PRESENTATION GROUP #2 - EASTERN ZONE OF THE PENINSULAR RANGES BATHOLITH

Question Sets that Group #2 needs to know the answers to:

STOP 3: DESERT TOWER

I. EASTERN ZONE OF THE PENINSULAR RANGES BATHOLITH - TECTONIC STAGE #2 - CONTINENTAL MARGIN ARC PERIOD

A. List the four stages of tectonic development for San Diego County, including their age ranges.

B. The PRB is divided into a western zone and an eastern zone based on differences in rock type, age and structure. What is the age range for each zone?

C. What is the tectonic origin (setting) for the EASTERN zone rocks (plutons) of the Peninsular Ranges Batholith?

D. What stage of tectonic activity does the EASTERN zone of the batholith represent?

E. What is the depth of emplacement for the plutons in the EASTERN zone of PRB?

F. List the three major plutonic rock types of the EASTERN zone of the PRB.

G. Describe the La Posta pluton's mineralogy (4 most common minerals) and rock texture.

H. What is the absolute age of the La Posta rocks (pluton) and how was this age determined?

I. Where did all the overlying rock, that once covered these Mesozoic-aged plutons, go to?

II. TECTONIC STAGE #3 - CRUSTAL DEFORMATION IN THE EASTERN PENINSULAR RANGES AND SALTON TROUGH

A. Origin of stress responsible for several different episodes of faulting and shearing in the eastern Peninsular Ranges and Salton Trough

1) Pre-Stage #3 Late Cretaceous to Early Tertiary (actually this would be within the last part of tectonic stage #2) development of the Eastern PRB ductile, compressional thrust fault/shear mylonite zones

2) Stage #3 Late Tertiary to Middle Cenozoic development of the western Salton Trough brittle-ductile normal detachment fault zones

a) Earlier (28 Ma to 12 Ma) tensional stress associated with plate boundary transition as the MOR encounters the trench

b) Later episode of tensional stress associated with the opening of the Gulf of California

- ✓ **Gulf of Ca opens at southern end around 12 MA**
- ✓ **Gulf of Ca opens at northern end around 6 Ma**
- ✓ **Gulf continues to open/grow northward today**

B. the topography, geologic structures, and sedimentary rocks that evolved in response to Stage #2 faulting/deformation

1) Where would you find the alluvial fans forming at that time?

C. Draw a simplified cross section form the PRB to the Salton Trough illustrating the "basin and range" topography (see figures 8 and 9)

1) Where are the younger sedimentary cover rocks and the older igenous/metamorphic basement rocks located on your cross section?

2) Be able to label all features on your cross section.

PROFESSOR'S COMPILED INFORMATION ON EASTERN ZONE OF THE PENINSULAR RANGES BATHOLITH (PRB)

A. Tectonic Origin of the Eastern Zone of the Peninsular Ranges Batholith

1. Evolution of the earlier island arc (western zone of PRB) into a continental margin arc system (eastern zone of PRB) occurred around 100 Ma.

a) Change from island arc subduction to continental margin arc occurred due a change in angle of subducting oceanic Farallon plate slab beneath the edge of the overlying North America plate

- ✓ **Subduction angle became more shallow**
- ✓ **Rate of subduction most likely increased**
- ✓ **Subduction mergence direction between the plates become more oblique**

b) Subduction of relatively younger, warmer, less-dense Farallon plate created a relatively shallower subduction angle

c) Coincides with hypothesized tectonic erosion of the forarc sedimentary accretionary complex

c) <u>Eastern zone of PRB formed during the middle subduction period</u> of San Diego's tectonic development (100 Ma to 80 Ma)

2. Birth and development of a continental margin arc system (eastern zone of PRB)

a) Extremely large volumes of silicic magmas form in the subduction zone

- ✓ **Starts with the dewatering of the down-going ocean slab**
- ✓ **Dewatering of the slab in the subduction zone acts like a flux for melting the materials in the subduction zone and overlying rocks**

- ✓ **Water flux lowers melting temperature of subduction zone rocks (melting the eclogite-composition oceanic slab and/or the subducted accretionary forarc material).**

b) Subduction-generated magmas are water-rich and tonalitic in composition.

c) These volatile/silica-rich, low-potassium tonalitic magmas rose up and begin to collect and pool at the base of overlying plate (at the juncture between continental and oceanic crust)

d) Over time, these silicic magmas intruded up into the overlying plate to form enormous mid-crustal magma chambers (many tens of kilometers across)

- ✓ **Eastern Zone plutons emplaced at depths ranging from 10 to 20 kilometers down**

e) The magma chambers feed an overlying system of conduits to the surface that fueled the growth of caldera-type super-volcanoes

f) A linear belt of these monster caldera volcanoes formed just to the east of the now extinct island-arc western zone plutons and CLMSZ.

g) The intrusions of the eastern zone magmas represent the climax of the batholith-building history of the PRB

h) These magma chambers later cooled and crystallized into very large mid-crustal depth (10 to 15 kilometers depth) plutons

- ✓ **These large plutons are named "La Posta-type" plutons after the La Posta pluton (the one found under stop #3)**
- ✓ **These eastern zone La Posta-type plutons extend from the middle of the batholith to the edge of the Peninsular Ranges where it drops off into the desert.**
- ✓ **The La Posta-type plutons have been isotopically dated (U-Pb in zircons) at 94 to 92 Ma, with ages getting younger eastward.**
- ✓ **The La Posta-type plutons are compositionally zoned, having a concentrically nested "bull's-eye" structure, with a more mafic edge, grading to a more leucrocratic, silicic core.**

i) The continental margin arc system effectively made room for itself by intruding up (and laterally outward) into the previously collapsed "back-arc" seaway region (the region between the western zone island arc and the North American continent).

- ✓ **The large bodies of eastern zone silicic magmas caused intense levels of regional and contact metamorphism to the country (pre-batholithic) rock during intrusion.**
  - **Pre-batholithic rocks were extremely softened and stretched and intensely folded and refolded.**
  - **Pre-batholithic rocks underwent medium to high-grade levels of metamorphism**

- **The collapsed back-arc oceanic crust, including its thick, continentally-derived sediment cover was totally deformed and metamorphosed by the intrusions and tectonism.**

j) Much smaller post La-Posta-type satellite plutons intruded to the east of the La Posta plutons (90 Ma to 85 Ma)

- **Garnet-bearing biotite granodiorites and granites**

k) At the very end of the eastern zone stage of magmatism, an extensive set of criss-crossing granite pegmatite dikes intruded the entire eastern zone of batholith (90 Ma to 80 Ma)

- **Many of these granite pegmatites are rich in rare-earth elements and contain gem-quality minerals like tourmaline.**
- **The granite pegmatites cross-cut all other rock units**

3. Post-intrusion evolution of the continental arc system

a) At the onset (around 100 Ma to 95 Ma) the continental arc became very thick, due to the massive intrusions, so much so, to become gravitationally unstable.

b) Later, probably by 90Ma (and definitively by 80Ma) the batholith began to collapse under its own weight, laterally spreading out along low-angle detachment shear zones

c) By 70 Ma, all magmatism had long since ceased, and the batholith was now undergoing major deflation and extension, and deep levels of exhumation and erosion.

d) The eastern zone of the PRB would eventually become uplifted and eroded down to mid-crustal depths, as shown today.

f) The entire upper crust of the eastern zone, including its thick volcanic layer, was completed weathered, eroded, and ultimately carried into the ocean - the final resting place for its sediment.

B. Structure of the Eastern Zone of the PRB

1) Areal extent of the eastern zone of the PRB:

a) Length is from Riverside to half-way down Baja California

b) Locally, the width is from center of the Peninsular Ranges to the east side of the Salton Trough desert

2) The crust is comprised of several tens of mid-crustal depth plutons that form large isolated intrusions that are surrounded by prebatholith metamorphic rocks and older eastern zone intrusions

3) The crust underlying the eastern zone varies from 45 kilometers (western edge) to 25 kilometers (eastern edge)

4) Average size of the plutons are twenty to sixty kilometers across.

5) Exposure of plutons, in terms of original crustal depth when the bodies formed is relatively deep

a) From 10 kilometers depth (on the western side) to about 16 kilometers deep (eastern side)

6) Eastern zone is differentiated (longitudinally along the center of the batholith) from the western zone of the PRB by several distinct differences in rock structure and composition

a) The boundary roughly coincides with Sunrise Highway and the CMLMSZ

b) The eastern zone rocks are younger, magnetite- free, have narrow compositional spectrum (overall of granodiorite composition), and chemically of mixed oceanic/continental origin

c) The western zone rocks are older, magnetite bearing, broad compositional spectrum; but overall, more mafic, less silicic, and chemically of purely oceanic origin

C. Rocks of the Eastern Zone of the PRB

1) There are Three Major Plutonic Rock Types in the Eastern Zone of the PRB -

a) Tonalite

- ✓ **Found across the eastern zone of the PRB: mainly forms the outer/older parts of the large La Posta plutons**
- ✓ **Rocks rich in quartz and Ca/Na-rich plagioclase, with only minor amounts of K-feldspar; also accessory amounts of hornblende and/or biotite.**

- ✓ **No magnetite in these rocks, but does have ilmentite instead.**
- ✓ **Parent magmas generated by partial melting of subducting hydrated (water-enriched) oceanic basalt slab, and/or the gabbroic crustal under-plate.**
- ✓ **The eruptions of these magmas probably created stratovolcanoes and very large caldera complexes.**
- ✓ **Absolute age determination of these rocks are abundant; ages ranges from 100 Ma to 94 Ma (= narrow age range)**
- ✓ **Forms mostly topographic mid- to low geographic relief (rolling hills and broad valleys) with moderate to thick chaparral cover.**
- ✓ **Examples are found all along Freeway 8 between Buckman Springs and Desert Tower.**

b) Granodiorite and Monzogranite

- ✓ **Found across much of the eastern zone of the PRB (most are found along the eastern side of eastern zone of PRB)**
- ✓ **Rocks rich in quartz, Na-rich plagioclase, and potassium feldspar; also accessory amounts of muscovite, biotite, and garnet.**
- ✓ **Moderate amounts of potassium feldspar in the eastern zone granodiorites rocks (more in the moozogranites).**

- ✓ **Parent magmas generated by partial melting of either, the subducting hydrated (water-enriched) oceanic slab sediments, or the tonalite rocks, or prebatholithic country rock, or a mixture.**
- ✓ **The eruptions of these magmas probably created stratovolcanoes, calderas, and rhyo-dacitic domes.**
- ✓ **Absolute age determination of these rocks give ages ranging from 92 Ma to 85 Ma (= narrow age range)**
- ✓ **Forms mostly topographic high geographic relief (blocky peaks with steep boulder-rich slopes); heavy chaparral cover.**
- ✓ **Examples are found all along Freeway 8 between Boulevard and Desert Tower.**

c) Granite Pegmatite

- ✓ **Found all over the eastern zone of the PRB (intruding every pluton and through pre-batholithic rocks)**
- ✓ **Rocks rich in quartz and potassium feldspar, with lesser amounts of Na-rich plagioclase; also accessory amounts of biotite, muscovite, garnet, and tourmaline.**

- ✓ **Parent magmas generated by the end differentiate of the crystallizing tonalite and granodiorite magmas, along with assimilation of the pre-batholithic country rock.**
- ✓ **Eruptions of these magmas is unlikely, although probably associated with hot spring activity.**
- ✓ **Absolute age determination of these rocks give ages ranging from 90 Ma to 80 Ma.**
- ✓ **Examples are found in all over the place.**

C. Post-batholithic Crustal Deformation in the Eastern Zone of the Peninsular Ranges Batholith

1) The eastern side of the PRB experienced two distinct episodes of crustal deformation

a) First episode occurred in Late Cretaceous to Early Tertiary, and involved compressional thrust faulting to form the Eastern Peninsular Ranges Mylonite Zone (EPRMZ)

b) The later episode occurred in Middle to Late Tertiary, and involved tensional low-angle normal (detachment) faulting to form the Western Salton Detachment System (WSDS)

2) The Eastern Peninsular Ranges Mylonite Zone (EPRMZ)

a) The EPRMZ is a brittle-ductile shear (fault) zone found along the eastern edge of the northern section of the PRB (within the eastern zone rocks)

- ✓ **<u>The EPRMZ formed during the late subduction period</u> of San Diego's tectonic development (80 Ma to 40 Ma)**
- ✓ **Active sometime between Late Cretaceous to Early Tertiary time in response to compressional tectonic forces.**
- ✓ **It formed at mid-crustal depths (10 to 12 km down) in response to extensional tectonic forces.**
- ✓ **The EPRMZ is about 100 kilometers long (strike is NW-SE), and is several kilometers in width.**
- ✓ **The shear zone forms a snake-like map-view pattern along the eastern edge of the northern PRB**
- ✓ **The EPRMZ is made up of several fault zones, has a high dip angle (60 to 70 degrees) to the east**
- ✓ **The EPRMZ was active in the Late Cretaceous to Early Tertiary**
    - o **Compressional W-E forces caused ductile east-dipping thrust faulting in the eastern zone rocks**
    - o **East side (hanging wall) up over west side (footwall)**
    - o **Rocks underwent intense mylonitization (formation of mylonitic S-C fabric schist and gneiss)**

- **Reached amphibolite-grade metamorphism**

✓ **The compressional tectonic event appears to coincide with final climax of batholith development in the eastern zone.**

- **All eastern zone rock types, including the granite pegmatites appears to have been affected**
- **Interestingly, this deformation event coincides with the later extensional episode of the CLMSZ.**
- **The timing of EPRMZ is somewhere between 80 MA to 40 Ma - not very well constrained.**
- **The timing of EPRMZ deformation probably coincided with either, the climax emplacement of eastern zone La Posta plutons, and gravitational collapse of an over-inflated crustal arc welt, and/or later on with the Laramide orgogeny.**

✓ **Good examples of the EPRMZ are found around the Borrego Springs and Santa Rosa mountains.**

3) The Western Salton Detachment System (WSDS)

a) The WSDS is a brittle-ductile shear (fault) zone found along the eastern edge of the northern section of the PRB (within the eastern zone rocks)

✓ **<u>The WSDS formed during the extensional period (Tectonic Stage #3)</u> of San Diego's tectonic development (30 Ma to 10 Ma)**

- **Earlier (28 Ma to 12 Ma) tensional stress associated with plate boundary transition as the MOR encounters the trench**
- **Later episode of tensional stress associated with the opening of the Gulf of California**
  - **Gulf of Ca opens at southern end around 12 MA**
  - **Gulf of Ca opens at northern end around 6 Ma**
  - **Gulf continues to open/grow northward today**

- ✓ **It formed at mid- to shallow-crustal depths (2 to 8 km down) during Middle to Late Tertiary time in response to extensional tectonic forces.**
- ✓ **The WSDS is about 100 kilometers long (strike is NW-SE), and is several kilometers in width.**
- ✓ **The shear zone forms a snake-like map-view pattern along the eastern edge of the northern PRB**
- ✓ **The WSDS is made up of several fault zones, has low dip angle (5 to 15 degrees) to the east**
- ✓ **The WSDS was active somewhere between Middle Tertiary to Middle Cenozoic time**

- **Extensional W-E forces caused ductile east-dipping normal detachment faulting in the eastern zone rocks**
- **East side (hanging wall) down off of the west side (footwall) -**
- **Rocks underwent various degrees of deformation ranging form catalysis (brittle) to mylonitization (ductile), depending of crustal depth.**
- **Reached greenshist-grade metamorphism**

✓ **A great amount of hot, chemically-reactive fluids were involved within the detachment fault zones**

- **Heavy chloritization of the fault rocks, and acid weathering (Ex. feldspar turned into clay)**
- **This deformation event most likely coincides with the Miocene extensional tectonic stage, and/or opening of the Salton Trough.**

✓ **Good examples of the WSDS are found around the Agua Caliente Hot Springs and the Santa Rosa and San Jacinto mountains.**

Additional Information on Eastern Zone Rocks and Tectonism of the Peninsular Ranges Batholith:

1) **San Diego Natural History Museum - http://www.sdnhm.org/research/geology/geo_eastpluton.html**

2) The La Posta Pluton - ANDREW A. SNELLING, Ph.D. – http://www.terrasonics.com/THE LA POSTA PLUTON.mht

3) Peninsular Ranges Batholith – Ray Rector - http://www.terrasonics.com/The Peninsular Ranges Batholith.mht

4) Peninsular Ranges Batholith Illustrations - http://www.terrasonics.com/Peninsular Ranges Batholith Figures.mht