

GEOLOGY OF COASTAL SONORA BETWEEN PUERTO LOBOS  
AND BAHIA KINO

FIELD TRIP No. 2 PREPARED FOR THE  
GEOLOGICAL SOCIETY OF AMERICA  
CORDILLERAN SECTION  
1981 ANNUAL MEETING

MARCH 22-24

TRIP LEADERS:

R.G. GASTIL, DEPARTMENT OF GEOLOGICAL SCIENCES, SAN DIEGO  
STATE UNIVERSITY, SAN DIEGO CA 92182 U.S.A.

L. ORTLIEB, INSTITUTO DE GEOLOGÍA, U.N.A.M.

AND O.R.S.T.O.M., AP. POSTAL 1159, HERMOSILLO, SONORA,  
MEXICO.



## ROADLOG FOR COASTAL SONORA FIELD TRIP--SUNDAY, MARCH 22nd

Time	Increment in Kilometers	
7:00AM	00	Depart from Hotel Valle Grande, Hermosillo.
9:00AM	169	North from Hermosillo to Santa Ana (Figure 1). The hills west of the highway are largely unfoliated granitic rocks of late Cretaceous age. Host rocks show only minor contact metamorphism. Near Santa Ana the host terrane is highly fossiliferous Albian-Aptian limestone in contact with older Precambrian metamorphic rocks (Salas, 1968).
STOP 1 10:15AM	96	Pitiquito. Between Santa Ana and Altar we cross presumably Jurassic volcanoclastic rocks. Near Altar we cross older Precambrian metamorphic rocks. At Pitiquito the rocks are Late Precambrian carbonates intruded by granitic rock of Cretaceous age (Longoria and Perez, 1979). Fill vans with gasoline; get out the coffee jug for mid-morning wakeup.
11:30AM	40	Rancho Bamori We drive south from the old town of Pitiquito, immediately crossing the Rio Asuncion. The prominent hills to the east of the road are the Cerro Pitiquito, Cerro Chino, and Cerro Rajon. These have recently been described by Longoria and others (1978) and Longoria and Perez (1979). The Cerro Pitiquitos consists of Late Precambrian quartzite and carbonate rock. The Cerro Chino consists largely of Jurassic andesite-rhyolite flows and tuffs, with older Precambrian granodiorite exposed near the southern end. The Cerro Rajon consists of Late Precambrian quartzite and carbonate rock overlain by Jurassic sandstones. The Cerro Berruga, just north of Bamori is an area of older Precambrian rocks investigated by Damon and Mauger (1962) and Anderson and Silver (1971).
	9	Enter the hills southwest of Bamori, following the pass between Cerro San Clemente and Cerro Calaveras. The quartzite and carbonate rock to the north of the road is the lowest part of the Late Precambrian sequence, the rocks south of the road are Lower Cambrian (Eells, 1972).
	5.3	Faint tracks lead to the left.
STOP 2 11:45AM	1.0	Reach a fence; time for lunch. Here we will hike about two kilometers up the canyon to view the Cambrian and Late Precambrian section (Figure 2). Our traverse is essentially

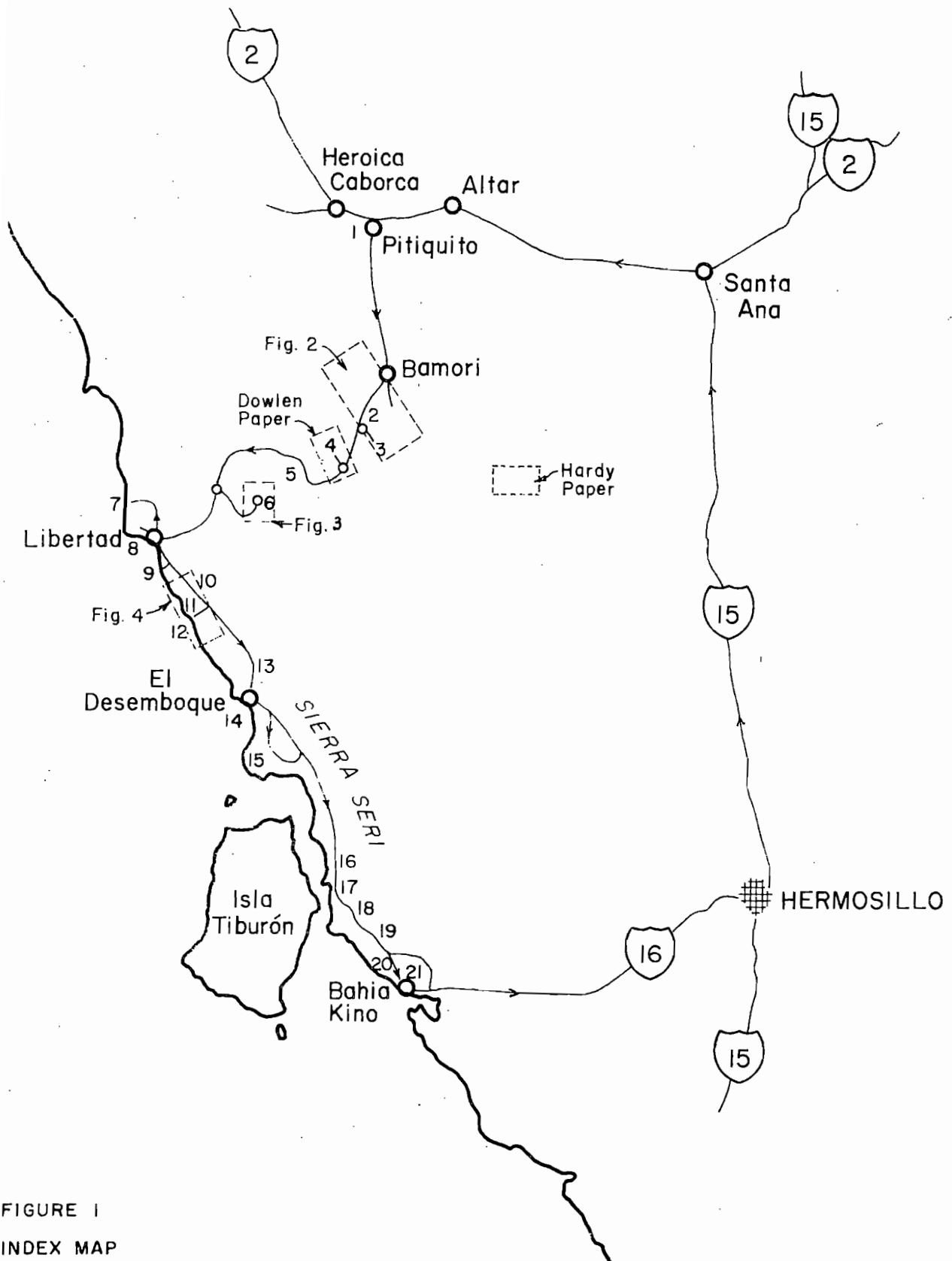
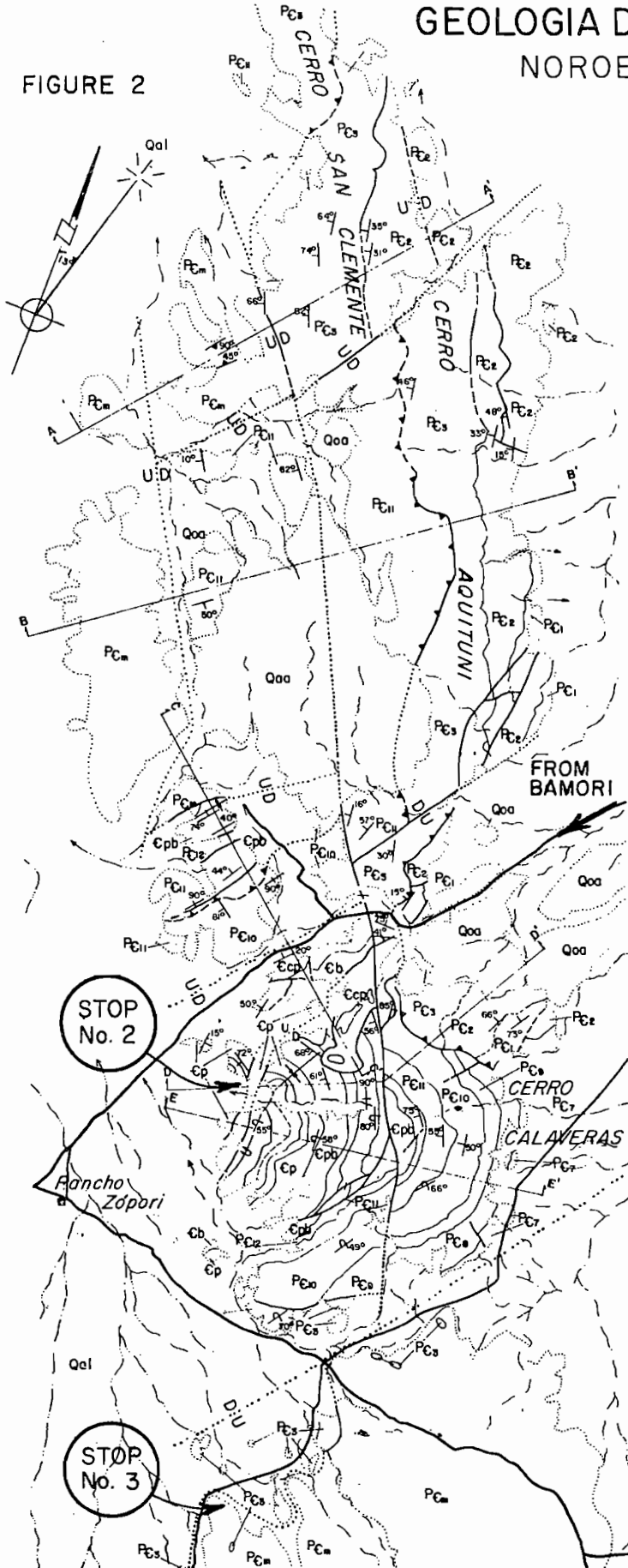


FIGURE 1  
INDEX MAP  
SONORA COAST FIELD TRIP

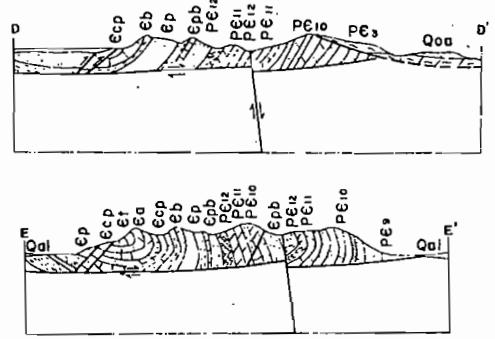
# GEOLOGIA DE LA SIERRA DE LA BERRUGA NOROESTE DE SONORA, MEXICO

Por John L. Eells. (1972)

FIGURE 2



- |  |   |
|--|---|
| <b>Qal</b><br>Aluvión  | <b>PC12</b><br>UNIDAD 12<br>Conglomerado volcánico y arenisca.<br>Espesor ≈ 90 m.                           |
| <b>Qaa</b><br>Aluvión Antiguo  | <b>PE11</b><br>UNIDAD 11<br>Dolomita café y cuarcita<br>Espesor ≈ 250 m.                                    |
| <b>Ql</b><br>Depósitos Lacustres   | <b>PE10</b><br>UNIDAD 10<br>Dolomita gris masiva<br>Espesor ≈ 490 m.  |
| <b>Tr</b><br>Riolita   | <b>PE9</b><br>UNIDAD 9<br>Dolomita mateada<br>Espesor ≈ 140 m.  |
| <b>Mlb</b><br>Brecha de Bloques  | <b>PE8</b><br>UNIDAD 8<br>Conglomerado de fragmentos finos<br>Cuarcita y lutita<br>Espesor ≈ 280 m.         |
| <b>E1</b><br>FORMACION TREN<br>Dolomita gris. Espesor > 100 m.                     | <b>PE7</b><br>UNIDAD 7<br>Caliza blanca y dolomita<br>Espesor > 150 m.                                      |
| <b>Ea</b><br>FORMACION ARROJOS<br>Lutita y Calizc. Espesor ≈ 300 m.                | <b>PE6</b><br>UNIDAD 6<br>Dolomita gris<br>Espesor > 450 m.   |
| <b>Ecp</b><br>FORMACION CERRO PRIETO<br>Caliza masiva. Espesor 88 m.               | <b>PE5</b><br>UNIDAD 5<br>Cuarcita vitrea<br>Espesor 184 m.   |
| <b>Eb</b><br>FORMACION BUELNA<br>Caliza, lutita y cuarcito. Espesor 68 a 104 m.    | <b>PE4</b><br>UNIDAD 4<br>Cuarcita y lutita<br>Espesor 139 m.   |
| <b>Ep</b><br>CUARCITA - PROVEEDORA<br>Cuarcita vitrea. Espesor 224 m.              | <b>PE3</b><br>UNIDAD 3<br>Dolomita gris que contiene material<br>algáceo y aloquímicos<br>Espesor > 1400 m. |
| <b>Epb</b><br>FORMACION PUERTO BLANCO<br>Lutita, caliza y cuarcita. Espesor 456 m. | <b>PE2</b><br>UNIDAD 2<br>Dolomita estrametalítica<br>Espesor ≈ 525 m.                                      |
|  | <b>PE1</b><br>UNIDAD 1<br>Cuarcita café. Espesor > 30 m.  |
|  | <b>ROCAS<br/>METAMORFICAS</b>   |



cross-section DD' down through the Lower Cambrian to the conformable Precambrian contact. Of particular interest is unit 12 the basic volcanic unit at the top of the Late Precambrian (Eells, 1972).

- 2:15PM depart
- 1.0 Back to main road, continue south.
- 3.5 Rancho Zópari, turn left (to east).
- 5.4 To road junction, turn right (south) by ruins of a building.
- STOP 3 2:45PM 3.3 To the point of the hill.  
Mylonitized older Precambrian granite, with inclination at low angle to the east.
- 3:15PM depart
- 8.8 Back to Rancho Zópari, continue west.
- 0.8 Back to main road, continue southwest.
- 3.6 Gate to the right of the road, sign says Puerto Libertad, take it.
- 8.1 Rancho Pozo Serna, turn right (take right hand fork immediately).
- STOP 4 4:00PM 2.1 Rancho Tilin, white buildings and windmill: time for afternoon beer. See note in this guidebook by Robert Dowlan. The paleontology of the Jurassic rocks has been described by Beauvais and Stump (1976). This little valley is a graben with overturned Cambrian strata both to the west and east. The rocks we will look at are volcanoclastic Jurassic sandstones which have been preserved in the center of the graben.

This is where we will prepare supper and camp for the night.

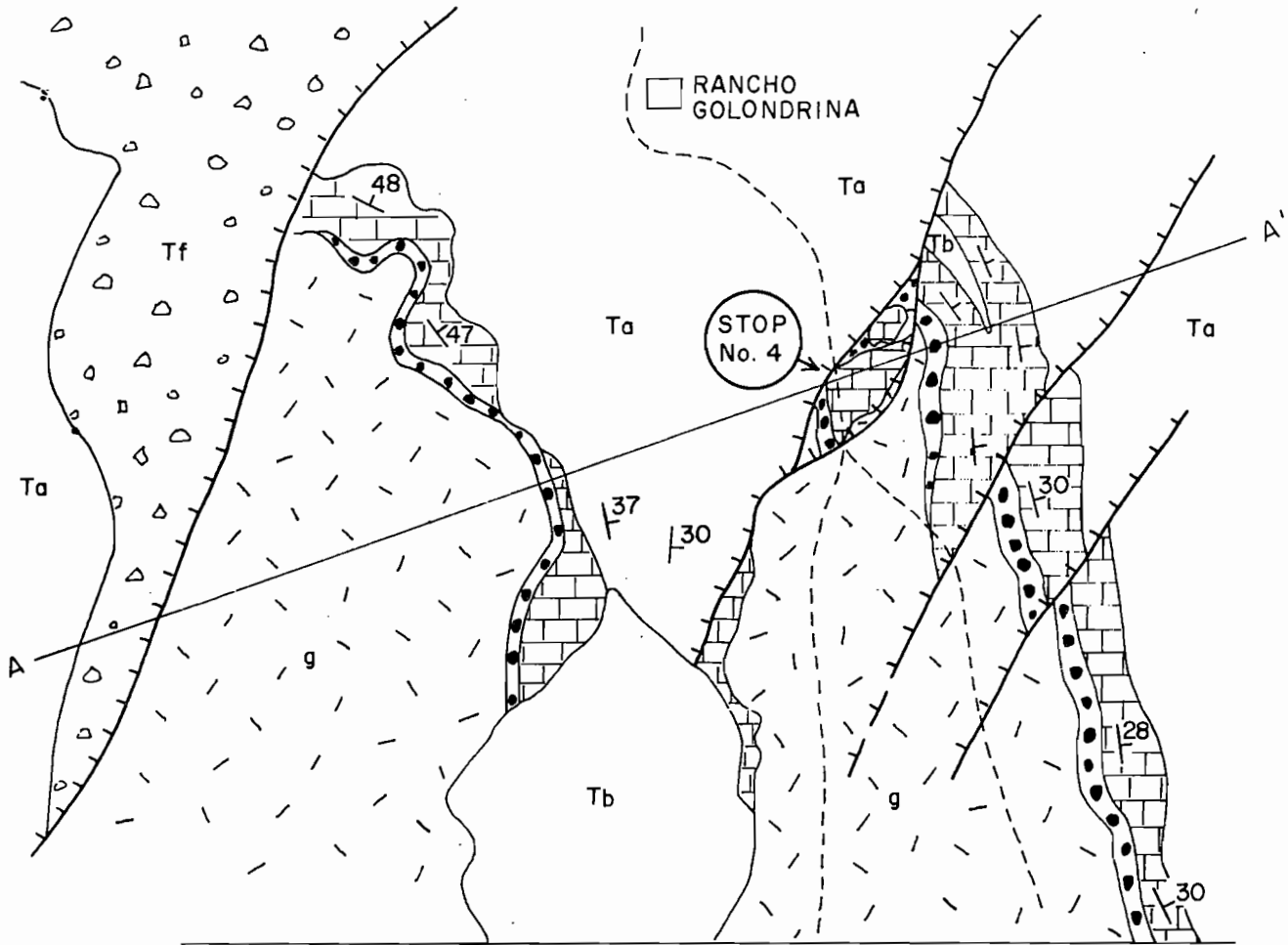
MONDAY, MARCH 23rd

- 6:00AM wake up
- 6:30AM breakfast
- 7:15AM depart
- 2.2 Back to the Libertad road at Rancho Pozo Serna, continue southwest. On both sides of the road are andesitic volcanic rocks believed to be of Mesozoic age.
- 5.8 Junction, follow main road to right.
- STOP 5 7:40AM 5.6 Granite outcrops.  
We have just crossed a boundary between two apparently fundamentally different types of crust. To the east rocks with very little regional metamorphism rest on older Precambrian basement. To the west the pervasive basement rock is Cretaceous

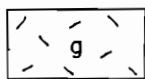
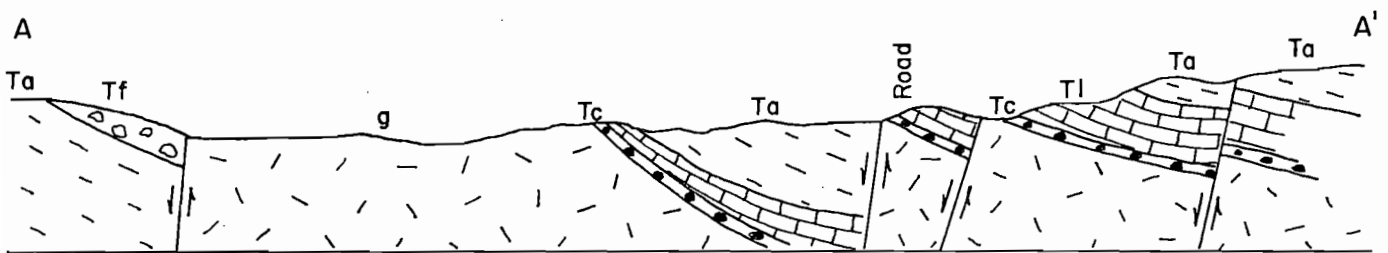
granitic rock, with all pre-Cretaceous rocks appearing to be "roof pendants." In 1977 Gastil and Krummenacher hypothesized a major fault (Figure 2) just to the northeast. Neogene (?) sedimentary rock exposed in the arroyos have been highly deformed. Any important faulting appears to pre-date the older alluvium. We now wonder if the boundary between two apparently different basement terranes is not a matter of erosional depth. We wonder if mylonite such as seen south-east of Rancho Zópari is part of a decoupling level, above which are rocks such as those seen in Cerro Calaveras and Cerro Pozo Serna, below which are Cretaceous granites such as seen here and regionally metamorphosed rocks such as will be seen the balance of the trip.

- approx. 12 Rancho El Carbón, follow main road to the south.
- approx. 6 Rancho El Americano, just west of here is a large porphyry copper deposit called La Fortuna. It is in volcanic rocks believed to be of Mesozoic age.
- approx. 3 Rancho Caracól, turn left (east) just south of the ranch buildings.
- 2.4 Gate, should be unlocked.
- 4.9 Rancho Pozo Nuevo.
- 5.8 Take fork to the left (north).
- STOP 6 9:15AM 3.5 Limestone outcrops, just short of Rancho Golondrina. Figure 3, this area was mapped by Wayne Mattox (1972). The small sketch map shown is modified from his map. He shows 55m of basal volcaniclastic redbeds resting on Cretaceous granite overlain by 150m plus of freshwater limestone and minor red beds. Fossils consist of gastropods and algal material, overlain by more than 230m of andesite tuffs and breccias, overlain by more than 100m of indurated fanglomerate. A rock from the andesite sequence near Rancho Golondrina yielded a K-Ar age of  $12.7 \pm 0.4$  m.y. (Gastil and Krummenacher, 1977).
- This will also be our mid-morning coffee stop.
- 10:30AM depart
- 16.6 Back to Rancho Caracól turnoff.
- 11:00AM 28.3 Puerto Libertad, turn right (north).
- 0.8 Opposite a group of trees the road crosses the new highway and proceeds northeast toward Santa Margarita (also known as Santa María).
- 9.4 Take fork to left (west) toward the beach.

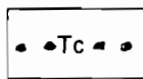
FIGURE 3 GEOLOGIC MAP OF RANCHO GOLONDRINA, SONORA



modified from W. A. Mattox, 1972



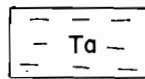
granite



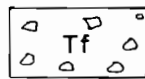
basal  
redbed  
conglomerate



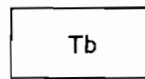
lacustrine  
limestone



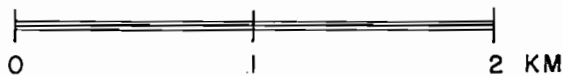
andesite



fanglomerate



basalt



- STOP 7 11:20AM 3.1 Reach the beach, Santa Margarita.  
Interbedded argillite and argillaceous sandstone with thin carbonate rock units, disharmoniously folded around northeast trending variably plunging fold axes. The axial plane strikes around N85°W, dipping 20°N. Greenschist facies regional metamorphism.
- The low wave-cut terrace here has a maximum elevation of +6m. In the first embayment south of the outlet various bench-like surfaces, veneered with pebbles of probable marine origin, are found at +11m, +16m, and +20m. These accumulations are only a few centimeters thick and lack significant fossil shells. These are the highest marine terraces found up to now on the coast of central Sonora. They might have resulted from brief surges, as described by Hollin in several parts of the world.
- This is our lunch stop.
- 12:30PM depart
- 12.5 Return to Puerto Libertad, turn right toward entrance to Comisión Federal Electricidad generating plant.
- STOP 8 12:50PM Here we hope to visit the outcrops designated T3 on the map by Gastil and Krummenacher (1977). These steeply inclined conglomerate beds are the principal evidence for the graben mapped across Punta Bola.
- On west edge of CFE enclosure is the Sangamon coquina (Tagelus and Chione sp. predominant) described by Stump (1975), Malpica and others (1978), Celis and Malpica, 1981, and Ortlieb and Malpica (1978, Fig. 8). The maximum elevation of marine deposits here is around 5m.
- 1:45PM Depart, return to Puerto Libertad.
- 3.6 Turn off road toward the beach.
- 2.0 At fork turn right.
- STOP 9 2:00PM 1.1 Reach the beach north of Punta Cirio. Conglomeratic sandstone with in situ echinoderms (Malpica and others, 1978, Fig. 5); presumed age is early or middle Pleistocene (or Pliocene?); maximum elevation is around +5m. These deposits are covered by old dunes (layers of calcified root molds and caliche), and locally by marine littoral sands, Sangamon (?).
- 2:30PM depart
- 3.1 Back to the highway, continue southeast.

- STOP 10 2:40PM 17.1 Highway cuts through a small granite hill.  
 This is the afternoon beer stop. Here you can see many fault surfaces. There are strike-slip faults striking N65°W, and a prominent fault striking north with slip surfaces dipping 35°E, and others. The movement planes exposed in this small hill are a hint of the movement surfaces that are presumably hidden beneath this broad alluviated pediment.
- 3:10PM Depart, continue south on highway.
- 4.4 Turn right onto dirt road leading west.
- 2.5 Volcanic hills.  
 An andesite from unit T4x yielded a K-Ar age of  $11.9 \pm .5$  m.y.
- STOP 11 3:25PM 1.3 Stop to look at the mylonitic gneiss exposed on the east side of the Falla Bacha (Figure 4). Note that the map by Gastil and Krummenacher (1974) erroneously labels the area as Mv (Mesozoic volcanic). The inclination of the mylonite is around 65° to the NE. Rotation of the Miocene volcanic rocks back to horizontal would leave the older structure inclined at a small angle to the east. Thus it is possible that we are looking at a rotated fragment of the same mylonitized older Precambrian granite observed southeast of Rancho Zópari.
- 4:25PM Depart, continue west.
- STOP 12 4:35PM approx. 4 Punta Cuevas.  
 Wave-cut platform, fossiliferous littoral deposits at the base of the coastal cliff, between +3 and +6m.  
 The fold of Miocene volcanic and clastic strata mapped in this area is atypical of the region, and presumably was caused by compression along the strike-slip Falla Bacha.

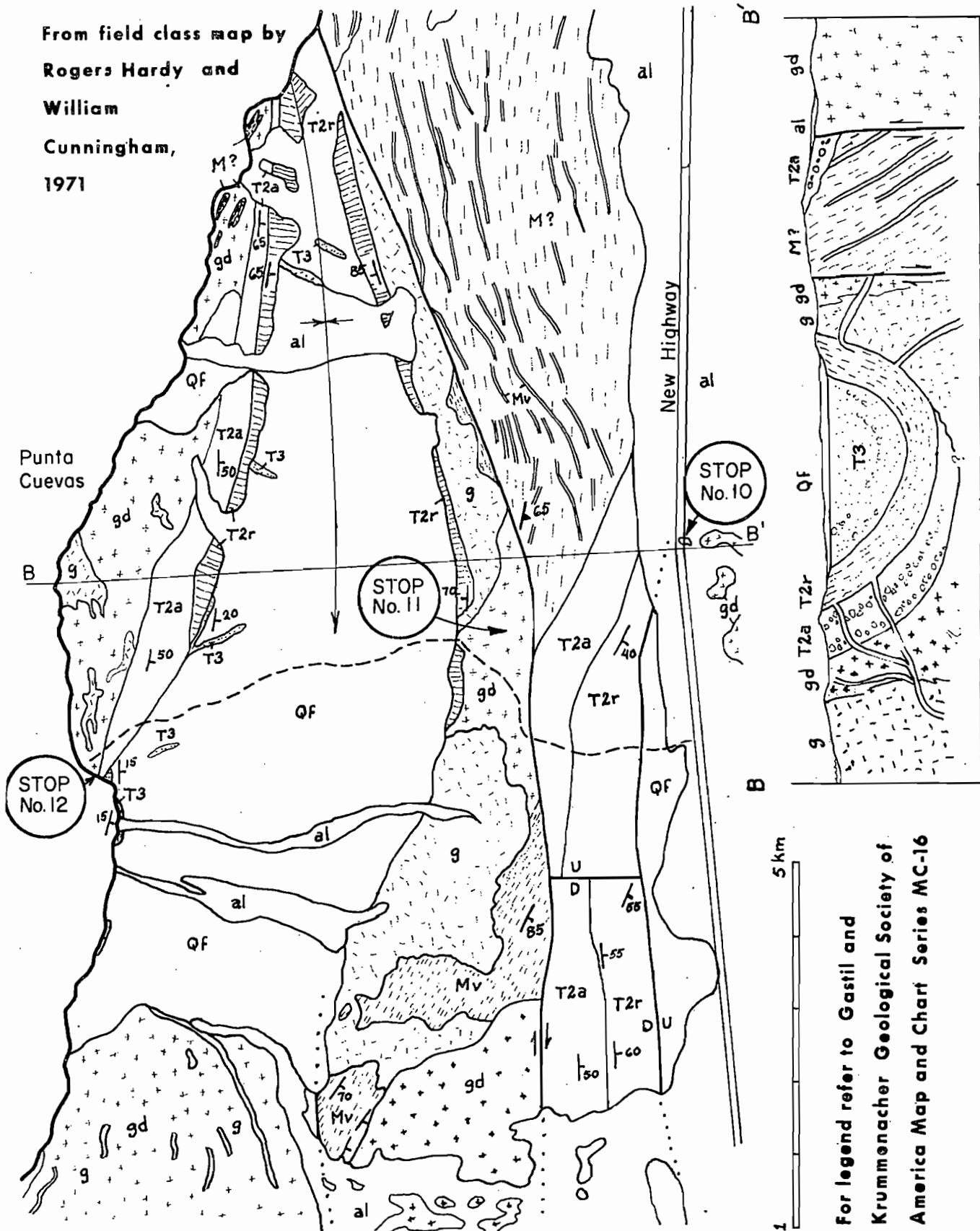
This is where we shall prepare supper and camp for the night.

TUESDAY, MARCH 24th

- 6:30AM wake up
- 7:00AM breakfast
- 7:45AM depart, return toward the highway
- approx. 12.2 back to the highway, continue south
- 8:15AM 16.9 Cerro Prieto basalt (K-Ar date  $6.4 \pm 1.9$  m.y., Gastil and Krummenacher, 1977).
- 2.1 Road to east leads to Rancho Arroyo Seco.
- 1.8 Another road to east.
- 1.5 Rancho Pozo Coyote.
- 1.7 Cross Rio San Ignacio.

**FIGURE 4 GEOLOGY OF THE PUNTA CUEVAS AREA, SONORA**

From field class map by  
 Rogers Hardy and  
 William  
 Cunningham,  
 1971



For legend refer to Gastil and  
 Krumenacher Geological Society of  
 America Map and Chart Series MC-16

- STOP 13 8:25AM 0.9 Massive quartzite.  
This could be a fragment of the Cambrian-Late Precambrian terrane visited in the Sierra Calaveras.
- 8:40AM depart
- STOP 14 9:00AM 12.3 Seri Village of Desemboque Del Rio San Ignacio.  
If you wish to barter for handicrafts we shall stop here for that purpose.
- 9:30AM depart
- 1.0 Road junction east of village, continue southeast on highway.
- 11.6 Take a fork to the right, road leads southwest toward the coast.
- 2.7 Turn onto a fork that leads east of south.
- 3.9 Take a left turn, the other road leads to Campo Dólar.
- STOP 15 10:00AM 1.0 "Laguna Tepoca": an area of playa morphology located between the piedmonts of Cerro Tepoca and Sierra Seri. Here sandy deposits with Chione sp., Protothaca sp., and Cerithium sp. have been dated by  $^{14}C$  at about 30,000 years B.P. (but are probably older: Sangamon). The maximum elevation is  $+3m \pm 2m$  (LeColle and Ortlieb, 1978; LeColle, 1979; Ortlieb and LeColle, in preparation; Richards, 1973; theses of B. Luna and R. Gonzalez, 1981).  
This will be our morning coffee stop.
- 10:30AM depart
- 5.9 Turn to the left, away from the salt marsh.
- 10:45AM 2.3 From here we can see the Estero Sargento with its mangrove vegetation. For the vegetation see the thesis of Sherwin (1971), for the geomorphology Lancin (1979), and the sedimentology Nichols (1965).
- 0.3 Take the straight road toward the northeast.
- 1.8 Back to the highway.
- 3.7 Pass a junction on the right leading toward Estero Sargento.
- 19.8 Punta Viboras: pull off onto a small parking area.
- STOP 16 11:25AM This is an opportunity to look at the mangrove.  
11:40AM depart

- STOP 17 12:00PM 11.6 This is a double stop. Up the hill on the left-hand side of the road are the metamorphosed banded cherts which have been correlated (by lithology) with rocks on Isla Turner, Isla Angel de la Guarda, and localities on the coast of Baja California.
- On the right-hand side of the road we will climb down to the beach where an infra-littoral coquina deposit and an intertidal sandy conglomerate are exposed in the sea cliff. The maximum elevation of the littoral material is +9m. The age is presumed to be Sangamon (this is an unusually high elevation for Sangamon material along this coast and may be disturbed by movement on the hypothesized fault: Gastil and Krummenacher, 1974).
- This is also our lunch stop.
- 1:10PM depart
- 1:17PM 4.5 Village of Punta Chueca: Seri
- STOP 18 1:20PM 3.0 Stop to look at the metavolcanic and metasedimentary rocks exposed along the left-hand side of the road. These include andesite, rhyolite, and both carbonate and clastic sedimentary rocks. Similar rocks are exposed immediately across the channel on Isla Tiburón. The age of these rocks is not known. Similar metavolcanic strata are not found along the eastern coast of northern Baja California.
- 1:45PM depart
- STOP 19 1:55PM 6.4 Stop briefly to look north and see the uplifted old conglomerate deposits.
- 2:15PM 8.1 Turn off of the highway to the right, road leads toward Punta Blanca.
- 1.1 Fork in road, keep left.
- STOP 20 2:25PM 2.3 Stop briefly for view. In the bay north of Punta Ignacio there is a Wisconsinian Bajada deposit overlying Sangamon marine strata. The former is several meters of light brown sandy gravel of sheet flood origin (Malpica and others, 1978; Ortlieb and Malpica, 1978, Figure 3).
- 2:35PM 2.5 Kino Bay Trading Post. Turn left and follow the Mar de Cortez Blvd. This is the "new town" of Bahia Kino, built on Holocene sand dunes.
- 2.8 Turn left onto Av. Punta Checa.
- 0.9 Turn left onto the "Periferico."
- 0.5 Turn right through hole in the fence.

STOP 21	2:45PM	2.0	<p>Stop at fence and walk to steeply inclined Miocene clastic and volcanic strata. A dacite from this locality has been dated at <math>17.8 \pm 0.8</math> m.y. (Gastil and Krummenacher, 1977).</p> <p>This is also our afternoon beer stop.</p>
	3:35PM		depart
		3.4	Back to Mar de Cortez Boulevard.
	5:00PM	117	<p>Hermosillo.</p> <p>We will be crossing a broad coastal plain of Pliocene-Quaternary alluviation. This alluviation has resulted in the partial burial of Siete Cerros and other hills. The gradual slope extends from sea level to Hermosillo at an elevation of 180 m.</p>

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GEOLOGY OF THE CENTRAL SIERRA DE SANTA ROSASONORA, MEXICO

L. Rogers Hardy  
Natomas International Corporation  
601 California Street  
San Francisco, CA. 94108 U.S.A.

ABSTRACT

An allochthonous Lower Jurassic marine sedimentary and andesitic volcanic sequence at least 2,360 m thick is exposed in the Sierra de Santa Rosa in northwest Sonora, Mexico. The Jurassic sequence is tectonically emplaced over older Precambrian regionally metamorphosed rocks and autochthonous younger Precambrian sedimentary rocks.

The Lower Jurassic Sierra de Santa Rosa Formation (new name) consists of 1,460 m of alternating andesitic lithic wacke, calcareous arkose, sandy biomicrite and argillite. The formation is interpreted to have been deposited in a shallow, nearshore marine environment with tidal shelf, lagoon and barrier bar facies. The source area for the formation is possibly an island arc proposed to have existed along the western edge of Sonora. The Lower (?) Jurassic Cerro San Luis Formation (new name) lies conformably on the Sierra de Santa Rosa Formation, is at least 900 m thick, and consists of 0 to 70 m of conglomerate containing quartz arenite and dolomite clasts, grading upward into approximately 860 m of andesitic agglomerate, lapilli tuff, lava flows and interbedded channel conglomerate and arenite. The Cerro San Luis Formation is interpreted to have been deposited subaerially. The tectonic events necessary for the deposition of the conglomerate at the base of the formation and the andesite volcanism could also be related to the presence of an island arc. The Precambrian and Jurassic rocks are intruded by a Late Mesozoic or Early Tertiary rhyolite porphyry.

The Jurassic sequence occurs as a set of north-south striking allochthons exhibiting a low-angle undulating fault contact with the underlying Precambrian rocks. The strata within the allochthons strike north-south, dip steeply to the west, and are repeated as imbricate sets along reverse bedding-plane faults. Sevier-age imbricate thrust faulting within the Jurassic sequence, and Laramide age gravity sliding of these allochthons might explain the observed geometry. Gently dipping beds of the Miocene (?) Baucarit Formation indicate that the central portion of the range was tilted to the west, but normal faulting has not altered the configuration of the allochthons in a major way.

## INTRODUCTION

### Physiography and Location

In the Sierra de Santa Rosa area, 70 km southeast of Caborca (Figures #1 and 2), a sequence of Lower Jurassic shallow water marine sedimentary and volcanic rocks crops out as a set of imbricate allochthons. The sequence is also exposed in the adjacent Cerro San Luis, and in the low lying foothills, including the Cerro Garambullo, to the west of the Sierra de Santa Rosa, Cerro San Luis and Sierra Yaqui. Throughout this paper, the location of this sequence will collectively be referred to as the Sierra de Santa Rosa.

This linear range of rolling hills is 3 to 10 km wide, 35 km long, and exhibits 1,000 m of relief. The eastern front of the range is bordered by a flat pediment valley, 300 m higher than the valley to the west. The west front of the range is less well defined, breaking up into a series of foothills and ridges toward the valley. The mapped area is bounded by 30° 12' N on the north, 30° 3' N on the south, 111° 37' W on the east and 111° 50' W on the west, comprising 357 square kilometers.

### Previous Work

Pioneering geologic expeditions through the State of Sonora early in this century determined many of the stratigraphic ages and field relationships observed in the Sierra de Santa Rosa. Most notable are by Jose Aguilera (1896, in Dumble, 1900), E.T. Dumble (1900), Teodoro Flores (1929), Carlos Burckhardt (1930), and an excellent regional synthesis by R.E. King (1939).

Since World War II, correlative rocks and structures similar to those in the Sierra de Santa Rosa have been described in the immediate area. Cooper and Arellano (1946) described the younger Precambrian and Cambrian strata in the Caborca area. White and Guiza (1948) described an Upper Triassic and Lower Jurassic section in El Antimonio mining district, 103 km west of the Sierra de Santa Rosa. This locality is the closest measured section of correlative rocks to the Sierra de Santa Rosa, and the depositional base is exposed. Gloria Alencaster De Cserna (1961) studied the paleontology and stratigraphy of the Upper Triassic Barranca Formation and elevated it to group status. Damon and others (1962) and Anderson and Silver (1971) have mapped and dated older Precambrian metamorphic rocks between Caborca and Rancho Bamori. Guillermo Salas, Jr. (1968) mapped similar older Precambrian metamorphic and Mesozoic volcanic rocks in the Santa Ana region. J.L. Eells mapped the younger Precambrian and Cambrian geology of the Sierra de La Berruga, (Anderson, Eells, and Silver, 1978) immediately west of the Sierra de Santa Rosa. T. E. Stump and R. Dowlen (Beauvais and Stump, 1976) mapped Upper Jurassic strata at Cerro Pozo Cerna. R.H. Merriam (1972) published a paper on the reconnaissance geology of the Sonoyta 1:250,000 quadrangle.

Active mining operations in the 1920's attracted four geologists to the Sierra de Santa Rosa itself. They published only very generalized stratigraphic observations and collected fossils. W.T. Keller (1929), with F.E. Wellings, made an east to west reconnaissance traverse through the central area

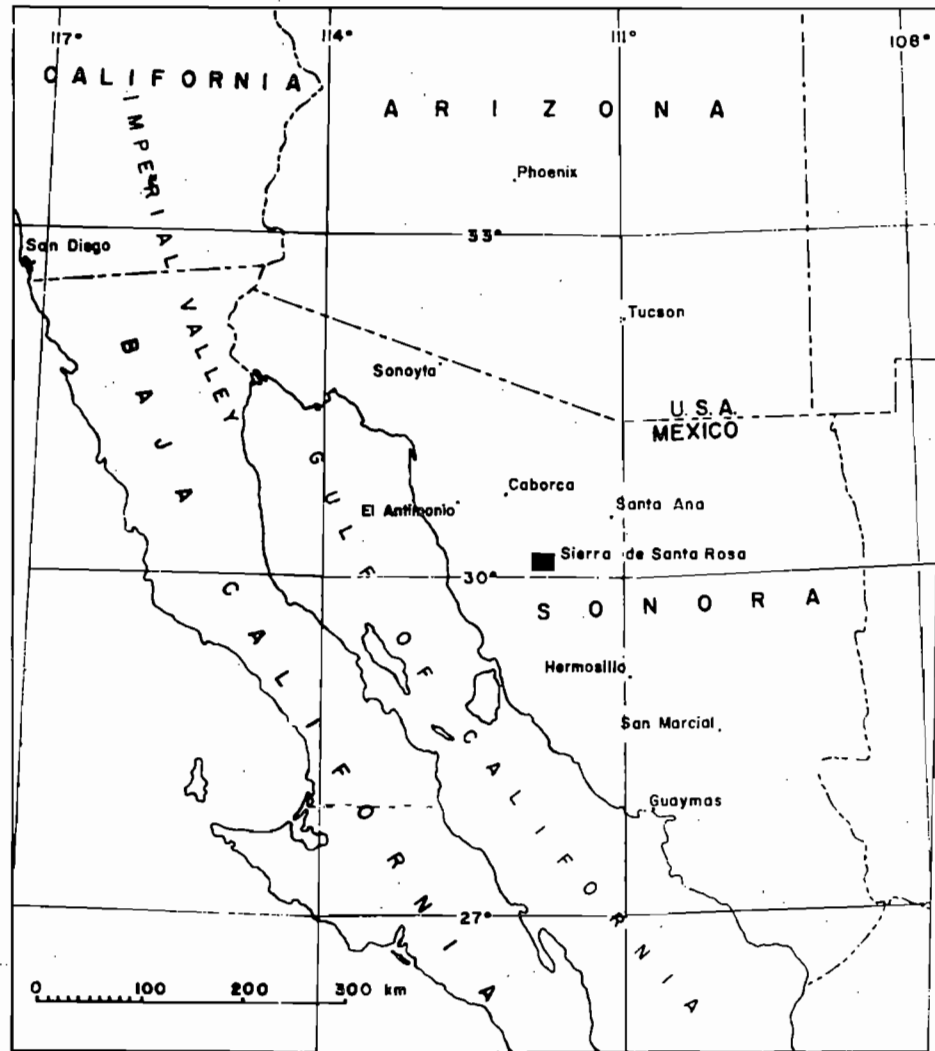


FIGURE 1 - Index Map of the state of Sonora.

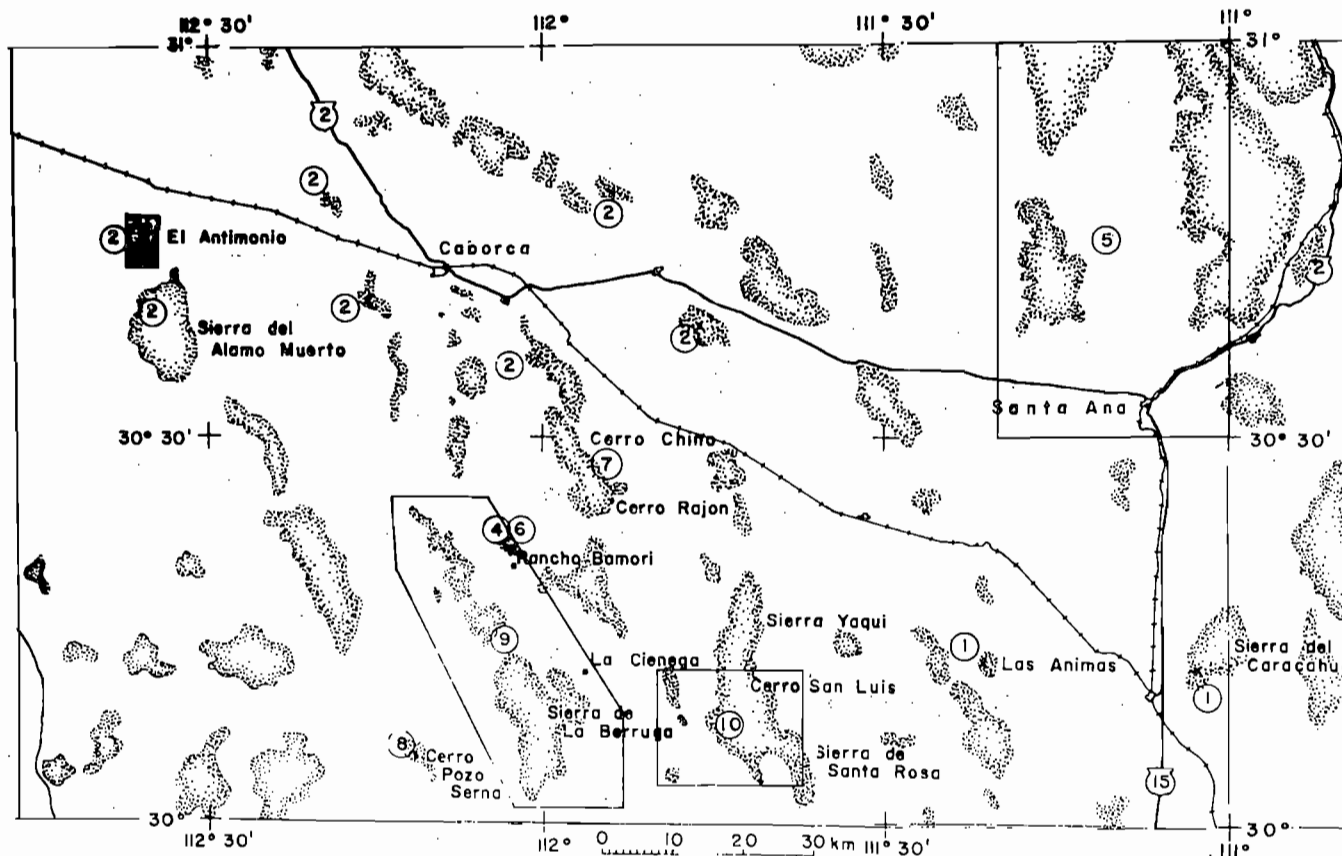


FIGURE 2 - Map of the Caborca region showing previous work and known Lower Jurassic outcrop locations: 1) Flores (1929), 2) Cooper and Arellano (1946), 3) White and Silvers (1971), 4) Damon and others (1962), 5) Salas (1968), 6) Anderson and Silvers (1971), 7) Merriam and Chandler (1971), 8) Beauvais and Stump (1976), 9) Anderson and others (1978), and 10) this paper. Jurassic strata crop out at 1, 3, 8, and 10.

of the range. They described four very general stratigraphic units totaling an estimated 2,350 m in thickness. The sequence was observed to be metamorphosed and highly fractured, but no major low-angle faulting was recognized. Keller and Wellings gave their fossil collection to Erich Jaworski (1929), who published a faunal description and assigned an age of Lias (Early Jurassic) to the sequence. Charles L. Baker also visited the area and supplied stratigraphic and paleontologic information to Charles Schuchert (1935, p. 145) and Burckhardt (1930, p. 23). Burckhardt reprinted the stratigraphic description of Keller and Baker, reviewed Keller's faunal collection and concurred with Jaworski's Lias age. Flores (1929, p. 150) included a brief summary of the major rock types in the vicinity of the mine and collected fossils. Baker's, Burckhardt's and Flores' comments support, but add little to, the observations and conclusions of Keller and Jaworski. R.E. King (1939) used Keller's lithologic information and Jaworski's age conclusions as evidence assigning the sequence to the widespread Barranca Formation.

### Base Map Construction

The most detailed topographic map available of the region is the Cananea 2<sup>o</sup> quadrangle with a scale of 1:250,000. The areal geology of the area, therefore, was plotted on a drainage map constructed planimetrically from air photos with a nominal scale of 1:62,500 (Figure #3).

## PRE-JURASSIC ROCKS

### Older Precambrian Metamorphic Rocks (pCM)

The oldest rocks in the Sierra de Santa Rosa are a complex assemblage of schist, gneiss, metaquartzite and mildly gneissose metaplutonic rocks. This assemblage forms a structural basement upon which younger sedimentary and volcanic rocks have been tectonically emplaced, and is exposed throughout the mapped area. The assemblage is similar petrologically, and exhibits the same field relationships, as older Precambrian rocks studied in the region by Anderson and Silver (1971; Anderson, personal communication) and Damon and others (1962).

The basement of the Cerro Colorado and western Cerro San Luis is predominately a medium to coarse-grained, chloritized quartz monzonite. The basement north and northwest of the mine at Cajon de las Amarillas consists of a quartzo-feldspathic gneiss porphyry. The porphyritic texture is due to large potassium feldspars. The basement terrane east of the Mina de Cajon de las Amarillas is an assemblage of dark gray, highly fractured metaquartzites and black hornfels. The basement in the southwest portion of the mapped area, in the vicinity of Rancho Tierras Blancas and Rancho San Carlos, is dominated by a medium-grained, gneissose pink granite with lesser amounts of gray muscovite schist. East of Rancho San Carlos and east of the crest of the Sierra de Santa Rosa, the basement is predominately a buff, medium-grained, foliated muscovite quartzite.

## Younger Precambrian Sedimentary Rocks (pCs)

Unconformably overlying the metamorphic complex is at least 900 m of dolomite with lesser thicknesses of quartz arenite and shale. This sequence exhibits petrologic and stratigraphic relationships similar to the younger Precambrian rocks studied by Cooper and Arellano (1946) in the Caborca area, and Eells (Anderson, Eells, and Silver, 1978) in the Sierra de La Berruga. No formal stratigraphic name has yet been assigned to this sequence, although its correlation to the latest Precambrian rocks of the Nopah Range in southeastern California has been suggested (Livingston and Damon, 1968).

The sequence within the mapped area is best exposed at Cerro Colorado and in the northwest portion of the area and on the western slope of the Cerro San Luis. In both localities the sequence strikes N 10° W and dips steeply to the west. The sequence is unmetamorphosed and much less fractured than the allochthonous Jurassic sequence. The nonconformity with the older Precambrian metamorphic rocks is exposed along the eastern side of Cerro Colorado, and 1 km due east of Rancho San Luis in a stream canyon. The nonconformity shows very little relief, and the weathered zone extends only a few meters into the older metamorphic complex. The basal bed is a pink, medium to coarse-grained, subrounded arkose averaging 3 m in thickness. The rest of the section is dominated by a light grey, mottled dolomite. The dolomite contains planar or cross-laminae sandstone beds and crenulated structures resembling algal mats. The dolomite is also massive, and intraclastic beds occur. Light pinkish gray, fine to coarse-grained, well rounded quartz arenite comprise about 10 percent of the section, in .5 to 3 m beds. In the Cerro Colorado a 40 m thick interval of reddish black laminated shale forms a series of low saddles in the resistant dolomite.

One small, highly fractured klippe composed of pinkish gray quartz arenite resting entirely on older Precambrian metamorphic rocks is exposed in the west central portion of the mapped area. This is interpreted to be the only allochthonous block of younger Precambrian strata in the Sierra de Santa Rosa region.

## PETROLOGY, STRATIGRAPHY AND ORIGIN OF THE JURASSIC ROCKS

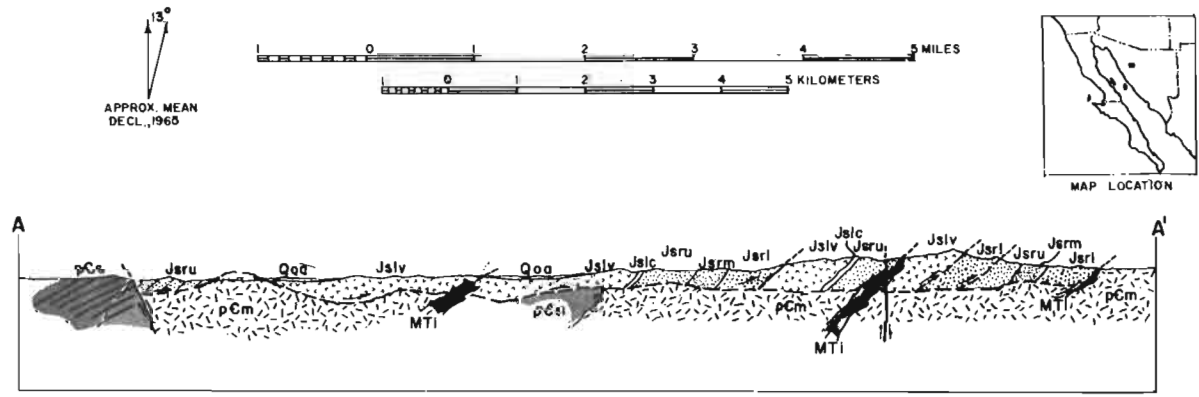
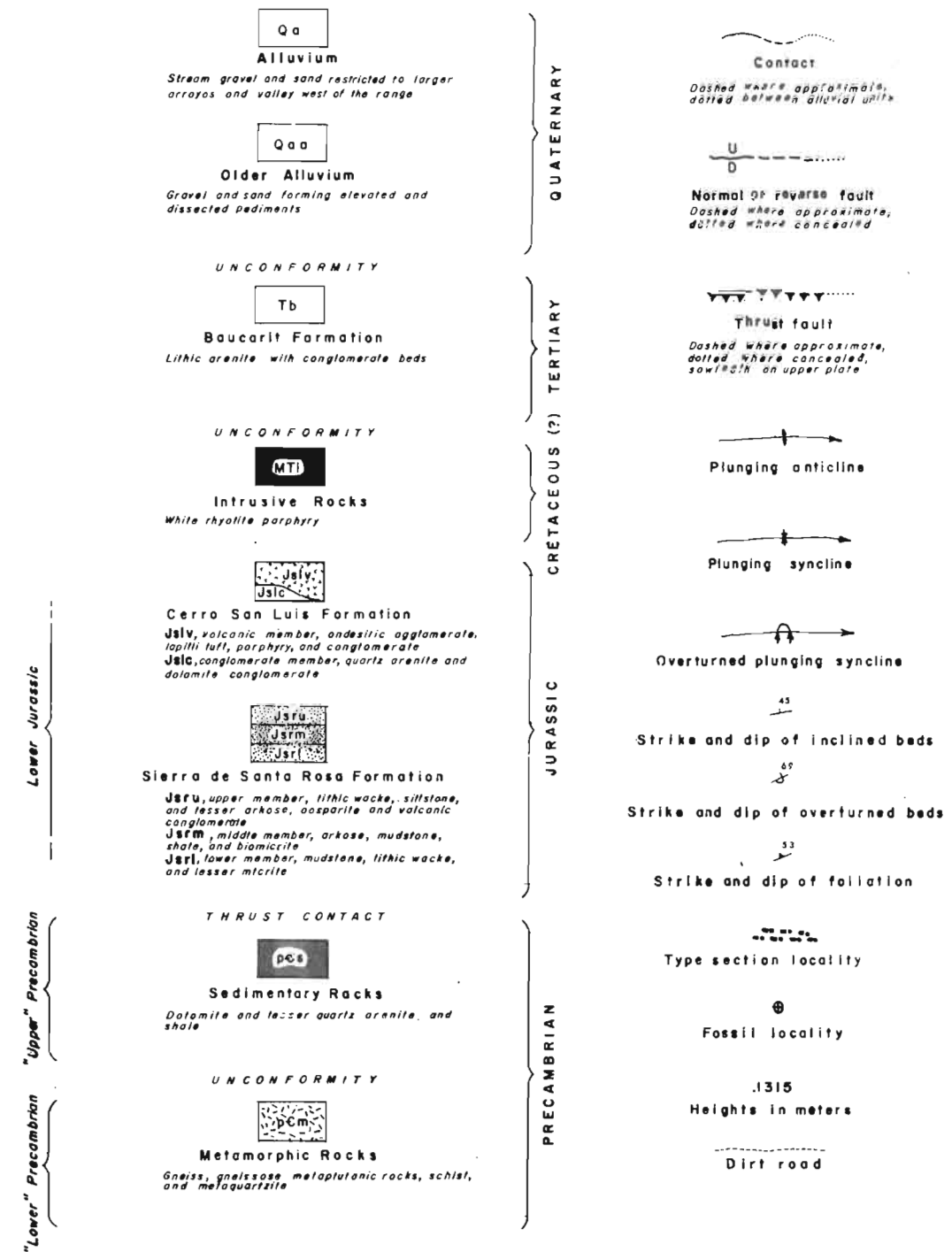
### General Statement

The Jurassic strata of the Sierra de Santa Rosa consist of a continuous section of at least 2,360 m of sedimentary and volcanic rocks distributed on the Precambrian basement in an assemblage of imbricated allochthons (Figure #4). They comprise the central portion of the Sierra de Santa Rosa and Cerro San Luis, and the foothills to the west, covering an area 11 by 15 km. The complex is intruded by post-thrusting rhyolite dikes of Late Cretaceous or Early Tertiary age, and is overlain by the moderately inclined continental Tertiary Baucarit Formation and flat lying Quaternary gravels.

The lower 1,460 m of the section is alternating volcanic and calcareous lithic wacke, calcareous arkose, sandy biomicrite and argillite with lesser thicknesses of volcanic conglomerate, shale and sandy oosparite. This portion of the section is interpreted to have been deposited in a shallow, nearshore marine environment with barrier bar, lagoon and tidal shelf facies. This marine sequence is conformably overlain by a lensing quartz arenite and dolomite cobble conglomerate up to 70 m thick, which



EXPLANATION



**Geologic Map and Section of the Sierra de Santa Rosa, Northwest Sonora, Mexico**  
By  
Rogers Hardy  
1973

*Figure 3*  
Geology of the Sierra de Santa Rosa, Northwest Sonora, Mexico

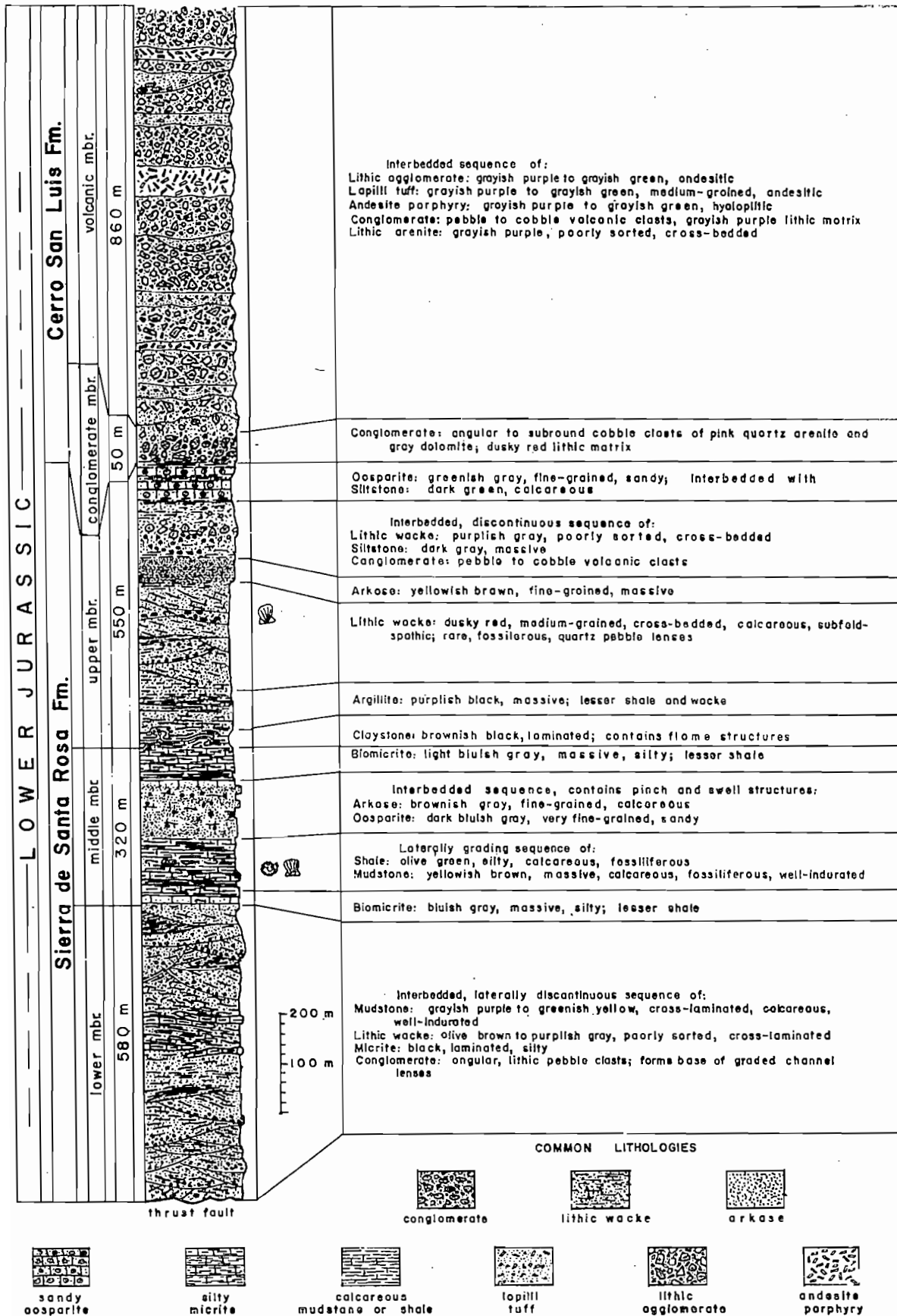


FIGURE 4 - Composite columnar section of the Sierra de Santa Rosa and Cerro San Luis Formations. See text for type localities.

grades upward into a sequence of andesitic agglomerate, lapilli tuff, lava flows and interbedded volcanic conglomerate and wacke. The thickest exposed section of the volcanic sequence is 860 m. The absence of any fossils or fossil fragments in the quartz arenite-dolomite conglomerate and the interbedded conglomerate of the volcanic sequence infers subareal deposition, although a nearshore marine environment is possible.

Hydrothermal alternation occurs throughout the Jurassic rock mass, but is concentrated in the volcanic rocks along contacts with the rhyolite intrusions, along minor fractures, and along the major low-angle faults. These zones are commonly fractured and show epithermal mineralization (Wisser, 1965). The entire Sierra de Santa Rosa is laced with diggings. Mina de Santa Rosa and Mina de Cajon de La Amarillas produced precious metal ore from the late 1800's to the 1940's.

### Sierra de Santa Rosa Formation (Jsrl)

The new name Sierra de Santa Rosa Formation is here proposed for the Lower Jurassic and possibly Upper Jurassic marine sedimentary rocks exposed in the central Sierra de Santa Rosa, and in the low-lying hills west of the range.

R.E. King (1939, p. 1655) included the Lower Jurassic strata of the Sierra de Santa Rosa in the Barranca Formation of Dumble (1900, p. 139). King grouped all the Upper Triassic-Lower Jurassic continental and marine strata spread over thousands of square kilometers of Sonora into this one formation. King's reason in so doing was to delineate a distinct, regional cycle of sedimentation, the deposits of which are separated by unconformities from the underlying and overlying strata. G.A. De Cserna (1961) elevated the Barranca to group status, dividing it into the Upper Triassic brackish water marine Santa Clara Formation lying between the continental Arrayanes and Coyotes Formations. According to De Cserna, these formations are restricted to the "San Marcial Basin" east of Hermosillo, but at times were connected to a marine embayment to the northwest where sedimentation was continuous into the Jurassic. Therefore, the Sierra de Santa Rosa Formation is contained in the upper portion of the Barranca Group.

The formation is informally divided into three members based on the predominance of a particular lithologic type, lateral continuity of beds and sedimentary structures. Because of the structural complexity of the Sierra de Santa Rosa, measurement of a continuous type section through the entire formation is impossible. Therefore, each member has its own section location, picked to show good, continuous exposure, and give a representative indication of the internal characteristics (Figure #3).

Lower member (Jsrl1). The lower member of the Sierra de Santa Rosa Formation is volcanic wacke and hard, calcareous mudstone, with lesser volcanic pebble conglomerate and sandy micrite. The member is distributed within several allochthons, primarily in the east-central Sierra de Santa Rosa. The thickest section is approximately 580 m, but the total thickness is unknown as the depositional base is not exposed. The rock types occur repeatedly throughout the section in laterally discontinuous, commonly cross-bedded lensoidal deposits, but no major facies change was noted in the member across structural boundaries. The type section was chosen to represent the relative abundances of the different lithologies, and does not show the stratigraphic position of any one lithology

throughout the area. It is located along the east-west ridge between the Cerro San Luis peak and the road from La Cienega to the ruins of the Mina de Cajon de Las Amarillas, starting 1 km west of the ruins.

Approximately 50 percent of the member is hard, massive, laminated and cross-laminated calcareous siltstone and mudstone occurring in 1 to 5 m lensoidal beds. They are highly fractured, commonly weathering into dark grayish purple to greenish yellow rectangular blocks from cobble to boulder size. The average composition is 50 percent subangular, coarse, quartz and feldspar silt, 35 percent authigenic and detrital clay, primarily sericite, and 15 percent authigenic calcite. These modes vary from 80 percent silt to thin lenses of claystone or marl with shell fragments. In at least three horizons, the mudstone grades into evenly laminated, silty black micrite beds, 2 to 3 m thick, which comprise about 5 percent of the member. They are the most laterally persistent beds in the member, traceable for over 1 km.

Forty percent of the member is well-indurated, cross-laminated, light olive brown, angular to subangular, fine to medium-grained lithic wacke. The laminae, .5 to .4 mm thick, are subtly defined by grain size and color variation, and form gentle, planar cross-laminations in prisms 1 to 10 m thick. The prisms commonly show channel grading from pebble to lutite beds. The wacke contain an average of 48 percent clay matrix, and 52 percent sand grains composed of polycrystalline quartz with sericite and monocrystalline quartz with vacuoles (37 percent), feldspars (30 percent) and aphanitic volcanic rock fragments with ferromagnesian minerals (33 percent). The clay matrix probably also contains some completely decomposed rock fragments and unstable mineral grains. Interbedded with the wackes, commonly at the bottom of a graded sequence in 10 cm thick lenses, are poorly sorted, angular pebble conglomerates.

Middle member (Jrsm). The middle member, averaging 320 m, is a relatively laterally persistent sequence of silty biomicrite, sandy, fossiliferous shale and arkose, well exposed in the east-central Sierra de Santa Rosa, and in the low hills between Cerro Garambullo and Rancho San Carlos. The type section is in a stream gully crossed by the dirt road through the range from Rancho Tierras Blancas to Rancho San Diego, 400 m north of the main shaft to the Mina de Santa Rosa. This is probably the principal fossil locality of Keller (Jaworski, 1929). The lithologic sequence described in the type section is present throughout the Sierra de Santa Rosa, although the relative proportion of the limestones is greater in the allochthon located in the southwestern low hills of the mapped area.

The bottom of the member is marked by the first occurrence of a light bluish gray, silty biomicrite. The micrite is commonly massive and contains 3 percent quartz silt and abundant bivalve shell fragments with geopetal spar. Interbedded in the micrite are 1 to 5 m beds of green, silty shale and rare sandy lenses with current-oriented bivalve fragments. This limestone-dominated assemblage ranges from 80 to 140 m in the thickness and is present at this stratigraphic position throughout the Sierra de Santa Rosa. At the type section, the limestone-dominated assemblage grades into a calcareous silty shale bed 20 to 80 m thick. In the allochthon located in the low lying hills southwest of the type section, this stratigraphic interval is occupied by a calcareous siltstone. The apparent facies gradation between the two is not readily observable in the area. The shales, similar to that interbedded with the biomicrite is pale olive green, contain 19 percent quartz silt, 33 percent calcite and are extremely fissile, weathering to unconsolidated, pebble size

blocks forming gentle slopes. The siltstone is moderate yellowish brown weathered and grayish black on fresh faces. It is massive, well indurated, highly fractured and weathers into cobble size rectangular blocks. The siltstone contains 70 percent subangular to round coarse silt, 30 percent authigenic spar and recrystallized fossil allochems and traces of sericite. The shale and siltstone contain the best preserved fossils in the formation. Well preserved specimens of Weyla (Weyla) mexicana Jaworski are abundant in the siltstone, along with other bivalves. Ammonite impressions are more common in the shale, although occasional bivalves are found.

At least two planar, 5 to 20 m beds of dusky red, laminated tuffaceous mudstone occur interbedded with limestones, shale, and siltstone, in the allochthon in the southwestern low hills, in the vicinity of Rancho San Ambrosio and Rancho San Carlos. The rocks are very porous and extremely soft, only cropping out in deep stream gullies. The bedding is denoted by 20 mm layers of devitrified volcanic ash interbedded with 5 mm laminae of subround quartz silt, with ammonite impressions and rare glauconite.

The upper 160 m of the middle member consists of fine-grained, calcareous arkose and fine-grained, sandy oosparite that show a sequence of sedimentary and penecontemporaneous compaction structures at this stratigraphic interval throughout the Sierra de Santa Rosa. The two rock types were originally interbedded in 1.5 to 3 cm tabular beds traceable up to 100 m laterally. Varying degrees of soft sediment grain flow contorted the oosparite beds into partially and completely detached pinch and swell, or sedimentary boudinage structures. Selective solution of the oosparite beds and spheroids gives the arkose beds a raised appearance.

The arkose weathers a brownish gray, is dark bluish gray on a fresh surface, and exhibits an even, conchoidal fracture. It contains 59 percent subangular to subround, very fine to fine sand, and 41 percent spar. The fraction contains 65 percent clear, mono- and polycrystalline quartz, and 35 percent feldspar, including orthoclase, twinned plagioclase and microcline perthite. The spar is primarily optically continuous pore filling cement, but a minor portion is very fine, round recrystallized intraclasts. The oosparite is dark bluish gray fresh and weathers to dark brownish gray. It contains 64 percent spar and 36 percent very fine to fine sand. Twenty percent of the spar is very fine and fine-grained, recrystallized oolites, many with sand nuclei. The remainder is authigenic spar matrix. The sand fraction mineralogy is similar to that of the interbedded arkose.

The uppermost 30 m of the middle member is composed of a silty biomicrite nearly identical to the biomicrite occurring in the lower portion of the middle member.

Upper member (Jsru). The upper member is a sequence of argillite, lithic wacke, volcanic conglomerate and oosparite showing poor lateral continuity, exposed primarily on the west slope of the Sierra de Santa Rosa. The thickness at the type section is 550 m, but the thickness varies, reaching 700 m in the south portion of the range. The type section is located along the second ridge south of the road from La Cienega to the ruins of the Mina de Cajon de Las Amarillas, in the same allochthon as the type section for the lower member. The section starts at the intersection of the road from Rancho San Carlos to the ruins where it crosses a ridge near Rancho Horchata.

The bottom of the member is marked in most places by a 20 m bed of brownish black claystone with white quartz silt laminae .5 mm thick, at 3 to 5 mm intervals, showing flame and bed load deformation structures not observed elsewhere in the formation. Overlying the claystone, or directly on the middle member, is an interval of purplish black argillite, weathering yellowish gray, with occasional interbedded mudstones, shales and volcanic sand beds similar to those in the lower and middle members. The argillite fractures into characteristic sharp conchoidal fragments, is typically massive and contains 60 percent very well indurated clay matrix, 25 percent quartz silt and 15 percent sand size angular andesite rock fragments. The argillite contains poorly preserved ammonites and rare bivalves. This argillite-dominated sequence averages 60 m in thickness.

The lutites that make up the bottom of the member grade vertically into a fine to medium-grained sandstone sequence dominated by a calcareous subfeldspathic lithic wacke with lesser sandy micrites and fine-grained, subangular arkose. This sandstone assemblage forms most of the middle portion of the member, averaging 220 m in thickness. The sandstone shows gentle cross-bedded, or planar, laminae .5 to 2 mm thick, but is locally massive. Rare, well-rounded quartz pebble lenses contain bivalve and ammonite shell fragments.

The calcareous subfeldspathic lithic wacke weathers to a diagnostic very dusky red, but is light brownish gray on fresh surface. Sixty-two percent of the wacke is a sand framework filled by 18 percent detrital clay matrix and 20 percent calcite cement. The sand fraction is 57 percent quartz, 2 percent feldspar and 41 percent rock fragments, black devitrified volcanic rocks and calcite-replaced plagioclase (?). The much less common fine-grained arkose is interlensing with the wacke, primarily in the upper portion of the sequence. The rock is massive, very well indurated, pale yellowish brown where weathered, and light bluish gray where fresh. It is composed of 92 percent subangular sand and 8 percent clay matrix. The sand is 52 percent monocrystalline quartz and 48 percent feldspar.

Above the sandstone sequence is a volcanic sedimentary sequence of interlensed siltstone, sandstone and conglomerate. Specific lithologic types within this sequence have poor lateral continuity, but the composite sequence is present at this stratigraphic horizon throughout the Sierra de Santa Rosa, averaging 90 m in thickness.

The siltstone and sandstone are very similar to those of the lower member in color, grain size and mineralogy, but more commonly show planar lamination rather than cross-bedding with channel grading. The angular pebble conglomerate beds are better washed than those in the lower member, sometimes containing no interstitial clay or silt, the voids being filled by spar cement. The rudite clast mineralogy contains 73 percent volcanic rock fragments, including devitrified welded tuff and fine-grained pilotaxitic andesite porphyry; 18 percent feldspar, mostly altered plagioclase; and 9 percent quartz. In the northeast and west-central Sierra de Santa Rosa, this assemblage includes cobble conglomerate beds 1 to 5 m thick. The matrix is a massive, poorly sorted, volcanic lithic wacke. The subround clasts include older Precambrian-type metamorphic rocks, welded tuffs, andesite agglomerates, and a white, hypabyssal granite. This granite does not crop out in the Sierra de Santa Rosa.

The uppermost portion of the upper member consists of a relatively continuous alternating sequence of well-indurated, dark green calcareous siltstone and massive, greenish gray, fine-grained, sandy oosparite averaging 130 m in thickness. The average composition of the oosparite is 25 percent very fine to fine, subangular arkosic sand, 25 percent fine-grained, recrystallized spar oolites and 50 percent spar matrix. The sand is concentrated in 1 to 5 mm vein-like stringers through the rock in contrast to the even alternation of

beds in the oosparite-calcareous arkose succession of the middle member. The siltstone and oosparite occur in tabular, laterally persistent beds 1 to 3 m thick.

Fossils, age and correlation of the Sierra de Santa Rosa Formation. Table 1 contains a composite list of the identified fossil species collected from the formation by W.T. Keller (1929) with F.E. Wellings, T. Flores (1929) and the present author, with updated generic and subgeneric geologic ranges (Moore, 1957). Figure 4 shows in which stratigraphic horizons these fossils are found, and Figure 3 shows the major fossil localities. Erich Jaworski (1929) identified and described Keller and Wellings' collection and designated an age of Lias (Early Jurassic) to the fossiliferous interval. Carlos Burckhardt (1930, and in Keller, 1929) reviewed the collection and also assigned a Lias age to it. Flores (1929, p. 150) assigned a Lias age to the area based on his own collection.

The most common and best preserved fossils in the Sierra de Santa Rosa are the bivalves. The two most common bivalve species, Weyla (Weyla) mexicana Jaworski and Trigonia inexpectata Sowerby, have updated geologic ranges restricted to the Lias (Morre, 1957b, p. N371 and p. N478). They occur in the silty shale and calcareous mudstone of the middle member. Flores (1929, p. 150) collected "...moldes de Pecten n. sp., del grupo Pecten pradoanus Verneuil et Collumb del Lias Inferior..." which is probably the same species as Neithea mexicana Jaworski, whose type locality is in the Sierra de Santa Rosa (1929, p. 3). Neithea has subsequently been elevated to group status, and the name is now Weyla (Weyla) mexicana Jaworski (Moore, 1957b, p. N371). Numerous impressions of at least two ammonite species commonly occur in the calcareous shale layer of the middle member, and occasionally in the lithic wacke and argillite beds of the upper member. Only the general outline and major ribs are preserved even in the best specimens, and none collected by the author could be identified. Flores (1929, p. 150) tentatively identified one of these species as belonging to the genus Arietites. Jaworski (1929, p. 9) assigned another type to the genus Deroceras. Both of these genera are restricted to the Lias (Moore, 1957a, p. L238 and p. L247). Star-shaped Crinoid columnals commonly occur with the bivalves. Flores (1929, p. 151) assigned them to the genus Pentacrinus, also restricted to the Lias (Shimer, 1944, p. 235). Poorly preserved gastropods and unidentified corals also occur in the limestones of the middle and upper members. A lone fragment of a fern leaf was found in an argillite layer in the upper member nearly adjacent to some ammonite fragments, but it was not identified. The lower 600 m of the formation, including all the lower member, has no age control. The lower member could quite possibly extend into the Upper Triassic, as the Triassic-Jurassic contact in Sonora is not marked by an unconformity (King, 1939, p. 1654).

White and Guiza (1948) described an unnamed sequence of marine sandstone, siltstone and conglomerate of Triassic and Liassic age resting unconformably on Permian limestone in El Antimonio District, 103 km west of the Sierra de Santa Rosa. The upper portion of the Antimonio section, Triassic (?) Unit H, and Jurassic Unit I might correlate to the lower and middle members of the Sierra de Santa Rosa Formation, respectively. Very general lithologic descriptions, an absence of paleontologic data, and the distance between the various localities make this correlation tenuous.

Table 1. Composite List of the Identified Fossils  
Occurring in the Sierra de Santa Rosa Formation.

Fossil	Flores (1929)	Publication		Geologic Range
		Jaworski (1929)	This report	
<b>BIVALVIA</b>				
<u>Camptonectes</u> ( <u>Camptonectes</u> ) sp. Cret.			X	L. Jur.-U. Subgeneric
<u>Weyla</u> ( <u>Weyla</u> ) <u>mexicana</u> Jaworski	X	X	X	L. Jur. Subgeneric
<u>Alectryonia</u> <u>gregarea</u> Sowerby		X		L. Jur.-U. Jur. Specific
<u>Lima</u> <u>nodulosa</u> Terq.		X		Jur.-Rec. Generic
<u>Plagiostoma</u> cf. <u>P. exaltata</u> Terq.		X		M. Trais.-U. Cret. Subgeneric
<u>Trigonia</u> cf. <u>T. inexpectata</u> Jaworski		X	X	L. Jur. Subgeneric
<u>Myoconcha</u> cf. <u>M. Valenciennesi</u> Bayle		X		L. Jur.-U. Cret. Generic
<u>Astarte</u> cf. <u>A. antipodium</u> Geibel		X		Jur. Rec. Generic
<u>Pholadomya</u> sp.			X	U. Trais.-Rec. Generic
<b>AMMONIODEA</b>				
<u>Arietites</u> sp.	X		?	L. Jur. Generic
<u>Deroceras</u> sp.		X		L. Jur. Generic
<b>CRINOIDEA</b>				
<u>Pentacrinus</u> sp.	X		?	L. Jur. Generic

The Sierra de Santa Rosa Formation is probably time equivalent to the upper portion of the original continental and brackish marine Barranca Formation in southeastern Sonora, now the Coyotes Formation of De Cserna (1961). Lower Jurassic marine fossils occur elsewhere in Sonora (See Discussion) and further mapping may determine them to be correlative to the Sierra de Santa Rosa Formation.

### Cerro San Luis Formation (Jsl)

The new name Cerro San Luis Formation is here proposed for a continuous sequence of Jurassic and possibly Cretaceous conglomerate and andesitic volcanic rocks conformably overlying the Sierra de Santa Rosa Formation. The formation is exposed primarily in the low hills west of the Cerro San Luis, but is also structurally juxtaposed to the Sierra de Santa Rosa Formation in the eastern portion of the range. The thickness of the volcanic sequence is unknown and probably exceeds the 860 m of the type section. The type section is through a stream gully cutting the west slope of the Cerro San Luis. The top and east end of the section is at Rancho San Luis. The formation is informally divided into two members on the basis of lithology.

Conglomerate member (Jslc). Conformably overlying the upper member of the Sierra de Santa Rosa Formation is a lensing, 0 to 70 m layer of quartz arenite and dolomite cobble conglomerate. The conglomerate is best exposed in the north-central portion of the range. Where exposed, the contact between the formations consists of a pebble bed on top of calcareous mudstones showing penecontemporaneous sediment flow and partially detached rip ups in response to the weight of overlying clasts. The matrix of the lower few meters of the conglomerate contains intraclasts of the underlying muds. The lower pebble bed grades rapidly upward into unoriented, angular to well-rounded cobble beds with rare, isolated boulders and pebble lenses. In gully outcrops, the conglomerate commonly fractures across clasts forming a smooth, mosaic pattern.

Bluish white to grayish orange pink, fine-grained, well-rounded supermature quartz arenite comprises 62 percent of the clast percentage. The remaining 38 percent is composed of a light greenish gray to pale yellow orange, sandy, massive, laminated and algal mat dolomite. These rudite clasts are virtually identical to younger Precambrian sedimentary rocks exposed in the area. The matrix is dusky red, very fine to medium-grained, massive and composed of 52 percent mono- and polycrystalline quartz, including sedimentary and metamorphic quartzites, 40 percent dolomite rock fragments and 8 percent clay matrix.

Volcanic member (Jslv). Conformably overlying the conglomerate member where present, and elsewhere directly on top of the upper member of the Sierra de Santa Rosa Formation, is a heterogenous assemblage of andesitic agglomerate, lava flows, lapilli tuff and flow breccia with lesser interbedded volcanic conglomerate and arenite. The maximum thickness of the member exceeds the 860 m of the type section, but is impossible to determine due to incomplete exposure, and the possibility of undetected reverse faulting within the member. The relative abundances of rock types in the type section are characteristic of the member in

the northern portion of the range, but the exposures east of Rancho San Carlos contain fewer agglomerate and flows, and a higher percentage of finer-grained tuff, pebble conglomerate and volcanic sandstone. The contact with the conglomerate member is a subangular pebble conglomerate layer a few meters thick that shows a rapid gradation from a quartz arenite and dolomite clast assemblage to a welded tuff and pilotaxitic volcanic rock fragment clast assemblage set in a lithic arenite matrix typical of the conglomerate member. This grades upward within 10m to cobble conglomerate or tuff and lava, with rare quartz arenite and dolomite clasts, and next above to an agglomerate.

The andesite lava, comprising only 5 to 15 percent of the member in the type section, is altered grayish green and grayish purple hyalopilitic cumulophyric hornblende andesite, occurring in flows 5 to 70 m thick. The phenocrysts are 62 percent oligoclase to andesine plagioclase, 36 percent chloritic aggregates with magnetite (?) rims formed from the alteration of hornblende, and 2 percent apatite. The phenocrysts range in size from .03 to 4.5 mm. The original matrix was mostly volcanic glass which devitrified into hyalopilitic quartz, feldspars and zeolites. Eighteen percent of the matrix is now secondary calcite and lesser epidote.

The flows are interstratified in grayish purple and grayish green lithic agglomerate, comprising 70 percent to 85 percent of the member. The agglomerate blocks range from lapilli size to 50 cm in diameter and form massive beds up to 70 m thick. Over 90 percent of the blocks are composed of andesitic lava, lapilli and fine tuff, and less than 10 percent are foliated metamorphic rock of the older Precambrian type exposed in the area. The interstratified, welded lapilli tuff forming 5 to 15 percent of the member show bedding denoted by medium to coarse plagioclase crystals and deformed pumice fragments .2 to 5 cm long. The matrix of both the agglomerates and tuffs is similar to that of the lavas.

Interbedded in this pyroclastic sequence are lensoidal deposits of pebble to cobble conglomerates and poorly sorted arenite consisting of clasts of andesite of the same composition as the pyroclastic sequence in which they are included. At the type locality and in the Cerro San Luis area, these sediments comprise only 5 percent of the member, but to the south, in the vicinity of Cerro Garambullo and Rancho San Carlos, the arenites comprise up to 40 percent of the member.

The conglomerate is grayish purple and contains unoriented, subangular to round pebble to boulder clasts, 80 percent cobble size. The arenite is grayish purple and grayish green, commonly channel graded and cross-bedded in 5 m thick lenses within the conglomerate. In some beds the only criteria for distinguishing these sediments from the agglomerate and tuff are the round shape and sharp boundaries of the conglomerate clasts and cross-bedding in the arenites. Thin-section inspection reveals subround quartz in most of the arenites and rudite matrix. Most of the conglomerate contains up to 15 percent well rounded, pebble and cobble size younger Precambrian sedimentary clasts identical to those in the conglomerate member, and foliated metamorphic rocks similar to those in the older Precambrian basement.

Age and correlation of the Cerro San Luis Formation. The base of the formation rests conformably on strata containing Lower Jurassic fossils. Therefore, the conglomerate member and at least a major portion of the volcanic member probably occupies the

Lower and Middle Jurassic. Thin sections of the lavas, agglomerates and feeder dikes to the formation were inspected for suitability for K/Ar dating, but the recrystallization was too great in every case.

The volcanic member of the formation exhibits petrologic and internal stratigraphic characteristics very similar to the Lista Blanca Formation of Dumble (1900, p. 147), whose type section is near San Marcial, 220 km southeast of the Sierra de Santa Rosa. Dumble stated:

The impression made on us in the field was very strong that they (the volcanics) and the underlying Triassic beds (Barranca Group) were part of one system.

This is interpreted as meaning that an actual conformable contact was not observed, but the two rock types were in close proximity and showed no angular discordance. The conformable relationship is positively observed in the Sierra de Santa Rosa. This is rare, however, as King (1939, p. 1655) found the widespread Lista Blanca variety of volcanic rocks unconformably on Barranca strata and interbedded with fossiliferous Cretaceous rocks. Salas (1968) mapped volcanic deposits very similar to the Cerro San Luis Formation volcanic rocks interbedded with Albian-Aptian Cretaceous sedimentary rocks just east of the town of Santa Ana, 100 km northwest from the Sierra de Santa Rosa. King assigned all the pre-Tertiary volcanic rocks in Sonora to the Cretaceous, but it appears that at least isolated andesitic volcanism occurred in northwestern Sonora as early as the Jurassic.

#### Origin of the Sierra de Santa Rosa and Cerro San Luis Formations

**Provenance.** Arenite and rudite clast mineralogies indicate that the source area of the terrigenous rocks of the Sierra de Santa Rosa Formation was primarily a coarse crystalline, regionally metamorphosed, and acidic plutonic terrane, partially covered by andesitic pyroclastic and possibly lava deposits. The chemical instability, angularity and poor sorting of the volcanic detritus suggests that they were eroded a relatively short time after eruption and were transported a relatively short distance to the site of deposition. However, the absence of all but the finest grained pyroclastic deposits in the formation implies that these eruptions, if syndepositional, were not in the immediate vicinity of the area of deposition. The absence of very stable, supermature Precambrian quartz arenite rock fragments in the Sierra de Santa Rosa Formation suggests that these strata and their associated dolomites, now common in the region, were not widely exposed during deposition.

The abrupt but conformable introduction of younger Precambrian quartz arenite and dolomite cobble clasts forming the conglomerate member of the Cerro San Luis Formation is evidence for a localized tectonic event near the site of deposition. Andesitic volcanic material was abruptly re-introduced to the area during deposition of the volcanic member, first in the form of volcanic conglomerate and wacke, and then directly as pyroclastic and lava deposits. The interbedded, channelized conglomerate and sandstone, mostly derived from the agglomerate, tuff and lava they were deposited on, are not believed to mark major episodes of volcanic quiescence. Younger Precambrian clasts in the interbedded conglomerate indicate that this source terrane for the conglomerate member was emergent throughout deposition of the volcanic member. Gneiss and schist xenoliths in the agglomerate and flow breccia suggest that the depositional basement for the entire Jurassic sequence was the older Precambrian metamorphic rocks.

Environment of deposition. The lower member of the Sierra de Santa Rosa Formation is composed of channelized, mixed carbonate-clastic rocks with benthonic shallow water marine fossil fragments. The entire member is interpreted to have been deposited on a shallow tidal shelf. The different lithologies and poor lateral continuities of the member are a function of the different subenvironments on the tidal shelf. The angular, cross-bedded pebbles and sands were deposited in tidal channels meandering across the tidal shelf. The muds were deposited in channels as current energy dropped and in adjacent tidal mud flats when flow spilled over the channels. The silty micrite probably formed in these same mud flats with a more restricted circulation.

The middle member is also a mixed clastic-carbonate assemblage, but this is attributed to a more limited detrital supply in a continually transgressing sea. The member was deposited in two subenvironments offshore from the shallow tidal flat shelf facies of the lower member. The fossiliferous calcareous shale and mudstone were deposited in protected but aerated lagoons away from any channel mouths, but still receiving silt and clay. The associated biomicrite was deposited in these same lagoons during periods of very low sediment influx. The interbedded calcareous arkose and oosparite of the upper portion of the middle member were deposited in a high energy, laterally persistent environment, most probably a barrier bar complex that protected the shoreward lagoon and tidal flat in the transgressing sea. These well sorted sands and oolites probably represent the most open marine deposition in the formation.

The uppermost biomicrite of the middle member and the mudstone and argillite of the upper member were most probably deposited in a protected shallow water environment, probably in a lagoon shoreward from the barrier bar. This would indicate the end of the marine transgression in the sequence, or at least a seaward migration of the barrier bar. The fern leaf fragment found in the argillite of the upper member indicates a low current energy between this basin and land. The remainder of the upper member contains features of both the lower and middle members, and probably represents a transition between the barrier and tidal flat environments and filling of any well-developed, widespread lagoon present in the lower portion of the upper member. This might have been caused by a progradation of the tidal flat or destruction of the barrier bar. The interbedding of clean, calcareous sands and oolites with poorly sorted, angular volcanic sands could have been caused by tidal channels breaching the barrier bar.

In the southwestern low hills and the southern portion of the range east of Rancho San Carlos, the middle and upper members contain a greater percentage of biomicrite. This is possibly due to a starved sediment supply in the lagoons because of a position farther offshore from the barrier bar-lagoon complex.

The sharp contact at the base of the conglomerate member of the Cerro San Luis Formation suggests a rapid filling of the shallow sea in the depositional area. This filling was caused by the nearly adjacent uplift of younger Precambrian sedimentary rocks already mentioned. Portions of the underlying marine sediments were most probably swept away, but soft sediment deformation at the contact and bedding concordance show that the conglomerate member is not a basal deposit upon a lithified, folded terrane. The conglomerate could have been partially deposited in a very nearshore marine environment with high relief, but no positive evidence supports this. Its texture is typical of flood plain and alluvial fan deposits in close proximity to the elevated source rocks. The absence of the conglomerate member in the southwest and south-central areas further suggests that these strata were deposited farther from the source area. The interbedded conglomerate and sandstone beds of the volcanic member show channel grading, cross-bedding and lensoidal geometries. This suggests that they were deposited subaerially in meandering streams upon the volcanic terrane.

## POST-JURASSIC ROCKS

### Late Mesozoic-Early Tertiary (?) Intrusive Rocks (MTi)

An intrusive, light colored rhyolite porphyry of post-low angle faulting and pre-mineralization age crops out at many places in the Sierra de Santa Rosa. The porphyry was emplaced as a set of irregularly-shaped dikes, generally oriented along strike of the Jurassic strata and commonly along low and high angle reverse fault zones. The intrusive bodies are resistant to erosion, forming the peak of Cerro San Luis and other ridges in the Sierra de Santa Rosa. In outcrop appearance the porphyry is commonly fractured into angular, boulder size blocks with planar sides, and weathers to a very pale orange. A fresh exposure is light gray with white phenocrysts. The phenocrysts comprise about 37 percent of the rock and are set in a sericitized quartz and feldspar matrix. The phenocrysts are anhedral quartz and sericitized megacrystic microcline, with lesser antiperthite, oligoclase and andesine. Many of the dikes have been subjected to epithermal mineralization, and were the major production rocks for the Mina de Cajon de Las Amarillas and the Mina de Santa Rosa.

Mesozoic granitic intrusions are common in central and northwest Sonora (King, 1939), but none crop out in the Sierra de Santa Rosa. Salas (1968) observed intrusive rhyolite porphyries associated with granites in the Santa Ana region 100 km northwest of the Sierra de Santa Rosa. Fine to medium-grained granites crop out adjacent to the Sierra de Santa Rosa, out of the mapped area. They show the same sericite alteration as the rhyolite dikes, but none of the regional metamorphism characteristics of the foliated older Precambrian rocks. Therefore, they might be phaneritic equivalents of the rhyolite porphyry in the Sierra de Santa Rosa.

Field relations in the Sierra de Santa Rosa do not permit the assignment of a precise age to the dikes, and sericite alteration prevents an accurate K/Ar age determination. Salas (1968) suggests a Late Cretaceous or Early Tertiary age for the rhyolite porphyry and associated granite in the Santa Ana area, but no evidence is given. Anderson and others (1969, p. 3) obtained isotopic U/Pb zircon ages in the Sierra Seri, along the coast of Sonora 120 km west of the Sierra de Santa Rosa, that show a Late Cretaceous magmatic event of regional dimensions. The ages of emplacement for Mesozoic granitic rocks appear to show a younger gradation eastward from the coast toward the Sierra de Santa Rosa region (Anderson, 1972, personal communication). The granitic emplacements of central Sonora were also suspected of being Late Cretaceous in age by King (1939). The rhyolite porphyry dikes of the Sierra de Santa Rosa are possibly of the same age.

### Late (?) Tertiary Baucarit Formation (Tb)

In the Sierra de Santa Rosa, the Baucarit Formation (Dumble, 1900, p.151) occurs as a poorly consolidated, thin-bedded, fine to medium-grained, moderate pink sandstone with beds of subround cobble conglomerate, cropping out in a low area east of Rancho San Carlos. The formation dips up to 25 degrees to the west forming an angular unconformity with the underlying, more steeply dipping Jurassic strata, and is partially covered by flat-lying older Quaternary boulder conglomerate beds. The conglomerate beds in the formation are composed of cobbles entirely derived from the sedimentary and

volcanic rocks of the underlying Jurassic strata, Late (?) Cretaceous granitic rocks and the older Precambrian basement. The sandstone is a volcanic lithic wacke containing primarily andesitic tuff and siltstone rock fragments, altered plagioclase and quartz. The sandstone beds contain mud cracks indicating subaerial deposition, probably on an alluvial flood plain during initial emergence of the Sierra de Santa Rosa. Exposure of the formation is restricted to this one valley, where subsequent structural tilting has preserved the sequence, and overlying gravels have been removed.

The Baucarit Formation was defined by Dumble to include poorly consolidated, evenly bedded pink sandstone with conglomerate that occurs throughout east-central Sonora. King (1939, p. 1681) refined the definition to include rocks of this type laid down as alluvial fan and flood plain deposits in intermontane depressions, commonly preserved from erosion by subsequent down faulting. King (1939, p. 1962) observed that the formation overlies volcanic deposits of Early Tertiary age and is covered by undeformed gravel beds of Quaternary age, so a Late Tertiary age is inferred by King. He considers the Baucarit Formation to be nearly the same age as the Miocene Gila Conglomerate of southern Arizona.

#### Older Quaternary Alluvium (Qoa)

Extensive deposits of flat-lying, unconsolidated, boulder to cobble conglomerate, presently undergoing dissection, occur on the flanks of the Sierra de Santa Rosa. These cap many of the low ridges west of the range crest and cover a portion of the west-central Sierra de Santa Rosa itself, 300 m higher than the valley floor 6 km to the west. The capping conglomerate is at the same elevation as the dissected alluvium on the valley floor to the east. Therefore, west of the range divide they are interpreted to be erosional remnants of extensive alluvial deposits that buried a major portion of the west slope of the range. These conglomerates show no evidence of structural deformation. Their occurrence at high elevations and their present dissection are attributed to a lowering of the regional base level by widespread crustal uplift, or the "undamming" of intermontane valleys.

#### Quaternary Alluvium (Qal)

Unsorted gravels, sands and muds lie in stream gullies flanking the range, in localized "dammed depressions" and on the valley floor to the west of the range. These are the only areas not presently undergoing dissection in the mapped area.

### STRUCTURAL GEOLOGY

#### Low Angle Faults and Folds

The structure of the Sierra de Santa Rosa is dominated by a series of imbricated and locally folded allochthons (Figure #3). They are entirely composed of rocks of the Sierra de Santa Rosa and Cerro San Luis Formations, except for

rare, isolated klippen of younger Precambrian sedimentary rocks. The structural basement is composed of the older Precambrian metamorphic complex and the autochthonous younger Precambrian sedimentary sequence. Older Precambrian rocks were not found to be emplaced over younger sedimentary rocks, as was observed in the Cerro Rajon and Cerro Chino 50 km to the north (Merriam and Chandler, 1971). However, the metamorphic terrane was not studied in enough detail to rule out the possibility of additional low angle faults within the older Precambrian complex. In the Cerro Calaveras area 30 km east of the Sierra de Santa Rosa, Eells, (Anderson, Eells, and Silver, 1978) mapped an extensive system of younger Precambrian and Cambrian strata emplaced eastward over similar age strata, and over the older Precambrian metamorphic complex.

The rocks adjacent to the fault planes are highly fractured and, in many cases, mineralized or intruded by the white rhyolite dikes. In some areas the fault planes are actually defined by a zone of brecciation or a series of minor detachment surfaces up to 50 m thick. However, the major fault planes themselves are generally unexposed, making it necessary to determine their locations by the recognition of stratigraphic units and abrupt changes in structural trend.

A set of bedding plane thrust faults within the Jurassic sequence in the Sierra de Santa Rosa define a set of imbricate allochthons (informally named in Figure #5). The lowermost is in the east front of the range and the uppermost is in the western foothills. The eastern and central allochthons, forming the crest and west front of the central range, are bounded by successive, overriding thrusts with surface dips averaging 40 degrees to the west. These contain Jurassic strata with dips nearly parallel to the fault planes.

East of Hill 1315, the "eastern imbricate allochthon" is bound by a frontal, mildly folded low-angle fault, which dips gently to the west. Two successive, overriding thrust faults dip up to 40 degrees to the west. This allochthon was overthrust by an allochthon containing the entire Jurassic section, homoclinally dipping to the west. This "central homoclinal allochthon" forms most of the eastern front and crest of the range. A major reverse fault along the western front of the range defines the base of the "western allochthon," which overthrust the central homoclinal allochthon. The western allochthon contains a repetition of the entire Jurassic section contained in the central homoclinal allochthon and the strata show nearly the same attitudes, striking N 5° - 15° W and dipping 30° - 80° to the west. The stratigraphy shows good correlation across the structural boundaries of these two "homoclinal allochthons," which suggests the strata forming the allochthons were deposited in close proximity to one another. Careful inspection of sedimentary structures and vertical lithologic sequences through the "imbricated" and "homoclinal" allochthons indicate no beds are overturned, precluding the possibility of a isoclinal fold complex. Also, the possibility that the repetition of beds through this sequence is due simply to a cyclic nature of a given set of sedimentary environments is highly unlikely, as the vertical succession of strata from fault block to fault block is virtually identical.

The "southwest folded allochthon" contains a series of east-west striking folds, steeply plunging to the west, consisting of correlatable, but less similar strata than the homoclinal allochthons, which suggests a tectonic juxtaposition of this allochthon from a more distant depositional location. The tight folding of the strata does not extend into the basement, and was possibly caused by a north-south compression prior to eastward emplacement.

The imbrication attitudes and drag fold axis measurements along faults within the allochthons indicate an eastward component of thrusting. The entire Jurassic allochthon

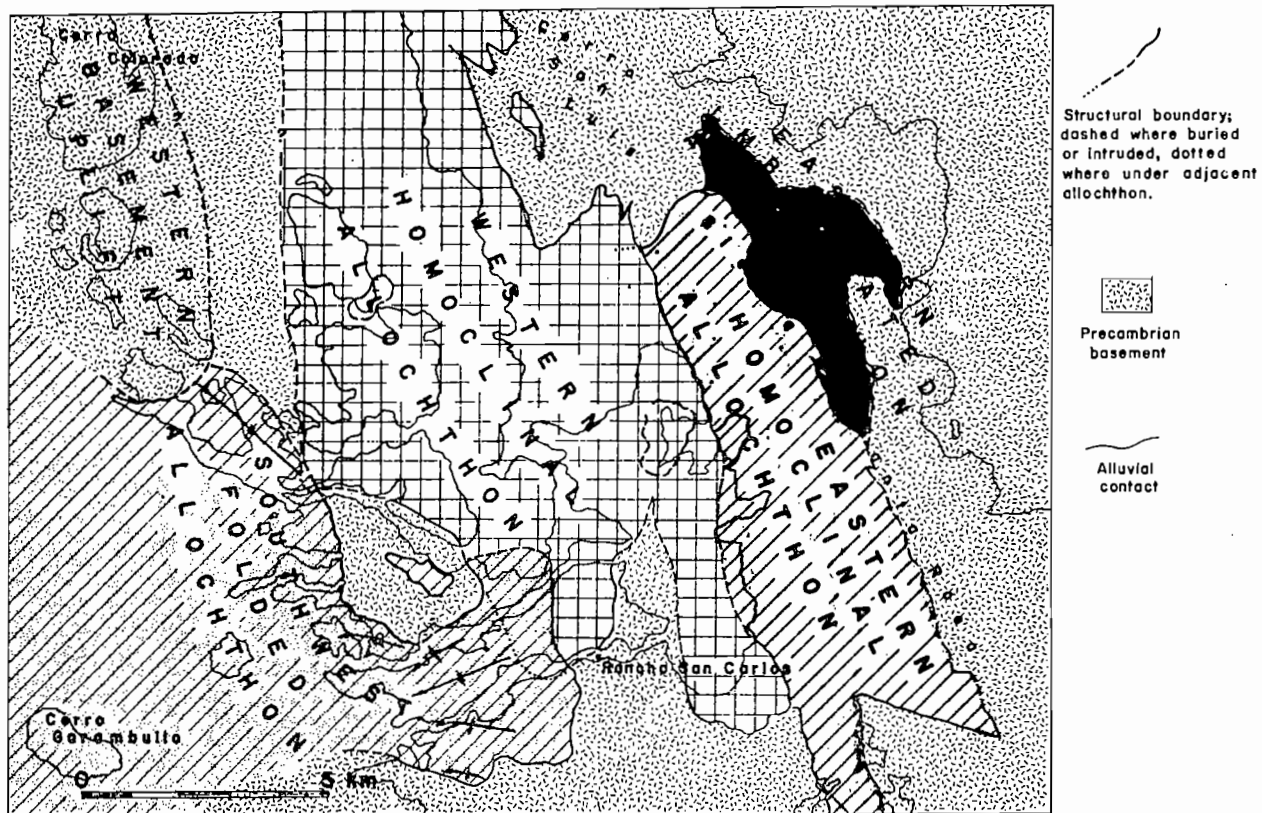


FIGURE 5 - Generalized structural map of the Sierra de Santa Rosa showing the distribution of the allochthons. Tertiary normal faults and mesozoic intrusions omitted.

complex was also probably emplaced from the west (Gastil and Krummenacher, 1977). This is consistent with Merriam and Chandler (1971) and Anderson, et. al., (1978) for movement in the ranges to the west. Regional geologic mapping is not sufficient to determine the distance of movement with certainty, but no autochthonous Triassic or Jurassic exposures are known for at least 50 km to the west. The low angle faults have displaced andesitic volcanic rocks of Jurassic or possibly Early Cretaceous age, but are cross-cut by rhyolite dikes of probable Late Cretaceous or Early Tertiary age. Therefore, the age of tectonic emplacement is generally correlatable to the "Mid" Cretaceous "Sevier Orogeny" of the Western United States. This age predates the Late Cretaceous Laramide age suggested by Merriam and Chandler in the Cerro Rajon, and by King (1939) for thrusting in central Sonora, 250 km east of the Sierra de Santa Rosa.

The angular relationship between the moderately dipping allochthonous Jurassic strata and the low angle fault plane juxtaposing this complex against Precambrian basement argues against a thrust fault emplacement. Either this thrust would have had to cut steadily down section for at least 10 km, or it would have had to cut through previously tilted intervals across strata of varying competency. Neither mechanism is typical of Western North America thrust fault style (Armstrong, 1968), or basic structural geologic principle. More likely the Jurassic allochthon complex was emplaced by gravity sliding from the west, as suggested by Gastil and Krummenacher (1977). The strata and imbricate thrust faults were probably rotated to their present moderate westward dip during emplacement.

An alternate explanation for the present geometry of moderately dipping Jurassic strata truncated by a low angle fault is described by Proffett (1977). In much of the western Basin and Range province of Nevada, originally high angle listric normal faults have been rotated to nearly horizontal attitudes by subsequent movement on younger, successive sets of high angle normal faults. However, evidence of such extensive subsequent normal faulting is lacking in the Sierra de Santa Rosa.

### Normal Faults

Post-thrust and post-intrusion normal faults occur throughout the Sierra de Santa Rosa, but no major, range-forming longitudinal faults are exposed in the mapped area. The normal faults do not show a predominant orientation throughout the range, nor do they alter the configuration of the allochthons in a major way.

In the north-central portion of the mapped area, in the vicinity of Cerro San Luis and Hill 1315, a set of normal faults trends approximately N 40° W. The displacement at the center of these faults is as great as 200 m and is observed to die out within 500 m laterally. A single fault striking N 30° E cuts the western homoclinal allochthon and the metamorphic complex in this same area. In the southeastern portion of the range, within the central homoclinal allochthon, a set of transverse normal faults of minor displacement striking N 80° W cut the intrusive rhyolite and the members of the Sierra de Santa Rosa Formation. The southernmost of these faults defines a portion of the boundary of the central homoclinal allochthon because erosion has removed the entire Jurassic section exposing basement rock on the southern, upthrown side. Vertical displacement on this fault need not be more than a few hundred meters because the allochthon is less than 300 m thick on the northern, downthrown side.

The south-central portion of the range has undergone approximately 25 degrees of tilting to the west since deposition of the Baucarit Formation in the Tertiary. This tilting does not extend west or south to where basement rock and the untilted southwest folded

allochthon crop out. A normal longitudinal fault concealed under the alluvial gravels along the front of the Sierra de Santa Rosa may define the westward limit of this localized tilting within the range. However, there is no positive evidence for such a fault.

## DISCUSSION

### Possible Areal Extent of the Sierra de Santa Rosa Formation

G. A. De Cserna (1961, p. 7) defined two major depositional realms for the Barranca Group. The Arrayanes, Santa Clara and Coyotes Formations were deposited in the fresh water and brackish marine "San Marcial Basin" in central Sonora, southeast of Hermosillo (Figure #2). The open marine shelf deposits of El Antimonio and the Sierra de Santa Rosa were deposited in the "Antimonio Paleobay" in the Caborca region of northwest Sonora. Figure 2 shows the known exposures of possible equivalents of the Sierra de Santa Rosa Formation also being deposited in the open marine shelf of the Antimonio Paleobay of northwestern and central Sonora. The descriptions of these locations are, for the most part, very brief, and thicknesses have only been measured at two locations outside the Sierra de Santa Rosa. Enumeration of these locations is not meant to propose that they be incorporated into the Sierra de Santa Rosa Formation, but simply as an aid to further field study and paleogeographic reconstruction of the marine Triassic-Jurassic System of Sonora.

At the mine at Las Animas (Figure 2) 35 km east of the Sierra de Santa Rosa, Flores (1929, p. 151) noticed a small outcrop of yellow-brown limestone with shales containing a fossil assemblage similar to that of the Sierra de Santa Rosa Formation. In the southern portion of the Sierra de Carachui 85 km east of the Sierra de Santa Rosa, Flores (1929, p. 150) found another assemblage of Lias fossils in a sequence of limestones, sandstones and argillites. At Cerro Pozo Serna 48 km southwest of the Sierra de Santa Rosa, R. J. Dowlen and T. E. Stump (Beauvais and Stump, 1976) described a 1,200 m thick sequence of laminated siltstones, biomicrites and litharenites containing Jurassic fossils. The sequence is in fault contact with all other rocks, but no low angle fault plane is exposed. During examination of the already mentioned sequence at El Antimonio 103 km west of the Sierra de Santa Rosa, White found Liassic fossils at the Sierra del Alamo Muerto just south of El Antimonio (Cooper and Arellano, 1946, p. 611).

### The effect of a Coexistent Magmatic Island Arc-Trench System on the Deposition and Deformation of the Sierra de Santa Rosa and Cerro San Luis Formations

Oceanic magnetic anomaly evidence and plate tectonics theory indicate that western Sonora was bordered by a magmatic island arc (andesite-diorite belt) during Jurassic time (Gastil and Krummenacher, 1977). This north-south arc was bordered on the west by an oceanic trench. Stratigraphic evidence indicates that the region east of the arc, which is now west-central Sonora, including the depositional site of the Sierra de Santa Rosa and Cerro San Luis Formations, was covered by a shallow sea during Late Triassic and

Early Jurassic time (De Cserna, 1961). The relation of this sea to the arc-trench system was that of a "foreland marine basin in a back arc area" (Dickenson, 1971, p. 167). Stratigraphic evidence indicates that a similar, though larger, sea existed behind a northward extension of the arc-trench system in western Nevada and eastern Oregon during the Early Jurassic (Stanley and others, 1971). A sequence of Triassic and Jurassic "Western Belt Sediments" with lithofacies similar to those of the Sierra de Santa Rosa Formation were deposited east of the arc in the present-day northwestern Basin and Range province. These sediments are interpreted to have been derived from volcanic islands and rapidly emerging "tectonic lands" of the arc to the west. Clast mineralogies of the wackes and conglomerates of the Sierra de Santa Rosa Formation suggest that the source area was this andesite and diorite arc to the west.

The orogenic events during the Mesozoic evolution of the Sierra de Santa Rosa might also be related to the arc-trench system. Land thrust belts have been observed in areas immediately behind arcs (Dickenson, 1971, p. 170), and are probably the result of adjustments of the arc mass to adjacent subduction forces and isostatic adjustments. The orogenic event responsible for the abrupt introduction of the quartz arenite and dolomite conglomerate of the Cerro San Luis Formation into the depositional area could be related to these compressive forces between the arc and the site of deposition. Similar "orogenic" conglomerates occur in the Early Jurassic "Western Belt Sediments" of northwestern Nevada, notably the Boyer Ranch Formation (Stanley and others, 1971, p. 16). These orogenic conglomerates are commonly followed by andesitic volcanism and this is also the case in the Cerro San Luis Formation. The eastward emplacement of the entire Jurassic sequence forming the present-day Sierra de Santa Rosa was probably the result of gravity sliding from the west due to regional uplift of this back-arc area after thrusting.

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## TERTIARY MARINE CONGLOMERATE SOUTHWESTERN TIBURON ISLAND

Benjamin F. Weaver  
 Department of Geological Sciences  
 San Diego State University  
 San Diego, CA 92182

ABSTRACT

An unexampled 988 meter thick section of fossiliferous volcanoclastic marine conglomerate outcrops in the southwest corner of Isla Tiburón. The section has been divided into three members, a lower fossiliferous member, middle nonfossiliferous, and an upper fossiliferous member. Microfossils extracted from the upper member give a tentative late Miocene or early Pliocene age. Deposition of the conglomerate took place in a subsiding, near shore basin, the origin of which is possibly the result of the initial dilation of the Gulf of California.

INTRODUCTION

Isla Tiburón, largest island in the Gulf of California, lies off the coast of Sonora Mexico at lat 29° N, long 112° 30'W (Fig. 1). Almost nothing of the geology was known prior to the mapping by San Diego State University students in 1970 and 1971 (Gastil and Krummenacher, 1977). Their reconnaissance revealed a thick section of fossiliferous, marine conglomerate in the southwest corner of the island (Fig. 1).

GEOLOGIC SETTING

The geology of Isla Tiburón is a continuation of that of coastal Sonora. The rocks of Isla Tiburón have been divided into several time/lithologic units (Gastil and Krummenacher, 1974 and 1977). In the southwest corner of the island a major fault separates two distinct rock assemblages (Fig. 1). South of the fault the rock assemblage is tantamount to Gastil and Krummenacher's T1 time/lithologic series (greater than 22 m.y.). The assemblage here is comprised of rhyolite, andesite, basalt, ash flow tuff, and a small amount of lacustrine limestone.

North of the fault the rock assemblage is comprised of Gastil and Krummenacher's T2 and T3 time/lithologic units. Rocks in this area are andesites and rhyolites (18-22 m.y.) and volcanoclastic conglomerate (8-12 m.y.?) respectively. The volcanoclastic conglomerate has also been mapped along coastal Sonora and elsewhere on Isla Tiburón, but only in the southern corner of the island has it been found to be marine in origin.

DESCRIPTION OF THE MARINE CONGLOMERATE

Outcrops of the marine conglomerate are exposed in the bluffs of arroyos A and B (Fig. 1 and 2). Outcrops in arroyo A first appear a few hundred yards inland, forming the northwest wall of the arroyo. This exposure continues southeast for 2,430 meters. Beds of the conglomerate dip consistently  $24^{\circ} \pm 5^{\circ}$  to the northwest, giving a true thickness of 988 meters. Top and bottom contacts of the conglomerate are covered. A few caliche filled joints cut

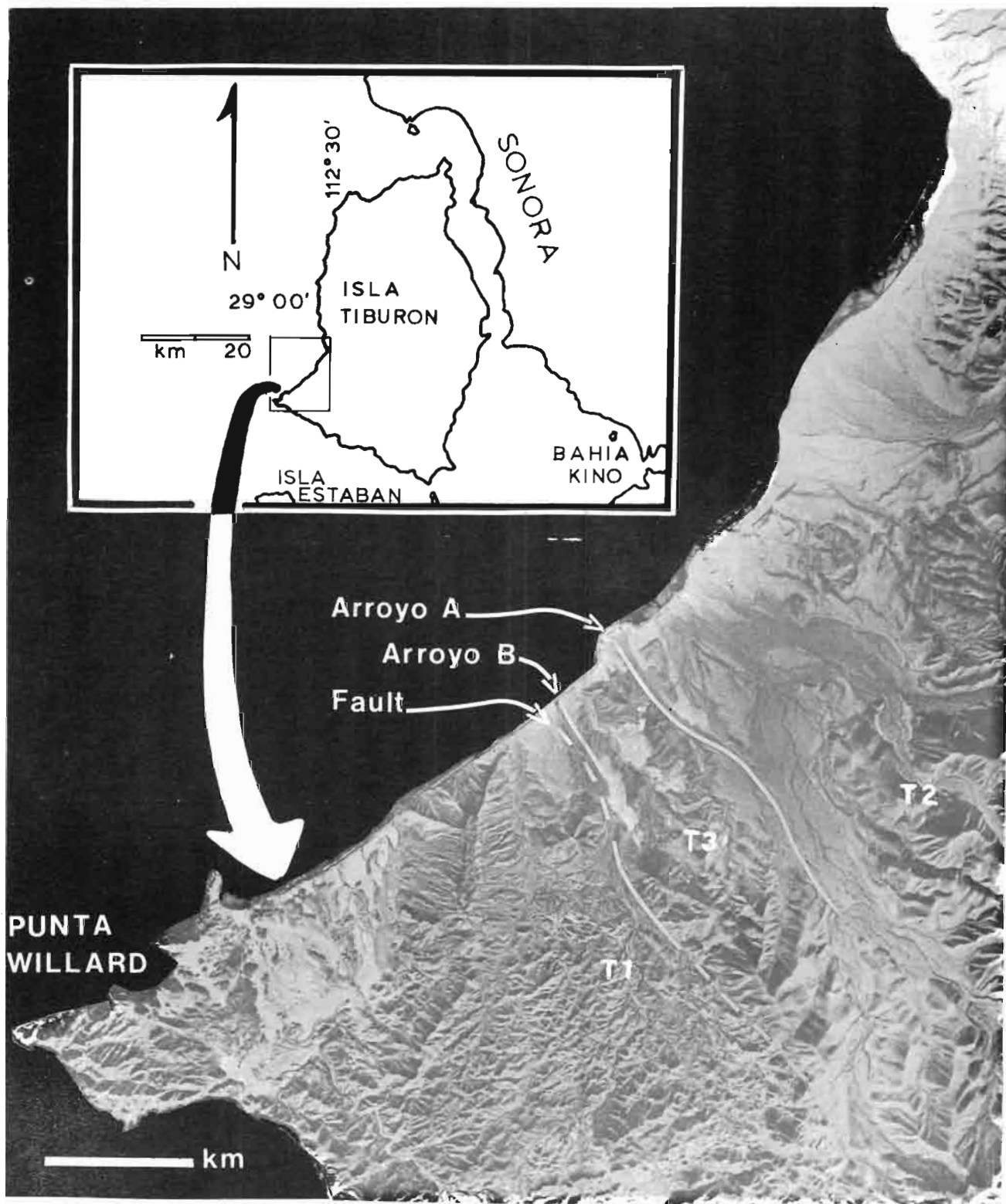


Figure 1. Index map to the southwestern corner of Isla Tiburón. Arroyos A and B are locations where the fossiliferous marine conglomerate outcrops.



A. View of conglomerate looking west in arroyo A.



B. Northwest dipping conglomerate overlain by flat lying quaternary deposits.



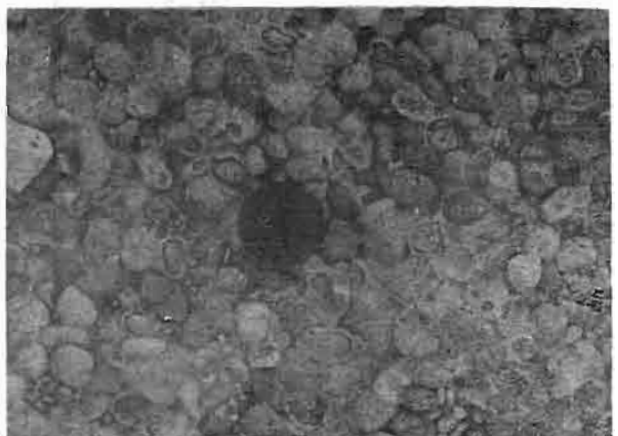
C. Pecten in arroyo A outcrop.



D. Oyster rich bed in arroyo A outcrop.



E. Typical individual sedimentation units.



F. Conglomerate bed with resistant carbonate cement.

Figure 2. Photographs showing features of the volcanoclastic marine conglomerate.

the conglomerate but no offset is apparent.

Three distinct divisions are recognized within the conglomerate outcrop, an upper fossiliferous member (mcg-1), a middle nonfossiliferous member (mcg-2) and a lower fossiliferous member (mcg-3) (Weaver, 1979). Member (mcg-1) forms the lower 400 meters of the exposed section. It is a bedded, poorly sorted, pebbly, light gray, fossiliferous conglomerate (Fig. 2). Clasts are well rounded rhyolite, andesite and olivine rich gabbro. Individual sedimentation units are 5 to 25 centimeters thick. Clast size ranges from grains to cobbles, with pebbles dominant. Individual beds tend to be clast supported. The matrix is a very immature, sandy, siltstone, in places grading to a clayey siltstone. Induration is moderate with increased cementation occurring in highly fossiliferous beds. Both biocoenose and thanatocoenose assemblages of oyster and pecten are present (Fig. 2). *Turritella* and rare coral have been reported (G. Gastil, oral commun., 1978).

Pebble-rich beds of a distinct texture occur in mcg-1 (Fig. 2). A resistant carbonate cement crust has formed on the pebbles and remains unweathered while the interior of the pebble has decomposed. The broken crust reveals the decomposed inner portion of the pebble resulting in the unusual texture of the outcrop.

Up section, the beds become unfossiliferous, member (mcg-2). Individual beds range in thickness from a few centimeters to over a meter. Sorting is very poor. Clast composition remains as that of mcg-1, but with an overall increase in clast size. Cross-bedding occurs in the more sandy facies.

Continuing up section, the return of pectins and oysters marks the beginning of member (mcg-3). The oysters are smaller than in mcg-1 and occur individually. Trace fossils are common and indicate the beds are right side up. Clast composition remains that of mcg-1 and mcg-2. Sorting is very poor with some clasts of boulder size.

Samples from a sandy facies of mcg-3, in arroyo B, contain abundant benthic and pelagic foraminifera along with lesser numbers of ostracods, fish teeth and echinoderm spines. The foraminifera *Lagena*, *Hanzawaia*, and *Elphidium* were identified with a tentative identification of *Globigerinoides obliquies*. The foraminiferal assemblage is representative of Neogene time and a Miocene to early Pliocene age has been suggested by A. D. Warren (oral commun., 1978).

#### CONCLUSION

An abundance of neritic mollusks, benthic foraminifera, and ostracods alternating with an apparently fluvial section indicates that the conglomerate was deposited in shallow water. The rate of deposition kept pace with and temporarily exceeded the rate of basin subsidence, with a total subsidence of at least 988 meters. Poor sorting and clast composition indicate that the conglomerate was locally derived. Whereas marine strata of Miocene age are reported at many localities beneath the alluviated basins of western Sonora (Lozano, 1975), this is the only known outcrop of marine strata interbedded with Miocene volcanic strata exposed on either side of the Gulf of California.

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THE MARINE MIOCENE FAUNAS OF TIBURON ISLAND, SONORA, MEXICO  
AND THEIR ZOOGEOGRAPHIC IMPLICATIONS

T. E. STUMP

Union Oil Company of California  
International Oil and Gas Division  
P. O. Box 7600  
Los Angeles, California 90051

Abstract

The known late Middle Miocene marine fauna of Tiburon Island is listed. Many species proved to be representative of widespread early Pliocene taxa. Others are interpreted as being progenitors of key pectinids lineages which became widespread and underwent adaptive radiation during the Pliocene in the Gulf of California. Striking similarities between the Tiburón Island fauna and Neogene Caribbean taxa suggest active faunal interchange throughout the Neogene between Panamaic and Caribbean waters.

Resumen

Se enlista la fauna marina conocida del Mioceno Medio Tardío en la Isla Tiburón. Muchas especies probaron ser representativas de taxa de amplia distribución del Plioceno temprano. Otras especies son interpretadas como progenitores de linajes de pectinidos claves, los cuales se esparcieron y se adaptaron en todo el Golfo de California durante el Plioceno. Similitudes notables entre la fauna de la Isla Tiburón y taxa neogenos del Caribe sugieren un intercambio faunístico activo durante todo el Neogene, entre las provincias Caribeñas y Panámicas.

During the reconnaissance mapping of western Sonora and Tiburon Island, previously unknown Miocene marine strata were discovered (see Gastil 1975 for locations of marine units). Here Gastil and his party collected a small but highly significant collection of marine invertebrates (Table 1). The Miocene section on Tiburon Island is composed of an extremely thick accumulation of volcanic pebble and cobble conglomerates interbedded with arkosic sandstone and volcanic flows. The marine intercalations on Tiburon Island remain of unknown thickness and aerial extent. Both the marine and non-marine beds were considered by Gastil as belonging to the Comondu Group. Fortunately a flow within the marine sequence was dated by Gastil and his associates as  $14.0 \pm 3.0$  m.y.b.p. (Gastil, 1975).

The small collection of specimens represents the oldest known Neogene sequence yielding megafossils from the Gulf of California depression. These species have been described and the pectinids illustrated in an earlier work (Stump, 1979). Due to the vagueries of preservation predominantly calcite-shelled species are better represented.

Therefore, oysters and pectinids dominate the faunal list. Undoubtly additional collecting will yeild additional specimens of these and other taxa. Many of these species were precursors of widespread Pliocene taxa of lasting phylogenic importance. Others appear

San Diego State University  
Localities

Bivalvia	S2R-19 (=S2R-18)	S2G-11	B2J-48
<u>Arca</u> ( <u>A.</u> ) cf. <u>A. pacifica</u>		x	
<u>Ostrea vespertina</u>		x	
<u>O.</u> cf. <u>O. columbiensis</u>		x	
<u>Anomia</u> cf. <u>A. peruviana</u>	x		
<u>Argopecten</u> n.sp. 1	x	x	
<u>A.</u> n.sp. 2		x	
<u>Chlamys</u> n. sp. 1	x	x	
<u>C. (Chlamys)</u> n.sp. 4	x	x	
<u>Euvola keepi keepi</u>	x	x	
? <u>Lyropecten</u> sp. indet.	x		
<u>Oppenheimopecten vodgesi</u>	x	x	
" <u>Pecten</u> " new genus & species			x
Gastropoda			
<u>Strombus</u> (? <u>Strombus</u> ) sp. indet*		x	
<u>Turritella imperialis</u>	x	x	
Anthozoa			
<u>Solenastrea fairbanksi</u>		x	

Table 1. The known fauna of the Tiburon Island Miocene.

Locality S2R-19(=S2R-18) is the lowest fossiliferous horizon, S2G-11 is about 1,000 m above S2R-18 (personal communication R.G.Gastil, 1973). \*Species preserved as internal molds.

to have become extinct at or about the close of the Miocene. Arca pacifica, Ostrea vespertina, O. columbiensis, Anomia peruviana and Turritella imperialis all have previously been reported from early Pliocene localities around the Gulf of California. These taxa, except for O. vespertina and Turritella imperialis, range into the Recent of Panamic-Pacific waters. Solenastrea fairbanksi, the only known anthozoan from the Tiburon deposits, has likewise been long known from early Pliocene deposits in the Gulf area. This species, plus several additional corals, were first described from the early Pliocene portion of the Imperial Formation, Imperial Valley. Certain members of this faunal association have subsequently been reported from other Gulf localities (see Stump, 1979). All known early Pliocene corals from the Gulf of California display remarkable similarities with several important taxa from the Caribbean Neogene. Likewise, to varying degrees, most or all of the early Neogene pectinids of the Gulf area also share affinities to the Neogene Caribbean. These similarities have convinced many workers of faunal interchange between the Neogene Caribbean and Panamic water masses. Affinities of Gulf Neogene mollusca stressing the pectinids have recently been restated in terms of transpecific evolution (Stump, 1979). The Tiburon Island Miocene marine faunas serve to reinforce and

add badly needed additional insight into the early faunal history of this region.

Tertiary migrations of several groups, notable among which are the Mollusca and Scleractinia, produced faunas of distinctive character along the Pacific basin. The resulting Pacific American faunas were assembled by immigration of northern taxa dispersing south and movement of other genera into the region from the Caribbean. Only a handful of genera appear to be Pacific New World Molluscan endemics, branching from either Caribbean or North Pacific stocks.

Many species of the large chlamytid Lyropecten Conrad (1862) have been described from early Miocene through late Pliocene deposits of western North America. The genus appears to be one of the very few tropical Pacific Neogene endemic pectinids. Species of this genus are common in deposits of southern California south to Baja California. But, Lyropecten is unknown for certain from the Miocene of the Gulf of California. Previous records of L. estrellanus Conrad from the early Pliocene portion of the Imperial Formation are undoubtedly based on adventitious specimens. The few fragments recovered of Lyropecten, a partial hinge plate, from the Tiburon have characters suggesting this genus (see discussion in Stump, 1979). If additional specimens of this taxon are recovered from Tiburon Island and substantiate my identification it will be the first known occurrence of

Lyropecten within the Gulf depression. As stated above Lyropecten is well known from the Pacific side of Baja California and its presence from the Gulf would shed invaluable light on migration paths of this important taxon.

Several workers have speculated on the origins of Lyropecten. Some suggest a Caribbean origin (Smith, 1919) or that its species are present in the Miocene of the Atlantic seaboard (Woodring, 1938). Many authors have also referred several Atlantic-Caribbean species to Lyropecten. It is true that certain of these taxa are superficially similar to Lyropecten s.s., though none are convincing. Even fewer are similar to the type of genus L. estrellanus Conrad (a west coast taxon). Olsson (1922) thought "Pecten (Lyropecten)" tucilla (= "P. (L.) hopkinsi Olsson, 1922 preoccupied) to be lyropectinid. The species was described from the late Miocene (?) Tumbes Formation, Peru. My restudy of the fragmentary types proved them to belong to Leopecten. Specimens indentified as "Pecten (Lyropecten) magnolia Conrad" from the Miocene of Carballo, Costa Rica (Haas, 1942) may also belong to Leopecten. Hertlein and Grant (1972:209) thought this occurrence to be a member of the "Pecten" jeffersonius Say group of species. This suggestion is highly improbable. Members of this group are unknown in the Caribbean at any time and are unreported in the east Pacific Neogene.

Species supposed to belong to the Pecten Jeffersonius group have from time to time been placed in Lyropecten. For example "Chlamys (Lyropecten)" sayanus Dall from the Miocene Oak Grove Formation of Florida is such an allocation (Gardner, 1926). Species also included in "Lyropecten" are taxa similar to the Miocene "Pecten" condylomatus Dall. Pectinids similar to this taxon are widely distributed in the Atlantic Coast Neogene and throughout the Caribbean. But, "P." condylomatus is a Nodipecten Dall (1898) while "C." sayanus has been placed in Chesapeecten Ward and Blackwelder (1975).

Authors have compared west American and European pectinids of this general appearance and have suggested that east coast United States taxa are intermediate in this series (for example Grant and Gale, 1931; Clark and Durham, 1942). European workers, while recognizing similarities between east American and European species of this type, have not placed their taxa in Lyropecten (for example Roger, 1939; North in Hertlein and Grant, 1972).

Conrad, who was familiar with the known American species, thought Lyropecten to be restricted to West America. Recent workers tend to conform to his belief (Hertlein in Moore, 1969; Hertlein and Grant, 1972).

The "Pecten" madisonius Say species-group from the Miocene of the eastern United States is also similar

to Lyropecten. Its members are also found in the Miocene of Europe and American species have recently been placed in Chesapecten Ward and Blackwelder, 1975. Details of hinge morphology, patterns of sculpture and their known zoogeography suggest Lyropecten and Chesapecten are probably unrelated lineages.

Other authors (for example Hertlein and Grant, 1972:209) suggest a relationships between members of the "Pecten" magnolia group of West America and "P." jeffersonianus group of east America. The latter group bears considerable resemblance to species of Macrochlamys Sacco of Europe. A relationship between members of the "P." jeffersonianus group and European Neogene Macrochlamys species may exist (compare pl. 27, fig. 3 of Mongrin, 1959 with Ostrea latissima Brocchi, 1814 the type of Macrochlamys Sacco, 1897). But, there is little morphologic or zoogeographic evidence to suppose that members of the "P." jeffersonianus group are related to Lyropecten. Details of hinge morphology cited by Hertlein and Grant (1972) militate against such a relationship. Probably the "Pecten" jeffersonianus group and Macrochlamys spp. have a common ancestor. Lyropecten, however, may be a descendent of late Paleogene or early Neogene Vertipecten stocks which migrated to the west Pacific from northeast Asia.

At present it is impossible to say where the

generic affinities of Lyropecten lie with certainty. The fragmentary specimens from Tiburon Island questionably placed in this genus pushes the geologic range of this taxon into the Miocene of the Gulf. They may also support a Caribbean origin for the group through some unrecongized precursor instead of an origin from North Pacific stocks.

The earliest known species of Oppenheimopecten come from the early Miocene Burdigalian stage of Europe. In the Mediterranean alone there are over a dozen of its species described. The genus is also diverse in the Neogene Caribbean (Stump, 1979) where it appears during the early Miocene. Deposits of middle to late Pliocene age in the New World also have several species of Oppenheimopecten. Its species are also known from the late Cenozoic of the Indo-Pacific region extending north to Japan.

The genus first appears in West Mexico in the Isidro Formation and on Tiburon Island and ranges into the Recent of the region. During the Miocene, the genus was more widely distributed than at present. But only a handful of distinct East Pacific fossil species belong to this genus. Restudy of them, comparisons with the Tiburon species and with growth seires of O. vodgesi suggest that O. hartmanni (Hertlein, 1925) and O. heimi (Hertlein, 1925) should be placed in its synonymy. Several valves of O. vodgesi are present in the late Middle Miocene of Tiburon Island thereby documenting its oldest known occurrence in the

Gulf depression.

The most widespread of the middle Miocene Caribbean Oppenheimopecten was O. bowdenensis (Dall). This taxon ranges from at least the middle Miocene and last occurs in the Pliocene Bowden Formation of Jamaica (Stump, 1979). Several individuals of this species were studied in the Smithsonian collections. Many appear similar to variants of O. vodgei, and it is probable that O. bowdenensis was the root stock of the Panamic species (figure 1).

Species of Euvola Dall, 1898 are widely distributed in New World deposits of late Oligocene to late Pliocene age. The Tiburon Island specimens record their oldest occurrence in the Gulf of California. The two taxa referred to the genus in the Gulf are commonly encountered here in strata of early through late Pliocene age. At the close of the Pliocene the genus became extinct on the West Coast of the Americas. Only one species, E. ziczac (Linne), lives in the Caribbean.

Many species similar to the earliest New World Euvola occur in the late Oligocene to early Miocene strata of Tethyan Europe. The genus first occurs about this same time in the Caribbean and many of its species are found in early through middle Miocene deposits here. By the late middle Miocene a species of Euvola reached the Gulf of California region. This species, E. keepi (Arnold, 1906) and its subspecies E. k.

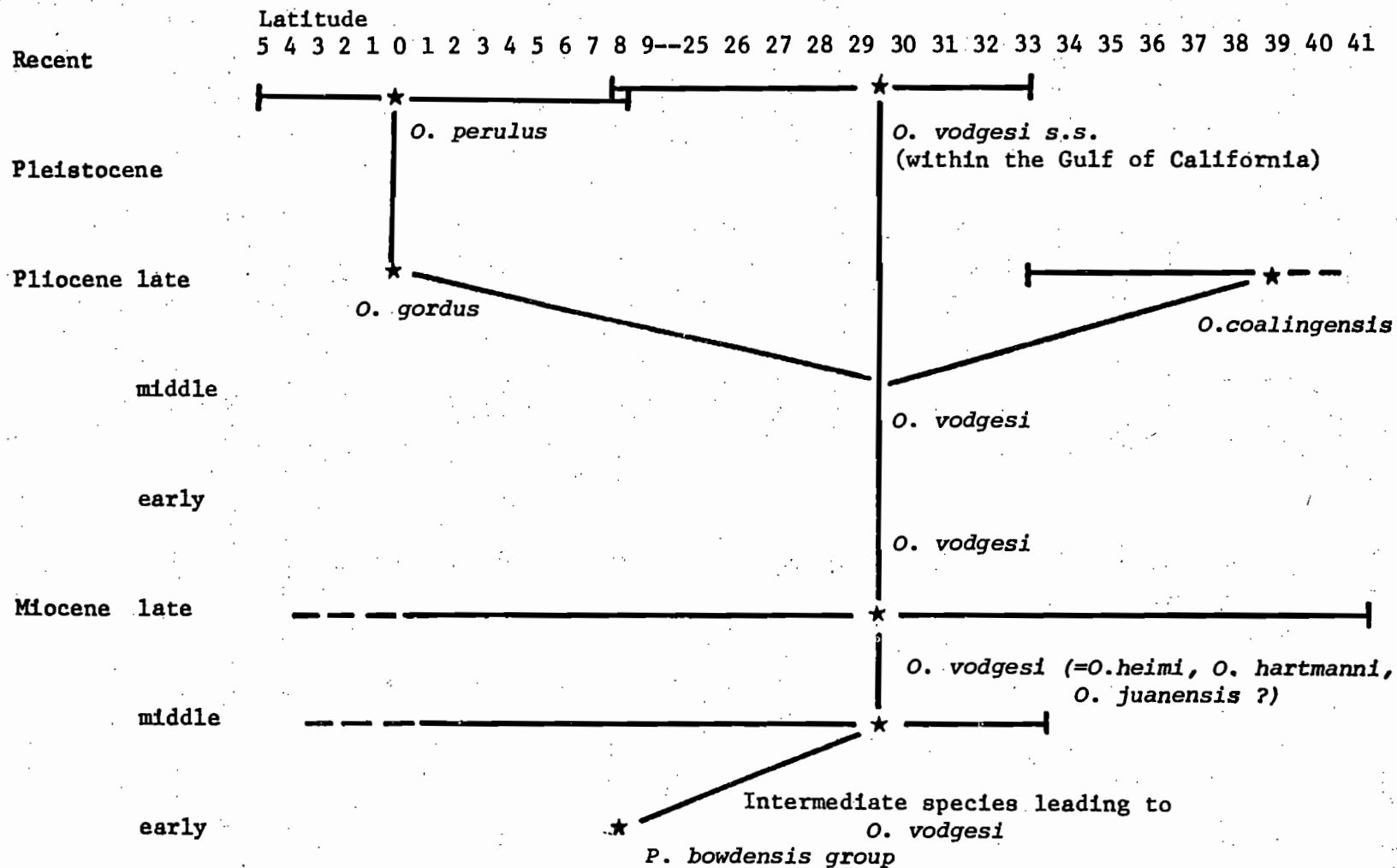


Figure 1 Biogeography and Phylogeny of New World Species of *Oppenheimopecten*.

refugioensis (Hertlein, 1925) flourished in this region from their first appearance until the late Pliocene. At this time both taxa and the genus became extinct in the Pacific Americas.

The oldest known Neogene Mexican Chlamys, C. n. sp. 1, appears in the Isidro Formation and is remarkably similar to the Miocene Caribbean C. buchivacoana F. and H. Hodson (1927). Species resembling the latter taxon first appear in the Oligocene of Venezuela (F. & H. Hodson, 1927).

Occuring with C. n. sp. 1 in the Isidro Formation and on Tiburon Island is C. n. sp. 4. The later species bears a remarkable resemblance to C. muscosa (Wood) from the Neogene and Recent Caribbean. Chlamys n. sp. 4, and other New World Neogene taxa, share characters which unite them with C. muscosa species-group. Likewise, its oldest members in the New World come from the early Miocene of the Caribbean.

Chlamys n. sp. 1, first known from the Isidro Formation, last occurs in the Tiburon Island Miocene. Its probable descendent, C. corteziana (Durham), however, is widespread in the Gulf of California Pliocene deposits (figure 2). The extention of this species during the late Pliocene ended the long history of the C. muscosa like group of species in the eastern Pacific New World.

The first known species of Argopecten, A. n. sp. 1, in the Gulf of California dates from the late Middle



Miocene. This species and its descendent, A. n. sp. 2, are both found on Tiburon Island. Apparently they are absent in the older Miocene and Oligocene of peninsular Baja California. Argopecten n. sp. 2 occurs several hundred meters stratigraphically above its progenitor (Gastil personal communication, 1976) but both occur in the highest fossiliferous Miocene horizons in their type areas. Neither species is known from younger horizons in the Gulf of California region. The Miocene species and their descendent, A. mendenhalli (figure 3), were probably all broadly adapted species living in coastal waters and ranging into shallow depths. The associated faunas of the Miocene taxa are poorly known and their paleobathymetries are largely conjectural. But, A. mendenhalli is widespread throughout the Gulf in deposits of early to late Pliocene age. It is also associated with many other molluscan taxa most of which are still living. The habitats and bathymetry of the communities A. mendenhalli occurs with suggest such a broadly adapted species.

The genus Argopecten has a long and complex history in the tropical East Pacific. Waller (1969) has described the evolutionary history of the genus in West Atlantic and certain parallel themes in the histories of both exist. Waller showed the West Atlantic species followed three broad evolutionary trends: 1) speciation associated with newly evolved taxa entering

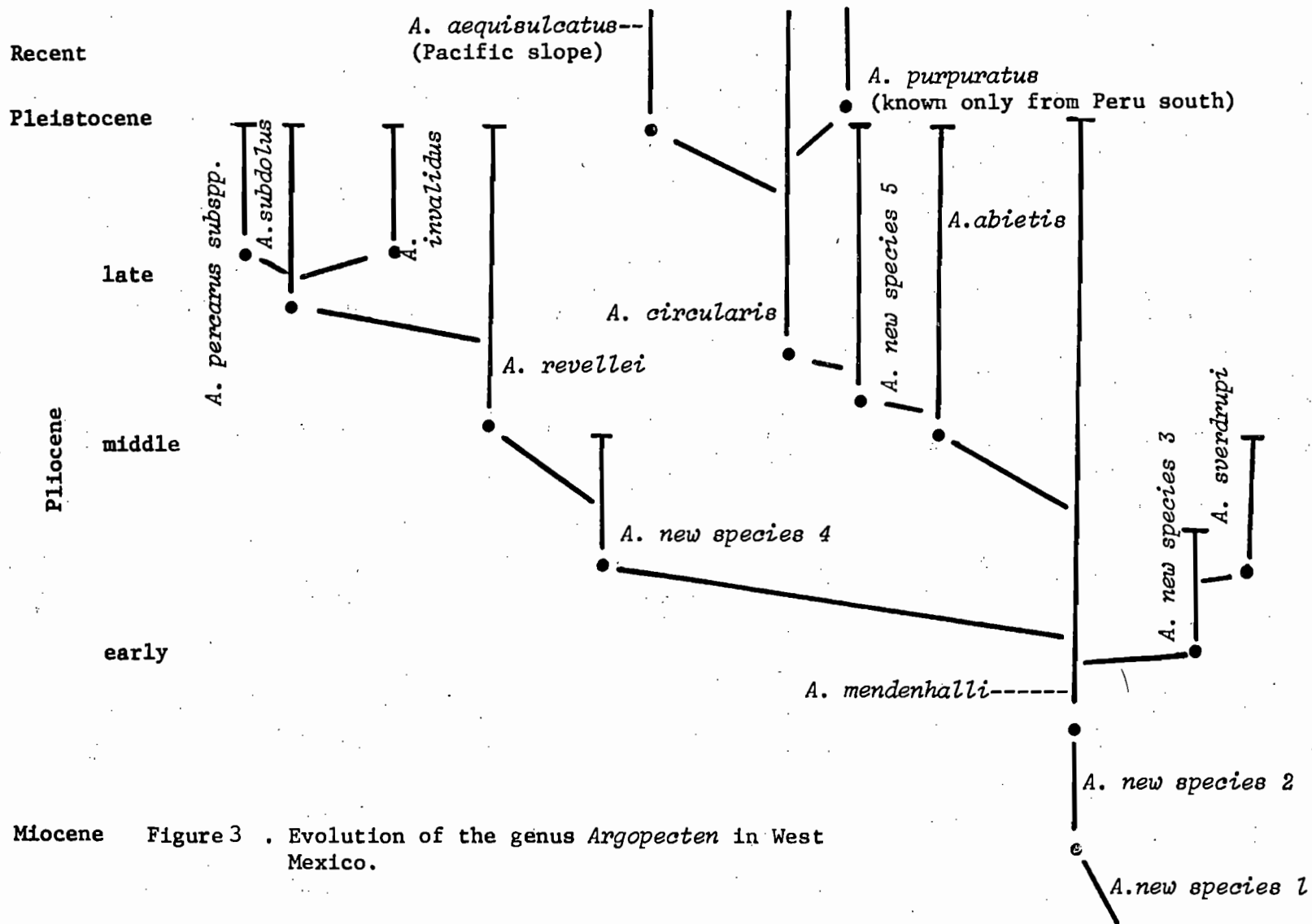


Figure 3 . Evolution of the genus *Argopecten* in West Mexico.

new adaptive zones; 2) evolutionary changes occurring within lineages leading to the "improvement" of the species (lineage anagensis); 3) changes occurring within two or more lines of descent leading to the improvement of the species group (species-group anagensis). These are common characteristics in the evolutionary histories of many groups. But, it is possible in the Gulf of California to relate species-successions of the East Pacific argopectinids with their entry into new adaptive zones and the production of allopatric species by the isolation of gene pools. During the Pliocene the Gulf of California argopectinids underwent rapid adaptive radiation resulting from taxa crossing adaptive thresholds and their moving into new habitats. This began not with the first appearance of Argopecten in the region (late middle Miocene) but much later (middle Pliocene). At this time three species of Argopecten first appear. The speciation accelerated through the middle Pliocene with the appearance of four additional taxa. The explosive radiation of the group ended progressively during the late Pliocene. Only one species, A. circularis, survived into the Recent of the tropical East Pacific.

The second and later theme in the diversification of the East Pacific argopectinids was allopatric speciation. Certain species of Gulf of California

Argopecten reached the outer coast of Baja California before the late Pliocene. During the late Pliocene they also underwent adaptive radiation giving rise to several additional taxa. Therefore, by the late Pliocene the outer and inner coasts of Baja California had similar suites of species adapted to similar habitats. Only two of the outer coast species, A. circularis and A. aequisulcatus, survived the Pliocene and are found there in the Recent.

Also present in the Tiburon Island Miocene was one poorly preserved pectinid that resembles no described taxon. Vaguely resembling a Nodipecten the one leached right valve probably is an undescribed genus.

The Tiburon Island Miocene deposits represent a highly significant discovery. When the section is more thoroughly recollected new and better insights will be gained on the degree and timing of trans-American faunal interchange and on the evolution of the Panamic faunas.

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SOME PLEISTOCENE FACIES AND FAUNAS OF COASTAL SONORA  
AND TIBURON ISLAND, MEXICO

T. E. STUMP

Union Oil Company of California  
International Oil and Gas Division  
P.O. Box 7600  
Los Angeles, California 90051

Abstract

Pleistocene marine faunas from the Puerto Peñasco, Puerto Libertad, El Infiernillo and Tiburon Island are listed.

It is tentatively concluded that the Puerto Libertad and El Infiernillo faunas are approximate time equivalent communities. The former assemblages lived in intertidal sandflats while the latter is a subtidal assemblage. The taxa from Puerto Peñasco may be slightly younger than the previous localities while specimens from Tiburon Island are probably very late Pleistocene.

Resumen

Se enlistan las faunas marinas del periodo Pleistoceno de Puerto Peñasco, Puerto Libertad, El Infiernillo y la Isla Tiburón. Se concluye tentativamente que las de Puerto Libertad y El Infiernillo son comunidades aproximadamente equivalente en tiempo. Las asociaciones mencionadas vivieron en llanuras arenosas de intermarea mientras que las otras corresponden a una asociación infralitoral. Los taxa de Puerto Peñasco pueden ser ligeramente mas jovenes que en las otras localidades, mientras que los especímenes de Isla Tiburón son probablemente del Pleistoceno.

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During the National Science Foundation funded mapping of the State of Sonora several previously unknown megafossiliferous Pleistocene localities were discovered. One of these faunas has been described (Stump, 1975). This paper summarizes an additional prolific location and its relationships to previously known coastal Sonora Pleistocene faunas. New data from localities briefly mentioned by Durham (1950) on Tiburon Island are also summarized. Previously Hertlein and Emerson (1956) documented a Pleistocene fauna from the Puerto Penasco area.

Along coastal Sonora several midden localities were discovered that, while having archaeological significance, were not collected for this paper. The major localities summarized below (Table 1) are found in the northern Gulf of California near Puerto Penasco, along the central Sonoran coast at Puerto Libertad and in the El Infiernillo area adjacent to Tiburon Island. Additional localities are also included from Tiburon Island which were briefly discussed by Durham (1950).

No radiometric dates are available from any of these localities. But from stratigraphic considerations, the preservational and composition of their included fossils it is probable that the Puerto Libertad and El Infiernillo deposits are approximately the same age. Based on similar reasoning it is thought that the Tiburon faunas are younger than either the Puerto Libertad or El Infiernillo communities. The assemblage discussed by Hertlein and Emerson (1956) may also be slightly younger than the Puerto Libertad-El Infiernillo faunas.

The Pleistocene molluscs recovered from Tiburon Island were collected at several discrete localities along the southernmost portion of the island and its western shore. All of these localities are very near the present shoreline and on low terraces. Higher terraces proved to be mostly unfossiliferous. All species recovered from these deposits presently live in adjacent waters. Deposits from the Puerto Libertad and El Infiernillo areas yielded the extinct Encope grandis inezana Durham. This species was regarded by Durham (1950) as a guide to deposits of Pleistocene age. Also present in either the Puerto Libertad or El Infiernillo deposits were a handful of species presently living further south in the Gulf of California. This may point to the greater age of the Puerto Libertad and El Infiernillo deposits when compared to the Tiburon Island or Puerto Penasco Pleistocene.

The faunas from Puerto Penasco and Tiburon Island compose a mixed assemblage of intertidal and subtidal sandy-bottom and rock-dwelling organisms. The Puerto Libertad

assemblage was considered to have been preserved mostly in situ (Stump, 1975) and its fauna lived on or within intertidal sand flats. The previously unreported faunas from the El Infiernillo area also undoubtedly are mostly preserved in situ, but clearly are a subtidal assemblage. The El Infiernillo faunas represent the deepest water Pleistocene community documented to date from western Sonora.

The general stratigraphy of the Puerto Penasco deposits was described by Hertlein and Emerson (1956). Here conglomeratic sandstones rest on basaltic or granitic basement. The enclosed faunas were collected from the lowest terrace which was capped by a thin superficial Pleistocene cover. The stratigraphy of the Puerto Libertad area was treated earlier (Stump, 1975). These units are also relatively thin and are composed of approximately seven meters of interbedded silty sandstone with local lenses of conglomerate. The Puerto Libertad units rest on an unfossiliferous boulder to cobble-bearing, medium-grained sandstone. The most abundantly fossiliferous horizon in the Libertad area occurs in approximate midsection and is only about 60 cm thick.

The El Infiernillo deposits are found approximately 70 km north of Kino Bay and compose the west facing bluffs adjacent to Tiburon Island. The Pleistocene section here has an exposed thickness of about 12 meters. The youngest preserved portion of the deposit is composed of about five meters of tan silty sandstone which is capped by alluvium and midden material. Its base is gradational onto about a two meter-thick pebbly sandstone which contains scattered intertidal molluscs. Below this sequence rest approximately three meters of abundantly fossiliferous, well sorted, light brown sandstone. Local cobble lenses are present in this unit and its fauna is dominated by subtidal species. This horizon was collected and summarized on Table 1. The subtidal sequence rests on an exposed thickness of about two meters of brown, medium-grained, feldspathic sandstone. The base of the Pleistocene sequence in the Infiernillo area

is not exposed and its lowest exposed horizons were unfossiliferous.

Durham (1950) mentions some Pleistocene localities from the southern portion of Tiburon Island. During the mapping of this portion of the island his localities plus others were collected. The Pleistocene sediments here rest in the lowest terrace of the region. Fossils were recovered from tuffaceous and arkosic sandstone which rest on Miocene volcanics or on conglomerates erosionally derived from them. Both the flows and the volcanogenic sediments were considered to belong to the Comondu Group. Additional localities were discovered on the western portion of the island in terraces of about three meters elevation above the present shoreline. These fossils also were inclosed in similar sediments and rest on a terrace cut into the Comondu Group.

Further exploration of the western coast of the Gulf of California will undoubtedly yield additional Pleistocene and perhaps older faunas. Badly needed radiometric dates on these units would further help clarify facies relationships that can now only be guessed at.

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Table 1. The known Pleistocene faunas of coastal Sonora and Tiburon Island.

	Pleistocene				Recent Coastal Sonora
	Puerto Penasco	Puerto Libertad	El Infiernilo	Isla Tiburon	
<u>Bivalvia</u>					
<i>Nucula declivis</i>			x		x
<i>N. exigua</i>			x		x
<i>Nuculana acrita</i>			x		x
<i>Arca pacifica</i>		x		x	x
<i>Barbatia gradata</i>	x	x	x		x
<i>B.reeveana</i>		x			x
<i>Anadara formosa</i>		x			x
<i>A. grandis</i>				x	x
<i>A. multicosata</i>		x		x	x
<i>Arcopsis solida</i>	x	x	x		x
<i>Glycymeris gigantea</i>		x	x	x	?
<i>G. multicosata</i>	x	x			x
<i>G. maculata</i>	x	x			x
<i>G. strigilla</i>			x		Guaymas
<i>Brachidontes adamsianus</i>	x				x
<i>B. semilaevis</i>	x				x
<i>Septifer sp. indet.</i>		x			x
<i>Crenela divaricata</i>			x		x
<i>Modiolus capax</i>	x	x	x	x	x
<i>Atrina tuberculosa</i>		x			x
<i>Isognomon janus</i>			x	x	x
<i>I. recognitus</i>	x				x
<i>Ostrea angelica</i>	x	x	x		x
<i>O. columbiensis</i>		x			x
<i>O. conchaphila</i>				x	x
<i>O. palmula</i>	x	x			x
<i>O. megodon</i>		x			x
<i>Pecten vodgesi</i>	x	x	x	x	x
<i>Argopecten circularis</i>	x	x	x	x	x
<i>Leptopecten tumbezensis</i>		x			x
<i>Nodipecten subnodosus</i>		x		x	x

(Table cont'd)

	Pleistocene				Recent Coastal Sonora
	Puerto Penasco	Puerto Libertad	Ei Infierno	Isla Tiburon	
<i>Plicatula</i> sp.indet		x			x
<i>Spondylus calcifer</i>		x			x
<i>Lima orbigni</i>			x		x
<i>Anomia peruviana</i>	x	x	x	x	x
<i>Crassinella pacifica</i>			x		x
<i>Cardita affinis</i>	x	x	x	x	x
<i>C. laticostata</i>			x		x
<i>Lucina approximata</i>		x	x		x
<i>L. centrifuga</i>			x		x
<i>L. excavata</i>		x			x
<i>L. fenestrata</i>			x		x
<i>L. lampra</i>	x		x		x
<i>L. mazatlanica</i>		x			x
<i>Codakia distinguenda</i>	x	x		x	x
<i>Ctena mexicana</i>		x	x		x
<i>Divalinga eburnea</i>		x			?
<i>Diplodonta suprema</i>			x		Panama
<i>Felaniella sericata</i>		x			x
<i>Amerycina colpoica</i>		x			x
<i>A. cultrata</i>		x			?
<i>Aligena cokeri</i>			x		x
<i>Mysella compressa</i>		x			x
<i>Orobitella trigonalis</i>		x	x		?
<i>O. secura</i>			x		?
<i>Ensitellops hertleini</i>			x		x
<i>Basterotia hertleini</i>			x		x
<i>Sportella stearnsii</i>			x		x
<i>Chama echinata</i>		x			x
<i>C. frondosa</i>	x	x			x
<i>C. mexicana</i>		x			x
<i>Pseudochama corrugata</i>		x		x	x

(Table 1 cont'd)

	Puerto Penasco	Puerto Libertad	El Infiernilo	Isla Tiburón	Recent Coastal Sonora
<i>Trachycardium panamense</i>		x	x		x
<i>T. procerum</i>		x			Oaxaca
<i>T. senticosum</i>		x			x
<i>Trigoniocardia granifera</i>		x	x		x
<i>T. biangulata</i>		x			x
<i>T. guanacastensis</i>		x	x		Cabo San Lucas
<i>T. obovalis</i>		x			x
<i>Laevicardium elatum</i>	x	x	x	x	x
<i>L. elenense</i>		x	x		x
<i>Periglypta multicostata</i>				x	x
<i>Ventricolaria isocardia</i>		x		x	x
<i>Tivela byronensis</i>		x			x
<i>Pitar concinnus</i>			x		x
<i>P. pollicaris</i>		x			x
<i>P. paytensis</i>			x		x
<i>Megapitaria squalida</i>	x	x	x	x	x
<i>Dosinia ponderosa</i>	x	x	x	x	x
<i>Cyclinella saccata</i>		x	x		x
<i>Chione californiensis</i>	x	x	x		x
<i>C. fluctifraga</i>		x			x
<i>C. gnidia</i>	x	x			x
<i>C. tumens</i>		x			x
<i>Protothaca grata</i>	x	x	x		x
<i>Mactra angusta</i>			x		x
<i>M. californica</i>		x			x
<i>M. nasuta</i>		x			x
<i>Raeta undulata</i>		x	x		x
<i>Tellina carpenteri</i>		x	x		x
<i>T. meropsis</i>			x		x
<i>T. ochracea</i>			x		x
<i>T. reclusa</i>		x			x

(Table I cont'd)

	Pleistocene				Recent Coastal Sonora
	Puerto Penasco	Puerto Libertad	El Infiernillo	Isla Tiburon	
<i>Tellina simulans</i>		x	x		x
<i>Florimetis cognata</i>	x		x		x
<i>Psammotreta viridotincta</i>		x			x
<i>Strigilla dichotoma</i>			x		x
<i>Donax californicus</i>			x		x
<i>D. gracilis</i>	x		x		x
<i>Tellidora burneti</i>		x	x		x
<i>Tagelus californicus</i>	x	x	x		x
<i>Semele bicolor</i>		x			x
<i>S. flavescens</i>	x				?
<i>S. guaymasensis</i>	x		x		x
<i>S. junonia</i>			x		Guaymas
<i>Ensis californicus</i>			x		x
<i>Cryptomya californica</i>			x		x
<i>Corbula biradata</i>		x	x		Guaymas
<i>C. bicarinata</i>			x		x
<i>C. nasuta</i>	x				x
<i>Gastrochaena ovata</i>			x		x
<i>Hiatella arctica</i>		x			x
<i>Cytopleura subtruncata</i>		x			x
<i>Martesia sp. indet.</i>		x			x
<i>cyathodonta dubiosa</i>			x		x
<u>Gastropoda</u>					
<i>Diodora alta</i>	x		x		x
<i>D. inaequalis</i>			x		x
<i>Collisella dalliana</i>			x		x
<i>C. turveri</i>			x		x
<i>Scurria mesoleuca</i>		x			x
<i>Calliostoma bonita</i>			x		Mazatlan
<i>Tegula globulus</i>		x			Topolobampo

(Table 1 cont'd)

	Pleistocene				Recent Coastal Sonora
	Puerto Penasco	Puerto Libertad	El Infiernillo	Isla Tiburon	
<i>Tegula mariana</i>	x		x		x
<i>T. rubroflammulata</i>	x				x
<i>T. rugosa</i>	x	x	x		x
<i>Parviturbo sp.indet.</i>		x			x
<i>Arene fricki</i>			x		x
<i>Turbo fluctuosus</i>	x	x	x	x	x
<i>Nerita funiculata</i>		x			x
<i>N. scabricosta</i>	x	x		x	x
<i>Neritina latissima</i>		x			x
<i>Theodoxus luteofasciatus</i>		x	x		x
<i>Littorina aspera</i>		x			x
<i>L. varia</i>			x		?
<i>Turritella goniostoma</i>	x		x		x
<i>T. leucostoma</i>			x		x
<i>Tripsyche centriquadra</i>		x			x
<i>Cerithium stercusmuscarum</i>		x	x		x
<i>Liocerithium judithae</i>		x			x
<i>Selia assimolata</i>		x			x
<i>Triphora hannai</i>		x			x
<i>Cerithidea mazatlanica</i>		x	x		x
<i>Rhinocoryne humboldti</i>	x	x			x
<i>Strombus galeatus</i>	x			x	x
<i>S. gracilior</i>		x		x	x
<i>S. granulatus</i>		x		x	x
<i>Epitonium acapulcanum</i>			x		x
<i>E. sp.indet.</i>		x			?
<i>Balcis mexicana</i>		x			x
<i>Crepidula onyx</i>		x	x		x
<i>Crucibulum spinosum</i>		x	x		x
<i>C. scutellatum</i>		x		x	x
<i>Natica chemnitzii</i>		x			x

(Table 1 cont'd)

	Puerto Penasco	Puerto Libertad	El Infiernilo	Isla Tiburón	Recent Coastal Sonora
<i>Polinices bifasciatus</i>				x	x
<i>P. recluzianus</i>	x	x	x	x	x
<i>P. uber</i>	x	x			x
<i>Trivia solandri</i>				x	x
<i>Erato columbella</i>		x			x
<i>Cypraea annettae</i> <i>annettae</i>	x	x		x	x
<i>Malea ringens</i>		x			x
<i>Cassis coarctata</i>		x		x	x
<i>Ficus ventricosa</i>		x		x	x
<i>Murex elenensis</i>			x		x
<i>M. (M.) sp. indet.</i>		x			?
<i>Hexaplex erythrostomus</i>	x	x		x	x
<i>Murexiella vittata</i>			x		x
<i>Muricanthus nigrinus</i>	x	x	x	x	x
<i>Coralliophila parva</i>			x		x
<i>Pteropurpura erinaceoides</i>			x		x
<i>Thais biserialis</i>	x			x	x
<i>Acanthina angelica</i>	x	x	x		x
<i>A. tyrianthina</i>		x			x
<i>Neorapana tuberculata</i>	x	x	x	x	x
<i>N. cf. N. muricata</i>		x			Guaymas
<i>Solenostiera anomala</i>		x	x	x	x
<i>S. pallida</i>	x				x
<i>Strombina angularis</i>			x		x
<i>S. maculosa</i>		x			x
<i>S. solidula</i>			x		x
<i>Columbella fuscata</i>		x			x
<i>Melongena patula</i>		x			x
<i>Nassarius moestus</i>	x				x
<i>N. tiarula</i>		x	x		x
<i>Fusinus dupetithousarsi</i>		x		x	x

(Table 1 cont'd)

	Puerto Penasco	Puerto Libertad	El Infiernillo	Isla Tiburón	Recent Coastal Sonora
<i>Fusinus ambustus</i>			x		Mazatlan
<i>Harpa crenata</i>				x	south Gulf
<i>Oliva spicata</i>	x	x	x	x	x
<i>O. incrassata</i>	x	x		x	x
<i>Olivella dama</i>	x	x	x		x
<i>O. gracilis</i>			x		Guaymas
<i>Vasum caestus</i>		x			Guaymas
<i>Cancellaria cassidiformis</i>				x	x
<i>Conus brunneus</i>		x			x
<i>C. princeps</i>		x		x	x
<i>C. purpurascens</i>				x	x
<i>C. regularis</i>	x	x	x		x
<i>C. ximenes</i>		x		x	x
<i>Terebra formosa</i>		x			Mazatlan
<i>T. albocincta</i>		x			Mazatlan
<i>T. hindsii</i>			x		x
<i>T. variegata</i>		x	x	x	x
<i>Hormospira maculosa</i>			x		x
<i>Pyramidella mazatlanica</i>		x	x		x
<i>Bulla gouldiana</i>		x	x		x
<i>Acteocina angustior</i>			x		x
<i>A. inculta</i>		x			x
<i>Melampus olivacea</i>		x			x
<u>Polyplacophora</u>					
<i>Stenoplax magdalenensis</i>		x			x
<u>Scaphopoda</u>					
<i>Dentallium pretiosum berryi</i>			x		x
<i>Cadulus cf. C. fusiformis</i>		x			x

(Table 1, cont'd)

	Puerto Penasco	Puerto Libertad	El Infiernilo	Isla Tiburón	Recent Coastal Sonora
<u>Anthozoa</u>					
Astrangia haimel		x			x
Porites californica			x	x	x
<u>Bryozoa</u>					
Schizoporella unicornis		x			x
Hippopodinella adpressa		x			x
Antropora tinctoria		x			x
Hippuporida janthina		x			x
Conopeum commensale		x			x
<u>Cirripedia</u>					
Balanus sp. A		x			?
Balanus sp. B		x			?
Balanus sp. C		x			?
<u>Schinoidea</u>					
Encope grandis inezana		x	x		extinct
E. g. grandis			x		x

RECENT INVESTIGATIONS ON QUATERNARY GEOLOGY OF THE COAST  
OF CENTRAL SONORA, MEXICO

Luc ORTLIEB

Mission de l'Office de la Recherche  
Scientifique et Technique Outre-Mer  
au Mexique, & Instituto de Geología,  
Universidad Nacional Autónoma de México,  
Apdo. Postal 1159, Hermosillo, Sonora,  
México.

INTRODUCTION

Between 1965 and 1980, Quaternary deposits of the coast of Sonora, between Puerto Lobos (30°15') and Guaymas (28°N) have been investigated from different points of view. This new interest in the recent evolution of this area, follows the important geologic, geophysical and oceanographic research accomplished in the Gulf of California around the mid-century.

The aim of this paper is to briefly present some aspects of these recent investigations and give a general idea of the state of knowledge in the field of Quaternary geology in the western Sonora coast. On-going research works will also be mentioned. With the exception of a few PhD dissertations, and other works, from U. S. scientists, a large part of the recent progresses were completed through a Franco-Mexican cooperative program (between O. R. S. T. O. M. and Instituto de Geología, U. N. A. M.) which began in 1974 (the publications related to this program, generally were written in Spanish, or in French, and not in English).

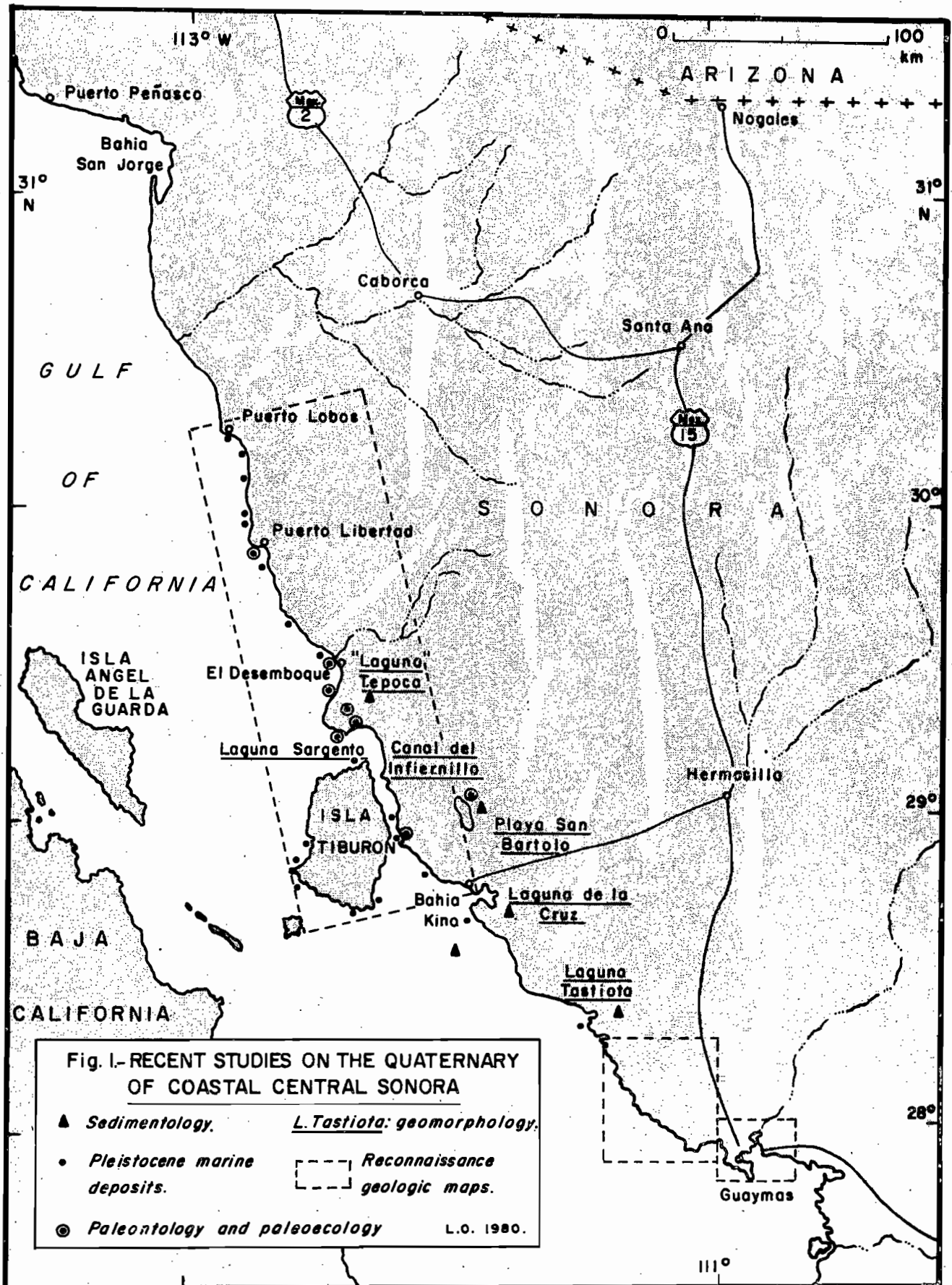
REGIONAL GEOLOGY AND RECONNAISSANCE MAPPING

In the early sixties, the geology of coastal Sonora was so poorly studied that Allison (1964) could write: "So little is known of rocks younger than Cretaceous that conclusions concerning the late geological history of land areas bordering the eastern side of the Gulf of California are hardly meaningful". At the time, for example, the only available geological map was at a scale of 1: 2,000,000 (Mejorada, 1956).

In 1974 the first authoritative reconnaissance map of the portion of the coast between Puerto Lobos and Bahía Kino (Gastil and others) appeared (Fig.1). This map, at a scale of 1: 150,000, was based on original field mapping, photo-interpretation, and a series of K-Ar dates on Mesozoic and Tertiary plutonic and volcanic units. The southern part of the area treated in this report, around Guaymas (Fig.1), was mapped by Johnpeer (1977) and Wilson (1978).

In 1976, López Ramos compiled a geological map of Sonora which included, for the coastal area, the basic information of Gastil and others (1974). In a short time, Detenal is going to publish a set of geological maps, at a scale of 1: 250,000, covering the whole State of Sonora. In addition, Roldán, at the Instituto de Geología U.N.A.M., is preparing another compilation of the geology of Sonora at a scale of 1: 500,000.

In the map of Gastil and others (1974), the Quaternary deposits are divided in: alluvium, sand, dissected fluvial deposits and marine. As is usual in this -



kind of reconnaissance map, no stratigraphic distinctions are made. In the explanatory note for their map, Gastil and Krummenacher (1977) emphasize the importance of the alluvial processes taking place in the wide coastal plains of central Sonora. The same authors report several localities where Quaternary alluvial, or fluvial, sediments are cut by faults. In coastal Sonora, the Quaternary faults are generally oriented NW-SE to N-S and belong to the Basin and Range system; in Isla Tiburón, a few Quaternary faults are oriented NE-SW, probably because they are related to the Gulf of California recent structural history. Up to now, no clear evidence of Quaternary strike-slip deformations have been found in this portion of Sonora (Gastil and Krummenacher, 1977; Colletta, oral communication).

The regional vertical compartment of the coastal region of Sonora during the Quaternary is studied through Pleistocene marine terraces data. In some previous works (Ives, 1951, 1963; Nichols, 1965; Richards, 1973), the coastal area of Sonora was considered tectonically active and recently uplifted. According to Gastil and Krummenacher (1977) only the coast north of Puerto Libertad appears emergent while south of Bahía Kino it appears submergent. Ortlieb (1978a, 1978b) considers that, on a regional scale, the coast of Sonora has been "stable", at least during Late Pleistocene and Holocene time; the only area which apparently suffered subsidence is the region of Guaymas. More detail on this question will be given below, in the chapter concerning the interpretation of the Quaternary marine deposits.

#### OCEANOGRAPHY, GEOMORPHOLOGY AND SEDIMENTOLOGY

##### Oceanography

The AAPG Memoir on "Marine geology of the Gulf of California", published in 1964 (Van Andel and Shor, eds), still constitutes a main source of information about the areas off the Sonoran coast. Of particular interest in this book, for Quaternarists, are the papers on recent marine sediments (Van Andel, 1964), on physical oceanography (Roden, 1964), on the late Quaternary history of the coast of Nayarit (Curry and Moore, 1964), on macroinvertebrates distribution (Parker, 1964) and on benthonic foraminiferas (Phleger, 1964).

Very few specific investigations were carried on in the nearshore area of the coast off central Sonora. Among them are to be mentioned the work of Curry (1961) on bathymetry and surface lithology of the continental shelf west of the Tastiota-Bahía Kino coast, and the study by Merifield and others (1970) of oceanographic processes in the Canal del Infiernillo, between Isla Tiburón and the mainland.

##### Geomorphology

In geomorphology two areas of the coastal central Sonora have been studied, with some detail, during recent years. The first one is Playa San Bartolo (sometimes also called "Playa, or Laguna, Noriega"), located east of the southern part of Sierra Seri, and the second one is the Canal del Infiernillo and its surrounding shores.

Playa San Bartolo is the largest dry lake of Sonora, about 13 Km long and 4 km wide; it is located 10 km from the seashore. As its elevation is only + 5 m above present mean sea level (MSL), it was sometimes interpreted as being of marine origin (Sherwin, 1971). Its western margin is limited by the piedmont (bajada) of the Sierra Seri, whereas the eastern shore of the playa is bordered by dune-like sandy bodies (probably of both eolian and fluvial origin). Geomorphic aspects of Playa San Bartolo were studied by Petit-Maire and Lancin (1976), Petit-Maire and Casta (1977) and Lecolle and others (1977).

The shores of the Canal del Infiernillo, and particularly the spits that recently grew on the Sonora and Tiburón side of the strait, have been investiga-

ted by Sherwin (1971) and Lancin (1979, in press). The geometry, the sedimentology and relative distribution of the 14 sandy spits were related to the hydrodynamic conditions of this area (relatively isolated from the Gulf of California) and were used to reconstruct the chronological evolution of these littoral features (Lancin, 1979, in press).

Another geomorphic peculiarity of western Sonora, specially where the coastline is backed by low lying coastal plains, is the extensive barrier dunes system. The morphology and the sedimentology of these Holocene coastal dunes are presently under study in the area comprised between Tastiota and Bahía San Jorge (Crespo, in preparation); only in a few localities are there older fixed <sup>dunes</sup> probably of early Late Pleistocene age.

### Sedimentology

A wide variety of Quaternary deposits and environments of the sonoran coastal region have been, or are being, studied from a sedimentological point of view.

First investigated were the coastal lagoons, and particularly the Laguna (Estero) Tastiota (Nichols, 1961, 1962, 1965). Coastal lagoons, generally bordered by mangroves, are numerous in the area of the Canal del Infiernillo, but the widest ones are located at Bahía Kino and Tastiota. These two lagoons evolved from estuaries, at the beginning of the Holocene, to open and later restricted, marine lagoons, when the sea level reached its present elevation (around 5,000 years ago?) and as the coastal barriers were building up. During the last few thousand years the lagoonal area has diminished as a result of alluviation and sedimentary deposition.

The sedimentology of inland lacustrine deposits was described, in Playa San Bartolo, by Lecolle and Villaseñor (1976), Lecolle and others (1977), Petit-Maire and Casta (1977) and Lecolle (1979). The sediments of the playa, studied from the surface to a maximum depth of seven meters are predominantly clayey silts and silty clays and include an important fraction of montmorillonite and analcime, as well as some evaporitic minerals (halite and trona). This classical clay-pan system developed during a more humid period when it was provided with fine grained sediments, by sheet flood on the bajada of the Sierra Seri, west of the playa.

The littoral sandy formations and dunes throughout the area have been examined briefly, primarily to determine their chronologic relation to late Pleistocene and Holocene marine and alluvial deposits (Lecolle and Ortlieb, 1978; Lecolle and others, 1978; Ortlieb and Malpica, 1978). The sedimentology of the Holocene coastal dunes are presently being studied by Crespo (doctoral thesis at U.N.-A. M.).

Quaternary alluvial sediments, despite their wide distribution in western Sonora, were not specifically investigated. In the early sixties, Curray (1961) produced a preliminary map of the surface lithology of the coastal plain between Bahía Kino and Tastiota. Some data of grain-size composition of bajada deposits, from various sonoran localities, were given by Ortlieb and Malpica (1978).

Pleistocene marine deposits were extensively surveyed on the mainland coast and around Isla Tiburón. Sedimentologic descriptions of emerged terrace sediments were included in numerous papers and thesis (Stump, 1975; Celis, 1975; Chávez, 1975; Malpica and Ortlieb, 1976; Malpica and others, 1978; Ortlieb and Malpica, 1978; Celis and Malpica, in preparation; Luna, in preparation; González in preparation). Sedimentologic aspects of a Late Pleistocene marine embayment, at "Laguna" Tepoca, have been studied by Lecolle and Ortlieb (1978), Lecolle (1979, in press, in preparation).

## PALEONTOLOGY

In the coastal region of Sonora, Quaternary marine deposits have yielded much more material to paleontologists than the terrestrial sediments. Among the relatively widespread outcrops of Quaternary marine deposits (Fig.2), a few fossiliferous localities have been investigated with some detail.

The first paleoecological study of Pleistocene marine mollusks, in this area, was provided by Stump (1975) near Puerto Libertad. In the same locality, Celis (1975) and Celis and Malpica ( in press ) examined the microfauna.

Another outcrop of Pleistocene infralittoral deposits, located between Punta Chueca and Punta Onah, yielded a large fossil assemblage, with most of the organisms in situ (Petit-Maire, 1976). The determination of these fossils, including the microfauna, was done by Chávez (1975) and Celis (1975, 1979). In this book, Stump reports a list of fossil material, collected a few years ago, in various Pleistocene outcrops in the Canal del Infiernillo, Isla Tiburón, Puerto Libertad and Puerto Peñasco.

Two thesis at U. N. A. M. devoted to the paleoecologic interpretation of four distinct Pleistocene littoral deposits, within the area of El Desemboque-Tepoca, are to be completed by early 1981 (Luna and González in press; González, in preparation; Luna, in preparation).

The microfauna of Holocene deposits, as well as its present distribution in Laguna Tastiota, was studied by Nichols (1965).

A general study of the fossil fauna collected by Ortlieb and collaborators in the localities of Pleistocene marine deposits mentioned in Fig. 2, is scheduled for 1981. Besides the paleontologic determinations and the paleoenvironmental interpretations, a series of isotopic measurements (  $^{18}\text{O} / ^{16}\text{O}$  and  $^{13}\text{C} / ^{12}\text{C}$  ) will be made on carbonates of fossil shells, in a attempt to reconstruct paleotemperatures of the past high stands of sea level registered on this coast.

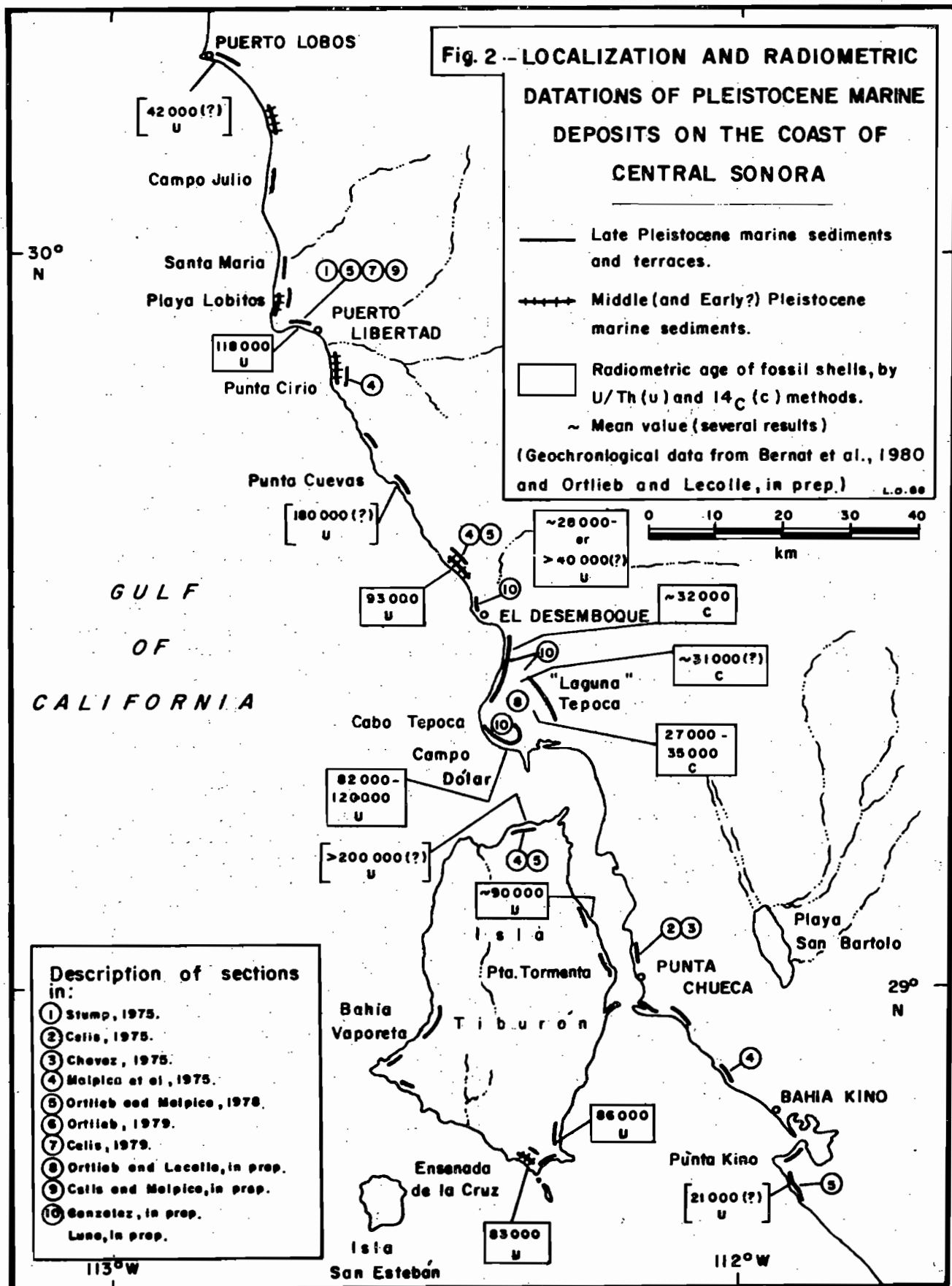
To our knowledge, the terrestrial fauna reported on the sonoran coast is essentially of Holocene age, and is generally associated with human occupation. No Early, or Middle, Pleistocene fossil vertebrates, like those found in eastern Sonora, have been described along the coast; this is due, in part, to the fact that the outcropping continental Quaternary sediments in western Sonora are mainly younger, and less dissected, than in the foothills of the Sierra Madre Occidental. Numerous archeological sites, between El Desemboque and Tastiota, (Bowen, 1976), provided an abundant fauna of Vertebrates which remains to be published (White, oral communication, and Braniff, oral communication). On the margins of Playa San Bartolo, were found fragmented bones and teeth of Elephas sp., Equus (?) sp., Bison sp., and of a Camelidae which was dated  $7\ 630 \pm 460$  years B. P., by  $^{14}\text{C}$  (Petit-Maire and Casta, 1977).

Very little is known of the paleobotany of this region. The present phytogeography was described by Shreve and Wiggins (1964), Felger (1966), Sherwin (1971), and Hastings and others (1972). Generally speaking, Holocene and late Quaternary hydrologic and sedimentologic conditions of coastal Sonora have not been suitable for the conservation of pollens. Only one section, in Laguna Sargento area, has been studied for its pollen content ( L. González, in preparation).

## SURVEY OF PLEISTOCENE MARINE TERRACES AND ASSOCIATED DEPOSITS

Reconnaissance study

The study of the deposits and coastal features related to Quaternary marine transgressions has been one of the principal themes of research during recent years in this region.



In 1973, the first  $^{14}\text{C}$  dates of Late Pleistocene shells were published by Richards. These shells were collected in two localities, one north and the other south of El Desemboque. In 1975 Stump studied the fossiliferous intertidal deposits outcropping a few meters above MSL in the area of Puerto Libertad. He interpreted the age of the deposits as late Pleistocene.

In 1976-78 Malpica, Ortlieb, and collaborators published several papers and abstracts on their general reconnaissance of Pleistocene marine remnants, all along the coast north of Guaymas. The first two abstracts (Malpica and Ortlieb, 1976; Ortlieb and Malpica, 1977) emphasized that marine terraces of the sonoran coast were low-lying (elevations inferior to + 10 m) and probably corresponded, one to the Late Pleistocene (Sangamon interglacial), and the other one to an older Pleistocene (?) transgression. The maximum Holocene sea level was reported to have been, at most, only a few decimeters above present datum. The paper of Malpica and others (1978) gave a descriptive list of 23 distinct outcrops attributed to the Sangamon interglacial, in coastal Sonora and in Isla Tiburón. In an other paper, Ortlieb and Malpica (1978), provided more data of the same localities and discussed the question of the chronological framework of these deposits.

Ortlieb (1978a, 1979) compared these data from the sonoran coast with the terraces found on the Pacific and the Gulf coast of Baja California to draw conclusions on the distinct rates of recent vertical deformations in the latter area.

#### Geochronology

After unsuccessful results of dating by amino-acids geochronology, U/Th dates of fossil shells (*Dosinia ponderosa*), samples in different localities between Punta Kino and Puerto Lobos, were published by Bernat and others (1980). These radiometric ages generally confirm the attribution to the Sangamon interglacial (120 000 to 80 000 years B. P.) of the majority of the sampled outcrops (See Fig. 2). A few U/Th dates are interpreted as resulting from uncontrolled contaminations (dates of 42 000? and 21 000 ? years B. P.). Two more dates of 180 000 ? and 200 000 ? years B. P., argue for a but last interglacial age (pre-Sangamon), in two localities mentioned in Fig. 2, but field interpretation suggests rather a Sangamonian age.

In the area of Tepoca, where  $^{14}\text{C}$  ages or around 30 000 years B. P. had been first reported by Richards (1973), further field work and sampling of marine fossil shells were done to check the hypothesis of a marine transgression during a late Wisconsin interstadial (Lecolle and Ortlieb, 1978; Lecolle and others, 1978). Twelve more dates from "Laguna" Tepoca provided apparent  $^{14}\text{C}$  ages comprised between 27 000 and 35 000 years B. P. (Ortlieb and Lecolle, in preparation); precise isotopic and mineralogic analysis of the dated material are still necessary to validate these results (which might be due to only 3% contamination by modern carbon). The question of a "eustatic" high stand of sea level (near or above present MSL), at about 30 000 years B. P., has been largely debated by many investigators (see discussion on this controversy in Mörner, 1971 and Thom, 1974).

#### Tectonic significance

Field observations and presently available radiometric and paleontological data of almost all the outcrops of Quaternary marine deposits found on this coast, at a few meter elevation, suggest a Sangamonian age. The reconstructed paleo-sea level of the last interglacial in coastal Sonora is about + 5 m (above present MSL). As there are very few significant differences in the present elevations of the remains of the Sangamonian paleo-shoreline, it is inferred that the whole coastal area has not been affected by late Quaternary vertical movements; furthermore, as the altitude of the paleoshoreline correspond to the level presumably reached during the Sangamon (as determined worldwide) this coastal region of Sonora may be consi-

dered as tectonically stable, at least during the last 100 000 years. In the area of Guaymas the lack of marine terraces and the typically drowned valleys (peculiarly visible in the main bay) indicate that this region has been subsident in the Late Quaternary.

In general, the Middle Pleistocene interglacial high sea level are very poorly documented in Sonora (Ortlieb, in press). The pre-Sangamon marine deposits, observed in the areas of Puerto Libertad, Bahía Lobos and El Desemboque, do not crop out at elevations superior to + 10 m and this might be another indication of general stability of the coast in the Quaternary. In Playa Santa María (or Santa Margarita), 10 Km N of Puerto Libertad, are remnants of high stands of sea level, at + 22, at + 15 and + 10 m (unpublished data) these features are hypothetically attributed to surges (Hollin, 1972, 1980) of unknown age (pre- or post-Sangamon).

#### CONCLUSION: QUATERNARY EVOLUTION OF THE COAST OF CENTRAL SONORA

At the end of the Tertiary western Sonora had already acquired its characteristic structure of parallel NW oriented basins and ranges. Up to now, no marine transgression of Pliocene age has been identified in the coastal region of central Sonora. The sedimentation, in the last few million years, was essentially terrestrial: lacustrine, fluvial, alluvial and colluvial (bajada) deposits accumulated in the down-faulted valleys west of the Sierra Madre Occidental.

The Pleistocene (and even Holocene) climatic evolution in northwestern Mexico is still very poorly known. The results of the numerous investigations on Quaternary paleoclimates that have been carried out in southern Arizona and southern California cannot be extrapolated to Sonora. This last region is located in an intermediate position relatively to the truly tropical zone to the south, the mid-continent divide to the east, and the desert basins of the southwestern U. S. to the northwest. It may be assumed that the glacial periods of the Pleistocene were characterized by relatively high rainfalls, and possibly mild (or cool?) temperatures, while the interglacials presented a semi-arid to arid climate, similar to that of today. The Playa San Bartolo lacustrine deposits, as well as the thick bajada sediments which overlap the last interglacial (Sangamon) marine beds, at least prove that during (the major part of ?) the late Quaternary, the runoff has been greater than today.

In central Sonora, which is bordered by a relatively broad and shallow continental margin, there is no doubt that the Pleistocene coastline fluctuated between its present location and several kilometers (locally, some 20 or 30 Km) to the west. Thus, during Pleistocene glacial periods, when the sea level was about a hundred meters below the present datum, alluvial and deltaic sediments accumulated in what is now the nearshore area. During the interglacial periods, the maximum elevation reached by the sea was about the same than today MSL (or a few meters above, in the case of the Sangamon interglacial) and the coastline was probably similar in many aspects to what we can observe today. As a consequence of the relative tectonic stability of the coast and of the cyclic pattern of the glacioeustatic variations of sea level during the Middle and Late Pleistocene, only the last interglacial-glacial depositional sequence is conspicuous along the coast, the previous sequences being either eroded or concealed.

Almost all the characteristic features of the present coastline: lagoons and mangroves, barrier dunes, tombolos and spits, seacliffs and shore platforms (cut in late Pleistocene or older rocks) narrow cobble beaches and wide sandy beaches, etc. were formed in the last 5 or 6 000 years, during the last stage of the Holocene post-glacial rise of sea level.

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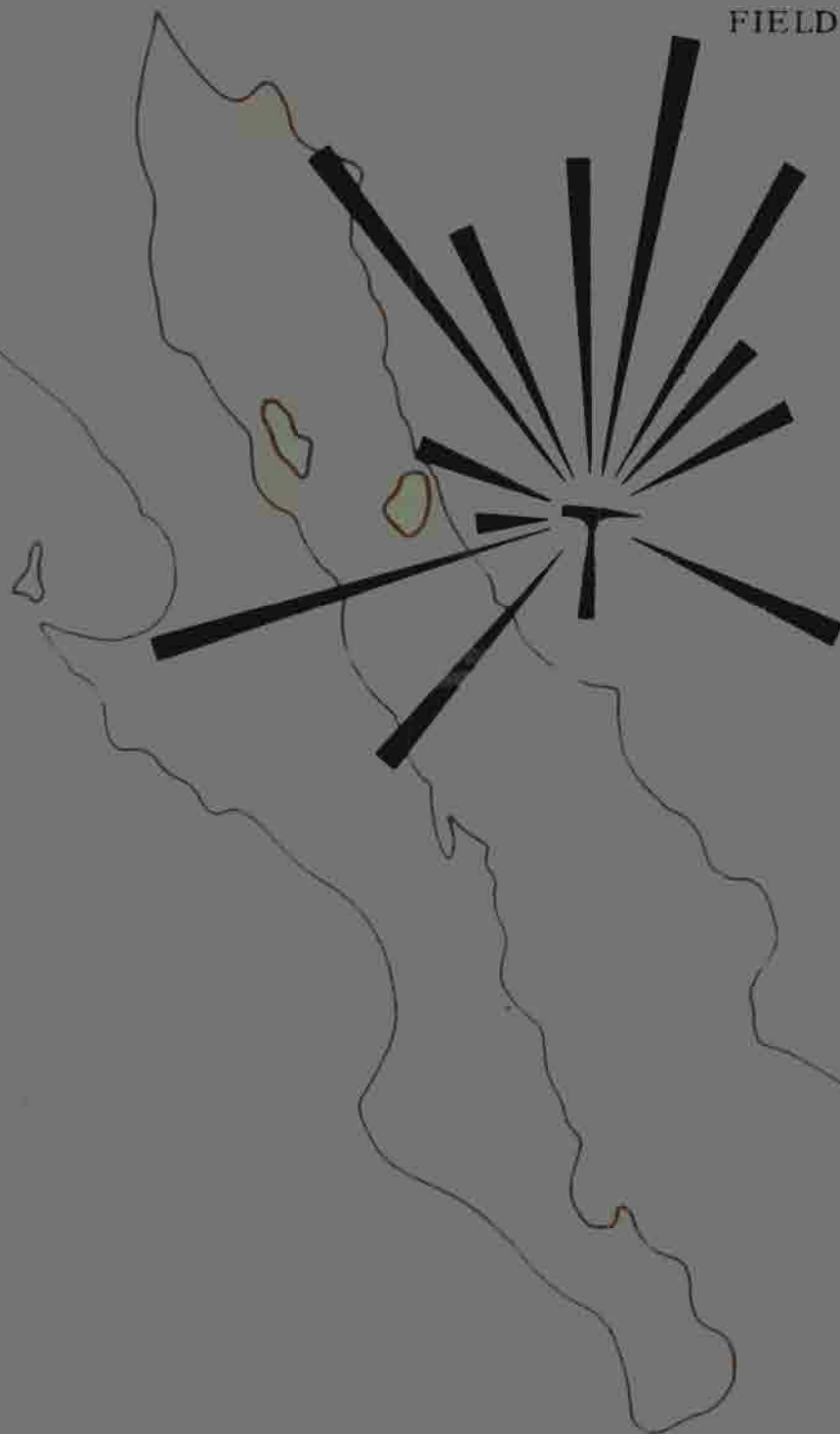
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FIELD GUIDES AND PAPERS



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GEOLOGY OF NORTHWESTERN MEXICO  
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HELD IN HERMOSILLO, SONORA, MEXICO, MARCH 21-30,  
AND SPONSORED BY THE INSTITUTO DE GEOLOGIA U.N.A.M.  
IN COOPERATION WITH THE UNIVERSIDAD DE SONORA.

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