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# RECONNAISSANCE GEOLOGIC MAP OF THE LORETO AND PART OF THE SAN JAVIER QUADRANGLES, BAJA CALIFORNIA SUR, MEXICO

By

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## INTRODUCTION

### PURPOSE

The Loreto area of Baja California Sur, Mexico, contains a diverse association of igneous, sedimentary, and metasedimentary rocks exposed in the foothills and arroyos between the Sierra La Giganta and Gulf of California. The Loreto area was selected for this study to examine the possible relation of the marine rocks to the opening of the Gulf of California, and to determine the stratigraphic and structural relations between basement rocks composed of granitic and prebatholithic rocks and overlying Tertiary (mainly Miocene) sedimentary and volcanic rocks, and by a sequence of Pliocene marine and nonmarine sedimentary rocks. The Pliocene marine rocks lie in a structural depression informally called here, the Loreto embayment. This geologic map and report stem from a cooperative agreement between the U.S. Geological Survey and the Consejo de Recursos Minerales of Mexico that was initiated in 1982.

### METHODS

Although previous reconnaissance mapping of the area had been completed at scales of 1:1,000,000 (Mina, 1957), 1:200,000 (Beal, 1948), and 1:110,000 (Chavez, 1978), the maps lacked accurate topographic bases, did not have accurately located structural attitudes, and did not delineate prebatholithic rocks that were subsequently reported by Minch (1979). The 1:50,000-scale topographic map series published by the Mexican Government in the early 1980´s provided the base for our geologic map. Interpretation of 1:50,000-scale black and white aerial photographs preceeded field investigations in March, 1983 (assisted by B.P. Hausback), in March, 1985 (assisted by T.J. Wiley), and April, 1986 (assisted by J.T. Smith).

The present geologic map includes most of the Loreto quadrangle and a small part of the adjacent San Javier quadrangle. Figure 2 shows areas traversed onshore and offshore, as well as locations of major arroyos mentioned in the following text. Listed in Table 1 are one new potassium-argon (K-Ar) age from the granitic rocks, two new ages from welded tuffs interbedded with early Miocene nonmarine sedimentary rocks, and three new ages from tuffs interbedded with fossiliferous Pliocene marine strata. Tuffs in the Pliocene marine sequence provide chronologic ages for associated fossil assemblages. Listed in Table 2 are the locations of fossils collected in 1986 and cataloged by J.T. Smith of the U.S. Geological Survey. Table 3 lists fission-track data for apatite and zircon in igneous rocks.

## PREVIOUS WORK

The earliest geologic reconnaissance in the Loreto area was reported by Gabb (1869), followed in the early 1920´s by Beal (1948). Other publications on Loreto area geology report K-Ar ages of Miocene intrusive rocks located approximately 20 km west of Loreto (Gastil and others 1979); on a granitic rock (Minch, 1979); and on a prebatholithic andesite (Gastil, and others 1978). Reconnaissance study of marine fossils in beds north of Loreto have been completed by several workers including Anderson (1950) and Durham (1950), who briefly visited the area during the 1940 cruise of the E.W. Scripps to the Gulf of California. Stump (1979) also studied selected molluscan genera north of Loreto as part of his doctoral dissertation.

Previous workers used the name "Comondú Formation" to describe most of the nonmarine Miocene rocks in the Loreto area and in the Sierra La Giganta. As a result, the name has become a catch-all for lava flows, volcaniclastic sandstone, mudstone, conglomerate, volcanic and sedimentary breccia, and ash-flow tuff. To cope with the nomenclature of Miocene units on the Bahía Concepción peninsula, McFall (1968) elevated Comondú to group status and named several new formations that have limited geographic extent. Hausback (1984, p. 226) and Sawlan and Smith (1984, p. 237) discussed some of the problems of using Comondú as a formation name. I prefer avoiding further complication of Comondú Formation nomenclature, by using informal unit designations for rocks that previous workers have called Comondú.

Nomenclature problems also exist for Pliocene marine rocks near Loreto that have been called the Salada Formation by Beal (1948), Mina (1957), and Chavez (1978). Anderson (1950) and Durham (1950) called the same rocks the San Marcos, Carmen, and Marquer Formations, and Smith (1984) suggested that the type section of the Salada Formation, which is located approximately 200 km south of Loreto, is probably middle Miocene in age. To avoid these problems, I informally designate these rocks the "marine rocks of the Loreto embayment" (unit Tm).

## GENERAL GEOLOGY

### BASEMENT ROCKS

#### Prebatholithic Rocks

Greenish-gray, complexly fractured, greenschist facies, nonfoliated metasedimentary rocks crop out for approximately 10 km along Arroyo de Gua west of Mexico Highway 1. These previously unmapped rocks have been metamorphosed by intrusion of Cretaceous granitic rocks. The weakly metamorphosed sequence consists of volcaniclastic sandstone, conglomerate, and breccia and dikes of coarsely porphyritic hornblende andesite. Both strata and dikes contain abundant secondary epidote and chlorite. The sequence is also intruded by unmetamorphosed dikes of fine-grained, biotite quartz monzonite and sugary-textured, very light gray aplite that may be apophyses of the plutonic rocks.

Dips within the prebatholithic sequence vary from horizontal to as high as 80° along the faulted east edge of the outcrop area. Estimates of thickness range from 300 to 400 m.

Volcaniclastic sandstone in the prebatholithic sequence consists of plagioclase that has altered to albite, altered volcanic-rock fragments, blue-green hornblende, abundant chlorite and epidote, opaque oxides, and rare quartz. Conglomerate clasts of andesite contain albite, epidote and chlorite. Rare interbeds of argillite contain little-altered grains of andesine (plagioclase) that lie in a nearly opaque clayey matrix. The hornblende andesite dikes that intrude the sedimentary rocks, contain large hornblende euhedra as long as 1.5 cm, set in a fine-grained greenish groundmass of chlorite and epidote. Gastil and others (1978) reported a K-Ar age of 94±2 Ma from hornblende andesite sampled near the headwaters of Arroyo de Gua (approximate location provided by R.G. Gastil, written commun., 1986). The age should be interpreted as a minimum value because the rocks have been metamorphosed.

### Granitic rocks

The northern and southern parts of the Baja Peninsula contain extensively exposed Cretaceous granitic rocks, but the central part between latitudes 26° and 28° N. contains mainly Tertiary sedimentary and volcanic rocks. Gabb (1869, 1882) reported granitic rocks northwest of Loreto, and reconnaissance maps of Beal (1948) and Mina (1957) show small poorly located outcrops. Minch (1979) reported that granodiorite located in Arroyo San Antonio (location provided by R.G. Gastil, written commun., 1986) yielded a K-Ar age of 145 Ma. Analytical data have not been published for this date, and the age is much older than similar granitic rocks reported by McFall (1968) and in this report. The closest granitic rocks to those of the Loreto area, crop out 60 km north on the Concepción Peninsula (McFall, 1968) and on offshore islands to the south such as Isla Santa Catalina (fig. 1; Anderson, 1950).

The granitic rocks of the Loreto embayment crop out in the low hills west of Mexico Highway 1 beneath a veneer of Tertiary and Quaternary deposits. Biotite quartz monzonite and hornblende biotite granodiorite predominate. Fresh outcrops have a salt-and-pepper color that weathers to a reddish brown. Dikes of aplite and leucocratic quartz monzonite locally intrude the main body of granitic rock. Fresh granodiorite that crops out along an unnamed arroyo 1 km north of the small ranch at Los Aguajitos yielded a biotite K-Ar age of 87.4±2.0 Ma (table 1, No. 8). The same rock yields a fission-track age of 90.15±13.0 Ma from apatite, and a possibly discrepant age of 61.82±9.5 Ma from zircon table 3).

## EOCENE(?) STRATA

### Quartzose sandstone

White, and reddish brown, well-indurated, well-sorted, trough-crossbedded, sandstone overlies granitic and prebatholithic basement rocks. White sandstone crops out locally in the upper part of Arroyo de Gua and in the arroyo on the north side of Cerro El Mogotito, and reddish brown and white sandstone crops out in Arroyo El Salto approximately 0.5 km downstream from Rancho El Salto. The sandstone consists of medium-grained, tightly packed quartz, plagioclase, microcline, orthoclase, and rare bluish hornblende. Modes of framework grains are $Q_{55}$, $F_{25-35}$, and $L_{0-17}$, representing quartz, feldspar and lithic fragments, and are plotted in Figure 3 (unit Ts). Secondary minerals include sericite, clay minerals, and small patches of calcite. The framework composition suggests a granitic source.

Inclinations of crossbedding in Arroyo El Salto red sandstone beds dip N. 80° E., which is the same general direction as northeast inclinations in the Salto Formation on the Concepción Peninsula reported by McFall (1968). The origin of the crossbedding in Arroyo El Salto (subaqueous or aeolian) remains unresolved.

F.J. Escandon (unpub. data, 1977) correlated red and white quartzose sandstone beds at Punta San Telmo located 120 km south of Loreto, with the Eocene Tepetate Formation, which is widely exposed on the Pacific side of southern Baja California Sur. The red and white crossbedded sandstone beds at Punta San Telmo are at least 28 m.y. old based on a K-Ar age from a directly overlying ash-flow tuff (Hausback, 1984). An Eocene age seems reasonable for the Loreto quartzose sandstone, which along with the Punta San Telmo beds may represent a nonmarine shoreline facies of the marine Eocene and Paleocene that is widely reported on the surface and in the subsurface of the Pacific coast (Mina, 1957).

## UPPER OLIGOCENE AND LOWER AND MIDDLE MIOCENE STRATA

### Sandstones of mixed provenance and welded tuff

Several distinctive lithofacies overlie granitic and metamorphic rocks and quartzose sandstones. The stratigraphic relations between these lithofacies are unclear, but they may mutually intertongue. The sandstone beds consist of granitic and greenschist metamorphic rock fragments (albite, epidote, and altered volcanic-rock fragments), mixed with fresh volcaniclastic grains (andesine, oxyhornblende, clinopyroxene, and unaltered volcanic rock fragments) and variable amounts of phosphate pellets.

Rocks in the upper part of Arroyo de Gua consist of greenish-gray, reddish-brown, and grayish-brown, moderately indurated, medium- to coarse-grained sandstone and contain abundant detrital epidote, whereas sandstone in Arroyo El León consists of grayish-brown, well-indurated, well-sorted, phosphatic sandstone that contains as much as 65 percent phosphatic pellets (fig. 3, unit Tnm-mixed provenance and phosphatic lithologies).

In Arroyos Las Parras, El Salto and San Vicente, and in the arroyo on the north side of Cerro El Mogotito, beds consist of well-indurated, reddish-brown, crossbedded sandstone. The Arroyo El Salto section contains pinkish welded tuffs that are interbedded with reddish-brown volcaniclastic sandstone, and a welded tuff also crops out along the Loreto-San Javier road 13 km west of Loreto.

Ages of local and regional sandstone interbedded with welded tuff--Granitic rock in Arroyo El Salto of the Loreto quad- rangle is unconformably overlain by a welded tuff that yields a fission track age on zircon of 29.57±35 Ma (table 3, No. 385-3-3). A stratigraphically higher welded tuff also located in Arroyo El Salto yielded a K-Ar age of 22.2±0.6 Ma (table 1, No. 7) and yielded a fission-track age on zircon of 20.4±2.4 Ma (table 3, no. 385-4-3). A welded tuff in Arroyo Las Parras approximately 50 m north of the Loreto-San Javier road yielded a plagioclase age of 21.4±1.0 Ma, and an age of 22.6±1.0 Ma from an analysis of argon 40/39 on hornblende (table 1, No. 6). The tuffs consist of moderately welded glass shards and slightly flattened pumice fiamme and crystals of plagioclase, sanidine, quartz, and brown biotite. The ages of the welded tuffs suggest that the mixed provenance sandstone section is as old as late Oligocene and as young as early Miocene.

Reddish-brown sandstone and interbedded welded tuff also overlie crystalline basement rocks approximately 60 km north of Loreto on the west side of Bahía Concepción and at Punta San Telmo 120 km south of Loreto. The Concepción Peninsula sequence was named the Salto Formation by McFall (1968) and yields a biotite K-Ar age of 28.1±0.9 Ma from a welded tuff near the top of the section. The above areas have stratigraphic sections that are coeval with the Loreto area.

### Volcaniclastic rocks

The beds of mixed provenance and welded tuff grade upward into as much as 1,400 m of light-brown to light-gray, moderately indurated, nonmarine, volcaniclastic sandstone, conglomerate, and breccia. The volcaniclastic sequence forms the conspicuous east-facing escarpment of the Sierra La Giganta, and forms spectacular outcrops along the road that climbs through the upper part of Arroyo Las Parras between Loreto and the village of San Javier. Within the Sierra, dips range from nearly horizontal to approximately 10$^{\circ}$ west. Stratification tends to be tabular-planar with abundant internal channeling, wedging, and lensing (features characteristic of fluvial sandstone). The sandstone and conglomerate facies of the section resemble the type section of the Comondú Formation located 50 km west of Loreto (Heim, 1922, p. 542).

Volcaniclastic sandstone consists of a poorly sorted assemblage of andesine (plagioclase) and a variety of vitreous andesitic rock fragments, and subordinate oxyhornblende, clinopyroxene (usually augite), orthopyroxene, and opaque oxides (fig. 3, unit Tnm-volcaniclastic). Matrix consists of a mixture of volcanic glass and clay minerals. Virtually all rocks of this unit that were examined petrographically contain zeolite cement.

The section exposed along the east-facing escarpment of the Sierra La Giganta appears to contain two or three low-angle, intra-formational unconformities, suggesting that deposition was synchronous with minor tectonic tilting. Radiometric ages of rocks that underlie and intrude the volcaniclastic sequence constrain its age to between approximately 18 and 22 Ma (table 1, Nos. 5 and 6). (See section on hypabyssal and volcanic rocks.)

### Near-Vent volcanic facies

A 1,500-m-thick sequence of yellowish-brown and reddish-brown sandstone, polymict andesitic breccia, and conglomerate that grade upward into porphyritic andesite lava flows, form the coastal hills between Arroyo Arce and Arroyo San Juan. Hausback (1984, p. 228) interpreted the sequence as a near-vent or volcanic-core facies that grades westward into medial and distal volcaniclastic facies in the Sierra La Giganta.

A structure that I interpret to be a faulted anticline located near the Loreto microwave tower (Estación Loreto), divides the near-vent facies section into a west-dipping section northwest of the tower and an east-dipping section southeast of the tower. Pliocene marine strata unconformably overlie both flanks of the anticline. A dark-gray (nearly black) plagioclase-phyric basaltic andesite flow exposed along the road to the microwave tower, yielded a whole rock K-Ar age of 14.9±0.5 Ma (table 1, no. 4).

### Breccia sequence and dike swarm

A sequence of massive, poorly sorted, polymict andesitic breccia, and subordinate beds of volcaniclastic sandstone form the low hills north and south of Arroyo Las Parras west of Mexico Highway 1. Approximately 8 km west of Loreto, a high-angle, north-trending fault with presumed normal displacement juxtaposes the moderately dipping breccia sequence against the gently dipping, volcaniclastic sandstone and welded-tuff sequence.

Breccia clasts consist mainly of medium-gray and brownish-gray hornblende and pyroxene andesite that lie in a poorly sorted sandy matrix. The polymict composition, sandy matrix, and interbedded sandstone suggest that much of the breccia was deposited by sedimentary (debris flow) rather than effusive volcanic processes.

The breccia sequence transected by Arroyo Las Parras is complexly faulted and intruded by at least two texturally distinct dike swarms. One system consists mainly of dark- to medium-gray dikes 1 to 2 m thick whose orientation and grain size vary widely. The dikes consist of very fine grained andesite that ranges from nearly aphyric to porphyritic with abundant phenocrystic plagioclase (andesine), hornblende, and clinopyroxene. Some dikes contain modal quartz and biotite and many contain secondary quartz, calcite, jarosite, sericite, zeolite, and clay minerals. Notably, the rocks do not contain epidote or chlorite, which distinguishes them from epidote-bearing prebatholithic rocks of similar texture.

A second and perhaps younger system consists of leucocratic hornblende andesite dikes as thick as 30 or 40 m can be traced as far as 7 km. Some of the more prominant dikes are mapped from their conspicuous, light-colored lineaments visible on aerial photographs. One of the dikes radiates eastward from the hypabyssal stock that forms Cerro Pilon de Las Parras (map unit Ti); the stock yielded a K-Ar age of 19 Ma (table 1, No. 5). The radiometric age and crosscutting relations suggest that the breccia sequence is a coarse grained facies of the volcaniclastic sequence, located closer to the volcanic core.

### Hypabyssal rocks

A plug-shaped stock of hypabyssal hornblende andesite porphyry (map unit Ti) forms the prominent peak of Cerro El Pilon de Las Parras, which is visible from the town of Loreto. The rock intrudes nearly horizontal strata of unit Tnm with no visible deformation of the volcaniclastic country rock. Nearby sedimentary rocks weather to an uncharacteristic reddish color, suggesting some thermal alteration. The intrusive rock is composed of phenocrysts of andesine, clinopyroxene, and megacrysts of green hornblende that lie in a holocrystalline groundmass of plagioclase microlites. Hausback (1984) reported a hornblende K-Ar age of 19.4±0.9 Ma (table 1, No. 5).

### Volcanic rocks

Interpretation of aerial photographs indicates that lava flows in the Sierra La Giganta locally overlie the section of volcaniclastic rocks. Although the flows in the mountainous area of this study were not sampled, flows along the road between the town of La Purísima and its intersection with Mexico Highway 1 at Rosarito yield K-Ar ages of approximately 11 Ma (Sawlan and Smith, 1984; samples located approximately 11 km north of the northwest corner of the geologic map of this study).

Lava flows that crop out west of Mexico Highway 1, just north of Loreto and form the hill called Cerro Gordo, consist of reddish-brown and gray porphyritic flow-banded andesite. The rock contains phenocrysts of andesine, oxyhornblende, and orthopyroxene in a glassy groundmass. The Cerro Gordo flows overlie prebatholithic rocks and lie beneath Pliocene marine strata. Flowbanding is visible in thin sections and in hand specimens. Aerial photographs locally show flowbanding liniaments and are plotted on the geologic map.

The Cerro Gordo flows have not been radiometrically dated, but stratigraphic relations and textural and mineralogic similarities to flows in the upper part of the near-vent facies suggest a Miocene age.

## YOUNG VOLCANIC ROCKS

### Lava flows

Andesitic flows that overlie Pliocene marine strata north of Arroyo San Juan are finer grained than most Miocene flows. The young flows range from fine to very fine grained, with aphyric or sparsely phyric textures. Phenocrysts consist of andesine and needles of yellowish-to greenish-brown hornblende that lie in a trachytic groundmass composed of plagioclase microlites and glass. Similar rocks form two cone-shaped hills at the base of the Sierra La Giganta escarpment at latitude 26°10′ N.

East of km 29 on Mexico Highway 1 and along the north side of Arroyo San Juan, the flows clearly overlie the marine beds. The relations exposed here suggest a latest Pliocene or Pleistocene age for the flows.

### Pyroclastic deposits

The youngest volcanic rocks consist of beds of reddish-brown cinders as thick as to 1 or 2 m thick that either overlie Pliocene marine beds or overlie Quaternary gravels. Clast size ranges from lapilli to bombs and blocks as large as 50 cm. The cinders might have been erupted from volcanic cones located a few kilometers east of Mexico Highway 1 north of the map area.

## PLIOCENE STRATA

### Marine rocks of the Loreto embayment

The low hills north and northwest of the town of Loreto consist of light-gray and light-yellow sandstone, gray conglomerate, brown mudstone, yellow siltstone, yellowish-white coquina, and rarely outcropping beds of white pumiceous tuff. Coquina beds contain well-preserved pectens, oysters, and subordinate strombid gastropods, barnacles, and rare coral fragments (see table 2 for fossil localities). The assemblage of fossil mollusks reflects a variety of shallow marine environments. At the base of the exposed section, the marine beds interfinger with grayish beds of unfossiliferous sandstone, conglomerate, and brownish siltstone.

The Pliocene section of the Loreto embayment has an estimated cumulative thickness of approximately 1,200 m. Local thicknesses measured from the surface to the basal unconformity may vary because of onlapping (buttress) relations with underlying rocks. East of Mexico Highway 1 the marine beds unconformably overlie the near-vent facies of the coastal section. West side of the highway, the Pliocene section unconformably overlies several older units and lies beneath an extensive cover of alluviums.

The interfingering of conglomeratic nonmarine beds with marine sandstone and conglomerate, suggests a paleoenvironment where alluvial fans probably supplied poorly sorted sand and gravel into a system of coalescing marine fan deltas; a similar environment now exists in Bahía Concepción, located approximately 50 km north of the map area.

In contrast to the shallow water depths suggested by the mollusks, benthic foraminifers from a reconnaissance study of samples from yellowish orange silty mudstone beds 800 m southwest of km 20.6 on Mexico Highway 1, indicate shelf and slope-break depths (Cecelia McCloy, written commun., 1985).

Age--Planktic formaminfers from the reconnaissance locality above, indicate a Pliocene age (Cecelia McCloy, written commun., 1985; Hillary Olsen, oral commun., 1987). Ostracods from shallow-water facies also indicate a Pliocene age (Thomas M. Cronin, written commun., 1985). Durham (1950, table 9) reported that the mollusk assemblages in Arroyo Arce and Arroyo de Gua range in age from early Pliocene to late Pliocene. Minch (1979) reported that marine strata at km 28.9 on Mexico Highway 1 were intruded by a volcanic dike that yielded a K-Ar age of 6.7 Ma, which suggests that the intruded marine section was no younger than late Miocene. New plagioclase K-Ar ages from this study however, yield ages of 3.3, 2.1, and 1.9 Ma from three pumiceous tuffs interbedded with the mollusk-bearing marine strata (table 1, Nos. 3, 2, and 1) and correspond with the Pliocene age indicated by the fossils.

## ALLUVIUM

### Terrace and alluvial deposits

Much of the map area is covered with a veneer of alluviums. Three units were distinguished based mainly on relative erosional dissection visible on aerial photographs. The oldest and most dissected unit forms terraces and consists primarily of andesitic-clast gravel cemented by caliche. Most of the volcanic clasts appear to be reworked from volcaniclastic conglomerate and breccia in the Sierra La Giganta. Weathered granitic clasts however, predominate where the gravel overlies granitic rocks.

Sand and gravel mapped as older alluvium lies at a slightly higher elevation and is more dissected than younger alluvium. Younger alluvium is restricted to active stream channels, whereas older alluvium lies in presently abandoned drainage areas. In some areas along the shore, younger alluvium includes deposits of dune sand, and older alluvium south of the Loreto International airport includes abandoned beach ridges. The two units of alluvium generally share similar consolidation, composition, and grain sizes.

## STRUCTURE

### Loreto embayment

The principal lithotectonic feature of the map area is the Pliocene Loreto embayment. The west side of the embayment is marked by a north-trending normal fault that truncates the east edge of granitic basement. The east side of the embayment is formed by the mostly west-dipping block of near-vent facies rocks.

Previous studies have suggested one or more major faults within the embayment. The geologic map of Chavez (1978) for example, shows the Loreto embayment as a graben with bounding faults that extend north as far as Bahía Concepción, and the map of Hamilton (1971) interpreted from satellite photographs shows a regional fault through the area. Hamilton proposed that a major strike-slip fault extended from Bahía Concepción to La Paz near the south tip of Baja California Sur, which he extended through the Loreto embayment. Evidence of normal (east side down) faulting is visible on aerial photographs along the west side of the embayment where fault traces displace older alluvium.

East-dipping pre-Pliocene strata along both sides of the west-side fault, suggest that the Pliocene fill overlies a syncline that developed within pre-Pliocene rocks. The basin probably began to subside in the early Pliocene with marine transgression in mid to late Pliocene, followed by uplift and folding of basin fill in latest Pliocene and early Pleistocene time. Minch (1979) reported that faults within the Pliocene section have a cumulative displacement of several thousand feet, but it appears to me that the major offsets involve pre-Pliocene strata (see cross-sections A-A′ and B-B′).

### Other structures

The breccia sequence and dike swarm west of Loreto, are found within a graben that is flanked on the west by the volcaniclastic sandstone sequence and on the north and northeast by prebatholithic rocks. The amount of graben subsidence is unknown, but was not associated with marine transgression.

Strata west of the belt of granitic outcrops show little deformation. Dipping strata throughout the Sierra La Giganta range from horizontal to approximately 10° west. This structurally stable region, includes little-deformed rocks as old as Paleocene and extends for several hundred kilometers from Laguna San Ignacio 200 km to the northwest of the study area, to La Paz 225 km to the south (Hausback, 1984; McLean and others, 1985, 1987).

## REGIONAL CORRELATIONS

### Mainland Mexico

Geologic mapping and radiometric dating by Henry (1975) and Henry and Fredrikson (1987) indicates that some of the rocks on the west coast of mainland Mexico (in the southwest part of the State of Sinaloa) may correlate with rocks of eastern Baja California Sur. The two regions can be juxtaposed paleogeographically by closing the Gulf of California and moving the Baja Peninsula 300 km south, in accordance with the cumulative displacement along the southern San Andreas fault system in southern California (Crowell, 1975, 1979; Gastil and others, 1981). Although more pre-Cretaceous units exist in southwest Sinaloa, the Cretaceous and early Tertiary rocks of both areas share some similar characteristics.

For example, both areas contain Late Cretaceous quartz monzonite and granodiorite plutons with initial ratios of $^{87}Sr/^{86}Sr$ in Sinaloa that range from 0.7030 to 0.7058 (Henry, 1975), and a value of 0.7036 reported here for the Loreto area. Both areas contain few pre-Oligocene Tertiary rocks, although both contain reddish sandstone and 28 Ma ash-flow tuffs. Miocene sedimentary and volcaniclastic rocks, however, do not seem to correlate in thickness, and Miocene volcanic rocks are petrologically dissimilar.

The early Miocene of southwestern Sinaloa consists of rhyolitic ash-flow tuff and minor airfall tuff, volcaniclastic sandstone, and basalt, which thins from 1,500 m in the Sierra Madre Occidental to a few hundred meters near Mazatlán on the coast. Pliocene marine rocks have not been mapped in Sinaloa, and the youngest rocks along the coast are 2-Ma basalts. The two areas shared a common geologic history until 22 or 23 Ma, a time when eastern Baja California Sur became dominanted by an andesitic volcanic arc (Gastil and others, 1979, and 1981; Hausback, 1984), and rhyolitic volcanism in the Mexican mainland arc died out. Ages of faults in southern Sinaloa appear to have little bearing on the age of the opening of the Gulf of California, whereas the marine strata of the Loreto embayment indicate a transgression of Gulf waters beginning about 3 Ma.

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Table 1.--Potassium argon ages of volcanic and granit

[Potassium analyses by P. Klock and S. Neil, argon an
**, percentage potassium, _ percent $^{40}$Ar (radiogenic)
recommended by the International Union of Geological .
$0.581 \times 10^{-10}$, $\lambda_{\beta} = 4.962 \times 10^{-10}$ yr$^{-1}$, and $^{40}K/K_{tot}$

| Map No. | Field No. lat N. long W. | Rock type, Map unit | Material dated | Percen $K_2O$ ± devia |
|---|---|---|---|---|
| 1 | 486-18-1 | | | |
| | 26°3'20" | Tuff, | Plagioclase | 0.295 |
| | 111°27'26" | Tm | | 0.294 |
| | | | | 0.289 |
| | | | | 0.282 |
| | | | | 0.290 |
| | | | | ±0.006 |
| 2 | 486-17-2 | | | |
| | 26°11'08" | Tuff, | Plagioclase | 0.280 |
| | 111°26'19" | Tm | | 0.276 |
| | | | | 0.259 |

Table 2.--U.S. Geological Survey Cenozoic fossil localities in Pliocene marine rocks of the Loreto area (unit Tm)

[Collected by J.T. Smith and Hugh McLean, 1986]

| Location symbol on map | Field sample number 86JS- | U.S. Geological Survey Cenozoic fossil location (catalog number) |
|---|---|---|
| a | 17 | M9061 |
| b | 16 | M9060 |
| c | 15 | M9059 |
| d | 18 | M9062 |
| e | 14a-e | M9058 |
| f | 7 | M9050 |
| g | 19 | M9063 |
| h | 8 | M9051 |
| i | 11 | M9054 |
| j | 10 | M9053 |
| k | 12 | M9055 |
| l | 9 | M9052 |
| m | 20 | M9064 |
| n | 13 | M9056 |
| p | 5 | M9048 |
| q | 4 | M9047 |
| r | 6 | M9049 |
| s | 21 | M9065 |
| t | 1 | M9044 |
| u | 3 | M9046 |
| v | 2 | M9045 |

Table 3.--Fission-track data for apatite and zircon from igneous rocks in the Loreto area

[Minerals separated by L.B.G. Pickthorn; slides prepared by Nancy Naeser; slides counted and ages calculated by R.G. Bohannnon. $p_s$, Fossil tracks; $p_i$, Induced tracks; r, Neutron dose; T±2a, Sample age and age range (standard deviation); DF, U.S. Geological Survey, Denver, fission-track file number. Sample 385-3-3 unconformably overlies granodiorite in Arroyo El Salto at lat 26°07'06" N., long 11°30'41" W.. Location of samples 385-5-3 and 385-4-3 are listed in table 1, No. 8.]

| Sample No. | Lab. No. (DF) | Number of grains counted | Mineral dated | $p_s \mathrm{x} 10^6$ t/cm (No. counted) | $p_i \mathrm{x} 10^6$ t/cm (No. counted) | $r \mathrm{x} 10^{15}$ | T±2a (Age, Ma) |
|---|---|---|---|---|---|---|---|
| 385-3-3 | 5493 | 7 | Zircon | 0.281<br>(632) | 0.596<br>(670) | 1.05 | 29.6±3.5 |
| 385-5-3 | 5495 | 6 | Apatite | 0.131<br>(262) | 0.904<br>(904) | 10.45 | 90.2±13.0 |
| 385-5-3 | 5496 | 6 | Zircon | 3.59<br>(539) | 3.60<br>(270) | 1.04 | 61.8±9.5 |
| 385-4-4 | 5494 | 6 | Zircon | 3.41<br>(546) | 1.05<br>(841) | 1.05 | 20.4±2.4 |

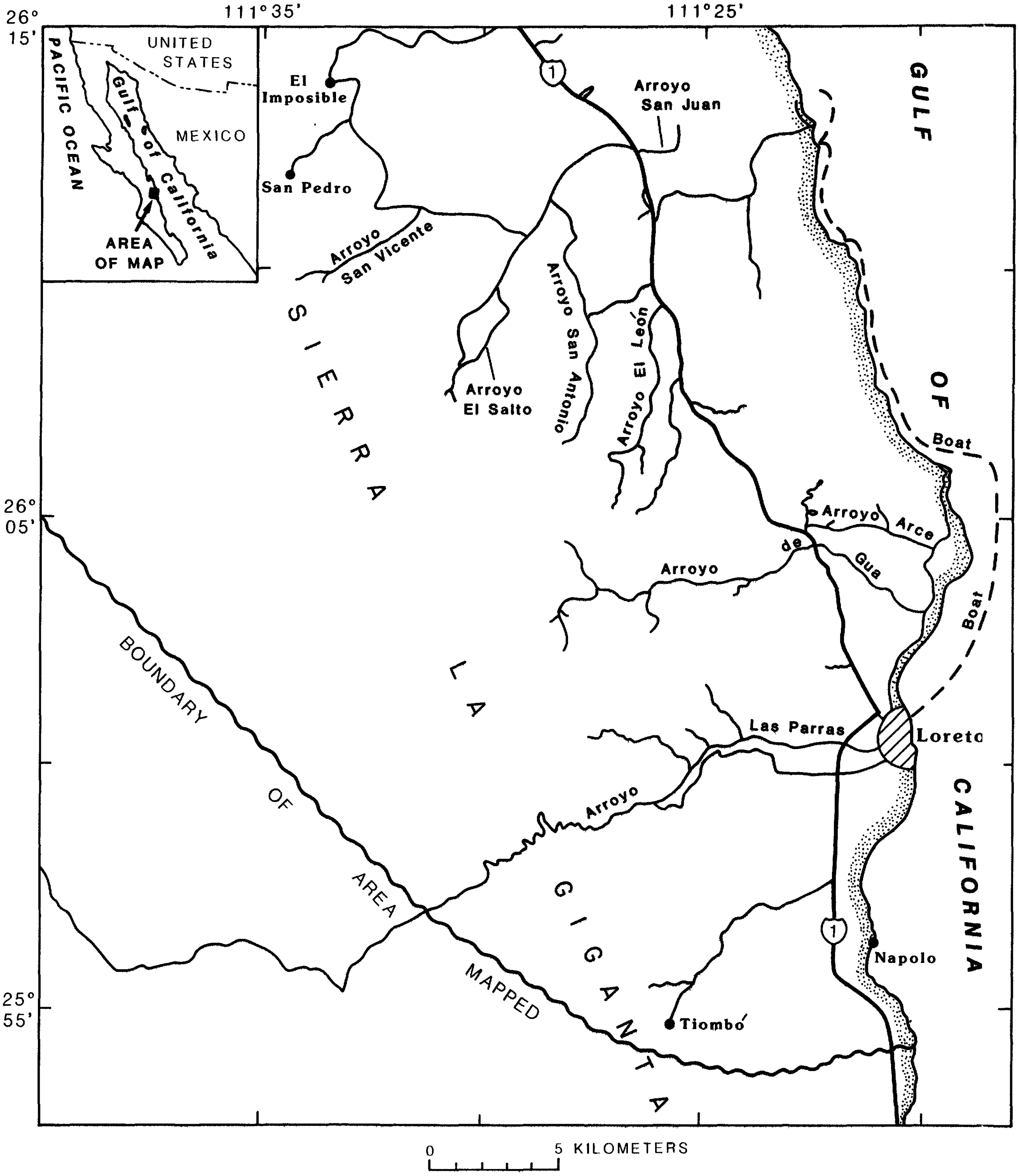

**Figure 2.** Map showing location of onshore and offshore traverses and locations of major arroyos. Solid lines, onshore traverses; dashed lines, offshore traverses made by small boat.

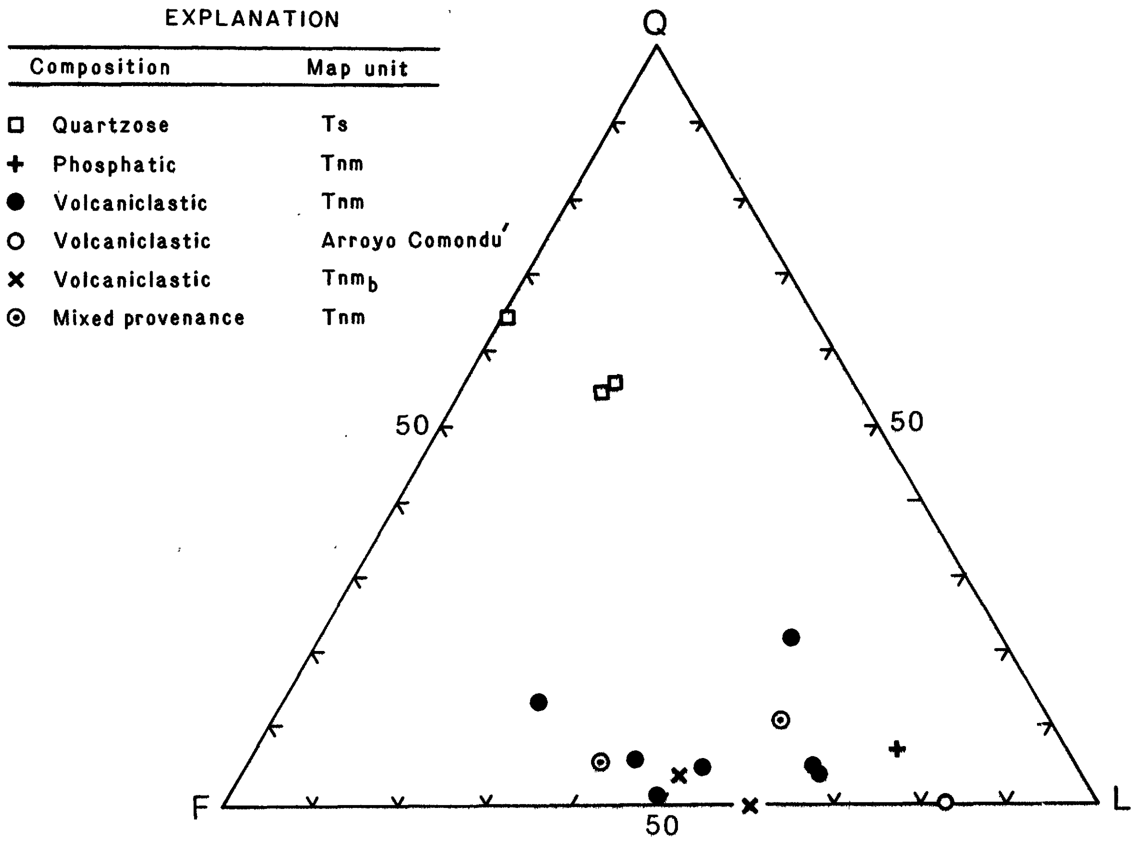

**Figure 3.** Ternary diagram showing framework modes of sandstone suites from the Loreto and part of San Javier quadrangles and one sample from Arroyo Comondú, Baja California Sur, Mexico. Q, total quartz; F, total feldspar; L, lithic fragments (mostly volcanic and phosphatic rock fragments). Modes based on a minimun count of 400 framework grains per thin section.