STANFORD UNIVERSITY PUBLICATIONS | GEOLOGICAL SCIENCES | VOLUME X, NUMBER 5

RECONNAISSANCE GEOLOGY OF THE CONCEPCION BAY AREA, BAJA CALIFORNIA, MEXICO

C. CAREW McFALL

SCHOOL OF EARTH SCIENCES | STANFORD UNIVERSITY | STANFORD, CALIFORNIA, 1968

STANFORD UNIVERSITY PUBLICATIONS | GEOLOGICAL SCIENCES | VOLUME X, NUMBER 5

RECONNAISSANCE GEOLOGY OF THE CONCEPCION BAY AREA, BAJA CALIFORNIA, MEXICO

C CAREW McFALL

SCHOOL OF EARTH SCIENCES | STANFORD UNIVERSITY | STANFORD, CALIFORNIA, 1968

William R. Evitt and William R Dickinson, Editors

VOLUME IV

GROUND-WATER HYDROLOGY OF PLEASANT VALLEY, FRESNO COUNTY, CALIFORNIA Yona Kahanovitz and John C Manning. 36 pages. 1954 $1 25

VOLUME V

MINERALOGY OF SOME JAPANESE MANGANESE ORES Donald Edward Lee 64 pages 1955. $1 50

VOLUME VI

WATER QUALITY OF EASTERN STANISLAUS AND NORTHERN MERCED COUNTIES, CALIFORNIA Stanley N Davis and Francis R. Hall No. 1 112 pages, 5 plates 1959 $2 00 (Out of print.)

RECENT FORAMINIFERA FROM THE PUERTO GALERA AREA, NORTHERN MINDORO, PHILIPPINES Joseph J Graham and Priscilla J. Militante No 2 170 pages, 19 plates. 1959. $3 00

VOLUME VII

STRATIGRAPHY AND STRUCTURE OF THE STISSING MOUNTAIN AREA, DUTCHESS COUNTY, NEW YORK Eleanora Bliss Knopf No 1 55 pages, 5 plates 1962. $3 50.

MINERAL RESOURCE DATA IN THE WESTERN STATES W. B Beatty. No 2 42 pages 1962 $1.00 (Out of print)

DINOFLAGELLATES, HYSTRICHOSPHERES, AND THE CLASSIFICATION OF THE ACRITARCHS. Charles Downie, William R. Evitt, and William A S Sarjeant No 3. 16 pages. 1963. $1.00

VOLUME VIII

CAMPANIAN FORAMINIFERA FROM THE STANFORD UNIVERSITY CAMPUS, CALIFORNIA Joseph J Graham and Clifford C Church. No. 1 106 pages, 8 plates 1963 $3.00.

MODERN CARBONATE SEDIMENTS OF SOUTHERN FLORIDA, BAHAMAS, AND ESPÍRITU SANTO ISLAND, BAJA CALIFORNIA · A COMPARISON OF THEIR MINERALOGY AND CHEMISTRY William H. Taft and John W Harbaugh No 2 133 pages, 15 plates 1964. $3.00.

VOLUME IX

COMPUTERS IN THE MINERAL INDUSTRIES George A. Parks, Editor No 1 480 pages No 2 400 pages. 1964 $10.00 per set

VOLUME X

DINOFLAGELLATE STUDIES. I DINOFLAGELLATE CYSTS AND THECAE. William R Evitt and Susan E Davidson No. 1 12 pages, 1 plate. 1964 $25

THE DEVELOPMENT OF DRAINAGE PATTERNS ON TIDAL MARSHES Raymond Pestrong No. 2 87 pages, 2 plates 1966 $3 00.

DINOFLAGELLATE STUDIES. II. THE ARCHEOPYLE William R. Evitt No. 3 82 pages, 9 plates, 50 text figs 1966 $1 00

DINOFLAGELLATE STUDIES. III *Dinogymnium acuminatum* N GEN, N SP. (MAASTRICHTIAN) MERLY REFERABLE TO *Gymnodinium* STEIN William R. Evitt, Robin Pierre Verdier No 4 27 pages, 3 plates, 23 text figs 1966 $1 00.

OF THE CONCEPCION BAY AREA, BAJA CALIFORNIA, MEXICO. 25 pages, 3 plates (incl. map), 2 figs 1968 $3 50.

SCHOOL OF EARTH SCIENCES
Stanford University

RECONNAISSANCE GEOLOGY OF THE CONCEPCION BAY AREA, BAJA CALIFORNIA, MEXICO

C. CAREW McFALL

Research Associate
School of Earth Sciences
Stanford University

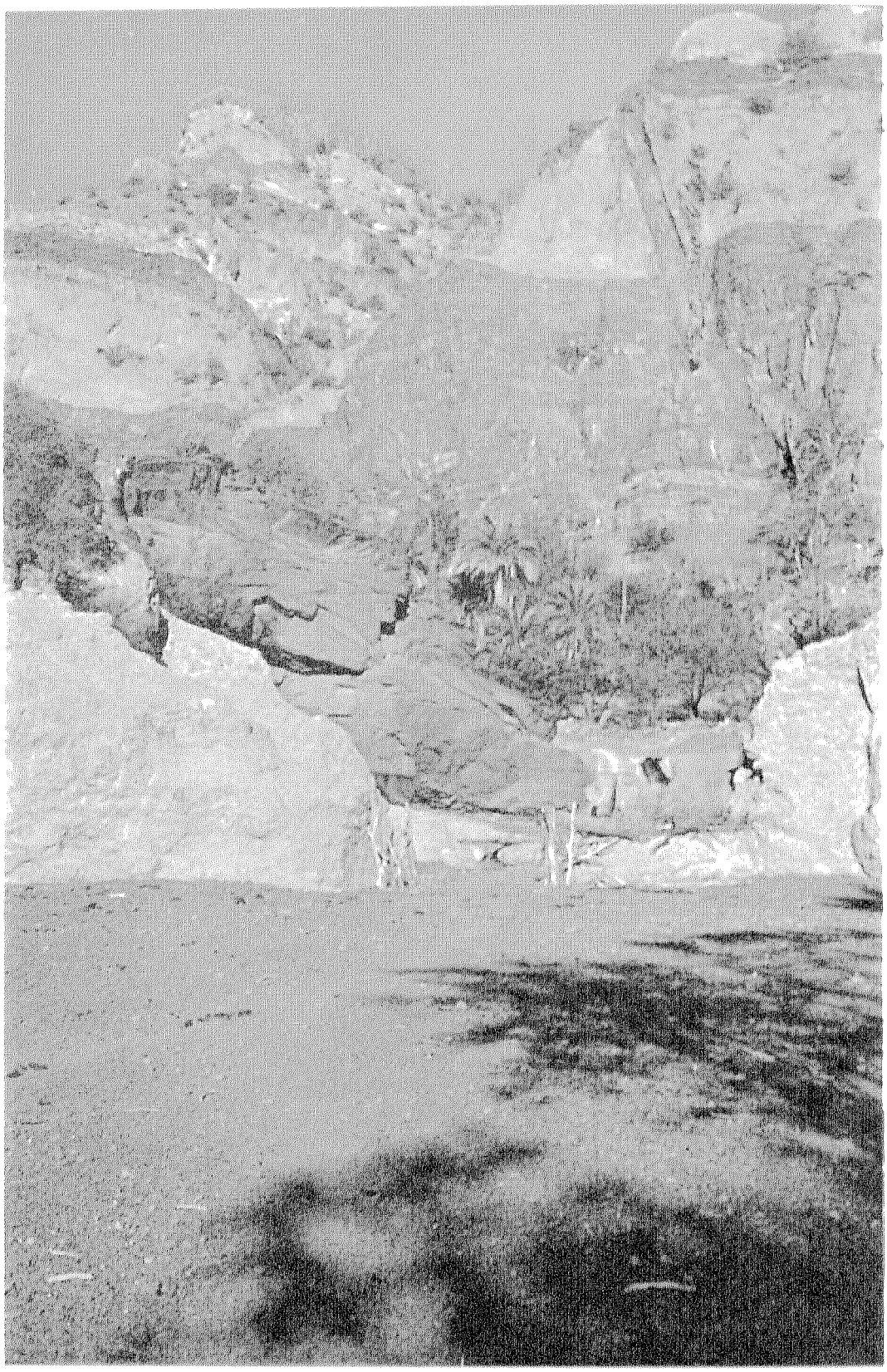
STANFORD UNIVERSITY PUBLICATION
Geological Sciences, Volume X, Number 5

SCHOOL OF EARTH SCIENCES
Stanford University, Stanford, California
February 1968

LIBRARY OF CONGRESS CATALOG CARD NUMBER: 67-30443

Printed in the United States of America

CONTENTS



ABSTRACT

This is a report of a three-month geological reconnaissance of a 450-square-mile area in Baja California, Mexico. The area, on the Gulf of California somewhat more than halfway south along the length of the peninsula, includes rugged, very arid, and sparsely populated land bordering Concepcion Bay Mulegé (population 1,000) is the only town in the area

The rocks of the area include a basement "granite," exposed on Concepcion Peninsula east of the Bay, about 13,500 feet of Oligocene and Miocene volcanics of the Comondú Formation covering almost the entire region, and late(?) Pliocene marls and coquinas of the Infierno(?) Formation which veneer the volcanics locally The granite (K-A date of 78.4 ± 2 9 m y , Late Cretaceous) is thought to be mostly recrystallized schist because the contacts of schist pendants with the "granite" are gradational

The report presents a geologic map, three potassium-argon dates on igneous and tuffaceous rocks of the area, and a study of the Comondú Formation, which is here made the Comondú Group. The six formations of the Comondú Group are, in ascending order· (1) the Salto Formation, up to 1,000 feet of reddish, cross-bedded sandstone, with interbedded varicolored tuffs, (2) the Pelones Formation, about 6,000 feet of andesitic agglomerates with interbedded basalt flows; (3) the Minitas Formation, about 500 feet of coarse, tuffaceous conglomerate, (4) the Pilares Formation, about 200 feet of dark gray, scoriaceous basalt, (5) the Hornillas Formation, about 500 feet of coarse, tuffaceous conglomerate; and (6) the Ricasón Formation, about 5,500 feet of dark gray, brown-weathering basalt flows, flow breccias, agglomerates, and light-colored tuffs A potassium-argon date on a tuff in the upper part of the Salto Formation indicated an age of 28 1 ± 0.9 m.y. (late Oligocene). Previously these beds were thought to be about 16 million years old (middle to late Miocene).

The granitic basement and the Comondú Group have been intruded by several small stocks of gabbro, numerous related diorite porphyry dikes, and by a 2 5-mile-wide granitic (tonolite) stock The latter, dated as 20.0 ± 2 0 m y., underlies the highest and most rugged part of Concepcion Peninsula.

The Concepcion Bay area has been considerably faulted, gently folded, repeatedly uplifted, and deeply dissected by erosion. The uplifts are recorded at least locally by marine terraces which range from 20 to 920 feet in elevation Just southwest of Concepcion Bay, well-developed erosion surfaces (accordant mesas), that could be marine terraces, range up to about 3,000 feet above sea level The estuary at Mulegé apparently formed along two easily eroded dikes.

The name "Concepcion Bay fault zone" is applied to the northwest-trending fault zone that delineates the Gulf coast of Baja California to the northwest of the mapped area, passes through Concepcion Bay and the aligned valleys 30 miles southeastward to Loreto, and delineates the coast to the southeast of Loreto. The displacement along this fault zone is unknown, but conceivably the Mulegé faulted anticline was originally

Frontispiece The Salto Formation at Rancho Salto on Concepcion Peninsula showing mostly light and dark tuff beds On the near side of the small oasis of palm trees is a typical reddish, cross-bedded sandstone A dike cuts the cliff on the right

part of the southwestern flank of the much larger faulted anticline that occupies most of Concepcion Peninsula. The 19-mile separation of these structures today could be explained by a right lateral offset along the Concepcion Bay fault zone. This is the same type of movement that characterizes the greater San Andreas fault system, of which the Concepcion Bay fault zone is thought to be a part. The largest displacements along faults of the San Andreas system in this area are probably in the Gulf of California.

The only known ore deposit in the area—manganese associated with travertine veins near the north tip of Concepcion Peninsula—has not been operated since World War II

INTRODUCTION

Location and Topography

Concepcion Bay is just south of latitude 27° N., a little more than halfway down the Gulf coast of Baja California, Mexico (see Figure 1 and Plate 1). This bay is 23 miles long, 2 to 3 miles wide, and parallels the Gulf of California, with which it is connected at the north.

The northwest shore of the bay is bordered by alluvial fans backed by hilly country with about 700 to 1,000 feet of relief. Farther south, the west shore rises abruptly from the bay in steep hillsides to 1,500 feet, and locally to 2,400 feet, elevation. Inland from the southwest corner of the bay there are accordant, mesa-like summits at about 3,000 feet.

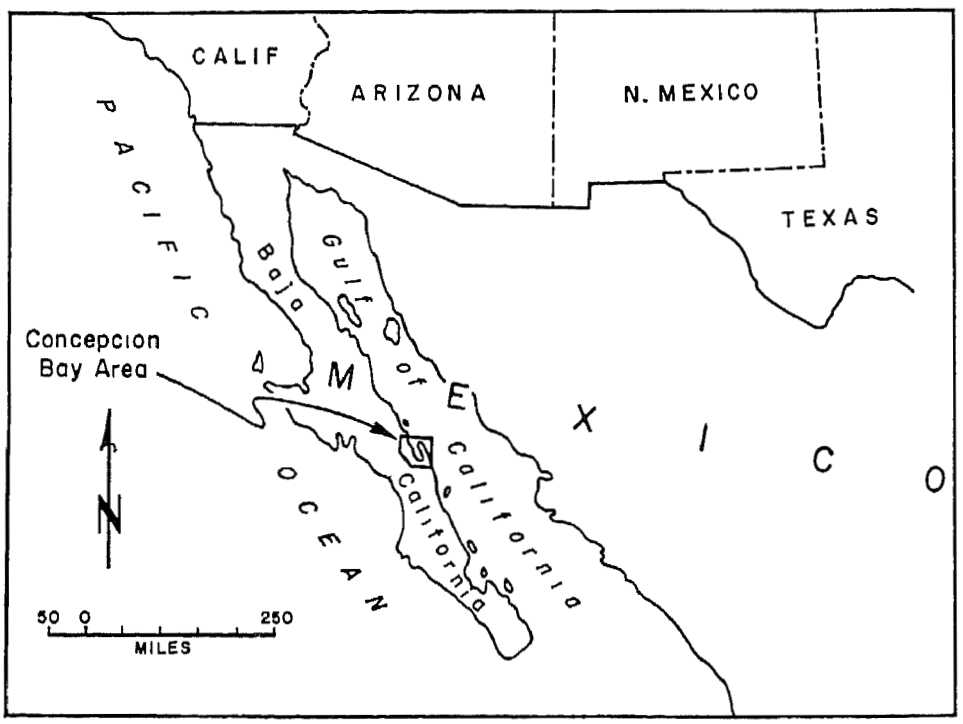


Figure 1. Location map

The south shore of the bay is a bajada with scattered hills rising from the alluvium farther south The east shore is formed by a broad bajada along the edge of the nine-mile-wide Concepcion Peninsula. This bajada is bounded on the east by a 500- to 1,500-foot-high, eroded fault escarpment. Elsewhere the peninsula consists of deeply eroded bedrock that rises somewhat gradually inland culminating in Cerro Blanco, at 2,434 feet elevation, northwest of the center of the peninsula.

Climate

The mean monthly maximum for the summer months of June through September is 90°–95° F. The winter months have mean minimums of 44° F. (Aschmann, 1959, Figure 2) Frosts are limited to inland areas. Average rainfall is about four inches per year (Aschmann, 1959). However, in April 1964, Concepcion Peninsula had not received rain in over two years The rain is commonly torrential and is associated with *chubáscos,* the tropical cyclones that move up the Pacific coast of Mexico during August and September. During the severe *chubásco* of September 9, 1959, the normally dusty arroyos carried as much as 60 feet of water in raging torrents Mulegé and most other towns of the region were devastated, and boulders as much as 12 feet in diameter disappeared from their accustomed places in the arroyos.

Vegetation

Various kinds of cactus and thorny bushes predominate in this desert country. The plant coverage is 30 to 40 percent on the sandy bajadas, but open to extremely sparse on the rocky slopes (Shreve, 1951, p 100).

The only change in vegetation correlated with a change in bedrock was a difference in the spacing and relative abundance of the sparse plants which grow on both the volcanics and the granitic basement complex. The shaggy-barked tree *Bursera microphylla* is unusually abundant on the granitic rock. The plants growing on the granitic basement complex are more evenly spaced than those growing on the volcanics. This even spacing is due to the homogeneity of the granitic rock and its sandy soil in contrast to the varying strata of the volcanics and their very sparse, slightly clayey soil.

However, there is considerable variation in the kinds of plants which grow in the major environments found in the area of this study· (1) the bajada slopes, (2) the rocky slopes, (3) the floors of arroyos, and (4) local areas of saltwater encroachment along the shore.

Bajada slopes Shreve (1951, p. 100) has listed the following as being plants which grow on the sandy or gravelly bajadas away from streamways near Mulegé·

Bursera hindsiana
Bursera microphylla
Cercidium microphyllum (palo verde, a legume; burros can live on its branches)
Colubrina glabra
Condalia globosa
Encelia farinosa
Fouquieria sp. (ocotilla-like plant)
Jatropha cinerea
Jatropha cuneata
Larrea tridentata (creosote bush)
Lycium brevipes
Machaerocereus gummosus (pitahya agria)
Olneya testoa (ironwood or uña de gato)
Opuntia cholla (cholla cactus)
Opuntia cribe (another cholla cactus)
Opuntia invicta
Pachycereus pringlei (cardón)
Pedilanthus macrocarpus
Simmondsia chinensis
Solanum hindsianum
Trixis californica

During a field visit Ira L. Wiggins pointed out these additional plants growing on the bajadas:

Cochemiea poselgeri
Karwinskia humboldtiana
Lophocereus schottii
Lycium andersonii
Opuntia tapona
Ruellia peninsularis
Sapium biloculare
Vallesia glabra

Rocky slopes. Shreve (1951) continues:

> The universally rocky slopes in the vicinity of Bahia Concepcion differ from the bajadas far more in their physiognomy than in their composition. The plant covering of the hills is open or extremely sparse, varying in density with the gradient of the slopes and the amount of soil which they afford *Fouquieria diguetti* is the most conspicuous of the abundant plants, and *Jatropha cuneata* is the commonest *Bursera microphylla* and *Cercidium microphyllum* are common, but seldom greatly exceed shrubs in height *Pachycereus* is infrequent, and other cacti are far less common than on the bajadas. *Larrea* is very infrequent on the slopes and often absent over large areas. Plants which are common on the slopes and infrequent on the bajadas include the following, for which the relative abundance would be difficult to determine
>
> *Abutilon palmeri*
> *Acalypha saxicola*
> *Atamisquea emarginata*
> *Bebbia juncea*
> *Bourreria sonorae*
> *Cercidium sonorae*
> *Ditaxis brandegeei*
> *Echinocereus brandegeei*
> *Euphorbia tomentulosa*
> *Fagonia californica*
> *Ferocactus rectispinus*
> *Lemaireocereus thurberi* (pitahya dulce)
> *Opuntia cubre*
> *Peucephyllum schottii*
> *Pithecellobium confine*
> *Porophyllum gracile*
> *Randia thurberi*
> *Ruellia californica*
> *Viguiera deltoidea*

To this list Wiggins added *Hibiscus denudatus* and *Yucca valida.*

Floors of arroyos. Wiggins pointed out the following common trees growing along the arroyo floor:

Acacia(?)
Cercidium microphyllum (palo verde)
Cercidium sonorae (palo verde with good trunk and long coarse spines)
Ficus palmeri (higera silvestre)
Forchammeria watsonii (palo San Juan)
Lysiloma candida (palo blanco)
Olneya tesota (ironwood or uña de gato)
Prosopis juliflora var. *torreyana* (mesquite)

Other plants along the arroyo floors pointed out by Wiggins were:

Eucnide cordata
Hyptus laniflora
Nicotina trigonophylla

Shreve (1951, p 101) noted that "on the inner edge of the alluvial land at the south end of the bay (Concepcion Bay) is the heaviest stand of *Pachycereus pringlei* (giant organ cactus) seen in Baja California. Magnificent examples of this massive cactus, 12 to 14 meters in height, well branched, and growing in a close stand, are found in the center of this area."

Local areas of saltwater encroachment The halophytes (salt-lovers) around the

sandy coves of the western side of Concepcion Bay occur in distinct zones. Wiggins pointed out the mangrove *Rhizophora mangle,* the low bushes *Allenrolfea occidentalis* and *Suaeda* sp., and a large bush with yellowish-green fleshy leaves, *Maytenus phyllanthoides,* growing progressively away from the water. The halophytes seen along gravelly stretches of the eastern shore of the bay were quite different from these and included *Avicennia germinans, Batis maritima, Frankenia palmeri,* and *Stegnosperma halimifolium.* The giant cardon cactus (*Pachycereus pringlei*) is sensitive to saltwater encroachment and very abruptly and uniformly decreases in size toward the shore.

Wildlife

Sparse populations of jackrabbits, deer, coyotes, mountain sheep, wildcats, squirrels, doves, quail, ducks, geese, and, reportedly, puma are present Rattlesnakes are abundant but hibernate from November until April. There are a few seals along the coast near Punta El Pulpito, south of Rancho San Nicolás. Fish, including yellowtail, sea bass, and many other fine varieties, are abundant locally, especially off the headlands along the Gulf coast Sea turtles are rather abundant from May through September. Sharks are abundant during the winter, particularly in Concepcion Bay Small butter clams, locally numerous, can be found in the sand just offshore from the mouth of the small lagoon at Playa Santispac. Large hatchet clams are also abundant locally, especially in the sandy bank north of Punta Blanca along the eastern shore of Concepcion Bay.

Culture

Near sources of fresh water in this area, there is evidence of Indian encampments which spanned a wide time interval The locations of these encampments are shown on Plate 1 Petroglyphs and red and black pictographs, featuring fish, sea turtles, trees, men, and patterns of lines, have been found on cliffs and cave walls Shell heaps, arrowheads, grindstones (*metates* and *manos*), smoke-blackened patches on the walls of natural shelters, and small ovens dug in the ground and lined with rocks give indications of the Indians' domestic activities.

The Indian population of the area, which numbered over 2,000 people at the beginning of the missionary era, died off as a result of susceptibility to European diseases and the culture-shattering impact of the Jesuit, Franciscan, and Dominican missionaries (Aschmann, 1959). The present inhabitants are of mixed ancestry and are descendants of immigrants who came from the Mexican mainland in the early 1800's following the abandonment of the missions.

Mulegé, with a population of approximately 1,000 inhabitants, is the only town in the mapped area It is situated mostly on a stream terrace about 50 feet above the head of a two-mile-long, narrow, and very shallow estuary in Arroyo de Santa Rosalia at the northwest end of Concepcion Bay Date palm groves and small irrigated plots of semi-tropical fruits and vegetables line the narrow valley below the large, warm spring, one-half mile upstream from the town At this spring is a dam and a mission built in 1766 by Jesuit Padre Escalante. The original mission was built here in 1705 on the site of an Indian rancheria called Caamanc-ca-galejá (Gerhard and Gulick, 1958, p. 123). The large shell heaps found near the coast suggest that this area has a long history of habitation.

The main businesses of Mulegé are based upon dates and tourists For the latter there

are resort lodges, small plane landing strips, and commercial air service from Tijuana to Mulegé by Servicio Aereo Baja, S.A

The main road in this area is the very rough Tijuana–La Paz road, which passes through Mulegé and skirts the west and south shores of Concepcion Bay before continuing southward. A very rough truck road branches off this main road, goes up the east side of the bay, and cuts across the northern end of Concepcion Peninsula to the abandoned Gabilán manganese mine on the Gulf coast. The only other significant road serving the mapped area goes from the main road to Rancho San Nicolás, which is on the Gulf coast just south of Concepcion Peninsula.

The area outside the city of Mulegé is very sparsely inhabited by families who live in thatch huts, raise goats and a few cattle, pigs, and chickens, and do some fishing The main income outside of Mulegé is provided by sale of goat meat and cheese, shark meat, and conch shells. The sharks are caught during the winter and salted filets (sold as cod) are shipped to other parts of Mexico through a cooperative. There is some shrimp fishing during the winter and spring, and from May through September sea turtles are harpooned on a small scale. Considering the abundance of fish along the Gulf shores, very little commercial fishing is done.

Mulegé offers primary education, and there is a one-room school at San Nicolás, but children must go elsewhere if they wish to attend high school.

Previous Work

The most important previous geological work was done by Carl H. Beal, who, during his 1921 pack train reconnaissance of Baja California, mapped the geology and outlined the stratigraphy of the entire peninsula He published his report and geologic map in 1948 However, in the area of the present report, Beal had time for only a general look while passing along the west shore of Concepcion Bay, as William Gabb had done in 1867 (published by Browne in 1869).

James A Noble studied the Gabilán manganese mine during World War II and in 1950 published a report and sketch maps of the northern tip of Concepcion Peninsula. Previous notes on this mineral deposit had been written by Edward Halse in 1892, H V Wallace in 1911 and 1916, and by C A McQuesten in 1916.

Present Work

The field work for the present study was done between January 20 and April 16, 1964 A base camp was established at Rancho Salto on Concepcion Peninsula, and arrangements were made to receive supplies and mail by sailboat. An International Travelall with four-wheel drive was provided by the Belvedere Scientific Fund. Work away from the roads was on foot and was supported by a three-burro pack train. Elevations were obtained by using a pocket barometer in the field with readings adjusted to sea-level readings and to a reference barometer monitored at a ranch house at Coyote Bay Air photographs obtained from the Mexican Army through the Instituto de Geología aided immeasurably in the field work.

STRATIGRAPHY

General Statement

The basement complex in the area consists of Cretaceous granodiorite and quartz monzonite with small inclusions and pendants of older schists. Unconformably

overlying the basement complex is an approximately 13,500-foot conformable sequence of late Oligocene and Miocene volcanics and interbedded clastics previously called the Comondú Formation. It is proposed here to call this the "Comondú Group" and subdivide it in ascending order as follows the Salto Formation, which consists of about 1,000 feet of red, cross-bedded sandstone and interbedded tuffs; the Pelones Formation, at least 6,000 feet of agglomerates, tuffs, and basaltic flows; the Minitas Formation, 0–500 feet of conglomerates; the Pilares Formation, about 300 feet of scoriaceous basalt; the Hornillas Formation, about 500 feet of coarse, tuffaceous conglomerates, and the Ricasón Formation, approximately 5,000 feet of agglomerates, tuffs, and basaltic flows.

The basement complex and the Comondú Group have been intruded by gabbro stocks and numerous associated diorite dikes and subsequently by a large tonolite stock. Locally, overlying these older rocks are veneers of Pliocene coquinas, marls, and sandstones, Pleistocene stream terrace gravels, and more recent dune sand and alluvium

Basement Complex

A peneplaned granitic batholith underlies the area but is exposed only in the south-central and west-central parts of Concepcion Peninsula Thin-section studies showed these granitic rocks to range from granodiorite to quartz monzonite. The minor minerals are sparse and consist of biotite, hornblende, magnetite, and rare titanite. Biotite extracted from this basement granitic rock was dated by the potassium-argon method as 78 4 ± 2.8 m y. (late Cretaceous). The batholith is cut by a few aplite dikes and numerous pegmatite dikes; the latter locally show a graphic texture. Epidote is in places a late, fracture-filling additive, especially associated with the pegmatites.

Dark gray, biotite-rich schist and minor outcrops of diorite are present in the batholithic rocks as inclusions and small pendants. Some of the "granite"-schist contacts are sharp, but locally, the schist grades into the "granite" through a 10- to 20-foot alternately light- and dark-banded schistose zone. There is an obvious correlation between the foliations of the schist and directional features in the granitic rock such as the orientation of crystals in gneissic streaks and the orientation of schistose inclusions and stringers.

The granitic rock is deeply decomposed. Its outcrops are hilly lowlands, and where capped by more resistant Comondú beds, the granitic rocks form steep, fast-eroding slopes.

Comondú Group

Salto Formation. Somewhat over 1,000 feet of red, cross-bedded, tuffaceous sandstone with interbedded light-colored tuffs unconformably overlie the basement complex It is here proposed to call these beds the Salto Formation and to designate as type section its exposures along the mountain front just north of the mouth of Arroyo Amolares, approximately 2 miles north of Rancho Salto in the west-central part of Concepcion Peninsula The contact of this formation with the overlying Pelones Formation is arbitrarily designated as the base of the lowest significant bed of agglomerate.

In general, the contact with the underlying basement complex is even and the basal beds of the Salto Formation are only slightly conglomeratic, with scattered subangular, fresh granitic pebbles and a few fragments of schist, both reworked from the base-

ment complex Locally along this contact, however, there are cross-sectional exposures of buried, shallow stream channels containing granitic boulders.

The sand grains of the Salto Formation sandstones are mostly quartz, very fine to medium grained, and subangular to subrounded. A few grains are well rounded and frosted The grains are stained with hematite as is the tuffaceous cement. The permeability of the sandstones is high to practically zero and varies inversely with the content of tuffaceous and ferruginous cement. The cross-bedding is on a fairly large scale, and generally of deltaic type (see Frontispiece). The foreset beds were originally inclined northeastward Near the mouth of Arroyo Amolares Canyon small-scale subaqueous slump structures contort the cross-bedding and indicate slumping toward the northeast No fossils have been found in the Salto Formation

Tuff interbeds increase in number and thickness upward in the Salto Formation Most are off-white, but others are light reddish gray, chocolate gray, or rarely, light greenish gray. One 30-foot tuff bed consists in its lower half of bulbous tuff "pillows" about 4 to 8 inches in diameter Biotite from one of the tuff beds in the upper part of the Salto Formation was dated by the potassium-argon method as 28.1 ± 0 9 m.y. (late Oligocene).

The Salto Formation sandstone is slightly friable but some of the tuff beds are well indurated and quite resistant to erosion; therefore, outcrops of this formation form a hilly, cliffy terrain with steep, locally benched slopes and deep canyons.

The lithology of the Salto Formation varies laterally Southward, within a few miles of the type section, it becomes noticeably more tuffaceous, and a few miles to the north it apparently grades into agglomerates like those of the overlying Pelones Formation.

Pelones Formation Conformably overlying the Salto Formation are over 6,000 feet of agglomerates with interbedded basaltic flows, minor tuffs, and rare conglomerate and tuffaceous sandstone beds It is proposed here to call these beds, which crop out over most of the Concepcion Peninsula and along the west shore of Concepcion Bay north of Cerro San Pedro, the Pelones Formation after its outcrops in a dark, irregular cockscomb ridge called Los Pelones, 1.5 miles north of Rancho Salto in the west-central part of Concepcion Peninsula

It was not possible to measure a section of the Pelones Formation because of faulting, great thickness, and lack of key beds The proposed type area is the central part of Concepcion Peninsula eastward from Los Pelones Ridge. The thickness in the type area, although unmeasured, is much greater than the estimated 4,000 feet in a somewhat faulted section near Rancho San Nicolás at the south end of Concepcion Peninsula.

The contact with the underlying Salto Formation is generally even and sharp. Locally, however, load-casting "dikes" and other more irregular protrusions of the underlying reddish tuffs of the Salto Formation extend as much as 10 feet up into the dark gray agglomerates of the overlying Pelones Formation Conformably above the Pelones Formation in the northern part of the mapped area are conglomerates of the Minitas Formation In the southern part of the area, where the Minitas and Pilares Formations are not differentiated from the Pelones Formation, the overlying beds are the conformable, thick, coarse conglomerates of the Hornillas Formation

The agglomerates making up the bulk of the Pelones Formation characteristically have a dark reddish gray or brick red or pale greenish tuffaceous matrix enclosing fragments of andesite and basalt porphyries of varying shades of gray (mostly light gray) and fragments of light-colored tuffs. Most of these fragments are 0 25 to 4 inches

in maximum dimension but fragments up to 18 inches are not uncommon. In many places, however, are found occasional fragments, two, three, or even five feet in maximum dimension Most are angular but locally these fragments show considerable rounding Reaction rims or weathering rinds on the fragments were not noted Thin sections of these agglomerates showed about 50 percent glass, 40 percent oligoclase (An_{17}?) crystal fragments with very indistinct outlines, and about 10 percent augite, partly in euhedral crystals Locally there are interbedded lenses of conglomerate and reddish tuffaceous sandstone.

The upper part of the formation in the northern and central parts of Concepcion Peninsula consists of indistinctly stratified, dark gray, aphanitic basalt porphyry with reddish phenocrysts of hematite after augite and olivine. Thin sections of these basalt porphyries consisted mostly of plagioclase (An_{33-60}) with minor hematite phenocrysts after pigeonite, augite, and olivine

In the southeastern part of Concepcion Peninsula the Pelones Formation consists of interbedded agglomerates, conglomerates, and basaltic flows which locally display scoriaceous pillows. Some of these conglomerate beds are apparently tongues from the Minitas Formation farther north, and some of the scoriaceous pillow basalts are tongues from the Pilares Formation which overlies the Minitas Formation

Minitas Formation. Along the Gulf coast in the east-central, northeastern, and northwestern parts of Concepcion Peninsula, the Pelones Formation is conformably overlain by roughly 100 to 500 feet of coarse, tuffaceous conglomerate Locally at the base there are up to about 150 feet of brightly colored, mostly yellowish gray, gypsiferous tuffs. This tuff-conglomerate sequence is here called the Minitas Formation after Arroyo de las Minitas in the northeastern part of Concepcion Peninsula The type section is designated as 0 25 mile south of and parallel with the general course of the lower portion of Arroyo Minitas.

West of Concepcion Bay, the Minitas Formation crops out north of Cerro San Pedro. Near Mulegé, only yellowish gypsiferous tuff and gypsum are present; the conglomerate is missing

The conglomerate is made up of subrounded pebbles and cobbles with scattered boulders up to 2 feet in diameter. These clasts are all from volcanics like those of the underlying Pelones Formation except for rare granitic cobbles like those of the basement complex In general, the clasts are rather fresh. However, they are partially decomposed in the caliche-cemented, basal 5 feet of an isolated outcrop of this conglomerate which caps a ridge near the northwest tip of Concepcion Peninsula At this outcrop, the clasts in the basal zone are from varicolored flows and tuffs, while those in the upper part are practically monolithologic light gray to light tan basalt porphyry with cream-colored, lath-shaped phenocrysts of plagioclase Just south of Arroyo Coloradito, the conglomerate of the Minitas Formation consists of a tuffaceous, light brown, medium- to coarse-grained sandstone matrix with subrounded clasts up to 18 inches in maximum dimension. These clasts are composed of grayish to reddish gray basalt porphyry and reddish brown, vesicular and amygdaloidal basalts. Manganese veins occur in conglomerates of the Minitas Formation at the Trinidad Prospect about 1 mile south of the mouth of Arroyo Minitas

Pilares Formation. Locally along the Gulf coast in the northeastern part of Concepcion Peninsula, the Minitas Formation is conformably overlain by up to 300 feet of dark gray, scoriaceous to dense, aphanitic basalt and basalt prophyry here named the Pilares Formation after Punta Pilares near the northeastern tip of Concepcion Penin-

sula. The type section is along an east-west line to the Gulf coast across the top of the hill just north of the site of the abandoned mill at the Gabilán mine. This formation hosted the important manganese veins at the Gabilán mine.

Thin section studies of Pilares lavas showed 65 to 75 percent plagioclase (An_{56-68}), 15 to 20 percent augite, and 10 to 15 percent magnetite (?).

Hornillas Formation. Conformably overlying the Pelones Formation in the southern part of Concepcion Peninsula and occurring in isolated fault blocks along the western mountain front of this peninsula are 400 to 500 feet of coarse, tuffaceous conglomerate, here named the Hornillas Formation. The type locality is the almost vertical, 300-foot cliffs formed by this conglomerate on the left bank of Arroyo San Sebastián, about 2 miles southwest of its mouth in the south-central part of Concepcion Peninsula.

The conglomerate generally forms moderate slopes. Its clasts are all of volcanic origin, are well rounded to slightly angular, and range in size from pebbles to 3-foot boulders. At the type locality the matrix is pale brownish gray sandstone, very tuffaceous toward the base, and the clasts are of dark gray, reddish gray, or light brown vesicular and/or amygdaloidal basalts or basalt porphyries except for a few of light-colored tuffs. Of 22 pebbles taken at random from a small, typical exposure of this conglomerate near Arroyo Cardoncito, nine were gray, reddish gray, or light brown basalt porphyries, six were scoriaceous, amygdaloidal, or vesicular basalt, four were classed as gray or brownish gray gabbro dike rocks, two were tuffs, and one was a non-porphyritic gray basalt.

A thin basalt flow, similar to those in the underlying Pelones Formation, is interbedded in the conglomerates near the base of the Hornillas Formation at the type section.

Ricasón Formation. Conformably overlying the Hornillas Formation are several thousand feet of interbedded dark gray, brown-weathering basalt flows, agglomerates, and light-colored tuffs

This sequence is here named the Ricasón Formation after its occurrence in the vicinity of Point Ricasón on the southwest shore of Concepcion Bay. The type section has not been worked out but should be chosen along the west shore of Concepcion Bay south of Punta Arena.

Outcrops along the south and west sides of Concepcion Bay are entirely of this formation except in the core of the Mulegé anticline north of Cerro San Pedro. The formation is also exposed in the core of the Los Llanos syncline at the south end of Concepcion Peninsula, and in down-dropped fault blocks along the mountain front in the southwestern part of the Concepcion Peninsula The thickness of the Ricasón Formation is unknown It is probably more than 5,000 feet thick

Agglomerates and flow breccias predominate in the Ricasón Formation in the Playa Coyote area and across Concepcion Bay near Ranch Salto on Concepcion Peninsula Basalt flows predominate around the south end of Concepcion Bay and on San Ildefonso Island, just east of the southeast corner of the mapped area.

The interbedded tuffs and bentonitic clays are easily and rapidly eroded. These weak beds encourage landsliding and their alternation with the flows and agglomerates is responsible for the bench-and-bluff profile of most hills carved from the Ricasón Formation. The outcrops of the tuffs and clays are generally thickly covered by scree from the flows and agglomerates

Thin sections of three representative samples of flows and flow breccias showed all to be basalt porphyries consisting mostly of plagioclase (An_{55-58}) with some augite and enstatite Some of the lath-shaped augite and enstatite phenocrysts have been replaced by dull red hematite.

Infierno(?) Formation Interbedded white to light yellowish-gray coquinas, and marly, slightly fossiliferous sandstone of late (?) Pliocene age veneer three extensive and numerous small marine terraces around the periphery of Concepcion Peninsula. The three extensive terraces are at the northern and southeastern edges and the south-central part of this peninsula Several small patches of these beds veneer terraces just north of Mulegé Estuary. These all resemble the late Pliocene Infierno Formation at Santa Rosalia (Wilson and Rocha, 1955), but may correlate with Wilson and Rocha's lower Pliocene Boles Formation or middle Pliocene Gloria Formation, as discussed below.

The following stratigraphic section was measured about 1 35 miles N. 60° E of the house at Rancho Santa Rosalillita in the southern part of Concepcion Peninsula:

	Infierno(?) Formation	*Thickness (in feet)*
7	Sandstone, white to light brown, even-bedded, with lenses of impure, cavernous, sandy, marly, limestone 1 to 2 feet thick	14
6	Sandstone, very pale brown, calcareous, even-bedded	4
5	Marl, white, sandy	2
4.	Sandstone, fine-grained, calcareous, argillaceous, yellowish gray to pale reddish gray, with oysters	12
3.	Coquina, mostly with *Pecten* and oyster shells, with some *Turritella* and other gastropods and "sand dollar" echinoids, in calcareous sand matrix	13
2	Conglomerate, lenticular, with volcanic pebbles 0 25 to 2 inches in maximum dimension	3
1.	Sandstone, highly calcareous and argillaceous, pale reddish gray, grading locally into calcareous mudstone, at 27 and 33 feet above base with 18-inch beds of highly porous to cavernous, white, marly limestone	56
	Total	104

Angular unconformity
Comondú volcanics (base not visible)

The following section was visible in the low sea cliff just north of Arroyo Saucito near Rancho San Nicolás:

		Thickness (in feet)
5.	Soil	1
4.	Interbedded sandstone and conglomerate, cross-bedded, very fossiliferous, with abundant fragments of mollusk (mostly *Pecten*) shells and some "sand dollar" echinoids The cross-beds are foreset beds built southward, apparently by strong, longshore current	7
3	Sandstone, even-bedded, with conglomerate lenses of slightly rotten, volcanic pebbles	2
2.	Marl, gypsiferous, white, very thin-bedded, considerably crinkled from load-casting of overlying sandstone	0–1
1.	Interbedded sand and clay, quite argillaceous at top and becoming "clean" downward, yellowish gray, well-stratified, locally with a few pebbly stringers, with a few scattered mollusk shells One thin zone contains broad, plicated *Pecten* shells 6 inches across and "sand dollar" echinoids 4 inches across and 0 75 inches thick, and a few oysters	7–8
	Total	17–19

Base not exposed.

Some fossils from these beds at the north tip of Concepcion Peninsula were identified for the writer by Leo G. Hertlein as:

Anomia peruviana, d'Orbigny
Conus sp. (cast)
Ostrea angelica Rochebrune
Ostrea heermanni Conrad
Pecten (Pecten) sp.
Pecten (Chlamys) of *C. (C.) corteziana* Durham
Pecten (Euvola) of *P. (E) keepi* Arnold
Turritella (cast)

Hertlein states that, of these, *Ostrea herrmanni* and *Pecten (Chlamys)* and *Pecten (Euvola)* are known only from beds of Pliocene age. Hertlein further felt that the preservation of two other fossils collected from the same place, *Chione californiensis* Broderip and *Turritella gonostoma* Valenciennes, was like that typical of Pleistocene material. Undoubtedly this mixing of Pliocene and probable Pleistocene fossils is due to sloughing from the Pleistocene marine terrace veneer overlying the Infierno(?) Formation at this locality.

Some fossils from Infierno(?) beds at the southwest end of Concepcion Peninsula were identified by Hertlein as:

Hanetia cf. *H. pallida* Broderip and Sowerby
Ostrea herrmanni Conrad
Ostrea aff. *O. californica* Marcon
Pecten (Argopecten) abietis E. K. Jordan and Hertlein
Pecten (Nodipecten) subnodosus Sowerby
Turritella cf. *T. imperialis* Hanna

Of these, all except *Pecten (Nodipecten) subnodosus* and *Hanetia* cf. *H. pallida* are stated by Hertlein to occur only in beds of Pliocene age.

Since the map and diagrams were prepared for this report, Emerson and Hertlein (1964, p 354, footnote) described most of the above "Infierno" fossils as early or middle Pliocene age. This would correlate with the Boleo or Gloria Formations respectively (Wilson and Rocha, 1955). The age and correlation of these Pliocene strata need further attention.

Marine terrace deposits. The numerous terraces bordering Concepcion Bay are described below. These terraces are veneered with fossiliferous gravels. The 35-foot terrace at the north end of Concepcion Peninsula yielded the following fossils which Hertlein identified and, based on their preservation and occurrence, dated as probably late Pleistocene. All are species living in the Gulf of California today.

Arca pacifica Sowerby
Chana cf. *C. frondosa mexicana* Carpenter
Pecten (Nodipecten) subdodosus Sowerby
Spondylus princeps Broderip

Stream terrace deposits. Gravels and sands of local derivation, presumably deposited during the Pleistocene, mantle the stream terraces which are scattered along the present stream courses. These terraces are discussed in more detail below.

Dune sands. Patches of dunes have formed and are still active south of the mouths

of large arroyos where the coastal configuration permits the prevailing north winds to move the sediment-laden water southward, stack the sediment along the beach, winnow out the fines, and drive the sand inland as dunes This has occurred at Punta Gallito, just south of Mulegé.

INTRUSIONS

Gabbro stocks and associated dikes. The rocks of the basement complex and of the Comondú Group, especially the older Comondú formations, are cut by gabbro stocks and numerous diorite porphyry dikes The stocks are found in many places on Concepcion Peninsula. in the north-central part, around the northern and western periphery of the Cerro Blanco tonolite stock; in the east-central part, and along the mountain front north of Arroyo Amolares Thin-section studies showed the rock to be gabbro with basalt and basalt porphyry chilled margins. The plagioclase, which comprised 80 to 85 percent of the rock is An_{50-60} as in the volcanics of the Pelones Formation. The other minerals are augite, hornblende, biotite, and magnetite(?) Most of the augite phenocrysts have been altered to reddish hematite, a characteristic of lavas of both the Pelones and Ricasón Formations.

Agglomerate-filled pipes associated with basalt were seen in the interior of one of these stocks just north of Arroyo Amolares.

Numerous and widespread diorite porphyry dikes up to 40 feet thick and up to 2 miles in length (see Frontispiece) are associated with these stocks The dikes are typically greenish-gray with prominent black hornblende phenocrysts and less prominent plagioclase (An_{45-48}) phenocrysts up to 0.75 inch long. These steeply dipping dikes strike mostly N. 70° W. and N 10° E.

Cerro Blanco tonolite stock and associated dikes The highest peak on Concepcion Peninsula, Cerro Blanco, and the surrounding high and rugged terrain in the west-central part of the peninsula are underlain by a somewhat triangular-shaped, 2 5-mile-wide tonolite stock, here named for Cerro Blanco. The intrusive contact is sharp, and the stock has a thick, fine-grained chilled border which is locally strewn with inclusions from older parts of the section, especially the basement complex A potassium-argon age for a sample from this stock was 20.0 ± 2 0 m y (early Miocene)

The tonolite looks like granite It is very light gray when fresh and light yellowish gray when weathered A study of three representative thin sections showed the mineral composition to be 10 percent quartz, 10–20 percent orthoclase, 57–65 percent plagioclase, 2–5 percent augite, 2–7 percent phlogopite or biotite, and 4–7 percent magnetite(?) The plagioclase is mainly An_{31-35} and very conspicuously zoned.

The surrounding agglomerates of the Pelones Formation are altered near the stock into a rock resembling gabbro porphyry

The stock is highly jointed, and the most prominent set of joints strikes N 10° W and dips 50° W At the surface the tonolite is considerably decomposed, especially near the joints Spheroidal weathering of joint-bounded cubes is well advanced along some high ridges.

A few granitic dikes, lithologically similar but not visibly connected to this tonolite stock, cut the Pelones Formation. One dike was about 2 5 miles to the north of the stock along the head of Arroyo Minitas; one was about 0 5 miles upstream from the mouth of the canyon of Arroyo Minitas de Guadalupe, and one about 3 7 miles to the south of the stock was along the first ascent out of Arroyo Salto on the trail from Rancho Salto

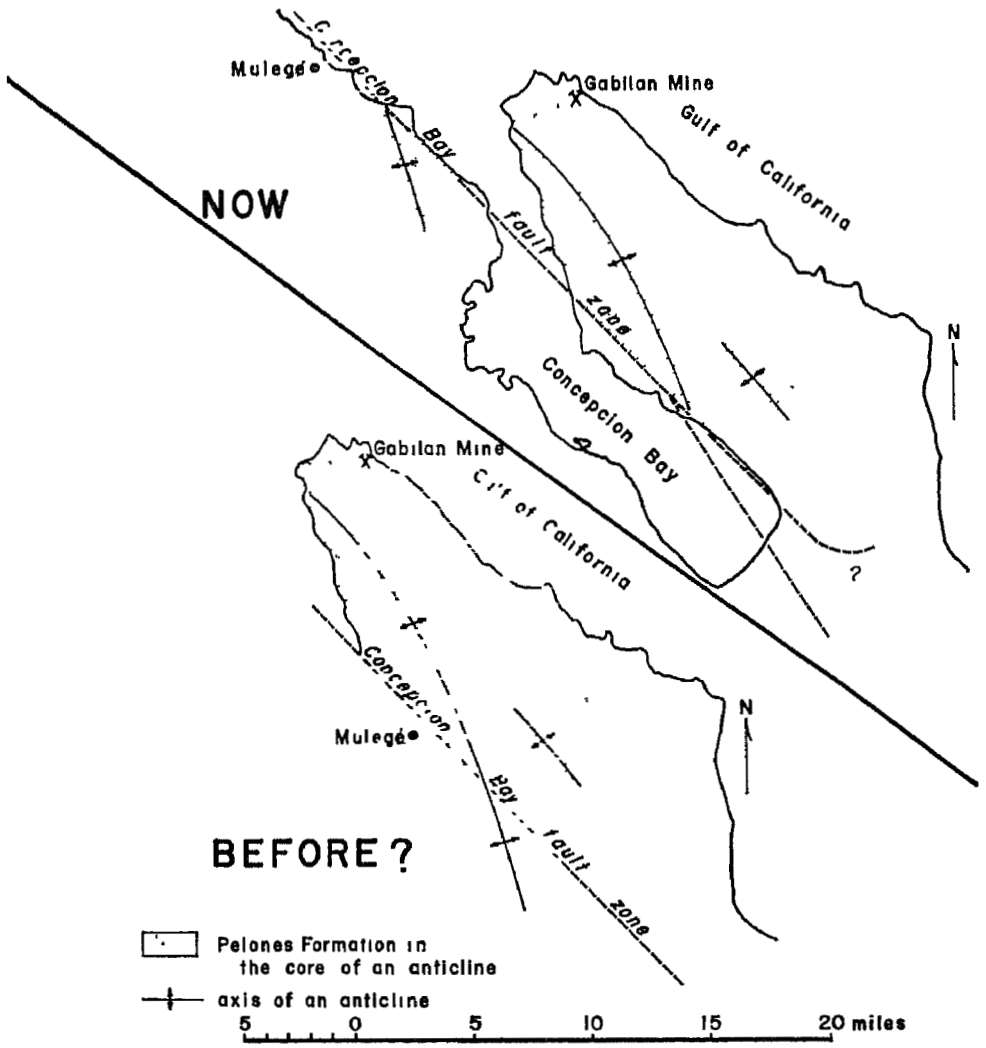


Figure 2. Diagram illustrating possible movement along the Concepcion Bay fault zone

east to Cerro Prieto. The first two contain inclusions from the volcanics and the basement complex. Some of these inclusions are so well rounded that it seemed almost certain on first glance that they were water-worn cobbles.

Pyroclastic dikes. Locally, small, light orange to pink tuff dikes with many angular tuffaceous fragments cut the volcanics of the Pelones Formation.

Dikes cutting the Ricasón Formation. In contrast to the many dikes that cut the Pelones Formation, only two dikes were seen cutting the Ricasón Formation. One is in the northeast face of the hill just north of the house of Bonifacio Diaz at Coyote Bay and the other along the trail leading near the head of Arroyo Ramada west of Coyote Bay. The latter is basalt porphyry (and probably so is the former), consisting mainly of plagioclase (An_{55}) with minor hornblende phenocrysts partly altered to hematite.

STRUCTURE

The structure of the Concepcion Bay Area is characterized by abundant normal and some lateral faulting superimposed on broad, gentle folds. The structure is presented rather schematically in Plate 2 because of the lack of key beds in the very thick volcanics of the Pelones and Ricasón Formations.

The rocks of Concepcion Peninsula form a large anticline with a northwest-southeast axis. Toward the northwest end of the peninsula the axis plunges moderately northwest, at the opposite end it is almost horizontal. What is here called the Concepcion Bay fault zone truncates the southwest portion of the fold.

To the northwest, across the mouth of Concepcion Bay lies another northwest-southeast-trending anticline This is the much-faulted Mulegé anticline. Toward the southeast the axis plunges moderately southeast and at the opposite end it is almost horizontal The northeast portion is truncated by the Concepcion Bay fault zone.

Conceivably, these two slices of anticlines are actually parts of the same structure, with a right lateral offset about 19 miles along the Concepcion Bay fault zone, as suggested in Figure 2 This fault zone delineates the Gulf coast far to the northwest of the mapped area, passes through Concepcion Bay, continues southeastward along aligned valleys 30 miles to Loreto, and again delineates the coast southeastward from there. This Concepcion Bay fault zone is probably an important branch of the San Andreas fault system which has large right lateral displacement in California and is believed to pass through the Gulf of California

The much faulted block to the southwest of the Concepcion Bay fault zone has dropped down and tilted toward this fault (forming Concepcion Bay in an area of low relief) and the block to the northeast (Concepcion Peninsula) has risen and tilted away from the fault.

There is evidence that some of the faulting in the area is recent. Some fault scarps are quite fresh, especially along the Concepcion Bay fault zone, and stream terrace gravels are faulted in an arroyo along a northwest-trending fault, about 1 25 miles west of the mouth of Arroyo San Pedro.

GEOMORPHOLOGY

Terraces and erosion surfaces. The shores of Baja California locally display marine terraces ranging between 20 and about 1,000 feet above sea level (Beal, 1948; Wilson and Rocha, 1955). In the Concepcion Bay area patchy remnants to well-developed terraces range between 20 and 920 feet above sea level They are most prominent at the northern and southwestern shore of Concepcion Bay, and along the shore near Mulegé. The terraces are veneered with well-rounded pebbles and cobbles locally cemented by caliche. The scattered shells on these terraces are of Pleistocene and Recent age (according to Hertlein, Hanna, and Wittich *in* Beal, 1948, p. 28–33).

Scattered shells, seemingly indigenous to the spot, have been reported by Beal (1948) up to 1,800 feet and by Wittich (1920) up to 2,600 feet elevation in other parts of Baja California Beal (p. 32–33) concludes.

Figure 3 An aerial view southward of the south end of Concepcion Peninsula. In the foreground are the promontory Punta Colorado, several marine terraces along the shore, and a lagoon with a salt-encrusted shore. A fault nearly parallels the line of sight and trends toward the south end of Concepcion Bay in the background

The evidence of terraces is so abundant that a Pleistocene submergence of the peninsula to about 1,000 feet can hardly be questioned. As the seashells observed during the present study are widespread and often far from fresh water, the natural camping places of the Indians, the writer favors the view that the peninsula may have been depressed as much as 1,600 to 1,800 feet below sea level. Collections of these shells must be carefully studied, however, before the matter can be properly determined.

Stream terraces are preserved locally along the arroyos. They are best developed near the coast where, in places, they merge with the lower marine terraces.

The accordant mesas at about 3,000 feet elevation southwest of Concepcion Bay are remnants of a very mature, post-Comondú erosion surface undoubtedly developed when sea level was not far below that surface.

Other features. Landslides and very thick taluses have developed on the interbedded agglomerates, flows, and tuffs of the Ricasón Formation along the west side of Concepcion Bay. A large toreva landslide block and its arcuate slip surface are clearly seen where the road starts the ascent southward from Playa Coyote.

In terms of the erosion cycle, the area is in youth after being repeatedly uplifted. Canyons are steep-walled, have high gradients, and numerous dry waterfalls. Some tributary ravines are vertically walled slots as much as 100 feet deep that have developed by selective erosion of a deeply decomposed dike.

The abrupt mountain front along the west side of Concepcion Peninsula is fault-controlled. In many places, nearly fresh fault scraps are exposed along the base of this escarpment, particularly south of Rancho Salto and at the mouth of Arroyo Amolares Canyon. There is a wide and extensive bajada between this escarpment and Concepcion Bay. Near the escarpment a thinly veneered pediment at least 0.5 miles wide was seen in several places south of Arroyo Amolares, whereas over 100 feet of alluvium is exposed adjacent to the escarpment at Arroyo Amolares.

The estuary at Mulegé is a drowned river mouth. Its curious double, very straight channels near the Gulf are probably due to differential erosion along dikes. Dike rock, in line with the northern channel, forms the small hill, El Sombrerito, at the mouth of the estuary.

Spectacular stream piracy was observed from the air just south of Concepcion Bay near Cerro Gigante and also north of Santa Rosalia. In both areas the drainage divide of the Baja California Peninsula is quite close to the Gulf shore. Short, steep, v-shaped arroyos draining toward the Gulf are intermittently beheading the wide, low-gradient upper reaches of the long arroyos draining toward the Pacific.

GEOLOGIC HISTORY

Probable Regional Geologic History

The rocks of the Concepcion Bay area fall into four units. (1) an old beveled granitic basement, which is overlain by (2) about 13,500 feet of volcanics, which are veneered locally with (3) marine sands, limy clays, and coquinas, and locally with (4) alluvium. Judging from these rocks and the information gathered elsewhere by others, the regional history is somewhat as follows.

The granitic basement was formed in the roots of a chain of mountains which stretched along the Pacific Coast of North America. Potassium-argon dating on the basement "granite" near Concepcion Bay indicates an age of 78 million years. All we know about the next 50 million years near Concepcion Bay is that these mountains

were uplifted and beveled nearly flat by erosion Evidently at this time there was no Gulf of California; Baja California was part of the mainland, and this granitic plain stretched far into Mexico

Probably Baja California has been sliding northwestward along the San Andreas fault zone for a long time About 28 million years ago offset of the San Andreas fault by the Garlock–Big Pine fault north of Los Angeles and continued movement along the San Andreas fault apparently caused Baja California to pivot away from the mainland.

The first manifestation of this splitting apart of the continental crust, which was to result in forming the Gulf of California, was the development of a string of elongate rift valleys, a huge discontinuous trench, like that in East Africa today As adjacent blocks of the crust (Baja California and the mainland) moved apart, pressure was released on the hot subcrustal material It expanded and liquified and spasmodically pushed up through the widening cracks to pour out of volcanoes and fissures as lava and other volcanic ejecta

The rift valleys along the crack that was to become the Gulf of California contained lakes, one of them on the site of the future Concepcion Peninsula. Fine quartz sand scoured from the up-faulted granitic plain was carried to this lake by streams flowing from the southwest and was deposited along the abrupt, fault-bounded lake shore forming dunes, beaches, and deltas At various times volcanic ash, spewed from the first volcanoes in the area, fell into the lake Biotite from one of these ash beds was dated as 28 million years old by potassium-argon dating

During the next 15 million years or so the volcanic activity increased and lakes in this rift valley were repeatedly buried by lava and volcanic ejecta There were also several intervals of renewed faulting when the sides of the rift valleys rose and the floors sank abruptly Boulder gravels, derived from the uplifted blocks of volcanic terrain, were deposited along the edges of the rift valleys. Since the climate was arid at that time, these gravels must have been deposited during flash floods

About 10 million years ago, widening of the crack in the continental crust that was to become the Gulf of California allowed the sea to flow into the string of rift valleys which extended into southern California and possibly into northwestern Arizona Circulation of the seawater was at first very restricted, probably confined to an inflow that barely kept up with the rapid evaporation in the arid climate. Evaporites of considerable thickness were deposited locally along the seaway; 400 feet of gypsum on San Marcos Island, hundreds of feet of gypsum near Santa Rosalia, and over 1,000 feet of nearly pure, common salt in northwestern Arizona near Lake Mead

About 8 million years ago the Gulf of California had become wider, and the circulation and salinity of the seawater became normal Limy muds and sands full of shells were deposited in embayments along the margins of the Gulf

That the Gulf of California is still a tectonically active area is witnessed by many things: by numerous earthquakes, and fresh fault scarps; by at least 13 fairly recent marine terraces recording the uplift of Baja California, and by still warm volcanoes and active fumeroles within and along the shores of the Gulf

As Baja California continues to slide northwestward and pivot away from the mainland, fragments are being left behind and they form the many steep-sided islands just off the Gulf shore of Baja California Concepcion Peninsula is in the process of breaking away from the rest of Baja California and has apparently already slipped 19 miles southeastward along the Concepcion Bay fault zone.

TABLE 1

SUMMARY OF THE GEOLOGIC HISTORY OF THE CONCEPCION BAY AREA

Era	Period	Epoch	Group	Formation and Thickness	Millions of Years Ago (Estimated)	Interpretation of Events	Potassium-Argon Age Determination
	Quaternary	Pleistocene and Recent		Mostly erosion	0–2	Earthquakes and recent fault scarps suggest that the Gulf of California is still in the process of formation.	
						Repeated uplift of Baja California was recorded in at least 13 marine terraces Concepcion Bay formed by movements along the Concepcion Bay fault zone	
				Infierno(?) Formation (0–200 feet)	2–4	As Gulf widens, the waters become normally saline, marl and sand were deposited in embayments along the coast	
		Pliocene		Erosion	4–17	Baja California pulling away from the mainland with broad folding and much block faulting, sea enters rift zone (narrow, embryonic Gulf of California), gypsum deposited at Santa Rosalia and salt deposited in Arizona	
				Ricasón Formation (5,000 feet)	17–22	Great volcanic activity with accumulation of agglomerates, lavas, and tuffs	
				Tonolite stock	20	Intrusion of a granitic (tonolite) stock, may be older or younger than the Ricasón Formation but probably is correlative	Stock intruded 20 ± 2 0 m y ago
Cenozoic	Tertiary	Miocene	Comondú	Hornillas Formation (500 feet)	22–23	Rims of rift valley repeatedly uplifted, more conglomerates dumped into rift valleys by streams flowing northwest	
				Pilares Formation (300 feet)	23	Basalt lava poured forth, initially into shallow lakes forming scoriaceous pillows	
				Minitas Formation (500 feet)		Repeated uplifts of the rift valley rims, streams flowing northeastward pour very coarse gravels into the rift valley.	
				Pelones Formation (6,000 feet)	23–28	Volcanoes along the rift zone ejected great quantities of coarse debris and some thick lava flows, numerous dikes and small stocks are intruded	
		Oligocene		Salto Formation (1,000 feet)	28–30	A river flowing northeast formed a delta of cross-bedded sands along the west edge of a rift valley lake, shifting dune sands bordered the lake, later volcanoes that had been forming along rift zone spewed out ash-forming tuff beds in the lake	Tuff bed in upper part of Salto Formation 28 1 ± 0 9 m y old
		Paleocene and Eocene		Erosion	30–75	Great uplift and millions of years of erosion; mountains beveled to plains, the continent begins to crack along the San Andreas rift zone, Baja California begins to pull away from the mainland and move northwest, rift valleys like those in East Africa are first manifestation of rifting	
Mesozoic	Cretaceous unknown, possibly Triassic	Upper		Basement complex	75–100	Mountain making, shale recrystallized to form schist and "granite" in the roots of mountains, most of "granite" intruded upward	"Granite" in basement complex. 78 4 ± 2 9 m y old
					100–200	Mud deposited in a seaway; compacted to shale, some dikes intruded.	

The presumed continuing movement of Baja California away from the mainland along the San Andreas fault zone should be documented Repeatedly this movement, which probably amounts to about two inches per year, can be measured with microwave equipment and possibly with lasers. Such data are needed to help predict earthquakes as well as to understand more about the dynamism of the Earth's interior.

Detailed Geologic History of the Concepcion Bay Area

Basement complex At some time during the Paleozoic Era or early Mesozoic Era, a sequence of muds was deposited, probably in a shallow and slowly subsiding seaway. The weight of subsequently deposited sediments compacted these muds to shale, and they were later intruded by diorite dikes.

Near the end of the Mesozoic Era there was a very important period of mountain building. The shales were folded and recrystallized to schists or metamorphosed even further to form granodiorite or quartz monzonite or other granitic rocks. This "granite" was formed 78 4 ± 2.8 m y. ago according to potassium-argon dating. The schist-to-"granite" transformation is shown by the gradational contacts between granitic rock and schist at several places along Arroyo del Granito in the southern part of Concepcion Peninsula. Much of the granitic rock became mobile and moved upward as magma Hence the more prevalent intrusive contacts between the granitic rocks and schists.

During the next 50 million years, the last part of the Cretaceous Period and the early part of the Tertiary Period, the mountains were eroded and apparently peneplaned. Decomposition of the granitic rocks underlying most of this plain resulted in the formation of a clayey, high-quartz sand.

Salto Formation About 28 million years ago during the last part of the Oligocene Epoch, this peneplaned granitic batholith began to split along what is now the Gulf of California A graben formed locally and streams carried the clayey sand to a lake in the graben. The clay was carried out into the deeper parts of the lake, and the sand was dumped along the lower parts of the streams and along the lake shores where it formed beaches and dunes. Eventually much of this sand was deposited in deltas that formed along the fault-bounded shores of the lake where sediments as much as 1,000 feet thick accumulated as the graben continued to deepen. Volcanoes formed along the fractures as the batholith broke up and with increasing frequency volcanic ash fell into the graben lake to form beds of tuff One tuff bed was deposited from a nuée ardente, which, when it hit the lake, formed tuff pillows much the same as in subaqueous flows of basalt. The southwest side of Concepcion Peninsula coincided more or less with the southwest side of the graben lake. The deltaic cross-bedding and slump structures show northeastward transport.

Pelones Formation. The volcanoes began to spew out angular tuff and chilled pebble-to-boulder-size lava fragments This material formed a layer across the water-saturated tuff in the graben lake and load casting resulted. In places along this abrupt contact the reddish tuffaceous mud was injected as much as 20 feet upward into fractures in the overlying coarse agglomerate. The graben lake was buried as over 6,000 feet of agglomerates accumulated in the central part of Concepcion Peninsula and somewhat less accumulated in the south. Locally, fragments in the agglomerates show rounding which probably occurred in mudflows coming off the volcanoes. Interbedded tuffs in the Pelones Formation record occasional ash falls The thick sequence of basalt in the upper part of the formation apparently formed as a series of thick lava flows.

Intrusions The several gabbro stocks and the many associated diorite porphyry dikes that cut the Pelones Formation and older rocks probably fed volcanoes that were the sources for the pyroclastics and lavas of the Pelones Formation. A few of the dikes are of pyroclastic material, showing a regurgitation or remobilization of a former ash or agglomerate that fell back into the throat of a volcano.

Minitas Formation During a pause in the volcanic eruptions, lakes formed in small basins in the northern part of Concepcion Peninsula and near Mulegé. The climate must have been arid as gypsum was deposited in the lakes along with tuffs formed from ash falls A caliche soil formed on the gravels near the lake on the site of the present northwestern tip of Concepcion Peninsula. A coarse conglomerate, remnants of which are as much as 500 feet thick, was derived from the up-faulted irregular volcanic terrain and was deposited over much of the area by streams flowing mostly northeast, but in the northern part of Concepcion Peninsula flowing south. The finer sediments must have been deposited farther east in a lower basin or graben trough in the present site of the Gulf of California.

Pilares Formation Basalt flows poured out into a lake or other body of water along the eastern edge of Concepcion Peninsula and pillows were formed as the lava balled up in the fine sediments on the bottom of this body of water It was not deep water because these lavas pass upward into scoriaceous and dense basalts within 10 to 40 feet During deposition of the Minitas and Pilares Formations in the northern part of Concepcion Peninsula and the Mulegé area, the southern part of Concepcion Peninsula continued to receive Pelones-like agglomerates interbedded with conglomerates and flows

Hornillas Formation During a time of renewed block faulting and graben formation about 500 feet of coarse conglomerates were deposited at the south end of Concepcion Peninsula. The clasts are derived from up-faulted volcanics, and the shingling of the pebbles shows that the streams flowed generally northeast. The finer material winnowed from this coarse conglomerate must have been deposited in a lower graben basin farther east, in the present site of the Gulf of California.

Ricasón Formation New and possibly old volcanoes poured out about 5,000 feet of basaltic flows, flow breccias, and agglomerates, and also varicolored tuffs Some of the coarsest agglomerate was seen about 10 miles southwest of Coyote Bay. This was probably near one of the many vents. One vent was Pilón de Canípole, south of the mapped area The Cerro Blanco tonolite stock, which cuts the Pelones Formation, may have been intruded either during deposition of the Ricasón Formation or later The potassium-argon date obtained on this stock is 20.0 ± 2.0 m y.

Infierno(?) Formation The volcanoes became quiescent and erosion ensued The Gulf of California apparently formed in the late Miocene and early Pliocene (Rusnak, Fisher, and Shepard, 1964), accompanied, in the Concepcion Bay area, by gentle folding and a great deal of normal and some important lateral faulting During the late(?) Pliocene some parts of the mapped area were downwarped enough to be covered by the waters of the Gulf with resultant deposition of a thin veneer of sands, marls, and coquinas, forming the Infierno(?) Formation.

Quaternary events Faulting, both normal and lateral, has continued to the present The northwest-trending Concepcion Bay fault zone conceivably has a right lateral displacement of about 19 miles This fault also involved thousands of feet of vertical displacement The Concepcion Bay block dropped below sea level and tilted into the fault, and the Concepcion Peninsula block rose and tilted away from the fault

The land areas have risen spasmodically, evidenced by at least 16 levels of marine

terraces, stream terraces, and old erosion surfaces The estuary at Mulegé is apparently due to differential erosion of two dikes and due to a recent worldwide rise of sea level.

The area has had many earthquakes During 1942 workers at the Gabilán manganese mine felt 36 earthquakes, some of which were quite strong On February 29, 1930, while in a boat about 1 mile south of Punta El Pulpito, just south of the mapped area, Guadalupe Ojeda Martinez and his father saw volcanic gas and steam rising out of the sea to a height of about 10 meters, just offshore. This went on for six days Three days later a strong earthquake centered there or near there. Air photos of that area show a fault heading southeastward, out to sea at this point, along the line described by Ojeda.

ECONOMIC GEOLOGY

Manganese

Numerous, thin, pyrolusite veins locally fill north-trending fractures in the Pilares Formation in the Gabilán mine area Small shipments of manganese beach cobbles were made during World War I, and considerable ore, up to about 50 tons per day, mined from open pits, was exported during World War II, especially after a Homestake Mining Company subsidiary, Compañia Mexicana de Manganeso, purchased the property and built a mill The mine closed in February 1947 and the mill was dismantled and shipped to Durango, Mexico All that remains at the site are the concrete-slab foundations of the various buildings and the open pits which have been to a large extent refilled The Mexican Government now has the claims in the national reserve.

In a published report on the deposit, Homestake geologist James A. Noble (1950, p 771–772) states:

> As exploration work proceeded, it became evident that a large tonnage of low-grade ore could be blocked out and mined by cheap methods Preliminary tests indicated that good milling recoveries could be made in spite of many handicaps, but subsequent operations presented many difficulties, and after the close of hostilities a profitable operation of large-scale mining could not be maintained

On p 781 and p 783–785 Noble continues:

> The striking feature of the manganese deposits on Punta Concepcion is the abundance of the pyrolusite veinlets In low-grade ore tiny veinlets up to an inch (two or three centimeters) wide are spaced at intervals of 10 to 15 feet (3 or 4 meters) In average ore the veinlets are of about the same width but closer spacing, and in high-grade ore the veinlets may constitute almost 50 percent of a face Disseminated ore is not common In typical ore the narrow, sharp-walled veinlets of pyrolusite break easily from the basalt and, except for some loss in fines, make almost ideal ore for hand sorting
>
> The manganese phase of the mineralization is the only one commercially important In most of the tiny veins of the mine area, pyrolusite or a manganese oxide mineral very near pyrolusite in chemical and physical properties is the only mineral In some veinlets, however, there are a few gangue minerals, in the following paragenesis (from youngest to oldest) vanadinite, phirolusite, quartz, limonite, dolomite, calcite, aragonite
>
> The veins are believed to be primary veins of hydrothermal origin

Charles F. Park, Jr , visited the Gabilán mine with the writer and found several veins of manganiferous travertine (Mexican onyx) Deposition of the travertine alone in the form of banded, cream and brown dolomite was followed by the deposition of travertine and pyrolusite together, and then by the deposition of pyrolusite alone. Park

suggested that these veins, which are probably related to hot springs, are primary and that the veins of pure pyrolusite, which make up the bulk of the ore and which Noble described, are supergene deposits in later fractures.

In a pit about 25 feet deep at the Trinidad prospect, 4.5 miles southeast of the Gabilán mine, the pyrolusite veins in the conglomerates of the Minitas Formation show the same type of origin. The veins of pure pyrolusite exposed in this pit are superficial; the mineralization decreases markedly or dies out approximately 15 feet from the surface. These veins, which strike north-south and dip 75° W, also continue only a short distance along strike. About 30 tons of ore were taken from this prospect after the pit was dug in June 1942 (Guadalupe Ojeda, personal communication)

The Guadalupe prospect pit, on the opposite side of the peninsula, apparently has only the primary, white calcite-pyrolusite veins and those in sub-commercial amounts. Minor manganese oxide and copper carbonate mineralization occur in a few other localities in the northern part of Concepcion Peninsula (Noble, 1950, fig. 4).

Age of the manganese mineralization. The primary veins at Gabilán mine, Trinidad prospect, and Guadalupe prospect are probably of the same age and origin. The primary, manganiferous travertine veins at Gabilán mine cut the Miocene(?) Pilares Formation, and manganiferous pebbles were reportedly found in the upper(?) Pliocene Infierno(?) Formation at the north tip of Concepcion Peninsula From these relationships it seems logical to assume that the primary mineralization is contemporaneous with the lower Pliocene copper and manganese deposits of the Boleo Formation near Santa Rosalia, 46 miles to the northwest.

Barite

Numerous north-south trending, white veins, mostly of quartz and calcite but locally containing minor amounts of barite, cut the Pelones Formation near the mouth of Arroyo de las Minitas de Guadalupe. These veins are on strike with and are quite similar to the veins at the Guadalupe manganese prospect 0 25 miles to the south, except that the veins in Arroyo de las Minitas de Guadalupe lack pyrolusite.

Travertine (Mexican Onyx)

Minor amounts of travertine occur along fractures on the east and to a lesser extent on the west side of the small hill just west of the mountain front and just south of the mouth of the canyon of Arroyo Amolares in the west-central part of Concepcion Peninsula The rock is quite similar to that in the veins at the Gabilán mine except that there is no associated pyrolusite. About two tons of this cream and light brown, banded rock in blocks up to 3 feet in diameter are lying on the slope at the point indicated on Plate 1.

Groundwater

The only permeable beds in the bedrock sequence are among the red, cross-bedded sandstones of the Salto Formation and among the conglomerates of the Minitas and Hornillas Formations. An economically feasible combination of a large groundwater reservoir in the bedrock and a nearby large area of good soil was sought in vain. The best possibility is drilling for water into one of the small, fault-bounded segments of the Salto Formation near Arroyo Amolares and irrigating the strip of soil-covered land just inland from the maximum saltwater encroachment along Concepcion Bay near

Punta Amolares. The supply of water would, however, soon be depleted because of small reservoir capacity and practically no recharge.

Although there is a possibility that the gravel and sands of the bajadas may locally be productive sources of deep water, shallow holes along the stream beds have been dry. Here also the water level would fall rapidly for lack of significant recharge.

Mulegé and the nearby irrigated fields are supplied with water by shallow wells along the arroyo and by the lukewarm springs below the mission. A considerable flow of unused water from these springs goes into the estuary. Two other warm springs, more or less "on trend" are just offshore in the northern part and just south of Coyote Bay The water in these springs is hot, probably for two reasons: (1) there is deep circulation along a fault, and (2) the area has a higher than normal geothermal gradient

The best spring on Concepcion Peninsula is at Rancho Salto near the fault-bounded mountain front in the west-central part During World War II, it supplied the drinking water for the 100 or so people at the Gabilán mine, where it was hauled by truck. There are three other springs near the mountain front to the north and south: in Arroyos San Ignacio, Amolares, and Hornillas Shallow and generally somewhat alkaline water wells serve the various other ranches in the area including the goat camps at Gabilán mine and in Arroyo Minitas near Cerro Guadalupe.

Tinájas (natural water tanks) are important sources of water locally, such as Tinája San Lino beside Arroyo San Lino near the mouth of Arroyo Granito, and Tinájas Carecól and Copál near the head of Arroyo de San Juan. When visited, Tinája de Trinidad at the Trinidad manganese prospect was dry.

Geothermal Power Possibility

Just south of the southeast corner of the map, in an area of numerous north-south fractures and small-scale, chaotic block faulting, there is a north-south line of fumeroles emitting very hot steam. The quantity of steam reportedly varies with the amount of recent rain. Apparently the rock is quite hot at not very great depth This reservoir of heat, which could be quite large, may prove to be a future geothermal power source, especially if seawater were pumped down into the hot area and then retrieved as steam.

POTASSIUM-ARGON DATES

The following tabulation summarizes reports of analytical work on potassium-argon dating of biotite concentrates from three samples from the Concepcion Bay area, prepared by Geochron Laboratories, Inc.

Laboratory Sample Number	Rock Unit	Location	Age (millions of years)
80476	"Granite" from basement complex.	Stream boulders from large arroyo just north of Rancho Hornillas, west central part of Concepcion Peninsula	78 4 ± 2 8 (late Cretaceous)
80436	Tuff from upper part of the Salto Formation	From canyon wall in Arroyo Salto about ½ mile upstream from canyon mouth at Rancho Salto on Conception Peninsula	28 1 ± 0 9 (late Oligocene)
80489	Tonolite stock	Stream boulders from Arroyo Beatriz near road to Gabilán mine on Concepcion Peninsula.	20 0 ± 2 0 (early Miocene)

ACKNOWLEDGMENTS

This project was conceived and financed by the directors of the Belvedere Scientific Fund, Kenneth K Bechtel, president, and carried out by the School of Earth Sciences of Stanford University The field visits of Walter A Haluk, Charles F. Park, Jr., and Ira and Dorothy Wiggins were both helpful and pleasant. The Instituto de Geología at the University of Mexico obtained and loaned the air photos which served as a basis for mapping; provided Instituto office space for photo geology and map work; provided a willing assistant in field and map work, José Tiribio Meneses Meneses; and arranged for drafting of the geological map The late Carl Fries, Jr of the Instituto was particularly helpful The writer is grateful for the reliable and competent help of Guadalupe Ojeda Martínez who was guide, source of most local place names, burro handler, cook, companion, and occasionally, at his pleasant home overlooking Concepcion Bay, genial host. Cost of printing has been sustained by the Belvedere Scientific Fund.

REFERENCES

Anderson, C A , and others, 1950 1940 E W Scripps cruise to the Gulf of California· Geol. Soc America, Mem. 43.

Aschmann, Homer, 1959 The Central Desert of Baja, demography and ecology Univ. Calif Press, Berkeley and Los Angeles, 282 p.

Beal, C. H , 1948 Reconnaissance of the geology and oil possibilities of Baja California, Mexico· Geol Soc America, Mem 31, 138 p.

Browne, J Ross, 1869 Mineral resources of the States and Territories west of the Rocky Mountains resources of the Pacific slope, New York

Darton, N. H , 1921. Geologic reconnaissance in Baja California· Jour. Geol , v. 29, p. 720–748.

De Cserna, Z , 1961 Tectonic map of Mexico (1 2,500,000) . Geol Soc. America

Emerson, W K and Hertlein, L G , 1964 Invertebrate megafossils of the Belvedere expedition to the Gulf of California· San Diego Soc. Natural History, Trans , v. 13, no 17, pp. 333–368

Emmons, S F , and Merrill, G P., 1894. Geological sketch of Lower California· Geol Soc America, Bull , v 5, p 489–514

Gabb, W M , 1869. Geol Survey California, Reports, v 2.

Gerhard, Peter, and Gulick, H. E , 1958 Lower California guidebook Arthur H. Clark, Glendale, California, 220 p.

Halse, Eward, 1892 Notes on the occurrence of manganese ore near Mulegé, Baja California, Mexico North of England Inst. Min. Mech Eng., Trans , v 41, p 302–307

Hanna, G. D , and Hertlein, L G , 1927 Expedition of the California Academy of Sciences to the Gulf of California in 1921, geology and paleontology· California Acad Sci , Proc , 4th series, v 16, no. 6

Hernandez-Sanchez Mejorada, Santiago, compiler, 1956 Carta geológica de la República Mexicana· 20th Cong Geol. Internat , Mexico (colored map at 1·2,000,000 scale).

Hirschi, H , 1926 Beitrage zur Petrographie von Baja California, Mexico Schweiz, Miner. Petrog Mitt , v 6, p 346–350

McQuesten, C A , 1916 Minas de manganeso en Punta Concepcion, Municipalidad de Mulegé, Baja California. Bol Minero (Mexico), v. 1, p 232–235.

NELSON, E. W., 1921. Lower California and its natural resources; Nat. Acad. Sci., Mem. 1, v. 16, p. 1–167.

NOBLE, JAMES A., 1950. Manganese on Punta Concepcion, Baja California, Mexico. Economic Geology, v. 45, p. 771–785.

RUSNAK, G. A., FISHER, R. L., and SHEPARD, F. P., 1964. Bathymetry and faults of the Gulf of California *in* van Andel et al., Marine geology of the Gulf of California: Amer. Assoc. Petroleum Geologists, Mem. 3, 408 p.

SHREVE, FORREST, 1951. Vegetation of the Sonoran desert. Carnegie Inst. Washington, Publ. 591, 192 p.

WALLACE, H. V., 1911. Deposits of manganese in Lower California. Mining World, v. 35, p. 103–104.

———, 1916. Informe sobre los depósitos de manganeso cerca del pueblo de Mulegé, Baja California. Bol. Minero (Mexico), v. 1, p. 209–212.

WILSON, I. F., and ROCHA, V. S., 1955. Geology and mineral deposits of the Boleo copper district, Baja California, Mexico. U.S. Geol. Survey, Prof. Paper 273, 134 p.

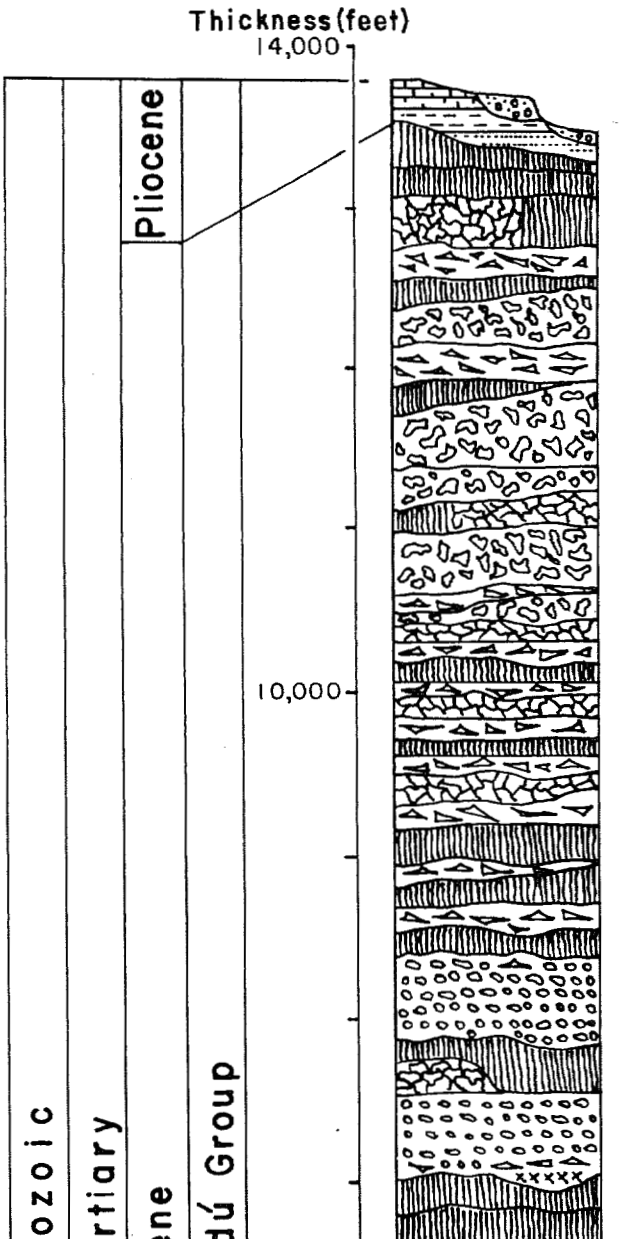
WITTICH, ERNESTO, 1920. La emersion moderna de la costa occidental de la Baja California. Soc. Cient. "Antonio Alzate" (Mexico), Mem., v. 35, nos. 3–4, p. 121–144.

Plate 3

1964-68

Columnar Section–Concepcion Bay Area

Baja California, Mexico



Recent Alluvium
Pleistocene Terrace Gravels

Infierno Fm.– White to pale yellowish gray, very fossiliferous sandstone, marl, and coquina

Ricason Fm.– dark gray, brown-weathering, basalt flows, flow breccias, agglomerates, and light-colored tuffs

Hornillas Fm.– coarse, tuffaceous conglomerate with volcanic clasts

Pilares Fm.– dark gray, scoriaceous basalt, locally with pillows

Minitas Fm.– coarse, tuffaceous conglomerate, locally with a tuff-gypsum sequence at base

Pelones Fm.– andesitic agglomerates with interbedded basaltic flows, minor tuffs, and rare conglomerate and tuffaceous sandstone beds

Tonolite Stock– with few associated tonolite dikes

Gabbro Stock – with associated diorite porphyry dikes

Salto Fm.– pale red, cross-bedded, fine-grained, well-sorted, tuffaceous, sandstone with interbedded, very light-colored tuffs

Basement Complex– peneplaned "granitic" batholith, ranging from granodiorite to quartz monzonite and locally with pendants of biotite-rich schist. Locally the schist-"granite" contact is gradational.

conglomerate
sandstone
shale
marl
limestone
gypsum
lava
lava breccia
lava pillows
tuff
agglomerate
schist
granitic rock
gabbro

Plate 2

Geologic Cross-sections — Concepcion Bay Area

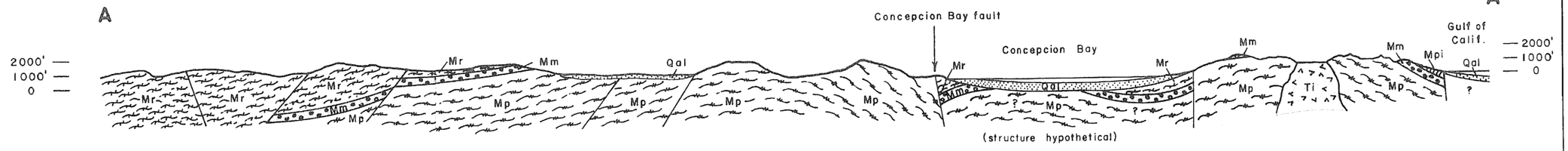
Baja California, Mexico

SW

A

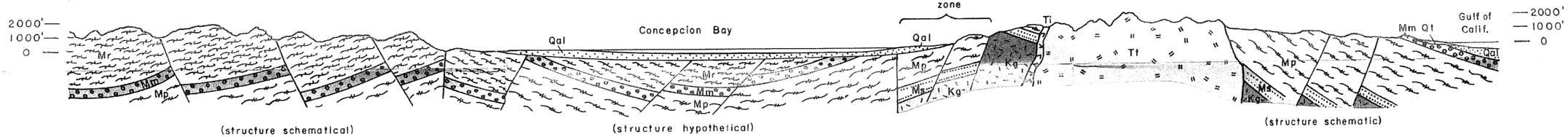
NE

A'



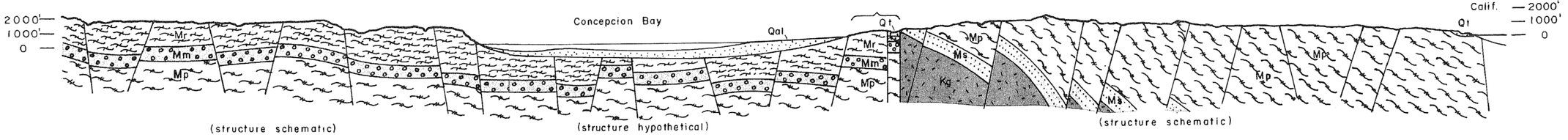
B

B'



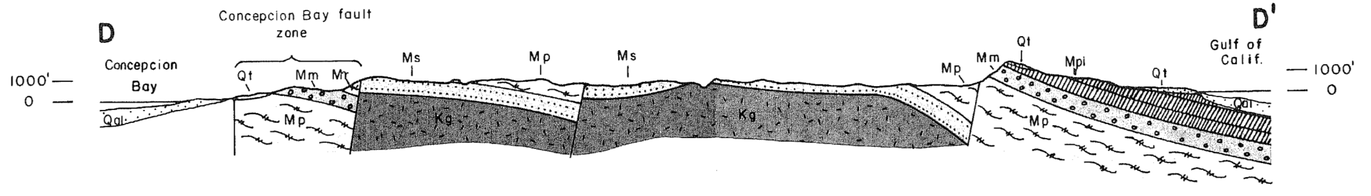
C

C'

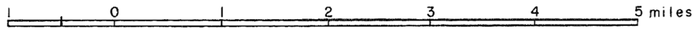


D

D'



Scale



See Plate I for legend

NTRUSIVE ROCKS

Dike

..... (Generally andesite porphyry)

st-Pelones Fm.

Tt Tertiary tonalite

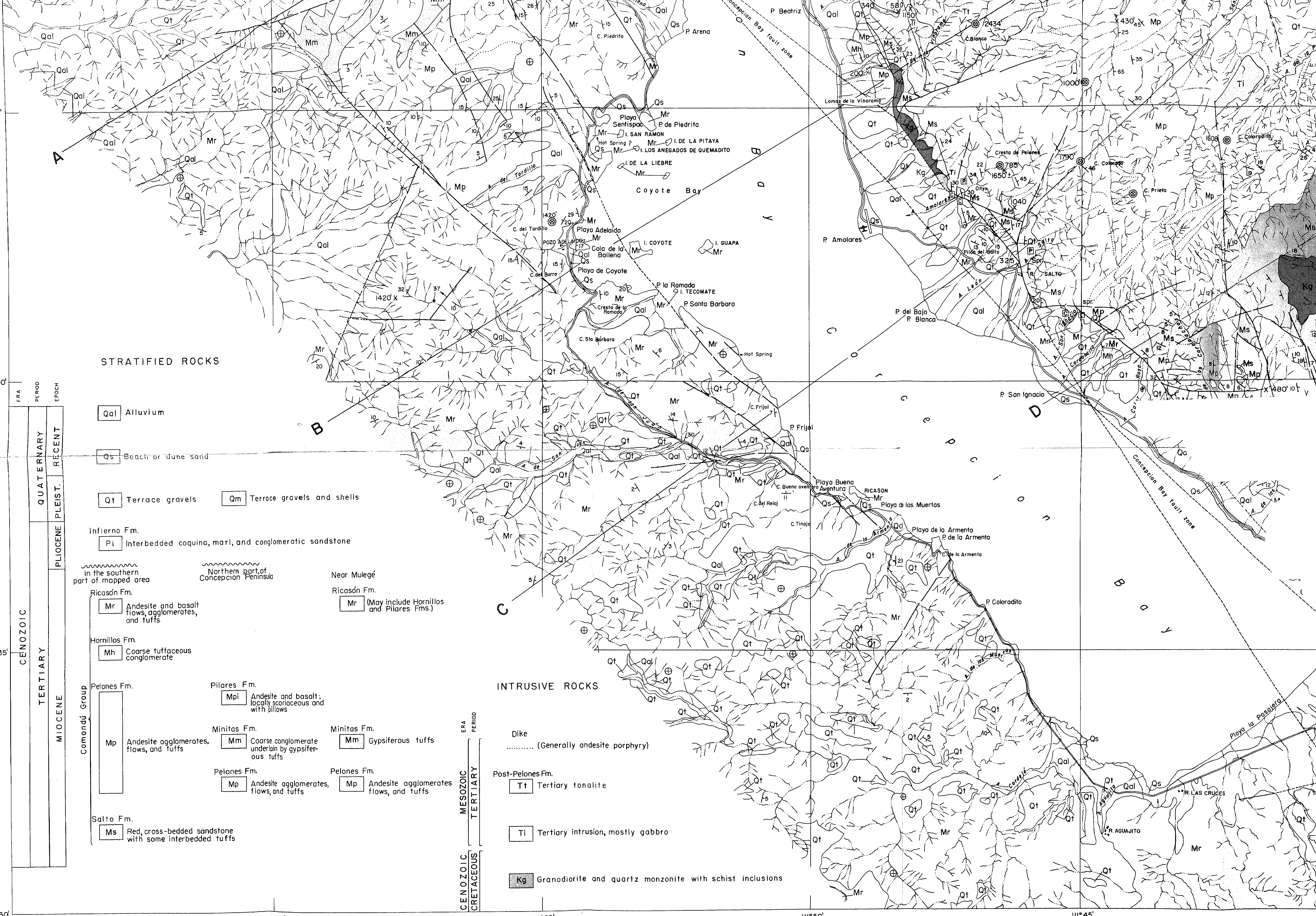
Ti Tertiary intrusion, mostly gabbro

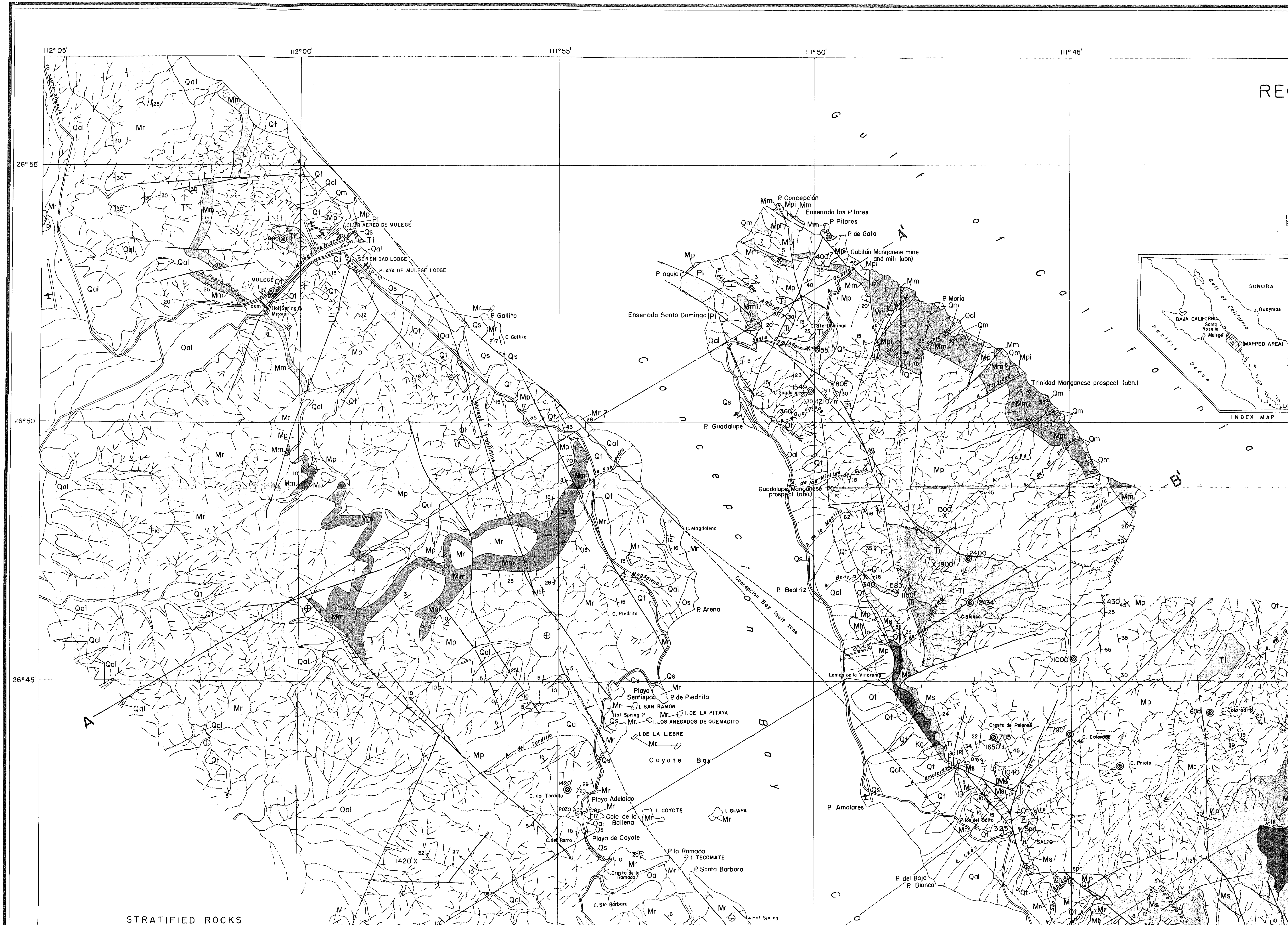
Kg Granodiorite and quartz monzonite with schist inclusions

111°55' 111°50' 111°45' 111°40' 111°35'

26° 45' 26° 40' 26° 35' 26° 30'

Williams & Heintz Map Corporation, Wash., D.C. 20027


STRATIFIED ROCKS
ERA
PERIOD
EPOCH
CENOZOIC
QUATERNARY
TERTIARY
RECENT
PLEIST.
PLIOCENE
MIOCENE
Comondú Group
Qal Alluvium
Qs Beach or dune sand
Qt Terrace gravels
Qm Terrace gravels and shells
Infierno Fm.
Pi Interbedded coquina, marl, and conglomeratic sandstone
In the southern part of mapped area
Northern part of Concepcion Peninsula
Near Mulegé
Ricasón Fm.
Mr Andesite and basalt flows, agglomerates, and tuffs
Ricasón Fm.
Mr (May include Hornillos and Pilares Fms.)
Hornillos Fm.
Mh Coarse tuffaceous conglomerate
Pilares Fm.
Mpi Andesite and basalt; locally scoriaceous and with pillows
Pelones Fm.
Mp Andesite agglomerates, flows, and tuffs
Minitas Fm.
Mm Coarse conglomerate underlain by gypsiferous tuffs
Minitas Fm.
Mm Gypsiferous tuffs
Pelones Fm.
Mp Andesite agglomerates, flows, and tuffs
Pelones Fm.
Mp Andesite agglomerates flows, and tuffs
Salto Fm.
Ms Red, cross-bedded sandstone with some interbedded tuffs
INTRUSIVE ROCKS
Dike
(Generally andesite porphyry)
MESOZOIC
CENOZOIC
TERTIARY
CRETACEOUS
Post-Pelones Fm.
Tt Tertiary tonalite
Ti Tertiary intrusion, mostly gabbro
Kg Granodiorite and quartz monzonite with schist inclusions
26°45'
26°40'
26°35'
26°30'
112°05'
112°00'
111°55'
111°50'
111°45'
A
B
C
D
Concepcion Bay
Concepcion Bay fault zone
Coyote Bay
Playa Santispac
P. de Piedrita
I. SAN RAMON
I. DE LA PITAYA
I. LOS ANEGADOS DE QUEMADITO
I. DE LA LIEBRE
Hot Spring ?
C. Piedrita
P. Arena
P. Beatriz
C. Blanco
Lomas de la Vinorama
C. Coloradito
Cresta de Pelones
C. Colorado
C. Prieto
Onyx
P. Amolares
A. Amolares
Pila del Salto
SALTO
A. León
A. del Tordillo
C. del Tordillo
Playa Adelaido
POZO ADELAIDO
Cola de la Ballena
I. COYOTE
I. GUAPA
Playa de Coyote
C. del Burro
P. la Ramada
I. TECOMATE
P. Santa Barbara
Cresta de la Ramada
C. Sta Barbara
Hot Spring
P. del Bajo
P. Blanca
P. San Ignacio
A. San Ignacio
A. Coloradito
A. de San Juan
C. Frijol
P. Frijol
Playa Buena Aventura
C. Buena aventura
RICASON
Playa de las Muertas
C. del Reloj
C. Tinaja
A. de la Armenta
Playa de la Armenta
P. de la Armenta
C. de la Armenta
P. Coloradito
A. de las Muertas
Playa la Pasajera
A. Cardeli
A. Aguajito
R. AGUAJITO
R. LAS CRUCES



112° 05'
112° 00'
111° 55'
111° 50'
111° 45'
26° 55'
26° 50'
26° 45'
RE
Gulf of California
Concepcion Bay
Coyote Bay
Concepcion Bay fault zone
TO SANTA ROSALIA
MULEGÉ
CLUB AEREO DE MULEGÉ
SERENIDAD LODGE
PLAYA DE MULEGÉ LODGE
Hot Spring & Mission
dam
A. Punta de Agua
Mulegé
P. Gallito
C. Gallito
C. Magdalena
A. Magdalena
C. Piedrita
P. Arena
P. Concepción
Ensenada los Pilares
P. Pilares
P. de Gato
Gabilán Manganese mine and mill (abn)
P. aguja
Ensenada Santo Domingo
C. Sta Domingo
P. María
Trinidad Manganese prospect (abn.)
P. Guadalupe
C. Guadalupe
Guadalupe Manganese prospect (abn.)
P. Beatriz
C. Blanco
Lomas de la Vinorama
Cresta de Pelones
C. Colorado
C. Coloradito
C. Prieto
P. Amolares
A. Amolares
Pilon del Salto
SALTO
A. León
P. del Bajo
P. Blanca
Playa Sentispac
P. de Piedrita
I. SAN RAMON
Hot Spring ?
I. DE LA PITAYA
I. LOS ANEGADOS DE QUEMADITO
I. DE LA LIEBRE
C. del Tordillo
A. del Tordillo
POZO ADELAIDO
Playa Adelaido
Cola de la Ballena
I. COYOTE
I. GUAPA
C. del Burro
Playa de Coyote
P. la Ramada
I. TECOMATE
P. Santa Barbara
Cresta de la Ramada
C. Sta Bárbara
Hot Spring
A
A'
B'
INDEX MAP
SONORA
Gulf of California
Guaymas
BAJA CALIFORNIA
Santa Rosalia
Mulegé
(MAPPED AREA)
Pacific Ocean
STRATIFIED ROCKS

Plate I