Name:____________________________

MT. SOLEDAD FIELD LAB

Part 1:

The Rose Canyon Fault and Uplift of Mt. Soledad

1. What type of fault is the Rose Canyon Fault?

2. What force uplifts Mt. Soledad?

3. What property of the Rose Canyon Fault causes this force?

4. What features do we see to indicate that this fault is still active?
   a)
   b)
   c)

5. What other features are associated with the fault? (Hint: It's offshore.)

6. The Rose Canyon Fault has moved __________times in the last __________years. It last moved in __________.
   What magnitude earthquake is possible/probable from this fault?

Part 2:

San Diego Marine Terraces and Quaternary Uplift

To determine the height and age use the chart provided, for the rate of the terrace uplift use this equation:

Height (ft) x 12/age (K years)

7. Nester Terrace: _____________ ft _____________ K years _____________ rate
8. Clairemont Terrace: _____________ ft _____________ K years _____________ rate
9. Tecolote Terrace: _____________ ft _____________ K years _____________ rate
10. Linda Vista Terrace: _____________ ft _____________ K years _____________ rate
11. Tierra Santa Terrace: _____________ ft _____________ K years _____________ rate

J. Turbeville

12. What is the average rate of uplift for the terraces from our emergent coast?

13. Does the rate change? If so, when does it change?

14. What terrace is on top of Mt. Soledad?

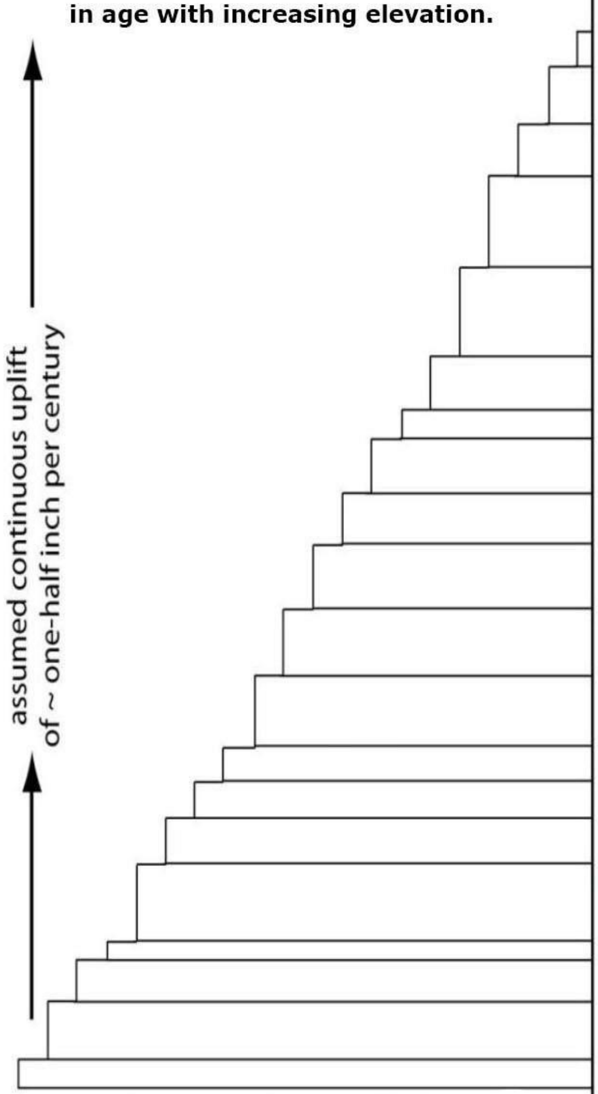
15. How high is this terrace of Mt. Soledad? What height should it be?

16. What is the rate of uplift on Mt. Soledad? (height (ft)/age (K years) x 12)

17. What additional rate of uplift does the Rose Canyon Fault create at Mt. Soledad. Method: subtract the average rate of uplift from question 12 from the uplift rate in question 16.

The names, average elebations, and ages of wave-cut terraces in San Diego.

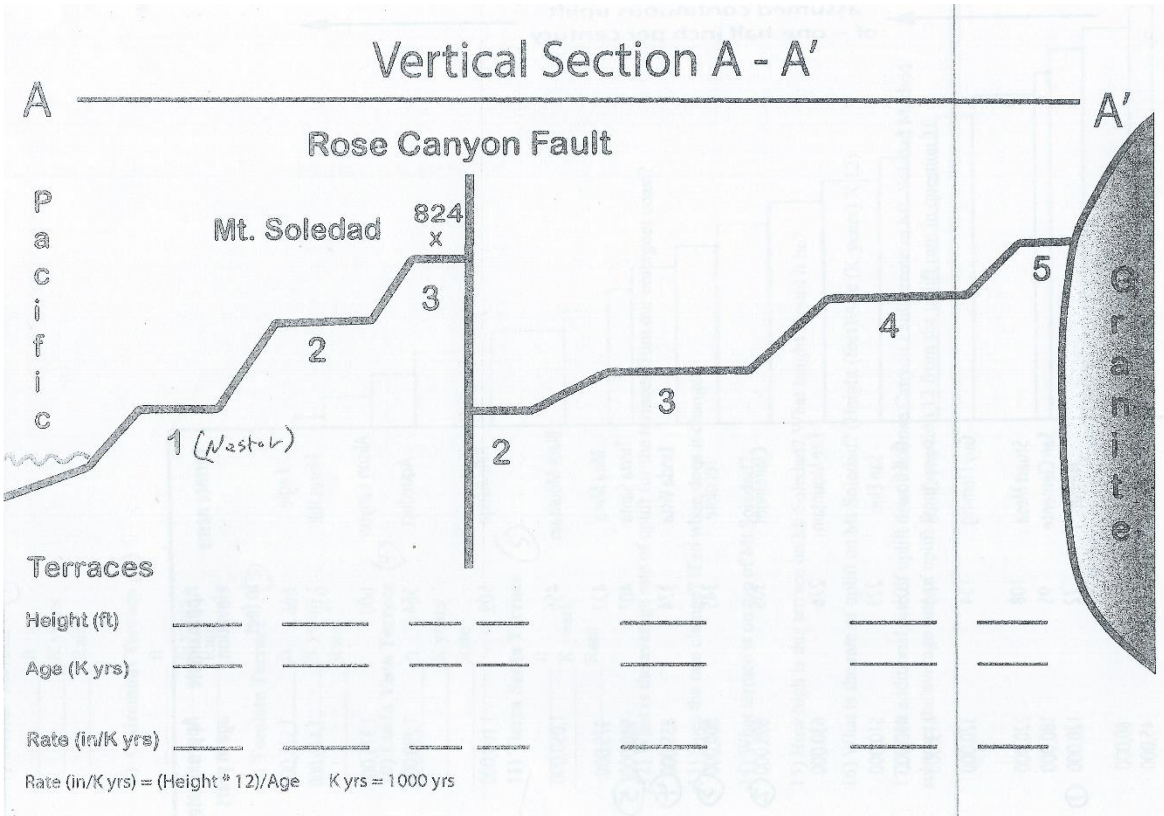
Note that the terraces increase in age with increasing elevation.

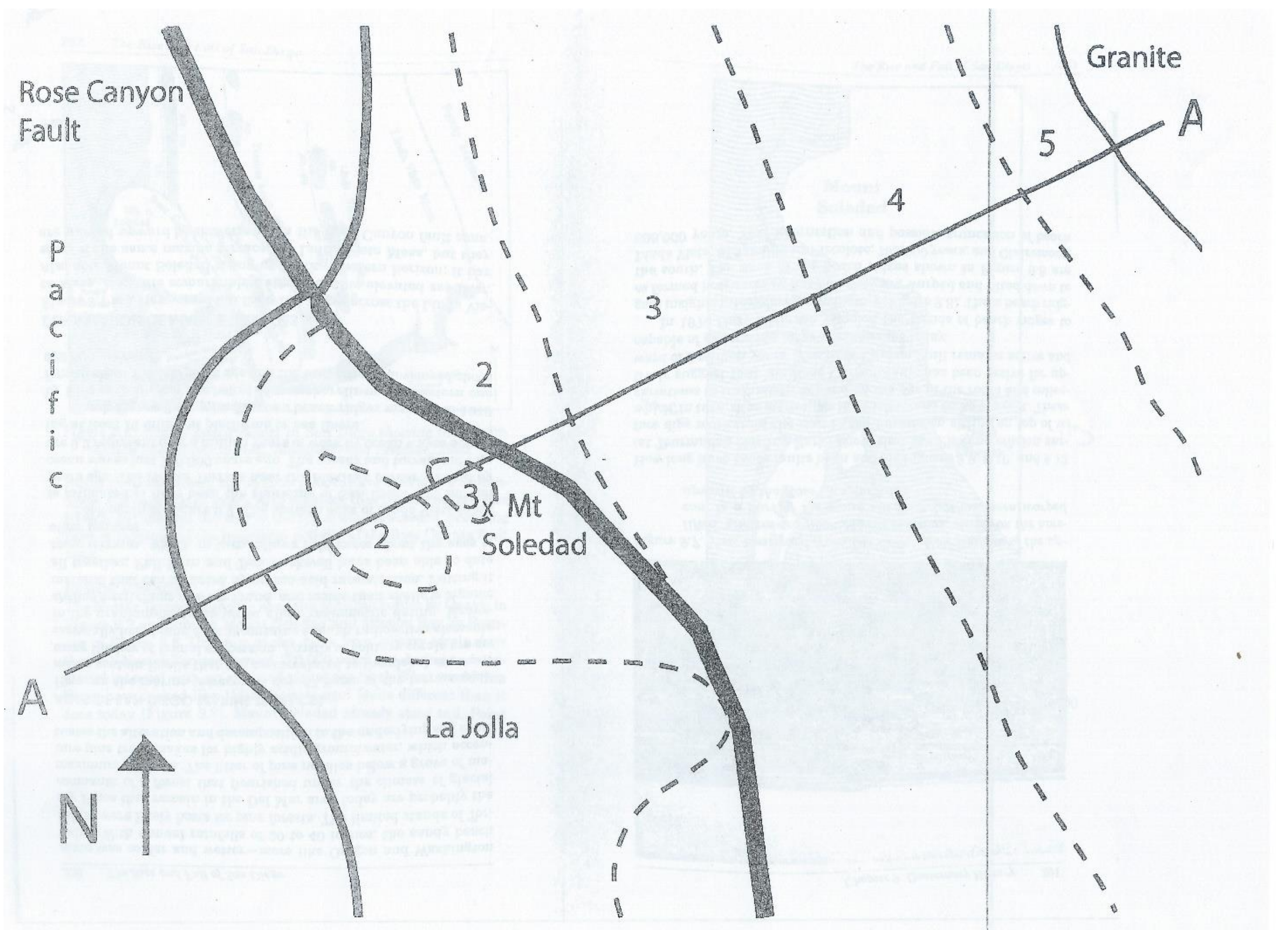


Marine terrace name	Approximate elevation in feet	Formation	Approximate age in years
Eagle	666	Lindavista Formation	1,525,000
Flores Hill	630	Lindavista Formation	1,445,000
Alison Canyon	600	Lindavista Formation	1,375,000
Aqueduct	564	Lindavista Formation	1,290,000
Rifle Range	509	Lindavista Formation	1,160,000
Black Mountain	456	Lindavista Formation	1,050,000
Mira Mesa	427	Lindavista Formation	975,000
Tierra Santa	407	Lindavista Formation	930,000
Linda Vista	374	Lindavista Formation	855,000
Tecolote	345	Lindavista Formation	800,000
Clairemont	305	Lindavista Formation	698,000
Fire Mountain	276	Bay Point Formation	630,000
San Elijo	223	Bay Point Formation	510,000
Golf Course	203	Bay Point Formation	450,000
Parry Grove	180	Bay Point Formation	413,000
Guy Fleming	154	Bay Point Formation	320,000
Stuart Mesa	108	Bay Point Formation	220,000
San Clemente	95	Bay Point Formation	180,000
Nestor	72	Bay Point Formation	120,000
Bird Rock	33	Bay Point Formation	80,000
St. Louis	20	Bay Point Formation	45,000

Modern coastal and marine deposits

Modified from Meldahl (2015, F.g 7.4 *Time Scale (Geol. Soc. Amer., 2020)


Vertical Section A - A'
A
A'
Rose Canyon Fault
Pacific
Mt. Soledad
824
x
1 (Nestor)
2
3
2
3
4
5
Granite
Terraces
Height (ft)
Age (K yrs)
Rate (in/K yrs)
Rate (in/K yrs) = (Height * 12)/Age K yrs = 1000 yrs


Rose Canyon Fault
Granite
A
Pacific
5
4
3
2
3
x Mt
Soledad
2
1
A
La Jolla
N

mate was colder and wetter—more like Oregon and Washington today. With annual rainfalls of 20 to 40 inches, the sandy beach ridges were likely hosts for pine forests. The limited stands of Torrey Pines that remain in the Del Mar area today are probably the remnants of a forest that flourished under the climate of glacial maximum advance. The litter of pine needles below a grove of mature pine trees makes for highly acidic groundwater, which accentuates the alteration and decomposition in the underlying soil zone.

AGES OF SAN DIEGO MARINE TERRACES

How can the marine terraces be dated? Some of the terrace sediments contain fossils that can be correlated to the global sequence using the law of faunal succession. Fossils of solitary corals are occasionally found, and a coral contains enough radioactive elements in the uranium-decay series to allow radiometric dating. Heavy-shelled fossil clams also are found, and inside their shells is organic material that can be dated by amino-acid racemization. Putting it all together, Phil Kern and Tom Rockwell have been able to date some terraces, which, in turn, allows inferences about the ages of other terraces.

Look again at Figure 9.2. The eastern edge of Linda Vista Mesa is estimated to have been the shoreline of San Diego 1.29 million years ago. The Nestor Terrace near the Mexican border was cut by ocean waves just 120,000 years ago. The mesas and terraces of Figure 9.2 represent over a million years of work by ocean waves abrading at least 16 different platforms or sea floors.

Check Figure 9.4 again. The two beach ridges mapped in 1919 by Ellis each lie just landward of two shorelines; the eastern one formed about 795,000 years ago and the western one developed about 698,000 years ago.

DEFORMATION OF MARINE TERRACES

Figure 9.7 is a view westward from Del Cerro across the Linda Vista Mesa. Note the remarkable flatness of this elevated sea floor. Also note Mount Soledad rising up on the western horizon; it has some of the same marine terraces as Linda Vista Mesa, but they are warped upward by movements in the Rose Canyon fault zone.

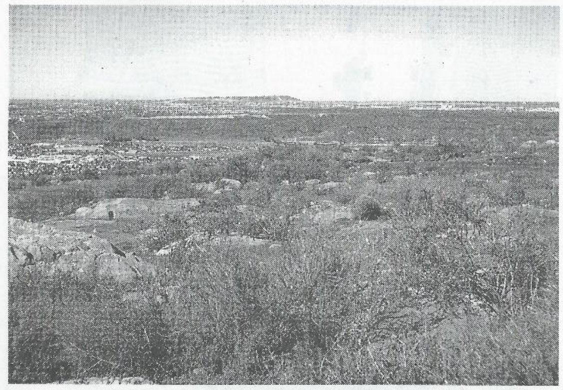


Figure 9.7. View westward from Del Cerro. Note flatness of the uplifted, ancient sea floor. Mount Soledad, visible on the horizon, is a part of the same sea floor but has been warped upward by the Rose Canyon fault.

How long have these faults been active? Figures 8.9, 8.10, and 8.12 (at Tourmaline Surfing Park) show that the Pliocene erosion surface dips more than the San Diego Formation sitting on top of it, which, in turn, dips more than the Pleistocene rocks above it. These variations in inclination depend on the age of the rocks and collectively suggest that the Rose Canyon fault has been active for upward of 2 million years. The Rose Canyon fault remains active and capable of generating large earthquakes today.

In 1970 Gary Peterson mapped the trends of beach ridges to gain insights into deformation history (Figure 9.8). These beach ridges formed horizontally, but now they are warped and tilted down to the south. The ages of the beach ridges shown in Figure 9.8 are Linda Vista, 855,000 years; Tecolote, 795,000 years; and Clairemont, 698,000 years. The deformation and possible truncation of beach

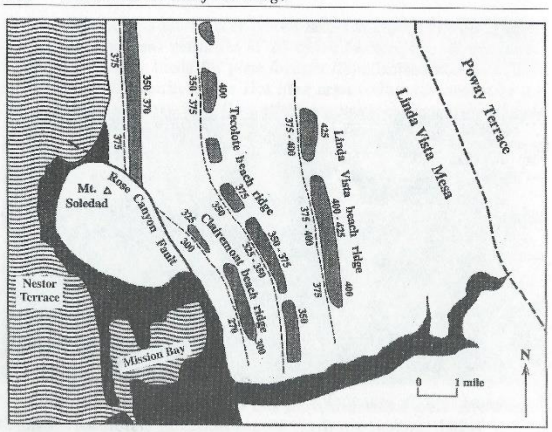


Figure 9.8. Map of beach ridges in San Diego showing their deformation (elevations in feet). Modified from Peterson, 1970.

ridges show the Rose Canyon fault zone to have been active for hundreds of thousands of years. Also consider that the marine terraces have been lifted all the way to the top of Mount Soledad, providing further evidence of the long-term activity of the Rose Canyon fault zone.

NESTOR TERRACE

The Nestor Terrace is shown near the Mexican border by Quayle in Figure 9.2 and around Mount Soledad and Mission Bay by Peterson in Figure 9.8. Uranium-series dates from solitary corals show that the Nestor Terrace formed 120,000 years ago during an interglacial interval with an elevated global sea level. What would San Diego have looked like 120,000 years ago? Quite different than it does today (Figure 9.9). Mount Soledad already stood tall, Point

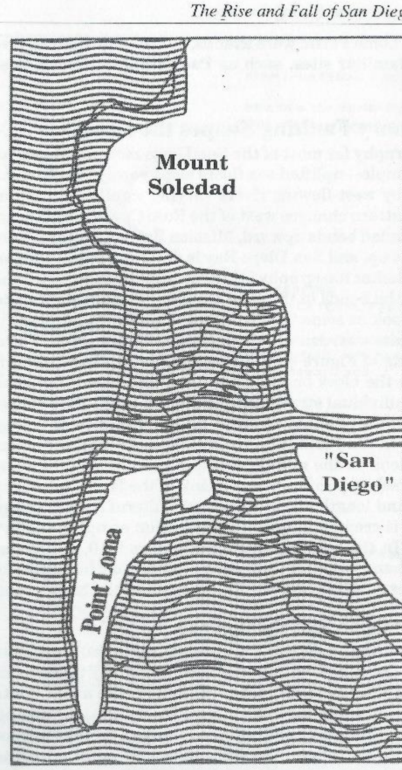


Figure 9.9. San Diego during the interglacial interval of 120,000 years ago.

Loma and Loma Portal were islands, but the elevated sea level flooded many familiar sites, such as Pacific Beach, Ocean Beach, and Coronado.

Quaternary Faulting Shapes the Land

The topography for most of the San Diego metropolitan area is reasonably simple—uplifted sea floors slope gently to the west and are dissected by west-flowing rivers carving significant canyons. This regional pattern changes west of the Rose Canyon fault zone, where Mount Soledad bends upward, Mission Bay warps downward, Point Loma rises up, and San Diego Bay is dropping down. This seemingly helter-skelter topography is logical once the geometric constraints placed by the bends in the Rose Canyon fault zone are understood.

Let's look at some basic concepts concerning strike-slip faults, that is, faults with dominantly horizontal movements. Notice in the top drawing of Figure 9.10 that a right-lateral strike-slip fault occurs when the block on the right-hand side moves horizontally toward an individual straddling the fault. For the Rose Canyon fault this occurs because the western side of the fault is riding northwestward on the Pacific plate at a faster rate than the eastern side.

Next look at the middle drawing of Figure 9.10 and mentally place yourself opposite a bend or kink in the fault. Notice that when the left-hand length of a crooked right-lateral fault is stepped closer to you, it creates a zone of compression or uplift at the bend in the fault. In the bottom drawing in Figure 9.10, notice that when the right-hand side of a bent right-lateral fault lies closer to you, it creates a zone of tension or pulling apart at the bend in the fault.

MOUNT SOLEDAD AND MISSION BAY

The preceding theoretical interpretations of fault geometry were applied to the Rose Canyon fault zone in 1970 by George Moore and Mike Kennedy. Let's apply these concepts to the major faults in San Diego (refer to the map in Figure 9.11). Notice that after the northwest-southeast trending Rose Canyon fault comes ashore at La Jolla, its path becomes more east-west until it reaches Rose Canyon where it resumes its northwest-southeast orientation. When the Rose Canyon fault zone in La Jolla is viewed from the side, it is

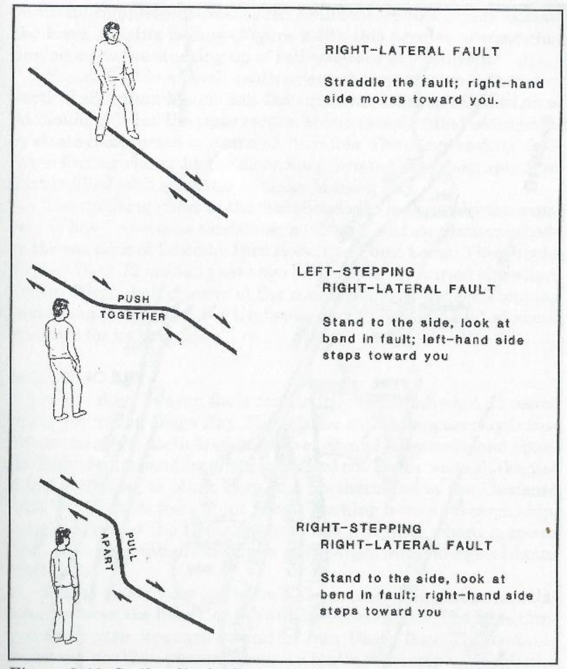


Figure 9.10. Strike-slip faults and the processes at their bends.

seen to have a prominent left step. In theory, this setting should produce uplift. In reality, there rises Mount Soledad. What is happening in La Jolla? The western side of the Rose Canyon fault zone is carrying La Jolla northwestward. When it reaches the left step just south of Ardath Road, its movement is hindered. The

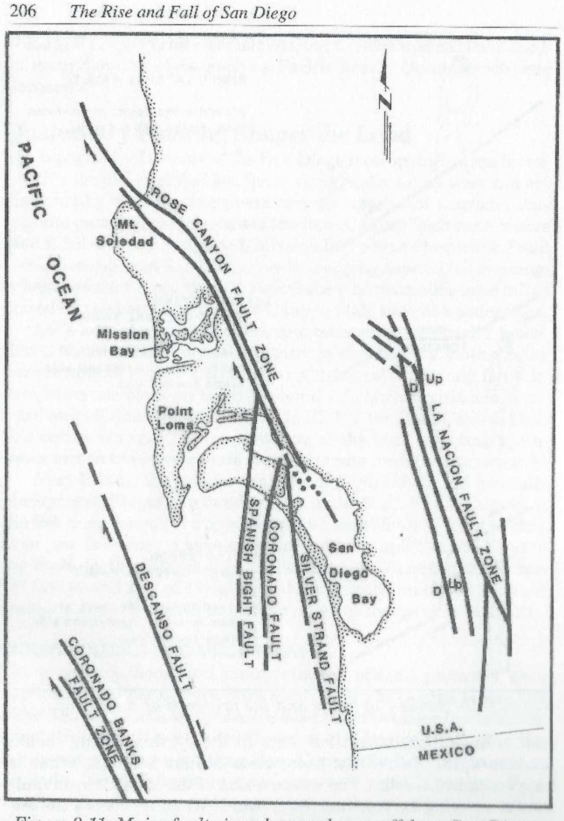


Figure 9.11. Major faults in urban and near-offshore San Diego.

resultant compression pushes the sedimentary rock layers against the bend, causing folding (Figure 9.12); this process is somewhat analogous to the stacking up of railroad cars in a collision.

Figure 9.12 is a north-south oriented cross section drawn as a vertical slice from Mount Soledad southward through Point Loma. At Mount Soledad the cross section shows steeply tilted sedimentary strata compressed into an anticlinal fold. The compressional folding is further shown by the downwarp forming the topographic low that is filled with seawater to make Mission Bay.

The uplifting effect at the fault bend also is shown by the exposure of late Cretaceous sandstone, mudstone, and conglomerate beds in the sea cliffs of La Jolla, Bird Rock, and Point Loma. These rocks formed 76 to 72 million years ago and are deeply buried elsewhere in San Diego, but because of the compression at the left-stepping fault bend in La Jolla, the Cretaceous rocks are being lifted above sea level for us to enjoy.

SAN DIEGO BAY

When the Rose Canyon fault zone is followed southward, it seems to die out in San Diego Bay. The seismic activity apparently transfers to the short, north-trending Silver Strand, Coronado, and Spanish Bight faults heading offshore toward the Descanso fault (Figure 9.11). According to Mark Legg, the northern end of the Descanso fault lies offshore from Point Loma. Working from a research ship, Legg has traced the Descanso fault southward to where it comes back onshore south of Ensenada and merges into the Agua Blanca fault zone.

Taking a side view in Figure 9.11, examine the geometric relations between the Rose Canyon and Descanso faults. The Rose Canyon fault zone appears to end in San Diego Bay. The tectonic pressures are then passed through a major right step with transfer of movement to the offshore Descanso fault. In theory, this right step should produce a pull-apart basin. In reality, there is San Diego Bay.

The right step between the ends of the right-lateral Rose Canyon and Descanso fault zones creates a releasing bend, causing the rocks to be stretched apart and dropped down. In response to this

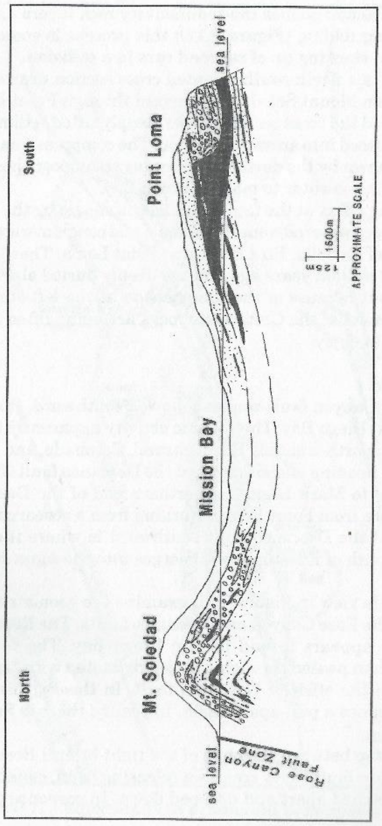


Figure 9.12. North–south-oriented cross section showing sedimentary rock layers folded by compression at the La Jolla left step in the Rose Canyon fault zone.

stretching the rocks do not deform elastically; instead they respond with brittle failure as faults. Specifically, the down dropping of the San Diego Bay region has been accommodated by a series of down-to-the-basin faults with dominantly vertical offsets—namely, the La Nacion fault zone. A typical fault in the La Nacion system has suffered a vertical drop on its western side in reaction to the sinking of the San Diego Bay basin.

COASTAL TOPOGRAPHY

The large-scale topographic elements of San Diego west of the Rose Canyon fault zone are directly attributable to movements along the faults (Figure 9.13). There also are numerous smaller-scale topographic features resulting from movements on faults of the Rose Canyon system. George Moore called attention to the shape of the coastline at La Jolla. The relatively smooth and arcuate coastline from Oceanside to La Jolla Shores beach takes a prominent westward jump to La Jolla Cove, as shown in Figures 9.11 and 9.13. This physiographic discontinuity is consistent with a few miles of northward movement on the west side of the Rose Canyon fault zone.

Notice also on Figure 9.13 that North Island and Coronado Island were once separate landmasses divided by bay water filling the elongate feature called Spanish Bight. See Figure 9.11 for a picture of why Spanish Bight existed—the Bight was eroded through ground-up rock debris along the Spanish Bight fault. But the U.S. Navy filled in the Bight to create more land. Did this burial of the fault end its earthquake-generating potential? In 1985 and 1986, numerous earthquakes occurred on these north-south oriented faults crossing Coronado, including a magnitude 4.7 earthquake on 29 October 1986.

Quaternary Field Trip: Out and About in La Jolla

On this field trip we will visit five separate localities (Figure 9.14). The first stop is on top of Mount Soledad, my favorite geological view site in San Diego. The other four stops can be done in any order you choose, even on different days. Pick a day following a