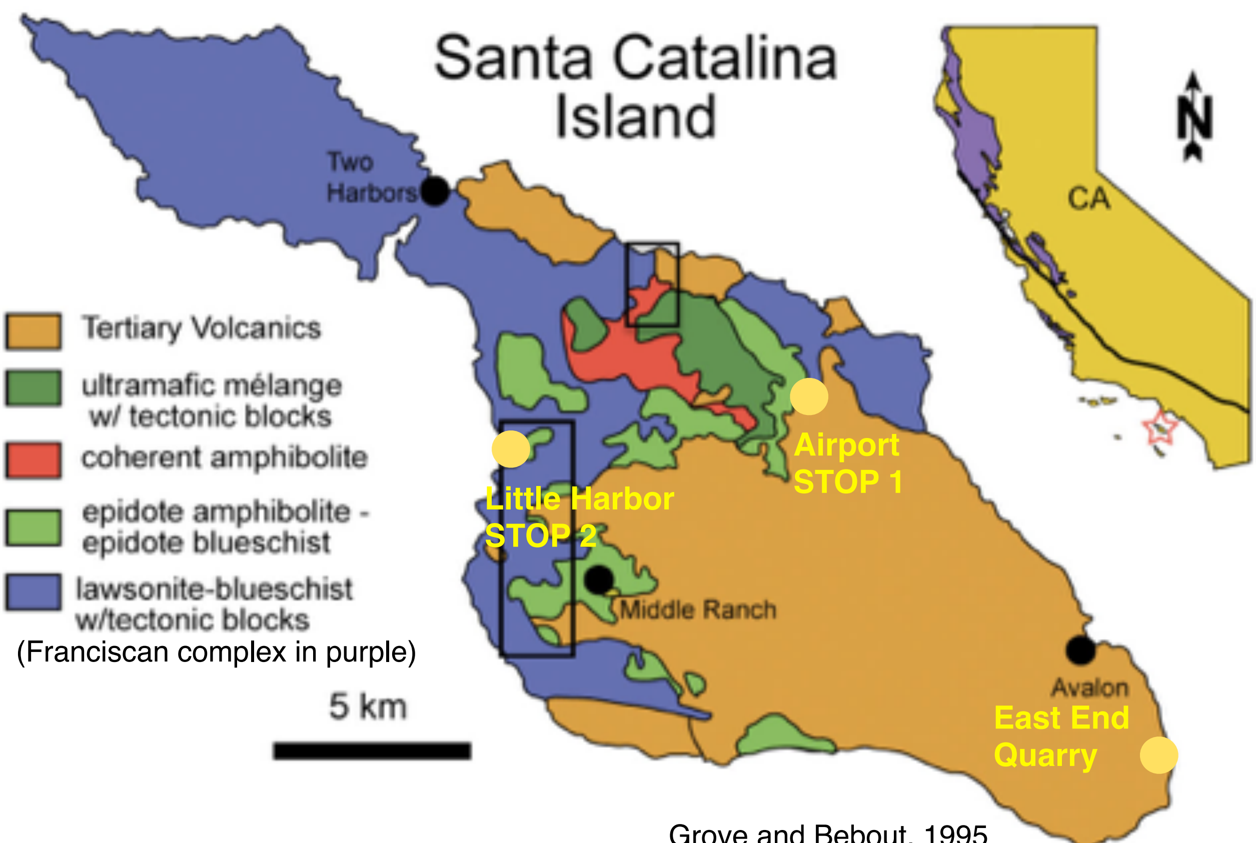
AWG SANTA CATALINA ISLAND FIELDTRIP

Association of Women Geoscientists, SDSU Student Chapter
August 31 - September 3, 2018
Bonnie Bloeser, Emma Vierra, Bonnie Flynn

Objective: We will visit Santa Catalina Island, a ridge crest in the California continental borderland geomorphic province, to examine Mesozoic metamorphic basement complexes (Catalina schist terrane of blueschist, greenschist and amphibolite facies) and the Miocene Catalina Pluton, a lower Miocene quartz diorite stock.



Grove and Bebout, 1995

https://keckgeology.org/2017/12/catalinagateway2018/

Friday, August 31

Arrive on the island and proceed to Hermit Gulch Campground via the Tour Plaza. Bonnie B. will meet the group at the boat dock upon arrival, distribute island maps, and give an overview of Avalon's points of interest while en route to the campground. We will briefly stop at the Tour Plaza, the location of Saturday's 7:30 am departure on the Conservancy's Wildlands Express Service, to insure you're familiar with this meeting location.

Hermit Gulch Campground is a ~2.4 km walk from the Catalina Express boat, located in Avalon Canyon near the Nature Center and the Wrigley Memorial and Botanical Gardens. Amenities include coin-operated hot showers (quarters only), BBQ stands, picnic tables, outdoor kitchen sinks, and vending machines. There is a Ranger at the campground.

Friday afternoon activities are on your own. Suggestions for excursions and restaurants are noted on the website below. A recommended hike is directly behind your campsite, the Hermit Gulch Trail, which winds up the mountain to the crest of the island. Once you reach the top of this hike, you're on the Trans Catalina Trail (TCT). You will be hiking in Miocene quartz diorite of the Catalina Pluton, a well exposed unit on the East End of the island, extending to Middle Canyon. This is the "intruded Miocene igneous" rock reference in numerous publications.

https://www.visitcatalinaisland.com/activities-adventures/land/rock-climbing-wall
is the official Santa Catalina Island Company website from which you can navigate to numerous island activities. Pick up a free copy of the Catalina Islander newspaper on the Catalina Express boat for island activity information and restaurant coupons. As this is Labor Day weekend, reservations for activities are highly recommended.

Friday, 4:00 pm, Campground Geology Discussions

In preparation for Saturday's "Geology Day" at the Airport-in-the-Sky and Little Harbor field location stops (see map, front page), please meet at the Campground, 4:00 pm, for an overview of Saturday's field trip, enjoy snacks and beverages, and engage in metamorphic geology discussions.

Please bring your ***geology article of choice*** to share in discussions (noted in the "Packing List"). As Saturday's field trip is interactive, your participation and sharing of geologic insights are appreciated. The more familiar you are with the the formations and their genesis, the more meaningful this field trip will be for you.

Saturday, September 1: Geology at the Airport-in-the-Sky and Little Harbor

Optional trip: cost $20.00/person for Wildlands Express Service, sign-ups required

Bring: daypack, 2 water bottles (water available at airport), lunch (sandwiches/burgers, drinks, etc. available for purchase at the Airport Cafe before we board the Wildlands Express to Little Harbor, or pack a lunch), hand lens, hat, sunscreen, sunglasses, long sleeves/pants for sun protection, closed-toe shoes, sandals, bathing suit, towel, and skin diving equipment. Excellent swimming and diving at Little Harbor. Little Harbor is a remote campground; outhouses and water only. We will bring 3 sun umbrellas as there is little shade. The stop at Little Harbor is 6 hours (11:00am-5:00pm) so don't forget sunscreen and plenty of water. There are excellent hiking trails in this area.

7:15 am meet at the Tour Plaza. This is the location where the island tour buses depart and the area identified Friday on the way to Hermit Gulch Campground. Make your way from the Campground to the Tour Plaza by 6:45 am to insure prompt arrival.

Depart 7:30 am, Wildlands Express Service, Conservancy van
Arrive 8:00 am Airport-in-the-Sky

Airport Loop Trail

Justin Bollum, Airport Manager and Sr. Systems Administrator, Catalina Island Conservancy, will join us and co-lead us on the Airport Loop Trail.

Of particular interest on the Airport Loop trail are the talc schist quarries (aka. steatite [talc], soaprock, soapstone). Talc schists are largely composed of talc, with varying amounts of chlorite and amphiboles (typically tremolite, anthophyllite, cummingtonite, and trace to minor iron-chromium oxides). They may be schistose or massive.

They are formed by the metamorphism of ultramafic protoliths (dunite or serpentinite) and the metasomatism of siliceous dolostones. Talc schists are produced by dynamothermal metamorphism and metasomatism, which occur in subduction zones. By mass, "pure" steatite is roughly 63.37% silica, 31.88% magnesia (MgO), and 4.74% water with minor quantities of other oxides (i.e. CaO or Al2O3).

Steatite (Soapstone) Archaeological Site

Some Native American tribes and bands make bowls, cooking slabs, and other objects from talc. Historically, this was particularly common during the Late Archaic archaeological period (6000-4000 BC). The native people of Catalina Island, the Tongva, lived here for thousands of years and used some of the geologic resources found on the Island. One of their most important trade items was the “olla", a heat resistant cooking pot made from soapstone, an impure form of steatite. The Tongva used quartz to carve bowls from soapstone deposits and would work them into desired shapes and sizes. Very fine-grained steatite was worked into beads, pendants, and pipes. One of these soapstone quarries is visible on our hike today. Informative placards are posted along the trail.

There are three major geologic themes for discussion and examination during the field trip: 1. basement rocks and the subduction history, 2. Neogene volcanic rocks and magmatism in the Inner Borderland Rift, and 3. neotectonics and the major geological processes occurring on the island today. The rocks observed on this field trip and their structural relationships provide important insights into the geologic history of the southern California continental margin that cannot be easily observed elsewhere.

Franciscan-like subduction-related metamorphic rocks (blocks of garnet-bearing blueschist and amphibolite) were recognized on Catalina by the first half of the twentieth century. However, the modern era of Catalina geology began with detailed mapping and a tectonic model by Platt (1975).

The metamorphic rocks of Santa Catalina Island (sometimes referred to as the Catalina Schist) consist of mappable units of dominantly metsedimentary rock that range from lawsonite-blueschist to amphibolite facies, with increasing grade correlated with structural height. Platt’s initial subdivision of the island into blueschist, greenschist, amphibolite, and ultramafic units bounded by shallow dipping thrust faults has been refined, with the “greenschist” unit now defined as epidote amphibolite and epidote blueschist overprinted with greenschist-facies assemblages (Grove and Bebout, 1995).

Selected websites for the Airport Loop Trail
http://www.geotimes.org/june08/article.html?id=Travels0608.html
https://www.catalinaconservancy.org/index.php?s=news&p=article_324
http://www.islapedia.com/index.php?title=Soapstone_Quarry,_Santa_Catalina_Island

https://www.researchgate.net/publication/249552114_Morphology_structure_and_evolution_of_California_Continental_Borderland_restraining_bends/figures?lo=1
Geology and Tectonics of Santa Catalina Island
and the California Continental Borderland
South Coast Geological Society, 2004 Annual Field Trip

Excerpt from the South Coast Geological Society: On the road into the interior from Avalon, we pass through quartz diorite porphyry and some andesite dike swarms on switchbacks going up the steep slopes. The pluton is a hypabyssal igneous body intruded during the early-middle Miocene rifting of the Inner Borderland. The Santa Catalina Island pluton has been described as a bulbous igneous body that approximately doubled in size by intrusion of the dike swarm. The composition of the dikes and pluton is mainly biotite-augite-hornblende quartz diorite. The dikes generally trend northeast, with northwest dips, although local variations may be significant. These dike swarms show that the intrusive mass grew by inflation as extension proceeded and the Catalina Schist basement was exhumed, from about 19-15 Ma based on K-Ar and Ar-Ar ages of igneous rock samples.

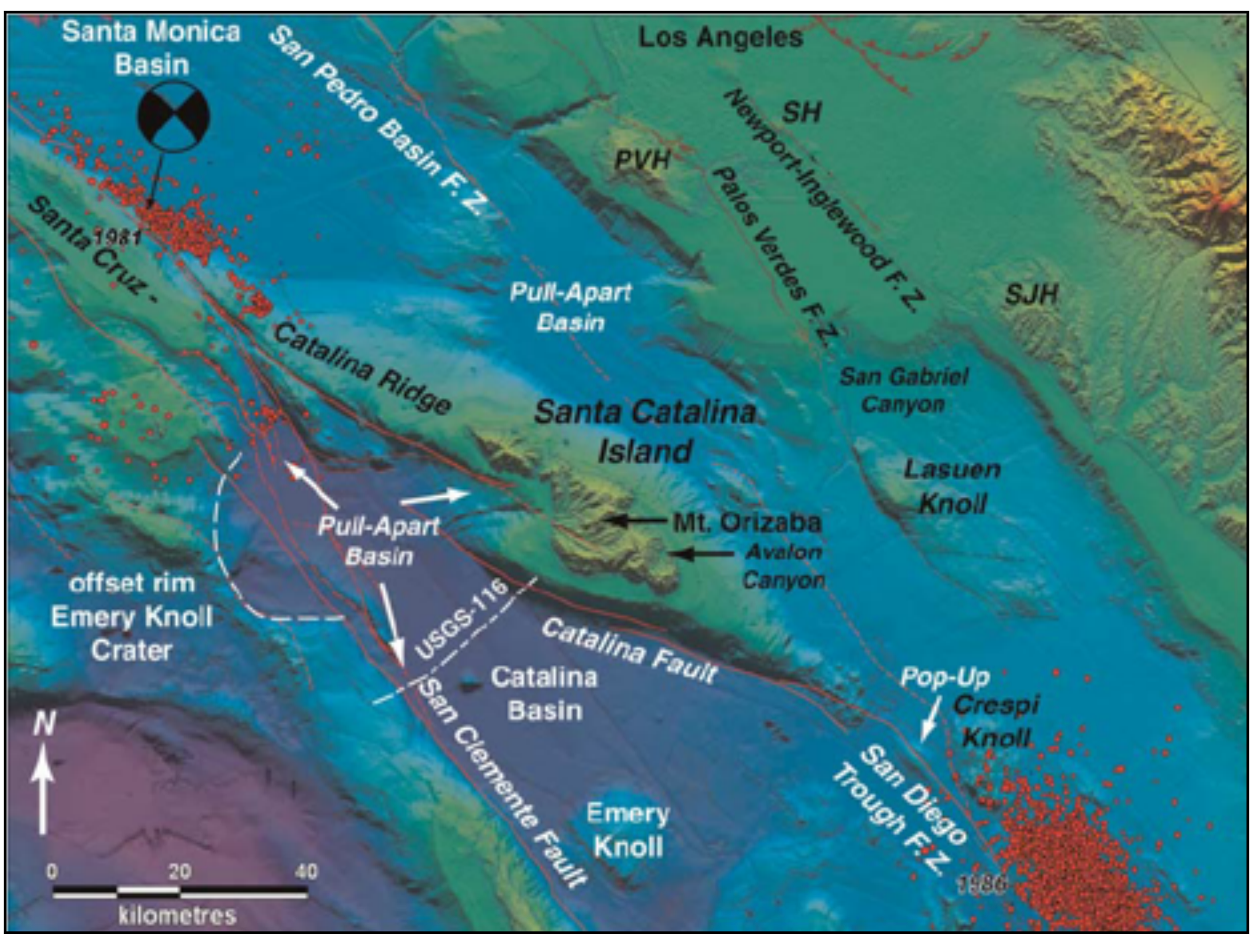
The areal extent of the pluton is comparable to the size of Emery Knoll and the central uplift of Catalina Crater, but does not show the sub-circular outline of the latter features. Seismic imaging shows a deep high velocity root beneath Santa Catalina Island, but lower velocities beneath Emery Knoll. On the road from Toyon Junction to the Airport-in-the-Sky, we cross into a major Miocene volcanic unit, composed primarily of pyroxene andesite flows and flow breccias and subordinate olivine basalt and rhyolite flows. Small basalt dikes, rhyolite dikes, and minor dacite stocks and dikes are also present. Road cuts between the Middle Ranch junction and the Airport provide excellent exposure of some of these volcanic units.

Garnet Amphibolite in Serpentinite Unit

Located a few hundred meters north of the Airport-in-the-Sky, along an older secondary road, two peaks provide exposures of garnet amphibolite and serpentinite. This exposure is within the serpentinite unit of the Catalina Schist and consists of a mélange matrix surrounding large blocks of garnet amphibolite, eclogite, and serpentinite. The underlying amphibolite unit consists largely of a mafic igneous protolith that was converted to mostly hornblende-zoisite schist/gneiss, with minor overlying semipelitic schist and garnet quartzite. The amphibolite unit is in contact with the greenschist unit along the Airport Fault, which is exposed south of the airport.

At the Airport-in-the-Sky, an excellent vista to the mainland coast is available. Large samples of the major rock types found on Santa Catalina Island are placed around the driveway area. The Catalina Island Conservancy has an excellent set of exhibits displaying the natural history and geology of the island. The airport runway is constructed on top of a hill, providing landing excitement, especially if there is a cross-wind. DC-3 aircraft make daily trips to deliver mail and supplies to the island.

Traveling from the Airport-in-the-Sky to Little Harbor, we will pass down through the major metamorphic units of the Catalina Schist, starting with the upper mantle serpentinite unit, followed by the underplated(?) amphibolite unit, then the greenschist and finally the blueschist unit. This sequence represents an inverted metamorphic gradient, with the highest temperature rocks at the top, and the low temperature, but still high pressure (~20-30 km depth), blueschists at the bottom. The contact between the serpentinite and amphibolite units is poorly exposed, but does not seem to be faulted. The contacts between the other units are generally faults and inferred to be thrust faults due to the structural configuration of a former subduction zone. It is possible that some Neogene detachment faulting occurred and high-angle normal faults juxtapose some metamorphic units near the airport.



The fault contacts are difficult to see, especially during the dry season when most outcrops are covered with dust. You may notice, however, that the color of the dust changes from a more red-brown to a more yellow-tan as some contacts are crossed. About half-way to Little Harbor, we pass through Rancho Escondido, where Arabian horses are raised and shown for sale at the arena next to the road. We cross a relatively level ridge line, which may be a true marine terrace, poorly defined, but possible. Some marine fossils have been found in this area, but if dry and dusty, they are difficult to spot.

The bedrock at Little Harbor is composed chiefly of Catalina Schist, (glaucophane schist or blueschist). Large rock outcrops in Little Harbor include many different varieties of metaconglomerate, metagraywacke, and greenstone in a mélange. The seacliffs provide excellent exposure and access, depending on tides, to examine the different metamorphic facies and effects of metasomatism. The rocks are very weak here, however, and subject to large-scale mass wasting. Numerous landslides are evident, and the relatively flat-lying surfaces have been interpreted as wave-cut terraces. Shells and shell debris found on these surfaces originally considered beach deposits are now recognized as midden deposits from a long history of human occupation."

The Catalina greenschist unit is exposed along the Avalon to Airport road in a fault block bounded by the Airport Fault on the west and the North Side Fault on the east. Roadcuts reveal grayschists, quartz schists, and mafic schists. The mafic schists are glaucophanic greenschists. The sodic amphibole crossite occurs as inclusions in epidote or albite porphyroblasts, but only rarely in the matrix of these schists. Most matrix amphiboles are sodic actinolites or barroisites. Crossite evidently crystallized before the relatively more calcic amphiboles (Rowland, et al., 1984).

Depart 10:30 am Airport, Wildlands Express Service
Arrive 11:00 am Little Harbor

Catalina Schist, exposed throughout the western and central parts of the Island, is a Mesozoic metamorphic basement complex, a southward extension of the Franciscan Formation. The highest-grade amphibolite unit from Catalina records peak conditions of 7-12 kbar and 650-750 °C based on cation thermometry and fluid inclusion barometry (Platt, 1975; Sorensen, 1984; Sorensen and Barton, 1987; Sorensen, 1988). The unusually high temperatures and Barrovian-like assemblages of the highest-grade rocks became the basis for the interpretation that the Catalina Schist was formed in a nascent subduction zone. In this model, the amphibolite-facies rocks were formed at the initiation of subduction and recorded high temperatures due to proximity with the hot mantle wedge; the inverted metamorphic gradient of underthrust lower-grade units recorded the subsequent cooling of the trench (Platt, 1975; Cloos,1983; Peacock, 1990).

More recent work on Santa Catalina Island by Jacobson, et al., (2011), suggests that amphibolite facies rocks that recrystallized and partially melted at ca. 115 Ma and at 40 km depth occur atop an inverted metamorphic stack that juxtaposes progressively lower grade, high-pressure/temperature (PT) rocks across low-angle faults. This inverted metamorphic sequence has been regarded as having formed within a newly initiated subduction zone. However, subduction initiation at ca. 115 Ma has been difficult to reconcile with regional geologic relationships, because the Catalina Schist formed well after emplacement of the adjacent Peninsular Ranges batholith had begun in earnest.

New detrital zircon U-Pb age results indicate that the Catalina Schist accreted over a ~20 m.y. interval. The amphibolite unit metasediments formed from latest Neocomian to early Aptian (122-115 Ma) craton-enriched detritus derived mainly from the pre-Cretaceous wall rocks and Early Cretaceous volcanic cover of the Peninsular Ranges batholith. In contrast, lawsonite-blueschist and lower grade rocks derived from Cenomanian sediments dominated by this batholith's plutonic and volcanic detritus were accreted between 97 and 95 Ma. Seismic data and geologic relationships indicate that the Catalina Schist structurally underlies the western margin of the northern Peninsular Ranges batholith. We propose that construction of the Catalina Schist complex involved underthrusting of the Early Cretaceous forearc rocks to a subcrustal position beneath the western Peninsular Ranges batholith (Jacobson, et al., 2011).

Furthermore, a single garnet blueschist block (see photo) found in the blueschist-facies mélange yielded high-error Rb-Sr and Ar-Ar ages of ~150 Ma suggesting that a pre-Catalina subduction zone existed in the region. The age of the garnet blueschist block was firmly established by a 155±8 U-Pb sphene age collected during the 2012 Keck project. However, the P-T history of this key sample remains unconstrained, possibly due to multiple episodes of subduction as the Catalina trench become superimposed on the remnants of a thermally mature subduction zone through subduction erosion (Grove et al., 2008).

Photo: Tectonic block of garnet blueschist in a lawsonite blueschist mélange that may have experienced multiple episodes of subduction metamorphism.

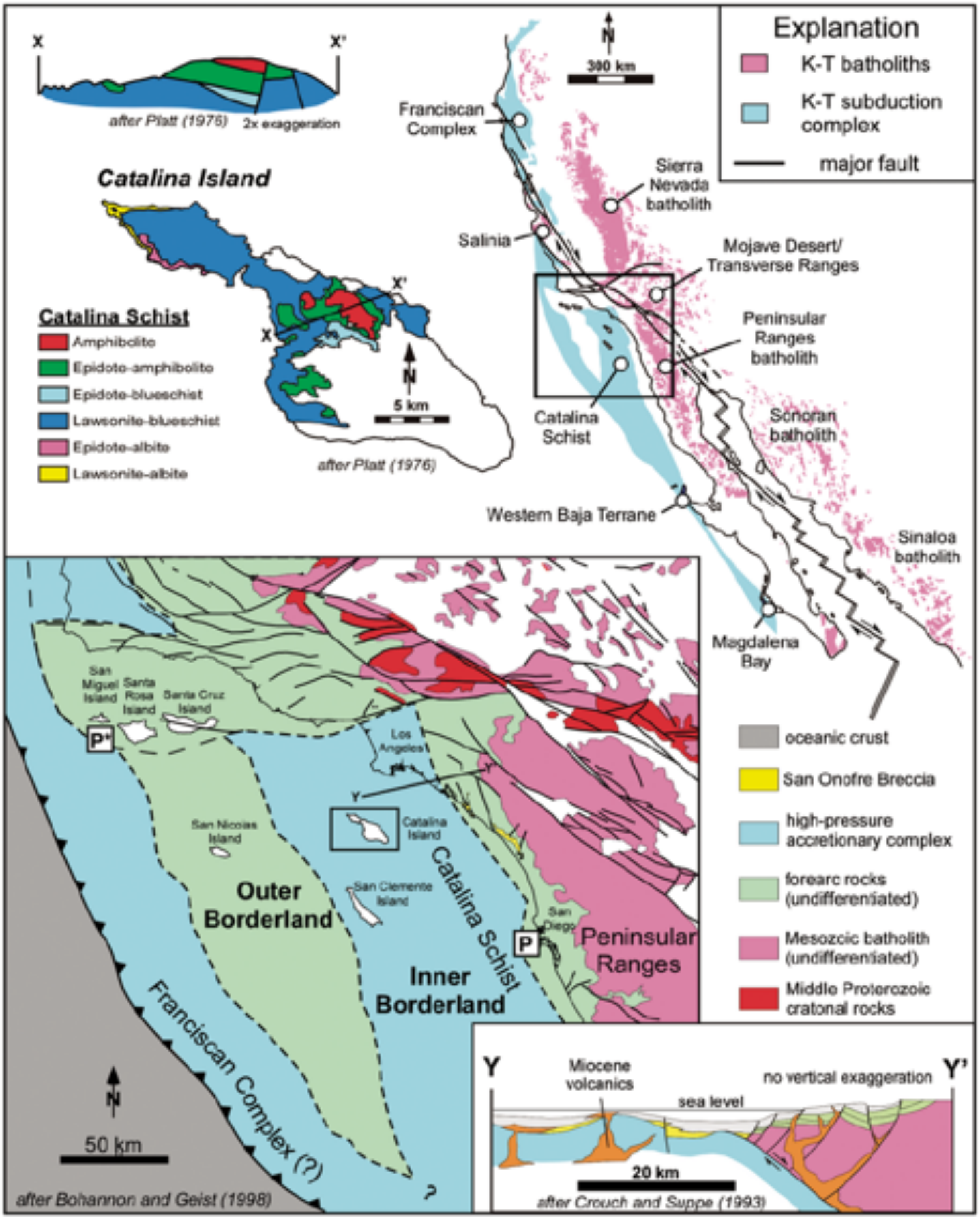
In addition to the quartz diorites of the Catalina Pluton and the Catalina Schist, there are various Miocene volcanic rocks (andesite) that form an exposure that nearly bisects the center of the Island from the channel shore to the windward side from White's Landing to Mount Banning. It is important to note that sedimentary rock is uncommon on the island except for a few deposits of marine limestone on Mount Banning and Twin Peaks, some diatomaceous limestone between Empire Landing and the Isthmus, and some ancient beach deposits above Little Harbor and at a few other locations.

San Onofre Breccia

The most extensive deposits comprised of Catalina Schist detritus are those of the San Onofre Breccia (Woodford,1924; Stuart, 1976). The San Onofre Breccia was named by A. J. Ellis (1919) for a sequence of sedimentary rocks exposed in the San Onofre Mountain area southeast of San Clemente, California. The San Onofre Breccia
became well known because of the excellent work of A. 0. Woodford (1925), who described the primary features that make the formation unusual: 1. the occurrence of massive, poorly sorted breccia beds which contain particles from clay to large boulder size (11 m maximum) and 2. the abundance of blueschist and other metamorphic clasts similar to the basement rocks exposed on Santa Catalina Island. Woodford concluded that the breccias were like alluvial-fan mud flow deposits found in Recent arid and semiarid climates and that the metamorphic clasts were derived from western, now submerged, California Borderland sources.

Although breccia at the East End Quarry is assigned to the San Onofre Breccia unit, rarity of glaucophane schist clasts and abundance of volcanic clasts suggests more similarity to the Blanca Formation of Santa Cruz Island according to Vedder et al.,1979. Clast composition includes quartz schist, amphibolite, actinolite schist, tremolite(?) schist, talc schist, saussuritized gabbro, vein quartz, aphanitic to porphyritic siliceous metavolcanic rocks, porphyritic basalt, and feldspathic sandstone (Vedder et al., 1979).

The breccia appears to be locally derived and includes increasing abundance upsection of dacite clasts from the nearby pluton, so that plutonism and tectonism were synchronous. Vedder et al. (1979) describe fossiliferous Upper Cretaceous(?) remnant forearc sedimentary rocks from the quarry, but today these may be all removed by quarrying.



The San Onofre Breccia, exposed in the California Borderland, is of late Saucesian, Relizian, and possibly Luisian age (stages in the Miocene after Kleinpell, 1939). The breccia contains glaucophane schist and other metamorphic rock types that are unknown in the Peninsular Ranges basement complex but are similar to rocks exposed on Santa Catalina Island (Platt, 1975), and at Palos Verdes. Thus, Woodford (1925) inferred that the San Onofre Breccia was derived from a western source terrane, now nearly all submerged.

The source metamorphic terrane apparently was uplifted as fault blocks, thus the San Onofre Breccia can be used to infer the trend of middle Miocene structures and ultimately to aid in interpretation of the middle Miocene tectonic development of the California Borderland.

The San Onofre Breccia records the uplift of high pressure metamorphic rocks followed by active volcanism during the transition from normal plate convergence to oblique convergence, rotation and extension.

Depart 5:00 pm Little Harbor, Wildlands Express Service
Arrive 6:00 pm Avalon

Dinner, 6:15 pm Antonio's Pizzeria & Cabaret. Upon departing our bus, let's head to Antonio's, a great and less expensive restaurant on the waterfront (230 Crescent Ave.). Even if you don't plan on staying for spaghetti, come join the group for the fun of it. We have reservations. **https://www.catalinachamber.com/visit/antonios-pizzeria-cabaret**

Safari Bus Schedule for On-Your-Own Activities

For those of you not on Saturday's scheduled activity to the Airport-in-the-Sky and Little Harbor, or for those wishing a Sunday /Monday adventure beyond Little Harbor, the Safari Bus, which links the City of Avalon with the village of Two Harbors, including stops at Little Harbor, Airport in the Sky, and the trailhead for Black Jack Junction, is the recommended mode of transportation to other island hiking locations. The Safari Bus is a quick and easy way to navigate Santa Catalina Island. Click "Book a Ride on the Safari Bus" at the site below or call 310-510-4205. The Safari Bus schedule is included below for quick reference and to help plan your time on the island.

https://www.visitcatalinaisland.com/activities-adventures/two-harbors/safari-bus

Two Harbors 8:30 am - Little Harbor 9 am - Two Harbors 9:30 am
Two Harbors 10:30 am - Little Harbor 11 am - Airport 11:30 am - Avalon 12 pm
Avalon 10 am - Airport 10:30 am - Little Harbor 11 am - Two Harbors 11:30 am
Two Harbors 12 pm - Little Harbor 12:30 pm - Two Harbors 1 pm
Two Harbors 2:30 pm - Little Harbor 3 pm - Two Harbors 3:30 pm
Two Harbors 4:30 pm - Little Harbor 5 pm - Airport 5:30 pm - Avalon 6 pm
Avalon 4 pm - Airport 4:30 pm - Little Harbor 5 pm - Two Harbors 5:30 pm
Two Harbors 5:30 pm - Little Harbor 6 pm - Two Harbors 6:30 pm
Two Harbors 8:45 pm - Little Harbor 9:15 pm - Two Harbors 10 pm (Fridays Only)
Depart Avalon 10:00am for Little Harbor; Depart Little Harbor 5:00pm for Avalon
or Depart Avalon 10:00am for Two Harbors; Depart Two Harbors 4:30 for Avalon

* In Avalon, purchase and pick up pre-paid tickets at any Discovery Tours ticket booth. Buses depart from the southeast corner of Island Tour Plaza.

One Way Adult Bus Fares between:
Two Harbors - Little Harbor: $25 Little Harbor - Airport: $16 Airport - Avalon: $16
The Safari Bus is sold in different sections. Two Harbors to Avalon requires Two Harbors - Little Harbor, Little Harbor to Airport and Airport to Avalon.

Sunday, September 2 and Monday, September 3: On Your Own

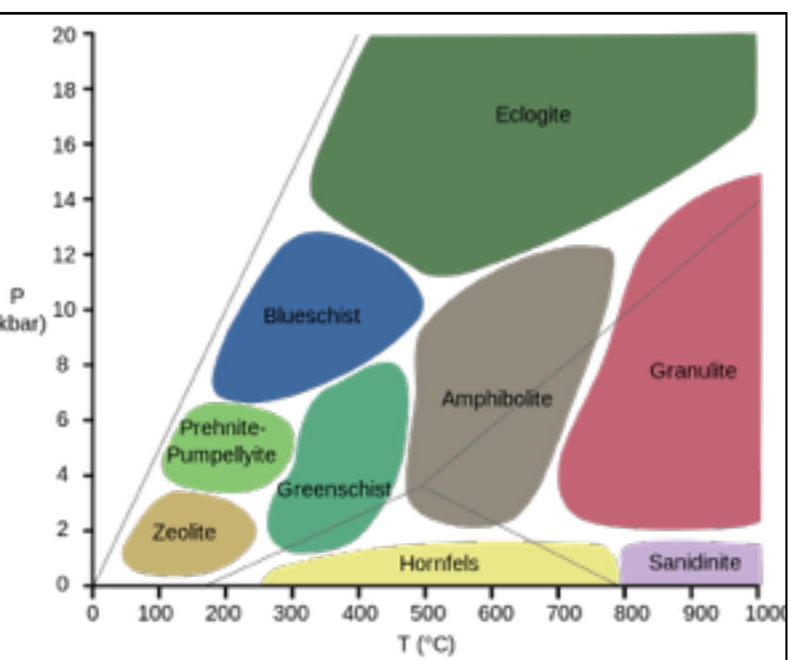
Sunday (1:00-3:00 pm) Optional East End walk. Meet 1:00 pm at Lover's Cove (the pebble beach cove east and directly adjacent to the Catalina Express boat dock) and enjoy a leisure walk to the east end of Avalon, location of the East End Quarry. Although we are unable to visit this quarry (operated by Connolly-Pacific Co.) on our trip due to the holiday weekend, we will have an opportunity to view Miocene rocks that form the majority of the southeastern half of the island (quartz diorite pluton, andesite and dacite extrusive rocks, and a variety of coarse to fine-grained sedimentary rocks). Water, bathrooms, and a restaurant (Buffalo Nickel) are available on this walk. Swimming and snorkeling is excellent along this section of coast (bathing suit and diving equipment are highly recommended).

Suggested Activities for Sunday and Monday

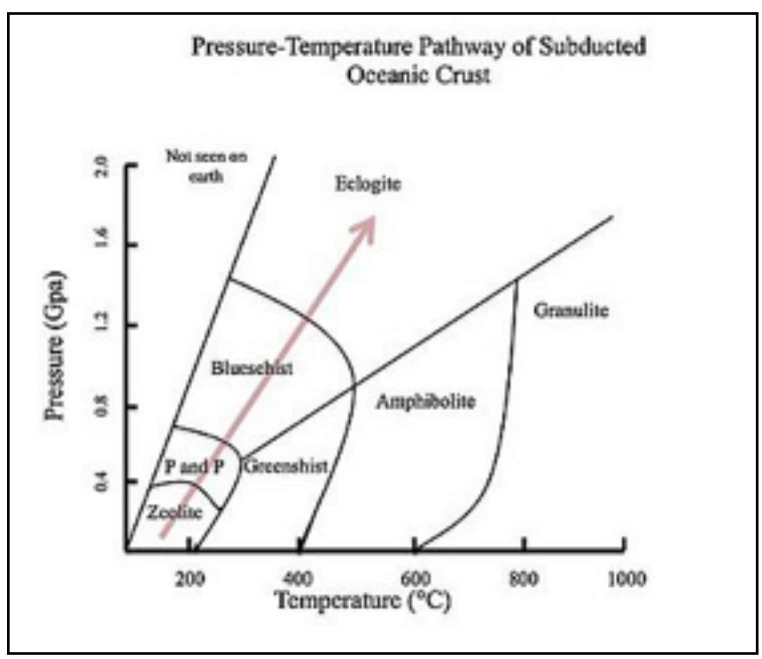
- Visit the Santa Catalina Island Company information kiosk on the Green Pier. Here you can review island activities and book excursions.
- Hike the Trans Catalina Trail (Renton Mine Trail); trailhead on road between Mt. Ada Hotel (home of William Wrigley) and the Edison Electric Company on the eastern end of Avalon. This trailhead will be identified on our Sunday walk to the east end.
- Swim or skin dive at Lover's Cove or the Casino Dive Park (stairs available into the ocean, located at the backside of the Casino).
- Catalina Marathon switchback trail behind chain link fence/gate at Wrigley Memorial (if facing Wrigley Memorial, there is a gate in the chain link fence that leads to the Catalina Marathon trail). Tell Conversancy Ranger at kiosk to the Wrigley Botanical Garden that you're hiking the trail. There is no admission charge to get to this trail.
- Catalina Museum (located just beyond Von's). Casino Tour to the upper balcony.
- Kayaking to Willow Cove. Rent kayaks at Descanso Beach, pack a lunch/water, and head to the West End .
- Hike to Hamilton Cove. Inform guard at the kiosk that you're going to the beach, sign their register, and enjoy the walk to their private cove. Great swimming and skin diving at this beach (bring snacks and water).

—————more recent geologic interpretations —————

As you have now learned from your readings and group discussions, on Santa Catalina Island, calcium high-grade amphibolite units overlie progressively lower grade blueschist units in an inverted stack structure. This juxtaposition of high grade and low-grade metamorphic units has long been the subject of much debate as to the tectonic origins of the formation and how it relates to California's tectonic evolution (Towbin, W. H., 2013).



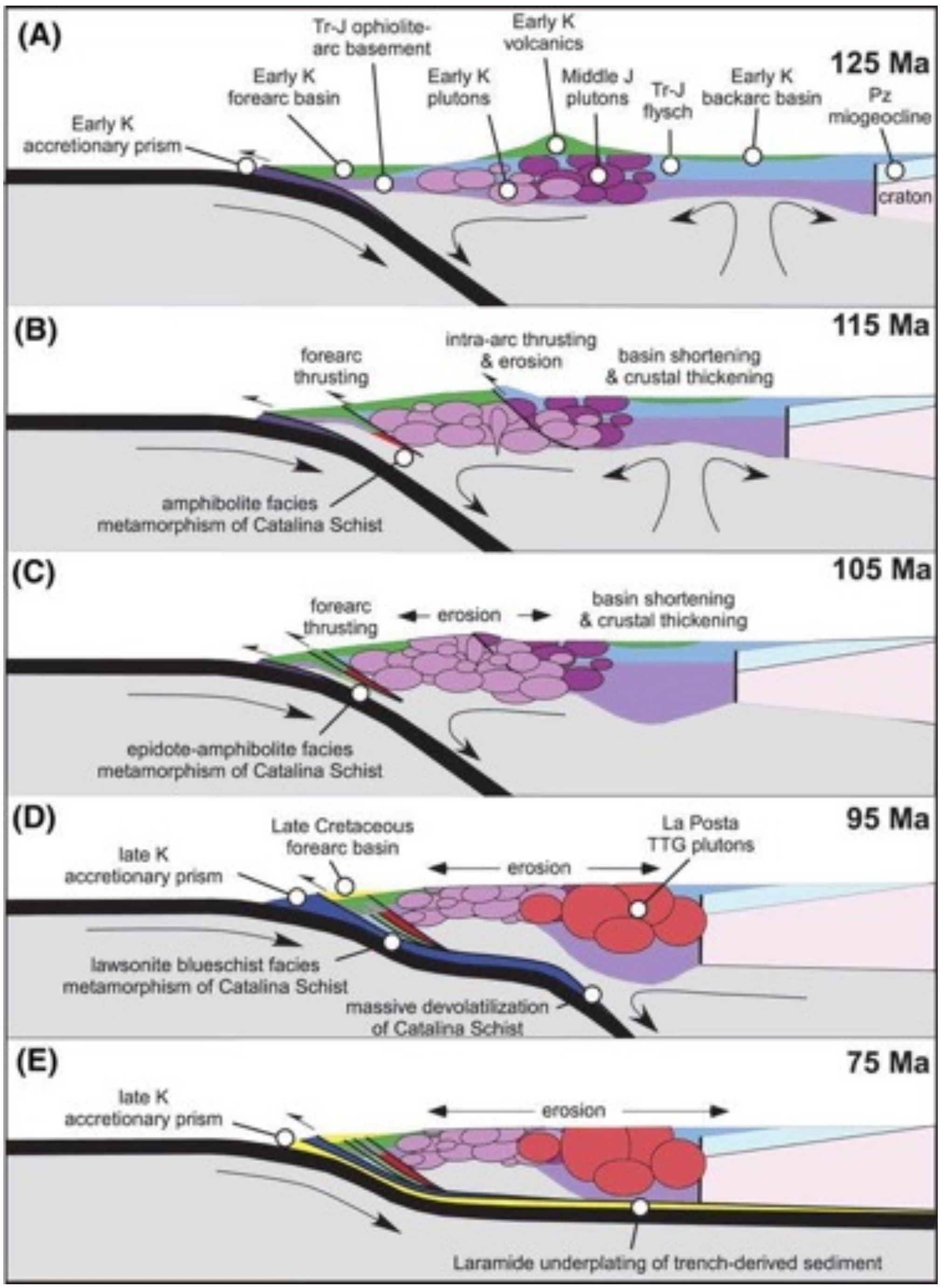
Graph of metamorphic facies temperature and pressure ranges



Previous petrography and thermobarometry of blocks in the amphibolite unit estimate pressures and temperatures of ~8-11 kbar and ~640-750 °C (Platt, 1975; Sorensen and Barton 1987). These estimates were calculated before many of the computational advances in modern thermobarometry.

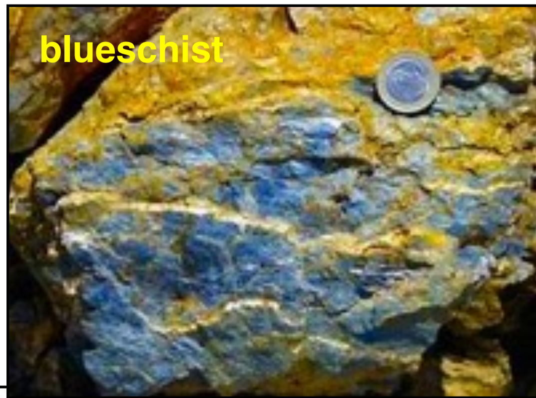
Using Equilibrium Assemblage Diagrams (EAD) calculated with Theriak Domino, estimates the peak of metamorphism at temperatures between 700 °C and 750 °C and pressures above 15kbar. Interpretation of textural features from a clinopyroxene bearing block previously studied by Sorensen (1988) and Sorensen and Grossman (1989) suggest the sample followed a near isothermal decompression path from 50km to 21 km of depth. EAD analysis also provides additional support for claims that large metamafic blocks in the Amphibolite unit melange were residual of Fe-Ti rich mafic rocks after extraction of an albite rich partial melt (Grove et al., 2008).

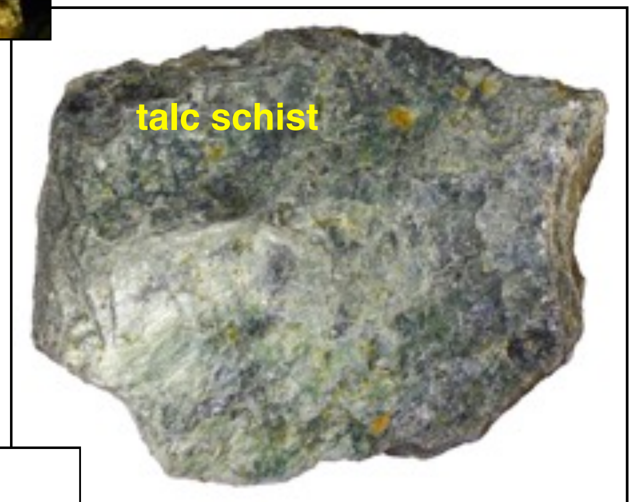
Greenschist-like rocks can also be formed under blueschist facies conditions if the original rock (protolith) contains enough magnesium. This explains the scarcity of blueschist preserved from before the Neoproterozoic Era 1000 Ma ago when the Earth's oceanic crust contained more magnesium than today's oceanic crust.



Tectonic Model for the formation of the Catalina Schist (Grove et al., 2008).

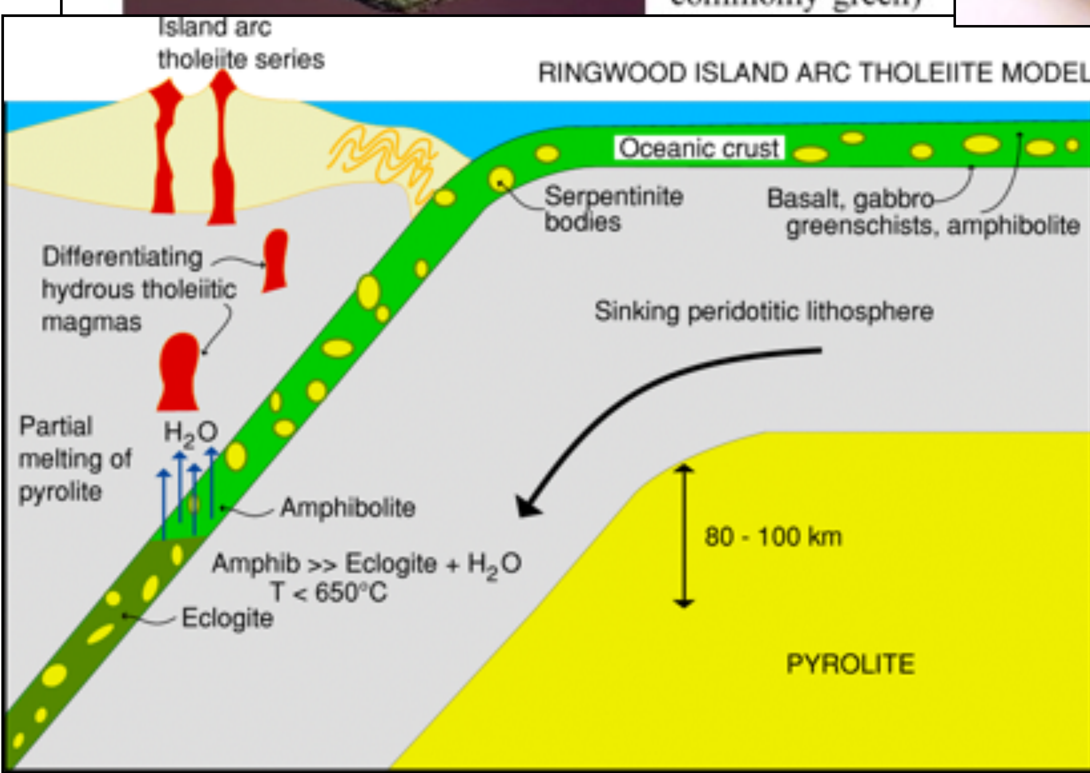
(A) Describes the Early Cretaceous convergent margin associated with the Peninsular Ranges Batholith. (B) Forearc basin underthrusts the Peninsular Range Batholith and metamorphoses forming the amphibolite.





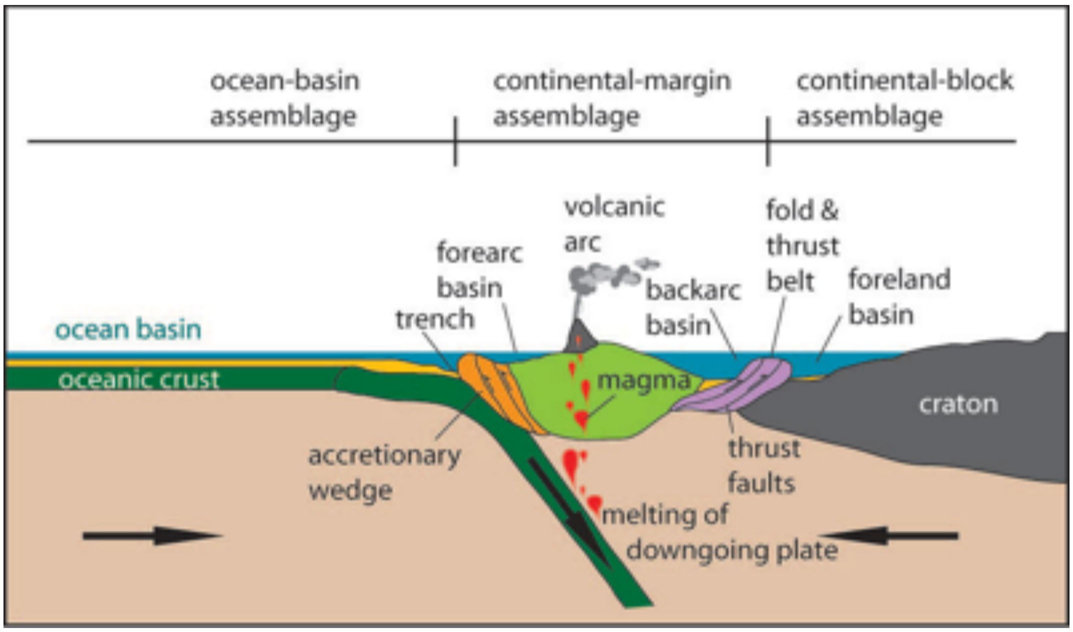
Greenschist –

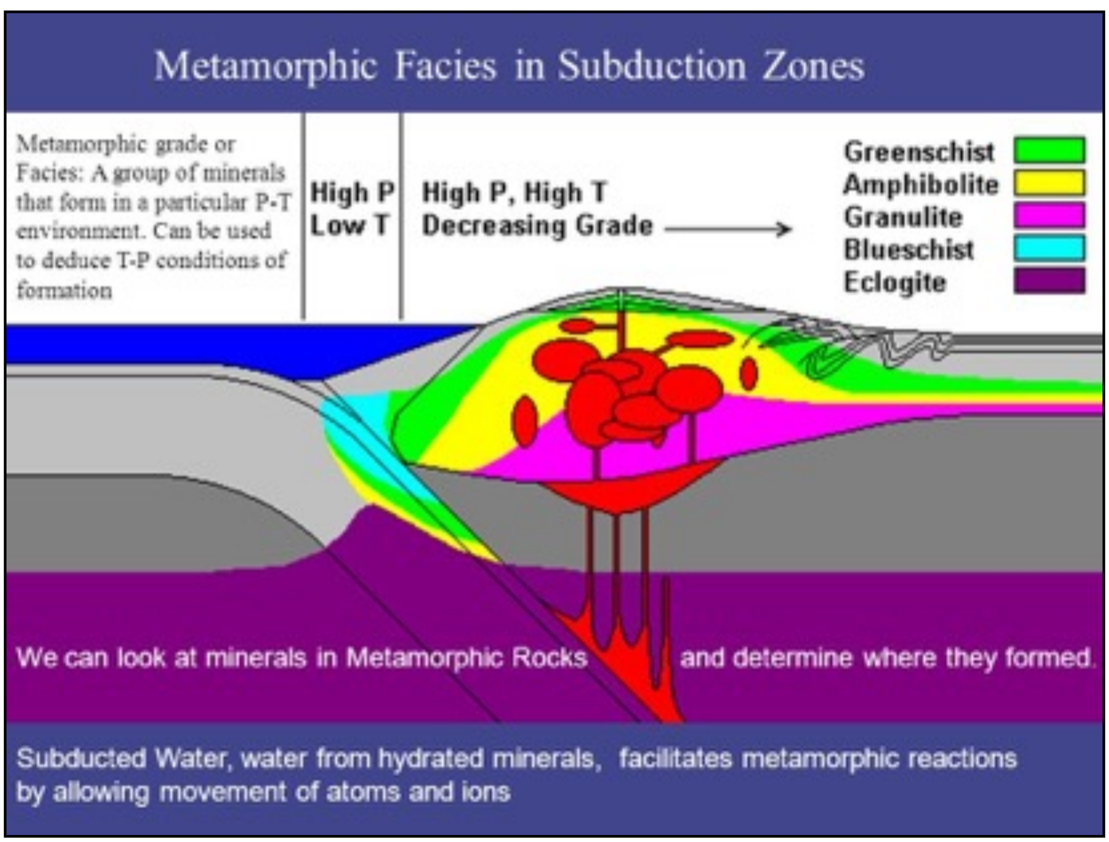
Olivine, pyroxene, and plagioclase in an original basalt change to amphiboles and chlorite (both commonly green)



epidote amphibolite


"greenschist"
"blueschist"


ocean-basin assemblage
continental-margin assemblage
continental-block assemblage
volcanic arc
fold & thrust belt
forearc basin
backarc basin
foreland basin
trench
ocean basin
oceanic crust
magma
craton
accretionary wedge
thrust faults
melting of downgoing plate


Metamorphic Facies in Subduction Zones
Metamorphic grade or Facies: A group of minerals that form in a particular P-T environment. Can be used to deduce T-P conditions of formation
High P Low T
High P, High T Decreasing Grade
Greenschist
Amphibolite
Granulite
Blueschist
Eclogite
We can look at minerals in Metamorphic Rocks and determine where they formed.
Subducted Water, water from hydrated minerals, facilitates metamorphic reactions by allowing movement of atoms and ions

Glossary

1. **Albite** - is a plagioclase feldspar mineral. It is the sodium endmember of the plagioclase solid solution series. As such it represents a plagioclase with less than 10% anorthite content. The pure albite end member has the formula $NaAlSi_3O_8$. It is a tectosilicate. Its color is usually pure white, hence its name from Latin *albus*.[4] It is a common constituent in felsic rocks. It occurs in granitic and pegmatite masses, in some hydrothermal vein deposits and forms part of the typical greenschist metamorphic facies for rocks of originally basaltic composition. NaAlSi3O8 or Na1.0–0.9Ca0.0–0.1Al1.0–1.1Si3.0–2.9O8

2. **Amphibolite** - Amphibolite is a grouping of rocks composed mainly of amphibole and plagioclase feldspars, with little or no quartz. It is typically dark-colored and heavy, with a weakly foliated or schistose structure. Amphibolites need not be derived from metamorphosed mafic rocks. Because metamorphism creates minerals entirely based upon the chemistry of the protolith, certain 'dirty marls' and volcanic sediments may actually metamorphose to an amphibolite assemblage. Amphibolites define a particular set of temperature and pressure conditions known as the *amphibolite facies*.

3. **Blueschist** - also called glaucophane schist, is a metavolcanic rock[1] that forms by the metamorphism of basalt and rocks with similar composition at high pressures and low temperatures (200 to ~500 degrees Celsius), approximately corresponding to a depth of 15 to 30 kilometers. The blue color of the rock comes from the presence of the predominant minerals glaucophane and lawsonite. Blueschists are typically found within orogenic belts as terranes of lithology in faulted contact with greenschist or rarely eclogite facies rocks. Blueschist often has a lepidoblastic, nematoblastic or schistose rock microstructure defined primarily by chlorite, phengitic white mica, glaucophane, and other minerals with an elongate or platy shape. Blueschist facies is determined by the particular temperature and pressure conditions required to metamorphose basalt to form blueschist. Felsic rocks and pelitic sediments which are subjected to blueschist facies conditions will form different mineral assemblages than metamorphosed basalt. Continued subduction of blueschist facies oceanic crust will produce eclogite facies assemblages in metamorphosed basalt (garnet + omphacitic clinopyroxene). Rocks which have been subjected to blueschist conditions during a prograde trajectory will gain heat by conduction with hotter lower crustal rocks if they remain at the 15–18 km depth. Blueschist which heats up to greater than 500 °C via this fashion will enter greenschist or eclogite facies temperature-pressure conditions, and the mineral assemblages will metamorphose to reflect the new facies conditions.

4. **Catalina Schist** - The Catalina Schist is a metamorphic rock complex primarily exposed on Santa Catalina Island of the Channel Islands of California. It formed during the Cretaceous Period of the Mesozoic Era. The Catalina Schist is broadly correlated with the Franciscan Complex, a similar metamorphic complex formed along the California margin.[1] Both of these units record high-pressure/low-temperature metamorphism associated with the subduction of the Farallon plate beneath North America during the Mesozoic Era. The Catalina Schist is differentiated from the Franciscan primarily in the style of mélange formed during subduction. In the Los Angeles Harbor Region, Catalina Schist is associated with the Wilmington Oil Field.

5. **Chlorite Schist** - Chlorite schist, a type of greenschist.It is a general field petrologic term for metamorphic or altered mafic volcanic rock. A greenstone is sometimes a greenschist but can also be rock types without any schistosity, especially metabasalt (spilite or picrite). The green is due to abundant green chlorite, actinolite and epidote minerals that dominate the rock. However, basalts may remain quite black if primary pyroxene does not revert to chlorite or actinolite. To qualify for the name a rock must also exhibit schistosity or some foliation or layering. The rock is derived from basalt, gabbro or similar rocks containing sodium-rich plagioclase feldspar, chlorite, epidote and quartz

6. **Clinopyroxene** -The pyroxenes (commonly abbreviated to Px) are a group of important rock-forming inosilicate minerals found in many igneous and metamorphic rocks. Pyroxenes have the general formula is XY(Si,Al)2O6 where X represents calcium, sodium, iron (II) or magnesium and more rarely zinc, manganese or lithium and Y represents ions of smaller size, such as chromium, aluminium, iron (III), magnesium, cobalt, manganese, scandium, titanium, vanadium or even iron (II). Although aluminium substitutes extensively for silicon in silicates such as feldspars and amphiboles, the substitution occurs only to a limited extent in most pyroxenes. They share a common structure consisting of single chains of silica tetrahedra. Pyroxenes that

crystallize in the monoclinic system are known as clinopyroxenes and those that cystallize in the orthorhombic system are known as orthopyroxenes. The name pyroxene is derived from the Ancient Greek words for fire (πυρ) and stranger (ξένος). Pyroxenes were so named because of their presence in volcanic lavas, where they are sometimes seen as crystals embedded in volcanic glass; it was assumed they were impurities in the glass, hence the name "fire strangers". However, they are simply early-forming minerals that crystallized before the lava erupted. Decompression path - "The EAD shows these coronas did not form in a single reaction but at separate points along the decompression path. As pressures fell below 15 kbar, hornblende could have formed as a reaction between clinopyroxene, garnet and water"

7. **Epidote** - Epidote is an abundant rock-forming mineral, but one of secondary origin. It occurs in marble and schistose rocks of metamorphic origin. It is also a product of hydrothermal alteration of various minerals (feldspars, micas, pyroxenes, amphiboles, garnets, and others) composing igneous rocks. Well developed crystals of epidote, Ca2Al2(Fe3+;Al)(SiO4)(Si2O7)O(OH), crystallizing in the monoclinic system, are of frequent occurrence: they are commonly prismatic in habit, the direction of elongation being perpendicular to the single plane of symmetry.

8. **Equilibrium Assemblage Diagrams (EAD)** - composition specific diagrams are called equilibrium assemblage diagrams(EAD) also known as pseudosections (de Capitani and Petrakakis, 2010; Powell and Holland, 2008). EADs now allow geologists to use the bulk rock chemical composition as an additional constraint on the range of mineral reactions considered in P–T calculations. In EAD modeling,the whole rock must be in equilibrium.

9. **Flysch** - is a sequence of sedimentary rock layers that progress from deep-water and turbidity flow deposits to shallow-water shales and sandstones. It is deposited when a deep basin forms rapidly on the continental side of a mountain building episode. Flysch consists of repeated sedimentary cycles with upwards fining of the sediments. At the bottom of each cycle are sometimes coarse conglomerates or breccias, which gradually evolve upwards into sandstone and shale/mudstone. Flysch typically consists of a sequence of shales rhythmically interbedded with thin, hard, graywacke-like sandstones. Typically the shales do not contain many fossils, the coarser sandstones often have fractions of micas and glauconite.

10. **Greenschist** - Greenschists are metamorphic rocks that formed under the lowest temperatures and pressures usually produced by regional metamorphism, typically 300–450 °C (570–840 °F) and 2–10 kilobars (14,500–58,000 psi). Greenschists commonly have an abundance of green minerals such as chlorite, serpentine, and epidote, and platy minerals such as muscovite and platy serpentine.[1] The platiness causes the tendency to split, or have schistosity. Other common minerals include quartz, orthoclase, talc, carbonate minerals and amphibole (actinolite).

11. **Greenschist Facies** - Greenschist facies is determined by the particular temperature and pressure conditions required to metamorphose basalt to form the typical greenschist facies minerals chlorite, actinolite, and albite. Greenschist facies results from low temperature, moderate pressure metamorphism. Metamorphic conditions which create typical greenschist facies assemblages are called the Barrovian Facies Sequence, and the lower-pressure Abukuma Facies Series. Temperatures of approximately 400 to 500 °C (750 to 930 °F) and depths of about 8 to 50 kilometres (5 to 31 miles) are the typical envelope of greenschist facies rocks. he equilibrium mineral assemblage of rocks subjected to greenschist facies conditions depends on primary rock composition. **Basalt:** chlorite + actinolite + albite +/- epidote; **Ultramafic:** chlorite + serpentine +/- talc +/- tremolite +/- diopside +/- brucite; **Pelites:** quartz +/- albite +/- k-feldspar +/- chlorite, muscovite, garnet, pyrophyllite +/- graphite; **Calc-silicates:** calcite +/- dolomite +/- quartz +/- micas, scapolite, wollastonite, etc.

12. **Prasinite** is a variety of greenschist (Mont-Cenis massif, French Alps)

13. **Lawsonite-blueschist** - "The lowest grade materials, the lawsonite-blueschist and lawsonite-albite formations, formed much later (~95 M.a.)in thermal conditions consistent with a subduction zone and were then juxtaposed with the rest of the Catalina complex after the intervening sediments were removed by subduction erosion (Grove et al., 2008)

14. **Mélange** - In geology, a mélange is a large-scale breccia, a mappable body of rock characterized by a lack of continuous bedding and the inclusion of fragments of rock of all sizes, contained in a fine-grained deformed matrix. The mélange typically consists of a jumble of large blocks of varied lithologies. Large-scale melanges formed in active continental margin settings generally consist of altered oceanic crustal material and blocks of continental slope sediments in a sheared mudstone matrix. The mixing mechanisms in such settings may

include tectonic shearing forces, ductile flow of a water-charged or deformable matrix (such as serpentinite), sedimentary action (such as slumping, gravity-flow, and olistostromal action), or some combination of these. Some larger blocks of rock may be as much as 1 kilometre (0.62 mi) across. Smaller-scale localized mélanges may also occur in shear or fault zones, where coherent rock has been disrupted and mixed by shearing forces. Examples include the Franciscan Formation along the Coast Ranges of central and northern California. Before the advent of plate tectonics in the early 1970s, it was difficult to explain mélanges in terms of known geological mechanisms. A particularly troubling paradox was the occurrence of blueschist blocks (low temperature and high pressure metamorphic rocks) in direct contact with graywacke (a coarse sandstone with lithic fragments) that was deposited in a sedimentary environment. Mélange occurrences are associated with thrust faulted terranes in orogenic belts. A mélange is formed in the accretionary wedge above a subduction zone. The ultramafic ophiolite sequences which have been obducted onto continental crust are typically underlain by a mélange. Both tectonic and sedimentary processes can form mélange. Olistostromes are mélanges formed by gravitational sliding under water, with accumulation of the flow as a semi fluid body without bedding planes.

15. **Metasedimentary Rock** - type of metamorphic rock first formed through the deposition and solidification of sediment. After burial, the rock is subjected to high pressures and temperatures, causing the rock to recrystallize. The overall composition of a metasedimentary rock can be used to identify the original sedimentary rock, even where they have been subject to high-grade metamorphism and intense deformation. *Franciscan complex:* Cretaceous and Jurassic sandstone with smaller amounts of shale, chert, limestone, and conglomerate. Includes Franciscan melange, except where separated--see KJfm. *Name:* Franciscan Complex, unit 2 (Southern California); *Geologic Age:* late Early to early Late Cretaceous; *Lithologic constituents:* Major Metamorphic > Metasedimentary (Blueschist). Includes metamorphosed sandstone, shale, conglomerate, and chert. Some of these rocks form blocks in a blueschist-matrix melange; Metamorphic > Schist (Blueschist); Comments Southwestern California (**Santa Catalina Island**, Palos Verdes Hills). Blueschist-grade metamorphic rocks more thoroughly recrystallized than most Franciscan rocks; ***Stratigraphic units:*** **Catalina Schist**

16. **Metasomatism** - Metasomatism is the chemical alteration of a rock by hydrothermal and other fluids. It is the replacement of one rock by another of different mineralogical and chemical composition. The minerals which compose the rocks are dissolved and new mineral formations are deposited in their place. Dissolution and deposition occur simultaneously and the rock remains solid.The term metamorphism refers to changes in a rock's mineral compositions where the geochemical composition stays mostly the same with the exception of volatile losses (usually water is expelled or at least necessary as an intermediary to enable any sort of reaction to take place). Metasomatism can occur via the action of hydrothermal fluids from an igneous or metamorphic source. In the metamorphic environment, metasomatism is created by mass transfer from a volume of metamorphic rock at higher stress and temperature into a zone with lower stress and temperature, with metamorphic hydrothermal solutions acting as a solvent. This can be envisaged as the metamorphic rocks within the deep crust losing fluids and dissolved mineral components as hydrous minerals break down, with this fluid percolating up into the shallow levels of the crust to chemically change and alter these rocks. ***Metasomatism*** or (hydrothermal) alteration refers to changing a rock's composition in an open system, i.e. a system where mass can enter and leave, not just volatiles but also refractory elements. Usually one would be looking at some form of water with dissolved components passing through a rock, dissolving some elements and precipitating others. The extent to which elements have been lost or gained can be estimated by using a mass balance approach if the original, unaltered rock composition can be estimated.

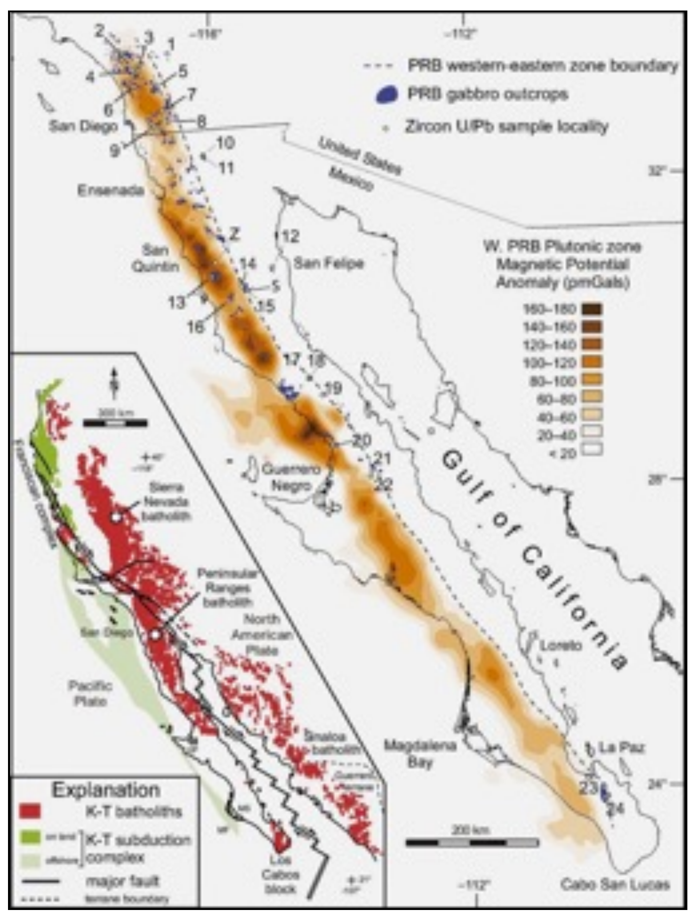
17. **Migmatite** - Migmatite is a rock that is a mixture of metamorphic rock and igneous rock. It is created when a metamorphic rock such as gneiss partially melts, and then that melt recrystallizes into an igneous rock, creating a mixture of the unmelted metamorphic part with the recrystallized igneous part. They can also be known as diatexite. Migmatites form under extreme temperature conditions during prograde metamorphism, where partial melting occurs in pre-existing rocks. Migmatites are not crystallized from a totally molten material, and are not generally the result of solid-state reactions. Commonly, migmatites occur within extremely deformed rocks that represent the base of eroded mountain chains, typically within Precambrian cratonic blocks. Migmatites often appear as tightly, incoherently folded (ptygmatic folds) dikelets, veins and segregations of light-colored granitic composition called leucosome, within dark-colored amphibole and biotite rich material called the melanosome. If present, the mesosome, intermediate in color between a leucosome and melanosome, is mostly a more or less unmodified remnant of the original parent rock (protolith). The light-colored material has the appearance of having been mobilized or molten.

18. **Migmatization (ultrametamorphism) -** is a kind of geological process and diagenesis between the metamorphism and magmatism with the greatest characteristic of partial remelting and diverse fluid. Melted felsic component and refractory component act and mix with each other under new conditions to form the rocks with different compositions and shapes, generally called migmatite. The migmatite usually comprises matrix and vein. The matrix refers to the residual dark refractory iron and magnesium metamorphic rock in the mixing process, including regional metamorphic rocks of gneiss, amphibolite, and leptynite; the vein refers to the fine crystalline parts of fluid entering the matrix during the mixing process, including felsite, granite, and pegmatite. According to the proportion of matrix and vein content, alternation intensity in the matrix, migmatite structure, and material composition of matrix and vein, the migmatite can be divided into injection migmatite, migmatite gneiss, and migmatite granite. According to the structure type, the migmatite is further divided into breccia migmatite, augen migmatite, reticular migmatite, band migmatite, and ptygmatic.

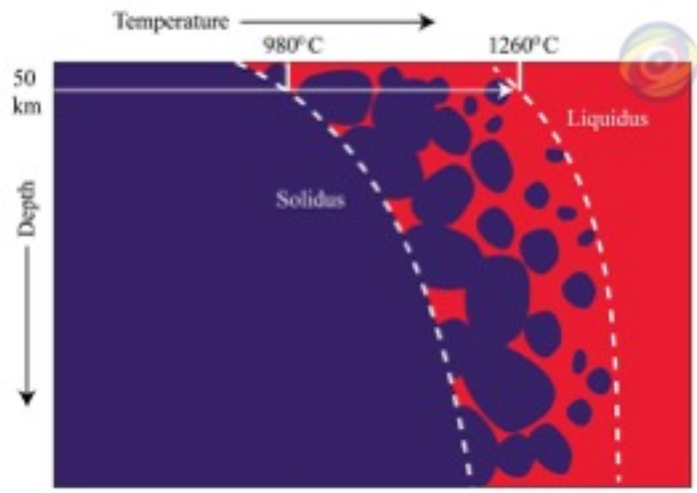
19. **MORB - Mid-Ocean Ridge Basalt** - A type of tholeiitic basalt (see tholeiitic magma series; this glossary), erupted from mid-ocean-ridge constructive-plate margins; it is one of the most abundant of all rocks and covers much of the Earth's surface. It is characterized by very low concentrations of K2O and TiO2; low iron, P2O5, Ba, Rb, Sr, Pb, Th, U, and Zr; and high CaO. When the concentration of each rare-earth element in the basalt is divided by its mean concentration in chondrite meteorites (a standard for comparison), this type of basalt shows a progressive lowering of the ratios for the light rare-earth elements (LREEs), compared to the ratios for the heavy rare-earth elements (HREEs). MORB is said to be LREE depleted, a reflection of the chemically depleted nature of the mantle source regions from which they are derived. Since leaving their source region in the mantle, these basalts, often termed low-potassium tholeiites, have not been contaminated by passing through any continental crust and therefore retain the chemical signature of the mantle from which they were derived. MORBs thus provide an insight into the composition of the sub-oceanic mantle. Oceanic crust and ophiolites. The oceanic crust (made of basalts) is formed on mid-ocean ridges. MORB = Mid-Ocean Ridge Basalt. This is the main site of volcanic activity on Earth, and the most abundant igneous rock! But most of it is underwater…Occasionally, slivers of oceanic crust are tectonically emplaced on continents (in convergence zone): ophiolites. They occur in early convergence stages (“obduction”, ex. in Oman), and are subsequently deformed and metamorphosed (typically to blueschists) in collision wedges (peri-Tethyan orogeny, from the Alps to Himalaya). Most of the ophiolites belong to the peri-tethyan system.

20. **Nappe** - or thrust sheet is a large sheetlike body of rock that has been moved more than 2 km (1.2 mi) or 5 km (3.1 mi) above a thrust fault from its original position. Nappes form in compressional tectonic settings like continental collision zones or on the overriding plate in active subduction zones. Nappes form when a mass of rock is forced (or "thrust") over another rock mass, typically on a low angle fault plane. The resulting structure may include large-scale recumbent folds, shearing along the fault plane, imbricate thrust stacks, fensters and klippe. The term stems from the French word for tablecloth in allusion to a rumpled tablecloth being pushed across a table.

21. **Peninsular Ranges Batholith** - The Peninsular Ranges (aka. Lower California province) are a group of mountain ranges that stretch 1,500 km (930 mi) from Southern California to the southern tip of the Baja California Peninsula; they are part of the North American Coast Ranges, which run along the Pacific Coast from Alaska to Mexico. Elevations range from 500 to 10,834 feet (152 to 3,302 m). The Peninsular Ranges include the Santa Ana Mountains, Temescal and other mountains and ranges of the Perris Block, San Jacinto and Laguna ranges of southern California continuing from north to south with the Sierra de Juarez, Sierra San Pedro Mártir, Sierra de San Borja. Sierra San Francisco, Sierra de la Giganta, and Sierra de la Laguna in Baja California. The Peninsular ranges run predominantly north-south, unlike the Transverse Ranges to their north, which mostly run east-west.



22. **Solidus** - the solidus is the locus of temperatures (a curve on a phase diagram) below which a given substance is completely solid (crystallized). The solidus is applied, among other materials, to metal alloys, ceramics, and natural rocks and minerals. *Figure: Schematic diagram of solidus and liquidus temperature of a rock.* Dark blue color indicates solid rock, red color indicates molten rock. At a certain depth, with increasing temperature, rock starts to melt. The first melt appears at solidus temperature. Then amount of solid portion reduces gradually with more temperature. The rock completely melts at liquidus. Beyond liquidus, not a single solid crystal exists.



23. **Thermobarometry** - aims to identify the pressure and temperature conditions at which a certain rock formed based on its mineral assemblage and mineral compositions. Thermodynamic parameters include enthalpy, entropy, and molar volume. Thermobarometry of metamorphic rocks is an important tool in evaluating tectonic histories of a rock unit.

24. **Tholeiitic Magma Series** - The tholeiitic magma series, named after the German municipality of Tholey, is one of two main magma series in igneous rocks, the other being the calc-alkaline series. A magma series is a chemically distinct range of magma compositions that describes the evolution of a mafic magma into a more evolved, silica rich end member. The International Union of Geological Sciences recommends that tholeiitic basalt be used in preference to the term "tholeiite".

25. **Ultramafic** - Ultramafic (also referred to as ultrabasic rocks, although the terms are not wholly equivalent) are igneous and meta-igneous rocks with a very low silica content (less than 45%), generally >18% MgO, high FeO, low potassium, and are composed of usually greater than 90% mafic minerals (dark colored, high magnesium and iron content). The Earth's mantle is composed of ultramafic rocks. Ultrabasic is a more inclusive term that includes igneous rocks with low silica content that may not be extremely enriched in Fe and Mg, such as carbonatites and ultrapotassic igneous rocks. *Metamorphic ultramafic rocks:* Metamorphism of ultramafic rocks in the presence of water and/or carbon dioxide results in two main classes of metamorphic ultramafic rock; talc carbonate and serpentinite. Talc carbonation reactions occur in ultramafic rocks at lower greenschist through to granulite facies metamorphism when the rock in question is subjected to metamorphism and the metamorphic fluid has more than 10% molar proportion of CO_2 (carbon dioxide). When such metamorphic fluids have less than 10% molar proportion of CO_2, reactions favor serpentinisation, resulting in chlorite-serpentine-amphibole type assemblages.

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Selected Abstracts and Websites

Catalina Island Conservancy https://www.catalinaconservancy.org/index.php?s=news&p=article_322

Preliminary results of marine paleo-seismology from MCS, CHIRP, and coring off Catalina Island. Ethan F. Williams, Christopher M. Castillo, Simon L. Klemperer, Kate Maher, Robert D. Francis, & Mark R. Legg https://www.scec.org/publication/6095

Abstract: Submerged paleo-shorelines around Catalina Island record information about the paleo-seismicity and evolving morphology of the Channel Islands, and provide constraints on Quaternary sea-level history of Southern California. We acquired high-resolution uniboom seismic data in 2014 across these paleo-shorelines and intervening marine terraces, with a particular focus on the Long Point Fault, a strike-slip fault subparallel to the San Andreas system. Each terrace corresponds to a low-stand in the
Quaternary sea-level curve and can be used as paleo-horizontal datum for constraining the ages of Quaternary tsunamogenic landslides and major vertical offset on the Long Point Fault. Determining the age of the terraces is essential to understanding the slip history of the Long Point Fault and the potential for future tsunamogenic landslides. Radiometric dates are necessary to refine our sequence-stratigraphic interpretation and constrain terrace-cutting events. Our SCEC-funded coring cruise off Catalina Island was conducted in June 2015 to retrieve dateable material from subsided terraces. We used high-resolution MCS and CHIRP data to locate outcrops of terrace deposits, which we then sampled using a gravity core and grab sampler while simultaneously running CHIRP to ensure that we successfully hit our target. Samples include carbonate-rich sands from depths of

32-350m bsl, and wave-rounded cobbles >8.75 km offshore at depths of >250 m bsl. At the time of writing, corals and mollusks recovered from the cores are undergoing U-series dating at the Stanford University ICP-MS/TIMS Facility and 418O measurements at the Stanford University Stable Isotope Biogeochemistry Lab. Further samples have been sent to Lawrence Livermore National Labs for radiocarbon dating through their SCEC partnership. Preliminary results from our SCEC cruise were used to motivate and guide two successful ROV dives off Catalina Island by the E/V Nautilus in August 2015. The dives yielded samples from outcrops of terrace deposits as well as high-definition video of these submarine features, and the fault-scarp of the Santa Cruz-Catalina strike-slip fault. Wave-rounded cobbles and intertidal fauna in deposits surrounding the island confirm the hypothesis that Catalina has experienced at least 250m of subsidence since its uplift during the Pliocene.

* Miocene Geologic History of Eastern Santa Catalina Island, California, Susan Q. Boundy-Sanders, John G. Vedder, Christopher O. Sanders and David G. Howell,(USGS) http://repository.library.csuci.edu/bitstream/handle/10139/3163/Bound-Sanders.etal_1987_MioceneGeologic~.pdf?sequence=3

* The Catalina Schist: Evidence for middle Cretaceous subduction erosion of southwestern North America. January 2008Special Paper of the Geological Society of America 436:335-361 https://www.researchgate.net/publication

* Sorensen, S., 1988, Petrology of amphibolite-facies mafic and ultramafic rocks from the Catalina Schist, southern California: metasomatism and migmatization in a subduction zone metamorphic setting. https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1525-1314.1988.tb00431.x

Abstract: The Catalina Schist of southern California is a subduction zone metamorphic terrane. It consists of three tectonic units of amphibolite-, high-P greenschist- and blueschist-facies rocks that are structurally juxtaposed across faults, forming an apparent inverted metamorphic gradient. Migmatitic and non-migmatitic metabasite blocks surrounded by a meta-ultramafic matrix comprise the upper part of the Catalina amphibolite unit. Fluid-rock interaction at high-P, high-T conditions caused partial melting of migmatitic blocks, metasomatic exchange between metabasite blocks and ultramafic rocks, infiltration of silica into ultramafic rocks, and loss of an albitic component from nonmigmatitic, clinopyroxene-bearing metabasite blocks.
Partial melting took place at an estimated P=˜8–11 kbar and T=˜640–750°C at high H2O activity. The melting reaction probably involved plagioclase + quartz. Trondhjemitic melts were produced and are preserved as leucocratic regions in migmatitic blocks and as pegmatitic dikes that cut ultramafic rocks.
The metasomatic and melting processes reflected in these rocks could be analogous to those proposed for fluid and melt transfer of components from a subducting slab to the mantle wedge. Aqueous fluids rather than melts seem to have accomplished the bulk of mass transfer within the mafic and ultramafic complex.

* Geology and Tectonics of Santa Catalina Island and the California Continental Borderland; https://www.scec.org/publication/875; Legg, M. R., Davis, P. M., & Gath, E. M. (2004). Geology and Tectonics of Santa Catalina Island and the California Continental Borderland. *In* Legg, M. R., Davis, P. M., & Gath, E. M. (Eds.), South Coast

* Santa Catalina Geology   http://www.rain.org/campinternet/channelhistory/geology/geo3.html

Mineralogy, petrology, and geology of Santa Catalina Island, California /
Bailey Edgar Herbert (Thesis, Stanford University) https://www.researchgate.net/publication/35815067_Mineralogy_petrology_and_geology_of_Santa_Catalina_Island_California

Abstract: The Catalina Schist underlies the inner southern California borderland of southwestern North America. On Santa Catalina Island, amphibolite facies rocks that recrystallized and partially melted at ca. 115 Ma and at 40 km depth occur atop an inverted metamorphic stack that juxtaposes progressively lower grade, high-pressure/temperature (PT) rocks across low-angle faults. This inverted metamorphic sequence has been regarded as having formed within a newly initiated subduction zone. However, subduction initiation at ca. 115 Ma has been difficult to reconcile with regional geologic relationships, because the Catalina Schist formed well after emplacement of the adjacent Peninsular Ranges batholith had begun in earnest. New detrital zircon U-Pb age results indicate that the Catalina Schist accreted over a˜20 m.y. interval. The amphibolite unit metasediments formed from latest Neocomian to early Aptian (122-115 Ma) craton-enriched detritus derived mainly from the pre-Cretaceous wall rocks and Early Cretaceous volcanic cover of the Peninsular Ranges batholith. In contrast, lawsonite-blueschist and lower grade rocks derived from Cenomanian sediments dominated by this batholith's plutonic and volcanic detritus were accreted between 97 and 95 Ma. Seismic data and geologic relationships indicate that the Catalina Schist structurally underlies the western margin of the northern Peninsular Ranges batholith. We propose that construction of the Catalina Schist complex involved underthrusting of the Early Cretaceous forearc rocks to a subcrustal position beneath the western Peninsular Ranges batholith. The heat for amphibolite facies metamorphism and anatexis observed within the Catalina Schist was supplied by the western part of the batholith while subduction was continuous along the margin. Progressive subduction erosion ultimately juxtaposed the high-grade Catalina Schist with lower grade blueschists accreted above the subduction zone by 95 Ma. This coincided with an eastern relocation of arc magmatism and emplacement of the ca. 95 Ma La Posta tonalite-trondjhemite- granodiorite suite of the eastern Peninsular Ranges batholith. Final assembly of the Catalina Schist marked the initial stage of the Late Cretaceous-early Tertiary craton-ward shift of arc magmatism and deformation of southwestern North America that culminated in the Laramide orogeny.

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Abstract: **Geology of Santa Catalina Island, California Continental Borderland**
VEDDER, J. G., R. G. BOHANNON, and HUGH McLEAN, U.S. Geological Survey, Menlo Park, CA
"Santa Catalina Island is within the Catalina terrane of the California continental borderland. This terrane makes up most of the inner part of the borderland province and is characterized by Miocene and younger sedimentary and volcanic rocks that lie directly on Catalina Schist. The Catalina Schist, which presumably is Late Cretaceous in age, is preserved throughout the northwestern half of the island. Metamorphic grades range from blueschist to amphibolite and although this unit is best known for its blueschist, most exposures consist of chlorite greenschist facies rocks. The Catalina Schist probably formed as part of an accretionary wedge associated with a subduction zone. Miocene rocks form most of the southeastern half of the island and include a quartz diorite pluton, andesite and dacite extrusive rocks, and a variety of coarse to fine-grained sedimentary rocks. The 19 Ma pluton intrudes the Catalina Schist and consists largely of pervasive, sheeted, nearly vertical dikes that locally contain xenoliths of schist and schist breccia. Repetitive intrusion of dikes within the pluton caused its outward growth in a way that suggests intrusion in an active extensional environment. The 15-14-Ma dacitic rocks form domelike masses that are flanked and overlain by 15-12 Ma andesitic flows, some of which may have been subaerial. Locally, schist breccia lenses and coarse-grained volcaniclastic strata abut and drape over the flow rocks, suggesting local differential uplifts. Middle Miocene diatomaceous shale and lapilli tuff in places overlie the volcanic rocks. The diatomaceous strata were chiefly deposited in a shallow marine environment, but they also include some freshwater species. Thin remnants of upper Miocene and lower Pliocene(?) calcarenite and tuffaceous mudstone contain fossils that indicate increasing water depth with time.

The Catalina terrane is distinct from the Santa Ana terrane to its east and the Nicolas terrane to its west, where thick sequences of Cretaceous through Oligocene forearc sedimentary rocks underlie Miocene and younger strata. The pre-Miocene sedimentary section was deposited in the forearc of the volcanic arc of the Peninsular Range. A tiny remnant of the forearc section is exposed in the easternmost part of the island and suggests that those rocks may have once covered parts of the Catalina terrane as well. Separation of the three terranes may have been caused by the tectonic unloading of the Catalina terrane on large oblique-slip and detachment faults. Displacement on these faults resulted in a west-southwest migrating hinge of uplift and tectonic denudation at the boundary between the Nicolas and Catalina terranes. The extension doubled the width of the borderland province in the Miocene."

Acknowledgements

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Packing List Suggestions

Tent (or share with a friend), ground cover, stakes, rain fly
Sleeping bag
Sleeping pad
Daypack
Headlight/Flashlight
Hand lens
Water bottles (2)
Toiletries, medications
Bath/Beach towel(s)
Hat
Sunglasses
Sunscreen, chapstick
Shorts
Long pants
T-shirt
Long sleeve shirt (recommended for Sat. "Geology Day" as we'll be in the field with no cover)
Sweater/Sweatshirt
Light jacket
Knit hat
Bathing suit
Hiking shoes
Socks
Sandals
Hiking pole(s) - *if you use them*
Fins, mask, snorkel [great skin diving at the Casino Dive Park, Descanso Beach (beach area beyond Casino), and Lover's Cove (pebbly beach cove left of the Catalina Express docking area)]
Wetsuit - *recommended if you have one and plan on snorkeling activity*
Beach, balls, campsite games

Please print a publication of your interest on the geology of Catalina to share at both Friday evening campsite Geology Discussion and in the field.

Other:

* **Von's grocery store & Von's Express** (sandwich station). You can purchase food, beverages, ice, etc. at Von's. Prices are equivalent to those in S.D.

* **Lloyd's Drugstore,** on Cresent Ave. Pharmacist available.

* **Union Bank of California.** & ATM, on Crescent Ave. Other ATM's around island.

* **Beach chairs**, floats, Boogie boards, beach umbrellas, some masks/snorkels/fins available to use from the house.

Best beach/game/lawn area: Adjacent to Descanso Beach is a large grass area perfect for a good meeting place and to put your towel, have lunch, and swim/snorkel.

EMERGENCY PHONE LIST & EMERGENCY CONTACT

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Island Emergency and Taxi - *in emergency, call 911*

- *Sheriff Department: (310) 510-0174*
- *Hospital (Catalina Island Medical Center): (310) 510-0700, 100 Falls Canyon Rd.; Avalon Canyon by Golf Course*
- *Avalon Taxi Dispatch: (310) 510-0025*

Liability Waivers must be signed for participation *(see Bonnie Flynn)*