentary rocks, as the grains are visible at outcrop-scale.  Also point out how the grain size controls how easily beds are weathered – generally, the coarsest beds are most resistant, while finest-grained beds are most easily weathered and eroded.

**Photo of tilted strata at Vasquez Rocks as viewed from location A on the included topographic map**

*Activity 1: Ask students to identify the sandstone stratum (layer of sedimentary rock), conglomerate, and breccia stratum. What clasts make up the pebbles and cobbles in the conglomerate and breccia?*

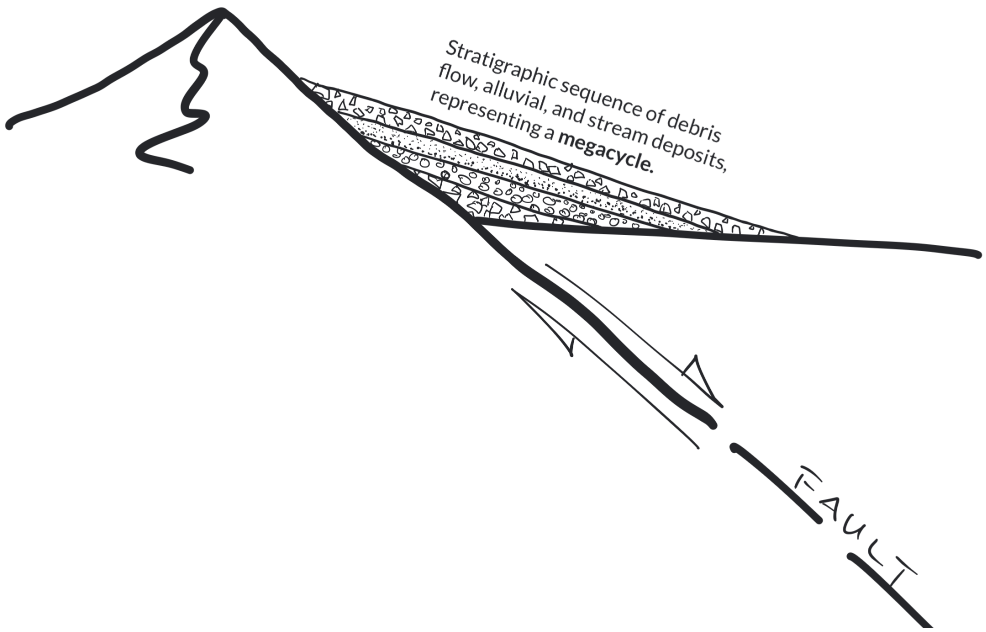



**Topographic map of Vasquez Rocks with locations, A, B, and C.**

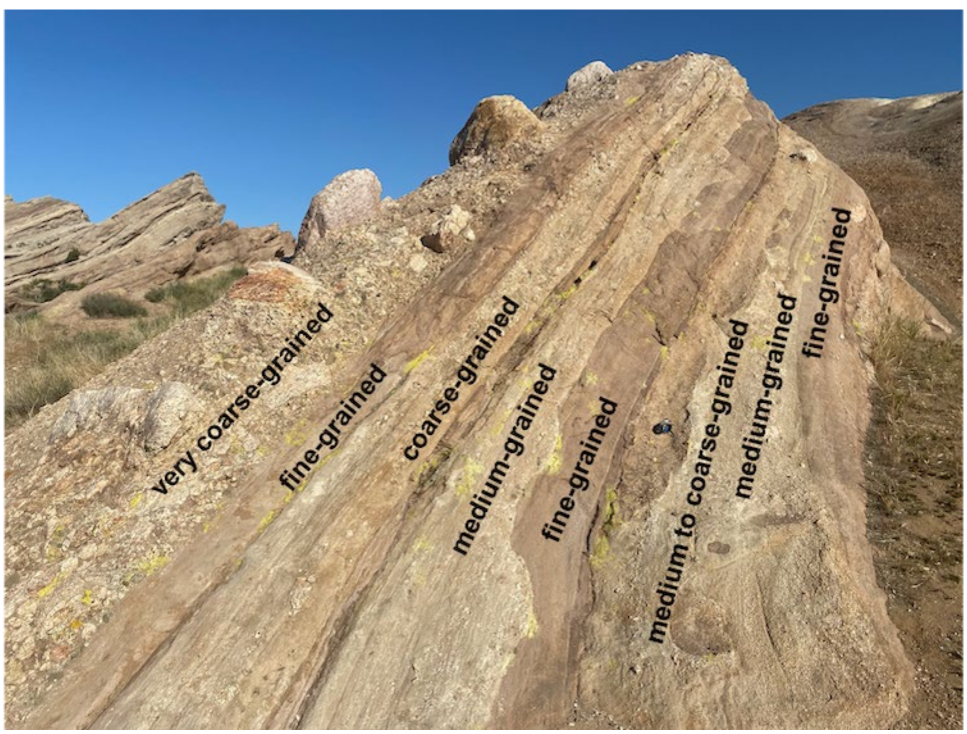



Topographic Map of Vasquez Rocks without labels.

Once you've checked for understanding amongst your group regarding their rock identification, ask: Is there any sort of pattern to the occurrence of the coarsest beds? Point out that within a sequence of strata, the grain size changes from fine to coarse then back to fine. In other words, if you were to start with the most coarse-grained bed of an outcrop and then look stratigraphically upward, each higher bed is finer-grained than the bed below until one reaches another coarse-grained bed, at which place the fining-upward sequence repeats. This stratigraphic pattern results from episodic mountain building during the time these sediments were being deposited. During a period of mountain building, slopes and stream channels would be steeper; consequently, streams would flow with greater energy and could carry larger clasts. When tectonic uplift/mountain building slowed or stopped, streams would erode their channels to lower gradients and in turn, would be flowing slower and with less energy and transporting progressively finer sediment. This is reflected in the Vasquez Formation with the coarsest beds, breccia, fining upwards to conglomerate then sandstones, as the streams eroded their channels flatter over time. Eventually, mountain building renewed, and the gradient of the stream channel would increase, meaning streams would flow with more energy and transport and deposit larger grains. As the tectonic uplift rate slowed again, the sediment transported and deposited would be progressively finer, repeating the cycle. A megacycle is a general term that can be used to describe this cycle of episodic mountain building as recorded by a fining-upward sequence of strata.




**Cartoon showing a cartoon of a megacycle: coarse to finer, back to coarser sediments being shed from a fault controlled mountain front.**




**A labeled photograph of tilted strata records an example of a megacycle.**

*Activity 2: Have students sketch a section of an outcrop, so they show a megacycle sequence. Label drawings with "megacycle", "breccia", "conglomerate", and "sandstone".*

*Activity 3: Ask student to provide written responses to the questions: "How does the strata at Vasquez Rocks violate the* ***Law of Original Horizontality****?" and "How does grain size control the rate of weathering of beds of stratum?"*

From here, walk southwestward across the parking area, so you skirt the southern terminus of the Star Trek outcrop, around the yellow road gate, then northwest along the trail at the base of the Star Trek outcrops. When you arrive at the trail junction, turn left and walk southwest to the next trail junction, where you'll turn left again, walking up the steep ridge to point "B". See the map below.

**Google Earth map of Vasquez Rocks Natural Area showing field trip stops A, B, & C, with suggested hiking route.**

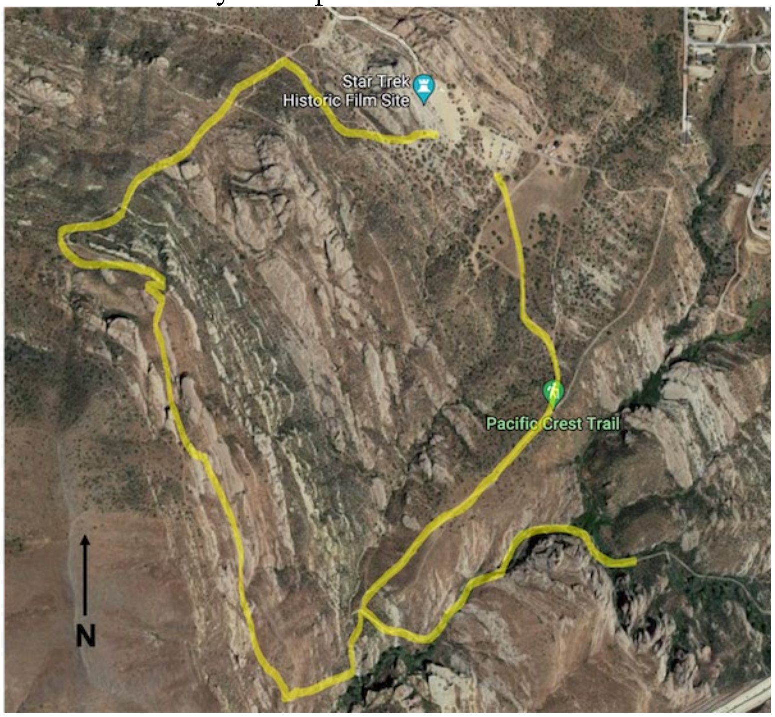
*Activity 4: Once assembled at stop B, ask students to take out compasses or use the compass utility on a smartphone to orient themselves and their map so they face north. Next, ask them to locate themselves, reminding them to keep their maps pointing north. As they are working, ask them to point out the "Star Trek" peak, which lies between "B" and "A", which may help them in pinpointing their location (which is around the "6" in 2600).*

*Question: What about our current location makes determining our position easier?*

This activity offers an opportunity to introduce topographic maps and the valuable skill of locating oneself on a topographic map and relating real-life topography to the topography represented by contour lines.

*Activity 5: At location B the outcrops offer more good examples of the previously discussed megacycles.*

From location B walk down to point "C" and repeat Activity 4. From point C, return to your vehicle(s). Alternatively, if you have an enthusiastic and physically fit group, you may want to extend your visit by hiking more and inspecting the rocks and nature. The map below highlights some of the many trail options.




**Google Earth image of Vasquez Rocks area with hiking trails highlighted.**

## Follow-up Questions

1. How did Placerita Canyon earn its name?
2. What could be deceptive about the Santa Clara River?
3. What was the depositional setting for the Vasquez Formation, and when did this happen?
4. Identify the texture and name sedimentary rocks (this could be done while still in the field, classroom, of virtually using photographs.
5. Describe or illustrate how a megacycle sequence is formed, including the geologic conditions needed to produce a megacycle and the types of sedimentary rock formed as the depositional environment and geologic conditions change over time.
6. If you found yourself lost in the wilderness but were equipped with a compass and topographic map of the area, what steps would you take to try to locate yourself on the map?

# Chapter 5 – San Gabriel Mountains and the San Andreas Fault

## Introduction

This trip will require traversing winding mountain roads, but will offer some beautiful vistas, close-up views of some of the striking bedrock making up the San Gabriel Mountains, and some of the most direct topographic evidence for the San Andreas fault in southern California. The itinerary also includes a visit to the Wrightwood debris flow and Pallet Creek, where the first paleoseismology study was done, yielding invaluable information about the recurrence rate of earthquakes on the San Andreas fault.

San Gabriel Mountains and downtown Los Angeles. - Photo by David McNew.

The route is accessible by car, van, or charter bus. However, it's possible that some drivers may find the windy, mountain roads challenging to drive and that charter busses may have difficulty finding enough room to park in some of the suggested turnouts. Ideally, your group would travel in a few vans, in order to keep them consolidated, but nimble. It is recommended that if a charter bus service is used, that you have a discussion with a bus company representative ahead of time to ensure that their driver is aware of the challenging driving conditions.

Plan a full day for this trip, but avoid days with inclimate weather or following snowfall. Check road conditions ahead of time. The itinerary starts in La Canada Flintridge, at the SR-2 and I-210 junction.

## Geology

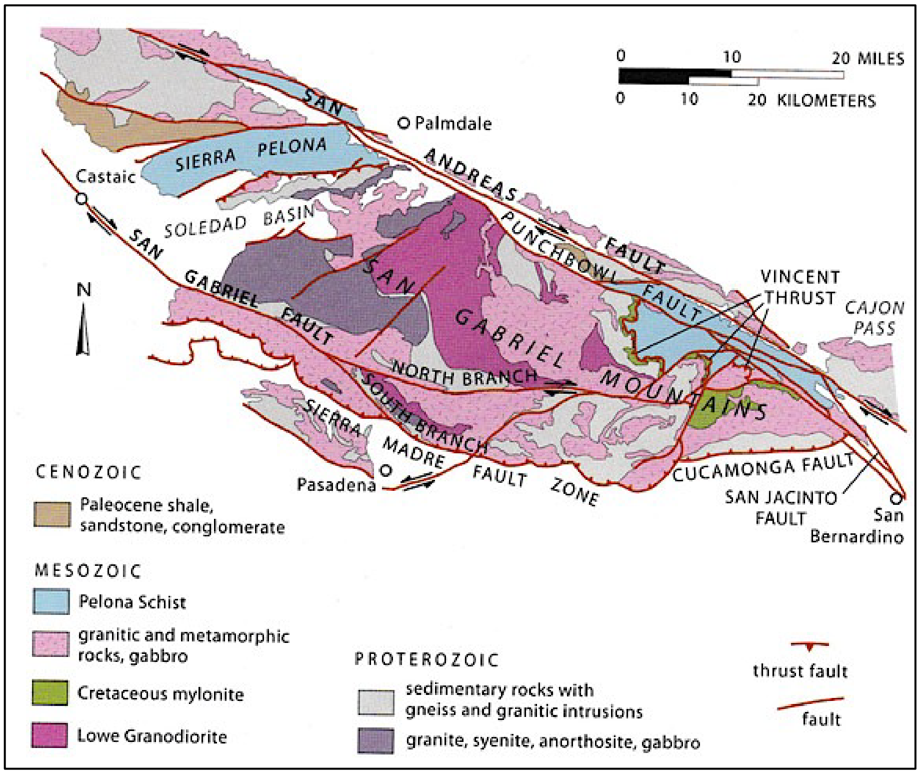
The San Gabriel Mountains are an east-west oriented mountain range about 65 miles long by 25 miles wide, separating the San Fernando and San Gabriel valleys to the south from the Soledad Basin and Mojave Desert to the north. They are part of the east-west trending Transverse Ranges; one of only a few mountain ranges that go "against the grain" of the other mountain ranges in North America, such as the Sierra Nevadas and Rockies, which are oriented north-south. The San Gabriel Mountains are rapidly being uplifted by the San Andreas fault along the northern margin of the range and by the Sierra Madre-Cucamonga fault system along its southern margin (Carter, B.A., 2011).

The rocks of the San Gabriel Mountains "contain some of the oldest and most unusual… rocks in California" (Sylvester and Gans, 2016). The lithology is mostly a complex mix of primarily Proterozoic to Mesozoic age igneous and **metamorphic rocks** that are tectonically separated into an upper and lower plate by the Vincent Thrust, a.k.a. Vincent-Orocopia-Chocolate Mountains thrust fault. The oldest upper plate rocks are nearly 1.7 billion years old high-grade metamorphic rocks, including gneiss, migmatite, and amphibolite. From approximately 1.4 to

1.2 billion years ago, these rocks were intruded by magma that solidified to form a complex anorthosite-syenite-gabbro body. The anorthosite is noteworthy in that it is a rare rock, consisting almost entirely of plagioclase feldspar, making it white in color. During subduction of the Farallon Plate, magma was generated, intruding Earth's crust along a line parallel to the trench, over the full length of California. Some of the main **plutonic rock** bodies found in the San Gabriels from this subduction include: the 220 million-year-old (myo), Lowe Granodiorite, the 122 myo Wilson Diorite, and the 80 myo Josephine granite. The Vincent Thrust separates these upper plate rocks from the lower plate rocks. The lower plate consists of the Pelona Schist, a rock body that formed when the Farallon Plate subducted beneath the North American Plate about 75 million years ago, metamorphosing and seafloor sediments covering the top of the plate. Consequently, the Vincent thrust fault represents the ancient plate boundary between the Farallon Plate and North American Plate.

At 750 miles long, the San Andreas fault is the most important tectonic structure in California. This right-lateral strike-slip fault represents the plate boundary between the Pacific and North Ameican Plates, accommodating about one inch of plate motion per year. Movement of the plates happens as intermittent slips or ruptures along the San Andreas fault, which can produce major earthquakes, such as the magnitude 7.9 San Francisco earthquake in 1906 and the 1857 Fort Tejon in southern California. Careful analysis of strata offset by past earthquakes show that major earthquakes happen along the San Andreas fault at a rate of one major earthquake per 150 years. Major earthquakes typically disturb the ground surface, making ground cracks or **fault scarps**, when one block of crust has been uplifted relative to crust on the other side of the fault.

Since 1857, disruptions to the ground surface, such as scarps and ground cracks, have been erased by erosion and urban development in most places, making the trace of the fault difficult to locate on the Earth's surface. However, this field trip will take us to several locations where the fault scarp from the 1857 earthquake is clearly evident, providing topographic evidence for the location of the fault.




**Geologic map of the San Gabriel Mountains (from Sylvester and Gans, 2016).**

## Learning Objectives

Through participation in this field trip, students should be able to:

1. Use texture to identify igneous rocks
2. Use texture to identify metamorphic rocks
3. Use topographic features, like scarps or vegetation patterns, to locate the trace of a fault
4. Identify landslide scars
5. Identify ductile structures in strata, such as folds
6. Recognize landforms associated with rapidly growing mountains

## Key Vocabulary

- **Fault Scarp –** a low, steep hill, caused by the vertical offset of the ground surface by movement along a fault
- **Metamorphic rock** – a rock that has been altered from a pre existing rock by heat, pressure, and/or hot fluids
- **Plutonic/Intrusive igneous rock** – a rock that forms from the crystallization of magma
- **Thrust Fault (thurst)** – low angle faults (closer to horizontal than vertical) that are caused by compressional stress

## Pre Field Trip Questions

1. Using the following link and/or your textbook, make a sketch of an igneous rock with coarse-grained (phaneritic) texture: igneous rocks
2. Using the following link and/or your textbook, (a) define *foliation* and describe how foliation texture is created, (b) make a sketch of a metamorphic rock with foliated, gneissic banding: metamorphic rocks

3. Draw a fault scarp in a profile/cross-section perspective that shows the fault extending down into the earth from the surface. Label your drawing.
4. Watch this short video, The San Andreas Fault then answer this question, "How likely is it that we could experience the *Big One*, a major earthquake on the San Andreas fault, while we are on our field trip?" Explain.

## En Route Talking Points: I-605 north, I-210 west, CA-14 north

- I-605 north
    - The 605 takes us across part of the Los Angeles Basin. This incredibly deep basin formed from roughly 16 million to about 1 million years ago as tectonic forces slowly peeled the Transverse Ranges away from the Peninsular Ranges, rifting open a series of basins. The sea flooded these pits as they slowly opened, meaning what is today the metropolis of Los Angeles and Orange counties were once at the bottom of the Pacific Ocean. All the while, sediment being eroded from the continental highlands filled these depressions with silt, sand, and gravel, up to 6 miles in thickness.
    - San Gabriel River
        - The San Gabriel River Freeway (formal name for I-605)
            - Follows a path of least resistance from river erosion
            - River erosion creates natural pathways
            - Pathways become footpaths
            - Footpaths become horse trails
            - Horse trails become thoroughfares
            - Thoroughfares become highways
        - River transports sediment from the San Gabriel mountains to its base level, the Pacific Ocean
        - Whittier Narrows water gap. The San Gabriel River and Rio Hondo River, just to the west, have created the Whittier Narrows by eroding faster downward than the hills have been uplifted, resulting in carving a topographic saddle, a "water gap", 2 miles wide and 800 feet deep, bisecting the Puente Hills into 2 parts: the Montebello Hills to the west and Whittier Hills to the east. For a more detailed description read the excellent discussion in *Geology Underfoot in Southern California,* "Vignette 9 – A Boon to Communication, The Whittier Narrows"
        - Similarly, Santa Ana River erosion has created water gaps through hills that are now occupied by the 91 and 57 freeways
    - Whittier and Puente Hills (east of the 605) are being actively uplifted along the Whittier fault, which runs along the base of these hills; this fault is active as evidenced by the recent Whittier (1987, M 5.9), Chino Hills (2008, M 5.5), and La Habra (2014, M 5.1) earthquakes.
    - Montebello (Repetto) Hills (west of the 605)
        - Western extension of Puente Hills
        - Like Puente Hills, the Montebello Hills are made up of steeply tilted, south-dipping sedimentary rock that is typical of sediment in the LA Basin: mudstone, siltstone, sandstone, and conglomerate

- On a clear day point out the San Gabriel Mountains making up the northern skyline and its highest peak, the 10,064 feet tall Mt San Antonio, a.k.a. Mt Baldy.
- San Gabriel Mountains
  - Mountains at northern end of the 605 freeway
    - Represent a block of crust that was peeled away from the Peninsular Ranges to the south and rotated 110$^{o}$ to its current position as Baja California was tectonically peeled away from mainland Mexico (for a more thorough discussion see the Introduction in *Roadside Geology of Southern California*, Sylvester and Gans, 2016)
    - Compressional tectonic forces have rapidly uplifted the San Gabriel Mountains in the past 5 million years
      - Could be growing as fast or faster than the Himalayan Mountains (Prothero, 2011), at a rate as fast as 70 feet per 1000 years (Sylvester and Gans, 2016)
      - Rapid uplift evidenced by very deep, steep canyons, like Arroyo Seco or Big Tujunga Canyon and triangulated ridges
      - Mountain range is being uplifted along 2 faults, the San Andreas fault along the north side and the Sierra Madre-Cucamonga fault zone along south side
  - Contains metamorphic rock as old as 1.7 billion years, as well as Proterozoic plutonic rocks; these were intruded by magma of diorite to granite composition that was generated by subduction of the Farallon Plate during the Mesozoic time. Note: there is a more thorough description of the rocks in the "Geology" section at the beginning of this chapter.
- After passing the I-10 and shortly before arriving at the I-210 interchange watch for deep pits on either side of the freeway
  - Gravel pits mining alluvium being shed off of the San Gabriel Mountains
  - Gravel used for concrete and roadways
  - Water in a pit means it is deeper than the water table (depth to groundwater)

- I-210 west
  - Sierra Madre fault zone
    - Runs along the base of the foot of the mountains
    - Has facilitated as much as 10,000 feet of vertical uplift of the crust, which is today expressed as the San Gabriel Mountains
    - Associated the San Fernando fault that produced the 1971 Sylmar earthquake
  - The foothills are a series of coalesced alluvial fans that formed as the San Gabriels Mountains were uplifted, weathered, and eroded by streams; when the streams flow out of narrow mountain canyons, they slow and lose their ability to transport their sediment load, resulting in deposition and the formation of alluvial fans

- Many of these stream channels are dammed where canyons open up, creating "catch flow basins" that trap or at least slow the dangerous boulder-sized clasts contained in inevitable debris flows
- Continuing on the I-210 west at the CA-134 interchange, look for "benched" road cuts, a common practice used to increase slope stability
- Exit at "2" north, Angeles Crest Hwy, La Cañada Flintridge

## Field Trip Stop Directions

- Starting in La Cañada Flintridge and traveling north/east on SR-2, Angeles Crest Highway
- Mileages associated with the stops 1-4 below are approximated from I-210/SR-2 interchange

Arroyo Seco Canyon.

### Stop 1 – Arroyo Seco Overlook; 2.4 miles

Addresses learning objective:
6. Recognize landforms associated with rapidly growing mountains

Arroyo Seco is one of the principal drainages of the south-facing watersheds of the San Gabriel Mountains. This deep, steep-sided canyon is characteristic of rapidly growing mountains, where uplift outpaces erosion.

*Activity 1: ask students to sketch the cross-section profile of Arroyo Seco Canyon. How might this profile look different than the profile across a meandering river? –* <u>The profile for a meandering river would more or less be flat, with the only slopes being those of the semi-circular stream channel itself.</u>

Traveling north, parking for stop 2 is on the left side of the road.

### Stop 2 – George's Gap trailhead to view the San Gabriel Fault; 8.3 miles (PM 32.8)

Addresses learning objectives:
3. Use topographic features, like scarps or vegetation patterns to locate the trace of a fault

Overview of the Transverse Mountain Ranges:

- From west to east the Transverse Ranges include the Santa Monica, San Gabriel and San Bernardino Mountains, terminating with the Little San Bernardino Mountains that contain JTree
- Unique in that they are one of the only east-west oriented mountain ranges in the western hemisphere, going against-the-grain of the other mountain ranges in California, which all trend roughly north-south

- Their transverse (crosswise) position relative to other mountain ranges is due to the startling fact that they were rotated 110 degrees clockwise over the past 16 million years, caused by the northward movement of the Pacific plate peeling-away a massive block of crust from what is now the Peninsular Range
- Geologically young, having grown within the past 5 million years and perhaps even less
- Rapid growth continues with an uplift rate of approximately 1-2 mm/yr or nearly 8 inches per 100 years!

The San Gabriel Fault was the main branch of the San Andreas fault from 11-4 million years ago. Looking north from the northeast end of the parking lot one can estimate the trace of the San Gabriel Fault, which is delineated by the alignment of the darkest green vegetation about a quarter of the way up the side of Josephine Peak, relative to Big Tujunga Canyon Road (marked by brown roadcuts). The light-colored rock making up Josephine Peak is the Josephine granite, one of the youngest plutonic rocks of the San Gabriel Mountains. (Sylvester and Gans, 2016).

**Photo of Josephine Peak and approximate trace of the San Gabriel fault.**

### Stop 3 – Clear Creek ranger station/information center; 9.2 miles

The San Gabriel Fault runs through the intersection SR-2 and Angeles Forest Highway, continuing eastward to the Red Box ranger station.

Continuing along SR-2, roadcuts expose San Gabriel Gneiss and the Josephine Mountain granite that has been shered-up, and oxidized along the San Gabriel Fault.

### Stop 4 – Red Box picnic area (at turn off for Mount Wilson); 13.8 miles

Addresses learning objectives:

1. Use texture to identify igneous rocks
2. Use texture to identify metamorphic rocks

Red Box offers a nice spot to get out and stretch your legs and use the potty (located on east side of Mount Wilson Red Box road) or take a lunch break. It also provides an opportunity to attempt identification of some of the rock types that make up San Gabriel Mountains. Imbedded in concrete fence supports, walls, and placed as boulders along the perimeter of the parking lot you'll find fine examples for study, including Lowe Granodiorite, Wilson Diorite, and Gneiss, perfectly exposed and a safe distance from the potentially noisy and dangerous SR-2.

Example of gneiss in Red Box picnic area parking lot.

Red Box picnic area parking lot.

*Activity 2: Choose some of a few rock specimens and ask students to, (1) identify the texture; (2) identify the type of rock (plutonic igneous or metamorphic); and, (3) the specific name of the rock, i.e. Lowe Granodiorite.*

Optional: proceed up to Mount Wilson, which offers a variety of interesting and educational options [Mount Wilson website](#) .

### Stop 5 – Lowe Granodiorite; exposed in roadcuts approximately 7 miles east of Red Box at PM 45.4.

Addresses learning objective:

1. Use texture to identify igneous rocks

The Lowe Granodiorite is one of the most significant and distinctive rocks rock bodies in the San Gabriel Mountains. Its white matrix is spotted with large crystals of hornblende, making it easily rocognizable. It's also the oldest of the Mesozoic plutonic rocks at 220 million years old. Its age has significant implications for changing our understanding of the timing of the break-up of Pangaea. Generally, most earth scientists believe that Pangaea began to break up around 190-200 million years ago, at which time subduction was initiated along the western margin of North America. However, the age of the Lowe granodiorite means that the supercontinent may have started breaking up 20-30 million years earlier than previously thought.

Lowe Granodiorite with car keys for scale.

### Stop 6 – Proterozoic Gneiss and granitic intrustions; 4.3 miles east of Red Box/~0.8 mile east of Upper Big Tujunga Canyon Road

Addresses learning objectives:

1. Use texture to identify igneous rocks
2. Use texture to identify metamorphic rocks

To observe a roadcut showing the interaction of granitic and metamorphic rock bodies, use these turnouts: (1) trailhead for Silver Moccasin Trail, approximately just over 1/2 mile east of Upper Big Tujunga Road of roadcut or, (2) 0.8 mile after Upper Big Tujunga Road. The outcrops are exposed in the roadcut between these two turnouts. The second offers better and safer access. To get the best views requires walking along the road, but this should only be done if extreme caution is exercised due to traffic.

**Roadcut exposing a complex mix of granitic and metamorophic rock.**

Other excellent exposures of gneiss can be found along both the north and south side of Big Tujunga Canyon Road, with turnouts, just 0.2 mile north of N2.

### Stop 7 – Punchbowl fault and Pelona Schist at Vincent Gap; 36.4 miles east of Red Box at PM 74.8

Addresses learning objective:

3. Use topographic features, like scarps or vegetation patterns, to locate the trace of a fault

In Vincent Gap the Punchbowl fault separates reddish brown Miocene age sanstone and siltstone from gray Pelona Schist (see Stop 8 discussion). Better exposures of the Pelona Schist can be found by utilizing the two large road pullouts, the first about 0.3 mile and the second about 0.5 mile from Vincent Gap.

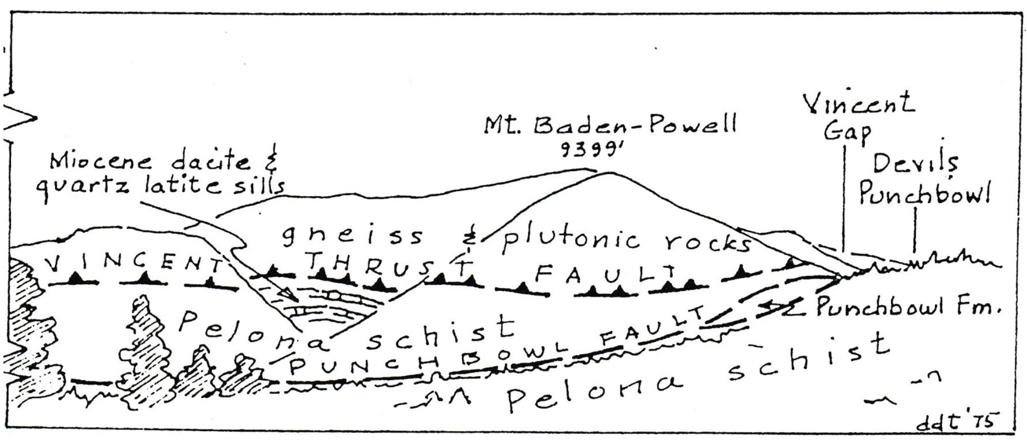
**Pelona Schist exposed in roadcut.**

## Stop 8 – Inspiration Point trailhead; 39.5 miles east of Red Box at PM 78.0 (park on right/south side of highway)

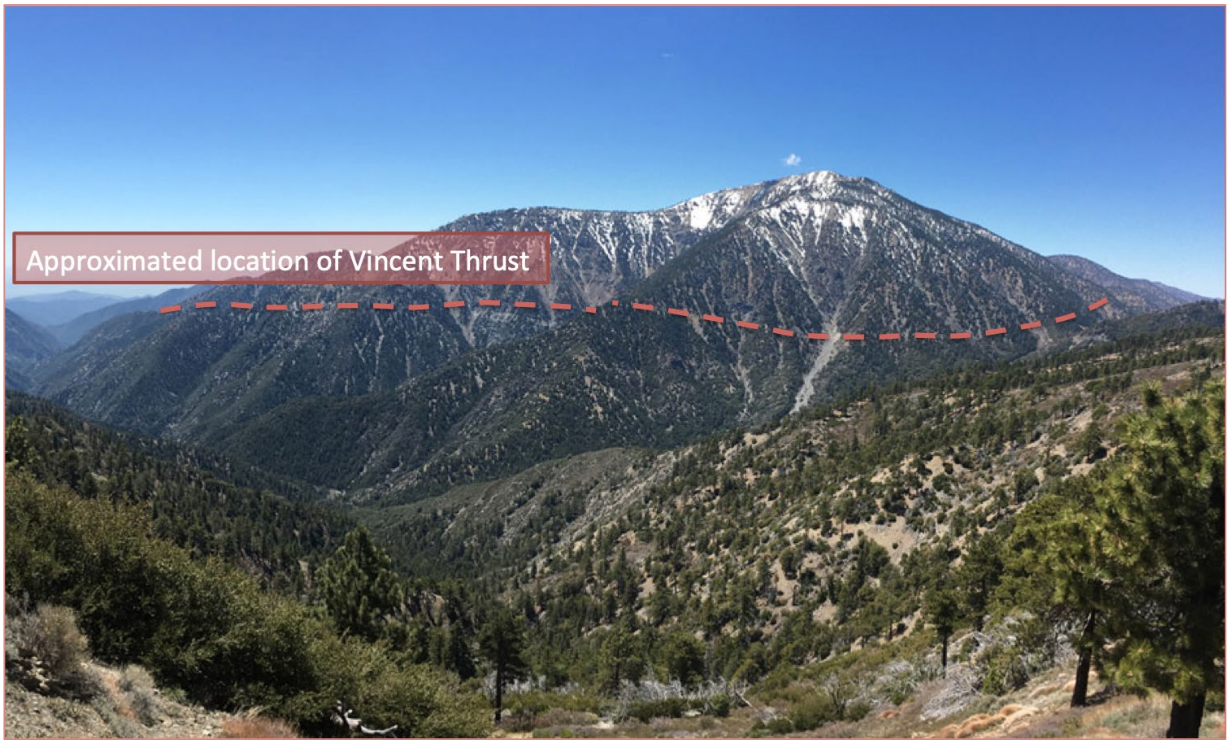
Addresses learning objective:

3. Use topographic features, like scarps or vegetation patterns, to locate the trace of a fault
6. Recognize landforms associated with rapidly growing mountains

- Geography:
  - Mt. San Antonio, a.k.a. Mount Baldy is to the southeast
  - Mt. Baden-Powell to the southwest
  - The East Fork of the San Gabriel River is at the bottom of the steep, deep canyon to the south
- Geology
  - One of the most important structures in southern California, the Vincent-Orocopia-Chocolate Mountain thrust (Vincent **Thrust**)
  - Visible at about eye-level along the northeast flank of Mt. Baden-Powell above light-colored sills of felsic composition
  - Seperates gneiss of over a billion years old in the upper plate from the Pelona Schist of about 75 million years old
  - Represents the ancient plate boundary between the subducting Farallon Plate containing the Pelona Schist from the overiding North American Plate containing the gneiss
  - Punchbowl Fault is inactive strand of the San Andreas fault




Cartoon of Vincent Thurst Fault as viewed from Inspiration Point. – D.D. Trent, 1975.



**Photograph from Inspiration Point showing approximate location of Vincent Thrust across Mt. Baden-Powel.**

## Stop 9 – San Andreas Fault; Big Pine Visitor Center Interpretive Site (Stone building) immediately east of the junction of SR-2 and N4.

Addresses learning objectives:

3. Use topographic features, like scarps or vegetation patterns, to locate the trace of a fault
   - Scarp from 1857 Fort Tejon earthquake is on the north side of junction, creating the slope behind the building
   - The San Andreas fault runs roughly parallel to SR-2 through the town of Wrightwood
   - Erosion along the fault has created Swartout Valley, in which the town of Wrightwood was developed in the years since the 1857 quake
   - Lone Pine Valley further east was also made by erosion along the fault

- Mountain High Ski Resort, on the south side of the highway, was the first commercial ski lift in California, opening in 1932 as the Blue Ridge Ski area

San Andreas Fault 1857 earthquake fault scarp behind visitors center building.

San Andreas Fault 1857 earthquake fault scarp forms steep slope at far end of parking lot.

*Activity 3: ask students to point out scarp and estimate its height. Discuss relationship between height of scarp and magnitude of earthquake.*

Drive approximately 4.6 miles east of the Big Pine Visitor Center Interpretive Site on SR-2, turn right on Sheep Creek Drive. Left when Sheep Creek Drive ends at Lone Pine Canyon Road, then proceed less than a quarter mile to Sheep Creek and park on the turnouts south or north of the road.

1941 debris flow scar represented by treeless patch near top ridgeline.

## Stop 10 – Sheep Creek and the 1941 debris flow scar

Addresses learning objective:

4. Identify landslide scars

Assuming you were able to safely park, exit vehicles and assemble on south side of road for good views of the scar from the 1941 debris flow. Evident in the photo as the nearly vegetation-free, snow covered part of the mountainside.

Debris flow deposits in Sheep Creek Channel.

Debris flows were triggered by rapid snow melt in May of 1941, which saturated older landslide deposits, creating a disordered mass of rock, mud, and tree parts that moved with a viscosity comparable to wet cement down the Sheep Creek channel, eventually flowing out of the mountains into the Mojave Desert.

*Activity 4: Identify three different types of rock found in the debris flow deposits.* – In particular look for actinolite schist.

*Activity 5: Using the Google "terrain view" map to the right, trace out the boundary of any landslide scars depicted by the contour lines. Note: Sheep Creek is represented by the dotted and dashed blue line; the vehichles are parked where the creek intersects Lone Pine Canyon Rd. North is to the top of the page.*

For stop 11, return to Wrightwood and the SR-2/N4 (Big Pines Highway) junction, then take CA 138 (N4) towards Palmdale in order to follow the westward trend of the San Andreas fault.

Alternatively, one could continue eastward on Lone Pine Canyon Road, following the trace of the San Andreas fault down Lone Pine Canyon, eventually reaching the junction with CA-138 at Mormon Rocks.

At about 0.8 mile from Sheep Creek there is a gated road on the left (north) side of the road with just enough room for a few vehicles, but not enough for a bus. Walk around the gate and down the road about 100 yards to the top of the small hill for a good view down Lone Pine valley and along the San Andreas fault zone.

Mileages for the following stops are given from SR-2/N4 junction to Pallet Creek Road.


**Google terrain view map of sheep creek debis flow and stream channel.**

Looking down Lone Pine Canyon and the San Andreas fault zone.

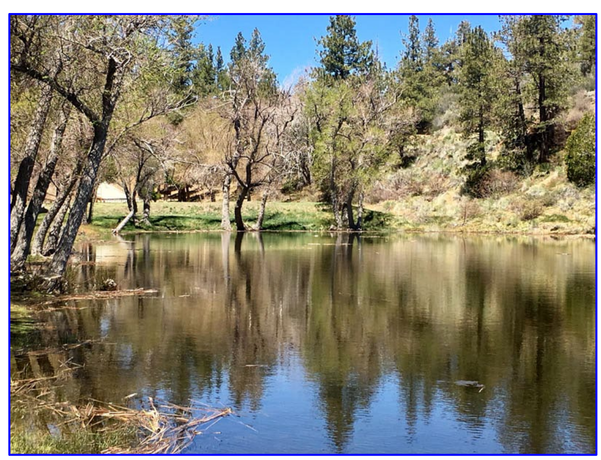
### Stop 11 – Apple Tree Campground and 1857 San Andreas fault scarp; 2 miles

Curved trunk of a tree toppled during the 1857 earthquake.

Addresses learning objective:
3. Use topographic features, like scarps or vegetation patterns to locate the trace of a fault

- Fault gouge – rock ground to a powder by movement along the San Andreas fault
- 1857 earthquake fault scarp can be found by taking the dirt road off the east end of the parking lot. Continue to the end of the road and have a look around. You'll find fault gouge zones and trees with dramatically curved tree trunks. These trees were toppled from the violent shaking and since have compensated by growing skyward – resulting in the curved tree trunks.

### Stop 12 – Jackson Lake; approximately 3 miles



Jackson Lake with a shutter ridge at the far end of lake.

Addresses learning objective:
3. Use topographic features, like scarps or vegetation patterns, to locate the trace of a fault

- Water has accumulated on one side of a shutter ridge, which is the hill on the far side of the lake. This ridge was formed by lateral offset along the San Andreas fault, so that it now impeades the flow of water in such a way that a lake has formed behind the shutter ridge (Hough, 2004).

### Stop 13 – San Andreas fault scarp; approximately 12 miles, at intersection with Bob's Gap Road.

Note: N4 becomes Valyermo Road at this point.
Addresses learning objective:
3. Use topographic features, like scarps or vegetation patterns, to locate the trace of a fault

- The scarp is most obvious on northeast corner of intersection and includes a house atop it for scale.

**House atop scarp from 1857 San Andreas earthquake.**

### Stop 14 – Pallet Creek; approximately 14.3 miles

Turn left on Pallet Creek Road, just past Saint Andrew's Abbey, continue about 1.4 miles on Pallett Creek Road to a pull-out on the south side of the road. This is a good spot to discuss one of the more important thesis studies undertaken in the field of geology during the past 50 years or so.

- Pallett Creek is where then graduate student Kerry Sieh performed his legendary (at least within earth science circles) study of the San Andreas fault. Kerry utilized "heavy equipment" in the form of a backhoe tractor to dig trenches along the fault. This gave him a cross-sectional perspective of the fault, where he could see strata offset by fault movement. He used carbon-14 radiometric dating to determine when specific stratum had been offset by earthquakes and through doing so, he was able to determine a recurrence interval for the San Andreas: on average, a major earthquake once per 150 years.

### Stop 15 – various spots to stop and observe the San Andreas fault scarp

Addresses learning objective:
3. Use topographic features, like scarps or vegetation patterns to locate the trace of a fault

From Pallett Creek, continue along Pallett Creek Road, then turn right onto Longview Road. Proceed about 0.8 mile then turn left on Fort Tejon Road. Continue for about 2.9 miles to the intersection with 106th street. The San Andreas fault is off to the left (south), trending along the base of the low hills. *Question, what mountain range is in the background?*
After another 1.9 miles or so, make a left onto Mount Emma Road, and continue 2.3 miles to Cheseboro Road. After making a right on Cheseboro Road, proceed about a third of mile

**Looking north along 47th street. Vegetation surrounds home perched atop the San Andreas fault scarp.**

and make a left on Barrel Springs Road. This runs parallel to the fault, which is marked by the hill immeditely to the north. At 47th street, the fault scarp is visible as the low hill, upon which vegetation surrounds the yard of a home.

As you approach 42nd street, notice the line of Cottonwood Trees taking advantage of groundwater trapped along the fault plane and therefore reflecting the trace of the San Andreas fault. At 40th, the fault scarp is immediately north of the road. After 37th street, Barrel Springs curves towards the north and crosses over the California aqueduct and the San Andreas Fault.

**Cottonwood tree make the trace of the San Andreas fault**

Barrel Springs becomes 25th street north of Pearblossom Highway. Make a left onto Avenue S and proceed west until you pass under the 14 freeway, parking in the dirt parking area just after passing the foot of the offramp for the northbound traffic.

## Stop 16 – Palmdale Roadcut

Addresses learning objectives:

3. Use topographic features, like scarps or vegetation patterns, to locate the trace of a fault
5. Identify ductile structures in strata, such as folds

In the parking area, one is standing on the San Andreas fault. Walk up the trail about ¼ mile towards the top of the ridge for excellent views of the Palmdale roadcut. This ridge formed through intense compression of the relatively young, Pliocene Anaverde Formation. This sliver of crust is caught between two branches of the San Andreas fault. The main branch is along the southern side and a secondary branch, the Littlerock fault, is found along the northern margin of the ridge, making it an example of a squeeze block (see Chapter 3) or a pressure ridge (Sylveter and Gans, 2016). Excavations for geolgic studies show that rock has been offset 50 feet in a right-lateral sense on the southside of the ridge.

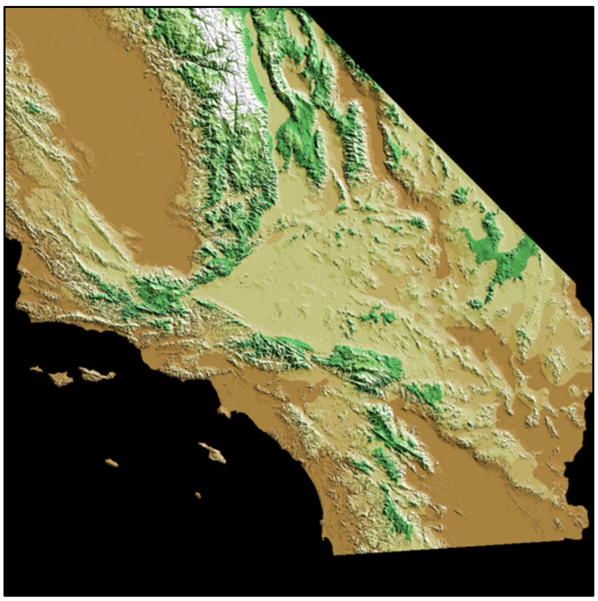
**Photo of Palmdale roadcut and the exposed deformed stata.**

*Activity 6: Ask students to answer the follwing questions: What type of rock is the Anaverde Formation and how can you tell?* – Sedimentary. You can see the strata. *What type of structures has the strata been deformed into?* – Anticlines and Synclines. *What type of stress caused these structures?* – Compression.

*Activity 7: Ask students to make a map-view perspective drawing of highway 14 before and immediately after a major earthquake along San Andreas fault at this location.*

## Post Fieldtrip Questions

1. What type of rock makes up the San Gabriel Mountains? Give some specific names of the rock units.
2. On the DEM map (digital elevation map) of southern California, mark the trace of the San Andreas fault.
3. Make a cross-sectional drawing showing a fault breaking through Earth's surface to make a fault scarp. Label the fault, fault scarp, and hanging wall and footwall. Name the type of fault.



**DEM map of southern California. –CC.**

# Chapter 6 – Crystal Cove State Park

## Introduction

This field trip takes us to the southern terminus of the Los Angeles Basin, across the coastal plain of southern Los Angeles County and northern Orange County and up and over the northernmost extent of the Peninsular Ranges, the San Joaquin Hills.

The beach at Crystal Cove State Park is not only beautiful, but also one of the best places in southern California to study coastal geology. It offers excellent examples of erosional coastal landforms like: **marine terraces**, **wave-cut platforms**, **cliffs**, **coves**, and **headlands,** as well as superb exposures of the Monterey Formation, one of the most important Miocene rock formations in California. It also serves as a nice opportunity to discuss the differences between an active and passive continental margin, using the west and east coasts as examples. The steep San Joaquin Hills and precipitous cliffs along the beach at Crystal Cove provide good examples of **active continental margin** geography.

The beach at Crystal Cove.

The shoreline at Crystal Cove represents the base level for local urban runoff, resulting in small streams working their way across the beach to the ocean, providing an opportunity to observe and discuss stream-related landforms. There is also an opportunity to observe igneous rocks in the form of rip-rap (imported boulders used to stabilize slopes) and columnar-jointed cliffs. Development along the beach has helped contribute to mass wasting with recent landslide scars visible, especially in the Crystal Cove Historic District area; there are also instructive examples of slope stability efforts. Finally, while strolling along the beach one can observe fossils clams, clam-drilled holes in rocks, concretions, badland topography, folded **strata**, an unconformity, and groundwater seeps.

This excursion requires only a half to 2/3 of a day and its proximity to Los Angeles and Orange Counties make it a relatively short drive. Consequently, this is a destination that lends itself to carpooling using personal vehicles, which makes for easier planning and less cost – no bus to hire. A visit mid-week might also be doable, especially for groups originating in south Los Angeles or north Orange counties. Any time of the year works for a visit, although in can be surprisingly warm on the beach, where there is no shade and the sun reflecting from the sea and sand.

**Note**: The beach at Crystal Cove is best experienced at low tide when exposure of the wave cut platform is best. At high tides, access along the beach will be limited and could make for hazardous trekking in spots if coupled with high surf conditions.

## Learning Objectives

Through participation in this field trip students should be able to:

1. Compare and contrast the topography of the east coast vs. west coast
2. Compare and contrast the geology of an active vs. passive continental margin
3. Describe the topographic differences between an active and passive continental margin
4. Identify coastal erosional landforms: marine terrace, wave-cut platform, cliff, cove, and headland
5. Describe how a marine terrace forms
6. Identify sedimentary rocks and strata
7. Identify igneous rocks
8. Identify soft-sediment deformation and describe how these types of folds can form
9. Explain why folds violate the Law of Original Horizontality
10. Discuss the origin of sand
11. Identify topographic evidence of mass wasting
12. Identify and explain the origin of concretions
13. Identify and explain the formation of columnar jointing
14. Identify stream related landform features, i.e. stream terraces, channel bars, distributaries
15. Identify and explain the significance of an unconformity
16. Discuss the "fate" of urban runoff

## Key Vocabulary

- **Active Continental Margin** – the transition from continental to ocean crust is marked by a plate boundary; narrow continental shelf
- **Cliff** – a steep slope adjacent to a beach caused by wave erosion
- **Columnar Jointing** – vertical fractures caused by contraction in a thick lava flow that cools slowly overtime, resulting in polygonal shaped columns
- **Constructive Geological Forces** – geologic processes that build up landforms and/or add new rock to the crust; e.g. volcanic activity
- **Continental Margin** – the transition zone from continental crust to oceanic crust
- **Cove** – a convex indention into the shoreline caused by erosion
- **Destructive Geological Forces** – geologic processes that wear down landforms and take away rock, e.g. erosion
- **Detrital** – texture of sedimentary rock composed of clasts or grains of rocks and minerals
- **Headland** – a protrusion of land into the ocean caused by erosion on either side
- **Law of Original Horizontality** – sediment is always deposited as strata that is horizontal or very nearly horizontal
- **Marine Terrace** – a wave-cut platform elevated above the beach by tectonic uplift and/or a drop in sea level
- **Passive Continental Margin** – the transition from continetal to ocean crust is not marked by a plate boundary; wide continetal shelf
- **Strata** – a vertical sequence of layers of sediment, which is considered the definitive characteristic for sedimentary rocks
- **Stream Terrace** – topographically flat surface elevated above the active stream channel representing the past position of the stream bed or flood plain for the stream

- **Unconformity** – contact between older rock below and significantly younger rock above, representing a gap in geologic time caused by prolonged erosion and/or lack of deposition
- **Wave-cut Platform** – the gently sloping surface extending from the beach out into the ocean caused by wave erosion

## Pre Field Trip Questions

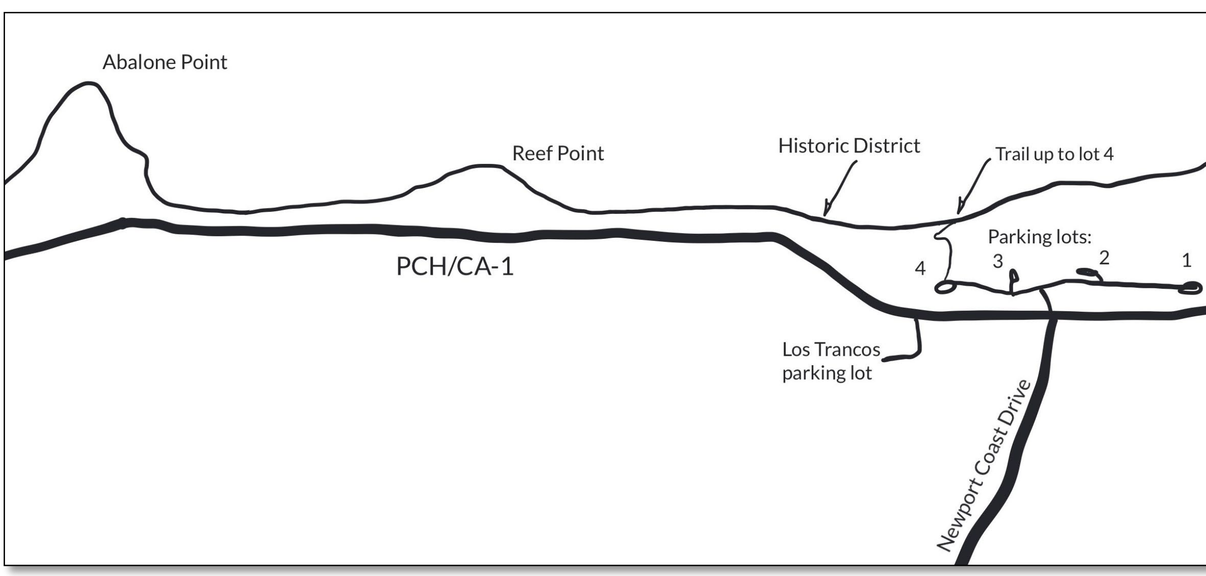
1. What physical characteristic makes sedimentary rocks easily recognizable in the field?
2. Refer students to the excellent coastal geology overview of Crystal Cove by Dr. Merton Hill at Saddleback College, Crystal Cove coastal geology (then click on: *Click here for Crystal Cove Geology Coast Guide*). Organize students into pairs or small groups, with each group being made responsible for teaching one of the numbered sections in this document to the others in the class. These short (perhaps 5 minute) lessons could be done during the class before the field trip or in the field at the start of the field trip.
3. Draw a simple diagram of a wave-cut platform, marine terrace, cove, and headland.
4. What is the difference between a passive and an active continental margin?

## Crystal Cove State Park Directions

I-405 south to CA-73, exit Newport Coast Drive and proceed south to Pacific Coast Highway (PCH a.k.a. CA-1). Turn left (south) onto PCH then left at the first signal into the Los Trancos Parking lot. Show preapproved fee waiver at the Kiosk.

Note that the CA-73 is a toll road. Charter busses assume the responsibility of the toll, but non-commercial vehicles will need to pay the toll, which can be done through the toll roads web site: *TheTollRoads.com*.

Crystal Cove can also be accessed via PCH/CA-1. However, this route takes longer and does not take students up and over the hills, which might make it more difficult for them to conceptualize the learning objective about "active vs. passive continental margins" (see next page).




**Map of parking lots and important landmarks at Crystal Cove.**

## Field Trip Stops

This field trip entails only one vehicle stop, the Los Trancos parking lot (or one of the parking lots serving Crystal Cove), which is accessible by large charter bus, van, or 2-wheel drive car and requires a $15 parking fee. This fee may be waived by requesting an academic fee waiver from Crystal Cove officials ahead of the field trip: Crystal Cove State Park fee waiver. If students are carpooling be sure to specify this in your fee waiver request. If visiting during a weekend, you may be denied a fee waiver for the Los Trancos lot due to popularity of this lot during weekends. To work around this for a charter bus, specify that you will direct the bus driver to drop your group off in the Los Trancos parking lot then park and pick you up in lots 3 or 4 (see map). Individual drivers using a fee waiver may be required to park lots 3 or 4.

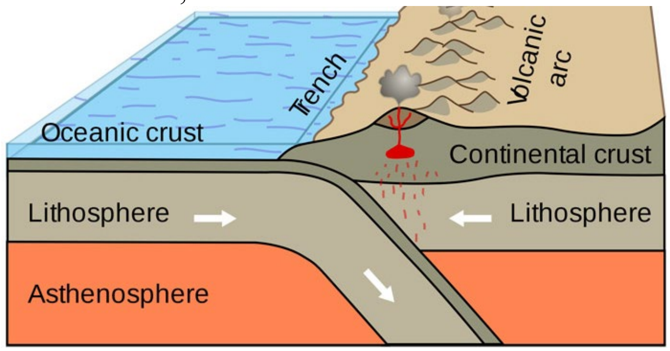
From the Los Trancos parking lot, groups will walk down to the beach, walk along the beach, then return to the Los Trancos parking lot or to parking lot 4, located on the southwest side of PCH and accessed via Newport Coast Drive.

Instructors should address the aforementioned learning outcomes at each of the instructional stops listed below, as they deem appropriate.

## Suggested Itinerary

1. In the parking lot
    a. East Coast vs. West Coast Geology
    b. Prompt: *As you may have noticed on the drive here, the road goes over some fairly steep hills. Here, in the parking lot, have we yet reached the beach? Where is the beach relative to the parking lot?*
    c. Suggested questions:
        i. *What was the topography like from the freeway to where we are now?* – Hilly; definitely not flat.
        ii. *What is the topography like along the east coast of North America?* – More subdued; gentle, low hills; flat.
        iii. *Why is the west coast hilly and mountainous and the topography relatively flat along the east coast?* – Active vs. passive continental margins; tectonic uplift is happening here, but not along the east coast.
    d. Discuss active vs. passive continental margins.
        i. **Continental margin**: the transition zone from the shoreline to the abyssal plain of the ocean floor; including the continental shelf, continental slope, and continental rise.

ii. **Active continental margins**: a plate boundary is crossed from continental to ocean crust; narrow continental shelf.

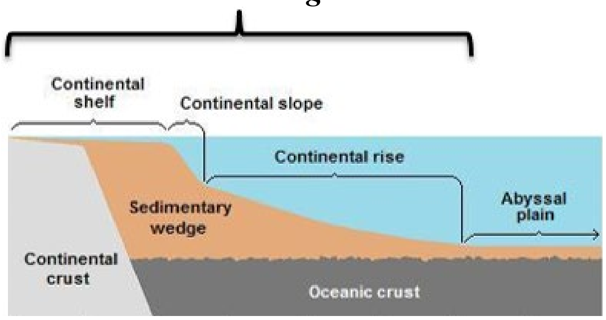



Active continental margin. –CC.

1. Interaction of the plates along the plate boundary drive **constructive geologic processes**, such as tectonic uplift, making hills, mountain, and even volcanoes.

iii. **Passive continental margin**: no plate boundary between continental and ocean crust; wide continental shelf.

***continental margin***

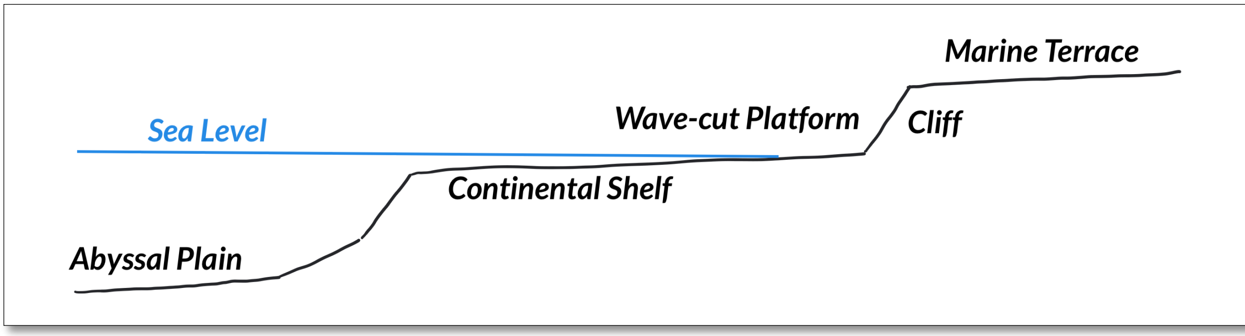



Passive continental margin –CC.

1. No plate boundary means no constructive geologic forces. Instead, **destructive geologic** processes dominate and the landscape is worn down by erosion.

**Note**: Utilizing Google Earth imagery can effectively demonstrate the geographic differences between the west and east coasts. I've brought an iPad into the field with me to do this. Students could also use their phones.

e. Introduce coastal landforms, again utilizing illustrations or perhaps hand-outs that show:
   i. wave base – the depth at waves no longer erode
   ii. wave cut cliffs – cliffs bordering the beach made by wave erosion at base of cliffs (shoreline angle)
   iii. headlands – narrow cliffs jutting out into the ocean, commonly separating one cove or bay from another
   iv. cove – a narrow bay or indention along the shoreline
   v. wave-cut platform – gently sloping erosional surface extending from the base of wave cut cliffs out the wave base
   vi. marine terraces – wave-cut platform elevated above sea level




Cross-sectional drawing of a passive continental margin and principal coastal landforms. Not to scale.

2. Bathroom break. Restrooms located at top of trail to beach principal.


Map view of Los Trancos parking lot and trail down to beach. –Google Earth Image

3. As students congregate on the path near the bathroom, you could point out the extensional cracks in the path. These are from slope creep, the slowest form of mass wasting.
4. Descending path to beach; note additional cracks and any mitigation efforts
    a. Looking up at the surrounding slopes, ask students to consider if mass wasting could effect these slopes
5. Storm Drain at bottom of trail
    a. This makes for a good opportunity to discuss the "fate" of precipitation and irrigation.
        i. Precipitation and urban runoff (typically polluted) eventually flows down to base level, the ocean.
    b. Suggested questions:
        i. *How do growing populations and development influence runoff?* – <u>Increase.</u>

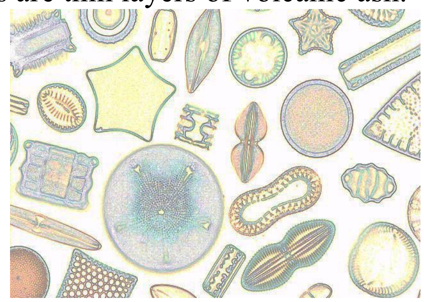
    ii. *Is there anything that could be done to reduce runoff?* – Answers will vary.

6. Rocks before tunnel
    a. Rip-rap for slope stabilization
    b. Suggested questions
        i. *What type of rock are we looking at (igneous, sedimentary, metamorphic)?* – Plutonic igneous (gabbro).
        ii. *Are these rocks from here?* – No (from local mountains).
        iii. *How can we tell?* – Don't match local geology; the arrangement of the boulders; background research on Crystal Cove, etc.
        iv. *Why are they here?* – Slope stabilization.
7. Rocks after tunnel – as above, but granitic.
8. River channel, if present, point-out and discuss stream-related landforms:
    a. type of stream channel (meandering/braided)
    b. channel bars
    **c. stream terraces**
    d. distributaries
    e. ripples
9. Beach cottages – Crystal Cove Historic District
    a. *Why are they abandoned*? - Mass wasting; beach erosion.
    b. Mass Wasting events (landslides) are common in the Monterey Formation. Clay layers interbedded within the strata can become very weak when wet and unable to resist the force of gravity acting on the strata above. For example, heavy rains can add enough water to the clay beds that they are transformed into a mud-like consistency, creating a plane of weakness or landslide slip-surface that triggers a rockslide. Wave erosion constantly removing rock and support from the base of a cliff is an additional trigger for coastal mass wasting.
    c. Behind the southernmost cottage is an obvious landslide scar from a past rockslide.
        i. Fun fact! This southernmost cottage is also the cottage in which the movie *Beaches* was filmed.

*From the cottages walk southward along the beach eventually reaching the impassible headland (Abalone Point)*

10. Origin of sand (at any place along the beach).
    a. Discuss sand "basics": what it is, how it's made, where it came from, where it's going, etc.
    b. Suggested questions:
        i. *Where does sand come from?* – Weathering of rock.
        ii. *What is sand mostly made of?* – Quartz.
        iii. *What happened to the dark minerals that were part of the original (parent) rock from which this sand was weathered?* – Chemically weathered away.
        iv. *Now that the sand is here, will it stay?* – No. Longshore drift.
11. Monterey Formation (at any place along the beach)

a. 12-6 million-year-old thinly bedded shale, mudstone, and chert form a mix of fine terrestrial sediment (from destruction of rock on land) and diatomaceous ooze (remains of microscopic planktonic creatures with silica shells called diatoms). Interbedded (interlayered) with these sediments are thin layers of volcanic ash.
b. Sediments accumulated on the deep ocean floor, about a mile below sea level, where they were compacted and cemented together over time.
c. During the lithification process the ash layers were converted to clay. These clay layers become very weak when wet, resulting in mass wasting. Landslides are common in the Monterey Formation.



**Photograph of diatoms. -CC**

d. One of the most economically important geologic formations in the country.
    i. Yielded 8 billion barrels of oil since 1880
        1. Enough to fill 4000 football stadiums
        2. At one time, accounted for 20% of world's oil production
        3. 8 million cubic feet of natural gas
        4. Formation could contain another 8 billion barrels

12. Concretions (at any place along the beach)
    a. Originally land-derived wood that sank and was buried in diatomaceous ooze of the deep sea
    b. Wood became "infected" in the ooze, filling and swelling these particles with silica, resulting in the petrified concretions
13. Springs/groundwater seepage (at any place along the beach)
    a. Groundwater flowing out of cliff
        i. Surface water infiltrates permeable sections of the Monterey Formation, eventually encountering impermeable clay layers, along which the water flows until exiting the cliff
        ii. The colors associated with the springs are iron oxide minerals: goethite limonite
14. Magnetite in sand (many places along the beach)
    a. Magnetite is a mineral associated with mafic rocks, like basalt that make up the ocean floor
    b. Will stick to magnet!
15. Badlands (many places along the beach)
    a. Deeply gullied landscape formed by runoff over the 120,000 years old weakly consolidated sediments atop the marine terrace
    **b. Unconformity**
        i. 120,000 years old sediment atop 6 million (at least) years old Monterey Formation
        ii. Represents an erosional surface and 6 million years worth of rock, and geologic time, that is missing
16. Fossils in rock (many places along the beach)
    a. Clams embedded in marine terrace deposits

    b. Look very similar to modern-day clams, because 120,000 years is a very short time ago (geologically speaking)

17. Clam-drilled rocks
    a. Bivalves
    b. Teeth on shell can burrow into rock
    c. Clams grow as they burrow and get trapped
    d. ~ 8 year lifespan
    e. filter feeders
18. Beach erosion
    a. wave base – the depth at waves no longer erode
    b. wave cut cliffs – cliffs bordering the beach made by wave erosion at base of cliffs (shoreline angle)
    c. headlands – narrow cliffs jutting out into the ocean, commonly separating one cove or bay from another
    d. cove – a narrow bay or indention along the shoreline
    e. wave-cut platform – gently sloping erosional surface extending from the base of wave cut cliffs out the wave base
    f. marine terraces – wave-cut platform elevated above sea level
19. **Columnar jointing** on headland
    a. Formed as a thick lava flow or lava intrusion like a dike or sill, cooled and contracted, fracturing the mass into columns
    b. This exposure is andesite
    c. More famous examples include Devil's Postpile and Giants Causeway

*Retrace your steps to the Crystal Cove Historic District. From here you can walk back through the tunnel and up to the Los Trancos parking lot or continue walking northward about a half mile to next trail leading up the cliff where you can address the topics under 20 below.*

20. Ascend cliff
    a. Folds – walking up the trail, look for folded strata within the Monterey Formation. Folded strata are typically associated with deformation due to compressive stresses. However, these folds are more likely the result of soft sediment deformation that occurred when unconsolidated sediment slid down the continental slope and was crumpled upon colliding with ocean floor.
        i. *Activity: ask students to make a cross-sectional sketch of the folded strata*
    b. Overlook – Continuing up the trail a bit further, shortly after it switches back, there is a small observation area that provides an excellent vantage point to observe and discuss the coastal landforms mentioned earlier: wave-cut platforms, marine terraces, coves, headland, etc.
        i. Marine Terraces
            1. Ancient wave-cut platforms (where the beach once was) that have been elevated above sea level
                a. Form during a pause in uplift, when wave action erodes a very gently sloping surface into the bedrock at sea level called a wave-cut platform

b. Tectonic uplift elevates this surface above sea level, resulting in a marine terrace

2. Over tens of thousands of years, the process then repeats, making a new wave-cut platform that will eventually be uplifted to make new marine terrace; in this way the oldest terrace will be the highest and the youngest marine terraces the closest to sea level

ii. *Activity: ask students to make a cross-sectional sketch of the coastal landforms above*

*After completing your discussing continue up the trail towards the restroom building and parking lot 4.*

## Follow-up Questions

1. Describe the differences between an active and passive continental margins.
2. Explain why the west coast of North America is mountanous, while the east coast is relatively flat.
3. Explain how a marine terrace is formed.
4. What is the economic significance of the Monterey Formation?
5. Why do landslides happen along beaches like Crystal Cove?

# Chapter 7 – Palos Verdes Peninsula

## Introduction

The itinerary suggested below could be completed in about 3 hours, making for an easy half-day trip. It includes just 2 vehicle stops, but due to limited parking on weekends it is recommended that this trip be done during a weekday or early morning if going on a weekend. In either case, limiting the number of vehicles in your group or using charter bus is advised. Any time of the year is good for a visit.

**View from Del Cerro Park of Portuguese Bend.**

The trip starts at the top of Del Cerro Park, which provides a perfect vantage point to observe and discuss the Portuguese Bend landslide and **marine terraces**, two big attractions for geologists. From there, you'll drive across and down a few of the marine terraces, then across the Portuguese Bend landslide, eventually arriving at White Point Park. At White Point, you will start out on the youngest of the Palos Verdes Peninsula (PVP) marine terraces, upon which you will have a better vantage point to observe and discuss common coastal landforms and a landslide: the recent Paseo Del Mar landslide. Afterwards, one can walk or drive (but be prepared to pay to park) down to the beach to see a superb **recumbent** (overturned) fold, a **wave-cut platform**, and riprap to mitigate beach erosion.

If you are interested in adding content to your field trip, there are several other excellent locations in the immediate area for further geologic study. Descriptions of some of these locations can be found in the National Association of Geoscience Teachers – Far West Section, Spring 2004 Conference field trip guidebook and in the online field trip guidebook offered by Brendan McNulty at California State University Dominguez Hills: CSUDH geology field trip guide to Palos Verdes.

## Addtional materials

Provide group with copy of Google Maps "terrain view" of field trip area: Google Map terrain view of the southern PVP.

## Learning Objectives

Through participation in this field trip students should be able to:

1. Compare and contrast the topography of the east coast vs. west coast
2. Compare and contrast the geology of an active vs. passive continental margin
3. Describe the topographic differences between active and passive continental margin
4. Identify a landslide on a topographic map
5. Identify evidence of mass wasting in the field
6. Identify coastal erosional landforms: marine terrace, wave-cut platform, cliff, cove, and headland

7. Describe how a marine terrace forms
8. Identify sedimentary rocks and strata
9. Distinguish sedimentary rocks in the field
10. Identify igneous rocks in the field
11. Explain why folds violates the Law of Original Horizontality

## Key Vocabulary

- **Active Continental Margin** – the transition from continetal to ocean crust is a plate boundary; narrow continetal shelf
- **Cliff** – a steep slope adjacent to a beach caused by wave erosion
- **Constructive Geological Forces** – geologic processes that build up landforms and/or add new rock to the crust; e.g. volcanic activity
- **Continental Margin** – the transition zone from continental crust to oceanic crust
- **Cove** – a convex indention into the shoreline caused by erosion
- **Destructive Geological Forces** – geologic processes that wear-down landforms and take away rock, e.g. erosion
- **Headland** – a protrusion of land into the ocean caused by erosion on either side
- **Landslide** – a general term describing the mass movement (mass wasting) of weathered rock and/or soil downslope under the influence of gravity
- **Law of Original Horizontality** – sediment is always deposited as strata that is horizontal or very nearly horizontal
- **Marine Terrace** – a wave-cut platform elevated above the beach by tectonic uplift and/or a drop in sea level
- **Passive Continental Margin** – the transition from continetal to ocean crust is not a plate boundary; wide continetal shelf
- **Recumbent fold (overturned fold)** – strata folded into a "U"-shaped and tipped on its side, like a taco shell; these structures are formed by compressional stress
- **Rock slide** – a type of landslide involving rock sliding down a distinct slip (slide) surface
- **Scarp** – the exposed slip surface at the head of landslide
- **Slide block** – a cohesive mass of material that has slid down a landslide slip surface
- **Strata** – a vertical sequence of layers of sediment and considered to be the definitive characteristic for sedimentary rocks
- **Translational slide** – a landslide where a cohesive mass of material (slide block) slides down a surface (slip surface) that is roughly parallel to the ground surface above
- **Wave-cut Platform** – the gently sloping surface extending from the beach out into the ocean caused by wave erosion

## Pre Field Trip Questions

1. Using the following link, CSUDH field trip guide about landslides, describe (in your own words) why landslides are common on the PVP.
2. Draw a simple diagram of a wave-cut platform, marine terrace, cove, and headland.
3. How do marine terraces form?

## Field Trip Stops

All stops listed in this chapter are accessible by large charter bus, van, or 2-wheel drive car.

## Stop 1 – Del Cerro Park, Palos Verdes

Directions: from I-110 south, exit PCH/CA-1 and head west for about 7 miles. Turn left (south) on Crenshaw Blvd and proceed nearly 4 miles to Del Cerro Park.

Addresses learning objectives:
1. Compare and contrast the topography of the east coast vs. west coast
2. Compare and contrast the geology of an active vs. passive continental margin
3. Describe the topographic differences between an active and passive continental margin
4. Identify landslides on a topographic map
5. Identify evidence of mass wasting in the field and principal landslide features: scarp and slide mass/block
6. Identify coastal erosional landforms: marine terrace, wave-cut platform, cliff, cove, and headland
7. Describe how a marine terrace forms

*Activity 1: Ask students to organize into groups of 2 or 3 and take out their Google "terrain view" maps and mark current location.*

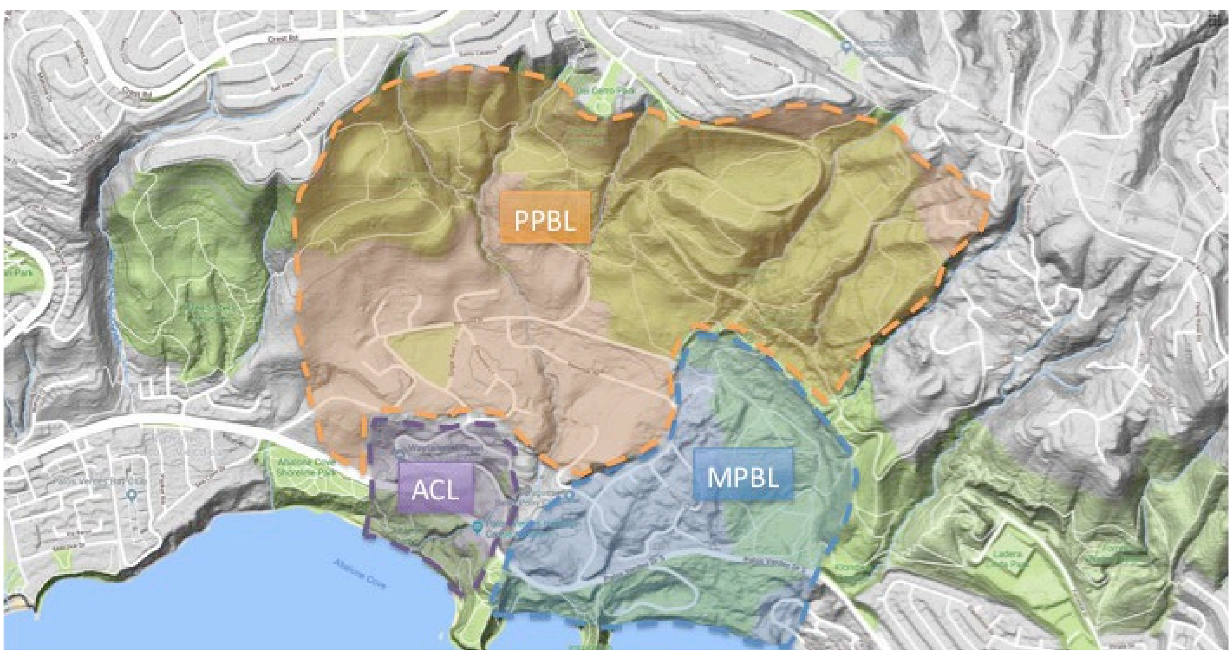
*Activity 2: Ask students to compare what they are observing in "real-life" to what they see on their maps; specifically, ask them to trace out top of the horseshoe-shaped depression in front of them (the head of the Portuguese Bend landslide) and then point out where it is in real-life.*

### *Geology overview*

a. Lithology: The bedrock of the PVP is comprised of two rock units, the Catalina Schist and the Monterey Shale.
    i. Catalina Schist
        1. The approximately 75 million years old Catalina Schist is comparable to the Pelona Schist (mentioned in Chapter 5), representing marine sediments that were deposited on top of the subducting Farallon Plate and metamorphosed into the metamorphic rock, schist, during subduction. Because the Farallon Plate subducted under the North American Plate, the Catalina Schist is referred to as a "lower plate" rock unit and is only sporadically exposed as "tectonic windows" in southern California. On the PVP, there is only one small exposure, which is unconformably overlain by significantly younger sedimentary rock units.
        2. The Catalina Schist was exhumed (brought towards Earth's surface) when the crust in southern California was stretched and ripped open during rotation of the Transverse Range
            a. Stretching and thinning of crust triggered volcanic activity; some of the lava flows associated with this event are exposed on the PVP
    ii. Monterey Formation
        1. 12 to 6 million-year-old thinly bedded shale, mudstone, and chert from a mix of fine terrestrial sediment (from destruction of rock on land) and diatomaceous ooze (remains of microscopic planktonic creatures with silica shells called diatoms). Interbedded (interlayered) with these sediments are thin layers of volcanic ash. See previous chapter for more details on the Catalina Schist.

2. Sediments accumulated directly on top of the Catalina Schist.

b. Mass Wasting (Landslides)
   i. PVP is a popular place for geologic study because of the size and number of landslides
   ii. The composition and structure of rock making up the PVP drives mass wasting
      1. Tectonic uplift of PVP has caused **strata** to dip (tilt) gently to the southwest
      2. Mass wasting is more common on the southwest side of the PVP
      3. Ash layers have been converted to bentonite, a clay that becomes very weak when wet, acting as slip surfaces for landslides
   iii. One of the largest landslides in the country, The Portuguese Bend landslide complex
   iv. Support for landslides continually removed by wave erosion, contributing to instability
   v. Portuguese Bend Landslide complex
      1. Prehistoric Portuguese Bend landslide (PPBL) active from 375,000 to 120,000 years ago
      2. Modern Portuguese Bend landslide (MPBL) started in 1956 and is sliding at an average of a ¼ inch per day
      3. Abalone Cove landslide (ACL) portion started moving in 1974
         a. Water from septic tanks saturated bentonite layers within the Monterey Formation, reducing the internal friction of these layers and initiating slope failure
         b. Geologists designed a pumping system to remove water, which stopped the sliding

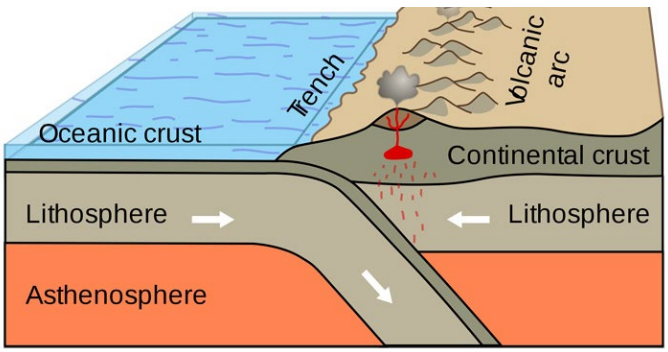



**Map showing the approximate locations of landslides observable from Del Cerro Park.**

c. East Coast vs. West Coast Geology
   i. Prompt: *Here, in Del Cerro Park are we at sea level?* – <u>No, we are over 1000 feet above the ocean surface.</u>

ii. Questions:
   1. *If we were standing this close to the Atlantic Ocean along the east coast of North America, would we be this high above sea level?* – No, because the topography is more subdued; with low hills and flat coastal plains.
   2. *Why does the west coast have steep, tall hills right next to ocean, while it's relatively flat along the east coast?* – Active vs. passive continental margins; tectonic uplift is happening here, but not along the east coast.

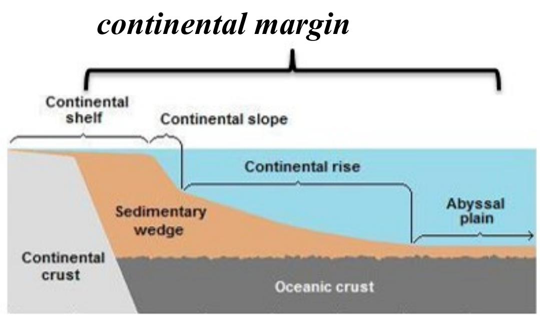
d. Discuss active vs. passive continental margins.
   i. **Continental margin**: the transition zone from the shoreline to the abyssal plain of the ocean floor; including the continental shelf, continental slope, and continental rise.
   ii. **Active continental margin**: a plate boundary is crossed from continental to ocean crust; narrow continental shelf.



Active continental margin. –CC

   1. Interaction of the plates along the plate boundary drive **constructive geologic** processes, such as tectonic uplift, making hills, mountain, and even volcanoes

   iii. **Passive continental margin**: no plate boundary between continental and ocean crust; wide continental shelf.



Passive continental margin. –CC

   1. No plate boundary means no constructive geologic forces. Instead, destructive geologic processes dominate and the landscape is worn down by erosion.

**Note**: utilizing Google Earth imagery can effectively demonstrate the geographic differences between the west and east coasts.

e. Marine Terraces
    i. Ancient wave-cut platforms (where the beach once was) that have been elevated above sea level
    ii. 13 terraces have been mapped, recording the episodic uplift of PVP over the past 1.5 million years (Sylvester and Gans, 2016)
        1. Form during a pause in uplift, when wave action erodes a very gently sloping surface into the bedrock at sea level called a wave-cut platform
        2. Tectonic uplift elevates this surface above sea level, resulting in a marine terrace
        3. Over tens of thousands of years, the process then repeats, making a new wave-cut platform that will eventually be uplifted to make new marine terrace; in this way the oldest terrace will be the highest and the youngest marine terrace will be the closest to sea level

Before loading vehicles to head for stop 2, instruct group to look for marine terraces as they descend down towards the beach – they should be easily visible off to the east, which will be out the left hand side of the vehicles. Also, ask them to look for signs (literally), where the road crosses over the active portion of the Portuguese Bend slide.

## Stop 2 – White Point Park, Palos Verdes

Departing Del Cerro Park, turn left on Crenshaw Blvd, left on Crest Rd., left Hawthorne Blvd., and left on Palos Verdes Drive. Turn right on Western then veer left where road splits on to Paseo Del Mar and park on road adjacent to the White Point Park parking lot.

### *Paseo Del Mar landslide overlook and coastal landforms*

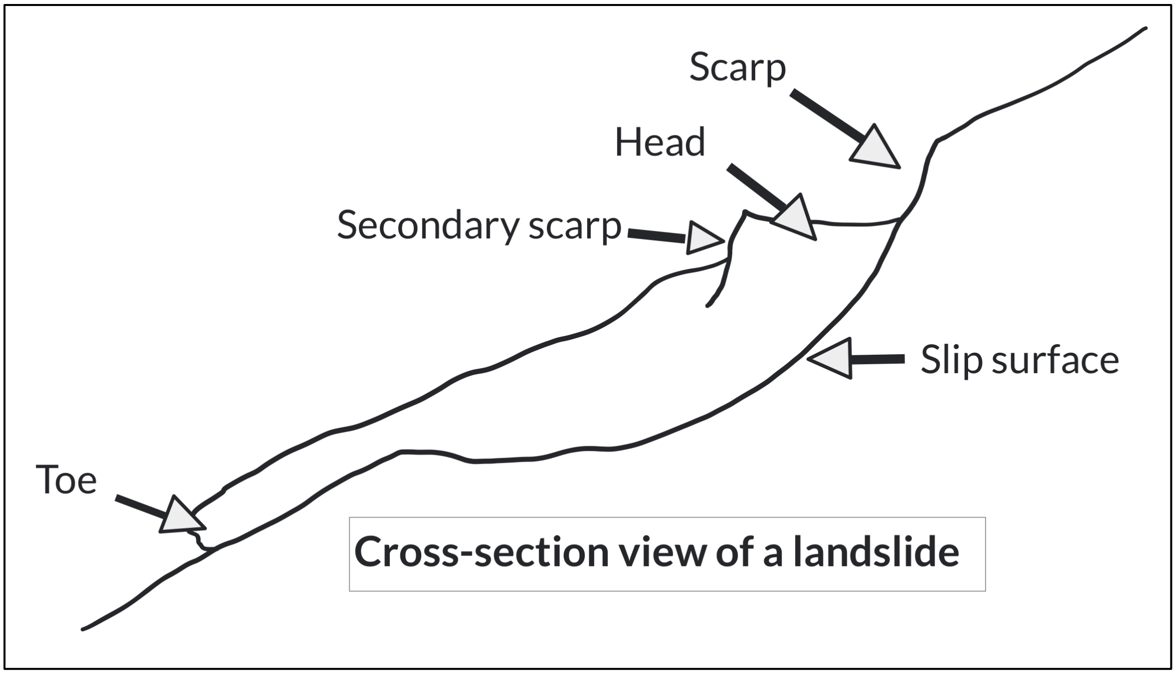
Walk through parking lot towards the ocean and past the buildings to the southeastern end of the dirt trail atop the sea **cliff** (don't walk down the road to the beach yet). The baseball field should be on your left as you face the ocean. Walk around railing at the end of the path and along the trail (Don't get too close the edge!) between the top of cliff and the baseball field. Walk around to the southeast side of the field, where you'll have an excellent view of the Paseo Del Mar landslide. From this vantage point one can also observe marine terraces, wave-cut platforms, headland, and cliffs.

**Map view of White Point and Paseo Del Mar landslide.**

Addresses learning objectives:
5. Identify evidence of mass wasting in the field
6. Identify coastal erosional landforms: marine terrace, wave-cut platform, cliff, cove, and headland
7. Describe how a marine terrace forms

*Activity 3: From the overview, ask students to point out the landslide and landslide features like the* ***scarp*** *and slide mass.*

*Activity 4: From the overview, ask students to point out marine terraces, wave-cut platforms, and sea cliffs. Directing their attention to the east, ask students to make a simple cross-section drawing of the wave-cut platform, cliff, and marine terrace.*



Cross-section view of landslide.

### *Paseo Del Mar landslide:*

- Early 2011 cracks were noticed in road
- November 2011 an approximately 400 foot long section of Paseo Del Mar road slid over 50 feet southward towards the ocean
- The rock unit that failed is the Monterey Shale, which is dipping about 10-20º to the south, making for a rough “dip slope”, which could be considered a trigger for this mass wasting event
- This **rock slide** could be classified as a “**translational block slide**”, because the slide mass slid as a cohesive block with little rotation
- Probable mitigation (repair efforts) includes building a bridge over the slide area or removing the unstable material and filling up this area with rock and soil (engineered fill) then supporting the base with a retaining wall. Cost estimates range from about 25-45 million dollars.

Return the way you came, perhaps stopping along the west side of the **headland** over which you are walking to observe other examples of marine terraces and wave-cut platforms. Walk back to Paseo Del Mar and go east (right) down to the end of the road. If the fence is open, go through and walk about 100 yards to the head scarp of the Paseo Del Mar landslide, exercising extreme caution with your group to prevent any falls. From here you have a closer look at the translational slide, the scarp, and the **slide block**.

*Activity 5: Ask students to identify landslide features like the scarp and slide block.*

### Stop 3 – White Point Beach

Addresses learning objectives:
8. Identify sedimentary rocks and strata
9. Distinguish sedimentary rocks in the field

10. Identify igneous rocks in the field
11. Explain why folds violates the Law of Original Horizontality

White Point Beach Background:

- Originally made famous as a natural spa, fed by hot, sulfur-rich water venting out near the base of the cliff
- Several million years ago lava rose up to Earth's surface along a fault that intersects the cliff
- Residual heat from the lava delivered the heated sulfur-rich waters
- The magnitude 6.3 Long Beach earthquake in 1933 disrupted the natural plumbing causing the hot water to virtually stop flowing
- Surprisingly, the earthquake did not close the spa; sadly though, internment of its Japanese owners during World War II did

Access White Point Beach via the sidewalk or 2-lane road at the west end of the parking area. Note: if you choose to drive down to the beach, you may be required to pay to park.

*Activity 6: Before starting the descent, ask students to observe the rock making up the cliff face to your right as they descend. What type of rock makes up the cliff? –* Monterey Shale
*How are the rock layers oriented/tilted? –* Tilted/dipping south

Recumbent fold

- At the bottom of the beach access road you'll see a beautiful example of recumbent or overturned fold.
- Structures such as these are formed due to compressive stresses. In this case, this fold might have formed as tectonic stresses squeezed and uplifted the PVP.

*Activity 7: ask students to sketch the fold in their field book and use arrows to indicate the direction of stress needed to fold the strata. Ask them how to explain how a fold violates the* ***Law of Original Horizontality****.*

Riprap has been placed along the beach in order to slow erosion of the beach by wave action.

*Activity 8: ask students if they think that the rock making up the riprap was collected from the PVP? Why not? –* No. Lithology does match the bedrock of the PVP.

*Activity 9: ask students to identify the rock type of the riprap (granodiorite, diorite, and gneiss).*

## Follow-up Questions

1. Explain in words and/or with drawing how marine terraces form.
2. What is the relationship between a marine terrace and a wave-cut platform?
3. Considering what was discussed during the field trip, explain why landslides are common on the PVP, especially on the southwest side.
4. What roll do clay layers play in triggering landslides?
5. Draw a picture of folded strata, name the type of fold, and use arrows to show the type of stress needed to make such a structure.

# Chapter 8 - Red Rock Canyon State Park

## Introduction

The Red Cliffs at Red Rock Canyon.

Red Rock Canyon State Park, like Vasquez Rocks Natural Area (Chapter 4), is probably a place you're familiar with, even if you have never been there in person. It has served as the backdrop for countless movies, TV shows, and car commercials. The steep and colorful cliffs have been weathered into accordion-like bellows, resulting in dramatic **badland topography** that serves as the perfect scenery to set an adventurous, Wild West mood.

The well-exposed and easily accessible strata make for an ideal outdoor classroom for the study of sedimentary and volcanic rock, as well as weathering processes, mass wasting, faulting, and stream erosion.

This field trip could be added to a visit to Vasquez Rocks Natural Area, as Vasquez Rocks is on the way as one leaves L.A., but this would also make for a long day (bad poetry intended). One could also make this a first stop for the multi-day field trip into Owens Valley (Chapter 9).

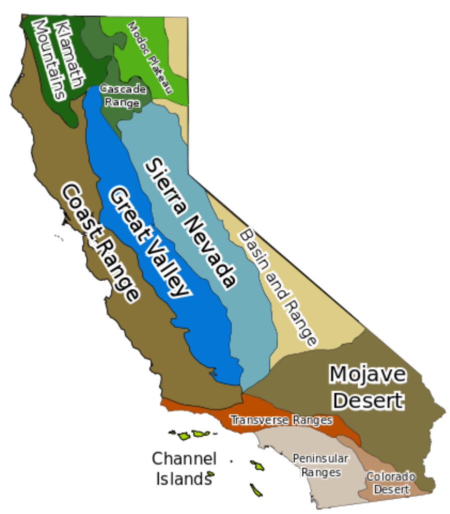
All stops are accessible by charter bus.

Academic parking fee waivers may be granted (parking fees are assessed at the visitor center parking lot, "Stop 2" in this itinerary). Call the park visitor center for information: (661) 839-6553. Note that the website for Red Rock Canyon State Park states that the visitor center is closed in winter and summer.

## Geography

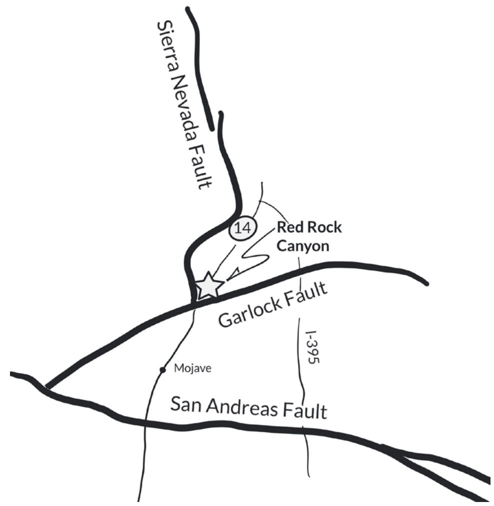
Red Rock Canyon State Park (RRC) is situated within the El Paso Mountains, at the junction of three of California's twelve geomorphic (physiographic) provinces, the Sierra Nevada Mountains, the Basin and Range, and the Mojave Desert. RRC lies within the Basin and Range, with the Garlock fault along its southern margin separating it from the Mojave Desert. The Sierra Nevada Frontal fault delineates the Basin and Range from the Sierra Nevada Mountains to the west.

The arid climate of RRC means sparse vegetation and excellent exposure of the bedrock. This rock is vividly colored and hosts wide assemblage of fossils, mainly ancient mammals, making this place a natural draw for geologists.




California's geomorphic provinces. – CC.

Geology
The geologic processes of the surrounding geomorphic provinces have helped author the geologic story of RRC. Extension of the crust in the Basin and Range initially rifted open a basin, creating a topographic lowland into which rivers flowed from ancestral highlands in the Mojave Desert; this is evidenced by the composition of grains in sedimentary rock at RRC. Subsequently, the Sierra Nevada Mountains started growing, which is revealed by a change in the lithology of the grains contained in younger strata at RRC.



The geomorphic setting for Red Rock Canyon.

## Dove Springs Formation

As has been discussed in previous chapters, tectonic stresses can compress the crust, leading to uplift, and can stretch the crust, resulting in subsidence. Starting around 19 million years ago, tectonic stresses stretching the crust, possibly related to Basin and Range extension, caused subsidence and the formation of basins. In one of these basins, meandering streams, draining the ancestral highlands in the Mojave Desert, flowed across floodplains, eventually emptying into a shallow lake, where fine to sand-sized sediments accumulated over time. This ancient environment, with abundant fresh water, a fertile floodplain, and a shallow lake would have provided ideal ecologic conditions for terrestrial flora, mainly grasslands, and fauna. In fact, this is the story preserved in the strata at RRC. The strata contains an abundance of mammalian fossils, including: early horses, camels, mastodons, rhinoceroses, wild dogs, pronghorn antelopes, deer, sabertooth cats, weasels, geese, a rabbit, a squirrel, a skunk, and a wolverine. Additionally, the fossil assemblage includes reptiles like alligators, lizards, and snakes (Prothero, 2011 and Sharp and Glazner, 1993). Flora fossils include pinyon pines, locust, cypress, acacia, and palm trees. Interbedded in the stratum of mud, silt, and sandstone are ash and lava flows, signifying that volcanic eruptions were also part of this ancient environment. It was probably a setting very similar to the ecosystem in which the Barstow Formation formed, as discussed in the previous chapter (Sharp and Glazner, 1993). The fossils also tell us that this ancient ecosystem was cooler and wetter, because the fossil plants would have required around 15 inches of annual rainfall, as opposed to the yearly rainfall of about 5 inches that this area receives today (Sharp and Glazner, 1993). Finally, the stratigraphically highest beds contain grains of granitic rock from the Sierra Nevada Mountains, indicating that the southern Sierras started to grow and shed sediment around 7 million years ago (the age of the youngest strata at RRC).

Together, the strata of mudstone, siltstone, and sandstone layers, interbedded with rhyolite tuff and basalt, comprise the Dove Spring Formation, representing one of the longest and most complete records of middle Miocene strata anywhere in the world. Radiometric dating techniques (analyzing the amount of radioactive decay of certain minerals to obtain a numeric age for the rock) and paleomagnetic signatures (the magnetic alignment of certain minerals contained in rock) tell geologists that the Dove Springs Formation was formed between 7 and 14 million years ago (Prothero, 2011). These dates are further substantiated by the assemblage of fauna and flora preserved as fossils in the formation.

More recently, the Dove Springs Formation has been tilted and uplifted along the El Paso fault (Carter, 1980), a major branch of the Garlock Fault, exposing the colorful strata. The rainbow of white, cream, beige, brown, pink, red, and green strata comes from the chemical weathering of minerals of the tuff layers. Volcanic ash commonly yields vivid hues as it weathers. Mechanical weathering has made a system of joints through the **cuestas**, creating fractures along which rainwater has infiltrated and eroded. This process called *slope wash* is especially effective at eroding fine-grained, poorly cemented grains and ash, resulting in carving-out deep, closely-spaced vertical gullies in cliff faces (scarp slopes) and producing the **badland topography** at RRC. Other places with similar geology and climate, like Cedar Breaks National Monument, Bryce Canyon (see photo above) National Park, and Badlands National Park exhibit even more striking examples of badland topography. Other destructive geologic processes shaping the landscape of RRC include mass wasting and stream erosion. The former is mostly in the form of rock fall, while the later happens mainly during flash floods, when the dry stream channels suddenly must transport torrents of water.

**Badland topography at Bryce Canyon National Park.**

## Learning Objectives

Through participation in this field trip students should be able to:

1. Identify landforms and locate position on a topographic map
2. Identify sedimentary rocks
3. Identify volcanic (extrusive) rocks
4. Describe the texture of sedimentary rocks
5. Describe the texture of volcanic (extrusive) igneous rocks
6. Recognize rock fall in the field
7. Recognize badland topography
8. Differential between the dip slope and the scarp slope
9. Identify a fault based on the disruption of strata
10. Using the relative position of the hanging wall and footwall, identify a fault as normal or reverse

## Key Vocabulary

- **Badland topography –** a landscape with closely spaced drainages on steep slopes made of weakly cemented, fine-grained sediments; typically in arid climates with little vegetation
- **Bedding contact** – the planer contact between two types or ages of rock
- **Channel bars** – piles of alluvium (sediment deposited by a stream) in the middle of a stream channel that water would be forced to flow around.

- **Cuesta –** a hill or ridge of tilted strata, steep on one side gently sloping on the other, often capped by a resistant rock layer.
- **Dip** – the amount of tilt of a planer surface, like a bedding plane, measured in degrees from horizontal
- **Dip slope** – the slope of a hill that is more or less parallel to the dip/tilt of the rock layers beneath
- **Fault** – a fracture in Earth's crust along which movement has occurred
- **Scarp slope** – the slope opposite the dip slope, where the slope surface is close to perpendicular to orientation of the rock layers
- **Stream terrace** – topographically flat surface elevated above the active stream channel representing the past position of the stream bed or flood plain for the stream

## Pre Field Questions

Read this webpage, Geologic summary of Red Rock Canyon then answer the following question:
1. Why would the rocks of RRC be of special interest to paleontologists?
2. In what ancient environment did these rocks forms?
3. About how long ago did the rocks form? How do geologist know?
4. What is the geologic name of the rock formation at RRC?
5. How many different species of plants and animals have been recovered from the rocks at RRC? Give a few examples.

## En Route Talking Points: I-605 north, I-210 west, CA-14 north

- I-605
  - The 605 takes us across part of the Los Angeles Basin. This incredibly deep basin formed from roughly 16 million to about 1 million years ago as tectonic forces slowly peeled the Transverse Ranges away from the Peninsular Ranges, rifting open a series of basins. The sea flooded these pits as they slowly opened, meaning what is today the metropolis of Los Angeles and Orange counties were once at the bottom of the Pacific Ocean. All the while, sediment being eroded from the continental highlands filled these depressions with silt, sand, and gravel, up to 6 miles in thickness.
  - San Gabriel River
    - The San Gabriel River Freeway (formal name for I-605)
      - Follows a path of least resistance from river erosion
      - River erosion creates natural pathways
      - Pathways become footpaths
      - Footpaths become horse trails
      - Horse trails become thoroughfares
      - Thoroughfares become highways
    - River transports sediment from the San Gabriel mountains to its base level, the Pacific Ocean
    - Whittier Narrows water gap. The San Gabriel River and Rio Hondo River, just to the west, have created the Whittier Narrows by eroding faster downward than the hills have been uplifted, resulting in carving a topographic saddle, a "water gap", 2 miles wide and 800 feet deep, bisecting the Puente Hills into 2 parts: the Montebello Hills to the west

and Whittier Hills to the east. For a more detailed description read the excellent discussion in *Geology Underfoot in Southern California,* "Vignette 9 – A Boon to Communication, The Whittier Narrows"
        - Similarly, Santa Ana River erosion has created water gaps through hills that are now occupied by the 91 and 57 freeways
    - Whittier and Puente Hills (east of the 605) are being actively uplifted along the Whittier fault, which runs along the base of these hills; this fault is active as evidenced by the recent Whittier (1987, M 5.9), Chino Hills (2008, M 5.5), and La Habra (2014, M 5.1) earthquakes.
    - Montebello (Repetto) Hills (west of the 605)
        - Western extension of Puente Hills
        - Like Puente Hills, the Montebello Hills are made up of steeply tilted, south-dipping sedimentary rock that is typical of sediment in the LA Basin: mudstone, siltstone, sandstone, and conglomerate
    - On a clear day point out the San Gabriel Mountains making up the northern skyline and its highest peak, the 10,064 feet tall Mt San Antonio, a.k.a. Mt Baldy.
    - San Gabriel Mountains
        - Mountains at northern end of San Gabriel Mountains
            - Represent a block of crust that was peeled away from the Peninsular Ranges to the south and rotated 110$^{o}$ to its current position as Baja California was tectonically peeled away from mainland Mexico (for a more thorough discussion see the Introduction in *Roadside Geology of Southern California*, Sylvester and Gans, 2016)
            - Compressional tectonic forces have rapidly uplifted the San Gabriel Mountains in the past 5 million years
                - Could be growing as fast or faster than the Himalayan Mountains (Prothero, 2011), at a rate as fast as 70 feet per 1000 years (Sylvester and Gans, 2016)
                - Rapid uplift evidenced by very deep, steep canyons, like Arroyo Seco or Big Tujunga Canyon and triangulated ridges
                - Mountain range is being uplifted along 2 faults, the San Andreas fault along the north side and the Sierra Madre-Cucamonga fault zone along the south side
        - Contains metamorphic rock as old as 1.7 billion years, as well as Proterozoic plutonic rocks; these were intruded by magma of diorite to granite composition that was generated by subduction of the Farallon Plate during the Mesozoic time
    - After passing the I-10 and shortly before arriving at the I-210 interchange watch for deep pits on either side of the freeway
        - Gravel pits mining alluvium being shed off of the San Gabriel Mountains
        - Gravel used for concrete and roadways
        - Water in a pit means it is deeper than the water table (depth to groundwater)
- I-210 west

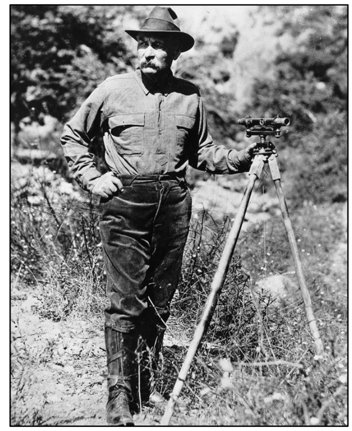
- Sierra Madre fault zone
  - Runs along the foot of mountains
  - Has facilitated as much as 10,000 feet of vertical uplift of the crust, which is today expressed as the San Gabriel Mountains
  - Associated with the San Fernando fault that produced the 1971 Sylmar earthquake
- The foothills are a series of coalesced alluvial fans that formed as the San Gabriels Mountains were uplifted, weathered, and eroded by streams; when the streams flow out of narrow mountain canyons, they slow and lose their ability to transport their sediment load, resulting in deposition and the formation of alluvial fans
- Many of these stream channels are dammed where canyons open up, creating "catch flow basins" that trap or at least slow the dangerous boulder-sized clasts contained in inevitable debris flows

- Continuing on the I-210 west at the CA-134 interchange, look for "benched" road cuts, a common practice used to increase slope stability
- Driving through Sylmar takes one past the epicenter of the 1971 magnitude 6.5 Sylmar earthquake that caused over a billion dollars in damage and 65 deaths, mostly from the collapse of the Olive View Hospital
- Los Angeles Aqueduct
  - As the 210 mergers with I-5 look ahead and you should notice a long pipe-like feature coming down the hillside just to the right of the freeway
    - This is a chute for carrying water, baffled for aerating
  - One of three aqueduct systems brings water to the greater Los Angeles area, the other two being the California Aqueduct that delivers water from the western Sierra Nevadas, and the Colorado River Aqueduct bring water from the Colorado River

**Los Angeles Aqueduct. – CC.**

  - Desgined by self-taught engineer William Mulholland to divert water from the Owens River and its tributaries to the burgeoning city of Los Angeles
    - Water would be used to boost land values and profits for developers
  - Remarkable engineering feat considering it was desinged and built over 100 years ago, so water flows downhill over its entire length, requiring no pumps and only gravity to transport water from its source 235 miles to L.A.
  - Building the aquaduct necisistated some shady business dealings, violence, and even deaths
    - Residents of Owens Valley had plans to use the water from the Owens River to develop agriculture and livestock Fred Eaton, a former mayor of Los Angeles and politically well-connected, used a contact in Owens Valley to, through deception, buy up land in Owens Valley and with it water rights to the Owens River

- Mullholland and Eaton were also working behind the scences with a collection of friends and business partners to buy up cheap land in the San Fernando Valley, which would be made drastically more valuable once it was provided with a reliable water source
    - This story serves as part of the plot for the critically acclaimed 1974 movie *Chinatown*, starring Jack Nickolson: movie clip from Chinatown

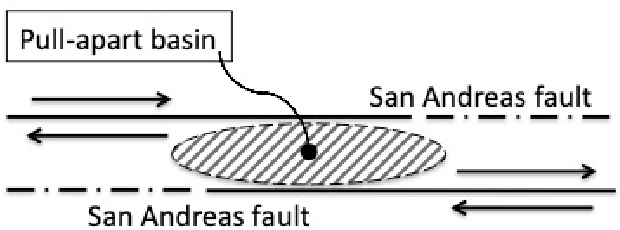


William Mulholand. – CC.

- While completed ahead of schedule and under budget, the completion of the aqueduct consumed machines, mules, and men, with several construction-related deaths
- Owens Valley residents rebelled upon learning that all the water of "their river" was being diverted to Los Angeles
    - In 1924 seventy armed Owens Valley men took control of an aqueduct gate and shut off the flow of water
    - In 1927 a 45-foot section was blown up
    - The uprisings were permanently squelched when Mulholland sent out machine gun armed horseback patrols with orders to shoot to kill anyone disturbing the aqueduct

- I-5/I-14 interchange
    - Some of the overpasses here collapsed during both the 1994 and 1971 earthquakes
- CA-14 (Aerospace Highway)
    - Placerita Canyon Road
        - Placerita Canyon earned its name and fame for the placer (gold deposited as sediment in a stream channel) deposits that were discovered here in 1842, six years before the Gold Rush began in the western Sierra Nevada Mountains.
    - Santa Clara River
        - Longest undammed river in southern California (Prothero, 2011) and significant in that its channel hasn't been modified by human construction
        - Braided stream, common in the foothills of mountains
        - Multiple intertwining channels, weaving around channel bars
        - Ephemeral stream channel in that it is dry unless it has just rained
        - The dry channel is deceiving, because water is flowing in the subsurface as groundwater, which will eventually be utilized by communities downstream (Sylvester and Gans, 2016)
    - Vasquez Rocks
        - After passing Agua Dulce Road, look to the left (north) for spectacular stacks of tilted, red-brown sediment, jutting out of the ground
        - See chapter 4 for a more thorough description

- Lamont Odet Vista Point
    - We are at the very edge of the Pacific Plate. Looking northward, our line of sight crosses the California Aqueduct, the San Andreas fault and the plate boundary with the North Ameican Plate, and Antelope Valley beyond.
    - Disappointlingly, the San Andreas fault is not an obvious gash, since it has been over 160 years since its last major break in southern California and erosion has "smoothed-out" disturbances, like scarps and ground cracks. Instead, the trace of the fault are the low hills, running northwest-southeast, through which highway 14 cuts through and lie on the opposite side of Lake Palmdale, continuing east into the mountains.
    - Lake Palmdale was originally a **sag pond**, a depression that collects water where there has been subsidence of the crust due to faulting. Here, the San Andreas fault is segmented, "stepping over" to create a **pull-apart basin** and sag pond – note how the arrows on either side of the pull-apart basin are pointing away from each other, creating tensional stress and subsidence. Recently, the sag pond was damned in order to store more drinking water for the cities of Paldale and Lancaster that spread out from the edge of the North American Plate before us.

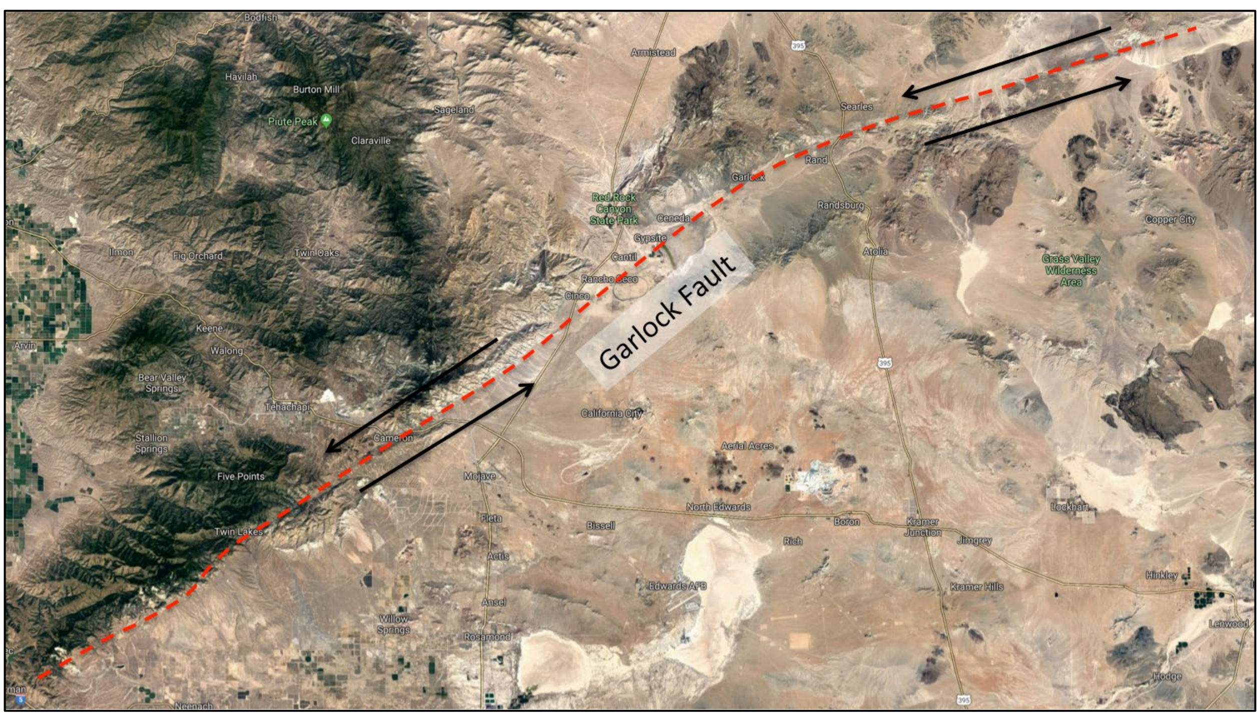


Forming a pull-apart basin.

    - The California Aqueduct provides the greater Los Angeles area with a significant portion of its water. Constructed in the 1960s, it brings water from the western Sierra Nevada Mountains and transports it 700 miles, making it one of the longest aqueducts in the world. It was built above ground so repairs can be made more quickly after damaging San Andreas fault earthquakes; a matter of days vs. weeks or even months if the water were contained in underground pipes (Sylvester and Gans, 2016)

- Palmdale Roadcut
  - The ridge through which CA-14 transects formed through intense compression of the relatively young, Pliocene Anaverde Formation. This sliver of crust is caught between two branches of the San Andreas fault: the San Andreas proper along the southern side and a secondary branch, the Littlerock fault, trending along the northern margin of the ridge, making the ridge an example of a squeeze block (see pages 18-19) or a pressure ridge (Sylveter and Gans, 2016). Excavations for geolgic study show that there is about 50 feet of right-lateral offset along the southside of the ridge.
- Antelope Valley
  - Once through the Palmdale roadcut, you have crossed onto the North American Plate. "Antelope Valley", containing the bustling communities of Palmdale and

Lancaster, is a more appealing name invented by developers to describe what is actually the southwestern corner of the Mojave Desert.
    - As recently as a few tens of the thousands of years ago, lakes covered large parts of Palmdale and Lancaster. As our climate has warmed and dried, the lakes evaoporated.
        - Many archaeological sites occupy what would have been ancient lakeside beaches (Sylvester and Gans, 2016)
- Rosamond Hills and Soledad Mountain (just north of community of Rosamond, west of the highway)
    - The colorful rocks that make up these hills are Miocene age rhyolitic volcanics, which have been hydrothermally altered, adding to the coloring
    - Mined extensively for gold, silver, and radioactive minerals
    - Rock collectors have frequented this area for geodes, chalcedony, and opal
- Garlock Fault
    - Trace is marked by the straight eastern mountain front of the Tahachapi Mountains
    - One of the longest faults in California at 160 miles
    - An exception to the norm, in that it is a left-lateral strike-slip fault – most horizontal faults in southern California are right-slip faults
    - Offset drainages abruptly jump to the right when crossing the fault
- El Paso Fault and El Paso Mountains
    - El Paso Fault
        - Runs along the foot of the El Paso Mountains
        - Branch of the Garlock Fault
        - Facilitating uplift El Paso Mountains




**Google Earth image with approximated location of the Garlock fault. – Google Earth.**

    - El Paso Mountains
        - Contain Red Rock Canyon State Park
        - Many cuestas of colorful sedimentary rock separated by empheral stream channels
- El Paso Mountains "Gorge"
    - Pass used by CA-14 through the El Paso Mountains
    - Formed by stream erosion, making it a *water gap* – note stream channel and stream terraces immediately to the right of highway

Prepare for stop 1, a little less than a 1.5 miles from the southern front of the El Paso Mountains.

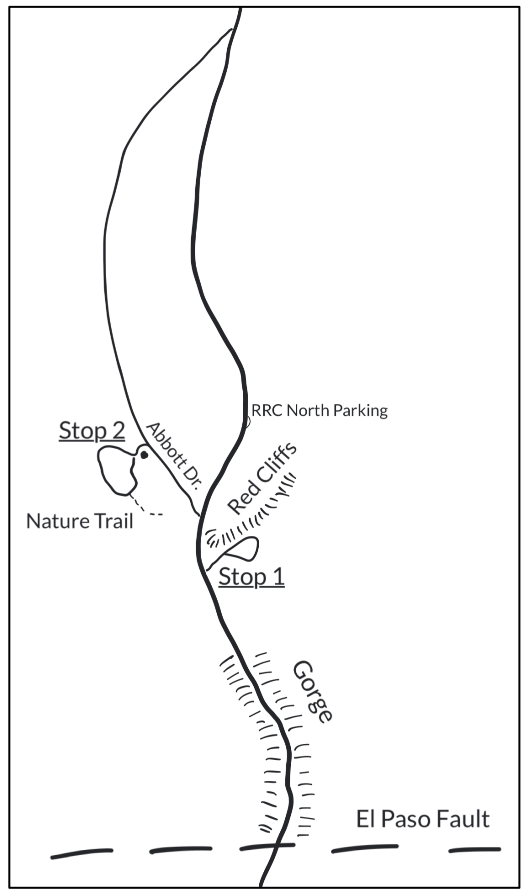
## Field Trip Stops

### Stop 1 – Red Cliffs at Red Rock Canyon State Park

Addresses learning objectives:
2. Identify sedimentary rocks
3. Identify volcanic (extrusive) rocks
4. Describe the texture of sedimentary rocks
5. Describe the texture of volcanic (extrusive) igneous rocks
6. Recognize rock fall in the field
7. Recognize badland topography
8. Differential between the dip slop and the scarp slope
9. Identify a fault based on the disruption of strata
10. Using the relative position of the hanging wall and footwall, identify a fault as normal or reverse

Turn right from CA-14 onto the Red Cliffs access road, just after the "side road right" sign (|–).

Depart vehicles and assemble at northwest end of parking area. Bathroom is structure along south side of parking area.




**Map showing approximated locations of field trip stops and points of interest.**

### *Introduction to Red Rock Canyon*

- Red Cliffs
    - Ask, *What type of rock are the cliffs made of?* – Sedimentary. *How can we tell?* – Strata. Strata are stacks of individual sedimentary layers or stratum. Each stratum represents a more or less continuous period of deposition. The boundary between one stratum and another is a **bedding contact**.
    - Instructors can use the *Geography* and *Geology* sections at the start of this chapter as a means to introduce RRC
    - Cliff face represents the **scarp slope** of a cuesta (more discussion at stop 2)
    - Cliff face also provides a good example of badland topography

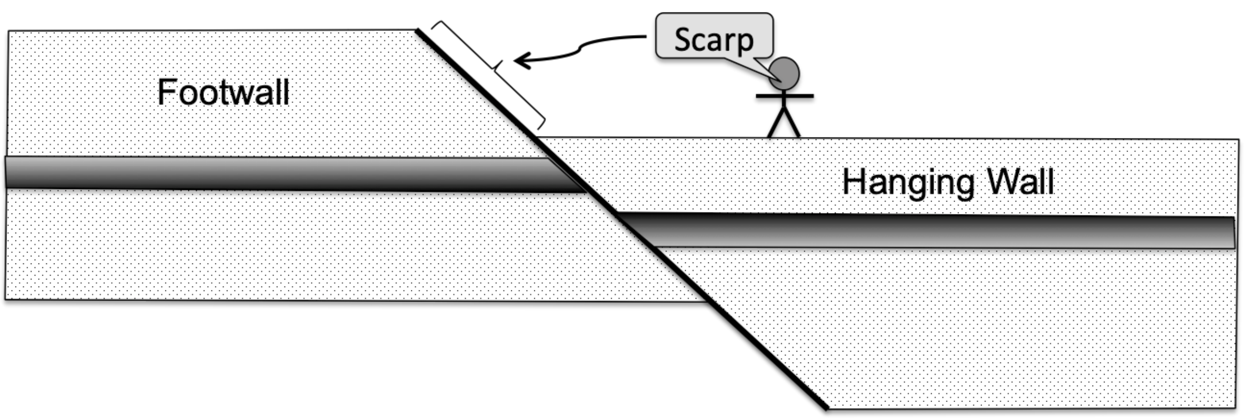
*Activity 1: Pair-up students and have them examine the texture of some of the cobbles and boulders near the base of the cliffs. Help them differentiate between fine-grained sedimentary rock and volcanic rock.*

*Activity 2: Have students come back to edge of parking area and ask them to point out any evidence of mass wasting. –* Rock fall should be evident.

Walk back towards the highway and just around the western edge of the Red Cliffs so you're standing in the wash. Direct students to look to the northwest, to where the buff-colored strata intersect the highway then look about 200 feet to the right, where a **fault** offsets strata.

*Activity 3: Ask students to identify the fault, then make a simple sketch that shows the strata offset and identifies the hanging wall and footwall.* Ask*: Considering the position of the hanging wall relative to the footwall, what type of fault is this? –* Normal


**Normal fault exposed at Red Rock Canyon State Park.**




**Cross-section perspective of normal fault**

Walk back and across the parking area to the far eastern side and up the trail to the saddle of the north-south trending ridge. From the saddle, one can see immediately to the east the confluence of 2 ephemeral streams, with a braided stream channel pattern. Looking southward, we see the stream channel at the bottom of the gorge, alongside the highway.

*Activity 4: Q & A with students:*

- *What type of stream channel pattern do the stream channels have?*
- *Does/did the stream have any roll in forming the gorge through which the highway runs?*

Discuss with students that most valleys and narrow, steep-sided valleys called "gorges" are formed by river erosion.

Return to vehicles and proceed to the visitor center. Turn off is about 1/3 mile north on CA-14; use left turn lane to turn left on Abbott Drive, and continue for a little less than a mile.

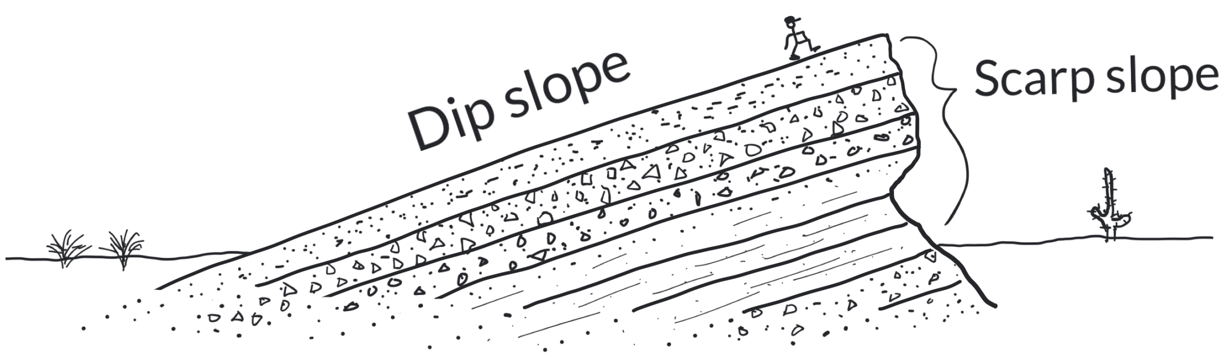
## Stop 2 – Visitor Center and Desert View Nature Trail Hike

Addresses learning objectives:
1. Identify landforms and locate position on a topographic map
2. Identify sedimentary rocks
3. Identify volcanic (extrusive) rocks
7. Recognize badland topography
8. Differential between the dip slope and the scarp slope

You might wish to start this second stop with a lunch or bathroom break. The picnic area will be evident as you enter the visitor center parking lot from Abbot Road. There are bathrooms in the parking lot area and inside the visitor's center. The visitor center is open during the spring and fall and has some informative exhibits that are worth a look if you have the time.

From the visitor center, walk to where the campground access road enters the southeast corner of the parking lot (far left corner if your back is to the visitor center) and proceed about 1/3 mile south to the Desert View Nature Trail trailhead. Take this trail up to the saddle, where you'll find a sign for "Whistler Ridge".

*Activity 5: Before starting the ascent up the ridge, ask students how this slope is different than the* scarp slope *(cliff face) that they saw at Red Cliffs (stop 1). Possible answers may include: "*not as steep"; "different color"; "can't see layers". Point out that the slope they are about to climb <u>is an example of a **dip slope**</u> – the slope of a hill that is more or less parallel to the **dip**/tilt of the layers beneath. This is the slope on opposite side of the scarp slope, where the slope surface is close to perpendicular to orientation of the rock layers.



**A cross-section cartoon of a cuesta, showing the dip slope and scarp slope.**

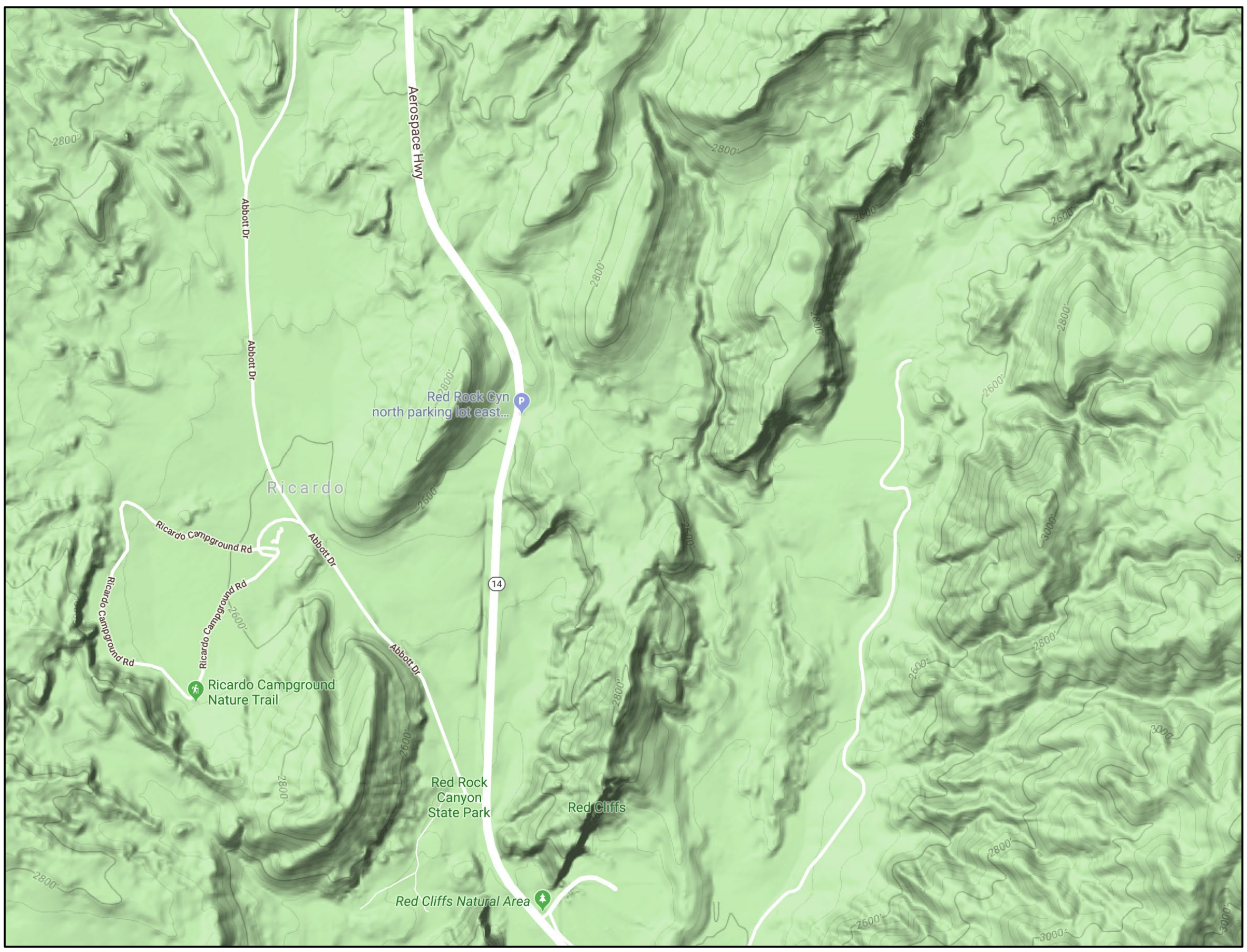
*Also, point out the difference in rock types between the rock upon which you are standing, sedimentary rock of the Dove Springs formation, and the dark brown-black basalt that makes up most of the steep slope of Whistler Ridge. This represents a geologic contact between these two distinct rock types.*

Proceed to top of the basalt-mantled slope. Remind students to exercise caution at the top of the slope to prevent falling. The top of the slope offers panoramic views. Point out the badland topography of the cliffs to the west and the dip slope/scarp slope of a cuesta to the north. This cuesta is also viewable from Abbot Road.

*Activity 6: Using the map below (or other topographic maps) ask students to locate themselves on the map.* In order to do this, the following steps are first recommended:

1. Orient the map and themselves so they are facing north
2. Identify CA-14
3. Locate Ricardo Campground Road and the visitor center

*Now ask them to locate themselves on the hilltop between Ricardo Campground Road and CA-14. Once everyone has been able to accurately indicate their place on the hilltop, you may want to ask them to locate other landmarks, like some of the hilltops (cuestas) to the north and west. Perhaps have them label each location: A (hilltop on which the group is standing), B, C, etc.*




**Google terrain view map of Red Rock Canyon area. –Google Maps**

*Activity 7: Have students make a simple cross section drawing of a cuesta, showing the tilted strata structure and labeling the dip slope and scarp slope.*

*Activity 8:* Point out the ephemeral stream channel and how it correlates to the valleys in between the hills. *Ask: Is this just a coincidence or does the stream channel play some roll in making the valley?*

## Follow-up Questions

1. What sedimentary feature makes sedimentary rocks most recognizable?
2. Make a cross-sectional drawing of a cuesta. The drawing should be labeled to include the tilted strata structure, dip slope, and scarp slope. Label drawing. Why are there cuestas at RRC?
3. Write a short essay summarizing the geologic history of the Dove Spring Formation that provides examples of the evidence used by geologist to construct its history.
4. What roll do streams play in forming valleys or gorges?

# Chapter 9 – Owens Valley and the Eastern Sierra Nevada Mountains

## Introduction

This field trip takes its participants to a land of natural extremes. You will drive along the valley with the greatest topographic relief when compared to the adjoining mountains in the lower 48 states, and can see the tallest mountain outside of Alaska, while standing only 70 miles from the lowest point in the western hemisphere. You can walk amongst the oldest living trees and hike up the youngest volcanic domes that are part of what has been called the world's youngest mountain range. You'll view the site of one of the largest volcanic eruptions known and see evidence of Earth's most recent Ice Age. All of this just a half day away from L.A.!

Students and the Sierra Nevada Mountains.

This itinerary is written for a 3-day, 2-night excursion during the very late summer, early-mid fall, late spring, or earliest summer. Accommodations could be in one of the many hotels within Owens Valley, but camping is encouraged. There are a multitude of campgrounds available, many of which are first-come-first served and others that require reservations. I've had excellent experiences at the McGee Creek campground and a colleague loves using Brown's Town campground, which might be a good option for novice campers. In any case, I think it's best from a logistics standpoint to camp close to or north of Bishop. Here's one of many internet resources for camping options: camping in Owens Valley and Inyo County. I also like this comprehensive and easy to use book on camping in California, California Camping.

Utilizing a charter bus is highly recommended for this trip. The bus will keep everyone together and prevent trailing vehicles from lagging behind or getting lost. Charter busses should be equipped with a microphone, which will allow you to communicate the suggested "En Route Talking Points" and will also have ample room for camping gear in their undercarriage. All stops outlined in this chapter are accessible by charter bus. When reserving the bus emphasize that an experienced driver comfortable with the daily itinerary is needed and that the driver will need accommodations for each night of the trip. At the end of each day, communicate with the driver as to when they should return to pick up the group for the next day. Get their cell phone number.

Accessing Devils Postpile National Monument (Day 2, Stop 5) requires some pre-planning and includes restrictions to consider. Devils Postpile is open at the earliest Memorial Day, but typically mid-June through mid-October; but this timeframe is weather dependent. A shuttle bus (Reds Meadow) transports visitors into Devils Postpile from the adventure center at Mammoth Mountain starting at 7:30 am. Tickets can be purchased in Mammoth Mountain Adventure Center. More information can be found here: Reds Meadow Shuttle.

If you wish to enter the National Monument with a charter bus, you can do so with restrictions:

- Call 760-924-5505 one month beforehand to inform officials at Devils Postpile of your group's visit
- Upon arrival at the Minaret Vista kiosk, you must present documentation that demonstrates your group's affiliation with a school or academic institution and a summary of the purpose of your visit written on official letterhead from your academic institution (contact Inyo National Forest Supervisor's Office at 760-873-2400 to confirm, as policies do change)
- Saturday and Sunday only
- If your vehicle is 25 feet or longer then you'll need a special use permit: National Park Service Special Use Permit.
- If your vehicle is longer than 25 feet then the bus must park at Reds Meadow after entering the national monument, Devils Postpile National Monument map
  - A shuttle service transports visitors every half hour to the Devils Postpile ranger station 10 am to 3:15 pm
- A vehicle 25 feet or less in length entering before 10 am or during weekdays can park at the Devils Postpile ranger station
- Drivers should be notified that the road is very narrow and windy in spots

Taking a group of students camping, many of which will be inexperienced with camping, will certainly require some preplanning. Assuming that your institution does not have a stockpile of camping equipment, here are few suggestions:

- Determine how many students have camping stoves or are certain they can acquire one before the trip
- Based on which students have stoves, assemble cooking groups around stove possessors; perhaps 6 students per group
- Once students have assembled into cooking groups, determine how many have tents. You may find that some groups do not have sufficient "tent space" for everyone, while others have excess. If so, consider rearranging students into different groups, in order to ensure that everyone will have a place in a tent.
- Determine who will provide a cooler, water, cooking gear, and cleaning supplies
- Ask students to come with a menu for the camping trip and to decide who is responsible for purchasing what and who will be cooking/cleaning and when. For a 3-day/2-night trip, they should plan for two breakfasts, lunches, and dinners. Lunch on day 1 should be prepared/purchased before they board the bus and on their person, NOT something that they will need to assemble while en route. Similarly, they should plan lunches that will transport in their daypacks for days 2 and 3. Also, remind them to bring fuel for stoves and keep meals simple. On one trip we had a group prepare a multi-course breakfast that resulted in delaying the entire class about ½ hour in the morning. Generally speaking though, I'm always impressed at how well my students do with the cooking.
- If you find that you will not have enough camping stoves or tents, you may have to request the purchase of these reusable items through your department.
- Additional camping equipment:
  - Sleep bag
  - Sleeping pad
  - Pillow
  - Long underwear/base layers
  - Heavy jacket

  - Windbreaker/rain jacket
  - Beanie
  - Long pants
  - Sweater/sweatshirt
  - T-shirts
  - Toiletries
  - Gloves
  - Flashlight
  - Personal plate and utensils
  - Coffee/hot chocolate mug
  - Underwear
  - Socks
  - Medications
- Essential field gear:
  - Day pack
  - Field notebook/clipboard
  - Hat and sunscreen
  - Comfortable walking shoes – no flip-flops
  - Water
- Encourage students to try to keep things simple and to pack everything in one bag

## Geography

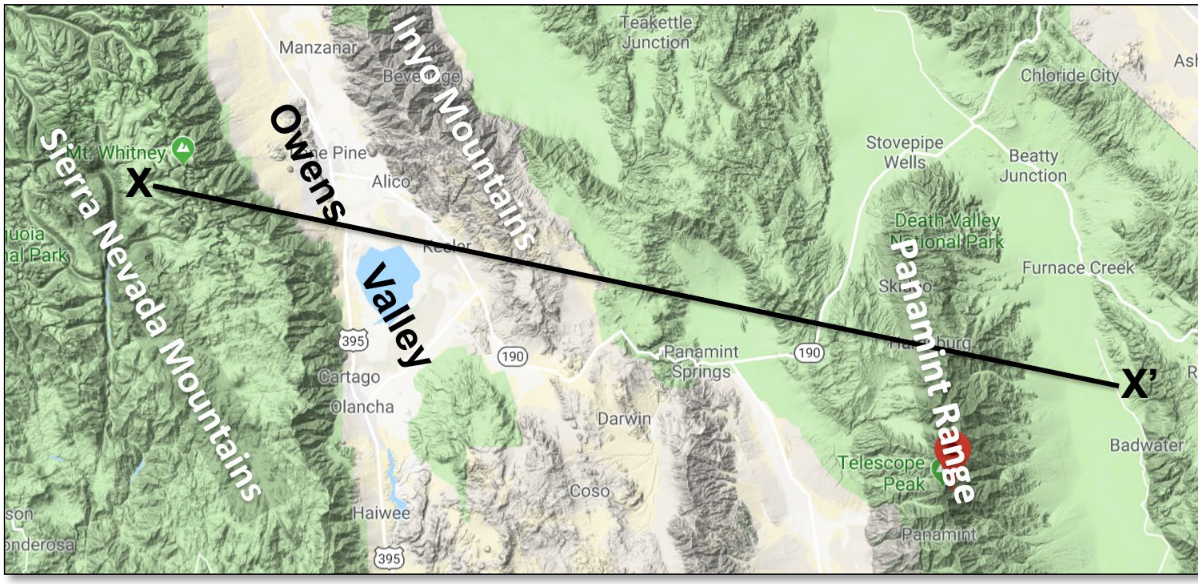
Owens Valley runs along the eastern side of the Sierra Nevada Mountain Range (Sierras). At around 75 miles long and 5 miles wide, Owens Valley represents the westernmost basin of the **Basin and Range geomorphic province**. From the eastern side of the Sierras, the Basin and Range stretches across Nevada to the Wasatch Mountains in western Utah, with a topography distinguished by a repeating sequence of roughly north-south oriented wide valleys (basins) separated by elongated mountain ranges (ranges). So persistent are the orientation and geometry of the basins and ranges, that this region was described by Charles Dutton, an important 19$^{th}$ Century geologist, as an "army of caterpillars marching toward Mexico".

The eastern boundary of the Basin and Range are the Sierra Nevada Mountains. This massive mountain range is 400 miles long and 80 miles wide, and contains the tallest mountain in the lower 48 states, Mt. Whitney, at 14,505 feet above sea level, as well as many other 14,000+ feet peaks. Owens Valley by comparison has an elevation of about 4000 feet above sea level, making for over 10,000 feet of elevation difference between the valley floor and the crest of the Sierras. This is the greatest topographic relief between two adjacent locations in the contiguous United States. For an even more dramatic comparison, if we start at Mt. Whitney, the highest place in the lower 48 states, we need only go 80 miles east to reach Death Valley, the lowest place in the western hemisphere, at -282 feet below sea level.

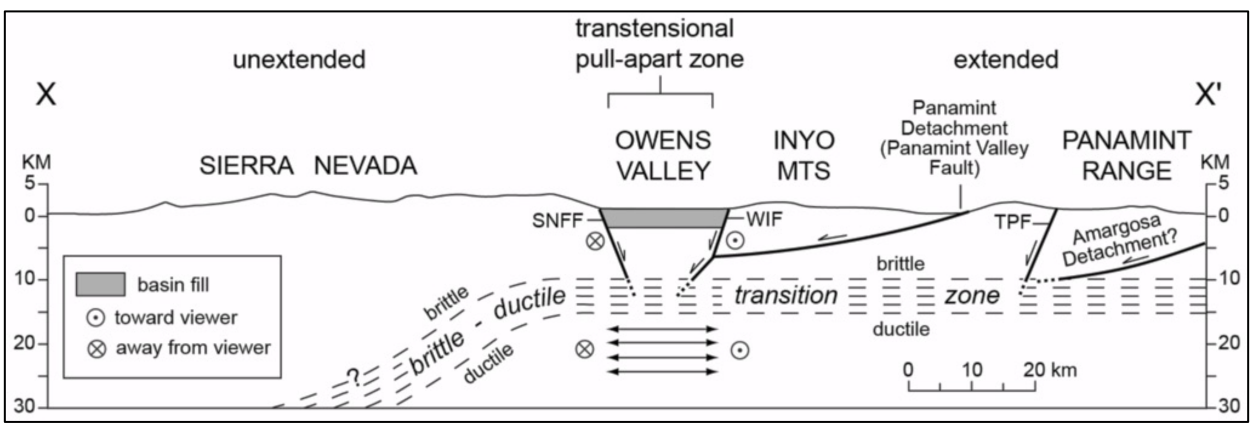
The Sierras also form a topographic barrier to westerly-moving weather systems, which are forced up and over the mountains, where they lose their moisture as snowfall along the western side and crest of the Sierras. The dry air then descends down the east side of the mountains, creating to the semi-arid to arid high desert climate of the Basin and Range.

## Geology

Owens Valley is a fault-controlled **graben** (meaning "ditch" in German) – typical of basins formed by crustal stretching within the Basin and Range geomorphic province. Faults bracket this block of crust on either side, structurally separating the Sierra Nevada and White-Inyo mountains along the western and eastern margins, respectively.




Map of Sierra Nevada Mountains, Owens Valley, Inyo Mountains, and the Panamint Range - Google terrain view map




Cross-section from the Sierra Nevada mountain range to the Panamint mountain range. SNFF = Sierra Nevada Frontal fault; WIF = White Inyo Fault. Circled indicates crust moving away from viewer, while the bullseye symbol indicates crust moving towards. From Stevens et al 2013.

Recent earthquakes and **fault scarps** signify that Owens Valley continues to deepen, as well as slide horizontally relative to the growing mountains. Fossils and radiometric dates from minerals found in ancient lakebed deposits indicate that Owens Valley started to develop some 2.5-5 million years ago. All the while, streams eroding the surrounding mountains have transported and deposited their load of sediment onto the valley floor to a thickness of at least 10,000 feet. In the recent geologic past, during the last ice age, streams were more abundant, bringing so much water onto the valley that lakes, like Owens Lake, covered large areas of the valley floor. Volcanism is also part of the geologic evolution of Owens Valley; lava flows, ash deposits, and volcanic cones are common and offer more examples of natural extremes. For example, the Long Valley Caldera just beyond the northern end of the valley, represents the aftermath of one of the powerful eruptions in the history of North America, while the Inyo Domes, a chain of rhyolitic volcano domes, are considered by some to be the youngest mountain range in the world.

The Sierra Nevada Mountains are the imposing western boundary to Owens Valley. The mountains are being actively uplifted along the Sierra Nevada Frontal Fault (SNFF), making the east side of the range essentially a large-scale fault scarp, called an escarpment. The Sierras can also be described as the Sierra Nevada Batholith. A **batholith** is a large crystallized **pluton**, or large body of magma, that covers at least 40 square miles if mapped on Earth's surface. However, the Sierras measure 400 miles by 80 miles, making for surface area of 30,000 miles… that would have been one huge pluton! Actually, the Sierras are a collection of many plutons, probably around 100, that formed, rose, cooled, and crystallized, coalescing into a more-or-less continuous, blimp-shaped mass. This process began with the start of subduction of the Farallon plate beneath the North American plate, which then continued to generate **felsic**-intermediate composition magma over the approximately 130 million years, slowly assembling the batholith at a depth of about 10 miles. Since, erosion of the overlying rock, isostatic uplift, and in the past 5 million years or so, tectonic uplift along the SNFF have acted to bring the batholith up to Earth's surface. Today, we see the upper portion of this "blimp" of granitic rock exposed as a mountain range.

Starting around 2.5 million years ago, Earth entered its most recent ice age, the Quaternary Ice Age. During this time, the climate has cyclically cooled and warmed, called glacial and interglacial periods. During glacial periods, glacial erosion played a major role in shaping the topography of the Sierras; since the last glacial period ended a little less than 12,000 years ago, the glacial landforms are still very "fresh", as there hasn't been much time for weathering and stream erosion to wear them down. Today, the Sierras offer a wonderful opportunity to observe many classic glacial erosional landforms, including: **U-shaped valleys**, cirques, tarns, horns, arêtes, and hanging valleys. As the glaciers flowed out of their valleys and the climate once again warmed, melting and with it deposition occurred, resulting in the formation of distinctive glacial till landforms, in particular, lateral moraines. Most recently, the Sierras have been shaped by stream erosion and mass wasting.

## Learning Objectives

Through participation in this field trip students should be able to:

1. Recognize strata and sedimentary rocks
2. Identify volcanic (extrusive) rocks
3. Describe the texture of sedimentary rocks
4. Describe the texture of volcanic (extrusive) igneous rocks
5. Identify plutonic (intrusive) rocks
6. Describe the texture of plutonic (intrusive) rocks
7. Recognize rock fall in the field
8. Recognize badland topography
9. Identify a fault based on the disruption of strata or the ground surface
10. Using the relative position of the hanging wall and footwall, identify a fault as normal or reverse
11. Identify and draw a fault scarp
12. Recognize spheroidal weathering and describe how the process weathers rock
13. Describe how Ice Age climate and ecology was different than today

14. Identify erosional and depositional glacial landforms
15. Explain and provide examples of the effect of the Ice Age on eroding rocks and shaping the landscape
16. Describe the significance of the Long Valley Caldera eruptions
17. Explain how a caldera forms
18. Identify volcanoes and volcanic features, such as, lava flows
19. Summarize the formation of a cinder cone
20. Describe the sequence of events that form a rhyolitic dome
21. Describe how tufa towers form
22. Describe how columnar joints form
23. Explain the selective distribution of the Bristlecone Pines
24. Summarize the history of the Los Angeles Aqueduct as it pertains to Owens and Mono lakes
25. Identify exfoliation and spheroidal weathering in the field
26. Explain the process of exfoliation and spheroidal weathering
27. Apply the law of superposition to determine the age of geologic events
28. Apply the law of crosscutting relationships to determine the age of geologic events
29. Summarize the geography and geologic history of the Basin and Range

## Key Vocabulary

**Badland topography –** a landscape with closely spaced drainages on steep slopes made of weakly cemented, fine-grained sediments; typically in arid climates with little vegetation

**Basin and Range geomorphic province** – continental rift zone comprising much of the southwestern United States where topography is characterized by a series of roughly parallel fault-controlled mountains and valleys

**Batholith** – a very large mass of intrusive igneous rock formed through the assimilation of numerous plutons

**Caldera** – a massive crater or depression (> 1 km) caused by the collapse of a single volcano or several volcanic features after a large eruption has partially emptied the magma chamber(s)

**Columnar jointing** – fracturing in basaltic (usually) lava flows resulting in polygonal columns, typically 6-sided

**Coulee** – very viscous lava flows of silica-rich lava that solidify to form a thick, “blobby” mass that extends from a vent outward

**Exfoliation** – mechanical weathering process where concentric fractures form curved sheets of rock, inches to a few feet thick, that break off, creating rock domes or rounded boulders

**Fault** – a fracture in Earth’s crust along which movement has occurred

**Fault Scarp –** a low, steep hill, caused by the vertical offset of the ground surface by movement along a fault

**Felsic** – a term used to describe igneous rocks rich in silica and light-colored minerals like feldspar and quartz

**Graben** – a block of crust down-dropping along faults resulting in forming a wide valley

**Glaciation** – a period of time during an ice age when glaciers are growing and actively eroding

**Lateral moraine** – eroded rock along the sides of a glacier that form low parallel hills after a glacier has retreated

**Law of crosscutting relationships** – a geologic feature is always younger than the geologic body across which it cuts

**Law of superposition** – in a sequence of sedimentary strata or volcanic rock, younger rock is atop older; i.e. each bed (sedimentary stratum) is younger than the bed beneath, but older than the bed above

**Metamorphic rock** – a rock that has been altered from a pre-existing rock by heat, pressure, and/or hot fluids
**Normal fault** – one of two types of vertical faults, where the hanging wall blocks slides down the fault surface relative to the footwall block in response to tensional stress during extension of the crust
**Pleistocene** – an *Epoch* of geologic time, beginning about 2.6 million years ago and ending about 10,000 years ago during which time Earth has been in an Ice Age
**Pluton** – large, irregular shaped blob of magma
**Plutonic/Intrusive igneous rock** – a rock that forms from the crystallization of magma
**Pull-apart basin** – wide valleys that form from tensional stress, e.g. graben
**Sag pond** – a type of pull-apart basin that fills with water to form a small lake
**U-shaped valley** – a valley formed by glacial erosion that has a "U" shape in cross-section

## Pre Field Lesson

Due to extensive and varied curriculum to be covered over this three-day trip, I would strongly encourage dedicating a class session or two to introducing or reviewing the topics to be covered. Using part of class session to discuss camping basics, equipment, clothing, etc. and to organize students into cooking groups is also a good idea. I also take this time to inform my group of the follow-up assignment and assessment (see end of this chapter). In particular, they should be notified that they are expected to take photographs at each stop and record notes in their notebooks.

## Pre Field Questions

1. Using the "Geology" section above, summarize in one paragraph the geology of the Sierra Nevada Mountains and Owens Valley.
2. What feature of sedimentary rocks makes them easily recognizable in the field?
3. Make a cross-sectional drawing of a normal fault; label the hanging wall and the footwall.
4. When was the last Ice Age? When did the last glacial period end?
5. What is spheroidal weathering and what type of rock does it typically affect?
6. How does the rock tuff form?
7. Describe how **calderas** can form.
8. How do lateral moraines form?
9. Compare and contrast the composition of the common igneous rocks basalt, rhyolite, tuff, obsidian, and pumice.
10. Summarize the geologic history of Devils Postpile National Monument; use the National Park website for the information: Devils Postpile National Monument. Scroll down and start with "The Postpile begins as a lake of lava".

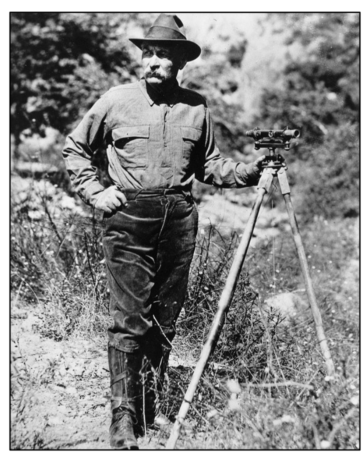
## En Route Talking Points: I-605 north, I-210 west, CA-14 north

- I-605 north
    - The 605 takes us across part of the Los Angeles Basin. This incredibly deep basin formed from roughly 16 million to about 1 million years ago as tectonic forces slowly peeled the Transverse Ranges away from the Peninsular Ranges, rifting open a series of basins. The sea flooded these pits as they slowly opened, meaning what is today the metropolis of Los Angeles and Orange counties were once at the bottom of the Pacific Ocean. All the while, sediment being eroded

from the continental highlands filled these depressions with silt, sand, and gravel, up to 6 miles in thickness.

- San Gabriel River
  - The San Gabriel River Freeway (formal name for I-605)
    - Follows a path of least resistance from river erosion
    - River erosion creates natural pathways
    - Pathways become footpaths
    - Footpaths become horse trails
    - Horse trails become thoroughfares
    - Thoroughfares become highways
  - River transports sediment from the San Gabriel mountains to its base level, the Pacific Ocean
  - Whittier Narrows water gap. The San Gabriel River and Rio Hondo River, just to the west, have created the Whittier Narrows by eroding faster downward than the hills have been uplifted, resulting in carving a topographic saddle, a "water gap", 2 miles wide and 800 feet deep, bisecting the Puente Hills into 2 parts: the Montebello Hills to the west and Whittier Hills to the east. For a more detailed description read the excellent discussion in *Geology Underfoot in Southern California,* "Vignette 9 – A Boon to Communication, The Whittier Narrows"
  - Similarly, Santa Ana River erosion has created water gaps through hills that are now occupied by the 91 and 57 freeways
- Whittier and Puente Hills (east of the 605) are being actively uplifted along the Whittier fault, which runs along the base of these hills; this fault is active as evidenced by the recent Whittier (1987, M 5.9), Chino Hills (2008, M 5.5), and La Habra (2014, M 5.1) earthquakes.
- Montebello (Repetto) Hills (west of the 605)
  - Western extension of Puente Hills
  - Like Puente Hills, the Montebello Hills are made up of steeply tilted, south-dipping sedimentary rock that is typical of sediment in the LA Basin: mudstone, siltstone, sandstone, and conglomerate
- On a clear day point out the San Gabriel Mountains making up the northern skyline and its highest peak, the 10,064 feet tall Mt San Antonio, a.k.a. Mt Baldy.
- San Gabriel Mountains
  - Mountains at northern end of San Gabriel Mountains
    - Represent a block of crust that was peeled away from the Peninsular Ranges to the south and rotated 110$^{o}$ to its current position as Baja California was tectonically peeled away from mainland Mexico (for a more thorough discussion see the Introduction in *Roadside Geology of Southern California*, Sylvester and Gans, 2016)
    - Compressional tectonic forces have rapidly uplifted the San Gabriel Mountains past 5 million years
      - Could be growing as fast or faster than the Himalayan Mountains (Prothero, 2011), at a rate as fast as 70 feet per 1000 years (Sylvester and Gans, 2016)

        - Rapid uplift evidenced by very deep, steep canyons, like Arroyo Seco or Big Tujunga Canyon and triangulated ridges
        - Mountain range is being uplifted along 2 faults, the San Andreas fault along the north side and the Sierra Madre-Cucamonga fault zone along the south side
    - Contains **metamorphic** rock as old as 1.7 billion years, as well as Proterozoic **plutonic** rocks; these were intruded by magma of diorite to granite composition that was generated by subduction of the Farallon Plate during the Mesozoic time
  - After passing the I-10 and shortly before arriving at the I-210 interchange watch for deep pits on either side of the freeway
    - Gravel pits mining alluvium being shed off of the San Gabriel Mountains
    - Gravel used for concrete and roadways
    - Water in a pit means it is deeper than the water table (depth to groundwater)
- I-210 west
  - Sierra Madre fault zone
    - Runs along the foot of mountains
    - Has facilitated as much as 10,000 feet of vertical uplift of the crust, which is today expressed as the San Gabriel Mountains
    - Associated with the San Fernando fault that produced the 1971 Sylmar earthquake
  - The foothills are a series of coalesced alluvial fans that formed as the San Gabriel Mountains were uplifted, weathered, and eroded by streams; when the streams flow out of narrow mountain canyons, they slow and lose their ability to transport their sediment load, resulting in deposition and the formation of alluvial fans
  - Many of these stream channels are dammed where canyons open up, creating "catch flow basins" that trap or at least slow the dangerous boulder-sized clasts contained in inevitable debris flows
- Continue on the I-210 west at the CA-134 interchange
  - "Benched" road cuts a common practice used to increase slope stability
  - Driving through Sylmar takes one past the epicenter of the 1971 magnitude 6.5 Sylmar earthquake that caused over a billion dollars in damage and 65 deaths, mostly from the collapse of the Olive View Hospital



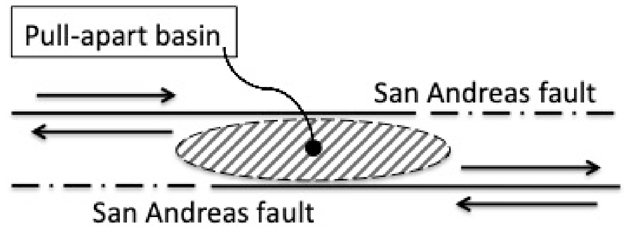
**William Mulholland. – CC.**

- Los Angeles Aqueduct
  - As the 210 mergers with I-5 look ahead and you should notice a long pipe-like feature coming down the hillside just to the right of the freeway
    - This is a chute for carrying water, baffled for aerating
  - One of three aqueduct systems bring water to the greater Los Angeles area, the other two being the California Aqueduct that delivers water from the western Sierra Nevadas, and the Colorado River Aqueduct that brings water from the Colorado River
  - Designed by self-taught engineer William Mulholland to divert water from the Owens River and its tributaries to the burgeoning city of Los Angeles

**Los Angeles Aquaduct**

    - Water would be used to boost land values and profits for developers
  - Remarkable engineering feat considering it was desinged and built over 100 years ago, so water flows downhill over its entire length, requiring no pumps and only gravity to transport water from its source 235 miles to L.A.
  - Building the aquaduct necisistated some shady business dealings, violence, and even deaths
    - Residents of Owens Valley had plans to use the water from the Owens River to develop agriculture and livestock
  - Fred Eaton, a well-connected former mayor of Los Angeles used a contact in Owens Valley to, through deception, buy up land in Owens Valley and with it water rights to the Owens River
  - Mullholland and Eaton were also working behind the scences with a collection of friends and business partners to buy up cheap land in the San Fernando Valley, which would be made drastically more valuable once it was provided with a reliable water source
      - This story serves as part of the plot for the critically acclaimed 1974 movie *Chinatown*, starring Jack Nickolson: movie clip from Chinatown
- While completed ahead of schedule and under budget, the completion of the aqueduct consumed machines, mules, and men, with several construction-related deaths
- Owens Valley residents rebelled upon learning that all the water of “their river” was being diverted to Los Angeles
  - In 1924 seventy armed Owens Valley men took control of an aqueduct gate and shut off the flow of water
  - In 1927 a 45-foot section was blown up

        - The uprisings were permanently squelched when Mulholland sent out machine gun armed horseback patrols with orders to shoot to kill anyone disturbing the aqueduct
- I-5/I-14 interchange
    - Some of the overpasses here collapsed during both the 1994 and 1971 earthquakes
- CA-14 (Aerospace Highway)
    - Placerita Canyon Road
        - Placerita Canyon earned its name and fame for the placer (gold deposited as sediment in a stream channel) deposits that were discovered here in 1842, six years before the Gold Rush began in the western Sierra Nevada Mountains.
    - Santa Clara River
        - Longest undammed river in southern California (Prothero, 2011) and significant in that its channel hasn't been modified by human construction
        - Braided stream, common in the foothills of mountains
        - Multiple intertwining channels, weaving around channel bars
        - Ephemeral stream channel in that it is dry unless it has just rained
        - The dry channel is deceiving, because water is flowing in the subsurface as groundwater, which will eventually be utilized by communities downstream (Sylvester and Gans, 2016)
    - Vasquez Rocks
        - After passing Agua Dulce Road look to the left (north) for spectacular stacks of tilted, red-brown sediment, jutting out of the ground
        - See chapter 4 for a more thorough description
    - Lamont Odet Vista Point and the San Andreas Fault
        - We are at the very edge of the Pacific Plate. Looking northward our line of sight crosses the California Aqueduct, the San Andreas fault and the plate boundary with the North Ameican Plate, and Antelope Valley beyond.
        - Disappointlingly, the San Andreas fault is not an obvious gash, since it has been over 160 years since its last major break in southern California and erosion has "smoothed-out" disturbances, like scarps and ground cracks. Instead, the trace of the fault are the low hills, running northwest-southeast, through which highway 14 cuts through and lie on the opposite side of Lake Palmdale, continueing east into the mountains.
        - Lake Palmdale was originally a **sag pond**, a depression that collects water where there has been subsidence of the crust due to faulting. Here, the San Andreas fault is segmented, "stepping over" to create a **pull-apart basin** and sag pond – note how the arrows on either side of the pull-apart basin to pointing away from each other, creating tensional stress and subsidence. Recently, the sag pond was damned in order to store more drinking water for the cities of Paldale and Lancaster that spread out from the edge of the North American Plate before us.




**Forming a pull-apart basin.**

- The California Aqueduct provided the greater Los Angeles area with a significant portion of its water. Constructed in the 1960s, it brings water from the western Sierra Nevada Mountains and transports it 700 miles, making it one of the longest aqueducts in the world. It was built above ground so repairs can be made more quickly after damaging San Andreas fault earthquakes; a matter of days vs. weeks or even months if the water were contained in underground pipes (Sylvester and Gans, 2016)

- Palmdale Roadcut
  - The ridge through which CA-14 transects formed through intense compression of the relatively young, Pliocene Anaverde Formation. This sliver of crust is caught between two branches of the San Andreas fault, the San Andreas proper along southern side and secondary branch, the Littlerock fault, along the northern margin of the ridge, making it an example of a squeeze block (see Indio Hills, Chapter 1) or a pressure ridge (Sylveter and Gans, 2016). Excavations for geolgic study show that about 50 of right-lateral offset along the southside of the ridge.
- Antelope Valley
  - Once through the Palmdale roadcut, you have crossed onto the North American Plate. “Antelope Valley”, containing the bustling communities of Palmdale and Lancaster, is a more appealing name invented by developers to describe what is actually the southwestern corner of the Mojave Desert.
  - As recently as a few tens of the thousands of years ago, lakes covered large parts of Palmdale and Lancaster. As our climate has warmed and dried, the lakes evaoporated.
    - Many archaeological sites occupy what would have been ancient lakeside beaches (Sylvester and Gans, 2016)
- Rosamond Hills and Soledad Mountain (just north of community of Rosamond, west of the highway)
  - The colorful rocks that make up these hills are Miocene age rhyolitic volcanics, which have been hydrothermally altered, adding to the coloring
  - Mined extensively for gold, silver, and radioactive minerals
  - Rock collectors have frequented this area for geodes, chalcedony, and opal
  - After Backus Road is a lower mined hill; the site of the Golden Queen Mine
    - This open pit mine produces gold and silver through cyanide leaching of crushed, conglomerated ore.
- Wind farm
  - Alta Wind Energy Center
  - 24 megawatts (MW)
  - 1 MW powers roughly 650 homes

- Garlock Fault
    - Trace is marked by the straight eastern mountain front of the Tahachapi mountains One of the longest faults in California at 160 miles


The trace of the Garlock fault. Note CA-14 and Red Rock Canyon. – Google Earth

    - An exception in that it is a left-lateral strike-slip fault – most horizontal faults in southern California are right-slip faults
    - Offset drainages abruptly jump to the right when crossing the fault
- El Paso Fault and El Paso Mountains
    - El Paso Fault
        - Runs along the foot of the El Paso Mountains
        - Branch of the Garlock Fault
        - Fascilitating uplift of the El Paso Mountains
    - El Paso Mountains
        - Contain Red Rock Canyon State Park
        - Many cuestas of colorful sedimentary rock separated by ephemeral stream channels
- El Paso Mountains "Gorge"
    - Pass used by CA-14 through the El Paso Mountains
    - Formed by stream erosion, making it a *water gap* – note stream channel and stream terraces immediately to the right of highway

Prepare for stop 1, a little less than a 1.5 miles from the southern front of the El Paso Mountains.

## Field Trip Stops

Utilizing a charter bus is recommended for this multi-day trip. Having everyone contained in one vehicle will allow for lecturing and giving instructions while the bus is moving, making for efficient and effective instruction. Considering the long distances that need to be covered, a charter bus service is probably the safest means of transport and eliminates the possibility of losing any members of your group while in transit.

## Stop 1 – Red Cliffs at Red Rock Canyon State Park

Addresses learning objectives:
1. Recognize strata and sedimentary rocks
2. Describe the texture of sedimentary rocks
7. Recognize rock fall in the field
8. Recognize badland topography
9. Identify a fault based on the disruption of strata
10. Using the relative position of the hanging wall and footwall, identify a fault as normal or reverse

Turn right from CA-14 onto the Red Cliffs access road, just after the "side road right" sign (|–).

**Red Cliffs at Red Rock Canyon.**

Depart bus (vehicles) and assemble at northwest end of parking area. Bathroom in block building immediately south of parking area.

- Red Cliffs
  - Ask, *What type of rock are the cliffs made of?* – Sedimentary. *How can we tell?* – Strata. Strata are stack of individual sedimentary layers or stratum. Each stratum represents a more or less continuous period of deposition.
  - Use the *Geography* and *Geology* sections at the start of this chapter to introduce RRC
  - Cliff face also provides a good example of **badland topography**

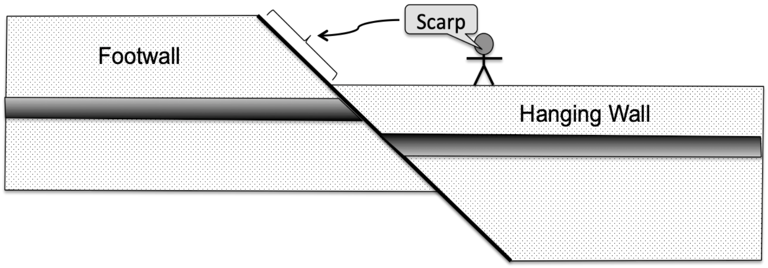
*Activity 1: Pair-up students and have them examine the texture of some of the cobbles and boulders near the base of the cliffs. Help them differentiate between fine-grained sedimentary rock and volcanic rock.*


**Normal fault exposed at Red Rock Canyon State Park.**

*Activity 2: Have students come back to edge of parking area and ask them to point out any evidence of mass wasting* – Rock fall should be evident.

Walk back towards the highway and just around the western edge of the Red Cliffs so you're standing in the wash. Direct students to look to the northwest, to where the buff-colored strata intersect the highway then look about 200 feet to the right, where a fault offsets strata.

*Activity 3: Ask students to identify the fault then make a simple sketch that shows the strata offset and identifies the hanging wall and footwall.* Ask: *Considering the position of the hanging wall relative to the footwall, what type of fault is this?* – Normal




Cross-section perspective drawing of a normal fault.

Return to bus and continue north on the CA-14. Once the 14 joins US-395, continue for another approximately 19 miles to Fossil Falls.

## En Route Talking Points: CA-14 north to CA-395

- Leaving the El Paso Mountains and Red Rock Canyon you enter the southwest corner of the Basin and Range geomorphic province, in which Owens Valley is contained
- As you approach CA-178 west note the southern terminus of the Sierra Nevada off to the left (northwest)
- Once you've reached CA-178 east, the route to Ridgecrest and Inyo-Kern, you should be able to observe the distinctive gray hue of the Sierra Nevada granite
- As CA-14 merges into CA-395 you may be able to make out the dark brown basalt flows that drape the low-profile Coso Mountains off to north-northeast and Red Hill
- The Pleistocene age basalt flows of the Coso Volcanic Field and our next stop, Fossil Falls, are clearly visible when you reach the turnoff for Kennedy Meadows and 9 Mile Canyon Road
- Little Lake was a vital stopover for northbound travelers in the first half of the 20th century, providing water, food, and bed for a journey that could take several days

## Stop 2 – Fossil Falls

Addresses learning objectives:
2. Identify volcanic (extrusive) rocks
4. Describe the texture of volcanic (extrusive) igneous rocks
13. Describe how Ice Age climate and ecology was different than today
15. Explain and provide examples of the effect of the Ice Age on eroding rocks and shaping the landscape
19. Summarize the formation of a Cinder Cone

Red Hill cinder cone and basaltic lava flows.

Exit at Cinder Road (~ ¼ mile past the brown wooden sign for Fossil Falls and just before the Red Hill cinder cone). Point out the volcano to your group. Proceed just over ½ mile, then turn right on the Fossil Falls access road and proceed to parking lot. Restroom is at southwest corner of lot; trailhead at southeast corner.

Assemble group at trailhead for a geologic overview of Fossil Falls:

- Three separate basalt flows
    - 10-20,000 years old
    - 100,000 years old
    - 400,000 years old
- The youngest flows are from Red Hill
    - Red Hill is a cinder cone
        - Built through the eruption of lapilli-sized (think pea to golf ball) basaltic pyroclasts (blobs of lava) during one more or less single eruptive episode that would have lasted weeks to months, to even a few years
        - Near the end of the eruptive cycle, basaltic lava flows were released, intermingling with older flows
- Fossil Falls is comprised of the 100,000 year old flow
    - Contains minerals of labradorite, augite, and inclusion of basalt glass
    - The lava flows represent the rapids and waterfall section of an ancient stream bed
        - Considering the degree of scouring and polishing of the resistant basaltic lava flows, the ancient river must have flowed with tremendous force and a tremendous load of sediment
        - About 10,000 years ago the stream was draining Queens Lake, an ancient pluvial (Ice Age) lake that formed during the cooler and wetter climates associated with glacial periods during the **Pleistocene**
    - Pot holes attest to highly erosive power of this ancient river

Return to CA-395 and continue north.

## En Route Talking Points: CA-395 to Owens Lake

- Owens Valley subtly begins north of the Coso Mountains and gradually opens up to what one could call Owens Valley "proper", at the south end of Owens Lake
- As you approach the small community of Grant, about 3 miles south of Olancha, look west for nice examples of alluvial fans
- After passing through Olancha and the Crystal Geyser bottling factory look east for Owens Lake
    - Today, Owens Lake is a playa, a dry or seasonally dry lake

For the Owens Lake stop, I recommend choosing a safe spot to pull off of the highway then discussing its interesting history from your vehicle. Since highway 395 is situated higher than the lake depression, you should have a reasonably good vantage point from the shoulder of the highway, or from the highway itself, if you choose not to stop and discuss while you roll along. There are two places near the north end of the lake that offer a wide shoulder for a bus-sized vehicle, the first is about 16.5 miles north of the CA-395/CA-190 junction at Olancha, just past the sign for "Visitors Center 5 miles ahead". The second shoulder pullout is about ½ a mile further north. Alternatively, one could circumvent the ancient shoreline of the lake by taking CA-190 from US-395, then north on CA-136 back to the 395, but this will add at least 15 minutes to your journey.

### Stop 3 – Owens Lake

Addresses learning objectives:
13. Describe how Ice Age climate and ecology was different than today
24. Summarize the history of the Los Angeles Aqueduct as it pertains to Owens and Mono lakes

- 30-50 feet deep until 1913
- During the peak of the last glacial period the lake was up to 300 feet deep
- It covered so much area that steam boats transported cargo back and forth
- From 1862-1917 extensive farmland developed around the lake
    - By 1912 sixty-two thousand acres were cultivated and 160,000 fruit trees had been planted
- Los Angeles started diverting water via the Los Angeles Aqueduct in 1913
- Lake was dry by 1926
- "Bathtub rings" of salt deposits show the lake levels of the not-so-distant past
    - should be visible at the north end of the lake

Continue north on US-395. If you choose to explore Stop 4, take the turn off for CA-136, then immediately turn into the parking lot for the Eastern Sierra Interagency Visitor Center.

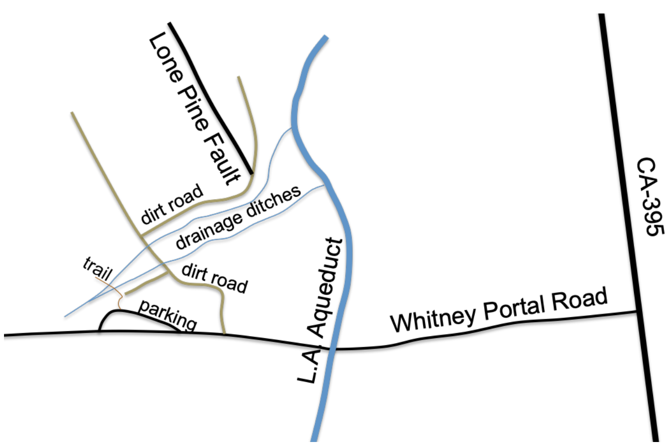
### Stop 4 – Eastern Sierra Interagency Visitor Center (optional)

- Restrooms
- Instructive exhibits
- Picnic tables
- Shade

Continue north on US-395 to the city of Lone Pine. Turn left (west) onto Whitney Portal Road and continue a little over half a mile, crossing over the Los Angeles Aqueduct (points will be deducted if you try to blow it up), to the paved pullout, just after a brown wood sign for "Alabama Hills Information".

### Stop 5 – Lone Pine Fault Scarp

Addresses learning objectives:
10. Using the relative position of the hanging wall and footwall, identify a fault as normal or reverse
11. Identify and draw a fault scarp



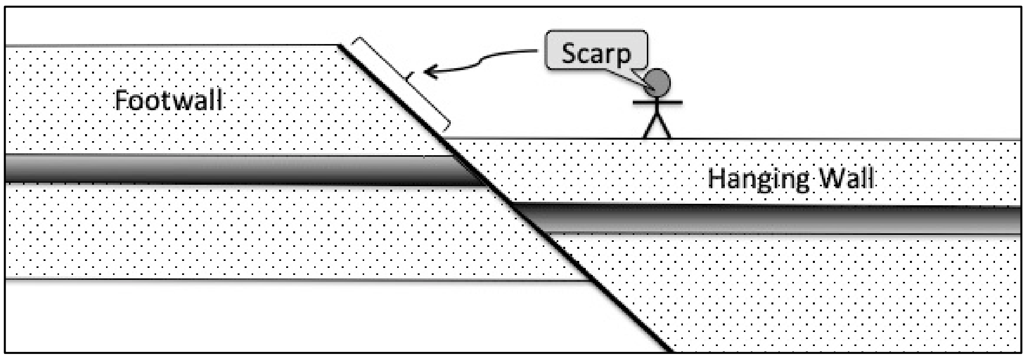

**Cartoon map showing location of Lone Pine fault scarp.**

Park bus in the "parking" area (see map below). If you've arrived using higher clearance vehicles, like vans, you could drive the "dirt road" to the scarp. Walking from the parking area, you could take the "trail" about 100 feet then climb up and over low embankment to connect to the dirt road. You could also walk back down Whitney Portal Road then turn left on the dirt road; walk over the two drainages, then turn right (east) on the dirt road immediately after the 2nd drainage. Proceed up to the 90° left turn. At this point the scarp intersects the path you are on. Assemble group.

*Activity 4: Ask students to point out fault scarp, estimate the height of the fault scarp then share their estimate with one other student.*

Fault scarps represent the uppermost portion of the fault surface, which is exposed after a fault breaks in an earthquake. In order for a fault scarp to show on Earth's surface there must be some component of vertical movement along the fault.

*Question: Considering that Owens Valley is a fault-controlled graben that formed in response to Basin and Range extension, what types of faults should we expect to find?* – Normal.




**Cross-sectional drawing of a normal fault.**

Here, we have a 15-20 feet tall fault scarp, along the Lone Pine fault, a branch of the Owens Valley fault zone (Sharp and Glazer, 1993). *Question, "How strong of an earthquake would be needed to produce a 20 feet tall high scarp?"* Careful geologic studies along this fault show the scarp to be the result of at least 3 earthquakes; the most recent being one of the three strongest recorded in California's history, the 1872 Lone Pine earthquake estimated to be a magnitude 8 or stronger. Paleoseismic studies imply a recurrence interval for the Lone Pine fault of 3000-4000 years. *Prompt: Now, let's try to determine if the Lone Pine fault is indeed a **normal fault**...*

**Lone Pine fault scarp.**

*Activity 5: Pair students and direct one to stand on top of the fault scarp and the other at the base of the fault scarp.* Take care to use any preexisting trails to minimize degradation of the scarp.

Question: *Are the students at the base of the scarp standing on the hanging wall or footwall block of the fault?*
Questions: *What type of fault do you think this is?* – Normal. *Is it possible that it also moved laterally in addition to moving vertically?* – We can't really tell from here, but let's look around for more evidence.

Continue walking north along the road, keeping to the left when it forks, to the dry stream channel. Observe the overall color of the sediment. Continue northward across the channel to where the road ends at a roughly east-west trending road. Looking north, ask if there is any difference between the sediment in the channel ahead and the sediment from the last channel.

*Question: Why is the sediment darker in color here?* – Different source (Alabama Hills vs. Sierras from the first channel).

The geologic studies mentioned earlier included mapping of the shape and alluvium in this channel. The data collected shows that the Lone Pine Fault has offset this channel to the right 35-40 feet.

*Question: What does this tell us about the Lone Pine Fault?* – It also moves laterally. This supports the belief among earth scientists that Owens Valley has developed through both sliding down along normal faults and horizontal sliding along "step-over" strike-slip faults (see Lamont Odet Vista Point in En Route Talking points above), which results in creating a pull-apart basin. Death Valley, the deepest basin in the western hemisphere, has formed similarly.

Return to vehicles then continue west on Whitney Portal Road for just under 2 miles to Movie Road

### Stop 6 – Alabama Hills

Addresses learning objectives:
5. Identify plutonic (intrusive) rocks
6. Describe the texture of plutonic (intrusive) rocks
24. Summarize the history of the Los Angeles Aqueduct as it pertains to Owens and Mono lakes
25. Identify exfoliation and spheroidal weathering in the field
26. Explain the process of exfoliation and spheroidal weathering

**Natural arch at Alabama Hills.**

Like Vasquez Rocks Natural Area and Red Rock State Park, the Alabama Hills are the site of many movies, television shows, and commercials. This dry, boulder-strewn landscape provides a quintessential western landscape and is easily accessible for Los Angeles based production companies.

The Alabama Hills are comprised of two types of igneous rocks of two distinct geologic ages: 90 million year old granite and 150-200 million years old metamorphosed volcanic rock. The granite is of similar composition to the rock of the Joshua Tree National Park landscape and has weathered in a very comparable manner, which is why these two places look related.

Drive along Movie Road to take in and discuss the landscape or pull over at an inviting spot if you have the time and desire to get up close and personal with the rocks. A 1.5 miles drive from Whitney Portal Road will take you to Arch Rock Loop Trail, with a large parking area where a bus could turn around. I'd recommend the loop trail, especially hiking it in a clockwise direction, which will get you to the arch rock in about 10 minutes. From there you could discuss the weathering process of **exfoliation**, which is nicely exemplified on many of the boulders, as well as the weathering process of **spheroidal weathering**, which is helping to shape the granitic landscape of the Alabama Hills.

Rock showing exfoliation.

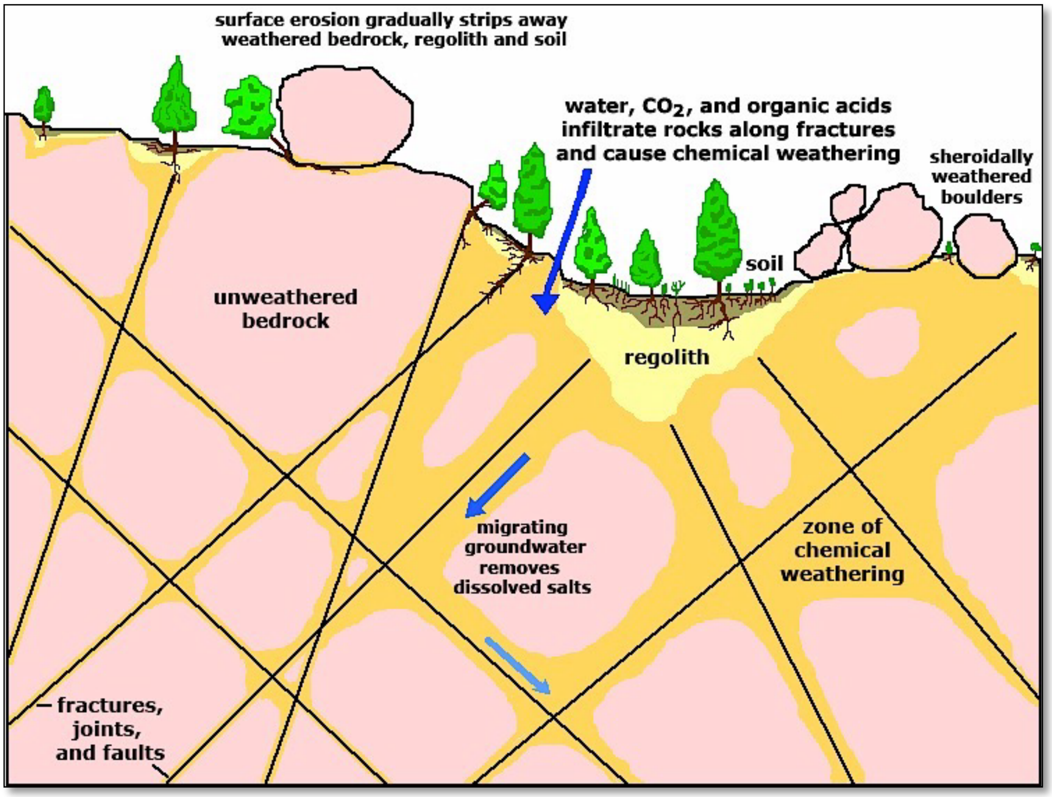
### *Spheroidal Weathering*

Weathering is the action of rock physically and chemically weakening and breaking down at or near Earth's surface. At Alabama Hills the rounded hills and boulders of granite were shaped by spheroidal weathering, which involves several steps over thousands of years:

1. Before reaching Earth's surface stresses acting on a batholith cause joints or sets of roughly parallel fractures in the body of rock. These intersecting fractures cut the rock into cubic shapes.
2. Through tectonic uplift and erosion the granite is brought close to Earth's surface.
3. Acidic water infiltrating from Earth's surface flows down and along the fractures, chemically reacting with feldspar in the granite and changing it into clay. 1

Rocks with Joints. – CC

4. Because the fracture pattern creates cube-like blocks of granite, the corners of the cubes are preferentially weathered faster than the rest of the block – just like sucking on an ice cube will result in the cube becoming rounded – and the cubes of granite become more spherical.




Rock undergoing spheroidal weathering.

5. Once erosion exposes granite on Earth's surface, the clay is easily washed away, leaving behind rounded hills and boulders of granite. The stripping away of clay and loose mineral grains is particularly effective when warming and drying climates reduce the density of vegetation, leaving soil and weathered rock more prone to water erosion.

Rock that has undergone spheroidal weathering at Alabama Hills.

Before departing, be sure to point out Mt. Whitney, the tallest mountain in the U.S. outside of Alaska.

Return to Whitney Portal Road and US-395. Continue north to Bishop. At the north end of town, the 395 makes a 90 degree turn to the left. From here it is about 11 miles to your next turnoff, Gorge Road (just after the brown, wood sign "Gorge Power Plant"). Turn right onto Gorge Road then a left where it "Ts" and proceed a little over 3 miles to another paved road that will take you east (right turn) towards Owens Gorge. After less than a ¼ mile, pull over on the shoulder just as the road curves back to the north. Exit vehicles and walk towards the edge of the gorge – urge students to exercise caution.

The Sierra Nevadas and Mt. Whitney. Whitney at arrow tip.

## En Route Talking Points: CA-395 to Owens River Gorge

- If you are conducting this trip during the spring, you may be able to point out the difference in the amount of snow that has fallen on the Sierras vs. the White-Inyo Mountains to the east – a consequence of the rain shadow effect
- Good examples of alluvial fans coming off of the White-Inyo Mountains
- Just after the turnoff for Rovana, lateral moraines are visible coming out of Round Valley in the Sierras

## Stop 7 – Owens River Gorge

This stop address the following learning objectives:
2. Identify volcanic (extrusive) rocks
4. Describe the texture of volcanic (extrusive) igneous rocks
16. Describe the significance of the Long Valley Caldera eruptions

Students at Owens River gorge.

- Situated on the flank of the Volcanic Tablelands, making up the northern end of Owens Valley
    - Volcanic Tablelands are 1000 feet high plateau made up of Bishop Tuff
        - Bishop Tuff
            - Pink, rhyolite tuff
            - Lithified ash fallout from the super volcanic Long Valley Caldera eruption, 760,000 years ago

        - The eruption expelled 150 cubic miles of ash, enough to bury all of Los Angeles county to a depth of 200 feet
    - The Owens River Gorge was formed catastrophically around 100,000 years ago, when the lake occupying the Long Valley caldera depression overtopped its southern rim, sending a torrent of water through the easily eroded Bishop Tuff

*Activity 6: Have students walk around to collect, examine and make a sketch of a sample of Bishop Tuff. The sketch should show the texture (pyroclastic) and any mineral (quartz) grains or rock fragments. Also include a description of the overall composition.*

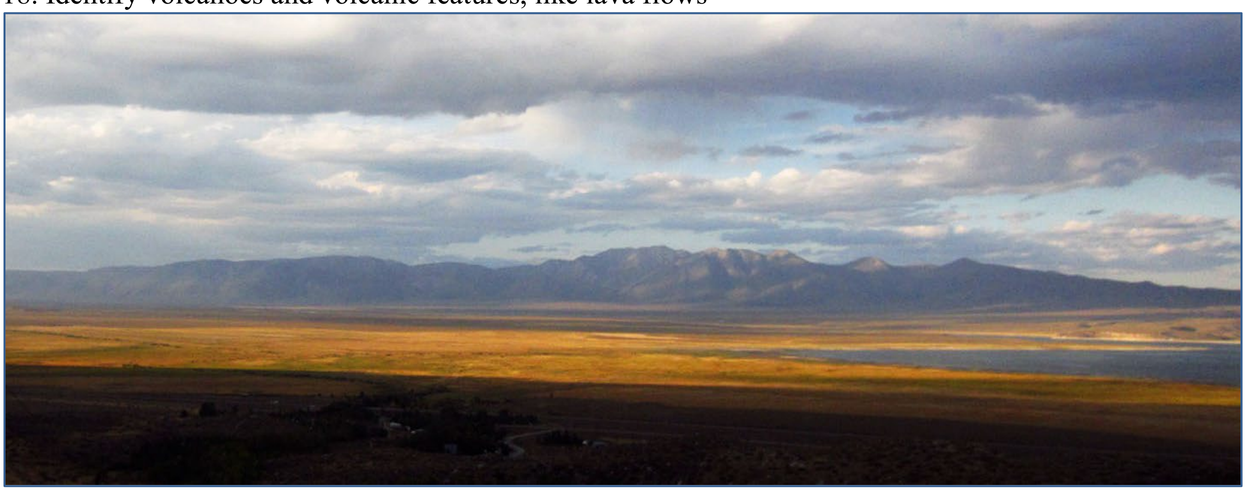
Walking up onto higher ground across the road one gets a great view of the Sierras and the **lateral moraines** coming out of Round Valley.

*Activity 7: Ask students to pointout the lateral moraines and discuss how they could have formed*

Return to US-395, via the way you came in. Turn right, and continue north on the 395, up the Sherwin Grade to the top of the Volcanic Tablelands.

### Stop 8 – Long Valley Caldera

Addresses learning objectives:
16. Describe the significance of the Long Valley Caldera eruptions
17. Explain how a caldera forms
18. Identify volcanoes and volcanic features, like lava flows



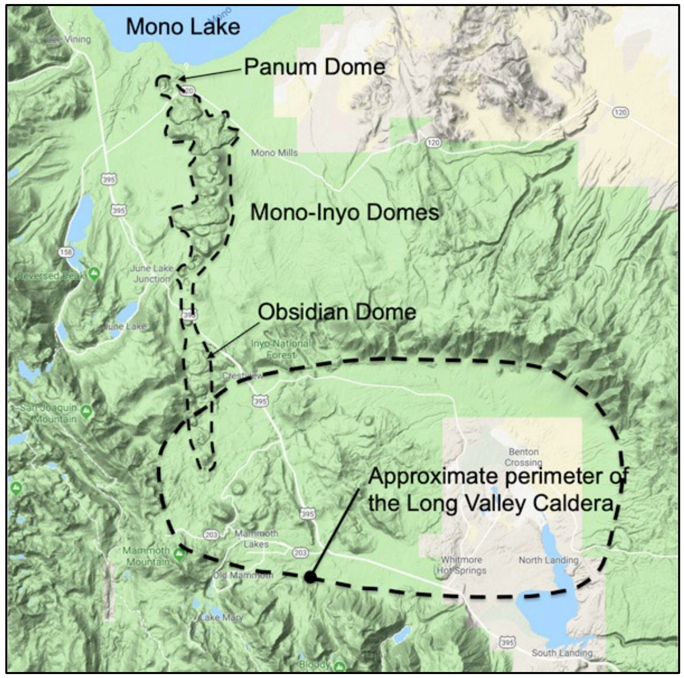
**Portion of Long Valley Caldera. Mountain front represents the eastern edge of caldera, while the caldera extends many miles off to the left (north) of the frame.**

Use the designated "Scenic Overlook" pullout for Lake Crowley, shortly after South Landing Road. Exit vehicle(s), take-in the majestic scene then discuss some of the dramatic highlights of one of the most destructive natural disasters known.

### *Long Valley Caldera*

- One of the largest **calderas** on Earth
    - 11 x 20 miles

- Caldera walls about 3000 feet deep
- Created by a super volcanic eruption 760,000 years ago
  - High silica rhyolite magma erupting from volcanoes and a series of vents partially emptied magma chamber(s), leaving them unable to support the weight of the overlying crust, which collapsed, triggering catastrophic eruption
  - Ash was as blasted as high 25 miles into the stratosphere, covering most of the western US, as far east as Nebraska and Kansas




**Map showing major volcanic features of the volcanic tablelands area.**

  - Pyroclastic flows moved down Owens Valley, past present day Big Pine and up and over the crest of the Sierras
  - Ash fall was most dense around the eruption site, where it accumulated and consolidated into the pink, rhyolite tuff of the Bishop Tuff Formation (Stop 7 above), building up the 1000 feet high plateau upon which we stand, known as the Volcanic Tablelands
  - Immediately following the catastrophic eruption, the caldera was as much as 2 miles deep (Sharp and Glazner, 1987)
    - Ash fell back to Earth, filling about 2/3 of the pit
    - Since the eruption, thick rhyolite domes have grown within the caldera, including Mammoth Mountain, 200,000 years ago
- Recent geologic activity reminds us that magma is still present
  - In 1980, four Mag 6.0 earthquakes in Mammoth Lakes area
    - 2 feet of ground swelling
    - 1990 earthquake swarm

This is probably a good place to call it a day and head to your campground or hotel. Since McGee Creek campground was mentioned at the start of this chapter, directions follow: From the Lake Crowley "scenic overlook" continue about 2 miles north on camping US-395. Turn left onto McGee Creek Road and head south towards the foothills. The road will wind its way up and around a lateral moraine before dropping down to the campground access road (~ 2 miles from US-395). It's a narrow road, but navigable by charter bus.

### Day 2, Stop 1 – McGee Creek Campground

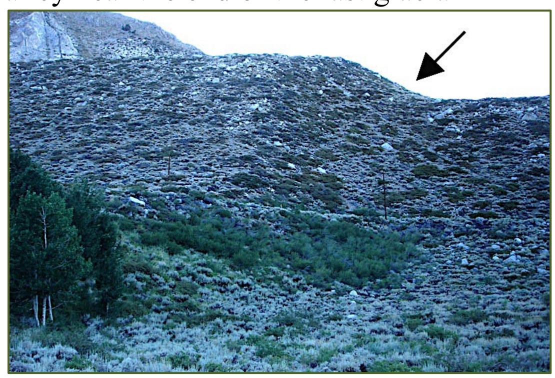
Addresses learning objectives:

9. Identify a fault based on the disruption of strata or the ground surface
10. Using the relative position of the hanging wall and footwall, identify a fault as normal or reverse

11. Identify and draw a fault scarp
14. Identify erosional and depositional glacial landforms
15. Explain and provide examples of the effect of the Ice Age on eroding rocks and shaping the landscape
16. Describe the significance of the Long Valley Caldera eruptions
17. Explain how a caldera forms
18. Identify volcanoes and volcanic features, like lava flows
28. Apply the crosscutting relationships to determine the age of geologic events

After you choose a lecture spot that won't disturb other campers, you can address the lateral moraines of the Hilton Creek fault scarp:

- Lateral moraines are the hills bracketing the campground
  - Formed as a glacier receded from this valley near the end of the last glacial (Tioga) period
- Hilton Creek Fault scarp
  - During the 1980 magnitude 6.3 earthquake, the lateral moraines were offset 2-6", compounding the past displacement caused by the 1872 Lone Pine Fault quake
  - The scarp is most obvious in the western lateral moraine, near the south side of the campground



**Hilton Creek fault scarp**

*Activity 8: Ask students to point-out the lateral moraines and discuss how they could have formed.*
*Question: What could they tell us about the climate here in the past?*

*Activity 9: Ask students to use the **law of crosscutting relationships** to determine the relative age of the fault scarp and the lateral moraine… Which came first?*

*Activity 10: Ask students to consider the geometry of the fault scarp, then make a cross-sectional drawing showing the fault offsetting the moraine. On the drawing, label the moraine, the hanging wall, the footwall, and draw and name the type (normal) of fault.*

From the McGee Creek Road/US-395 junction, proceed north on the US-395 for about 29 miles to CA-120. Turn right onto 120 then drive about 3 miles to Mono Craters Road (just past the trail/hiking road sign). Turn left and proceed to the parking area for Panum Dome.

## Day 2, Stop 2 – Panum Dome and the Mono-Inyo Craters

Addresses learning objectives:
2. Identify volcanic (extrusive) rocks
4. Describe the texture of volcanic (extrusive) igneous rocks
18. Identify volcanoes and volcanic features, like lava flows
19. Describe the sequence of events that form a rhyolitic dome
27. Apply the Law of Superposition to determine the age of geologic events

After leaving vehicles assemble group at the trailhead to talk about the geologic story of Panum Dome. You may want to utilize the interpretive display near the trailhead.

## Panum Dome

- Geologically speaking… Just formed!
  - Carbon-14 ($^{14}C$) radiocarbon dating techniques were used to determine the age of vegetation trapped between ash layers, yielding an age for the first eruption of 700 years ago (Sharp and Glazner, 1997)

*Activity 11: Create an illustration showing the* $^{14}C$-dated *vegetation between ash layers then explain how the* ***Law of Superposition*** *can be used to determine the age of the lava flows.*

- Typical volcanic dome (rhyolite dome)
  - Initial eruption produces ash and pumice, building the dome
  - Explosion from central vent creates the crater and a ring of volcanic rock, mostly pumice (pumice ring); explosion probably caused by rising magma superheating groundwater triggering a phreatic (steam explosion) eruption

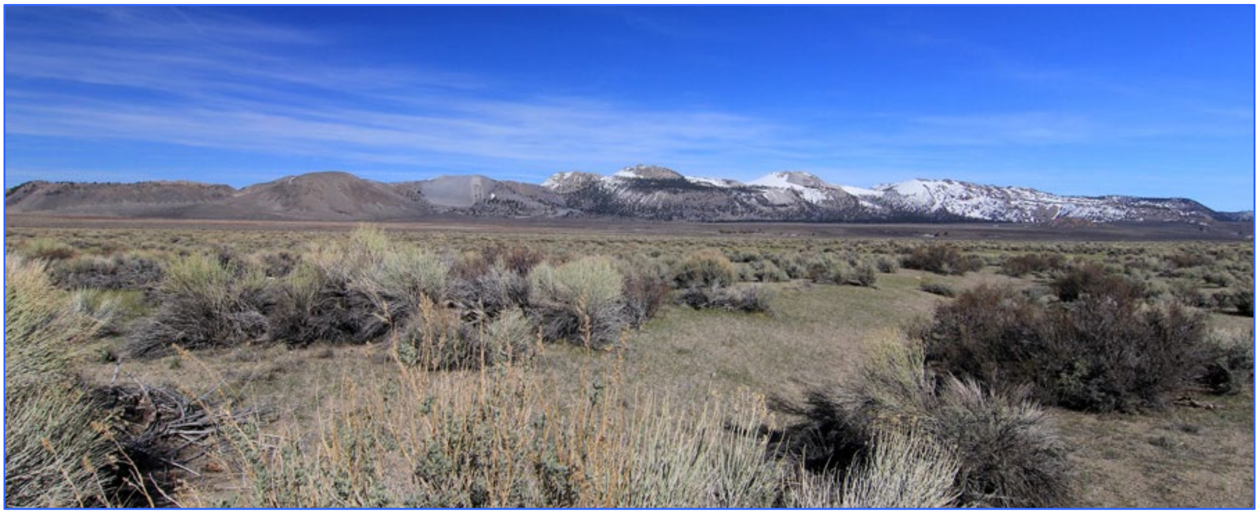
The resurgent dome and with spires of obsidian.

  - Once all the gas from the magma chamber has been exhausted thick, rhyolite lava oozes out like toothpaste to partially fill the crater, creating a resurgent dome of obsidian
  - While the resurgent dome was growing, another eruption blasted out the crater wall, sending fresh volcanic glass (obsidian) down into Mono Lake
  - The last bit of magma slowly oozed up through cracks in the hardened lava of the resurgent dome, making spires of obsidian that are especially visible if you hike the Plug Trail onto the resurgent dome
  - Panum Dome is unique in that some of the volcanic rock contains clasts of granitic and metamorphic rock (xenoliths) that were eroded from the Sierras; these pebbles were incorporated into the magma as it rose to the vent
  - Geologists hypothesize that Panum Dome is fueled by a dike connecting it to a larger magma chamber.

East side of Panum Dome.

You may wish to complete your field lecture atop the volcano, where you have a better view of Mono-Inyo Craters and coulees.

### *Mono-Inyo Craters*



Mono-Inyo Craters.

- Panum Dome is part of the Mono-Inyo Craters (see map under "Stop 8 – Long Valley Caldera" above)
    - Formed from silica-rich rhyolite eruptions 40,000-700 years ago
    - Comprised principally of obsidian and pumice
    - Three massive **coulees** or obsidian lava flows
    - Volcanoes are oriented in an arc, reflecting the shape of fracture that connects Earth's surface to a magma source
    - Very active in recent time, erupting every 250-700 years
    - The most recent volcanic activity formed Paoha Island within Mono Lake about 200 years ago
    - One of Earth's youngest mountain ranges, rising about 2000 feet above the adjacent plains of Mono Basin
    - Tallest peak, Crater Mountain, is 9,172 feet above sea level
    - Coulees
        - Very viscous lava flows of silica-rich lava that solidify to form a thick, "blobby" mass that extends from a vent outward
        - Three large coulees are expressed as steep-sided plateaus flanking the Mono Dome

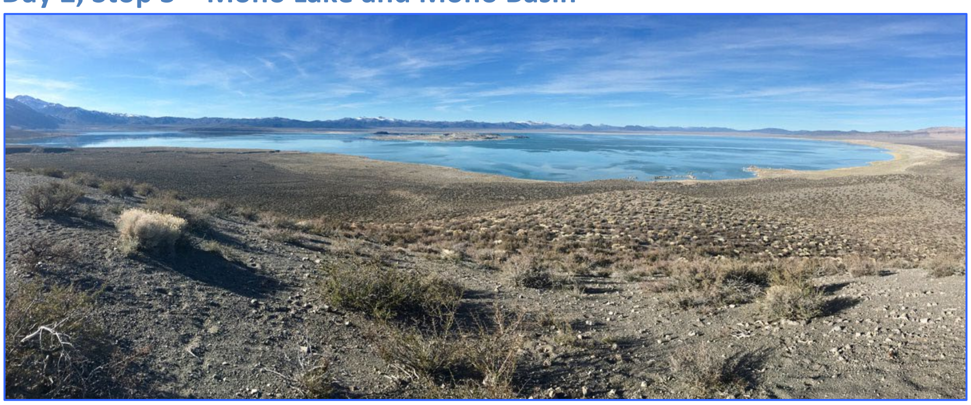
North coulee at the base of the Mono-Inyo Craters.

        - From the top of Panum Dome, we see the front of "North Coulee" making up the steep northern slope of the Mono Domes, directly south across highway 120
        - North coulee is about 630 years old (Sharp and Glazner, 1997)
        - Permanent ice is contained deep within some of the fractures
    - In 1941 construction of a 11.5-mile tunnel under the southern part of the Mono Domes was completed as part of the Los Angeles Aqueduct system. This tunnel carries water diverted from Rush, Walker, Parker, and Lee Vining Creeks and into the Owens River, then down to Los Angeles. This diversion deprives Mono Lake of water and by 1982 the lake level has dropped dramatically by 45 vertical feet. Concerned locals started the "Save Owens Lake" movement, which has since helped bring the lake level back up and restore its ecology.

*Question: What type of rock is Panum Dome made of? Is this rock high or low in silica?* – High. *Is this rock high or low in iron/magnesium.* – Low.

Take Mono Crater Road back to CA-120, turn left (east) and proceed about 1.6 miles to the Mono Lake access road. Turn left just after the sign for "Mono Lake South Tufa". Alternatively, you could continue for an additional ¼ mile to a shoulder pullout on the left side of the road for a good vantage point of one of the coulees that flowed eastward from the Mono Domes.

## Day 2, Stop 3 – Mono Lake and Mono Basin



**Mono Lake.**

Addresses learning objectives:
2. Identify volcanic (extrusive) rocks
4. Describe the texture of volcanic (extrusive) igneous rocks
18. Identify volcanoes and volcanic features, like lava flows
21. Describe how tufa towers form
24. Summarize the history of the Los Angeles Aqueduct as it pertains to Owens and Mono lakes
29. Summarize the geography and geologic history of the Basin and Range

Exit vehicles and give students a chance for a potty break. Escort group down main path to the Mono Lake shoreline. At some point assemble your group to provide a Mono Lake overview.

- Mono Lake occupies the low spot within Mono Basin
    - Mono Basin is situated within the Basin and Range geomorphic province

- The Basin and Range is characterized by a repeating sequence of roughly north-south oriented wide valleys (basins) separated by elongated mountain ranges. The western margin is marked by Mono Basin and Owens Valley, while the eastern side is bound by the Wasatch Mountains in western Utah, and includes all of Nevada and portions of Arizona and New Mexico. The distinctive topography is the result of continental rifting that started acting on the crust of western North America 16 million years ago, significantly stretching and fracturing the crust into linear, north-south trending **faults**, along which blocks of crust down-dropped to form deep basins, while uplifted blocks have formed mountains. Today this region displays dramatic relief, with mountain ranges rising as much as 10,000 feet above basins, including the lowest spot and deepest basin in the western hemisphere: Badwater Basin, 282 feet below sea level in Death Valley, California.

- Mono Basin
  - Subsided approximately 6000 feet over the past 3 million years coinciding with the growth of the Sierras
  - *Question: Why is it subsiding?* – <u>Down-dropping along faults.</u>
- Mono Lake
  - 700,000 years old
  - 60 times larger at its peak
  - 3 times saltier than the Pacific Ocean and 80 times more alkaline
    - The alkalinity was attested to by Mark Twain who, while traveling in this area, wadded-up his travel-worn clothing and submerged the wad into Mono Lake. When he returned a day later he found that his entire bundle of clothes had completely disintegrated due to the extreme alkalinity.
  - The islands are Paoha and Negit. Both were formed by very recent volcanic activity, the lighter-colored Paoha as recently as 200 years ago.
    - Paoha was formed as eruptions beneath lakebed sediments pushed the sediments upwards to their present elevation above the lake surface.
    - Mark Twain recounted his misadventure to the island in his book *Roughing It*, when he and his companion were lured to the island by a tale that told of cold, bubbling, pure spring water. With empty canteens they took a boat to the island, only to find "nothing but solitude, ashes, and heartbreaking silence". If that wasn't bad enough they had not moored their boat, which drifted out into the

**Tufa towers in the foreground and Paoha and Negit in the background.**

lake that contained "venomous water (that) would eat a man's eyes out like fire, and burn him out inside too". Miraculously, a passing storm blew their boat close enough to shore that his companion was able to leap in so they could get back to the mainland.

- Tufa Towers (note: there is an interpretive "pullout" along the main trail back to the parking lot which is a good spot to discuss the tufa towers)
  - Misshaped columns of limestone
  - Formed when the alkaline, carbonate-rich water of Mono Lake chemically reacts with calcium ions introduced to the lake water through fresh water springs issuing from the lake bottom:
    - $CO_3 + Ca = CaCO_3$ (limestone)
    - Limestone precipitates around the spring, building up column of limestone (tufa tower) over time
  - Tufa towers are now well exposed due to recent lowering of the lake level

*Activity 12: Have students summarize in written words or with an illustration the process of formation for the tufa towers*

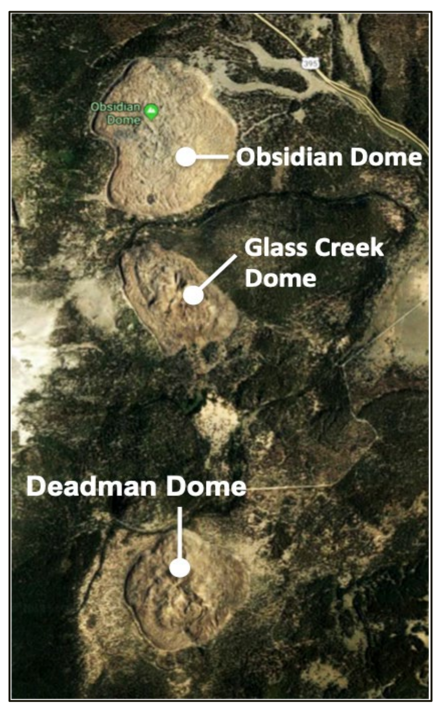
Return to CA-120, then turn left (south) onto US-395. Continue for just over 9 miles to Obsidian Dome/Glass Flow Road (just past green road sign for Obsidian Dome) and make a right. After about a mile, bear left at the intersection with the road for Hartley Springs Campground. Continue 0.4 mile for a turnout with an interpretive sign and nice view of the side of the dome. This might be worth a quick stop, but the final destination is another 0.3 mile further, just past the gated road to the top of the dome; bear left and park next to Obsidian Dome. From here you'll walk to the top of Obsidian Dome.

## Day 2, Stop 4 – Obsidian Dome

Addresses learning objectives:
2. Identify volcanic (extrusive) rocks
4. Describe the texture of volcanic (extrusive) igneous rocks
18. Identify volcanoes and volcanic features, like lava flows
19. Describe the sequence of events that form a rhyolitic dome

Before starting the short walk to the top of Obsidian Dome, instruct your group to stay on the trail and to walk carefully. The ground surface can be dangerously sharp due to obsidian shards.

Obsidian Dome is situated near the southern end of the Mono-Inyo Craters. Like Panum Dome at the north end of the mountain range, it is an excellent example of a very young rhyolitic dome, having formed along with two volcanoes to the south, Glass Creek and Deadman Creek, 600 – 1350 years ago (Sharp and Glazner, 1997; USGS, 2012). Because they erupted concurrently and are aligned topographically, it is




Google Earth image of Obsidean Dome, Glass Creek Dome, and Deadman Dome.

thought that the magma source is a single, sheet-shaped dike, leading down to a larger magma body at depth. Furthermore, it's been proposed that the infamous 1980 earthquakes that rocked the nearby community of Mammoth Lakes were triggered by the intrusion of a similar dike (Sharp and Glazner, 1997) in this volcanically active area.

These volcanoes started off spectacularly through phreatic eruptions, when rising magma superheated groundwater, triggering an explosive escape of steam, lava, and rock. Following the initial explosion, pyroclastic eruptions threw ash to pumice-sized particles in the air, building up the juvenile cones. After most of the gasses had been released through pyroclastic eruptions, the final stage of the eruption commenced with the extruding of viscous, rhyolitic lava that solidified to form the domes of obsidian and pumice.

Obsidian and pumice are the product of very silica-rich magma. Silica ($SiO_2$) readily bonds to other silica molecules, forming long chains that prevent other atoms from migrating to crystallization sites (imagine trying to lift a fork up through a large pot of cooked spaghetti). Consequently, if high-silica lavas cool rapidly, it may solidify before crystallization happens and the unbonded atoms are simply frozen in place, making volcanic glass. If the lava solidified without gasses, then you get compact obsidian; while the presence of dissolved gases can cause the lava to froth (think of the milk froth on a cappuccino) and solidify around abundant vesicles making pumice.

*Activity 13: Have students examine (Carefully! The rocks can be quite sharp.) rocks to differentiate between pumice and obsidian, and to identify any minerals if present.*

*Activity 14: Describe the effect silica has on the viscosity of magma/lava. How might silica contribute to the explosiveness of an eruption?*

Return to CA-120, then US-395. Turn left (south) and drive nearly 6 miles to Mammoth Lakes Scenic Loop road and turn right, then proceed about 6 miles to CA-203, Minaret Road. Turn right, taking you up to the Minaret Summit kiosk for Devil's Postpile National Monument. This 4.5 miles drive takes you past "Earthquake Fault" and the Mammoth Mountain ski resort. Both of which offer instructional opportunities. Earthquake Fault makes for a fun, relatively quick stop, while Mammoth Mountain will necessitate 2-3 hours and paying for a lift up to the summit. Excellent fieldtrip guides and geologic discussions for these optional stops are available in *Geology Underfoot in Death Valley and Owens Valley*, vignettes 26 and 27.

## Day 2, Stop 5 – Devils Postpile and Minaret Summit Vista

Addresses learning objectives:
2. Identify volcanic (extrusive) rocks
4. Describe the texture of volcanic (extrusive) igneous rocks
7. Recognize rock fall in the field
13. Describe how Ice Age climate and ecology was different than today
15. Explain and provide examples of the effect of the Ice Age on eroding rocks and shaping the landscape

**Devils Postpile.**

18. Identify volcanoes and volcanic features, like lava flows
22. Describe how columnar joints form

### *Minaret Vista*

If you are able to enter Devils Postpile using your own vehicle(s), be sure to stop at Minaret Summit Visit. To do so, take the road immediately to the right of the kiosk for Devils Postpile. This can be a short 10-15 minute stop or longer if you choose to utilize the picnic area for your lunch spot. Charter busses will likely need to drop off the group, as the parking area is small then return for pick up. From the vista you look across a wide, **U-shaped valley** that contains the Middle Fork of the San Joaquin River. The jagged peaks on the far side of the valley are called the Minarets; two of the most prominent peaks are Mount Ritter and Mount Banner, at 13,157 and 12,945 feet tall, respectively. The Middle Fork of the San Joaquin River is an important part of the watershed (a.k.a. drainage basin) for the western side of the Sierras, where it collects runoff, flows through Devils Postpile National Monument, then out across the San Joaquin (Central) Valley to its ultimate base level, the Pacific Ocean.

After arriving at the Devils Postpile Ranger station, you have an easy 0.4 mile walk to the base of the Devils Postpile. Once there, assemble your group in one of the small observation areas for your lecture (maybe walk up the trail a bit to find a good spot) or, if you've not had lunch, take a lunch break at the riverside bench, immediately west of the trail.

Start off your lecture with some questions: *What type of rock is Devils Postpile?* Allow students to inspect the texture of some of the columns. *What's going on here? Why the columns?*

*Activity 15: Have students first discuss with one another then write a quick hypothesis about how Devils Postpile formed.*

### *Devils Postpile*

- 100,000 years ago, lava flowed down this valley and solidified into this mass of basalt
- *Question: Are basaltic lava flows low or high viscosity?* – <u>Low (fluid)</u>
- Individual basaltic lava flows are typically thin due to their fluidity (recall how thick the coulees are)
    - *Considering the cliff in front of us, was this flow thin or thick?* – <u>Thick</u>
    - *Why is this flow so thick?* – <u>Geologists imagine that this lava flow encountered a barrier as it flowed down the valley, causing it to pond, like a river that encounters a dam. Considering the age of the flow, the barrier might have been a glacial moraine that has since been removed by river erosion</u>.
- **Columnar jointing** (fracturing in basaltic lava flows resulting in polygonal columns, typically 6-sided) has weakened the rock
- Gravity pulls the columns exposed on the cliff face down as a form of rock fall
- *Why did columns form in this particular flow?* – Call on students for their answers from the activity above.
    - There are two important characteristics of this lava flow that allowed the columns to form:
        - The lava flow was very thick, 100 feet or more, so it cooled slowly
        - The lava flow was homogeneous basalt and without vesicles (small holes)

- The lava slowly cooled and solidified to rock
- As the very hot rock mass continued to cool, it contracted
- The stress on the rock mass from contraction was relieved by fracturing in a direction perpendicular to stress direction (imagine pulling each end of a piece of paper in opposite directions ←▭→ until it tears down the middle)
- As these fractures intersected one another, they formed polygonal columns of basalt
- Weathering agents, like frost wedging, have enlarged fractures over time and gravity has pulled down columns through the process of mass wasting, i.e. rock fall

*Activity 16: Have students discuss and modify their descriptions about how the columns formed.*

**Looking upon the top of Devils Postpile columns.**

Now hike to the top of Devils Postpile. This is a short, but steep hike that offers some nice views and an opportunity to inspect the columns in cross-section, and to see evidence of glacial erosion (glacial grooves).

*Activity 17: Pair up students and have them count and record the number of sides on 20 individual columns. How many sides are most common?*

If you have more time and an enthusiastic group, you might want to consider hiking to Rainbow Falls, a little over 4 miles round trip from the base of Devils Postpile.

End day 2.

## Day 3 Stop – Ancient Bristlecone Pine Forest

Addresses learning objectives:
1. Recognize strata and sedimentary rocks
23. Explain the selective distribution of the Bristlecone Pines

The Ancient Bristlecone Pine Forest is located about 10,000 feet up in the White Mountains, the mountain range along the eastern margin of Owens Valley. It is generally accessible from Memorial Day to the end of October, but you'll want to confirm accessibility ahead of your visit.

**Ancient bristlecone pinetree.**

Be prepared for cold temps and thin air!

If you're returning to Los Angeles today, then I'd recommend getting started with your day as early as possible. Depending on where you've stayed the night, you'll need to find your way to the intersection of US-395 and CA-168, just north of Big Pine. The turn off for the Ancient Bristlecone Forest is White Mountain Road, 12.6 miles east on CA-168 east. On your way up the mountains, look for exposures of some of the bedrock. Starting in the first "narrows" section, about 8 miles from the 395, you'll see the 500 million year old, dark brown Campito Formation. The second and third narrows expose bluish limestone of the Poleta Formation. TJust after the sign for the Bristlecone Forest, turn left (northwest); the parking lot for Schulman Grove, which contains the ancient Bristlecone Pines, is a 10 miles drive from the highway. At 7.7 miles, make a quick stop at "Sierra View", which aptly offers spectacular views of the Sierra Nevada Mountains.

**Sierra View, view.**

Once parked at Schulman Grove, walk back to the parking lot entrance and assemble on southeast corner, near the welcome sign. This makes for a good place to give an overview of the White Mountains and the importance of the geology as it relates to the Bristlecone Pine trees.

### *White Mountains*

- Notably different than the Sierras – one could argue "drearier" in appearance, because:
    - Drier
        - Lie in the rain shadow of the Sierras
        - Less trees and no lakes
        - Less snowfall means there has been less **glaciation**
            - Peaks are more rounded and subdued than the sharp, dramatic, glaciated peaks of the Sierras
    - Rocks
        - Older and different lithology
            - 550 to 700 million years old
            - Mostly metamorphosed sedimentary rock
            - Darker in color – compared to the relatively bright granite of the Sierras
            - Well exposed in roadcuts along CA-168

Ancient Bristlecone Pines

- Oldest living trees in the world
    - The Schulman Grove contains 17 trees over 4000 years old and the oldest known single tree at 4845 years old (website: *Rocky Mountain Tree-Ring Research*), although another tree has unverified age of 5,068 years.
    - For comparison, the oldest giant Sequoias are around 1400 years old

- How can they live so long?
    - Very hardy – survive where other vegetation can't
        - Low precipitation
        - Cold
        - Thin air
        - Persistent wind
        - Nutrient-poor soil…

**Sage covering the foreground slopes and slopes to the left; bristlecone pines blanket the slopes to the right.**

- 
    - Growing on slopes above us, but not in the valley opposite the road, which is covered in sagebrush. *Why is this?* Perhaps point out the color of the soil supporting the bristlecone pines vs. the color of the soil for the sagebrush.

*Activity 18: Allow students to discuss the answer to your question. Perhaps walk amongst your group to facilitate this discussion.*

Before answering this very important question, hike amongst the majestic bristlecone pines. There are a few trails, but the sake of time, fitness of typical students, and for instructional value use the "Discovery Trail". Walk back through parking lot to the Discovery Trail trailhead, at the far northeast end. Before starting the hike, differentiate the bristlecone pine from another tree that you will see on the trail, the limber pine. The bristlecone needles are darker and grow in spirals around and along stems, while the limber pine needles are lighter green and cluster at the end of stems. For comparison, the tree in the middle of the parking lot circle is a limber pine; the tree on the left side of the pathway to the visitor center is a bristlecone pine (Sharp and Glazner, 1997). The oldest bristlecone pines will look, well…old. They won't have a full set of branches, but instead only few living branches. They have dead, jagged tops, and a thin strip of bark twisting around the tree up to the living branches.

Before starting the hike, it might be a necessary to allow for a potty break. Once everyone is ready to go, mention a few important notes for the hike:

- While admiring the bristlecone pines, without disturbing them in any way, consider the coloring and weathering of the rock and soil around the ancient trees
- Look out for an abrupt change to the coloring and weathering of the rock and soil
- Look out for an abrupt change to vegetation
- Don't get too far ahead of the group, because there will be at least one lecture stop
- Walk single-file to allow room for other hikers

The trail climbs through the edge of the bristlecone pine forest, but eventually emerges out onto a barren slope, mantled by brown, angular rocks. Choose a good spot for a lecture, perhaps starting with a few questions:

- *Did you notice a change in the coloring or weathering of the rock and soil?* – <u>Yes, the rock/soil is darker and more angular here.</u>
- *How about the vegetation?* – <u>No bristlecone pines grown here.</u>

- Let’s go back to the question we discussed before we started our hike: *Why don’t bristlecone pines grow here and down in the valley below us?* – Take/call on students for answers.
- Answer: the distribution of bristlecone pines is restricted by geology
  - Note the variations in color of the soil upon which the bristlecone pines are growing vs. the color of the soil that supports the sagebrush: white to very light brown vs. a more medium brown
    - Medium brown soil comes from the weathering of the blocky brown rock – sandstone of the Deep Springs Formation
  - Bristlecone pines would probably like very much to grow in the darker brown soil, found where we are standing and down in the valley, but cannot because the sagebrush outcompetes the bristlecone pine seedlings for water and nutrients, preventing them from growing
  - Instead, the bristlecone pines grow where other plants can’t – in the nutrient poor soil produced by the weathering of the Reed Dolomite
    - Dolomite is composed of magnesium calcium carbonate, which breaks-down to form a very alkaline soil (remember the extreme alkalinity of the carbonate-rich Mono Lake)
    - Sagebrush, like most all other plants, can’t grown in such alkaline soil
  - Generally speaking, geologists can use the distribution of different types of vegetation to estimate the distribution of rock units and the location of rock structures

*Activity 19: Have students edit their answers to the question they discussed in activity 18.*

Before returning home you might want to spend a little time in the visitor center.

## Follow-up Activities

1. Multiple choice quiz or exam with a mix of question types, including essay responses.
2. Students prepare a 5-10 minute PowerPoint (or other multimedia platform) presentation discussing a topic from the field trip. I like to utilize the downtime of the return trip for getting students started on this assignment. I’ll pass around a pad of paper and ask them to record their name and a topic they learned about. Examples include: geology of the Red Cliffs at Red Rock Canyon State Park, formation of Fossil Falls, spheroidal weathering and the Alabama Hills, history of Owens Lake, and the geologic story of the Long Valley Caldera. Once they’ve chosen a topic, I encourage them to utilize the time of the long bus ride home to compose an outline. For myself, I’ll use the time to modify any assessments I plan to give, in order to most clearly reflect the learning objectives covered or emphasized on the trip.

Student presentations need to include photographs from the trip and content from their notes, as well as additional resources. In addition to teaching about their topic, the presentations should include an introduction and a summary, as well as a list of additional resources used. Text on each slide should be kept to a minimum; students should instead be encouraged to use note cards. Grading criteria should consider:

- Well organized slides with limited text and illustrative photos
- How authoritatively do students speak about their topic

- The use of additional resources to introduce relevant and interesting facts and/or interpretations of facts presented during the field trip
- Overall clarity of presentation

3. Photo journal. I do not use this as an assessment tool, but a colleague does so with great success. Students create a photo album with descriptions and discussions around their field trip photos.

# Chapter 10 – Rainbow Basin Natural Area

## Introduction

This chapter is written for a 3 day, 2-night field trip; over which time students learn how to make a geologic map. This area could also be studied during a daytrip or even briefly visited en route to or from Pisgah/Amboy craters, but this chapter is written with assumption that groups will participate for 3 days, which is the minimum amount of time needed for an introductory group to map a portion of the Rainbow Basin Natural Area (Rainbow Basin).

Rainbow Basin Syncline.

Accommodation options include camping at Owl Canyon Campground, which is within a part of the study area, or using hotels in nearby Barstow. Groups will NOT be able to access the Rainbow Basin by charter bus and high clearance vehicles are recommended; but 4-wheel drive is not necessary.

Rainbow Basin is situated in the Mud Hills within the Mojave Desert, about 20 minutes north of Barstow and has, for very good reasons, long been a draw for earth scientists. Vegetation is scant, resulting in nearly 100% exposure of the sedimentary rock strata, making for easy observation and study. These rocks are vividly colored and have been deformed into a nearly perfect syncline, with limbs of the syncline being offset by movement along **faults**. Paleontologists also value this area, because the excellent mammalian fossils collected from the strata have provided valuable information about animals and the ecology from 12-16 million years ago. This is all contained within a geographically small area, making it ideal for a weekend-long project.

## Addtional materials

- Map board (large clipboard, drawing board, something with a clear cover and without metal would be best)
- Hiking shoes/boots with good soles
- Field book
- Protractor
- Ruler
- Mechanical pencils w/0.5 mm lead and good erasers
- Drafting pens (00 and 2 weight or 0.3 mm and 0.6 mm)
- Liquid paper pen/white out
- Box of colored pencils
- Brunton compass – provided by instructor
- Mud Hills USGS 7.5 minute topographic map – provided by instructor

## Safety Considerations

- Rattlesnakes – watch where you step and where you place your hands
- Cliffs and Climbing – climbing steep slopes is not necessary to complete the assignment and pose a unnecessary safety hazard; follow trails and if you reach an area that is uncomfortably steep, don't push it
- Water – all students need to have a means of carrying at least 2 quarts of water (more in warm weather) on their person and should be encouraged to hydrate before and after field work
- Weather – It can be dangerously warm during late spring, summer, and the early fall, so visits should be made during the late fall, winter or early spring months. On the contrary, it can also be quite cool in the mornings and evenings, so be sure to consider the weather forecast when packing for a visit.
- Wide brimmed hats will help reduce the possibility of heat exhaustion and sunburn

## Geology

The principal strata exposed at Rainbow Basin are part of the Miocene Barstow Formation, which has been dated at 12-16 million years old, based on the excellent assemblage of mammal fossils that have been recovered from the strata. The upper and middle sections of the Barstow Formation are a fine-grained and colorful mix of tan, brown to red-brown, and green-brown mudstone, siltstone, fine sandstone, and tuff that accumulated as ancient lakebed deposits. The lower section is distinctly coarser grained, consisting of sandstone and conglomerate from ancient stream and alluvial fan deposits. The tuff deposits within the upper and middle members of the Barstow Formation stand out in relief and color and are useful as "marker beds". Three of the most conspicuous tuff deposits, Puma Tuff, Thin Tuff, and Skyline Tuff, will be mapped and used to subdivide the Barstow Formation into 4 members: Tertiary upper Barstow 1, Tertiary upper Barstow 2, Tertiary upper Barstow 3, and Tertiary middle Barstow, named Tbu1, Tbu2, Tbu3, and Tbm, respectively. The lower member will not be mapped. These rocks have been deformed into a syncline around an east-west trending **fold axis** and have been offset along several faults.

Below the Barstow formation is the early Miocene, brown to red conglomerate and breccia of the Pickhandle Formation. The bedding contact between the two units represents an unconformity: an erosional surface separating a younger rock unit above from an older rock unit below, with a significant volume of rock (and geologic time) between the two units missing due to erosion. The top of the Barstow Formation at Rainbow Basin also represents an unconformity. Quaternary sand and gravel has been deposited upon the tilted and eroded beds of the Barstow Formation, providing a nice example of an angular unconformity. These pinkish gravels cap the cliff tops around Rainbow Basin and are the product of geologically recent alluvial fan deposits, hence this rock unit is called *fanglomerate*. Younger, but geologically similar fanglomerate deposits are found in-between stream channels within the mapping area, as buff-colored sand to boulder-sized gravels, which will be mapped as Qf, for Quaternary fanglomerate. The active stream channels contain unconsolidated deposits of sand and gravel (alluvium), which will be mapped as Qa.

Taken as a whole, the rock units at Rainbow Basin record a sequence of geologic events: abrupt, episodic mountain building, represented by the breccia of the Pickhandle Formation, then erosion of the mountains and deposition of the sediment in alluvial fans and stream beds. These deposits are the conglomerate and sandstone of the lower section of the Barstow Formation. Finally, these deposits were submerged by a lake, upon which fine-grained sediments and volcanic ash accumulated, consolidating to become the siltstone, mudstone, and tuff of the middle and upper Barstow Formation (Sharp and Glazner, 1993). Sporadic volcanic eruptions produced the interbedded tuff layers.

## Learning Objectives

Through participation in this field trip students should be able to:

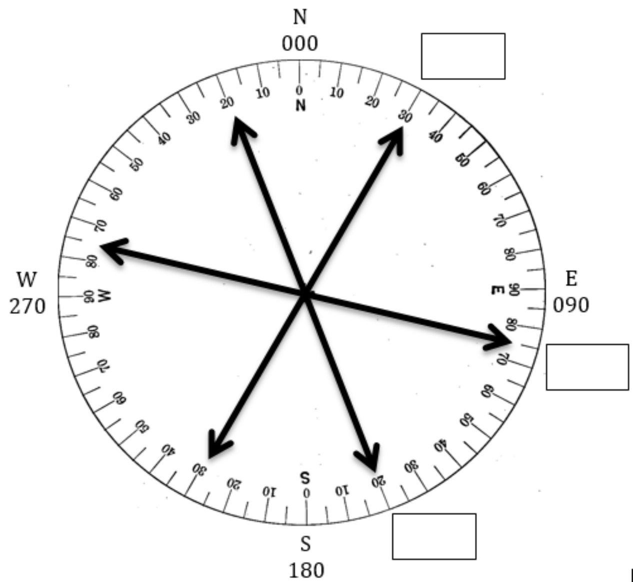
1. Identify unconformities and name the specific type, i.e. angular unconformity, disconformity, nonconformity
2. Accurately locate position on a topographic map
3. Accurately measure and record bedding attitudes
4. Measure and record bedding attitudes, strike and dip, and the attitude of faults and fold axis
5. Accurately locate and map contacts between different rock units by drawing lines on the map delineating the contact between different rock units on Earth's surface
6. Accurately locate and map faults and the fold axis of the Barstow syncline
7. Describe lithology of rock units
8. Summarize geologic history of field area
9. Create a geologic map that clearly conveys the structure and geology of the field area
10. Create a geologic cross-section that clearly conveys the structure and geology of the field area

## Key Vocabulary

- **Attitude** – the position of a horizontal surface, like a bed of sedimentary rock, relative to horizontal
- **Azimuth** – direction a compass needle is pointing based on the 360º of the compass rose, e.g. 030, 170
- **Bedding contact** – the planer contact between two types or ages of rock
- **Compass bearing** – direction a compass needle is pointing as measured in degrees east or west, relative to north or south, e.g. N 30 E, S 10 E
- **Dip** – the amount of tilt of planer surface, like a bedding plane, measured in degrees from horizontal
- **Fault** – a fracture in Earth's crust along which movement has occurred
- **Fold axis** – the hypothetical line around which the strata of fold was bent
- **Plunge** – the amount of tilt or dip of the fold axis, measured in degrees from horizontal
- **Stream terrace** – topographically flat surface elevated above the active stream channel representing the past position of the stream bed or flood plain for the stream
- **Strike** – the trend of planer surface, like a bedding plane, measured as a compass direction
- **Syncline** – a fold where rock layers have been compressed downward, into a U-shape

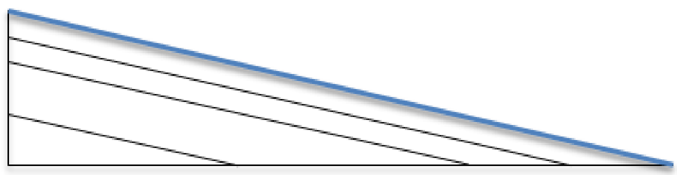
## Pre Field Trip Questions/Activities

1. Draw a syncline and label the fold axis and the limbs.
2. What is an unconformity? Draw an example of each of the three types of unconformities.
3. Using the compass wheel below, indicate in each box the direction the compass needles are pointing as **azimuth** and **compass bearing**.



Compass rose.

4. Using the cross-section cartoon below, measure the **dip** of the bedding plane. The diagonal lines represent tilted strata, with the top diagonal line representing the ground surface.


Cross-section of a slope. Ground surface represented by blue line.

## En Route Talking Points: I-605 north, I-10 east, I-15 north, I-40 east

- I-605 north
  - The 605 takes us across part of the Los Angeles Basin. This incredibly deep basin formed from roughly 16 million to about 1 million years ago as tectonic forces slowly peeled the Transverse Ranges away from the Peninsular Ranges, rifting open a series of basins. The sea flooded these pits as they slowly opened, meaning what is today the metropolis of Los Angeles and Orange counties were once at the bottom of the Pacific Ocean. All the while, sediment being eroded from the continental highlands filled these depressions with silt, sand, and gravel, up to 6 miles in thickness.
  - San Gabriel River
    - The San Gabriel River Freeway (formal name for I-605)
      - Follows a path of least resistance from river erosion
      - River erosion creates natural pathways
      - Pathways become footpaths
      - Footpaths become horse trails
      - Horse trails become thoroughfares
      - Thoroughfares become highways

        - River transports sediment from the San Gabriel mountains to its base level, the Pacific Ocean
        - Whittier Narrows water gap. The San Gabriel River and Rio Hondo River, just to the west, have created the Whittier Narrows by eroding faster downward than the hills have been uplifted, resulting in carving a topographic saddle, a "water gap", 2 miles wide and 800 feet deep, bisecting the Puente Hills into 2 parts: the Montebello Hills to the west and Whittier Hills to the east. For a more detailed description read the excellent discussion in *Geology Underfoot in Southern California,* "Vignette 9 – A Boon to Communication, The Whittier Narrows"
        - Similarly, Santa Ana River erosion has created water gaps through hills that are now occupied by the 91 and 57 freeways
    - Whittier and Puente Hills (east of the 605) are being actively uplifted along the Whittier fault, which runs along the base of these hills; this fault is active as evidenced by the recent Whittier (1987, M 5.9), Chino Hills (2008, M 5.5), and La Habra (2014, M 5.1) earthquakes.
    - Montebello (Repetto) Hills (west of the 605)
        - Western extension of Puente Hills
        - Like Puente Hills, the Montebello Hills are made up of steeply tilted, south-dipping sedimentary rock that is typical of sediment in the LA Basin: mudstone, siltstone, sandstone, and conglomerate
    - On a clear day point out the San Gabriel Mountains making up the northern skyline and its highest peak, the 10,064 feet tall Mt San Antonio, a.k.a. Mt Baldy.
- Eastbound on I-10
    - "The 10" takes advantage of the San Gorgonio Pass, 1 of 3 topographic passes through the mountains surrounding the greater Los Angeles area, the other two being the Tejon and Cajon passes, utilized by I-5 and I-15, respectively.
    - Just east of Azuza Ave. the hills (San Jose Hills) buttressing the north side of I-10 are partly composed of lava flows know as the "Glendora volcanics"
        - ~16 million years old
        - Volcanic eruptions were triggered by the rifting that formed the Los Angeles Basin
        - Exposed as olive brown rock, as opposed to buff-orange rock exposed in preceding hills
- Northbound on the I-15
    - The 15 freeway takes advantage of the Cajon Pass, one of three topographic passes through the mountains surrounding the greater Los Angeles area, the other two being the Tejon pass, utilized by I-5 and the San Gorgonio Pass, over which the I-10 stretches to Arizona and beyond.
    - San Gabriel and San Bernardino Mountains
        - Represent part of the Transverse Ranges, a block of crust that was peeled away from the Peninsular Ranges and rotated 110° to its current position (for a more thorough discussion see the Introduction in *Roadside Geology of Southern California*, Sylvester and Gans, 2016)

        - Stream erosion along the **San Andreas fault** Zone has created the Cajon Pass, which divides the Transverse into 2 geographically distinct mountain ranges, the "San Gabriels" and the "San Bernardinos"
        - Compressional tectonic forces have uplifted the mountains, over the past 5 million years at a rate as fast as 70 feet per 1000 years (Sylvester and Gans, 2016)
            - San Gabriels could be growing as fast as the Himalayan Mountains (Prothero, 2011)
            - Rapid uplift evidenced by very deep, steep-sided canyons and triangulated ridges
        - Contains metamorphic rock as old as 1.7 billion years, as well as Proterozoic plutonic rocks; these were intruded by magma of diorite to granite composition that was generated by subduction of the Farallon Plate during the Mesozoic time
    - The I-15 crosses over Lytle and Cajon creeks, at 5 and 7.5 miles north of I-210 interchange. These two major tributaries of the Santa Ana River contain abundant cobble and boulder-sized clasts of bedrock from the adjacent mountains.
    - The San Andreas fault and the plate boundary
        - About 2.5 miles after passing Kenwood Ave, just after I-15 curves due north, you cross over the San Andreas fault, the plate boundary between the Pacific and North American plates
- I-15 to the I-40 interchange
    - The 15 climbs up the Cajon Pass, then descends onto the southern margin of the Mojave Desert
- After crossing the truss bridge (see directions below) you may wish to stop at the Mother Road and Railroad Museum occupying the old Harvey House.
- Just after passing the Railroad Museum First Street traverses the Mojave River
    - Normally dry
    - Streamflow is as groundwater through porous channel deposits

## Directions to Rainbow Basin

As you near the I-40 interchange, prepare to exit Barstow Road (SR-247), turn left and proceed north for 0.8 mile. Turn left (west) when Barstow Road ends at Main Street. Proceed 0.2 mile to First Avenue and turn right (north), following signs for CA-58: Bakersfield, Fort Irwin, Las Vegas. Continue for 0.9 mile, passing over the truss bridge spanning the train tracks and Mojave River, then make a left on Fort Irvin Road, which is just after Buzzard Peak. Buzzard Peak is a resistent plug of Miocene dacite (Sylvester and Gans, 2016) that forms a prominent red-brown hill topped with a white water tower. After about 6 miles look for the road signs indicating a sharp right curve and a road intersecting Fort Irwin Road, and a small sign for Rainbow Basin. Make a left on Fossil Bed Road and proceed for 3 miles until you reach the entrance to Rainbow Basin. Turn right onto Rainbow Basin Road and continue about 2 miles into Rainbow Basin to "Rainbow Basin Basecamp", passing the road for Owl Canyon Campground along the way.

## Rainbow Field Trip Stops

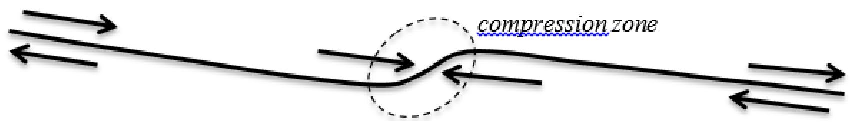
As stated in the introduction, the stops in this chapter are NOT accessible by charter bus. Instead, commercial vans or high clearance 2-wheel drive cars are recommended.

### Day 1, Stop 1 – Rainbow Basin Observation Area

Vehicles will enter Rainbow Basin and park in the designated parking area, referred to as "Rainbow Basin Basecamp" on some maps and signified by a binoculars road sign. From here, exit vehicles and walk east about 20 yards to the "Rainbow Basin observation area", which lies between the two low knobs, where there is a wide, flat area with the semi-circular remains of a building foundation.

Rainbow Basin observation area.

Here, you have a good look at the structure of the Barstow Formation and a sense of the area to be mapped, starting tomorrow. Looking to the left, or north, strata is tilting or **dipping** to south, whereas strata off to the right, is dipping to the north. These strata dipping in opposite directions make up the limbs of **syncline** and the viewing area upon which you are standing is more or less the **fold axis** around which the rock was bent. Folds like this one are the result of compressive stresses squeezing the crust, folding it like a rug being pushed into a wall (see short explanatory video: video description of making a fold). In the Mud Hills the compressive stresses are caused by a bend in the Calico fault; a right-lateral strike slip fault that bends in the same way the San Andreas fault does in southern California. Shear stresses act on either side of a straight strike-slip fault, but when a fault bends, compressive stresses are localized on either side of the bend (see illustration below). This is similar to what happens when a fault splits into separate branches (like the Indio Hills discussed in Chapter 1).




Map view of a right lateral strike-slip fault that bends, causing a zone of compression.

From this observation area, several faults may also be observed. One is just north of the fold axis, where it offsets strata in this limb of the syncline and another should be visible by turning around and looking at the west wall of the basin. With more time and geologic mapping several other faults will become evident in the study area.

Looking back to the eastern wall and towards the top of the slope one can see that the tilted strata has been truncated and capped by a bed of sediment that is nearly horizontal. This is an example of an unconformity, where rock has been eroded and sediment has been deposited on the erosional surface.

Return to the vehicles and head to the Owl Canyon Campground.

### Day 1, Stop 2 – Owl Canyon Hike and warm-up exercises

Continue along Rainbow Basin Road until you come back to Fossil Bed Road. Turn left (east), then left again on to the Rainbow Basin access road. Turn right on the road to Owl Canyon

Campground and park at your campsite, or at the end of the road at the Owl Canyon Hiking Trail. Park and prepare for 1.5-2 hour hike. Ask students to pair-up.

Addresses learning objectives:
1. Identify unconformities and name the specific type, i.e. angular unconformity, disconformity, nonconformity
4. Measure and record bedding attitudes, strike and dip, and the attitude of faults and fold axis
5. Locate and map bedding contacts
6. Describe lithology of rock units
7. Summarize geologic history of field

At trailhead sign, inform group of learning objectives.

*Activity 1: Direct students to use compasses to help them position their bodies so they are facing north. Ask: What direction is the surrounding strata tilting/dipping?* – <u>North.</u> *How much?* – <u>110/36 N</u>

*Activity 2: Have students work with their partner to measure the bedding **attitude** of strata at trailhead. Good places to take **strike** and **dip** measures are between the tan-colored fenced structure and campsite to the right (#25).* If students are inexperienced, expect that many will need lots of guidance. Have them repeat until they can get consistent answers. Walk amongst groups of students to help them measure bedding attitudes.

*Activity 3: Assemble students at trailhead sign and ask them to point out the stream channel and evidence of mass wasting.* – <u>Stream channel is just below you and mass wasting is happening across the stream channel.</u>

Walk down trail and stop where it encounters the **stream terrace**, just above the dry wash that is the active streambed. Here you can point out the angular unconformity between recent gravel deposits and the Barstow Formation, as well as the lithology of the Barstow Formation, which consists of alternating layers of mudstone, siltstone, sandstone, and some volcanic ash. This fine-grained stratigraphy represents ancient lake and stream deposits.

*Activity 4: Ask: Are the beds oriented the same as they were where we parked?* – <u>Yes</u>. *Are we on the southern or northern side of the fold axis?* – <u>South.</u> *Ask: As we walk towards the fold axis, should the strata be getting younger or older?* – <u>Younger</u>

*Activity 5: Direct students to observe the lithology of the clasts in the streambed.* – <u>Lots of granitic cobbles and boulders, and boulders of a pink conglomerate.</u> *Ask: Where are these boulders coming from?* – <u>Upstream; lower Barstow Formation and Pickhandle</u>

*As you proceed upstream, as well as upsection within the Barstow Formation, direct students to observe the lithology.*

About 500 feet from the trailhead, after the 2nd zigzag in the channel, the unconformity is nicely exposed on the eastern wall. Walking up onto the stream terrace on the western side of the channel offers a nice view. Look left to right.

**Unconformity.**

*Activity 6: Ask: What direction are the beds tilting?* – <u>North</u>. *Are you south or north of the fold axis?* – <u>South</u>

*Activity 7: Measure the bedding attitude by taking strike and dip measurements of beds.* If students are inexperienced, expect that many will need lots of guidance. Have them repeat until they can get consistent answers.

*Activity 8: Describe lithology of Barstow Formation*. Descriptions should include: (1) name and member, i.e. upper Barstow Formation; (2) fresh and weathered color; (3) texture, including grain size, angularity, and sorting; (4) composition of grains, i.e. granitic, basaltic, gneissic; (5) thickness of bedding; (6) sedimentary structures, i.e. ripple marks, cross bedding, etc.; and, (7) and evidence of fossils/trace fossils.

*Activity 9: Draw and name the unconformity*. – <u>This is a great example of an angular unconformity.</u>

As you walk upstream, watch for light-colored tuff bed, which stands out in relief, compared to the mudstone strata above and below it.

After another 100 feet or so note the oversteepened terrace walls.

*Activity 10: Ask: What will eventually happen to the terrace walls? Why?* – <u>Collapse due to oversteepening</u>. Look upstream to observe several blocks that have fallen into the channel, as a result of oversteepening.

Continuing upstream you'll encounter another tuff bed then a little further an approximately 8-inch high "step" in the streambed. Here, bedding is essentially flat lying, because you are very close to the fold axis of the syncline. After proceeding another 100 feet or so, look to the east wall of the channel where it makes a sharp right turn. Here, you can get a sense of the fold axis, although discerning the attitude of bedding may be challenging due to faulting. If you keep a close watch, you may find some smaller faults further upstream.

About another 100 feet farther north, observe the strata is now dipping towards the south, meaning… You have crossed the fold axis.

*Activity 11: Measure the bedding attitude on the north side of the syncline.*

At the fork in the stream channel, stay to the right where you can observe the dip of strata and an angular unconformity.

**Normal fault with car keys on the fault for scale.**

After another couple hundred feet rock fall has resulted in large blocks of the Barstow Formation blocking the channel. Here you may wish to discuss rock fall and mass wasting.

About 150 feet past the large rock fall is a tunnel that extends 20 yards into the cliff. You'll need a flashlight if you wish to explore. From here and over the next several hundred yards, the Barstow Formation is coarser grained, comprised mostly of sand and pebbles. This is the sandstone and conglomerate of the lower member of the Barstow Formation.

**Angular unconformity.**

*Activity 12: Describe the lithology of the lower Barstow Formation.*

As the walls of the wash begin to close in, observe that the Barstow Formation becomes coarser grained. Eventually, the stream channel becomes a dry waterfall and impossible to navigate without climbing. You've reached the **bedding contact** between the Barstow Formation and the underlying Pickhandle Formation.

*Activity 13: Describe the lithology of the lower Pickhandle Formation. Students should note that the grains are very coarse and angular. If possible, measure the dip of the Pickhandle Formation, which should be about 20 degrees steeper than the Barstow Formation.*

If you are feeling adventurous and confident in your group's climbing skills, continue through the narrow section until the slot canyon opens up to a slope of granite peppered with Joshua Trees. This is the end of the hike and provides a good place to review what's been observed and discussed, take questions, and enjoy a little rest before heading back for the night.

## Day 2 – Rainbow Basin Mapping Assignment

Remind students to pack everything needed for the day: water, food, sunscreen, hat, jacket if needed, and all field equipment. Prepare maps by drawing a north arrow and/or a grid of lines spaced at 2 inches, trending north-south and east-west.

Drive back into Rainbow Basin and park in same spot as yesterday. With all gear needed for the day, walk back to the "observation area". Organize group into 2 student-mapping teams. Resist requests for larger groups, as larger groups tend to be more prone to socializing. Remind students of the safety considerations: snakes, climbing, and dehydration. With inexperienced groups, you might suggest that they stick to pathways trodden by past students and to stay away from overly steep slopes and cliffs.

Addresses learning objectives:

1. Identify unconformities and name the specific type, i.e. angular unconformity, disconformity, nonconformity
2. Accurately locate position on a topographic map
3. Accurately measure and record bedding attitudes
4. Measure and record bedding attitudes, strike and dip, and the attitude of faults and fold axis
5. Accurately locate and map contacts between different rock units by drawing lines on the map delineating the contact between different rock units on Earth's surface
6. Accurately locate and map faults and the fold axis of the Barstow syncline
7. Describe lithology of rock units
8. Summarize geologic history of field area
9. Create a geologic map that clearly conveys the structure and geology of the field area
10. Create a geologic cross-section that clearly conveys the structure and geology of the field area

### *Mapping Assignment Directions*

1. Students: orient your map with north, so that you and the top of the map are facing north.
2. *Instructors: clarify the limits of the area to be mapped. It's recommended that the east-west limits include The Sphinx and Curvier, while the north-south limits are Cope and 3323 (see map included in back cover insert).*
3. Students: working with your partner, identify on your map the following topographic features (you don't need to mark them on your map, simply point each topographic feature to your partner on your map):
    a. *Cope*, the highest, gravel-capped peak rising above ridge of light-colored rock on the skyline to north
    b. *3418*: High peak to northeast formed by steeply dipping resistant bedding
    c. *3195*: The Sphinx: the sharp, reddish point rising from basin floor 500 feet to northeast
    d. *3323*: To southeast on rim of basin
    e. *Double Peak*, 3258 and 3244 on skyline to southwest
    f. Try to locate where *you are* and the *parking area*, which is not designated on the map. Hint: use the small closed loop in the (heavy) 3150 foot contour near the observation point.
4. *Instructors: walk your students down into the wash, about 400 feet to the east. There, define the difference between loose alluvium and consolidated terrace gravels. Students will map these separately. Demonstrate where mapping contacts with dotted, dashed, and solid lines. Walk back up to the observation area.*

5. Students: these are the primary mapping objectives:
    a. Map the contacts between different rock units, Tbu1, Tbu2, Tbu3, and Tbm, as delineated by the 3 tuff units, Puma Tuff, Thin Tuff, and Skyline Tuff
    b. Map in the trace of faults and the axis of the syncline
    c. Begin mapping with the resistant yellow-brown tuff bed that forms the prominent south-facing slope, approximately 250 north of the northwest corner of the parking area. This is the Puma Tuff. The Puma Tuff delineates the contact between stratigraphically highest and youngest members of the Barstow Formation, Tbu1 and Tbu2 (the next member down). Walk with your partner to your first location, locate your position on the map, and take a bedding attitude (strike and dip). Record the strike and dip symbol and dip measurement in pencil on your map. Remember to use a straight edge to draw the strike and dip symbol and to write, small and neat.
    d. Measure and record bedding attitudes along the contact between Tbu1 and Tbu2. Do this at least once every 300 feet or so, on either side of the fold axis. Once you've confidently located the contact at a few locations, begin to "connect the dots" with a pencil line. Take measurements more often when close to the fold axis and faults. Map the Puma Tuff on both limbs of the syncline as far east as 3195. Hold off mapping the unit where it is exposed on the low hill immediately southwest of the parking area (near the road) until you've accurately mapped it elsewhere. Map the tuff beds down section from the Puma Tuff on both flanks of the syncline.

IMPORTANT – mapping assignment considerations:

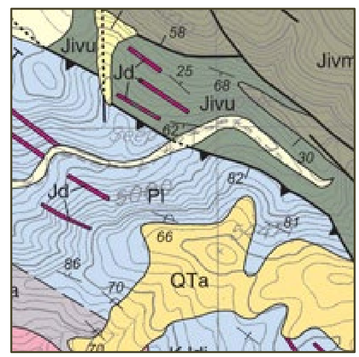
- Record all attitudes, comments, rock descriptions, etc. in your field notebook while you are there. Forgetting something then having to come back will waste time and effort.
- Abbreviate, e.g. outcrop = oc, fold axis = fa, etc. BUT, make a glossary of your abbreviations because you will forget what some of them mean, even the ones that seem completely obvious at the time.
- Zoom out! When up close on the outcrop, it's easy to be overwhelmed by the detail and to lose sight of the big picture. If you're stumped, take some steps back and consider the bigger picture. Sit down and soak it in. Perhaps take a drink of water, have a snack, sketch it out in your notebook, and generally allow your eyes and brain to absorb what you are seeing. What have initially seemed a chaotic mess, will resolve itself into distinct structures given time and an open mind… Ommmmmm.
- Before marching on to the next outcrop, consider the upcoming geology from a distance. Make a sketch. Estimate where the trace of a bedding contact or fault is. Sketch on the map what you see in the distance.

**Puma Tuff at tip of black arrow.**

- Be prepared to erase and correct where you've located contacts and/or bedding attitudes – it is often the case that moving on to a new location gives a fresh perspective and with it, better confidence about locations.
- Get in the habit of making sketches of complicated areas in your notebook.

*Additional instructor notes for mapping assignment:*

- *As students map, they should carefully observe and describe the lithology of the Puma Tuff and the other marker beds. This will help in recognizing them throughout the study area, especially in areas where faulting makes identification more challenging.*
- *If students are succeeding with the mapping, encourage them to find some attitudes directly on the axis of the syncline in order to determine the **plunge**.*
- *During the first few hours, try to visit each group at least once to ensure that they are able to complete the objectives. Encourage them to keep moving. Inexperienced mappers can easily get bogged down.*
- *Remind students to map the stream alluvium and terrace gravels. It will be convenient to color the stream alluvium yellow and the terrace gravel orange on their map as they go.*
- *Measure and plot attitudes of fault surfaces where possible. Faults are not as well exposed as marker beds; their position will be established in part by accurately plotting locations where marker beds are truncated.*
- *As they work their way through the assignment, keep in mind: accuracy is more important that quantity, but don't get bogged down. Consider the size of the area to be mapped and try to keep on pace to cover this entire area. Neatness counts.*




**Example of a geologic map. – CC.**

6. Students: post-fieldwork assignment. Once back in camp or at the hotel, complete the following:
    a. Ink all contacts (#00 pen or 0.3 mm) and faults (#2 pen or 0.6mm), and color the map.
    b. Erase stray marks.
    c. Color each unit with color that seems appropriate.
    d. Consider places that you'll need to revisit tomorrow. The map to the right is an example of how your map should start to look.
    e. Construct and arrange your map legend so it describes to the viewer what is depicted on your map. Set up your legend using the example below as a guide. Be sure to color the explanation boxes to match the map.

Stratigraphic Units

Quaternary

| | |
|---|---|
| Qa | Alluvium – *lithologic description* |
| Qf | Fanglomerate – |

Tertiary

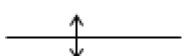
| | |
|---|---|
| Tbu1 | Upper Barstow Formation 1 – |
| - - - - - - - | *Puma Tuff* |
| Tbu2 | Upper Barstow Formation 2 – |
| - - - - - - - | *Thin Tuff* |
| Tbu3 | Upper Barstow Formation 3 – |
| - - - - - - - | *Skyline Tuff* |
| Tbm | Middle Barstow Formation – |

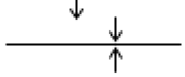
Map Symbols



Rock unit contact – solid where known, dashed where uncertain, dotted where concealed

Fault – solid where known, dashed where uncertain, dotted where concealed

Folds  Anticline

 Syncline

Strike and dip of bedding 


7. Before turning in your map, be sure it includes all of the following:
   a. Title
   b. Author and date
   c. Scale
   d. North arrow
   e. Geologic unit contacts
   f. Strike and dip symbols
   g. Structures: fold axes and faults
   h. Explanation of symbols (legend)
   i. Age and description of geologic formations
   j. Location of cross-section

8. On a separate sheet of graph paper construct a north-south cross section (A –B) at a location of your choice that you believe will best illustrate the structure (syncline and faults). Be sure to show line of section on your map.
9. In addition to the map and cross section, write a geologic report. This report will include 5 paragraphs: (1) *Introduction* that includes why the area was studied, what you did and the geographic setting; (2) *Methods* that describes how you did your research; (3) *Rock Units* or *Stratigraphy* where you describe the rock units in order of decreasing age, thicknesses, description of contacts, fossils (if observed), and origin; (4) *Structure* where you describe folds and faults; and, (5) *Geologic History* to discuss the sequence of geologic events recorded by the rocks at Rainbow Basin.

# Chapter 11 – Los Angeles County Natural History Museum Field Trip

## Introduction

Skeletons of Tyrannosaurus Rex and Triceratops.

The Natural History Museum of Los Angeles County (NHM) is the largest natural and historical museum in the western United States, with a collection that includes nearly 35 million specimens and artifacts, spanning 4.5 billion years of history (www.lacounty.gov). The museum opened in 1913 in what is now called Exposition Park and has since gone through at least 5 expansions and renovations.

This chapter will focus on the earth science related exhibits in the museum: the Gem and Mineral Hall, the Dinosaur Hall, and The Age of Mammals exhibit. The intent of the questions is that they will serve as an inquiry-based means of motivating students to undertake an interesting and educational self-guided tour of the museum. You could also consider using this activity as a "make up" field trip for students that were unable to attend other field trips required by your course.

Students should plan for a half a day or longer at the museum. I encourage my students to "make a day of it" and go with classmates, significant others, brothers, sisters, parents, or friends and embrace the experience. The magnificent building housing the museum is officially listed as a National Registry of Historic Places, and the outdoor grounds and Rose Garden are beautiful as well. In addition to the three exhibits students need to visit to complete this assignment, there are many other interesting permanent and "special" exhibits within the NHM that add to the experience. The NHM museum shares the Exhibition Park campus with the California Science Center (free entrance), the Los Angeles City Rose Garden (free entrance), and the California African American Museum, all of which are just few minutes walk from the NHM.

Admission costs are reduced for students and for groups. If you wish to arrange a group visit call the museum at (213) 763-3218. There are a variety of resources offered through the NHM website that can help you and your students prepare for an educational visit to NHM, as well as academic fee waiver applications for qualifying individuals or institutions: resources for teachers.

Parking in the NHM lot is currently $13 and can be found immediately southwest of Bill Robertson Lane and Exhibition Boulevard. Encourage students to carpool or take the metro to the Expo Park stop, which is immediately north of the NHM.

Note that Exhibition Park also contains the LA Memorial Coliseum and Banc of California stadium, which can make for horrific traffic if either are hosting an event. Plan accordingly.

## Learning Objectives

Through participation in this field trip students should be able to:

1. Name California's geologic provinces
2. Identify the geologic province most associate with California's gold and silver deposits
3. Collect data to compile a "research report" about a mineral
4. Describe the role the San Andreas Fault has played in forming the mountains of southern California
5. Describe how the amount of offset in sedimentary layers relates to the magnitude of an earthquake
6. Summarize the potential impacts of a major earthquake on the San Andreas Fault in southern California.
7. Identify the luster and crystal shape/habit in mineral specimens
8. List the physical traits that are definitive of dinosaurs
9. Relate geologic Eras and Periods to geologic events during the time of the dinosaurs
10. Relate plate tectonics to the distribution of dinosaurs
11. Describe how environmental factors can drive the evolution of mammals

## Key Vocabulary

**Chemical formula –** a means of representing the ratio of atoms of elements that make up a compound using symbols and numbers, e.g. $H_2O$
**Crystal habit –** the general shape of a crystal; can be variable for a given type of crystal depending on the environment in which the individual crystal grows
**Dinosaur –** any reptile of the subclass Archosauria distinguished from other reptiles especially by features of the pelvic bones (Bates and Jackson, 1987)
**Evolution –** how a group of related organisms adapt to environmental conditions over time
**Fault** – a fracture in Earth's crust along which movement has occurred
**Fossil** – the preserved remains, impression, or trace of a past living organism
**Luster** – the quality of light reflected by a mineral
**Mammal** – warm-blooded vertebrates that have fur or hair and secrete milk to young produced through live birth

## Pre Field Questions

1. Using your textbook or other resources provided by your instructor, answer the following questions:

   a. What physical properties are used to identify minerals?
   b. What controls the color of different minerals?
   c. What controls the crystal shape/habit of a mineral?
   d. What is meant by the "**luster**" of a mineral? What are the two principal types of luster?
   e. List the different types of non-metallic luster, from most lustrous to least lustrous.

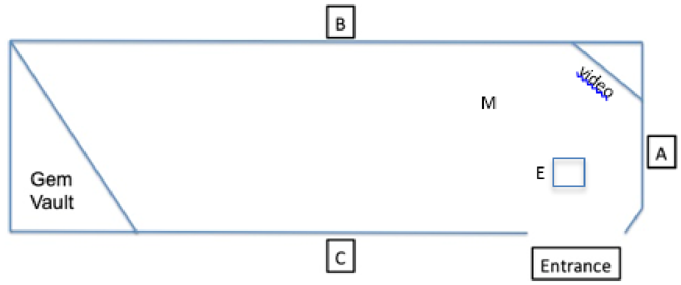
## Gem and Mineral Hall

### Entrance

1. Describe the color of amethyst, malachite, pyrite, microcline, and rhodochorsite.

**A. Walls to the right of entrance**

1. List California's 7 geologic provinces.
2. List your favorite mineral from each geologic province (keep same order as above).
3. In which geologic province are gold and silver most important?
4. List 5 minerals found in San Diego County.




**Simplified map of Gem and Mineral Hall. Letters correspond to lettered sets of questions below.**

**E. Elabaite Tourmaline**

5. How does this specimen differ from those you've observed in class?

***Video Questions***

6. How were the mountains of southern California made?
7. How are the magnitude of an earthquake and the amount of offset in sedimentary layers related?
8. Which segment of the San Andreas **fault** hasn't had an earthquake in historic times?
9. What sequence of events is needed to produce a magnitude 8 earthquake in southern California?
10. Why would a major earthquake on the San Andreas fault jeopardize the water supply for Los Angeles?
11. Describe the role the San Andreas fault has played in causing Transverse Ranges to have an east-west orientation.

**M. Meteorites**

12. What is the difference between *meteoroids*, *meteors*, and *meteorites*?
13. Which type is most rare?
14. What minerals to meteorites contain?
15. What is the origin of meteors?

**B. Forming minerals**

16. What are the three environments in which minerals form? Give an example of a mineral from each.

**C. Systemic Mineralogy Wall**

17. Which common minerals are included in the Tectosilicates?
18. Find at least three varieties from the feldspar mineral group. Chemically, how do they differ from one another?
19. List the different colors are the quartz specimens?
20. What mineral class does muscovite belong to?
21. What mineral class does staurolite belong to?
    a. Sketch a staurolite crystal.
22. What is the most obvious difference between azurite and malachite?
23. How many different colors do the barite specimens show?

24. What mineral class does calcite belong to?
25. How would you describe the shape of the galena crystals?
26. How would you describe the shape of the stibnite crystals?
27. How would you describe the shape of native gold and silver?
28. What is one mineral that contains Mercury? (Hg)
29. What are some of the minerals that contain Lead? (Pb)
30. What are some of the minerals that contain Zinc? (Zn)
31. What are some of the minerals that contain Copper? (Cu)
32. Take a little time to admire the minerals in the 12 freestanding cases in the middle of the room. Write down your favorite mineral specimen in each case.
33. Name one mineral that shows an example of:
    a. metallic luster
    b. vitreous luster
    c. pearly luster
    d. waxy luster
    e. dull/earthy luster
    f. fibrous habit
    g. cubic shape/habit
    h. needle shape/habit
    i. tabular shape/habit
    j. prism shape/habit
    k. bladed shape/habit
    l. dodecadhedron shape/habit

**Gem Vault**

34. Find the gemstones of fluorite, orthoclase, calcite, pink tourmaline, and blue topaz. List their color and carat weight.
35. Which state produces the greatest number and variety of gemstones?

## Dinosaur Hall

Refer to the museum map if you're not sure where to go.

1. What makes a **dinosaur** a dinosaur?
2. What is a defining feature of all dinosaurs?
    a. What two anatomical features allow for this physical trait?
3. What animal group do dinosaurs belong to?
4. What span of time is covered by the Mesozoic Era?
5. What descendants of the dinosaurs do you see most every day?
6. What are the two main dinosaur groups?
    a. Which group of dinosaurs would Tyrannosaurus Rex belong to?
    b. Which dinosaur group was made up of mostly plant eaters? Give one example of dinosaurs from this group.
7. What was the "headgear" of dinosaurs used for?
8. What were the tail spikes and bony plates along the spine of a Stegosaurus used for?
9. During which geologic *Era* did dinosaurs thrive?
10. During which 3 geologic *Periods* did dinosaurs evolve?
11. During which geologic *Period* did Pangaea begin to disassemble?

12. In which geologic *Period* did dinosaurs originate?
13. During which geologic *Era* did **mammals** diversify?
14. Which geologic *Period* is defined by appearance of humans?
15. What explains why **fossils** of some dinosaurs, like Majungasaurus, can be found as far apart as South America and Madagascar?
16. How is it possible that dinosaurs once lived near the South Pole?
17. How do rocks tell us about past environments?
18. Where was the Western Interior Seaway?
    a. How did this seaway impact the geography of North America?
    b. What geologic evidence do we have for the existence of this seaway?
19. Why did dinosaurs evolve from walking on just two legs to walking on four?
20. Were most dinosaurs carnivorous or vegetarians?
21. During which geologic period did T-Rex live?
22. Is the large T-Rex named "Thomas" fully grown?
23. How common are T-Rex fossils?
24. How long ago did the dinosaurs go extinct?
    a. What caused the extinction?
    b. Name four pieces of evidence scientists use to support this theory.
25. What is the name of the largest dinosaur species on display?
26. What are the same traits that survivors of the mass extinction shared?
27. What features do the dinosaurs of today share with dinosaurs of the Mesozoic?
28. Give one trait of dinosaurs during each of the three geologic Periods of the Mesozoic.

*Upstairs*

29. In general, did dinosaurs grow faster or slower than other animals?
30. What might a dinosaur have sounded like?
31. What was dinosaur skin like? How do we know?

*Atrium* (start at "Early Cambrian Scene" then walk clockwise around the balcony)

32. Answer the following question for each animal below: How long ago did ________________ exist?
    a. Ammonoids and trilobites
    b. Archaeopteryx
    c. Stegosaurus
    d. Pteranodons
    e. Giant rhinoceros
    f. Wooly mammoth

## Age of Mammals Exhibit (start on first floor)

Refer to the museum map if you're not sure where to go.

1. Did dinosaurs and mammals exist on Earth at the same time?
2. When did the "Age of Mammals" begin?
    a. Why did it begin at that time?
3. What are four physical traits that make a mammal, a mammal?
4. Watch the video "Mammals Evolve" on the flat panel screen to the right of the American Mastodon. When did the dinosaurs die out?
5. Do mammal species typically get larger or smaller over time?
    a. Why?

b. Why would a species become larger through **evolution**?
c. Why would a species become smaller?

6. What was the main reason large carnivores, like saber-tooth cats, went extinct?
   a. When did this happen?
7. What are 3 factors that could have led to the extinction of large herbivores, like the giant camel?
8. Where were the fossil remains of the mastodon skeleton found?
9. What were 2 things that allowed humans to migrate out of Africa?
10. When did Homo sapiens first appear?

*Upstairs*

11. What evidence do we have that the climate was cooler 50,000 years ago in Los Angeles?
12. What was the environment of the L.A. Basin like 15,000,000 years ago?
    a. How do we know?
13. What was the climate like in the Mojave Desert 10,000,000 years ago?
    a. How do we know this?
14. What was the environment of the L.A. Basin like 27,000 years ago?
15. What is meant by "Older is Deeper" when referring to sedimentary rock?
16. What do foraminifera tell us about past climates?
17. During the past 65 million years, when has the climate warmed the fastest and why?

To add to this field trip study of the history of mammals through museum exhibits, refer to the next chapter, *The La Brea Tar Pits*.

## Follow up Questions

1. What controls the color in minerals? Give some examples.
2. What controls the cleavage of a mineral? Why do some minerals not have cleavage?
3. What controls the crystal shape (**crystal habit**) of a mineral?
4. Mineral Report. Choose a mineral and identify the following for that mineral:
   a. Color(s)
   b. **Chemical formula**
   c. Mineral class; explain why the mineral belongs in that class
   d. Crystal habit
   e. Luster
   f. Hardness
   g. Cleavage
   h. Typical occurrence in nature
   i. Industrial uses/economic value
5. Why did the dinosaurs go extinct? Site more than one cause using information from the museum as well as at least two additional resources.

# Chapter 12 – The La Brea Tar Pits and Museum

## Introduction

The La Brea Tar Pits contains the most complete record of **fossils** from the latest **Pleistocene** Period, the last part of the Ice Age. Fossils have been formally collected since 1905, yielding over a million bones, representing 231 vertebrates, and another two million fossils from plants and invertebrates. Excavations for fossil collecting and preparation of specimens are ongoing and can be observed during a visit to the tar pits and Page Museum.


Entrance to the Page Museum at the La Brea Tar Pits.

The Los Angeles region has produced over nine billion barrels of oil, this according to the American Oil and Gas Historical Society. These oil reserves are the source of the relatively rare **asphalt** seeps that are the pools of "tar" at the La Brea Tar Pits, in Hancock Park. Asphalt, also called bitumen, pitch, or tar, is a highly viscous, semi solid form of petroleum that can be used as a waterproofing sealant. In the 19th century, the La Brea Tar Pits were part of Rancho La Brea, where asphalt was being collected for commercial use for sealing leaking roofs and boats. In 1875, a fossilized canine tooth from a Saber-toothed cat was discovered. This was the first bone recognized as being from extinct fauna and the historic and scientific significance of this area was realized.

Three to four hours should be allotted to complete this field trip. This itinerary could also be combined with the field trip to the Natural History Museum, covered in the previous chapter. Parking is available on the premises for the La Brea Tar Pits and LACMA for $15 (at the time of this writing). Metered street parking may also be available. For pre field resources, including making reservations for your group, examine the La Brea Tar Pits website: resources for teachers. Additional information may obtained by calling (213) 763-3529.

## Learning Objectives

Through participation in this field trip students should be able to:

1. Recognize the paleontological significance of the La Brea Tar Pits
2. Describe how and why so many fossils have been collected from the La Brea Tar Pits
3. Compare and contrast the ecology of Los Angeles today to the ecology during the "late Pleistocene"/"late Ice Age"
4. Describe the process of radiometric dating using the carbon-14 method

## Key Vocabulary

**Asphalt** – highly viscous form of petroleum used as waterproof sealant and binding agent for roadways
**Fossil** – the preserved remains, impression, or trace of a past living organism

**Microfossils** – fossils that are very small in size, generally less than 1 mm
**Pleistocene** – an *Epoch* of geologic time, beginning about 2.6 million years ago and ending 10,000 years ago, during which time Earth has been in an Ice Age

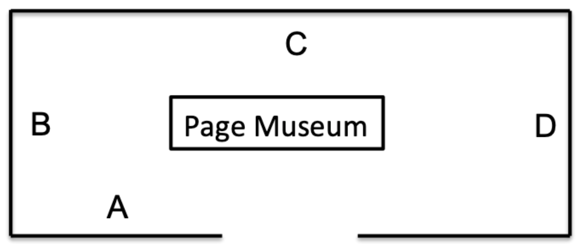
## Pre Field Trip Questions

Access the La Brea Tar Pits web page for the information needed to answer the following questions:

1. How long ago was the "late Pleistocene"?
2. Describe the concentration of wildlife in Los Angeles during the late Pleistocene compared to today.
3. Were mastodons and mammoths the same animal? If not, how were they different?
4. Which Late Pleistocene mammal is most common in the fossil record of the La Brea Tar Pits?
5. True or false, camels evolved in Africa then migrated to North America?

## Page Museum Questions

A. (area A on map). The La Brea Tar Pits contain the most complete record of fossils from the "late Ice Age" (Late Pleistocene). This time frame spans: ___ to___ years ago.



**Simplified map of the interior of the Page Museum. Letters correspond to the locations of answers to the lettered sets of questions. Not to scale.**

B. Why did animals get trapped in the tar?

- Why would nocturnal animals be less likely to be trapped in the asphalt?
- What does the presence of mollusks tell us about the past position of sea level in the La Brea Tar Pits area of Los Angeles?
- Compare and contrast Mastodons to Mammoths.

C. Why are there so many Dire Wolf Skulls in the collection?

- What **microfossils** are being studied?

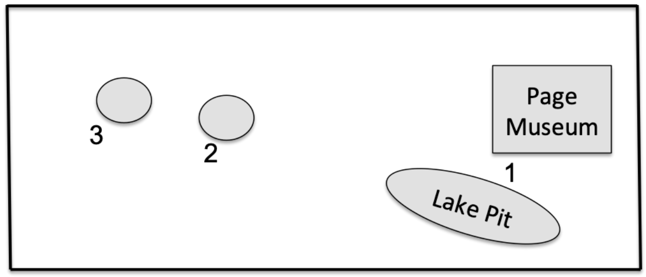
D. Radiocarbon Dating Questions:

- Carbon 14 ($^{14}C$) starts off as which element?
- What happens to this element to convert it to $^{14}C$?
- How does $^{14}C$ get into plants and animals?
- How long is the half-life of $^{14}C$?
- What does $^{14}C$ change into as it decays?
- Explain how the percentage of decay of $^{14}C$ is used to determine how long ago an organism died?

"The La Brea Tar Pits have a remarkable collection of dinosaur fossils!" How would you correct this false statement?

## La Brea Tar Pits Questions (outside of the Page Museum)

1. Summarize the origin of the Lake Pit. Explain the origin of the tar.
2. How does the tar help preserve bones as fossils?




**Map of the exterior grounds of the La Brea Tar Pits. Numbers correspond to location of answers to numbered questions below.**

3. Explain why the name, "La Brea Tar Pits" is technically incorrect.
a. Where does asphalt come from?
b. Why does asphalt bubble?
c. Why would it be more likely for animals to be trapped during the summer than the winter or day vs. night?

**Post Field Trip Assignment**. Choose one of the questions below then prepare a one-page response.

1. Using information gathered during this field trip, your course textbook, or information from other sources, such as open source textbooks summarize the process a scientist would follow in order to obtain a radiocarbon date from a fossilized bone.
2. Describe how the fossil record gathered from the La Brea Tar Pits indicates that the climate was different in Los Angeles during the late Pleistocene compared to today.
3. Why have so many fossils been collected from the La Brea Tar Pits, especially considering that the animals were buried in asphalt?

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