NINTH ANNUAL SPRING FIELD SPECTACULAR
THE
BIG BAJA BASH

GEOLOGY AND EARTH SCIENCE FIELD TRIP
Departments of Geological Sciences and Geography
California State University, Northridge

January 22-25, 1992

Coordinators: Gene Fritsche and Frank Hanna

Wednesday, Jan. 22 — Meet at the Monterey Hall parking lot at **7:00 a.m.** See the list below for things to bring. It is **not** wise to leave cars at the University during the trip. Several have been broken into during past trips, so try to arrange a ride to campus. If you must leave a car, you can park it in student parking lot "O" behind the campus police station. If you intend doing this, notify Arlene, (818) 885-3541, of your intentions and your car license number, make, and model by 3:00 p.m. on Tuesday, Jan. 21, so that she can tell the parking officers about the cars that will be left overnight in the lot.

The first leg of our journey will take us via Highway 118, Interstate 210, and Interstate 10 to Indio. In Indio, switch to Highway 111 (see map) and continue south to Thermal. In the event of cars getting separated along the way, we will gather in Thermal at the corner of Highway 111 and Airport Blvd. Turn left off of Highway 111 onto Airport Blvd. and wait near the railroad track. When we are all back together, we will continue on Airport Blvd. east to our first stop in the Mecca Hills.

In the Mecca Hills we will look at the San Andreas fault, folds and faults in the Pleistocene Palm Spring Formation, and the Bishop Tuff. Depending on the time, lunch will either be in the field in the Mecca Hills or later in the town of Mecca, so be sure to have a sack lunch with you and available in the vehicle (not packed away in your duffel).

After lunch; continue following Highway 111 clear to the Mexican border. All gas tanks will be filled before crossing the border. After crossing the border, go about 0.5 mile on the main road to La Casita de Patzcuaro where we will get our Mexican insurance. Once we are properly insured we will continue south on Mexico Highway 5 to San Felipe (see map) and then on farther south on dirt roads for about 33 miles to the CSUN Los Pulpos Science Station. Hopefully, we will arrive before dark to set up camp, enjoy the beach, and cook a simple, but filling, beef stew dinner.

Weather — Winter in the desert can be extremely variable. It could be warm, it could be cold; it might be dry, it might rain; it could be calm, or it could be very windy. Come prepared for any eventuality.

Accommodations — The CSUN Los Pulpos Science Station is very primitive. Essentially it's just a storage shed where a modest amount of equipment is kept. There are outhouse facilities, but there is no water of any kind; we have to bring all of our water. Sleeping will have to be done in tents, and cooking will be outdoors. Basically, we will be camping out!

What to bring — Be prepared, but conservative. We do not have room to transport large volumes of personal gear. Do **not** bring an ice chest. Suggested items for your consideration include:

Money (cash or check made out to CSUN Geology Department equal to $45.00 minus the amount of your deposit, plus money for snacks, souvenirs, and dinner on the way home)

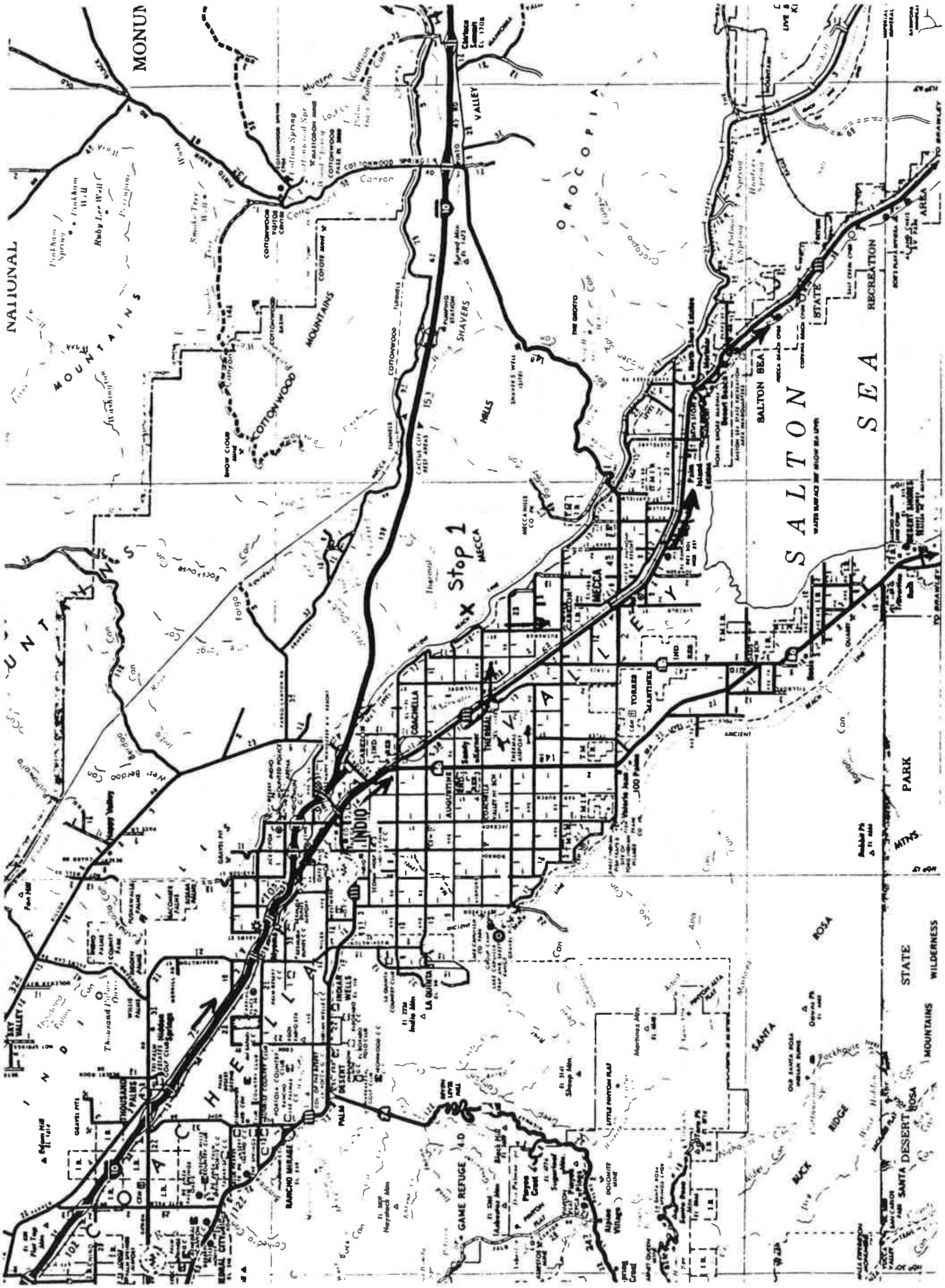
One lunch for Wednesday (all other meals will be provided)
Water bottles (2 liters total) — to be filled **before** leaving CSUN

Tent, with rainfly
Sleeping bag (warm winter bag)
Sleeping pad (not a huge, thick foam mattress)

Clothes (sufficient for four days, including warm coat, hat, and gloves, and perhaps a swimming suit)
Shoes for field work
Rainwear

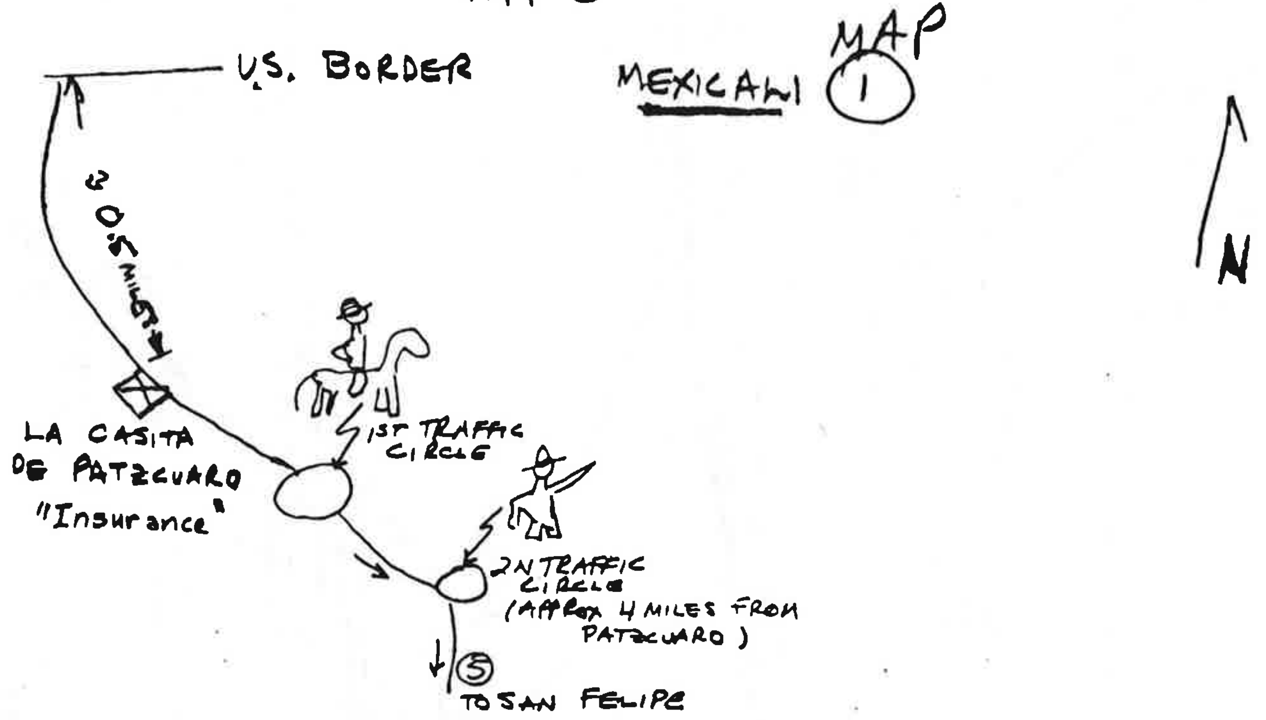
Plate, bowl (essential for this trip), cup, and utensils
Towel and toiletries (especially toilet paper, toothbrush and paste, suntan lotion, hand lotion, and chapstick)
Any prescribed medicine that you need

Optional equipment:
  Day pack
  Hammer and hand lens
  Dark glasses
  Flashlight
  Camera and film
  Binoculars
  Notebook and pencil


NATIONAL MONUMENT
COTTONWOOD MOUNTAINS
OROCOPIA
SHAVERS VALLEY
HILLS
Stop 1
MECCA
THERMAL
COACHELLA
INDIO
LA QUINTA
INDIAN WELLS
PALM DESERT
RANCHO MIRAGE
THOUSAND PALMS
SALTON SEA
SALTON SEA STATE RECREATION AREA
DESERT SHORES
SANTA ROSA
SANTA ROSA MOUNTAINS STATE WILDERNESS
GAME REFUGE
BUCK RIDGE
SANTA DESERT ROSA
PARK
TO BRAWLEY

MAPS

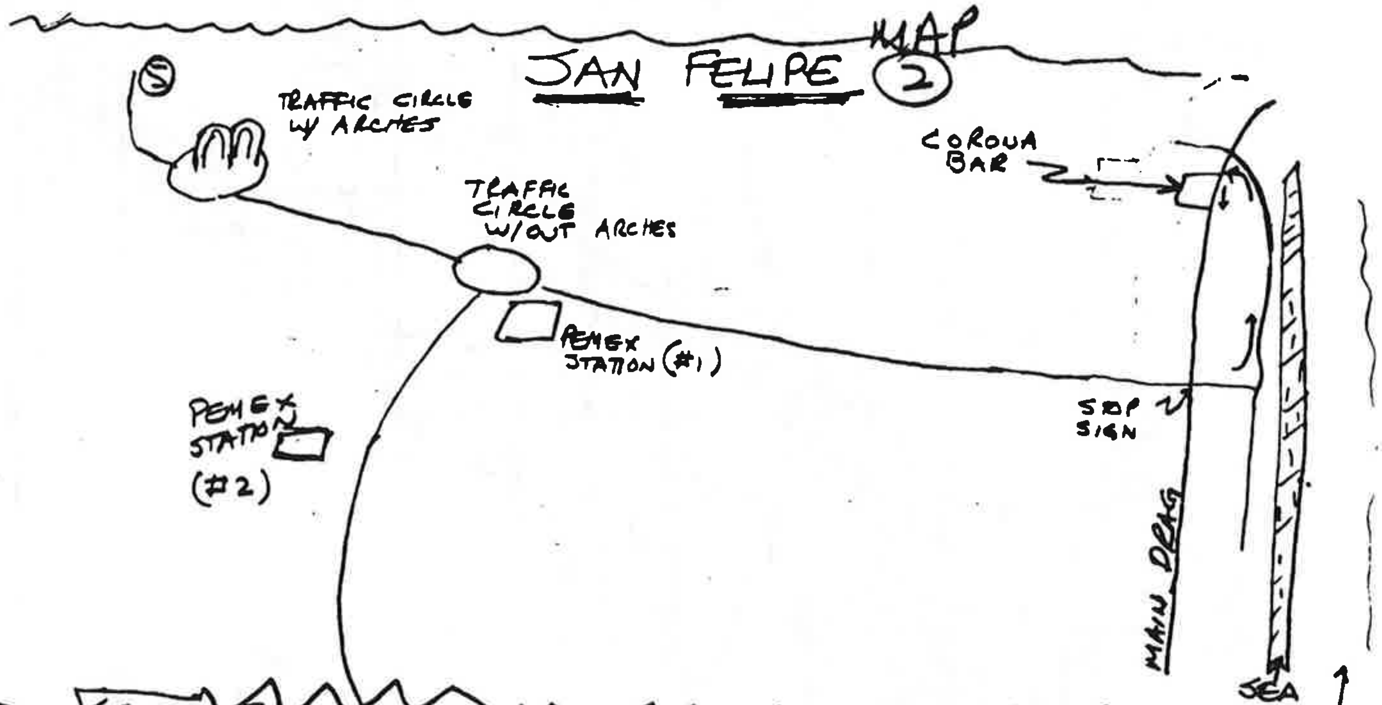
MEXICALI MAP ①



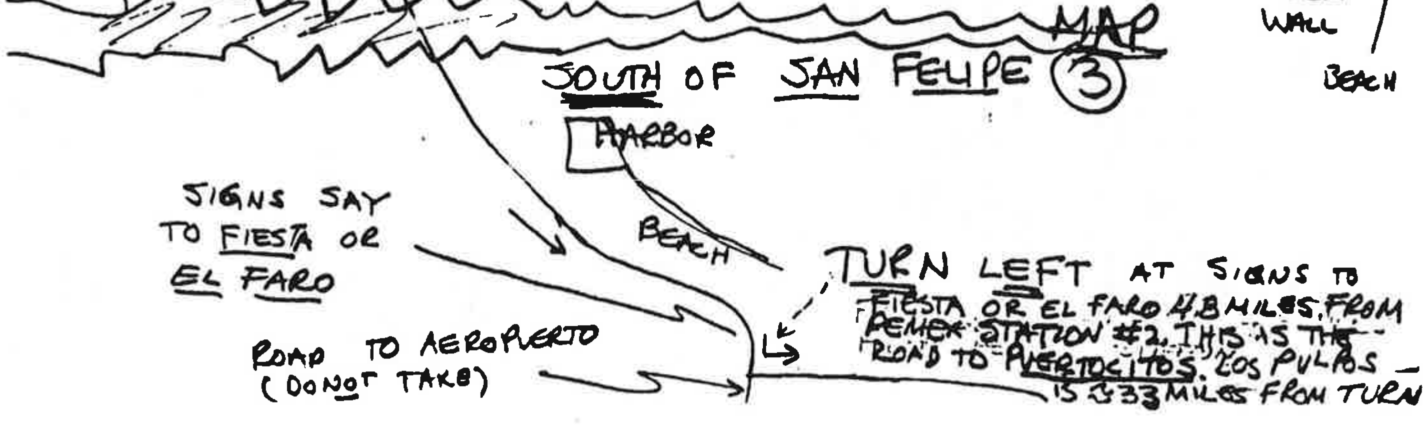
(APPROX 4 MILES FROM PATZCUARO)

TO SAN FELIPE

SAN FELIPE MAP ②



SOUTH OF SAN FELIPE MAP ③



SIGNS SAY TO FIESTA OR EL FARO

ROAD TO AEROPUERTO (DO NOT TAKE)

TURN LEFT AT SIGNS TO FIESTA OR EL FARO 4.8 MILES FROM PEMEX STATION #2. THIS IS THE ROAD TO PUERTOCITOS. LOS PULPOS IS 33 MILES FROM TURN

RULES AND INFORMATION FOR THE SCIENCE STATION AT LOS PULPOS, B.C.

The field station at Los Pulpos is a science station and has no other function.

1. Camp only within the area indicated by the instructor or the owner ([illegible]iva)
2. Unload the vehicle at the station and then park them on top of the hill.
3. At night, keep the noise down. Other property owners have complained. Also students will have to get up at approximately 6 am, and they need their rest.
4. No illegal drugs (controlled substances), no fire works, or guns.
5. The tables are for class material or cooking.
6. There will be bags for burnable and non-burnable garbage. Please separate the garbage.
7. Don't go off into the desert or swim by yourself. If you walk in the desert, take water with you.
8. Keep an eye out for scorpions and rattlesnakes.
9. When walking or swimming over sandy areas, be sure to shuffle your feet. Sting rays do occur.
10. Take no live specimens unless instructed to do so by the professor. Be careful of the small red octopus. They bite.
11. If you have an accident or injury, inform the instructor.
12. Use only your own equipment unless you have permission from the owner.
13. Before leaving, Clean your area and the station. Everyone will leave together.
14. To go to the garbage dump, go to the main road and turn left. Then take a right turn (approx. 50 meters). Follow the road to the left to the dumping pit.

Muchas gracias!

Geologic Structure, Transpression, and Neotectonics of the San Andreas Fault in the Salton Trough, California

Part 2

The Bishop Ash Bed in the Mecca Hills [1]

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in Walawender, M. J., and Hanan, B. B., 1991, Geological excursions in southern California and Mexico: San Diego State University, Department of Geological Sciences, 515 p.

STRUCTURAL SETTING

The dominant structural feature in the Mecca Hills is the right-lateral strike-slip San Andreas fault (Figs. 1, 2). The San Andreas fault has displaced all the above-mentioned late Cenozoic deposits. The San Andreas is marked by thick sections of fault gouge, widely divergent dips on opposite sides of the fault, and abundant geomorphic features (Clark, 1984). Sections of fault gouge are commonly exposed only on the southwest side of the fault. Sites southwest of Stop 3 and the area labeled 'not mapped' (Fig. 2) contain red-brown clay gouge along with extensively sheared strata of the Palm Spring Formation.

Northeast of and subparallel to the San Andreas fault is the Skeleton Canyon fault, which is characterized by a 1- to 6-m-thick section of red-brown fault gouge. Slip along the Skeleton Canyon fault is dextral with a component of fault-normal compression. The Skeleton Canyon fault, like the San Andreas, has contrasting rock types along much of its length (Fig. 2; Sylvester and Smith, 1976). Within about 400 m of its exposed northwestern end, the Skeleton Canyon fault is composed of two branch faults (Figs. 2, 3).

Folds developed in the Mecca Hills are in one of two general orientations. Orientations are either approximately west-northwesterly or northwesterly, subparallel to the San Andreas fault. Folds of the former orientation are located on Mecca Hill and are described by Sylvester and Smith (1976). Nearly all folds developed in the upper Palm Spring Formation in the area of Figure 2 are subparallel to the San Andreas fault.

The most pronounced of the more fault-parallel folds is the syncline northeast of the Skeleton Canyon fault. This syncline has a length of at least 7 km, extending through upper Palm Spring and Ocotillo strata. Throughout most of its length it maintains a nearly constant distance from the San Andreas fault and is always strongly asymmetric, with the more steeply dipping beds on the southwest limb. QTpu and Qo strata northwest of Thermal Canyon have dips as great as 45° on the southwest limb. Folding that produced this syncline has significantly affected the Bishop ash bed; the strong asymmetry of the syncline has forced bedding-plane thrusts to locally repeat strata (see Stops 6 and 7, below).

BRIEF DISCUSSION

Exposures of the Bishop ash bed in the Mecca Hills aid stratigraphic correlations in the region. The Bishop ash bed elsewhere in the Coachella Valley is similarly near the top of the upper Palm Spring Formation, except at Durmid Hill,

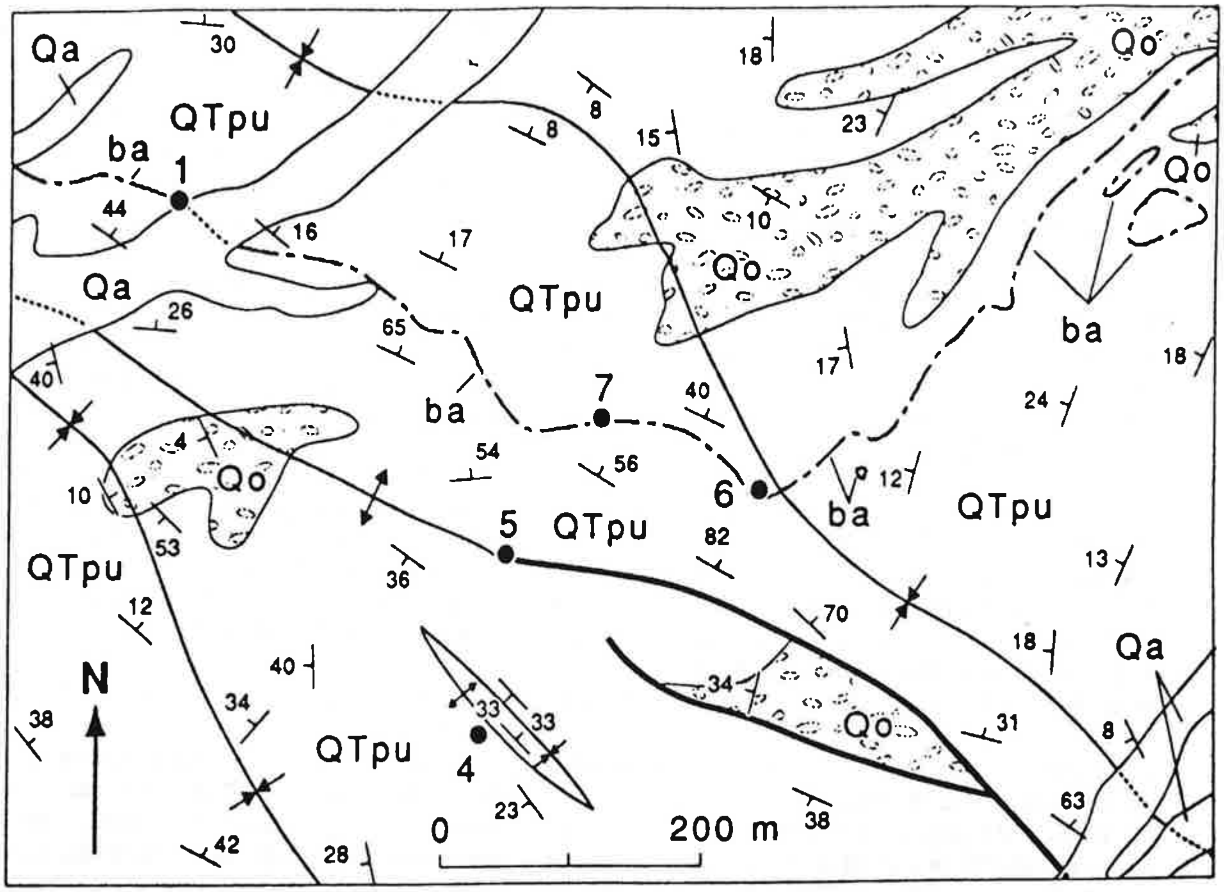

Figure 3. Sketch geologic map showing details of Bishop ash bed exposed in the northwestern part of the Mecca Hills (see Fig. 2 for location). Units and unit labels same as in Figure 2, except for introduction of Qo, Pleistocene Ocotillo Conglomerate. Geology by M.J. Rymer, 1990-1991.

where it is in the Borrego Formation, a lacustrine equivalent of the Palm Spring Formation (Babcock, 1969, 1974; Sarna-Wojcicki and others, 1984). The Bishop ash bed near the top of the upper Palm Spring Formation also indicates that deposition of the Palm Spring in this part of the Salton Trough ceased shortly after 0.74 Ma, or in the mid-Pleistocene, and deposition of the unconformably overlying Ocotillo Conglomerate began shortly after 0.74 Ma. These ages, albeit imprecise, further constrain the timing of folding, uplift, and erosion of the QTpu to the period before deposition of the Qo. One caveat on the timing of folding is that Qo deposits overlying uplifted and eroded QTpu strata are also folded, but to a lesser extent (Fig. 3). Thus, there was a major pulse of uplift and folding that later decreased in magnitude after deposition of the Qo.

Although the stratiform Bishop ash bed cannot be used directly to determine lateral offset along the San Andreas or other strike-slip faults, mapping details of depositional environments at exposures of the Bishop ash bed throughout the Coachella Valley increases understanding of the paleogeography at 0.74 Ma. Detailed descriptions of the stratigraphic thickness, sedimentary structures, color, and other sedimentary or environmental featues can descriminate unique settings. To date, the approximately 15 mapped exposures of the Bishop ash bed in the Coachella Valley represent lacustrine, calm-water fluvial, more energetic fluvial, and even alluvial-fan deposition, but no clear across-fault matches. Continued fieldwork in the region is aimed at resolving these problems.

FIELD GUIDE

STOP 1—BISHOP ASH

The Bishop ash exposed at this site consists of fresh glass shards and is interbedded with ponded and calm-water fluvial deposits of the upper Palm Spring Formation. The ash is white, about 32 cm thick, and easily eroded. The exposure lies on the southwest limb of a northwest-trending syncline that parallels the San Andreas fault for more than 7 km. [We will visit exposures of this asymmetric syncline later in the trip.] Other fold axes, all of which are subparallel to the San Andreas fault (Figs 2, 3), are visible from this site.

STOP 2—LATE PLEISTOCENE FOLDS

About 0.7 km farther into the canyon we are between an anticline-syncline pair. The folds bring into view additional exposures of the Bishop ash bed (Fig. 5), as do other folds farther to the southeast (Fig. 2). At the time of deposition the Bishop ash bed was fairly flatlying, an interpretation based on sedimentary structures and inferred depositional environments. Thus, the present configuration of the Bishop ash bed developed since deposition at about 0.74 Ma. The folds also can be seen to warp the locally unconformably overlying Ocotillo Conglomerate, further indicating recency of fold development. While leaving the canyon, notice that about 0.3 km downstream there is only spotty preservation of the Bishop ash bed where it was deposited on sites of later erosion. These exposures are on the northwest side of the canyon between Stops 1 and 2 (Fig. 2).

STOP 3—SAN ANDREAS FAULT AND ANGULAR UNCONFORMITY BETWEEN QTpa AND QTpu

A thick section of red-brown clay gouge associated with the San Andreas fault is exposed on the north side of the wash. An entrenched subsidiary stream and contrasting lithologies are present along the San Andreas fault on the south side of the wash. This site had sympathetic or triggered surface slip of a few millimeters after the nearby 1968 Borrego Mountain earthquake (Allen and others, 1972) and the 1979 Imperial Valley earthquake (Sieh, 1982).

Also notice the angular unconformity between the older, steeply dipping QTpa (dips of up to 83°) and the younger, more gently dipping QTpu (dips of 35° to 42°). Unconformities between these two units are present elsewhere in the Coachella Valley, likewise the two units are locally in depositional contact, most abundantly in the Indio Hills.

STOP 4—CONVERGENT FOLDS

While walking up the small side gully to Stops 5 through 7, we pass rather tightly folded strata in QTpu. Folds here comprise an anticline-syncline pair that cancel one another by convergence at both northwest and southeast ends. This fold pair exemplifies the tight San Andreas-parallel folding of the region. Folds parallel the San Andreas fault for several kilometers to the northwest and southeast from this site (Fig. 3). [Other fold sets in the area are oriented more westerly, as described by Sylvester and Smith (1976).]

STOP 5—SKELETON CANYON FAULT AND ITS TERMINATION

The Skeleton Canyon fault in the area is marked by a 1- to 6-m-thick zone of red-brown fault gouge. At this stop the fault consists of two strands. The more northerly is aligned with an anticline that extends farther to the northwest in the QTpu (Fig. 3). Slip along the Skeleton Canyon fault in the QTpu is constrained to about 30 m worth of QTpu deposition before airfall of the 0.74 Ma Bishop ash bed. However, the anticline that extends farther to the northwest is at least in part younger than the Bishop ash bed because the unconformably overlying Qo is also folded (Fig. 3).

STOP 6—STRUCTURAL REPETITION OF THE BISHOP ASH BED

At this stop the Bishop ash bed is repeated by faulting (Fig. 6A). Only one bed of Bishop ash was deposited in the Coachella Valley, similar to at other sites in the western U.S. (Izett and others, 1988). However, at this stop two 62-cm-thick beds are present. Slickensides on the bottom of the structurally higher bed indicate bedding-plane thrust movement has repeated the section (Figs. 6B to D). Grooves in the slickensides trend southwest, normal in plan view to the strongly asymmetric syncline seen at Stop 1 (see also Figs. 2, 3). Tight folding of the syncline apparently caused compression and repetition of strata, with the base of the Bishop ash bed acting as the slip plane. About 20 m to the southeast a four-fold exposure of the Bishop ash bed results where the doubled ash bed shown in Figure 6A is tightly folded.

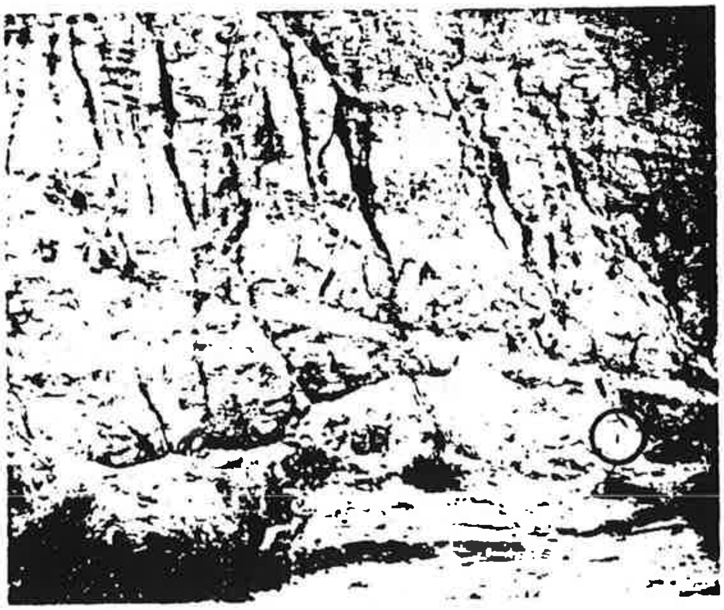

Figure 5. Bishop ash bed as exposed in canyon wall. Note rock pick (circled) for scale.

STOP 7—MULTIPLE BEDDING-PLANE THRUSTS ALONG BASE OF THE BISHOP ASH BED

Nearly complete stratal exposure present in the Mecca Hills reveals fault, fold, and thrust complexities that are seldom seen, even though they may be widespread. At this stop the Bishop ash bed is repeated in a much more complicated fashion than that at Stop 6. Figure 7 shows multiple bedding-plane thrusts and semi-bedding-plane dislocations developed along the base of the Bishop ash bed. Along most of the 'ramp' where the ash bed is subhorizontal in this view, faulting at the base of the Bishop ash bed has truncated the underlying strata (Fig. 7). Multiple beds of the Bishop verge upward from this thrust to where they die out. Short sections of the Bishop are involved in folds above the main thrust. The most prominent bed of

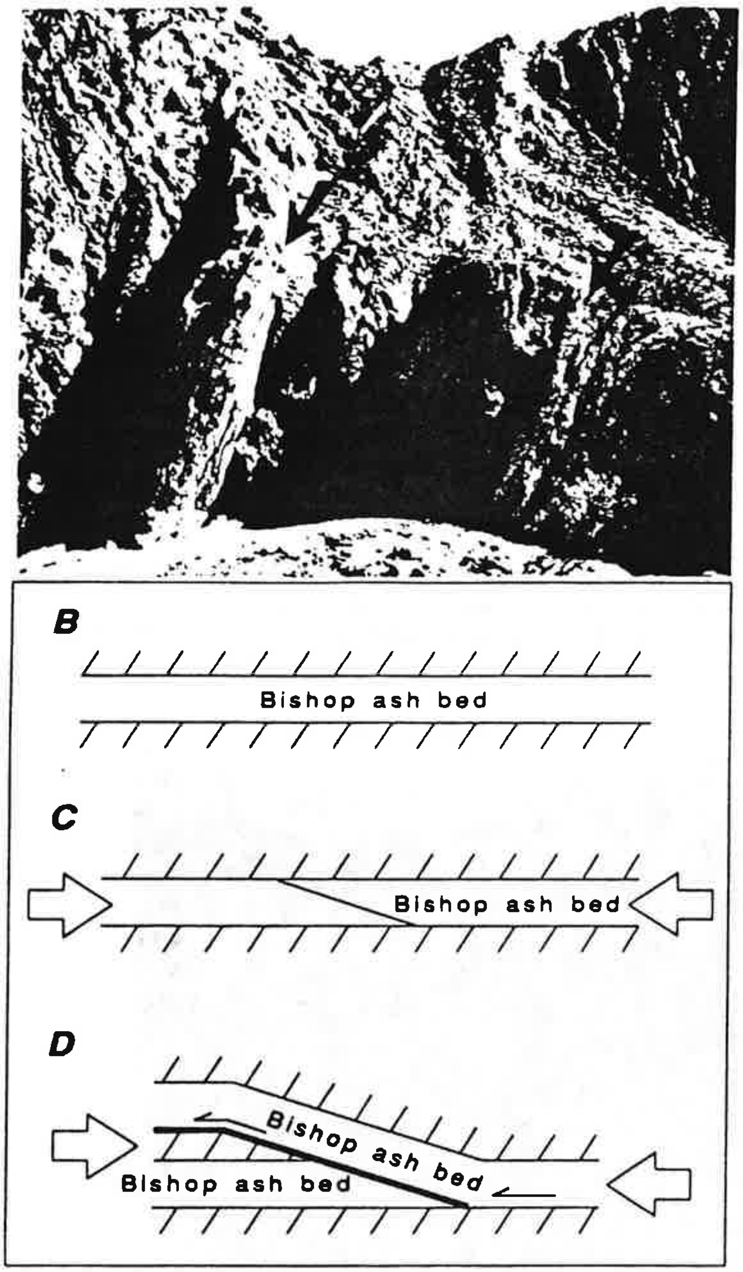

Figure 6. Fault-repeated Bishop ash bed at Stop 6 (Figs. 2, 3). A Photograph of exposure, view to the southeast. Slickensides on the bottom of the structurally higher ash bed suggest movement normal to nearby synclinal axis. Arrows mark location of Bishop ash beds; note rock pick (circled) for scale. B to D interpretive cross-sectional view showing origin of repeated ash bed seen in A. Heavy line in D is fault, or slip, plane.

Bishop ash, the one that extends to the northwest, is the one shown farthest to the west in Figure 7. The Bishop ash bed is repeated only for a short distance; approximately between Stops 1 and 6, and lies only on the southwest limb of the nearby asymmetric syncline (see Fig. 8 for another view of this fold). Apparently, fold development caused sufficient compression on the steeply dipping southwest limb of the syncline that slip occurred along the weak (or water-saturated) Bishop ash bedding plane. An interesting facet of this setting is that most the folding is constrained to between 0.74 Ma and the time of deposition of the Ocotillo Conglomerate. Thus, there was very localized, but intense, folding during the QTpu-Qo depositional time span in this part of the Mecca Hills.

STOP 8 (OPTIONAL)—ANGULAR UNCONFORMITY BETWEEN QTpl AND QTpu

Drive or walk up the middle of three washes (Figs. 2, 4) to see good exposure of the angular unconformity between QTpl and QTpu. The difference between the better lithified, coarser grained, and more conglomeratic QTpl relative to the QTpu is quite apparent. Also note the difference in styles of erosion in the two units; QTpl, because of its greater resistance, forms steep-walled canyons with local precipitous dropoffs along stream courses.

STOP 9 (OPTIONAL)—SMALL-DISPLACEMENT FAULTS IN BRITTLE QTpl

Walk up (cars cannot pass through this narrow canyon) the more southeasterly of the three washes to reach Stop 9. Deep canyons are typical of the QTpl in the Mecca Hills, and within them one can see abundant evidence of small-displacement, steeply inclined faults (Fig. 4). These faults, easily recognized in the thick-bedded and well-cemented QTpl, commonly delineate topographic lows because the sheared rock along the faults permit rapid erosion. Individual faults are from about 1 to 5 m wide and consist of nested slip planes. Locally a plane of fault gouge may be seen in a set of fractures in one of the faults. Slickensides and mullions on slip planes indicate approximately horizontal motion. Some cracks may be joints, but most show demonstrable offset and hence are faults.

STOP 10 (OPTIONAL)—GEOMORPHIC FEATURES ALONG THE SAN ANDREAS FAULT

After exiting the Mecca Hills, turn north along the Riverside County borrow-pit road to intersect the main trace of the San Andreas fault. Park and walk along the fault to see geomorphic features created by recent right-lateral movement along the San Andreas. Remember, these features are developed in Holocene alluvium. Some of the many features to be seen are deflected alluvial-fan channels, both northeast- and southwest-facing scarps, and small grabens. Clark (1984) mapped and described many of these features.

REFERENCES CITED

Allen, C.R., Wyss, M., Brune, J.N., Grantz, A., and Wallace, R.E., 1972, Displacement on the Imperial, Superstition Hills, and San Andreas faults triggered by the Borrego Mountain earthquake, in The Borrego Mountain earth-

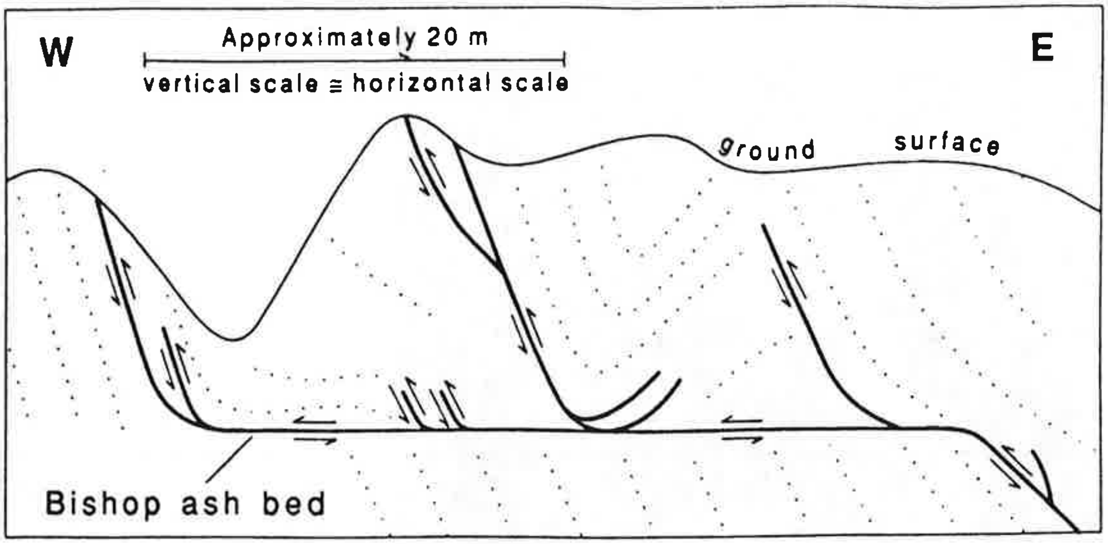

Figure 7. Multiple bedding-plane thrusts along base of Bishop ash bed, Stop 7 (Fig. 2). Field sketch of bedding (dotted lines) and multiple exposures of Bishop ash bed. Small arrows indicate inferred faulting directions. Slip plane would be at base of Bishop ash bed as in Figure 6D. Westernmost bed of Bishop ash is the one that extends to the northwest on other side of ridge.

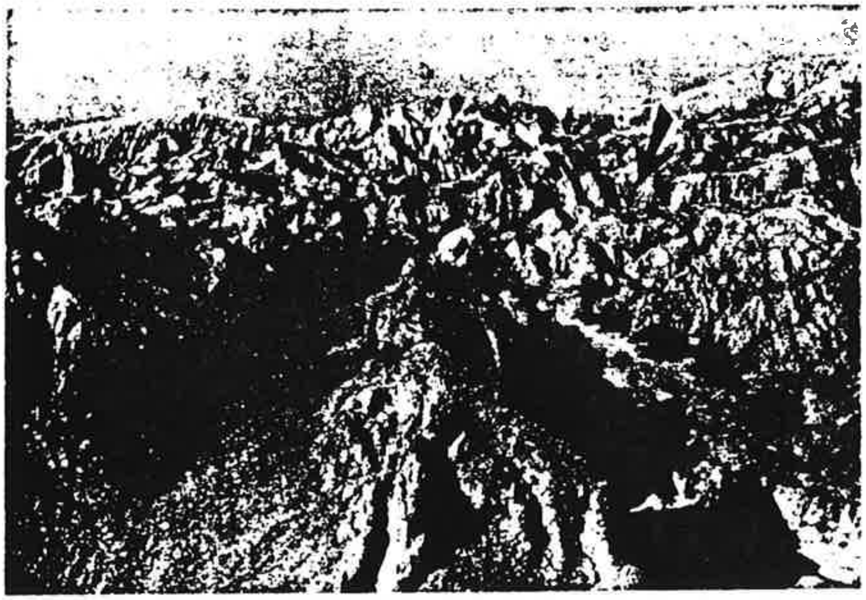

Figure 8. Northwest view of the Skeleton Canyon fault with red-brown (dark gray) fault gouge in bottom left of view to midground. Farther to the northwest the surface fault becomes an anticline (see geologic map, Fig. 3). Also present in this view are exposures of the Bishop ash bed, including Stops 6 and 7 (Figs. 3, 6, 7). The asymmetric syncline with steep dips (up to 86°) on the southwest side of the fold axis is located northeast of the Skeleton Canyon fault (arrow, compare with Fig. 3).

quake of April 9, 1968: U.S. Geological Survey Professional Paper 787, p. 87–104.

Babcock, E.A., 1969, Structural geology and geophysics of the Durmid area, Imperial Valley, California [Ph.D. thesis]: Riverside, University of California, 149 p.

_____ 1974, Geology of the northeast margin of the Salton Trough, Salton Sea, California: Geological Society of America Bulletin, v. 85, p. 321–332.

Chang, S.-B.R., Allen, C.R., and Kirshvink, J.L., 1987, Magnetic stratigraphy and a test for block rotation of sedimentary rocks within the San Andreas fault zone, Mecca Hills, southeastern California: Quaternary Research, v. 27, p. 30–40.

Clark, M.M., 1984, Map showing recently active breaks along the San Andreas fault and associated faults between Salton Sea and Whitewater River-Mission Creek, Cali-

AN OVERVIEW OF THE LITHOSTRATIGRAPHY, BIOSTRATIGRAPHY, AND PALEOENVIRONMENTS OF THE LATE NEOGENE SAN FELIPE MARINE SEQUENCE, BAJA CALIFORNIA, MEXICO

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ABSTRACT

The San Felipe marine sequence is a series of bathyal to littoral marine sediments originally deposited at the northwestern limits of the Protogulf and Gulf of California embayment from late Miocene through Pleistocene time. This sequence is unique in that it the only known sedimentary section in the Gulf north of Isla Maria Madre which contains unequivocal Miocene age Protogulf marine sediments.

Lithostratigraphic and biostratigraphic analyses of the sequence indicate that the basal San Felipe Diatomite Member of the Llano el Moreno Formation was being deposited in the Sierra San Felipe-Sierra Santa Rosa Basin at middle bathyal depths under dysaerobic conditions, before 6.0 m.a.. The modern San Pedro Martir Basin is a good analog for this Protogulf basin. The aggregate stratigraphic thickness of the Diatomite Member is over 30 m.

Increased volcanic activity and global climatic deterioration around 5.0 m.a. resulted in gradual diminution of primary productivity and supplantation of waning siliceous biogenic rain with hemipelagic volcaniclastic sediment. The contact between the Diatomite and Mudstone Members is thus a gradational one. In addition to this major change in sediment character, paleontologic and sedimentologic evidence shows that deposition of the Mudstone Member occured under progressively more aerobic conditions and records a shoaling to uppermost middle bathyal depths by late Pliocene time. Total thickness of the Mudstone Member is nearly 65 m.

Rapid uplift to shelfal depths, an increase in sediment size, a major change in sediment provenance, and a marked angular unconformity signal the initiation of Gulf of California transtensional rifting and Salada Formation deposition around 3.0 m.a.. An aggregate thickness of over 250 m of Salada Formation clastics occur in the San Felipe marine sequence area.

Continued tectonic adjustments and rapid sedimentation rates during the late Pliocene led to subaerial emergence and erosion. Subsequent folding and faulting of coastal NE Baja, including the marine sequence area, related to continuing Gulf rifting, has occured since latest Pliocene time.

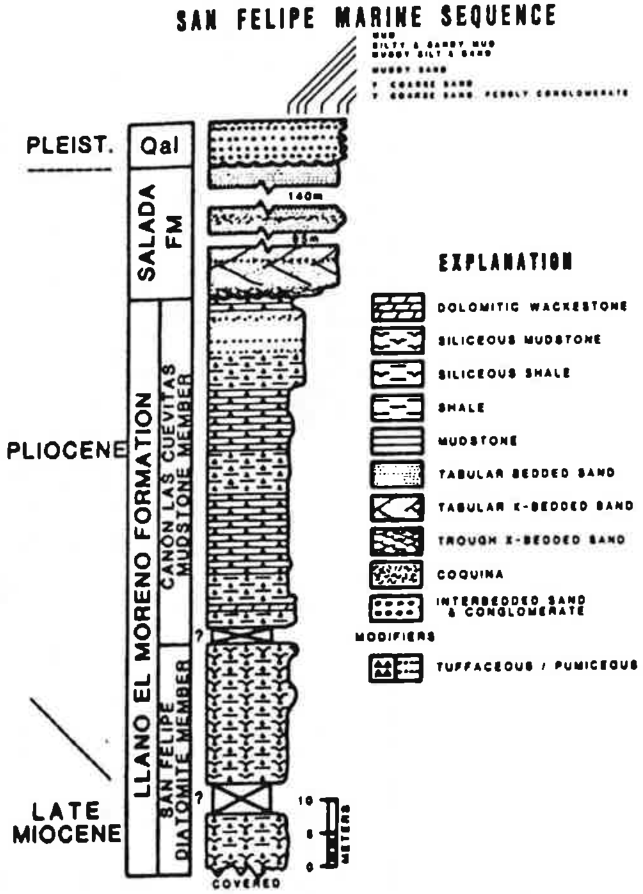


Figure 3. Stratigraphic column for the San Felipe marine sequence, Baja California, Mexico. Stratigraphic position of sample locations is indicated. Composite section is located in Area I of Figure 2.

in Frizzell, Virgil A. Jr., ed., 1984, **Geology of the Baja California Peninsula**: Pacific Section S.E.P.M., Vol. 39, p. 253-265

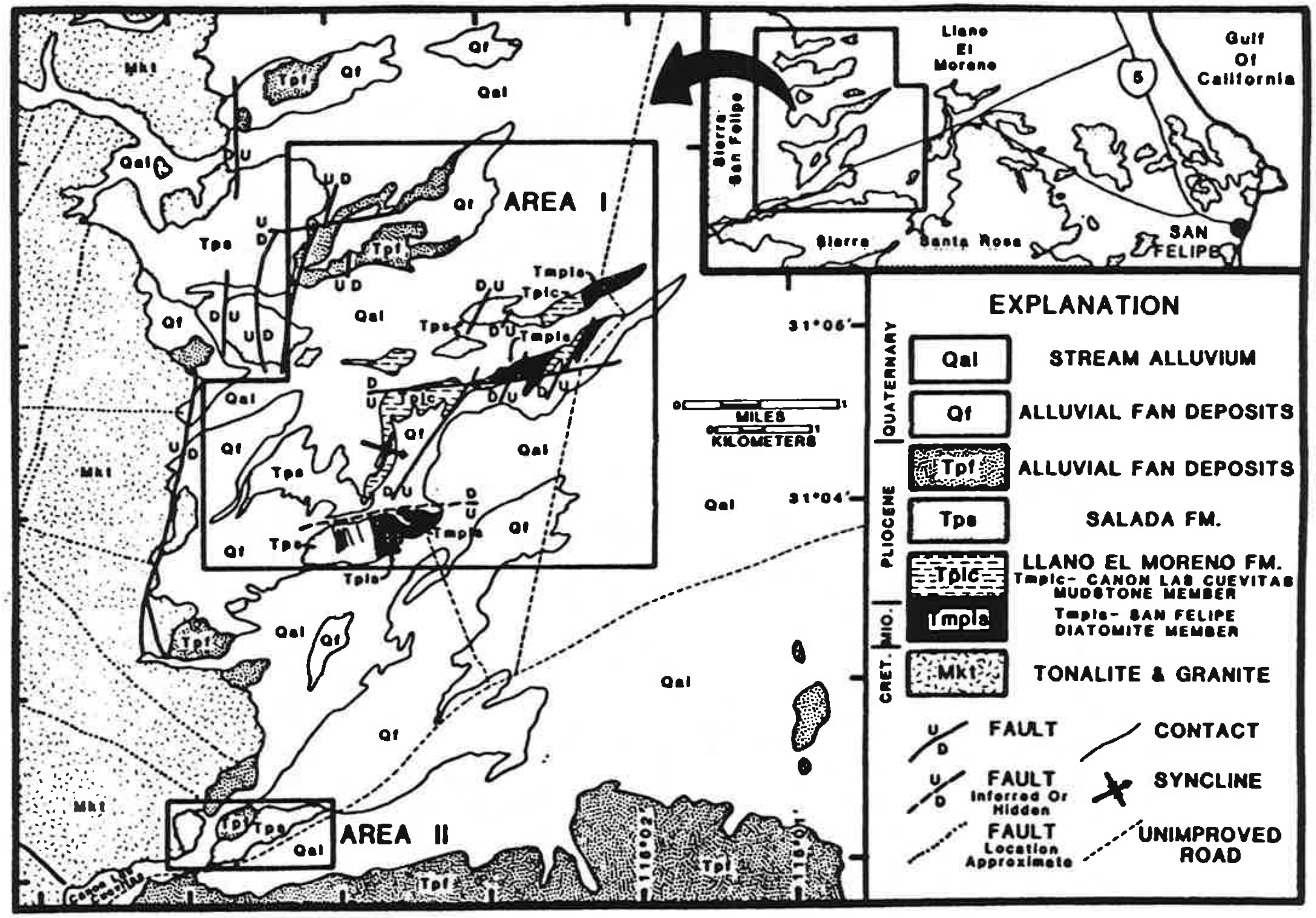
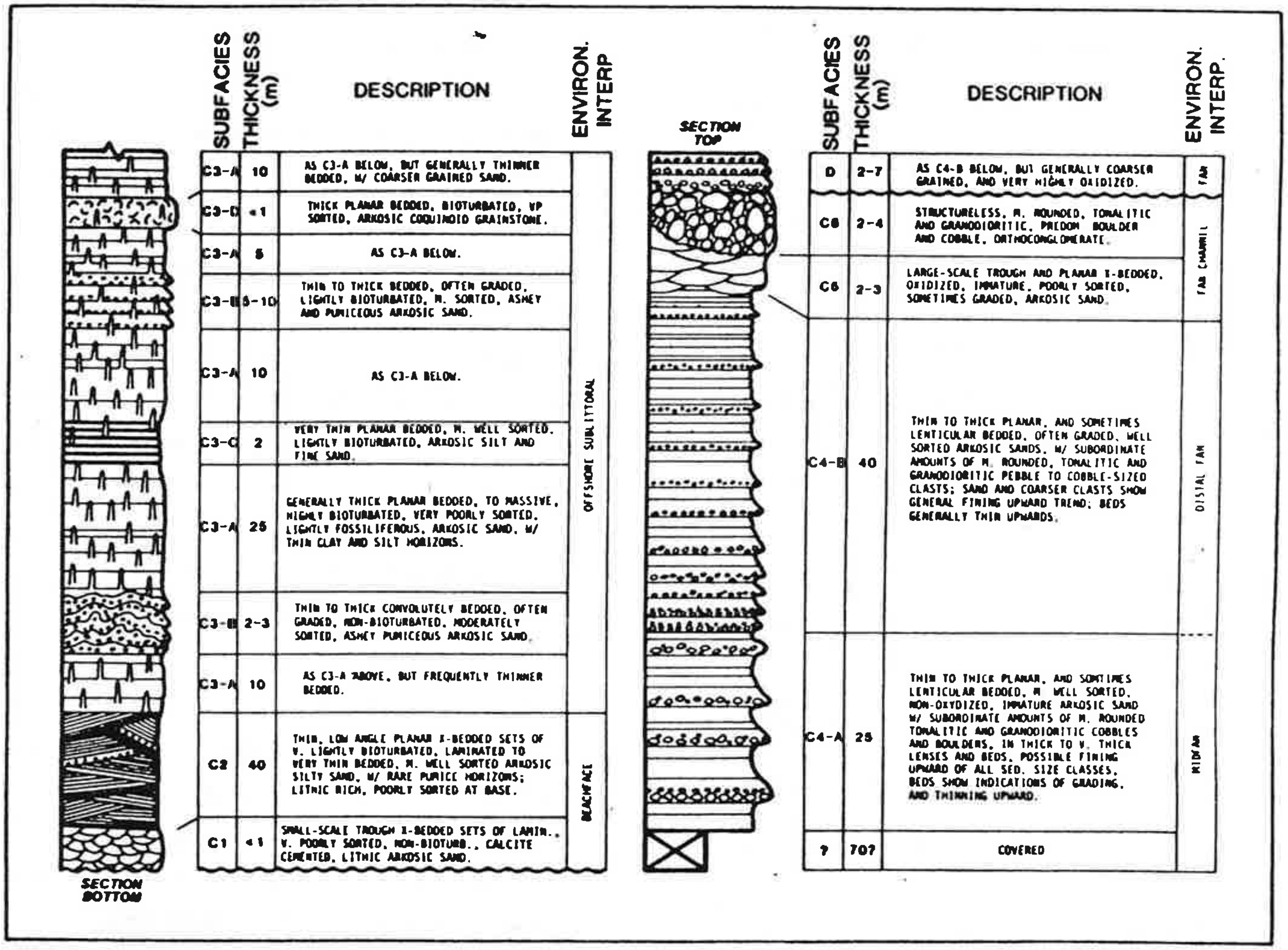


Figure 2: General geologic and location map of the southwestern Llano el Moreno region, Baja California, Mexico. The composite stratigraphic column shown in figure 3 is for Area I. For detailed geology and sample locations, see Boehm (1982).



SUBFACIES	THICKNESS (m)	DESCRIPTION	ENVIRON. INTERP
C3-A	10	AS C3-A BELOW, BUT GENERALLY THINNER BEDDED, W/ COARSER GRAINED SAND.	OFFSHORE SUBLITTORAL
C3-D	<1	THICK PLANAR BEDDED, BIOTURBATED, VP SORTED, ARKOSIC COQUINOID GRAINSTONE.	
C3-A	5	AS C3-A BELOW.	
C3-B	5-10	THIN TO THICK BEDDED, OFTEN GRADED, LIGHTLY BIOTURBATED, M. SORTED, ASHEY AND PUMICEOUS ARKOSIC SAND.	
C3-A	10	AS C3-A BELOW.	
C3-C	2	VERY THIN PLANAR BEDDED, M. WELL SORTED, LIGHTLY BIOTURBATED, ARKOSIC SILT AND FINE SAND.	
C3-A	25	GENERALLY THICK PLANAR BEDDED, TO MASSIVE, HIGHLY BIOTURBATED, VERY POORLY SORTED, LIGHTLY FOSSILIFEROUS, ARKOSIC SAND, W/ THIN CLAY AND SILT HORIZONS.	
C3-B	2-3	THIN TO THICK CONVOLUTELY BEDDED, OFTEN GRADED, NON-BIOTURBATED, MODERATELY SORTED, ASHEY PUMICEOUS ARKOSIC SAND.	
C3-A	10	AS C3-A ABOVE, BUT FREQUENTLY THINNER BEDDED.	
C2	40	THIN, LOW ANGLE PLANAR X-BEDDED SETS OF V. LIGHTLY BIOTURBATED, LAMINATED TO VERY THIN BEDDED, M. WELL SORTED ARKOSIC SILTY SAND, W/ RARE PUMICE HORIZONS; LITHIC RICH, POORLY SORTED AT BASE.	BEACHFACE
C1	<1	SMALL-SCALE TROUGH X-BEDDED SETS OF LAMIN., V. POORLY SORTED, NON-BIOTURB., CALCITE CEMENTED, LITHIC ARKOSIC SAND.	

SUBFACIES	THICKNESS (m)	DESCRIPTION	ENVIRON. INTERP.
D	2-7	AS C4-B BELOW, BUT GENERALLY COARSER GRAINED, AND VERY HIGHLY OXIDIZED.	FAN
C6	2-4	STRUCTURELESS, M. ROUNDED, TONALITIC AND GRANODIORITIC, PREDOM. BOULDER AND COBBLE, ORTHOCONGLOMERATE.	FAN CHANNEL
C6	2-3	LARGE-SCALE TROUGH AND PLANAR X-BEDDED, OXIDIZED, IMMATURE, POORLY SORTED, SOMETIMES GRADED, ARKOSIC SAND.	
C4-B	40	THIN TO THICK PLANAR, AND SOMETIMES LENTICULAR BEDDED, OFTEN GRADED, WELL SORTED ARKOSIC SANDS, W/ SUBORDINATE AMOUNTS OF M. ROUNDED, TONALITIC AND GRANODIORITIC PEBBLE TO COBBLE-SIZED CLASTS; SAND AND COARSER CLASTS SHOW GENERAL FINING UPWARD TREND; BEDS GENERALLY THIN UPWARDS.	DISTAL FAN
C4-A	25	THIN TO THICK PLANAR, AND SOMTIMES LENTICULAR BEDDED, M. WELL SORTED, NON-OXYDIZED, IMMATURE ARKOSIC SAND W/ SUBORDINATE AMOUNTS OF M. ROUNDED TONALITIC AND GRANODIORITIC COBBLES AND BOULDERS, IN THICK TO V. THICK LENSES AND BEDS, POSSIBLE FINING UPWARD OF ALL SED. SIZE CLASSES, BEDS SHOW INDICATIONS OF GRADING, AND THINNING UPWARD.	MIDFAN
?	70?	COVERED	

Figure 4: Detailed composite stratigraphic column for the upper 250 meters of the San Felipe marine sequence, including the Salada Formation and Quaternary alluvium (from Boehm, 1982).

From thesis of Robert Anderson (1973) SDSU

Pliocene marine deposits (Tpm) occur along the western and southern margins of the basin. The deposits range from silty fine-grained fossiliferous buff to tan tidal flat deposits, fossiliferous gray brackish water mudstones to fossiliferous marine conglomeratic sandstone beds containing abundant cobble to boulder-sized clasts of locally derived granitic material. Fossils from the Pliocene strata are listed in Table 3.

Pliocene marine strata are well known from the Gulf of California area: Salada Formation (Heim, 1922), and San Marcos Carmen and Marquer Formations (Touwaide, 1930). Marine Pliocene strata are also documented from the Imperial Valley depression: Imperial Formation (Hanna, 1926; and Allison, 1964); and the Bouse Formation (Metzger, 1968; and Smith, 1970).

The Pliocene marine outcrops located west of the north end of the Sierra Santa Rosa (fossil localities B6G-29 and B6B-159, Figure 17, page 57) contain a diverse molluscan fauna. In this area the unit unconformably overlies Miocene diatomaceous siltstone. Three stratigraphic members were recognized in the area; however, they were grouped together for mapping purposes. The lower member is a mudstone containing a varied oyster fauna. The intermediate member is a varied conglomerate, gritstone, sandstone, and siltstone unit containing varied neritic mollusk faunas. The upper member is composed of siltstone, fine-grained sandstone, and conglomerate stringers and includes a restricted echinoid and oyster fauna.

The lower member is typically buff to gray

Pliocene Fossil Occurrences

	B6G-27	B6G-29	B6G-41	B6A-65&66	B6B-79	B6B-159	B9B-11&12	Figure Nos.
MOLLUSCA								
GASTROPODA								
Architectonica nobilis Bolten, 1798		R			R			30 b 32 c
Bittium asperum (Gabb, 1866)							C	42 f,g
Bulla sp.								
Conus regularis Sowerby, 1833	R						C	30 c,d,e
Conus sp.		R						
Cymatium cf. *C. wiegmanni* (Anton, 1839)							C	32 d
Cyprea sp.		R				R		30 l,m,n
Ficus spl				?			R	31 d
Heliacus sp.							R	42 d
Malea ringens (Swainson, 1822				C				30 i
Malea sp.				C				
Melongena patula (Broderip & Sowerby, 1829)	R							31 a 32 a
Oliva spicata (Bolten, 1798)	C	R					C	30 g,h 30 j,k
Polinicies sp.	R						C	30 f 32 b 42 e
Strombus cf. *S. galeatus* Swainson, 1823							R	33 a
Strombus gracilior Sowerby, 1825	R	R		R			R	30 a 32 h
Strombus cf. *S. granulatus* Hawe, 1823				C			R	32 f,g
Strombus cf. *S. subgracilior* Durham, 1950							C	32 i
Turritella imperialis Hanna, 1926							C	31 c,e
Turritella sp.				C	C		C	
Vassum caestus (Broderip, 1833	R							31 b 32 e
BIVALVIA								
Anadara (A.) cf. *A. famosa* (Sowerby, 1833)	R							36 a

Anadara sp.								
Anatina sp.		R						
Atrina cf. A. maura (Sowerby, 1835)		R						
Dosinia cf. D. ponderosa (Gray, 1838)		C						36 b,c
Dosinia sp.		C						
Lucina cf. L. californica Conrad, 1837		C					A	37 c,d
Lyropecten modulatus (Hertlein, 1925)		C	R				C	38 g,h
Ostrea californica Marcou, 1858		C				R		40 c
Ostrea heermanni Conrad, 1855		C	R	R			C	33 b,c
Ostrea lurida Carpenter, 1853		C						34 a,b
Ostrea megadon Hanley, 1846		A	C					35 b
Ostrea vespertina Conrad, 1854		A	C		C		C	34 c,e,f 35 d
Ostrea sp.							R	37 g
Pecten bosei Hanna & Hertlein, 1927		A	C		A		C	38 c,d
Pecten gibbus (Linnaeus, 1858		C		C			A	35 e 38 e,f
Pecten keepi Arnold, 1906		A					A	38 a,b
Pholadidae						R		35 c
Pinnidae		R				R		35 a
Spondylus victoriae Sowerby, 1859		C	C				R	39 a,b
Tagelus cf. T. affinis (C. B. Adams, 1852)							C	37 e,f
ECHINODERMA ECHINOIDEA								
Clypeaster bowersi Weaver, 1908	R	R				C		
Encope tenuis Kew, 1913	C	A				A	C	40 a,b,d
ARTHROPODA CRUSTACEA								
Balanus sp.*							R	
PROTOZOA SARCODINA								
Elphidium sp.**		X			X			
Globigerina sp.**		X						

A = 10 or more specimens
C = 3 to 9 specimens
R = 1 or 2 specimens
? = tentative identification of very poor specimen

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*Barnacle identified by Arnold Ross, San Diego Museum of Natural History.

**Foraminifera identified by Patsy J. Smith, U.S.G.S., Menlo Park, Calif.

mudstone with local calcareous nodules, sandstone, and conglomerate lenses. The member is highly fossiliferous and several species of oysters have been identified. The most abundant species are two plicated varieties, Ostrea megadon Hanley and O. vespertina Conrad. Other oysters identified are O. californica Marcou, O. heermanni Conrad, and O. lurida Carpenter. All of the species have been reported from the Pliocene Imperial Formation of California or from the Pliocene Salada Formation of Baja California. Ostrea heermanni Conrad, a large thick shelled variety, is considered indicative of the Pliocene and is extremely common in the Imperial Formation. The strata and contained fauna are indicative of brackish water deposits as indicated by Heckel (1972). The thickness of the lower member is approximately 10 meters (33 feet). A list of identified species is provided (Table 3).

The intermediate member is composed of buff, tan, and cream sandstone containing siltstone, gritstone and conglomerate lenses. The lower part is generally more fine-grained than the upper part. The upper part contains coarse-grained sand and conglomerate lenses with abundant mollusk fragments. A diverse mollusk fauna is present in the member. The fauna in the lower part is composed primarily of the bivalve genera Dosinia and *Lucina* with a very few gastropod genera. The middle part of the member is characterized by a diversity of bivalve and gastropod genera that are indicative of a shallow water neritic environment. The fauna of the upper part of the intermediate member is characterized by an abundance of pectenid bivalves, namely *Lyropecten modulatus* (Hertlein), *Pecten bodei* Hanna and Hertlein, *Pecten gibbus* Linnaeus, and *Pecten keepi* Arnold. Another commonly occurring pelecyped in the upper part of the interval is the thick shelled and highly ornate *Spondylus victoriae* Sowerby. Two species of echinoids, *Clypeaster bowersi* Weaver, and *Encope tenuis* Kew, are also present. The strata and fauna indicate an offshore environment that grades upward to near shore and transitional environments. *Pecten keepi* and *Encope tenuis* are indicative of the Pliocene of Imperial Valley, California. The total thickness of the intermediate member in this region is approximately 16 meters (53 feet).

The thick upper member is composed of fossiliferous tan to buff siltstones and sandy siltstones interbedded with unfossiliferous conglomeratic (pebble sized clasts) sandstone. Many of the fossils are fragmental and undiagnostic as to species; however, they indicate the transitional nature of the upper member. Locally common beds of *Encope tenuis* Kew and oysters are present in the member. The upper member is considered to be a progradational sequence of tidal flat, estuarine, and transitional marine and fluvial strata. The thickness is about 45 meters (147 feet).

The combined thickness of the three members of the marine strata in this area is about 71 meters (233 feet).

A somewhat similar sequence of Pliocene marine strata occurs at the southwest end of the basin (fossil localities B9B-11 and B9B-12, Figure 17, page 57). The top of the marine section in this area is a massive oyster reef composed of the thick shelled species, *Ostrea heermanni* Conrad. The base of the marine section is not exposed in this area. The marine section is overlain by Pliocene fanglomerate (Figure 22, page 71, columnar sections #8 and #9). At least 98 meters (300 feet) of Pliocene marine strata are exposed in the southwestern part of the basin. A thin sequence of similar fossiliferous strata is reported a few kilometers to the south (Artin, 1971). Nearly all identified Pliocene megafossils are illustrated (Figures 30 to 40 and 42).

in Walawender, M. J., and Hanan, B. B., 1991, Geological excursions
in southern California and Mexico: San Diego State University,
Department of Geological Sciences, 515 p.

Miocene to Holocene Extensional Tectonics and Volcanic Stratigraphy of NE Baja California, Mexico

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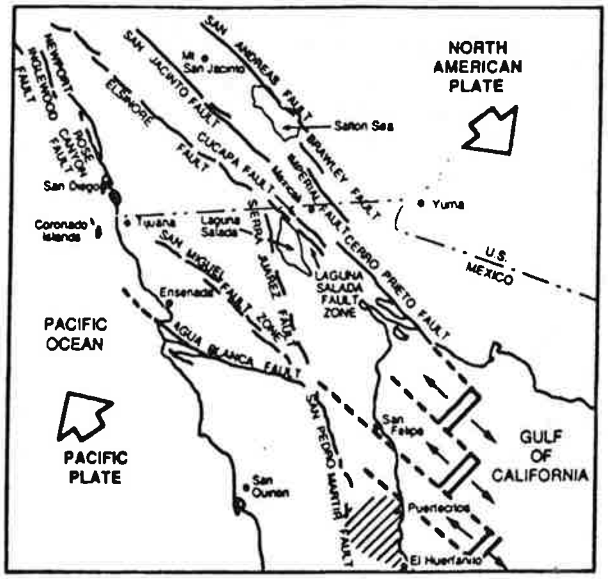


Fig. 1. Major fault systems of southern California and northern Baja California. The region of the Gulf Extensional Province in NE Baja California is shaded; cross-hatching indicates the Puertecitos Volcanic Province.

SIGNIFICANCE

Northeastern Baja California presently experiences active extensional and strike-slip faulting related to the transtensive Pacific-North America plate boundary in the Gulf of California. Some of the active structures are fairly new, whereas others appear to have a movement history as far back as Miocene time. This trip focuses on the history of Miocene to Recent extension, and its relation to the development of the Pacific-North America plate boundary, in the Gulf Extensional Province of NE Baja California. We will see the extensional structures at the latitudes of San Felipe to Puertecitos, and view the stratigraphic relationships of the volcanic and marine rocks that constrain the timing of this extension. Several major structural features are well-exposed here: the Main Gulf Escarpment and its structural variations along strike; the E-W variations in extensional styles within the extensional province; the extreme narrowing of the Gulf Extensional Province near El Huerfanito; and evidence for variations in timing and amount of extension throughout the extensional province.

On the basis of deformational history and active tectonics, the northern part of the Baja California peninsula can be divided into three structural domains: the gulf extensional province (in the east), the transpeninsular strike-slip province (across the northern part of the peninsula), and the stable central peninsula. The transpeninsular strike-slip province contains right-lateral strike-slip faults roughly parallel to, and broadly part of, the plate boundary strike-slip fault system: the Elsinore, San Jacinto, and San Miguel faults (Fig. 1). The WNW-striking Agua Blanca fault is considered to be the boundary between the transpeninsular strike-slip province and the stable peninsular block to the south. The Agua Blanca fault and the San Miguel fault approach one another at the juncture of all three structural provinces; geologic relationships here will be discussed at stop 1-1 (Fig. 2).

The stable peninsula, west of the extensional province and south of the Agua Blanca fault, consists of Cretaceous intrusive rocks of the Peninsular Ranges batholith and their metasedimentary screens, overlain locally by Neogene sedimentary and volcanic rocks (Fig. 3). This appears to be a single, west-tilted, structural block, despite the complexity of faulting along its N and E boundaries. The eastern boundary of the stable peninsula at this latitude is the San Pedro Mártir fault, part of the Main Gulf Escarpment (Gastil et al., 1975).

The Gulf Extensional Province extends south from the Salton Trough along the eastern side of the Baja California Peninsula. It contains basin-and-range style topography and active extensional basins. The extensional province contains rocks similar to those in the stable peninsula to the west, as well as a varied assortment of Neogene sedimentary and volcanic rocks. The western boundary of the province, the E-facing Main Gulf Escarpment, is controlled by fault structures of the Sierra Juárez fault zone (north of the Agua Blanca fault) and the San Pedro Mártir fault

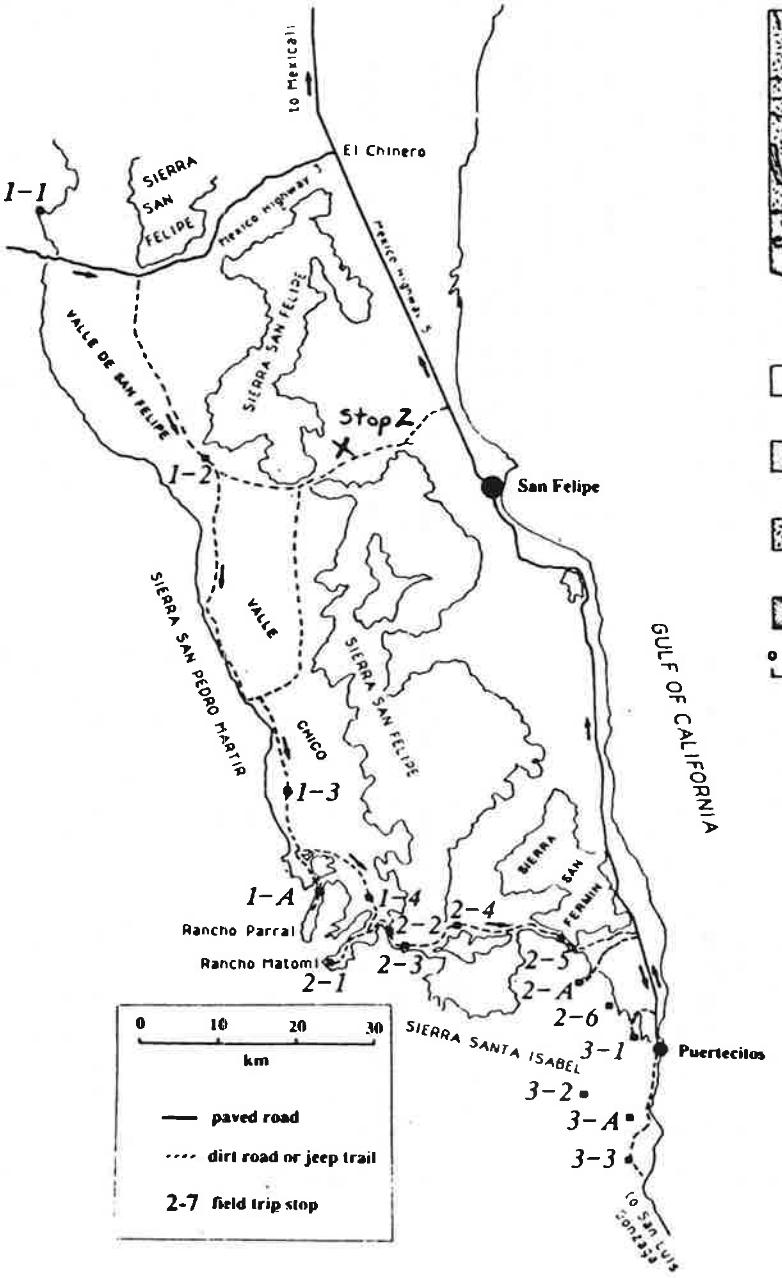


Fig. 2. Field trip route with stops indicated.

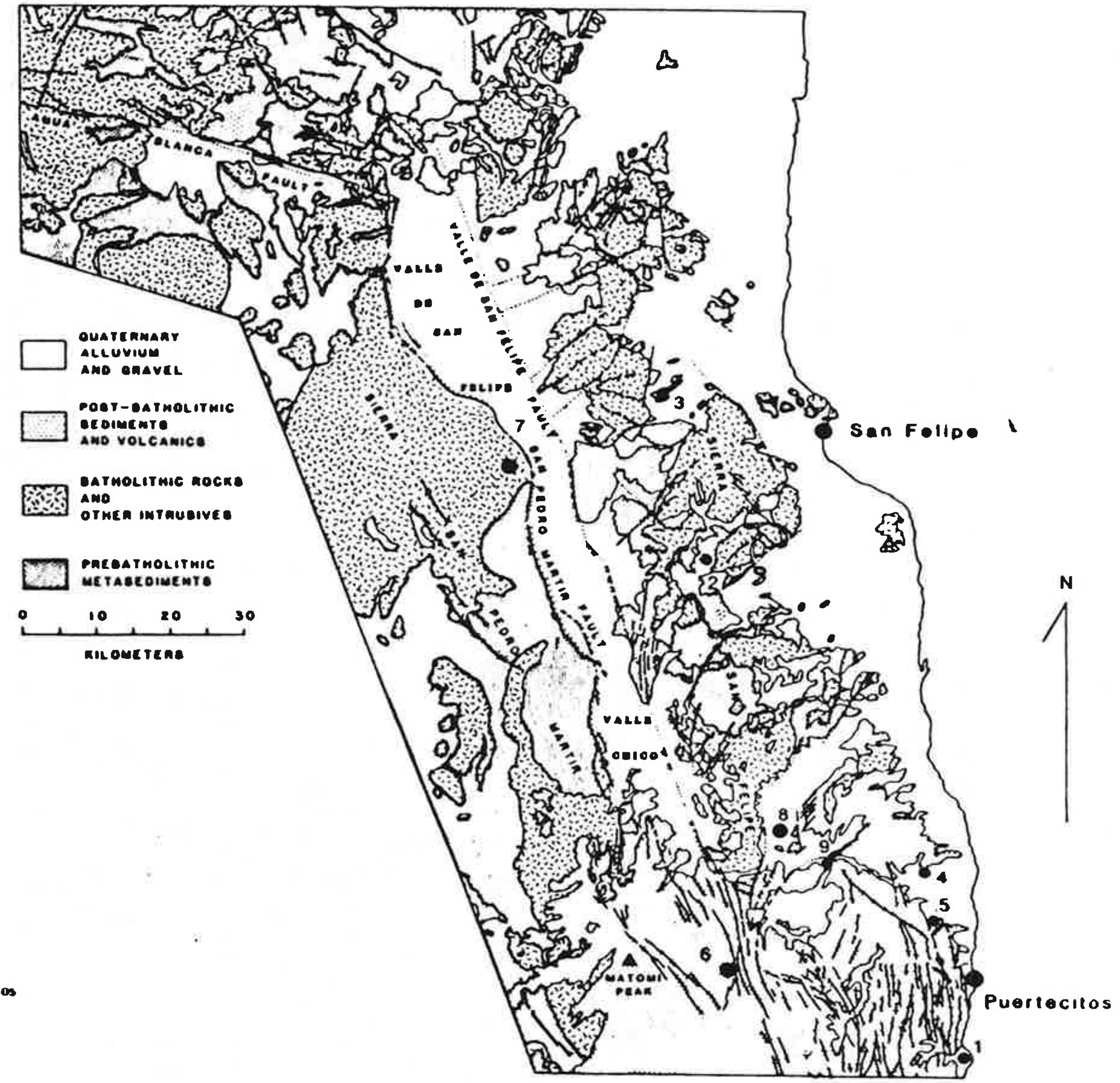


Fig. 3. Regional simplified geology of the area of the field trip, modified from Gastil et al. (1975). Numbered localities are: 1, Volcán Prieto; 2, Santa Rosa Basin; 3, outcrops of the San Felipe marine sequence near Cuevitas pass; 4 and 5, outcrops of the marine sequence near Puertecitos and Sierra San Fermín; 6, Dry Lake Mesa pull-apart basin; 7, Picacho del Diablo; 8, Llanos de San Augustín; 9, Puerto El Parral.

zone (south of the Agua Blanca fault) (Fig. 1). Along-strike structural variations of the escarpment fault systems will be discussed at stops 1-1, 1-2, 1-3, and 2-1, and can also be seen at alternate stop 1-A.

Stratigraphic packages

Felsic rocks of the Cretaceous Peninsular Ranges batholith, and their metamorphic wall rocks, crop out in all three structural provinces. Rocks of the Peninsular Ranges batholith are mainly granodiorite to tonalite in composition (Gastil et al., 1975). Pre- or syn-batholithic rocks include, on the west side of the batholith, coeval epiclastic and pyroclastic deposits (Alisitos Formation) and on the east side, marbles, quartzites, schists, and rare amphibolites whose protoliths may be Precambrian to Mesozoic in age (Gastil et al., 1975).

Locally derived continental sandstones and conglomerates overlie the batholithic rocks in scattered locations throughout northern Baja California. These deposits record latest Cretaceous or Early Tertiary planation of the uplifted Cretaceous batholith and country rock, and subsequent local dissection of the older surface (Minch, 1979). We will view probable mid-Tertiary quartzo-feldspathic sandstone and granitic- and metamorphic-lithic gravels of fluvial origin, and interbedded mafic volcanic rocks at stop 1-1. Rocks of the early to middle Miocene subduction-related volcanic arc overlie these deposits, and are extensively exposed in the Sierra Juárez, at the southern end of the Sierra San Pedro Mártir (Fig. 3) and at various locations within the extensional province. These rocks consist of andesitic to dacitic volcanic necks, flows, and vent complexes (common in the eastern part of the extensional province) and debris flows, breccias, conglomerates, and other more distal epiclastic deposits (more common in the west, both within the extensional province and covering the batholithic rocks of the stable peninsula). Ages of these rocks range from 20 Ma to at least 14 Ma within the area of the field trip; similar ages are reported from elsewhere in northern Baja California (Gastil et al., 1979). In appearance, age, and genetic significance, rocks seen on the field trip are similar to a package of proximal to distal epiclastic deposits ("Comondu") from the early to mid-Miocene subduction-related volcanism in Baja California Sur (e.g., Hausback, 1984; Sawlan and Smith, 1984).

Even after subduction ceased (by 16 - 12 Ma), volcanism continued in NE Baja California (e.g., Gastil et al., 1979). Younger volcanic rocks within the region of the field trip consist of silicic ignimbrite sheets of Miocene (and probably also Pliocene) age, numerous fields of rhyolite domes and vents, local small-volume mafic lavas, and a Quaternary basaltic volcano, Volcán Prieto, on the east coast south of Puertecitos (loc. 1 of Fig. 3). Thick sequences of late Miocene volcanic rocks crop out in the Sierra Las Pintas (east of the Sierra Juárez, along the coast) and in the Puertecitos Volcanic Province; thinner sequences are found overlying the batholithic rocks throughout NE Baja California. In some places (for instance, within the Santa Rosa Basin, loc. 2 on Fig. 3) the volcanic rocks are interbedded with nonmarine sedimentary deposits of significant thickness.

In the northern gulf region, extensive Miocene or Pliocene marine sequences have been recognized from the Imperial Valley region (Imperial Fm. of Woodring, 1932) and the Sonoran coastal plain (Gomez, 1971). Within the extensional province, marine rocks are exposed near the eastern coast of the Peninsula, west of San Felipe, (loc. 3 on Fig. 3) and in the region between the SE Sierra San Fermín and Puertecitos (locs. 4 and 5 on Fig. 3). In addition, marine deposits as old as 13 Ma crop out on Isla Tiburón in the Gulf of California (Smith et al., 1985); this region was close to Puertecitos prior to the opening of the Gulf of California.

Timing constraints on extension

Our present knowledge of this part of the Gulf Extensional Province in NE Baja California suggests that extensional faulting began sometime before 6 Ma, and possibly as early as 10-11 Ma. The E-dipping normal faults along the San Pedro Mártir segment of the Main Gulf Escarpment experienced about half of their displacement after 11 Ma and prior to 6 Ma, as indicated by structural relationships and hanging wall rollover of units of these ages in S. Valle Chico (Stock and Hodges, 1990; stops 1-3 and 1-4). Observations from the Santa Rosa Basin, (loc. 2 of Fig. 3), suggest a change in provenance of gravels, indicating uplift of the granitic ranges to the west, sometime around 8-9 Ma (Gastil et al., 1975; Bryant, 1986). In the coastal part of Arroyo Matomí, and in Arroyo El Canelo to the south of Arroyo Matomí, there is clear evidence for multiple episodes of extension (stops 2-5 and 2-A); earlier welded tuffs and rhyolite flows (7-9 Ma according to Gastil et al., 1975) are extended and tilted (up to steep or vertical dips) by a set of WNW-striking NE-dipping high-angle normal faults, and are also cut by some low-angle normal faults; these strata and structures are overlain by structurally coherent, largely horizontal, younger welded tuffs which are only moderately tilted by NNW-striking rangefront structures. Thus a phase of extreme extension appears to predate 6 Ma in this part of the field trip area.

The second day of the field trip will highlight diachronous timing of extension in a W-E transect across the extensional province, along Arroyo Matomí. Normal faulting along the eastern rangefront of the Sierra San Felipe has caused at least 800 m of normal separation of 11 Ma rocks; however, these fault blocks are overlain by post-tectonic rhyolite flows, domes, and welded tuffs that constrain the youngest age of possible motion along the fault zone (stop 2-4). By contrast, the rangefront faults of the Sierra San Pedro

Mártir have continued to be active until the present time (stops 1-3, 1-4, 2-1).

Escarpment fault structures

The western edge of the Gulf Extensional Province in NE Baja California is an east-facing, NNW-trending topographic escarpment with as much as 2500 m of topographic relief. It coincides with two major fault zones: the Sierra Juárez fault zone, to the north, and the San Pedro Mártir fault zone to the south (Fig. 1).

The San Pedro Mártir fault is a 100 km long, E-dipping normal fault. It controls the eastern edge of the relatively unfaulted Sierra San Pedro Mártir and the western edge of a composite basin (Valle de San Felipe/Valle Chico). It is probably a listric fault, based on its sinuous geometry in map view and the westward rollover of marker horizons in the upper plate of the fault as they approach the fault (Hamilton, 1971; Dokka and Merriam, 1982). The San Pedro Mártir fault may have as much as 5 km of normal separation at the latitude of Picacho del Diablo (loc. 7 of Fig. 3), based on the height of bedrock above the valley floor and the inferred depth to basement in the northern part of the valley (Slyker, 1970). However, the displacement along the escarpment fault systems decreases southward; at the latitude of southern Valle Chico the normal separation on the escarpment fault systems is estimated to be less than 1 km since 11 Ma (Stock and Hodges, 1990).

Along the length of the San Pedro Mártir fault, the maximum elevation of the Sierra San Pedro Mártir varies from over 3000 m to as little as 1600 m. To the south of the San Pedro Mártir fault, the escarpment fault system becomes more diffuse; it is still dominated by down-to-the-east normal faults, but they increase in number and the individual displacement on each fault decreases. Antithetic (west-side-down) normal faults increase in importance within the upper plate. This structural transition within the footwall and hangingwall will be visible at stops 1-3, 1-4, and 2-1.

Active faulting and seismicity

The major active or Holocene fault zones of northern Baja California include the San Miguel fault, the Agua Blanca fault, the San Pedro Mártir fault, the Sierra Juárez fault zone, and the Laguna Salada fault zone (Fig. 1). Of these, only the San Miguel fault zone, the Laguna Salada fault zone, and the Sierra Juárez fault zone have significant historic seismicity. The largest recorded earthquake in the region was an M_L = 6.8 event on the San Miguel fault in 1956 (Shor and Roberts, 1958). However, the Laguna Salada fault zone may have been the site of a great or large earthquake in 1892 (Strand, 1980) that caused much of the free face still visible along the scarp of the Laguna Salada fault (Mueller and Rockwell, 1991). The NW-striking San Miguel fault zone and the WNW-striking Agua Blanca fault zone cross the unextended province and approach the escarpment near the juncture of the Sierra Juárez fault zone and the San Pedro Mártir fault zone (Stop 1-1). Observations of instrumentally recorded seismicity on these fault systems have been most recently summarized by Brune et al. (1979).

Although the San Pedro Mártir fault is seismically quiet, it has Holocene scarps along 80 km of its length; segments of these scarps have not moved since at least 3500 years ago (Brown, 1978). Nevertheless, some small seismic events may have gone undetected; one M=4.5 event reported in the ISC catalog in 1974 may have been located beneath central Valle de San Felipe (Brown, 1978).

Minor fault zones with visible scarps are also present in the region. In the Llanos de San Agustín, east of the S end of the Sierra San Felipe (loc. 8 of Fig. 3), a N-S striking, E-facing scarp is visible in an old alluvial surface (Fig. 6 of Dokka and Merriam, 1982). Lineaments and small shutter ridges can be found along the trace of a NE-striking left-lateral fault on the E-W ridge south of Arroyo Matomí where it bounds the S side of the Llanos de San Agustín. Another NE-SW striking left-lateral fault system controls the edges of a small dry lake within a pull-apart basin on Dry Lake Mesa (loc. 6 of Fig. 3), along the southern projection of the Valle de San Felipe fault. The morphological expression of all of these fault segments suggests that they are recently active.

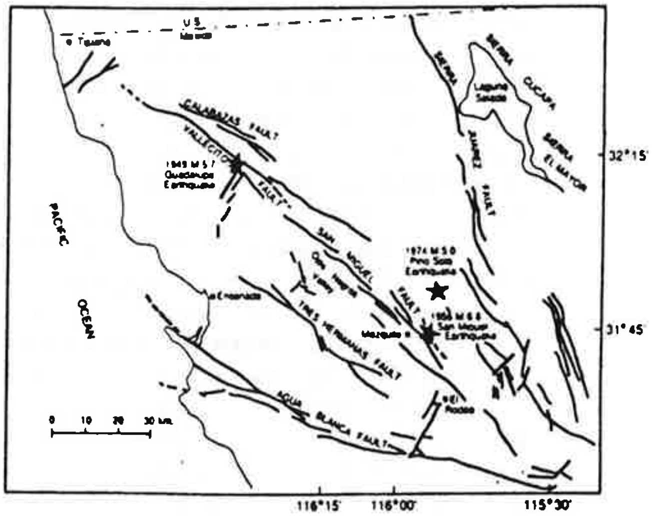


Fig. 4. Major faults within the Transpeninsular strike-slip province. Epicenters of recent large earthquakes are from Brune et al. (1979).

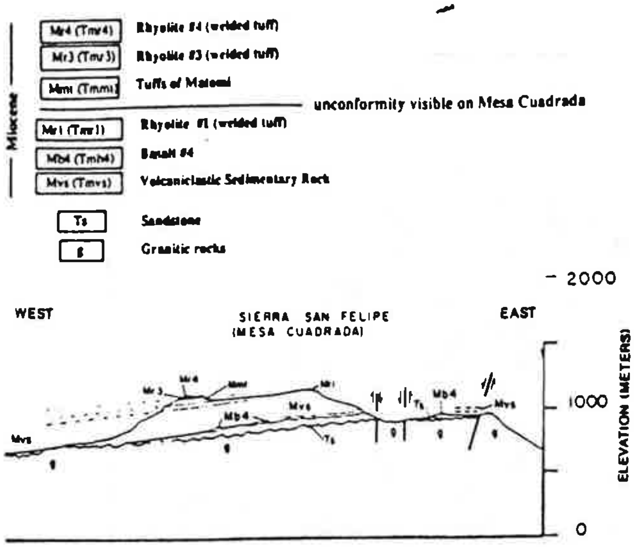


Fig. 8. East-west cross-section across Mesa Cuadrada, showing the unconformity between 6 Ma tuffs (Tmr4, Tmr3, and Tmmt) and 11 Ma tuff (Tmr1).

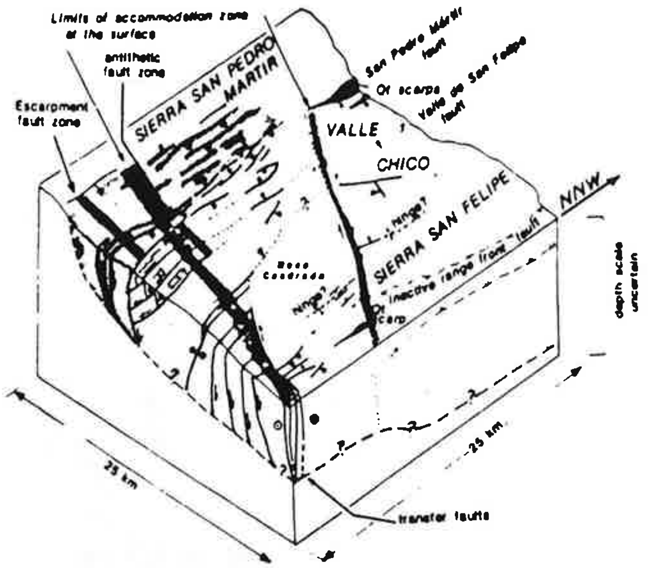


Fig. 9. Schematic block model of southern Valle Chico.

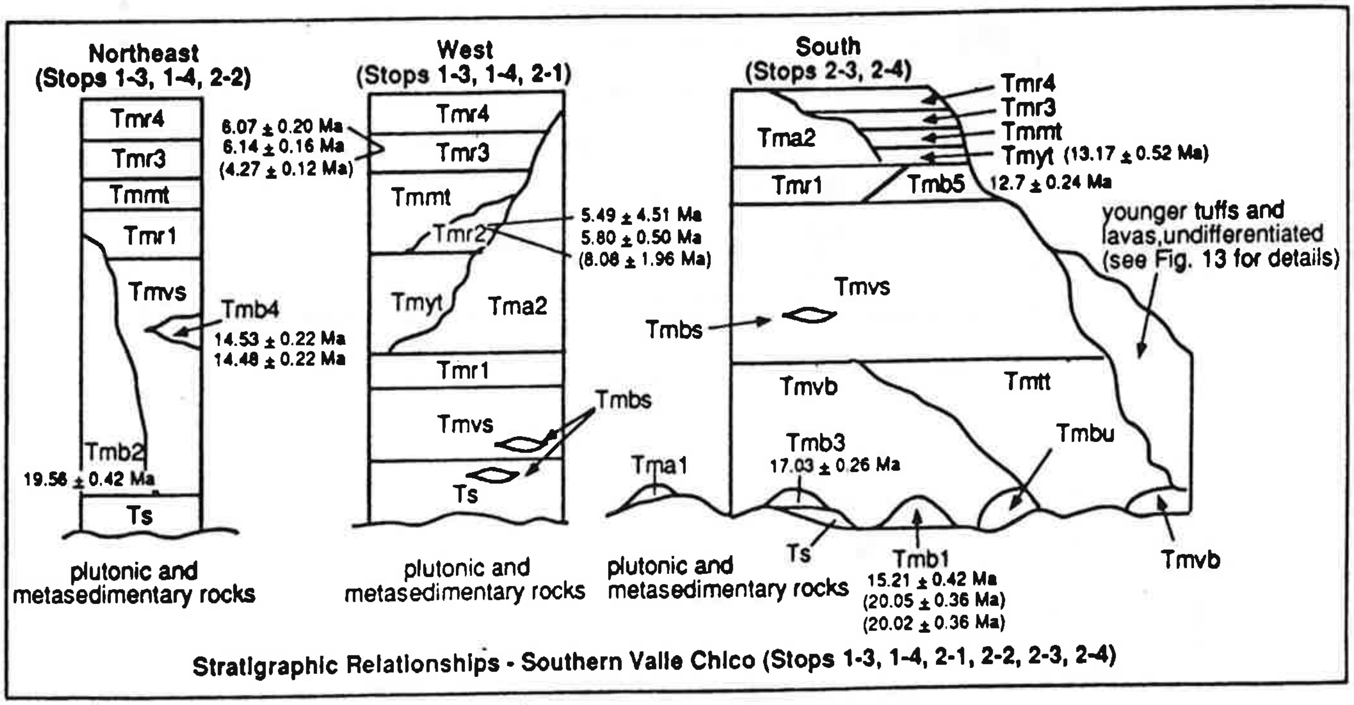


Fig. 10. Stratigraphic relationships in southern Valle Chico. See text for lithologic descriptions of units. Ages are K-Ar and total fusion $^{40}Ar/^{39}Ar$ (Stock, 1989). Ages in parentheses are considered unreliable.

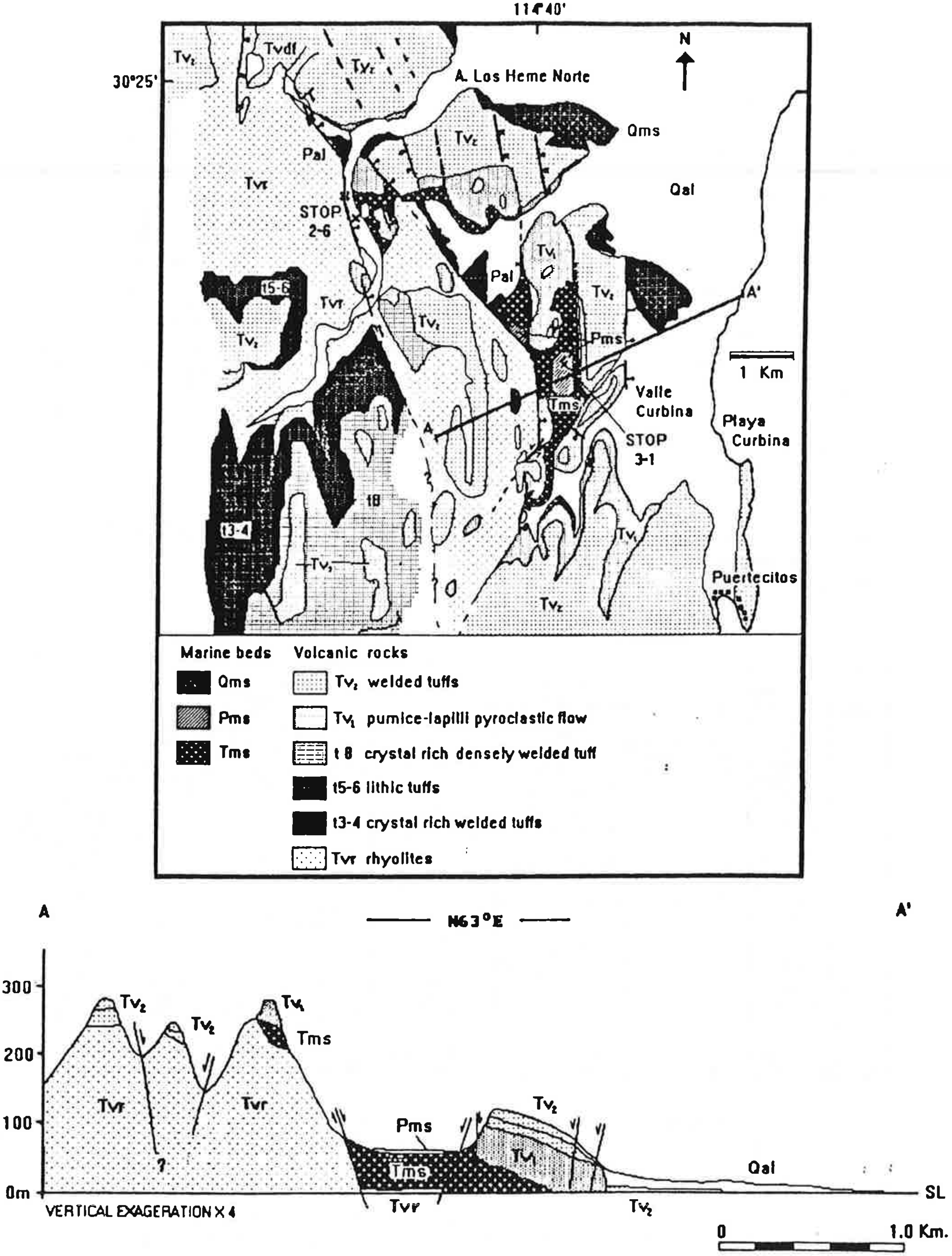
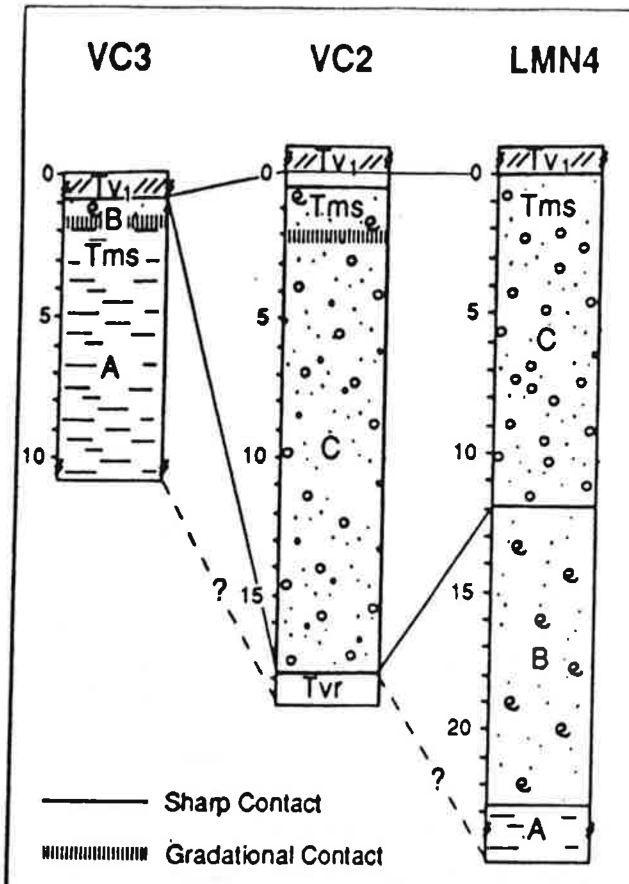


Fig. 17. Top: Simplified geologic and key map of the northern part of the Puertecitos Volcanic Province. See Fig. 21 for lithologic descriptions of map units. Bottom: East-west cross section showing the lithostratigraphic relationships within the volcano-sedimentary sequence in Valle Curbina.



Lithofacies A: yellow-orange to grey mudstone with slightly to non fissile structure and massive to laminar bedding (silty strata). Clay and silt with less than 5% fine sand. Smectite and illite, probably derived from the in situ alteration of the volcanic glass. Quartz and lithic fragments are common; trace amounts of hornblende, biotite and opaques. Palygorskite and sepiolite in the clay fraction. Kaolinite is rare or absent. Gypsum-anhydrite, halite and colemanite (?), either as a cement in the muddy matrix, or as fracture filling material. Fossils are scarce. The upper part of Lithofacies A contains worm tubes and rare bivalve shell prints. No microfossils were observed.

Lithofacies B: yellow-beige muddy sandstone with high fossil content. Mud and evaporitic minerals decrease from bottom to top. Thin beds with graded and small scale crossbedding. Bioturbation (tubes). Mainly devitrified, and fresh glass, and volcanic lithic fragments. Shell and carbonate cement abundant, some horizons contain primary shell banks. Quartz, hornblende, and plagioclase are common in the sand-size fraction. Gasteropoda fossils include: *Turritella broderipiana* d'Orbigny, *Patella mexicana* Broderip and Sowerby, *Ranella (Priene) oregonensis* (Redfield) and *Oliva spicata* (Bolten). However, there is a broad distribution from Miocene to Recent (Buitron, written communication, 1990).

Lithofacies C: sandy to pebbly conglomerate 10 to 15 m thick, graded with planar cross bedded structures a few cm to more than 30 cm thick. Sandy strata 3.0 m thick are interstratified with 2 conglomerate subfacies located at the base and at the top of this unit. The conglomeratic subfacies is poorly cemented and contains boulders as large as 60 cm in diameter, in a sandy to pebbly clay-free, matrix. Rock fragments are mainly rhyolite, with minor welded tuff and pumiceous material. Sand-size material is mainly lithics with minor amounts of volcanic glass, quartz and plagioclase. Reworked shell fragments are common, as well as calcite cement.

Tv1: yellow to white, matrix supported, pumiceous tuff. Glass shards and pumice are mostly fresh. 10 to 15% lithics, mostly of rhyolite composition. Crystal fraction is 15 to 20% phenocrysts, mainly plagioclase, quartz, biotite, opaques, and a few hornblendes. Traces of pyroxene.

Fig. 18. Stratigraphic log and lithofacies description of Tms (Tertiary marine sediments). VC = Valle Curbina, LMN = Los Heme Norte. See text for description of underlying rhyolite flows (Tvr).

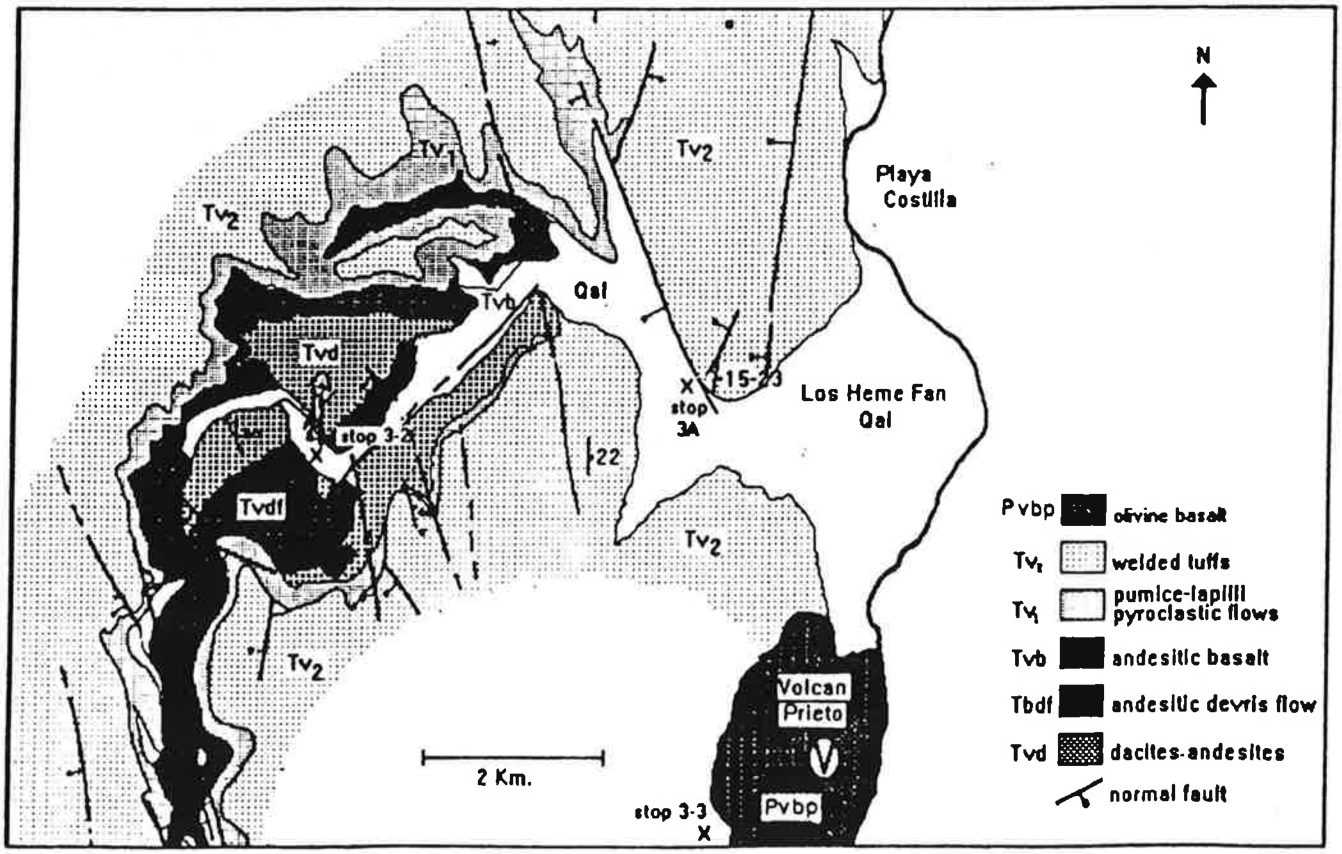
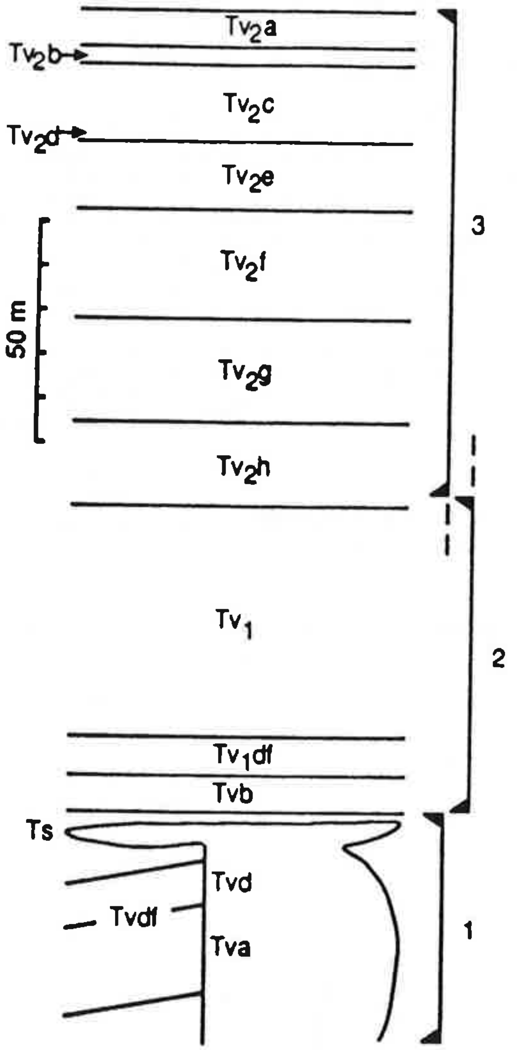


Fig. 20. Simplified geologic and key map of Los Heme area (stops 3-2, 3-A, and 3-3). For descriptions of units please refer to Fig. 21.



Tv_2a: dark reddish, crystal-lithic poor, densely welded vitric tuff. Phenocrysts: plagioclase > opaques $\geq$ cpx = opx. Base of unit is a black vitrophyre.

Tv_2b: lithic fiamme-rich welded tuff. Dark reddish with mafic lithics. Phenocrysts: plagioclase > opx-cpx = opaques.

Tv_2c: crystal-rich pumiceous tuff, moderately to non welded (upward). Phenocrysts (15%): plagioclase > opx-cpx = opaques > hornblende.

Tv_2d: grey-green color, lithic rich pumice-lapilli airfall (?) - ash flow. Bimodal.

Tv_2e: fiamme-rich, pumice-lithic rich welded tuff.

Tv_2f: reddish to dark-grey lithic fiamme-rich welded tuff. Includes scoria fragments in a glassy matrix.

Tv_2g: pink-yellow (orange weathered). Crystal-poor pyroclastic flow with pumice-lapilli.

Tv_2h: grey-reddish lithic-pumice rich welded tuff. Basal vitrophyre and baked ash-fall (?) at the base; grades to less densely welded upward. Phenocrysts (5-10%): plagioclase > opaques > opx-cpx. Devitrified glassy matrix.

Tv_1 : white to grey crystal-rich pumice-lapilli tuff. Matrix-supported; pumice "float" in a fine ashy matrix. Phenocrysts: 2 feldspars > quartz $\geq$ biotite > hornblende. The base of this unit is slightly welded.

Tv_1 df: dacitic-andesitic matrix and clast-supported reworked tuff.

Tvb: dark grey, aphyric to microphyric basaltic andesite. In thin section: plagioclase > opx = cpx > opaques> olivine (iddingsite) > biotite. Selective hydrothermal(?) alteration.

Ts: nonmarine sediments, mostly lithic sandstone with thin horizontal bedding and crossbedding.

Tvdf: Miocene(?) debris flows, tuffs and conglomerates of andesitic to dacitic composition.

Tvd-Tva: Miocene(?) dacitic to andesitic, hornblende-plagioclase phyric, lava flows and intrusive rocks.

Fig. 21. Stratigraphic relationships and general description of the 3 main volcanic sequences in the eastern belt of Puertecitos Volcanic Province.

WNW TO NW MID-MIOCENE TO RECENT EXTENSION ASSOCIATED WITH THE DEVELOPEMENT OF THE SIERRA EL MAYOR CORE COMPLEX, NE BAJA CALIFORNIA, MEXICO

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Mid -Tertiary to recent extension in the southern Salton trough - northern Gulf Extensional Province has resulted in the formation of the Sierra El Mayor core complex. Structural geometries and style of deformation closely resemble those of the turtleback structures in central Death Valley, as opposed to the core complexes in southeastern California and southern Arizona. Displacement along a stacked system of detachment faults was accomplished by brittle deformation and placed unmetamorphosed late-Miocene to Pleistocene marine and non-marine sedimentary rocks on upper amphibolite facies metamorphic tectonites. The metamorphic rocks have been pervasively intruded by igenous rocks ranging in composition from tonalite to monzogranite. Mid-Miocene (?) hydrothermal metamorphism retrograded the core rocks to greenschist facies, and clasts of these rocks are found in a syntectonic sedimentary breccia indicating that hydrothermal fluids preceded and facilitated faulting.

Foliation within metamorphic rocks has been transposed and refolded into a WNW to NW trending antiform. A parallel trending antiform is defined by the dips on the uppermost detachment fault. Penetrative high angle conjugate normal faults and fractures that are oriented perpendicular to the antiform have pervasively brecciated the rocks within the core. The maximum strain direction as determined from the orientation of the high angle faults beneath the upper detachment is east-west. This is consistent with kinematic indicators that give a WNW sense of movement on the detachment faults. Orientation of the high angle normal faults above the upper detachment indicate a more NW directed maximum strain.

The structurally lowest detachment zone exposed represents a mid-crustal shear zone upon which mid- to upper crustal rocks were tilted and cataclastically deformed in response to the opening of the proto-gulf. Syndepositional marine sediments were deposited directly on the uplifted shear zone. Continued extension along detachment faults tectonically thinned and removed the late-Miocene to Pliocene marine deposits and locally placed Pleistocene redbeds directly against the metamorphic basement. Subsequent high angle normal faults that cut the detachments are considered to sole into a presently active mid-crustal shear zone.

Extension associated with the development of the Sierra El Mayor core complex is consistent with mid-Miocene to present Pacific-North America plate motions.