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Helman, Daniel S

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Public Geology at Griffith Park in Los Angeles: A Sample Teachers' Guide

Daniel S Helman

California State University, Long Beach, USA

While in graduate school the author discovered Griffith Park and its examples of local geology (Figures 1 and 2). The structural geology is very clear. From the location of the faulting, you look across the basin and see notches in the local mountains where the faults have dictated the ends of the nearby ranges. These subtle, slow faults control the entire region. In one location several faults converge at a single point. It is not breathtaking – but to realize that one can see the underlying structure in such a big edifice as a mountain does make a mental impact. There is math behind the valley's limbs. That is what a geologist sees: a puzzle of subtle connections, coaxed into a story which has a past and a future. That story is what your students will see when you take them to a public park or focused place with good landform relations and rock exposures. They deserve this process, and they need it in order to come to terms with today's changing environment. These connections will help them contribute to a global future.

Griffith Park in Los Angeles, California is not the only urban park which can be used thus. A list of "Urban Parks by Size" on a page of Wikipedia as of this writing has 202 entries, and these range in size from 60,070 to 334 acres (or 24,310 to 135 hectares).ⁱ Many of them will provide the same kind of opportunity as Griffith Park - with no bags to pack, no tents to set up, and both water and safety well within reach. This paper is an outgrowth of direct observations, and comes along with the great joy in finding such wonderful local geology within the city limits of Los Angeles. Such a park has the potential to lend environmental awareness to the spirit of the city, especially to its children.

At Griffith Park, there are no parking fees, and the trails are more disability-friendly than many. They are wide enough for a wheelchair, though often not paved. Lessons are possible for a good range of skills and abilities (Figure 3 for a park map). The terminology in this guide is typical of that for an intermediate university-level geology course. Some readers will be very happy with the glossary of terms at the back. Please take this writing as a sample, an example of what is possible. If you have the notion, you can certainly put something similar together for your local area. Do not be daunted – the study of geology is slow by nature.



Figure 1. Los Angeles' skyscrapers from the Lower Beacon Trail in Griffith Park about 5 miles away. The inset shows the location of major freeways in Southern California. (Helman, 2010g; Modified from Los Angeles Freeway Map).



Figure 2. The Los Angeles River in its concrete channel. The view is from Beacon Hill, at 1001 feet above sea level, and about 600 feet above the river, looking north. The Verdugo Mountains are in the background (Helman, 2010h).

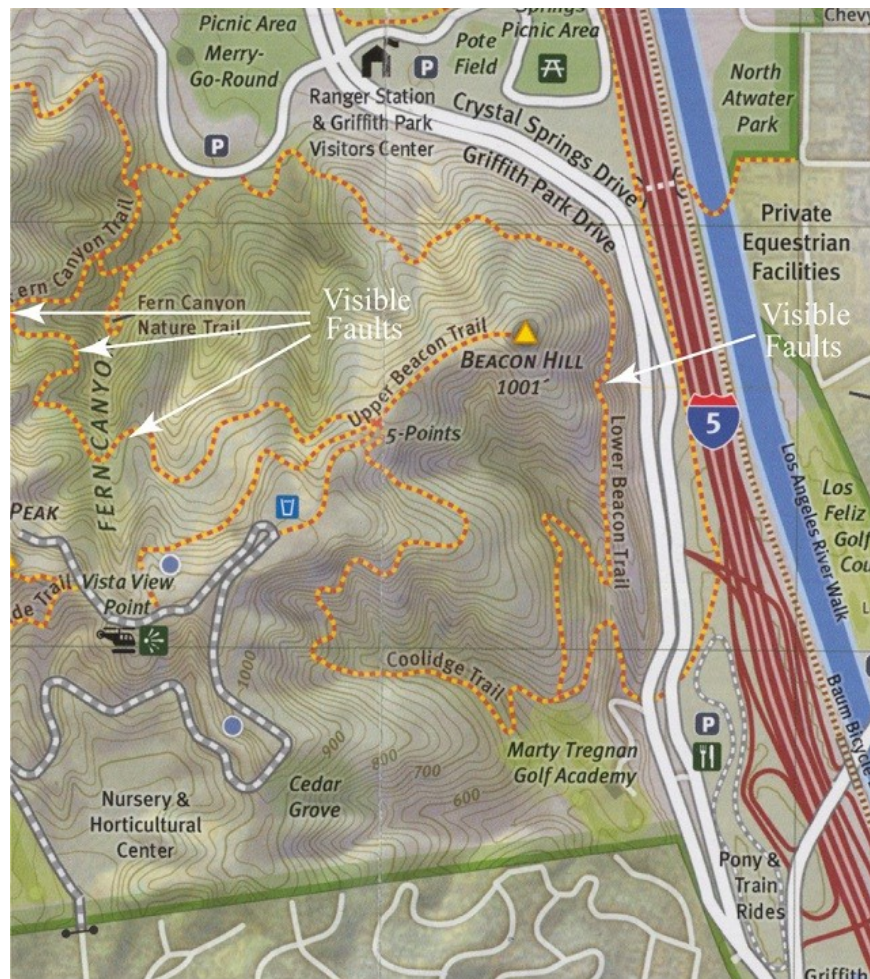


Figure 3. Section of the Griffith Park Visitors' Map, showing the portion of the park discussed in this article. The map is available free at the ranger stations in the park. Arrows show the locations of obvious faulting found by the author. The gridline-delineated squares are 0.5 miles to a side. This depicts only about 1/20 of the park area (Modified from Cartifact, Inc., 2010).

Background

Griffith Park is adjacent to the Los Angeles River, a few miles to the northwest of downtown Los Angeles. It comprises approximately 4,000 acres, and is part of the eastern extent of the Santa Monica Mountains (Eberts, 1996). It is bounded on the north by the Benedict Canyon Fault, followed by a wide basin and then by the Verdugo Mountains. To the south, there are two faults intermingling, the Hollywood Fault, and the Santa Monica Mountains Fault / Fault Zone. The tallest peak in Griffith Park is Cahuenga Peak, with a summit at 1820' above sea level, but technically this is not true—the peak lies about 400 feet outside the park's boundaries. The "Hollywood Sign" is on Mt. Lee, within Griffith Park, at 1680' above sea level (Cartifact, Inc., 2010). Lake Hollywood, a reservoir, sits on the western edge of the park. The

Los Angeles River, and now the interstate 5 freeway, are at its eastern edge. The park is home to a good sampling of California chaparral, and includes native trees like sycamore, pecan, and oak, as well as pine species, which the author suspects may not be native. Smaller plants include several kinds of grasses; edible plants like chicory, milk thistle, and currant; and many other typical flora, such as laurel sumac, monkey flower, sage species, and poison oak. There was a major fire in the park in 2007 (Griffith Park). Aside from the fire's charring on rocks and trees, and some evidence of loss, the park's natural environment has already recovered. The most abundant fauna are birds, including crows, mockingbirds, sparrows, and many others. Coyotes and rattlesnakes also live here, and I had the joy of seeing each while working on this project. Neither poses a major threat, but students should be aware of what to expect when they come to the field. Note that a rattlesnake should be quite obvious if it is present, usually sunning itself along the trail (Figure 4). Snakes are shy and will not seek out interactions with people.

Owing to its river-proximity, and to Quaternary history, some of the exposed rock within the park is alluvium – remnants of flood-driven debris flows. There are Pleistocene beds of sedimentary rock made from material taken out of the earlier Santa Monica Mountains. These beds are labeled Quaternary older alluvium (marked "Qoa") on the Dibblee map of the area (Dibblee, 1991). The author has found charcoal fragments in an exposure here, which may be well-placed in time if someone wishes to perform the Carbon-14 dating (Figure 5).



Figure 4. Rattlesnake seen south of where the Coolidge and Lower Beacon Trails meet, not far from the train ride parking lot. The view is to the northwest (Helman, 2010f).



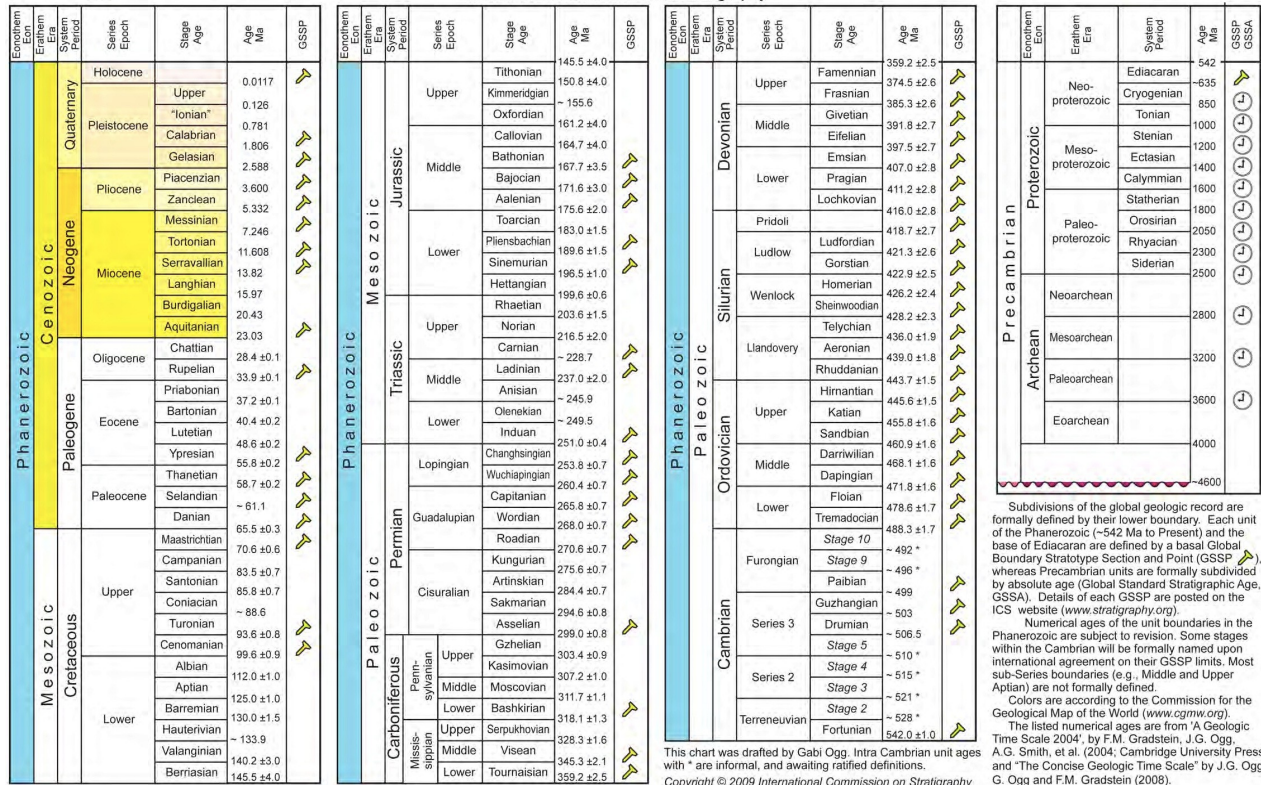
Figure 5. Charcoal present in an exposure of Quaternary older alluvium, which is located on the northeast face of rock beside the trail. It is south of where the Coolidge and Lower Beacon Trails meet, not far from the train ride parking lot. This image is of rock about 25 feet above the trail. The larger fragment is approximately 2 cm across (Helman, 2009a).

The area of Griffith Park is composed of fifteen different rock formations (Dibblee, 1991). The majority of the exposures are Neogene and Quaternary marine and non-marine sedimentary rock. See Figure 6 for a geologic time scale showing their context. The Lower, Middle and Upper Topanga formations are well-exposed, as are the Monterey and Fernando Formations. Inclined bedding is obvious throughout the park, and fossils are sometimes present. Figure 7 shows bedding from a typical exposure. There are good opportunities for rock description here, with much of the clastic rock accessible. Late Miocene intrusive rock is also quite common in the park. Major contacts are sometimes well-characterized as obvious faults. Much of the granitic rock is friable and weathered. Dikes are present, as well, and some are extrusive, with purple and grey andesites being the most common of this class. Among some loose rock piles there are also denser, iron-rich specimens suitable for smelting. The author was not able to find their original provenance.



INTERNATIONAL STRATIGRAPHIC CHART

International Commission on Stratigraphy



August 2009

Figure 6. The most prevalent marine and non-marine sedimentary rock units in Griffith Park are Neogene and Quaternary in age, shown as the colored portion of this geologic time chart. Note that this chart is current, updated in 2009 by the International Commission on Stratigraphy (modified from International Commission on Stratigraphy, 2009).



Figure 7. Listed as Monterey formation on the Dibblee map, showing dipping beds. The view

is from the trail south of where the Coolidge and Lower Beacon Trails meet. The thicker bed is about 1.5 ft thick (Helman, 2010a).

Griffith Park and Water Rights

The Los Angeles River has been a resource for animals and people for thousands of years, and this has not changed in recent times. Griffith J. Griffith's sale of the water rights along the property to the city of Los Angeles in 1885, and later his gift of this land in 1896, then called Rancho Los Feliz, favorably concluded several decades of lawsuits in the region for Los Angeles (Eberts, 1996). The city aimed to assert its claim to control all of the water from the river, and Rancho Los Feliz held the clearest, oldest and most politically documented history of use, primarily agricultural. The riverfront land guaranteed rights to the water. The city might not have agreed to take ownership of the park, with the costs involved, if not for the boon related to water and the lawsuits about water rights. The city saved about \$1,000,000 at the time by accepting the gift (Eberts, 1996). Griffith Park would not exist if not for the political wrangling over water during this period. The natural history is inseparable from its political history.

In Southern California, water is very important. Severe flooding and loss of life over the course of several years in the 19th and early 20th centuries inspired the city of Los Angeles to encase the entire local riparian habitat in concrete channels (Eberts, 1996). Recent activism has been making some headway at restoring the habitat, and there is a plan to have a series of parks all along the river (Landers, 2007). Griffith Park has a very good view of the Los Angeles River's concrete bed, and provides a good backdrop for a discussion on both of these topics.

Strain Markers

Tectonic stresses have shaped the landscape of Griffith Park. Joints are common, though they are often not very well developed. Several of these are partially filled with a carbonate material, likely from groundwater percolation. The area the author looked at is small, reaching from the Lower Beacon Trail up to Beacon Hill and along the nearby slopes. These are the areas most easily accessible from the Pony Ride and Carousel parking lots. The author measured 86 joints, including at least seven very clear joint pairs, like the one depicted in Figure 8. This is a good site to bring students to, for practice taking measurements. Figure 9 shows stereonet diagrams of seven pairs of joints. Joints were plotted as curves within the hollow projection surface of the stereonet. Each pair of joints forms an angle, and the angles between the joint planes seem to be of two types, 60° or 30°, which are similar to those well-described in experiments on the strength of the lithosphere.ⁱⁱ A regular angle is consistent with a coulomb-shear fracture, named for Charles-Augustin de Coulomb, the scientist who made a general theory for brittle failure. It is in contrast to plastic deformation, which occurs under higher confining pressures.

Under low confining pressures, rock fails if there is enough directed stress present in the system (Griggs, 1936). The rupture surface and the principal stress direction do not coincide

exactly. The rupture surface is always inclined. This allows one body of rock to slip past the other, much like the wind slips in front of a sail when a boat heads into the wind. If there are two fractures, they will make a V shape. The principal stress direction can now be found. It is the midplane between the two limbs of the V. Often Vs are present point-to-point, as “bow ties”. If there is enough stress in a V pair, one limb allows for slip-motion and becomes a fault plane, while the other is truncated and remains a joint. The angle between the planes depends on the confining pressure (Donath, 1961). In structural geology, the stress vectors are taken as orthogonal to each other, with the primary stress as the direction with the greatest magnitude. The secondary stress direction is perpendicular to the primary, but of lesser magnitude. The tertiary is in the direction with the least stress. If a secondary stress direction is strong enough, and the confining pressure right, it will make a smaller second V pair in the rock, orthogonal to the first V pair. Thus a V structure can be used to locate a principal stress direction, and a second, narrower V pair can show a secondary direction of stress. These can be eyeballed by students as they are walking along the trails. The joint pairs from Griffith Park are very clear, good examples.



Figure 8. Jointing along the Lower Beacon Trail in Griffith Park. The two prominent joints form a 60° angle. The Silva Ranger Transit in the corner is here for scale (Helman, 2009b).

From Figure 9, the principal stress directions in the larger-angle pairs are N70E and N80E. (That is, for the two leftmost stereonet in the top row, and the middle stereonet in the bottom, whose midplane is the same as for that in the top left.) The direction N70E is significant. It is the same general orientation as for the Raymond and Hollywood Faults, which are both active.

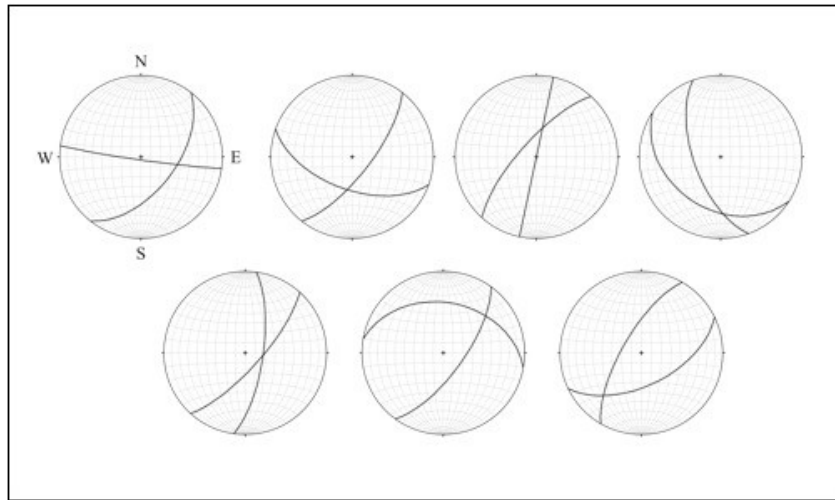


Figure 9. Stereonet plots of prominent joint pairs, from the area near Beacon Hill in Griffith Park. These are projections of joint planes, and each gridded circle is meant to be the hollowed out bottom half of a sphere. The top left stereonet in the figure was measured from the joint pair shown in Figure 8. These are equal-area stereonets, meaning each “square” on the figure represents an equal area. Angular relationships are preserved (assembled using Richard Allmendinger’s Stereonet program).ⁱⁱⁱ

For the smaller-angle pairs, the principal stress directions are N15E, N25E, N50E, N40W, from left to right in the middle-top (and then bottom) rows, respectively. Stereonet diagrams of 86 joints from the Beacon Hill area and also 11 joints from the summit itself are shown in Figure 10. Next to these are contour maps, showing the joint planes’ orientations. These are plotted as poles, that is, lines perpendicular to the joint planes. They are easier to see on a stereonet, since each pole is represented as a single point slicing through the surface of a sphere rather than as a line. More poles are in the more darkly shaded regions. If joints are in V-shaped pairs, then the polar directions should average and the relative inclinations cancel to reveal the direction of principal stress. Note that the predominant polar alignment is at approximately N60W, and the direction perpendicular to this is N30E. The direction N60W is the same general bearing as the Verdugo Fault, which is a low angle thrust fault, also currently active. A secondary stress perpendicular to this fault would be at N30E. It is useful that the jointing follows some of the same bearings as the closest faults here, as a teaching opportunity. The V-shapes are often obvious, and so is, for example, the front of the Verdugo Mountains, beside which the Verdugo Fault runs.

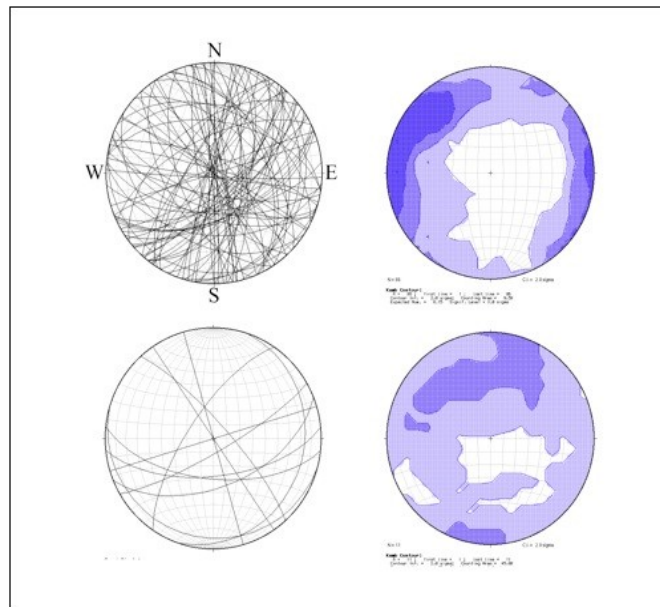


Figure 10. In the top row there is a stereonet plot of 86 joints near the Beacon Hill area of Griffith Park. To the right of this is a contour graph of the associated poles to the joint planes. (A pole is the line perpendicular to the plane, and is easier to plot on a stereonet, since it is represented by a point rather than a line.) In the bottom row there is a stereonet plot of 11 joints on the summit of Beacon Hill, along with a contour graph of the associated poles. Each contour represents two standard deviations, and the greater the number of poles the darker the region (assembled with Richard Allmendinger's Stereonet program).

What follows now is some background information about the faults in the region. The Hollywood Fault, a major fault, ruptured within the last six to eleven thousand years, and has a recurrence interval of perhaps ten thousand years, and a slip rate of 1.0 to 5.0 mm per year (Dolan, Stevens & Rockwell, 2000; Treiman, 2000). The Raymond Fault, another major fault, was responsible for the 1988 Pasadena earthquake (Southern California Earthquake Data Center). It also ruptured between one and two thousand years ago, with a recurrence interval of three to four-and-a-half thousand years, and a slip rate of 1.0 to 5.0 mm per year (Crook et al., 1987; Weaver & Dolan, 2000; Treiman, 2000). Neither of these earthquakes occurred in the basin directly adjacent to Griffith Park (Jennings & Bryant, 2010). An earthquake in the surrounding area is likely, but perhaps not for a thousand years. Data were gathered with a Silva Ranger, whose declination readings are less precise than Brunton transits, but are much easier to take readings with for a novice. The stereonets were generated using a free academic application available on the internet, Stereonet 6.3.3, by Richard Allmendinger, who teaches structural geology at Cornell University.

Fault Traces

Faulting is obvious in Griffith Park, and this is true along both the Lower Beacon Trail and the

Fern Canyon Trail. See Figures 11 and 12, which show examples. For some faults there are slickenlines present, plus a characteristic planar undulation. Fault gouge can be found both within the obvious faults and nearby. Some faults have trees growing directly in front of them, or plants growing through them, and there's even one beehive placed in a fault. Much of the gouge is carbonate—it reacts with acid.



Figure 11. Faulting along the Lower Beacon Trail in Griffith Park, facing west. This fault plane is depicted as Fault 3 in Figure 13. The planes of all three faults are intersplaying nearby (Helman, 2010c).



Figure 12. Fault along the Fern Canyon Trail of Griffith Park. The cleft of the fault points towards the Verdugo Mountains (Helman, 2010b).

Figure 13 shows the converging of three of faults on the Lower Beacon Trail, and though all three faults interplane with each other, the major geometry can be worked out, both with slickenlines and based on the shape of the clefts.

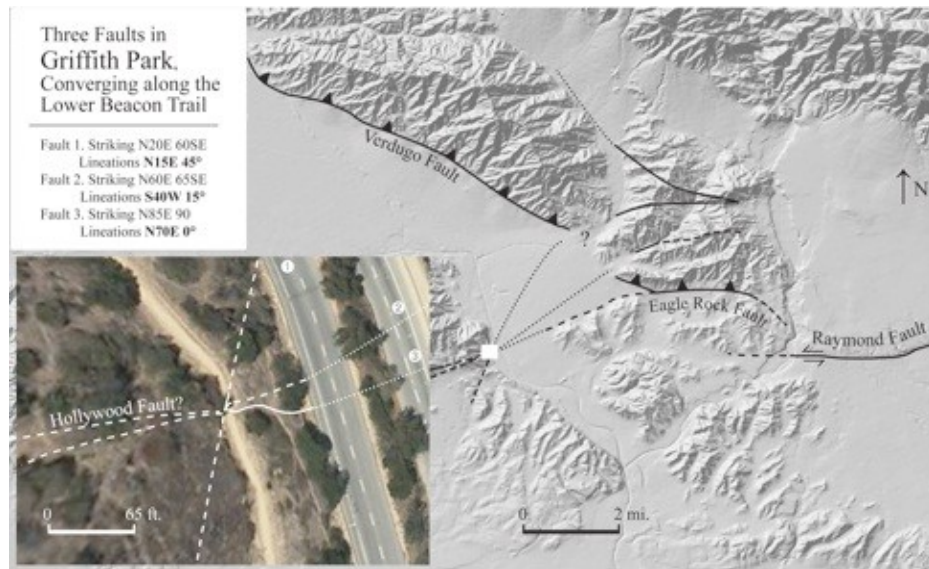


Figure 13. Digital Elevation Model of the faults opposite the Lower Beacon Trail in Griffith Park. The unnamed faults in the top-right are from the 2010 California fault activity map (Seamless Data Warehouse, 2010 (digital elevation model image); Google Earth, 2007 (inset image); Jennings & Bryant, 2010; Jones et al., 1990; Neuerburg, 1953; Dolan, Sieh & Rockwell, 2000 (fault data)). The mountains lying to the north of the Verdugo Fault are the Verdugo Mountains and past these are the San Gabriel Mountains. Highland Park is south of the Eagle Rock Fault, and just north of the inferred extension of the Raymond Fault. The hills in the center of the image, just below the dashed lines of the Eagle Rock Fault, are Glassell Park. Mount Washington is the elevated area adjacent to the south of this. The Los Angeles River can be seen meandering through the center of the figure from NW to SE. The City of Los Angeles lies about where the “2 mi.” rests on the page. Northwest of Los Angeles is Elysian Park and Silverlake, and northwest of here is Griffith Park, the easternmost extension of the Santa Monica Mountains. The white rectangle represents the satellite image inset. Of the three faults, the one labeled Fault 3 is the most impressive. Looking out to the east, the sloping edge of Adams Hill lies directly opposite, and is very clear. This edge forms the northeast boundary of the high terrain called Glassell Park, and Highland Park lies beyond. Fault 3 perhaps connects with the Eagle Rock Fault, which runs through the foothills just to the north of that city. It does not seem to connect with the Raymond Fault, which runs more southerly, through Mount Washington (Figure 14).

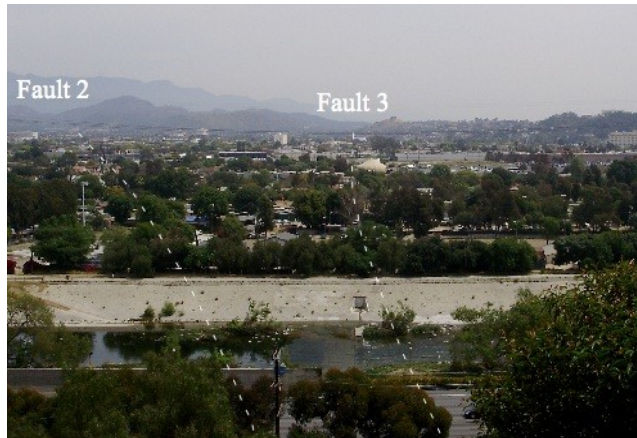


Figure 14. The view from the Lower Beacon Trail towards Eagle Rock. Fault 2 faces the 134-2 interchange and an unnamed fault listed on the 2010 California Fault Activity Map, probably intended to be part of the Santa Monica Fault Zone. Fault 3 possibly extends from the Hollywood Fault and connects with the Eagle Rock Fault (Helman, 2010d).

With one's back to Fault 2, one can look out over the basin and also see how its presence has also influenced the forms of the nearby mountains. The line of sight lands directly at the notch where the 134-2 freeway interchange is situated, and to the fault which underlies Chevy Chase Dr, near the city of Eagle Rock. Faults 2 and 3 seem to be related—their headings are only about 30° apart. Figure 15 shows what author has labeled Fault 1 in Figure 11. A large tree sits along its path. Looking around it, one's gaze heads towards downtown Glendale, and to Verdugo Road, which was built over a fault (Jennings & Bryant, 2010). Fault 1 is inclined about 45° from the vertical, dips to the SE, and has a large, smooth, undulating surface plane. It strikes at N20E. The direction of motion is along the plane, to the northeast/southwest.

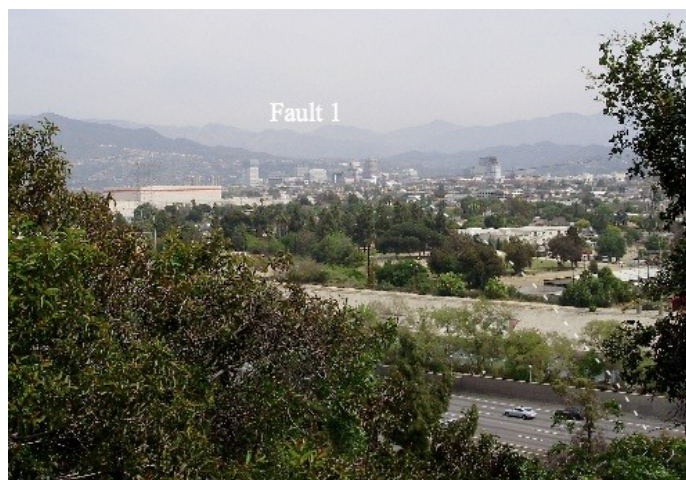


Figure 15. Looking towards Glendale from the Lower Beacon Trail. Fault 1 faces downtown Glendale and the notch created by an unnamed fault listed on the 2010 California Fault

activity Map, probably intended to be part of the Santa Monica Fault Zone (Helman, 2010e).

To get one's bearings while on the trail, Figure 16 shows a small cave which is in the rock face next to the trail where these faults converge. It is about 4.5 feet wide, 3 feet tall and 3.5 feet deep at its deepest. The cave is a good marker for the spot. Its semimajor axis follows the bedding of the surrounding rock. My opinion is that this cave is man-made, the start of a mine. Whatever waters percolate through the faults might carry something of economic worth to deposit.



Figure 16. View of the small cave along the Lower Beacon Trail of Griffith Park, where three faults converge. The camera is facing SW, and a Silva Ranger transit is open in front of the cave, on the right, for scale (Helman, 2009c).

The direction of motion, and/or laterality of all three of these faults are hard to characterize. The author was not able to find Riedel shears with which to definitively say, and slickenlines seemed unreliable. Much of the rock is quite loose, and the opposite faces do not have obvious markers. The San Gabriel Mountains lie to the north, nearby, and these three faults are undoubtedly related in some fashion to that mountain range's rotation. There is recent work on the Santa Monica fault system (Dolan, Sieh & Rockwell, 2000), but it doesn't list this junction. There are also three or more fault exposures which can be easily found on the Fern Canyon Trail facing north and northeast, towards the Verdugo Mountains, and some face towards the same notch as Fault 1. There are undoubtedly other fault traces present in Griffith Park.

Elysian Park Anticline

An anticline is rock folded by tectonic stresses, with an axial structure. The axis is the higher, and the limbs of the fold are the lower parts of the structure. The Elysian Park Anticline runs parallel to the northeast edge of Elysian Park, and is asymmetrical. It can be seen in Figure 11 as the hilly region through which the black mile marker (saying "0" and "2 mi") runs. The northeast half of Elysian Park's hills are taller than those in the southwestern half. The axis of the anticline runs from northwest to southeast, and is parallel to the Los Angeles River's bed. The high part, or the crest of the fold, is parallel to its axis. Rocks to the northeast of the axis dip to the northeast, and rocks to the southwest dip to the southwest. The anticline is underlain by a blind thrust fault, similar to the one which caused the 1994 Northridge earthquake (Oskin et al., 2000). The Elysian Park Anticline passes through Griffith Park. There is, for example, a small synclinal fold that can be seen adjacent to the summit of Beacon Hill, to the west, near the Upper Beacon Trail. Its axis lies at N80W, with a dip of about 55° NW. The outcropping rock is only a few feet across. The timing of the fold is current as uplift is going on presently (Oskin et al., 2000). That which formed the Elysian Park Anticline formed the geologic structures here, and the compressive forces driving the motion along the Hollywood and Raymond Faults have a similar orientation.

Further, dips in bedding on and near Beacon Hill can vary by as much as 40° within a few hundred feet, but most changes are not so dramatic. Many of the beds on its northern and eastern faces dip to the northwest. The folding is complex enough to hold a person's interest, and no clear, simple structure is obvious. Bedding planes are often easy to measure. There are no corresponding southwestern-dipping beds. Their absence may give credence to an inferred extension of Fault 1 south along the western edge of the Elysian Hills.

Regional Tectonism

It is perhaps not hard to underestimate how tectonically active the Southern California region is, but faults are subtle structures. They are subtle enough for people to build houses next to them, and generally walk past even a well-exposed surface. However, people do notice earthquakes. Within historic times, there have been more than 50 earthquakes in Southern California with magnitudes equal to or greater than 4.5. A source like the Southern California Earthquake Center (SCEC) lists most of these on its clickable map, including all the major ones, like the Northridge and the Whittier-Narrows earthquakes.^{iv} Whittier narrows, which is just east of the region shown in Figure 11, lies to the southeast of the Raymond Fault. One can look out from the vantage in Griffith Park and perhaps see that far. The recent earthquake there, like the Northridge earthquake, was caused by a previously unknown thrust fault, a blind thrust fault.

Conclusion

Griffith Park is at the same time interesting, accessible, and pointed, and therefore a good place to bring a class of K-12, college, or university students. It has the added benefit of being quite close to much of the city. It is on the bus lines, but may take a very long time to reach. From Long Beach, for example, it takes 3 hours each way, so driving is more reasonable. Of the 4,000 or so acres in Griffith Park, the author has described about 200

(about 5% of the park). The rest is likely to also have interesting features, and these will likewise be valuable for introducing people to the geology of Southern California. There are certainly more features waiting to be discovered.

This article may serve as a model for what is possible to put together. If one is interested in teaching geology at an urban or near-urban park or other exposure, then this might serve as a proper guide. The research itself did not take years – the major features began to come together within a few weeks of poking around. The background information was easily accessed at my university library and through its electronic access agreements. That also was not a huge task, taking no more than a week to gather most of the relevant information. It seems like a worthwhile thing to do – to educate youth about the environment of an area.

Summary

The article presented some of the natural history of Griffith Park and much of its geological features in order to promote people using local sites for teaching geology, especially in urban settings. Such is seen as a real goal for improving humanity's chances of getting out of the current environmental crisis. In the park jointing is prominent, and reflects the principle tectonic stresses in the region. Faults are also common, and often may be followed at some distance, to see their effects on the landscape. Folding is also present here. The faulting may be especially useful in communicating major concepts in the geologic history of Southern California. The park itself is accessible and generally available, often with less preparation than field trips to more faraway places. This guide can serve as a model for similar teaching resources.

10. Acknowledgements

No money or other support was received in preparing this guide. It grew out of observations made while the author was a graduate student at California State University, Long Beach, and was written for the class English 419, Writing for Science, Social Science and Technology, taught by Jillian Kemper. Special thanks to the rangers of Griffith Park, who were helpful, friendly, and fun to be around. Love always to my parents.

Glossary

Geologic Terms

Alluvium	River-transported sediment. The term comes from the Latin "ab + fluvium."
Andesite	An extrusive igneous rock of intermediate composition, less ferromagnesian than basalt.
Anticline	A geologic structure in which beds are folded axially, with the limbs draped down. The axis is the higher part. If the axis is lower than the limbs, then it's called a syncline rather than an anticline.
Bed	A planar mass of sedimentary rock seen as a unified feature, often on the order of a few feet or less -- though there are sometimes massive beds!
brittle failure	A fracture caused by stress.
carbon-14 dating	Chemistry is used to measure the mass of isotopes of carbon present in a sample. This process works because living things are constantly adding the radioactive isotope C-14 from the atmosphere into their systems. When an organism dies, all of this will eventually decay into C-13. The ration of C-14 to C-13 should give an accurate date. The age is based on a standard exponential decay function. The process is not sensitive enough to give a date older than about 60,000 years before present.
Carbonate	CaCO_3 - the main component of seashells and limestone. In mineral form, it is called calcite (or aragonite if it is in its high-pressure phase, commonly known as "mother-of-pearl"). Geologists use very dilute hydrochloric acid to detect carbonate. It should effervesce on contact.
Clastic	Rock made up from fragments of other rock. Usage is not based on size or chemical composition. The term "clastic" is related to the word "cleave."
Contact	This refers to the end of one rock unit and the beginning of another. The nature of the contact tells something about the geologic history of the area. An angular unconformity, for example, can imply a history of deposition followed by

tectonism, erosion, and then more deposition.

coulomb-shear fracture

A fracture following the Mohr-Coulomb Law, in which the angle of failure is defined by the stress, by its incident angle, and by the shear strength of the brittle material.

dike

A planar feature, whereby lava has squeezed into a fissure in the host rock, and expanded. Pegmatite dikes are composed of the leftovers of a cooling process, where incompatible elements segregate themselves while the more common minerals are forming. Pegmatite dikes often contain exotic or economically important minerals. Kimberlite dikes often contain diamonds.

debris flow

This is the geological term for what is commonly called a "mud slide." These often include a broader range of materials than mud, hence the new expression.

Extrusive

An igneous rock which has been formed at or near the surface, with cooling often fast enough so that few minerals are visible to the naked eye. Lava rock, such as pahoehoe, is a good example, as are pumice and scoria.

fault gouge

Unconsolidated material pulverized by a fault. Fault gouge will become suspended in water if you wet it. It may initially appear solid.

Formation

Sequential collections of beds are called formations, and these can be composed of a few related rock types coming from adjacent depositional environments. Formations are distinguished from each other by major changes in rock type, depositional environment, or other features. Formations have a type locality, where good specimens of the rock units can be found, and for which the formation is often named.

Friable

Easily broken. It is related to the word "fragile."

Joint

A planar fissure in a rock, along which there hasn't been significant offset. If there is offset, it is called a fault.

plastic deformation

Under enough confining pressure, solid materials will flow, as with a fluid.

Riedel shear

Secondary fractures in faults. These can be used to assign a direction of fault motion, its laterality.

Slickenlines	Grooves visible on the face of a fault plane, which result from motion along the fault. They can be used to indicate the direction of fault motion.
Subduction	The process whereby one lithospheric plate plunges below another, to be recycled into mantle material.
Tectonic	Related to plate tectonics and how mountains are built by the motion of plates on the surface. "Tect-" is the same root as in the word "architect" (which means "laws for building").

Geologic Names

Dibblee Map	A Geologic Map made by Thomas Dibblee, whose work in California was so prolific that it warranted the establishment of a Dibblee Geological Foundation to manage the collection. It is currently overseen by the Santa Barbara Museum of Natural History.
Miocene	The geologic period spanning the time from about 23 to about 5 million years ago. In California, the Miocene fairly well coincides with the end of offshore subduction and the beginnings of activity along the San Andreas Fault. Oil production can be traced to abundant marine organic matter which was a feature of that subduction. Marine microbes from the Miocene are the source of the oil found here today.
Neogene	The Tertiary and Quaternary Periods made up the Cenozoic Era, which started 65 million years ago and includes the present. The term "Tertiary" is currently being split and replaced by two periods, the Paleogene Period (which includes the Paleocene, Eocene and Oligocene Epochs) and the Neogene Period (which includes the Miocene and Pliocene Epochs).
Pleistocene	The ice age series, from 2.5 million to 11,700 years ago. The term comes from two words, "Mostly" and "Recent," referring to the character of fossils present.
Quaternary	The most recent of the geologic periods, made up of the Pleistocene Epoch (2.5 million - 11,700 years ago, informally known as the ice age) and the Holocene Epoch (the present). The root "-cene-" stands for "recent." Historically, if a bed had fossils which were wholly recent, it would have been labeled a "Holocene" bed. Similarly, beds with 50%

recent fauna would have been called "Miocene." These are divisions within the Cenozoic Era, the era of "recent animals." The Geologic Eras which have included animal forms are the Paleozoic, Mesozoic, and Cenozoic and these terms superseded a prior set of terms - Primary, Secondary, Tertiary, and Quaternary.

Geometric Terms

Contour	Representative of the surface of a feature. Contour lines are lines of equal elevation on a map.
Declination	The angle of a plane compared to the horizontal. A vertical plane has a declination of 90 degrees.
Orthogonal	Making a 90 degree angle. Synonym for perpendicular.
Perpendicular	Making a 90 degree angle. Synonym for orthogonal.
Pole	The line perpendicular to a plane, often plotted in place of the plane on a stereonet projection if the data are very dense.
Projection	A line which intersects with a plane can be plotted as the shadow of the original line, and this is an example of a projection. It is the representation of one form in terms of another.
semimajor axis	The major axis of an ellipse is the longer of the two. The semimajor axis has the same alignment as the major axis, but only half its length. Its length is the distance from the center to one of the ellipse's farther edges. The major and semimajor axes are perpendicular to the minor and semiminor axes.
Stereonet	For making two-dimensional projections of a three-dimensional figures, imagined in the bottom (or top) half of a hollow sphere. It is used for plotting points, lines and planes in space. A vertical plane cutting through the hypothetical sphere looks like a straight line, while an inclined plane looks like a curved line. A fully horizontal plane will plot on the outermost edge of the stereonet, as a circle. Stereonets are commonly used by Structural Geologists to plot faults and joints, and also by Mineralogists to plot crystallo-

graphic axes and faces. The earliest known use of a stereonet is in ancient Greece, plotting stars in the sky - the astrolabe.

Agricultural Terms

Acre	4,840 square yards = 43,450 square feet = the area of a square ~209 feet per side.
Hectare	10,000 square meters = a hundredth of a km ² .

Statistical Terms

standard deviation	If data follow a random distribution, and are plotted, then 68% will fall within one standard deviation on either side of the average value. Standard deviation is defined as the square root of the variance of a set of data.
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Footnotes

ⁱ Urban Park. Wikipedia, the Free Encyclopedia at: http://en.wikipedia.org/wiki/Urban_park.

ⁱⁱ A good summary of these experiments, along with references, can be found in Kohlstedt et al. (1995) at <http://europa.agu.org/?uri=/journals/jb/95JB01460.xml&view=article>

ⁱⁱⁱ Available free at <http://www.geo.cornell.edu/geology/faculty/RWA/programs.html>

^{iv} Southern California Earthquake Center at <http://www.data.scec.org>

Helman, D. S <danielhelmanteaching@yahoo.com> California State University, Long Beach,
Department of Geological Sciences, 1250 Bellflower Blvd., Long Beach, CA, 90840, USA.

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