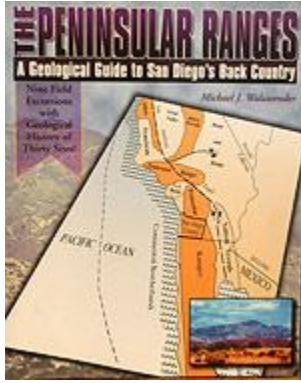


Geologic History of San Diego County



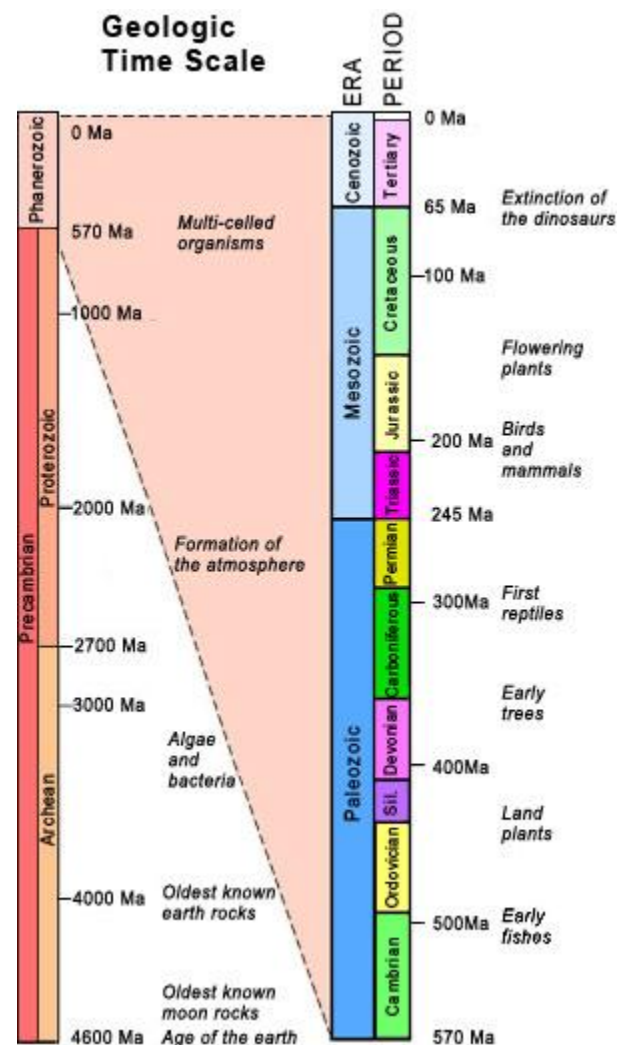
Article by Dr. Michael J. Walawender, Professor Emeritus, Dept. of Geological Sciences, San Diego State University; Research Associate, Department of Mineralogy, San Diego Natural History Museum

The following article draws heavily from *The Peninsular Ranges: A Geologic Guide to San Diego's Back Country* by Dr. Michael J. Walawender. Refer to that volume for additional details on the geologic processes discussed below.

The original version of this article can be found on the SDNHM web site at http://www.sdnhm.org/archive/research/geology/geo_intro.html - it keeps changing, though...

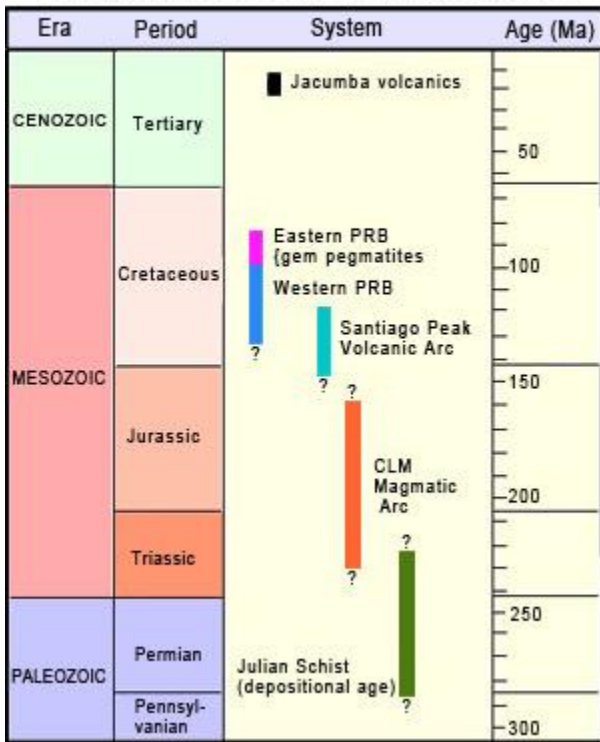
If we were to go back in time about 200 million years and view what is now all of southern California, a very different picture would emerge. Ocean waters would stretch eastward to Arizona and northern Mexico. There, ancient granites, as old as 1800 million years, and associated metamorphic rocks would form the western edge of the North American continent. A low rolling landscape with rivers that have long since disappeared would wash sediment weathered from those rocks into the shallow seas adjacent to the continent. These sediments would thin westward under the ocean waters. The landmass on which we all now live and work was yet to be created.

To understand the history of our area, we must first unravel the present geologic picture. Although earthquakes and active faults are now a very recognizable part of life in southern California, they are a very recent addition to a much longer and more complex pattern of geologic activity. Part of this picture is hidden by geologically young sedimentary rocks on which much of metropolitan San Diego is built. As we travel eastward, however, into the less populated mountain and desert areas, the exposed rocks record a long history of plate collisions, volcanic activity, and crustal uplift. From 250 million-year-old sedimentary rocks, through 100 million-year-old granites and 18 million-year-old volcanic eruptions, to the faults that shake us into today's reality, the San Diego area has been a very active place indeed.



The Oldest Rocks

Geologic Time Scale for Southern California



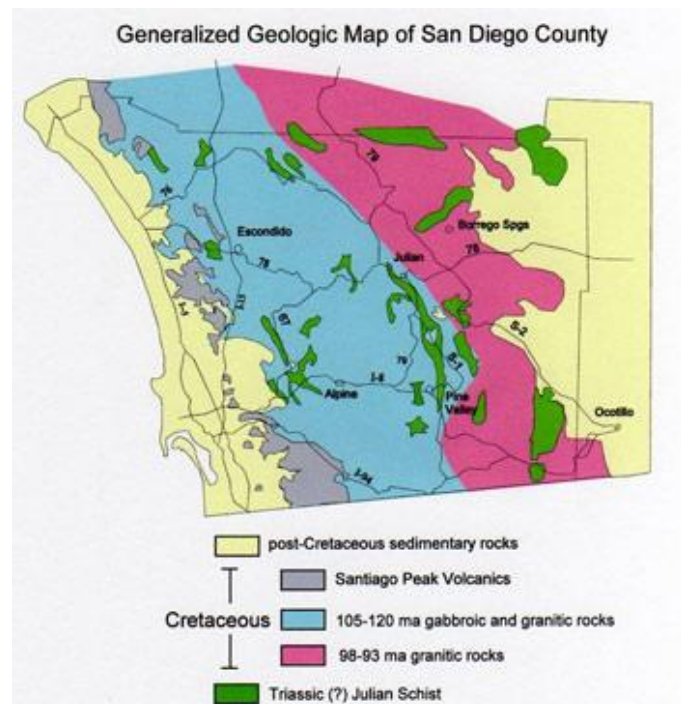
The oldest rocks in San Diego County are a series of scattered exposures of metamorphosed sedimentary rocks called the Julian Schist. Named after the historic community in east San Diego County, these rocks represent the sediments that accumulated in the shallow seas off the coast of North America nearly 200 million years ago. This thick blanket of sediments extended miles off-shore and wrapped eastward around the then edge of the continent into what is now central Mexico. The sediments have since undergone extensive uplift and erosion so that they now exist only as the scattered exposures depicted in the figure below.

The story of the sediments begins in the shallow seas adjacent to the North American continent. There, muds and sands derived from the Precambrian rocks that now underlie western North America and northern Mexico began to accumulate in layers. As sea level in the ancient Pacific Ocean rose and fell, alternating layers of mud and sand began to form in deeper waters. These sediments accumulated into greater and greater thicknesses until the weight of the overlying material compressed the base of the sediment pile. Remnant ocean waters were squeezed out, grains were compacted, and sedimentary rocks such as mudstone and sandstone were

created.

Later, during the Jurassic and Cretaceous Periods, these deeply buried sedimentary layers were disrupted at least twice by rising magmas and were twisted into the steeply tilted segments now exposed throughout the central and western part of San Diego county. Along Sunrise Highway (S-1) in the Laguna Mountains, near-vertical layers of mudstone and sandstone, now schist and quartzite, respectively, attest to the uplift and metamorphism that must have accompanied these magmas.

Further to the east, near the San Diego-Imperial County line, massive bodies of white marble are associated with lesser amounts of quartzite and mica schist. These marbles were once ancient limestones that formed in warm, shallow seas adjacent to North America. They are similar to rocks found elsewhere in southern and Baja California that contain an Ordovician fossil assemblage. Although these marbles are generally grouped together with the Julian Schist, they may be much older and may represent a package of sedimentary rocks transported into position by as-yet unrecognized faults.



Generalized geologic map of San Diego County.



Outcrops of Julian Schist along Sunrise Highway (S-1). The banding represents the different rock layers in the original sedimentary rock.

Also within this eastern metasedimentary package are exposures of amphibolite (a dark metamorphic rock composed of hornblende and plagioclase) that were basaltic lavas before metamorphism. They have an unusual chemistry, one that indicates formation in an ancient oceanic spreading center. This suggests that the ocean basin along the western edge of the continent was pulled apart in a manner similar to the rifting of Baja California from mainland Mexico or the separation of the Japanese arc from Asia.

Both the marbles and the amphibolites described above hint at a long and complex history for these ancient rocks that formed the earliest vestiges of what is now San Diego County.

Ancient Gneisses: The first arc

Exposed along the winding stretches of Sunrise Highway (S-1) in the central part of San Diego County is a north-northwest trending belt of granitic rocks called the Cuyamaca-Laguna Mountain Shear Zone (CLMSZ). Mostly described as gneisses, these rocks have the same minerals found in normal granites such as quartz, feldspar, mica, and hornblende. What makes these rocks different is that the darker minerals, biotite mica and hornblende, have been recrystallized into tiny rod-like aggregates by large-scale tectonic forces.



Close view of the alignment of dark minerals in the Jurassic granite gneiss.

This realignment occurred at depths of about 8 miles (13 kilometers) and at temperatures approaching 600°C (1100°F). This information, gleaned from many decades of laboratory studies on the behavior of minerals under varying pressures (depth) and temperatures, indicates that these rocks have undergone over 9 miles of uplift to reach their present elevation of nearly 6000 feet above sea level.

These granitic gneisses also contain very small amounts of the mineral zircon which crystallized from the original granite magma. Although zircon has a rather simple chemical formula ($ZrSiO_4$), it commonly contains trace amounts of the radioactive element uranium (U). This element decays at a known rate to a series of secondary elements such as lead (Pb) whose abundance can be measured and then used to calculate the age at which the original granite crystallized.

Several measurements of the secondary elements, made from samples collected along Sunrise Highway, indicate that most of the original granites were solidified during the Jurassic Period between about 160 and 170 million years ago. Geologists interpret this to indicate that subduction of an oceanic crustal plate had created a volcanic arc and its underlying plutonic basement adjacent to the western edge of the North American continent. Remnants of this volcanic-plutonic arc can also be found in the western Sierra Nevada foothills and in smaller mountain ranges scattered throughout the Mojave Desert. The recrystallized and aligned minerals in the rocks in central San Diego County suggests that these granites contain the record of another, more recent geologic event that transformed them from normal granites into granitic gneisses.

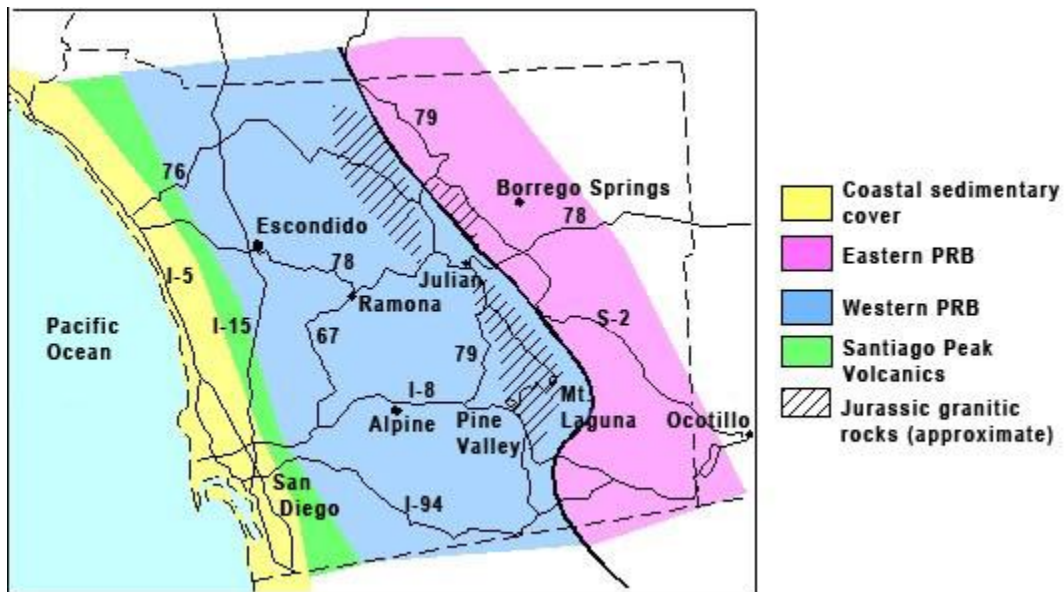


Weathered outcrop of Jurassic gneiss with several dark, wispy fragments of Julian Schist. Enclosure of these fragments by the gneiss indicates that the schist fragment must be older than the original granite.

Typical outcrop of Jurassic gneiss along Kitchen Creek in the Laguna Mountains.

The Western Plutonic Belt

The belt of granitic gneisses exposed in the Laguna Mountains essentially divides the county into two zones of plutonic igneous rocks. To the west, the rocks are much more diverse in composition and character, and form what is referred to as the western zone of the Peninsular Ranges Batholith (PRB).



Generalized geologic map of San Diego County showing the approximate distribution of Jurassic gneisses.

These rocks can be generally divided into three categories, each of which can be recognized from a combination of their topographic profile and general soil or outcrop color.

1st category in western PRB:

Gabbroic bodies are composed of olivine, pyroxene, and plagioclase, and are the coarse-grained equivalent of basaltic rocks that are found in ocean basins. These appear to be the oldest plutonic rocks in the western zone but attempts to determine their actual crystallization or emplacement ages have been met with very limited success. These rocks weather slowly to form some of our most familiar mountain peaks. Cuyamaca Peak, along with neighboring Middle and North Peaks, Los Pinos Mountain, and Viejas Mountain, are but some of the high-relief features in the county held up by gabbroic underpinnings. Since gabbroic rocks also contain an abundance of iron-bearing minerals, deep reddish soils tend to mark the lower elevations of these monolithic structures.



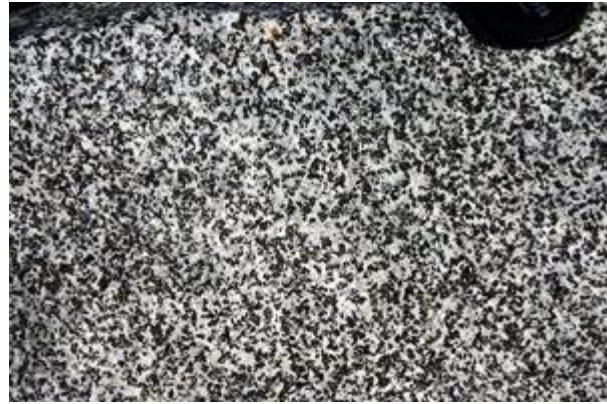
Cuyamaca Peak (left) and Viejas Mountain (right) are underlain by gabbroic rocks that are more resistant to erosion than the surrounding tonalite.



Mount Poser, another gabbroic body, rises above less resistant tonalite

2nd category in western PRB:

Half or more of the western zone is underlain by tonalite, a specific form of granitic rock that has plagioclase feldspar as its main constituent. The remaining minerals include abundant quartz, as well as biotite and hornblende. Radiometric ages for these rocks range from 102 to about 110 million years. Tonalite can be recognized by the grayish soils that develop around similarly colored outcrops and by the low rolling topography that is created by its relatively rapid rate of erosion.



Left: Outcrop of deeply weathered tonalite (grus) surrounding relatively unweathered cores of fresher rock along Sunrise Highway (S-1) and close-up view (right) of fresh rock.

3rd category in western PRB:

The remaining igneous rocks in the Peninsular Ranges batholith are granites that are mineralogically similar to the granitic gneisses found along Sunrise Highway. These plutons are easily recognized from the light-colored, bouldery outcrops that dot their slopes and by their topographic profile. They, like the gabbroic plutons, eroded slowly relative to the tonalite and form high topographic features such as Chiquito Peak, Lawson Peak, and Woodson Mountain. The few available radiometric ages for these rocks range from about 120 to about 110 million years. However, the field relationships of some of these plutonic bodies indicate that they are clearly younger than adjacent tonalites and suggests that the emplacement of these two rock types overlapped in time.



Cuyamaca Lake as seen from the top of Stonewall Peak. The abundance of chemically resistant quartz slows the rate of chemical weathering and leaves these rock types high above more easily weathered igneous materials.

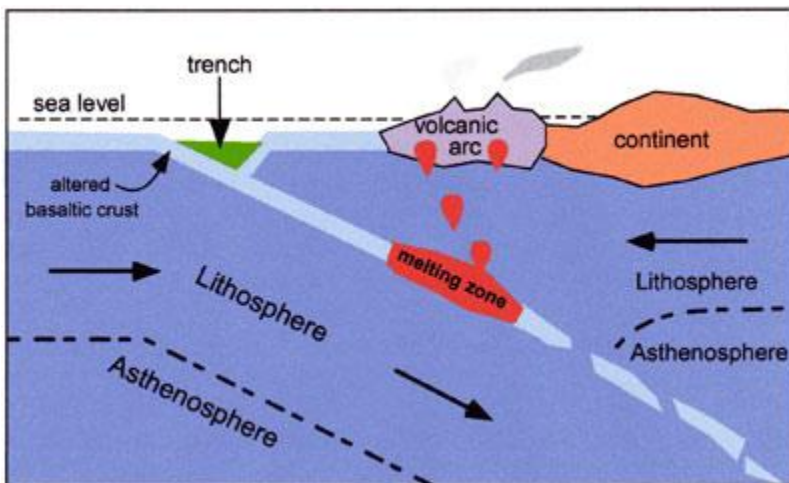
A close-up view of granite at Stonewall Peak with gray quartz and abundant whitish feldspar.



Chiquito Peak is a typical example of the higher topographic profile of this granitic rock.

How and where do these igneous rocks form?

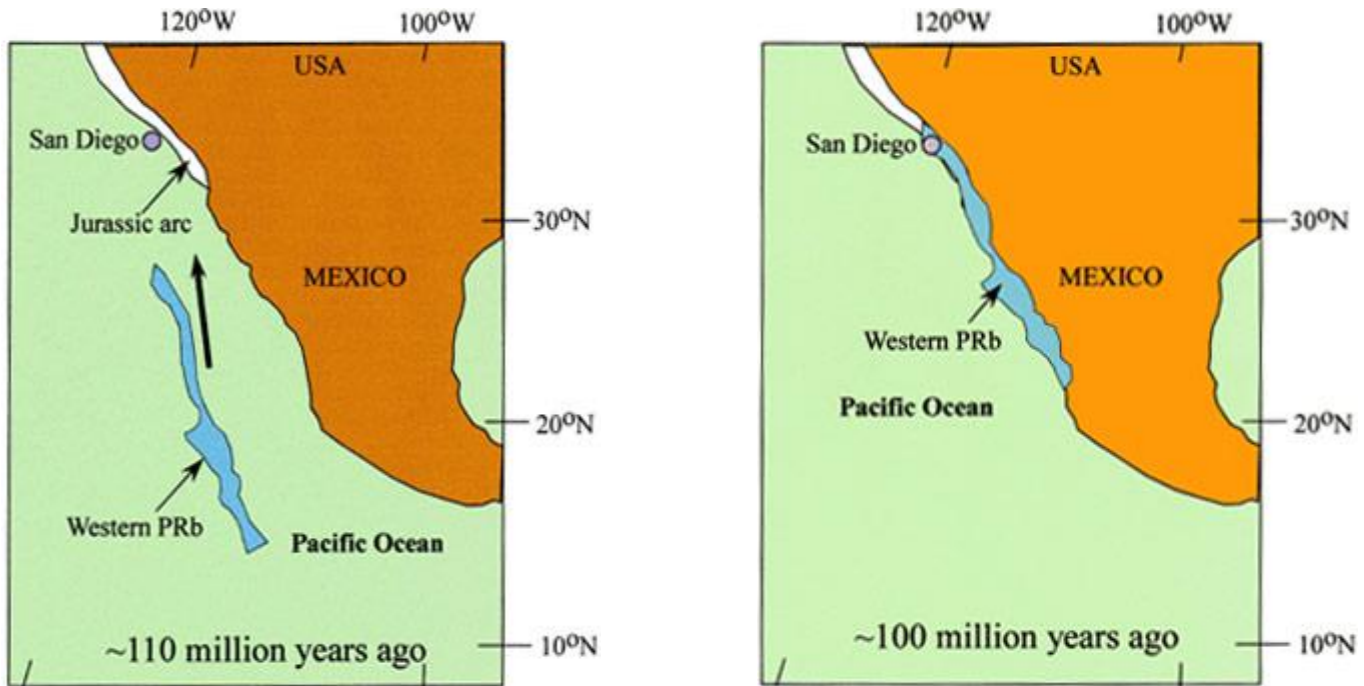
Geologists still debate the exact mechanism(s) by which these diverse rock types were formed but all agree that subduction of ancient oceanic crust was the overall mechanism. During subduction, cold oceanic crust (*light blue*) is thrust deep into the earth's mantle (*dark blue*) and heated by its ambient conditions to the point of partial melting. These melts or magmas then rise upward to create the different rock types so prominent in the western zone. Some rocks are created by partial melting of the down-going ocean crust, others from partial melting of the underlying mantle, and yet others by various combinations of these two sources.



What is of special interest, however, is *where* this subduction occurred. Recent studies have suggested that the entire western zone of the batholith is an exotic terrain, i.e., one that did not form where it is presently found but instead drifted in as part of one of earth's tectonic plates. Paleomagnetism is the study of earth's ancient magnetic fields as recorded in the iron-bearing minerals found in igneous rocks. As

newly crystallized minerals such as biotite, magnetite, and hornblende cool below a certain temperature (referred to as their Curie Point) the nature and direction of the earth's magnetic field at the time of crystallization is locked into the structure of these minerals. If the crustal plate that holds the rock has moved since its crystallization, the iron-bearing minerals still retain information such as the paleolatitude at which the sample formed. This data can then be used to reconstruct plate motions and unravel the enormous jigsaw puzzles that are today's continents.

The paleomagnetic data from the igneous rocks in the western zone of the batholith indicate that this enormous package of rocks, running from Riverside County southward through Baja California, formed at least a thousand kilometers south of its current position and must have been rafted into place by plate movements.



The growing western zone arc moved more or less northwestward and roughly parallel to the present coastline along strike-slip faults similar to the infamous San Andreas fault. This would have been a somewhat complicated geologic setting, with subduction west of the arc and strike-slip motion to the east. *Left illustration.*

This 100 km thick tectonic plate that carried the developing western zone (and its overlying active volcanoes) ground into the older Jurassic arc that lay just offshore of the continent at more or less the present latitude. In doing so, the collision compressed and deformed the Jurassic plutons and created the gneissic textures in the granitic rocks now exposed along the core of our Laguna Mountains. *Right illustration.*

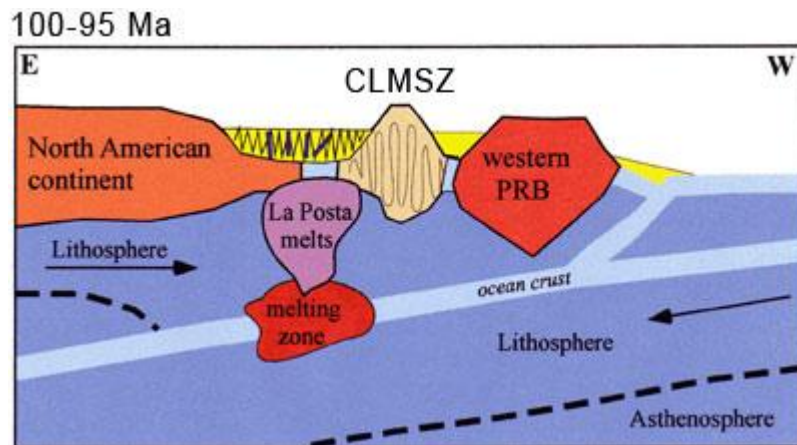
As the western arc migrated towards its eventual collision with the Jurassic arc, it was growing larger and larger as gabbroic, and later granitic magmas, were being created at depth in the subduction system. Some of these magmas rose to form large active volcanoes whose remnants can still be found just inland from the coast and protruding from its cover of younger sedimentary rocks. These rocks, the Santiago Peak Volcanics, underlie familiar peaks such as Del Cerro, Cowles Mountain, Black Mountain, and Mount Miguel. These rocks are chemically similar to the granitic plutons found throughout the western zone of the batholith. It has been argued that they represent the volcanic cover that formed the roof of the batholith. If so, then the entire western zone is tilted so that shallower volcanic rocks are exposed near the coast and their deeper plutonic equivalents exposed further inland.



Cowles Mountain, overlooking the community of San Carlos, is composed of remnants of ancient volcanoes that are part of the older western batholith. Left photo.

The Eastern Plutonic Zone

Another consequence of this collision is that the two tectonic plates, one carrying the western zone arc and the other hosting the North American continent, were both topped with relatively low-density crustal rocks. When the plates ground into one another, neither could be forced below the other. The motion of the northeast-directed Pacific plate was impeded so that eventually, in another 5 or 10 million years, the tectonic plate that was responsible for the western arc broke away and continued its drive under both of the two preexisting arcs and the North American continent. This new motion would create the third magmatic arc that forms the eastern zone of the Peninsular Ranges Batholith.

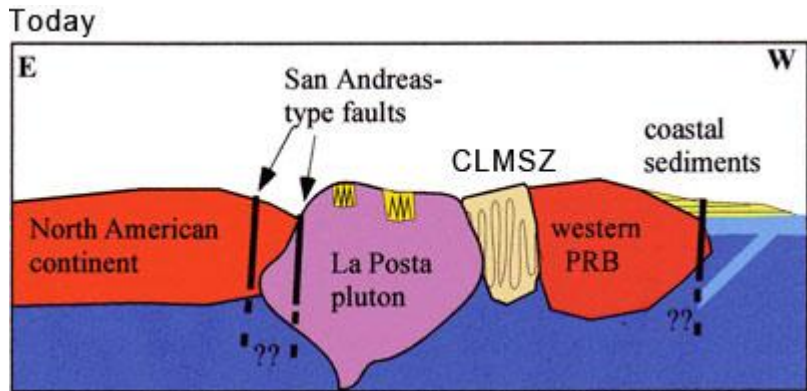


The new, shallower subduction plane begins to create the La Posta-type melts that will form the large plutons of the eastern zone. The cross section faces southward as if looking into Baja California.

By about 100 million years ago, the subducting oceanic plate had broken away from the western arc and magmatism in this zone had all but ceased. The western 'faucet' had been turned off and a new magmatic 'tap' was about to be turned on. An increase in the spreading rate back in the central Pacific basin began to push the

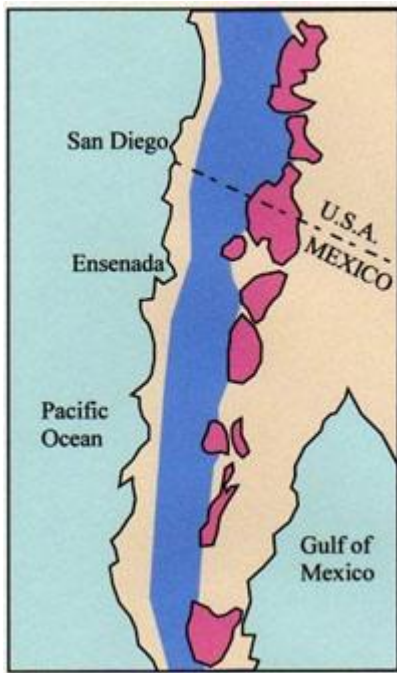
oceanic plate under the newly accreted western batholith but now at a much shallower angle. This change shifted magmatism eastward towards the boundary between the continent and the Jurassic arc.

For reasons not fully understood, the melting rate of the rapidly subducting plate increased dramatically. Unlike the western zone with its diversity of rock types and the several tens of millions of years for its creation, large bodies of homogeneous melt ballooned into existence within a few million years. These new dynamic conditions resulted in the rapid rise of enormous bodies of melt at the approximate juncture between the newly accreted western zone and the then western edge of the North American continent.



The present-day situation has the La Posta-type plutons east of both the Jurassic granites and the western zone of the batholith. The small yellow segments shown in the figure represent pieces of the older sedimentary materials engulfed by the rising melt (south-facing cross section).

The melts rose quickly, before much crystallization could occur, and came to rest at moderate depths in the crust. Here, they cooled in place to form a series of plutons with similar ages, compositions, and internal structures. Between about 97 and 93 million years, the bodies crystallized inward to form a string of concentrically zoned plutons that extend from Riverside County southward through Baja California. The largest of these, the La Posta pluton, occupies much of eastern San Diego County and covers an estimated 1700 km². Its counterparts, to the north in Riverside County and to the south in Baja California, range up to 1200 km² in exposed area.



Distribution of 90-100 million year old granitic plutons (pink) of the eastern zone of the Peninsular Ranges batholith. Blue approximates the western zone of the batholith.



Typical outcrops of the La Posta pluton along Old Highway 8.

The rise of these melts into crustal rocks that were already warmed to some extent by the magmatism associated with the western zone of the batholith caused great changes. As the melts rose, the crustal rocks above them were quickly forced upwards into young mountain ranges that may have rivaled the Sierra Nevada of today. The static magma chambers cooled slowly and crystallized inward to create the internal zoning observed in these plutons. In doing so, they released their latent heat of crystallization to the older overlying metasedimentary assemblage.

These ancient sediments, now micaceous schists, marbles, and quartzites, were uplifted, faulted, and heated to extreme temperatures. Experimental studies indicate that initial magmatic temperatures may have been close to 1000° C (1830° F), sufficient indeed to begin melting in mica-laden schists. Muscovite, quartz, and feldspar fused together to form water-rich granite magmas which were less dense than the surrounding schists.

Trace elements such as beryllium, boron, lithium, and phosphorus were selectively concentrated into the newly formed melts. They rose buoyantly and worked their way upwards to crystallize into the myriad of pegmatite dikes whose gem minerals have made southern California world famous. Pink and green tourmaline, aquamarine, golden topaz, and blood-red almandine garnet are but a few of the gems found in these earliest igneous rocks of the eastern zone. The pegmatites occur as somewhat irregular, light-colored bands or dikes cutting through the darker colored metasedimentary rocks from Jacumba northward to Riverside. Even today, small mines near Mesa Grande, Pala, and Warner Springs produce museum quality specimens.



Two separate pegmatite dikes slice through older rocks near Sacatone Overlook in eastern San Diego County.



Whitish streaks on Tule Mountain, near Jacumba, are pegmatite dikes which have been explored for gem minerals.

But gems were not the only consequence of the rise of the La Posta-type magmas into the overlying metasedimentary rocks. Hot, water-based fluids derived from the metamorphic breakdown of the micaceous minerals in the schists diffused their way into the sandstones, now quartzites, interbedded with the mica schists. These fluids selectively dissolved bits of placer gold between the quartz grains and carried the precious metal upwards to cooler environments where the fluids would crystallize into the gold-bearing quartz dikes for which Julian became so famous.



Examples of gem tourmaline from San Diego County.

Near the paleosurface, deeply circulating groundwater became heated by the magmas at depth and rose back to the surface creating hot springs, geysers, and a Yellowstone-like landscape. Metals such as copper, lead, and zinc were leached from the surrounding rocks by the circulating hot meteoric waters and concentrated into sulfide ore deposits. Most of this is gone, the result of 100 million years of erosion. All that remains of that hostile but beautiful landscape are a series of thin, clay-filled fractures barely visible in scattered road cuts along I-8.

Glossary

- Arc**
See volcanic arc.
- Asthenosphere**
The weak layer in the earth's mantle that sits below the lithosphere. It deforms plastically when stressed and is the layer in the earth on which the lithospheric plates ride.
- Absolute age**
Age as measured in a specific quantity such as years, millions of years (Ma), or billions of years (Ba) before present.
- Basalt**
A fine-grained (volcanic) igneous rock composed of olivine, pyroxene, and plagioclase. See also gabbro.
- Batholith**
An exposed, irregular mass of igneous rock greater than 100 km² in total area and composed of individual plutons.
- Continental crust**
A large mass of lower density material, consisting of granitic igneous and/or sedimentary rocks, that sits on top of the earth's mantle. Continental crust varies from about 70 to 30 kms in thickness.
- Dike**
A planar or tabular mass of igneous rock that formed by the injection of melt into a preexisting fracture that cuts across older rock structures.
- Emplacement age**
The time at which an igneous body solidifies in the Earth's crust.
- Gabbro**
A coarse-grained (plutonic) igneous rock composed of various amounts of olivine, pyroxene, and plagioclase. See also basalt.
- Gneiss**
A metamorphic rock with elongate clusters of dark minerals.
- Grus**
Deeply weathered, disintegrated igneous rock.
- Igneous**
A category of rock formed by the crystallization of molten material. See also magma.
- Lithosphere**
The outer, rigid shell of the earth that consists of continental and oceanic crust as well as approximately 80-100 kms of underlying mantle.
- Lithospheric plate**
A segment of the earth's lithosphere that is overlain by either oceanic crust or continental crust. Same as tectonic plate. See oceanic crust, continental crust.
- Magma**
Molten rock material consisting of melt and any contained solids.
- Mantle**
That portion of the earth that lies between the crust and the earth's outer core.
- Melt**
The molten portion of a magma.
- Metamorphic**
A category of rock formed deep within the earth from pre-existing rock material as the result of high temperatures and pressures, or by reaction with chemically active fluids.
- Metasedimentary**
Metamorphosed sedimentary rocks.
- Oceanic crust**

A large mass of medium density material, consisting of basaltic igneous and/or sedimentary rocks, that sits on top of the earth's mantle. Oceanic crust typically underlies ocean basins and varies from about 5 to 10 kms in thickness.

Paleomagnetism

The study of fossil magnetic fields as recorded in iron-bearing minerals.

Paleolatitude

The initial latitude of a rock mass prior to its movement via plate tectonic.

Pluton

An intrusion of igneous material that solidified at depth. See also batholith.

Rift zone

See spreading center.

Schist

A metamorphic rock characterized by an abundance of platy minerals such as mica or chlorite.

Sedimentary

A category of rock formed by the accumulation and lithification of weathered rock debris.

Spreading center

A linear zone in the earth's crust whose opposite sides are moving away from one another.

Spreading rate

The speed at which two sides of a spreading center are moving apart. Generally given in inches or centimeters/year.

Strike-slip fault

A vertical fault in the earth's crust whose sides are moving in opposite directions.

Subduction

The process whereby one tectonic plate is forced beneath another.

Volcanic arc

An arcuate band of volcanic rocks formed at approximately the same time from a single subduction event.