GEOG, GEOL, OCEA, BIOL 150

Natural History of San Diego County

BACKGROUND INFORMATION AND HOMEWORK PACKET

Trip 1

By Gary Jacobson

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P. 12 **Plate Tectonic Evolution of Southern California** *(Color and fill in the blanks in the profiles on pages 15 a. and b.)*

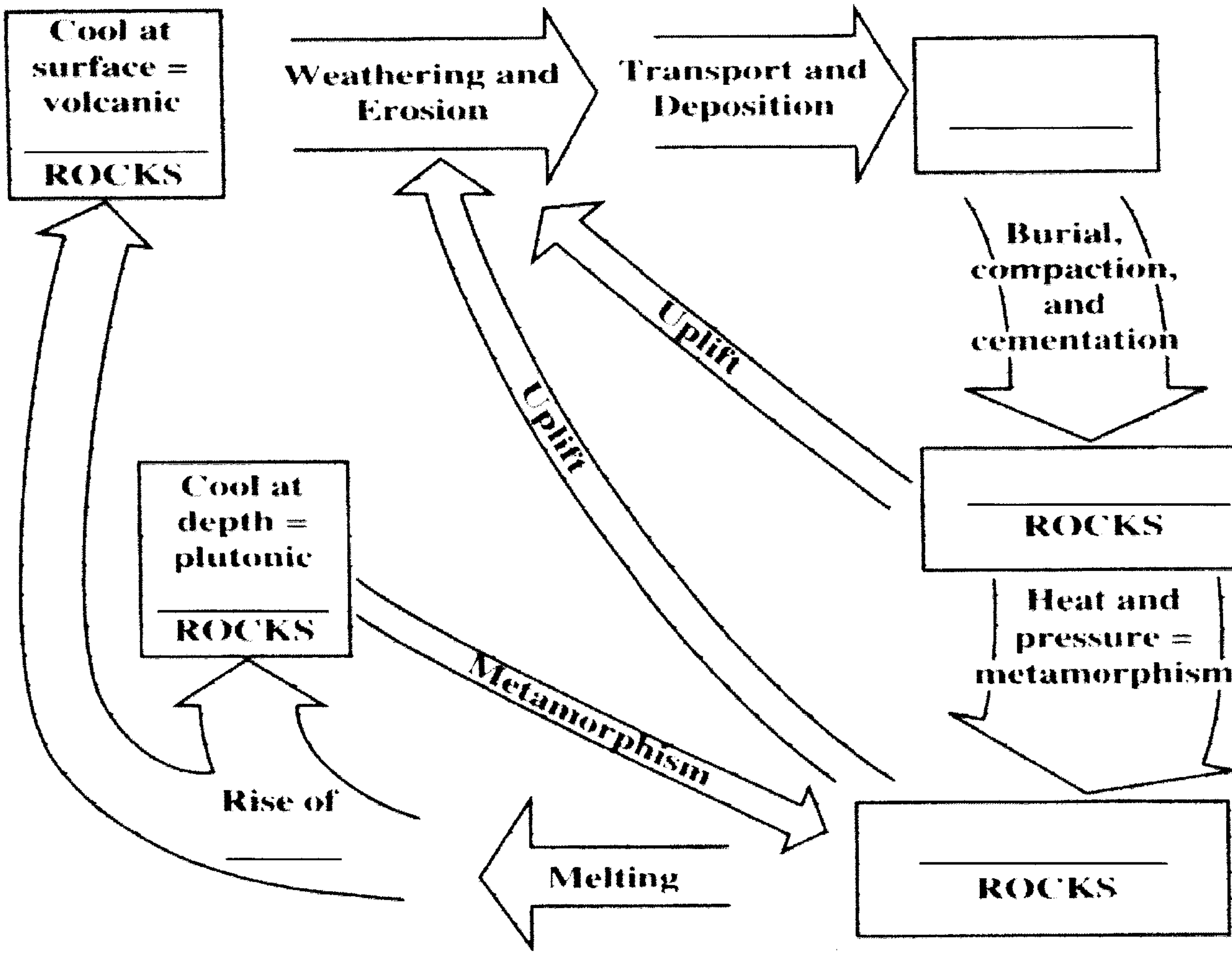
P. 17 **Geology of the Mecca Hills** *(Read and highlight the article and/or make margin notations.)*

A) GEOLOGICAL OVERVIEW

(Complete pages 4 and 5, and read pages 6-11)

Write the following words in the diagram below where appropriate:
IGNEOUS (used twice); SEDIMENTARY; METAMORPHIC; MAGMA; SEDIMENT

Color the diagram using red for igneous, blue for metamorphic and yellow for sedimentary rocks.



The rock cycle. Magma rises; some cools deep underground, forming plutonic igneous rocks, and some cools on the surface, forming volcanic igneous rocks. Rocks exposed at the surface disintegrate and decompose during weathering; loose debris is carried away by the agents of erosion and deposited in topographically low places as sediments, which accumulate and are compressed into sedimentary rocks by the pressure of deep burial. If burial continues, the increasing temperature and pressure transform the sedimentary rocks into metamorphic rocks.

ASSIGNMENT: ***Using Shannon O'Dunn's "Overview of S.D. Co. Geology,"*** (pg. 6)

1) on the profile below, name and label the four fault zones
2) on the profile below, simply label each rock suite
3) using the boxes below as a legend, more thoroughly describe each rock suite

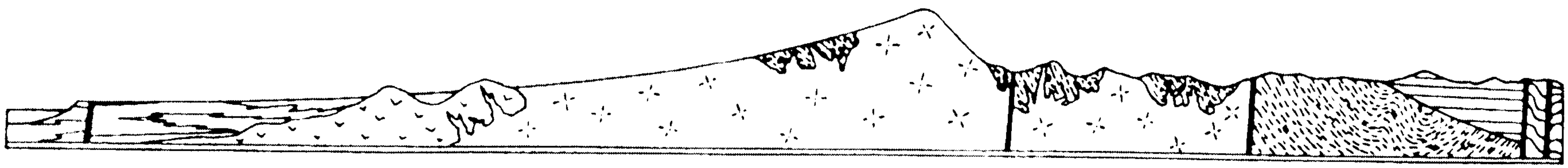
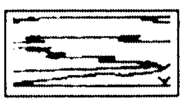
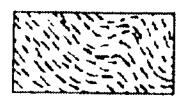
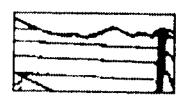
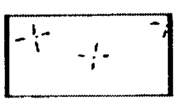


Fig. 1: General Cross-section of San Diego County Geology (looking north)









Overview of San Diego County Geology

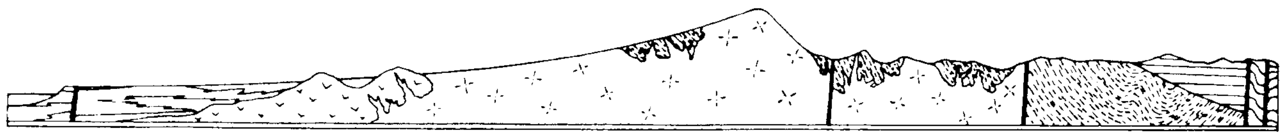
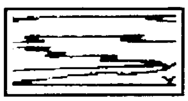


Fig. 1: General Cross-section of San Diego County Geology (looking north)

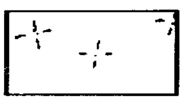
In 1975 the San Diego Association of Geologists created this cross-section (**Fig. 1**) and adopted it as their organizational logo. We will use it as a framework for an overview of San Diego County rock units and primary structural trends.

Six Major Rock Suites, West to East



Suite A.): These are sedimentary rocks which underlie the San Diego coastal plain: in this guide, Cretaceous, Eocene, Miocene, Pliocene, and Pleistocene marine and non-marine conglomerates, sandstones, and mudstones (shales). Formations are the Cretaceous Point Loma (Kp) and Cabrillo (Kp); the Eocene Del Mar (Td), Torrey (Tt),Ardath (Ta), Scripps Canyon (Tsc), Friars (Tf), Stadium (Tst), Mission Valley (Tmv), and Pomerado (Tp); Miocene San Onofre (Tso) and Monterey (Tm); Pliocene San Mateo (Tsm) and San Diego (Tsd); Pleistocene Lindavista (Qln), Bay Point (Qbp), and various quaternary terrace units (Qt).

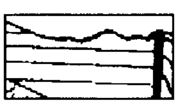
Suite B.): These Jurassic-Cretaceous andesitic rocks are the roots of an Andean-type volcanic chain associated with Mesozoic subduction. They are relatively resistant, and form high areas in the coastal plain and foothill regions. Formation: the Santiago Peak volcanics (Jsp).



Suite C.): This symbol includes a variety of plutonic rocks which are all part of the southern California Batholith, emplaced in Jurassic-Cretaceous time: composition ranges from granite to gabbro, with some highly silicic dikes. General designation is Kg; may be subdivided by rock type, such as Kgr (granitic) or Kgb (gabbroic) plutonic rocks.

Suite D.): These pods of metamorphosed Triassic-Jurassic submarine fan sandstones and shales are suspended in the younger batholithic rocks. They were metamorphosed to high-silica schists by the intruding batholith. Includes the Julian Schist.

Suite E.): Originally sandstone, shale and limestone deposited offshore on the Paleozoic continental shelf, these rocks have been metamorphosed to marble, slate, schist and gneiss by batholithic intrusion in the later Mesozoic.



Suite F.): These sedimentary rocks include marine and nonmarine mud- and-debris-flow breccias, conglomerates, sandstones, mudstones, limestones, and evaporites deposited in the Salton Trough in late Neogene to Recent time. Includes rock units at Split Mtn., Font's Point, and Painted Cn.

Four Primary Structural Features, West to East

The cross-section (**Fig. 1**) shows four fault zones as nearly vertical lines. The Rose Canyon Fault Zone (RCFZ) cuts the coastal plain sediments on the west side; the Elsinore Fault slices through the crystalline basement rocks; the San Jacinto Fault Zone bounds the western side of the Salton Trough; and the San Andreas Fault zone, the official plate boundary in this part of North America, defines the eastern side of the Salton Trough.

All of the fault zones trend NW-SE (**Fig. 2**), and display right slip displacement with offset varying from about 2.5 mi. (Rose Canyon) to 350 miles (San Andreas).

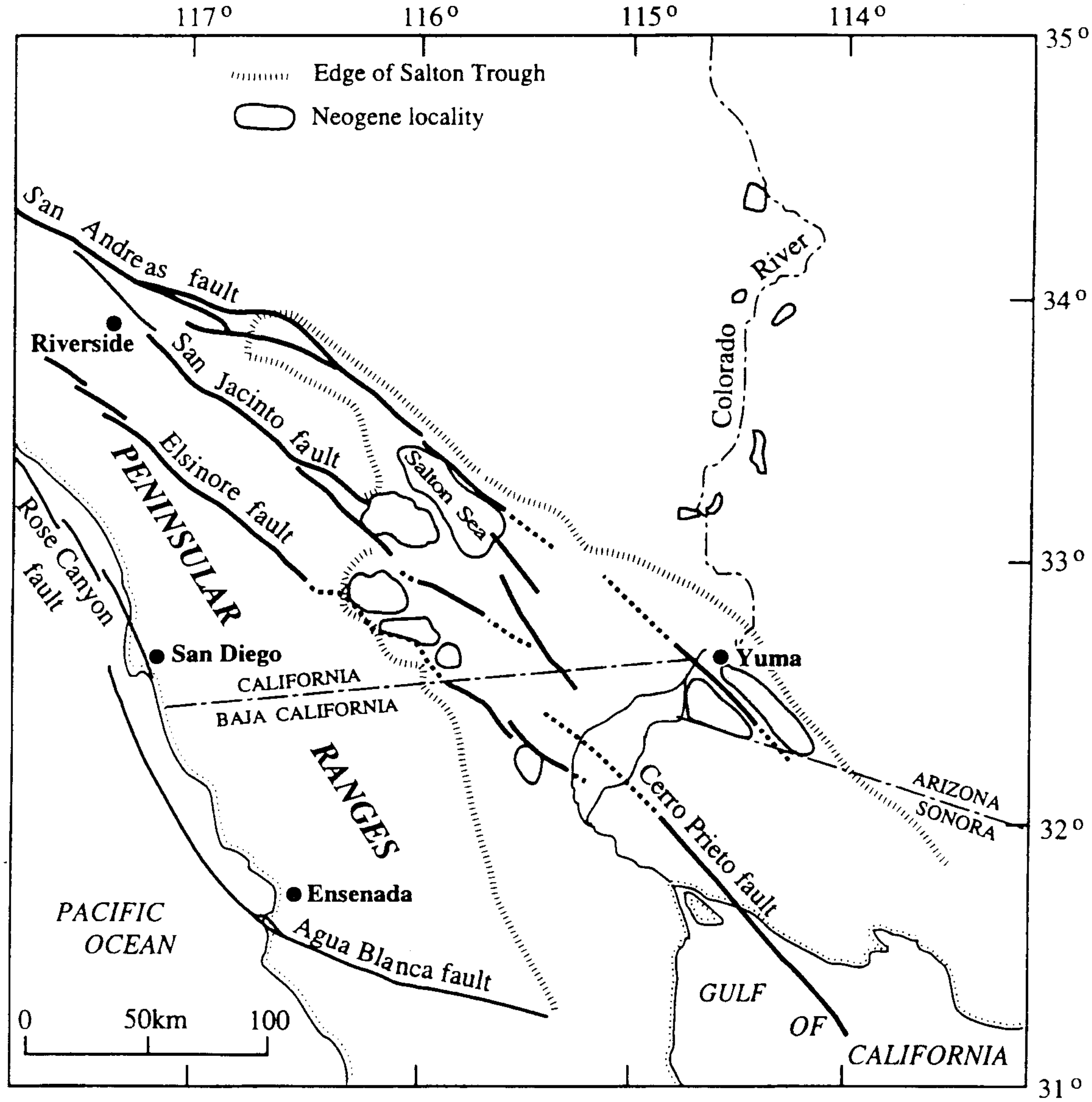


Fig. 2: Map of Major Structural Features, San Diego and Environs (after Abbott, 1997)

Geologic History

The region which is now San Diego County has been adjacent to a continental margin (i.e. coastal) for all of the time represented by rock units in this Field Guide: that is, from the lower Paleozoic to the present. During the *early to middle Paleozoic*, North America was part of Laurussia (or Laurasia), a continental mass which included North America, Europe, Greenland, and much of Asia. San Diego was just a few degrees south of the paleoequator, which cut diagonally through North America from NE to SW.

Active North American plate boundaries at this time were the eastern seaboard, which suffered collisions with island arcs, microcontinental fragments, and western Europe; and another collision-type boundary far to the north. The western edge of the continent was a passive margin, like the eastern seaboard is today; rocks of **Suite E.)**, metasedimentary shelf deposits, were deposited at this time.

In the Devonian, the west coast of North America became an active plate boundary. Subduction was initiated as the Farallon Plate ocean floor moved eastward and plunged under the North American continental mass. This conveyor belt mashed island arcs and continental fragments onto the west coast, creating compressional features (reverse and thrust faults) and uplifted of mountains as far east as central Nevada. By the end of the Paleozoic, the supercontinent Pangaea was fully assembled.

During the Mesozoic, subduction continued to prevail along North America's west coast. Rocks of **Suite D.)**, the Julian schist, are typical offshore deposits of just such an active plate margin. In late *Jurassic-Cretaceous* time, a chain of andesite volcanoes spewed out some of the melt products of subduction, including the prebatholithic metavolcanic rocks, **Suite B.)** which are about 130 million years in age (130 Ma).

Rocks of the *Cretaceous* southern California Batholith, **Suite C.)** above, were emplaced between 120-90 Ma. At about 90 Ma, the subducting Farallon Plate changed to a shallow angle of descent and failed to reach sufficient depth in the mantle for melting to occur. This effectively shut off magma production for the southern California Batholith.

Beginning *about 90 Ma*, erosion began stripping the roof off the batholithic rocks, and debris swept west by streams and delivered to the sea formed mudstone and sandstone of the Point Loma and Cabrillo Fms., the oldest units in **Suite A)**.

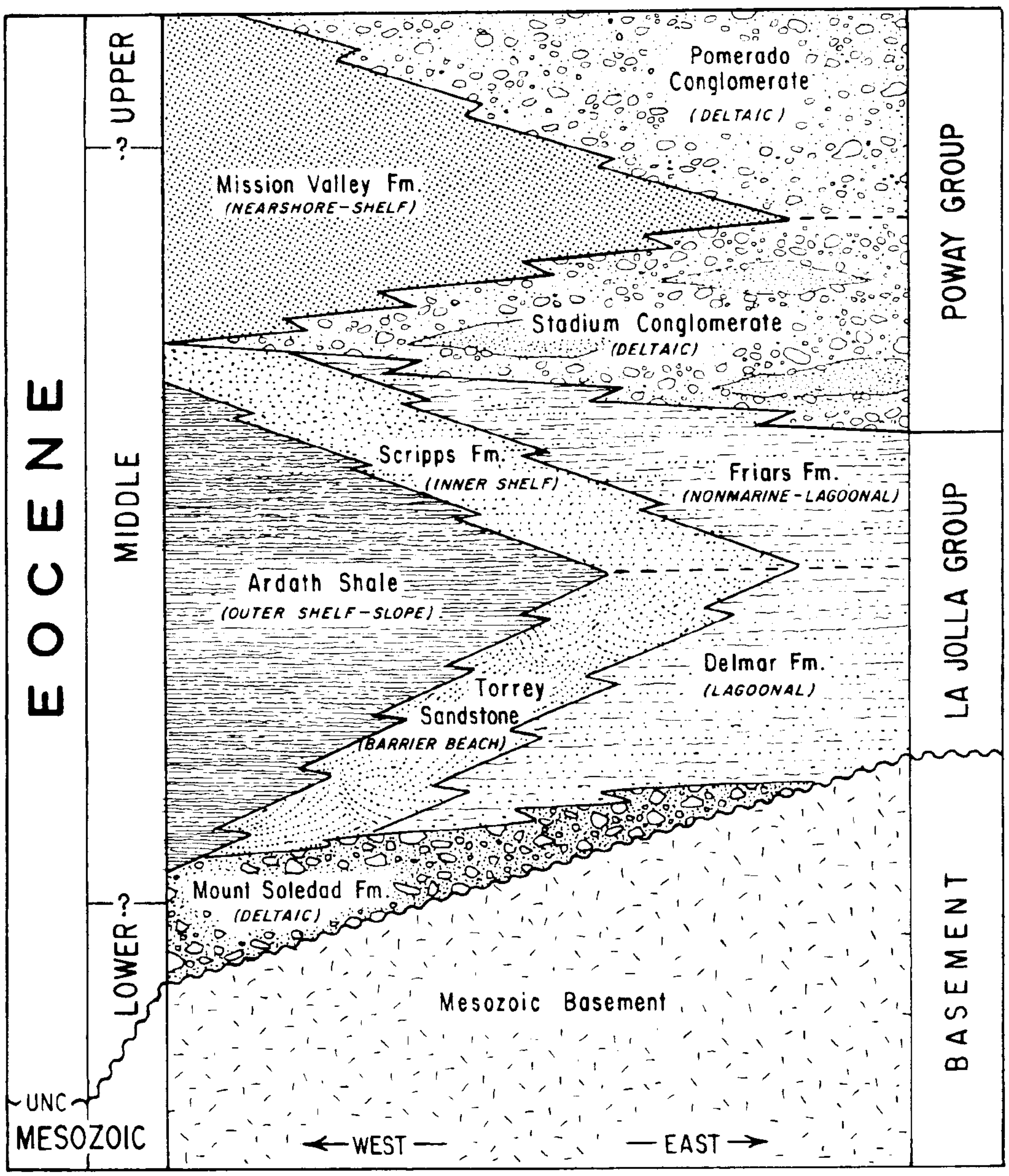


Fig. 3: Eocene Sedimentary Units, San Diego Coastal Plain (John Holden, © 1987)

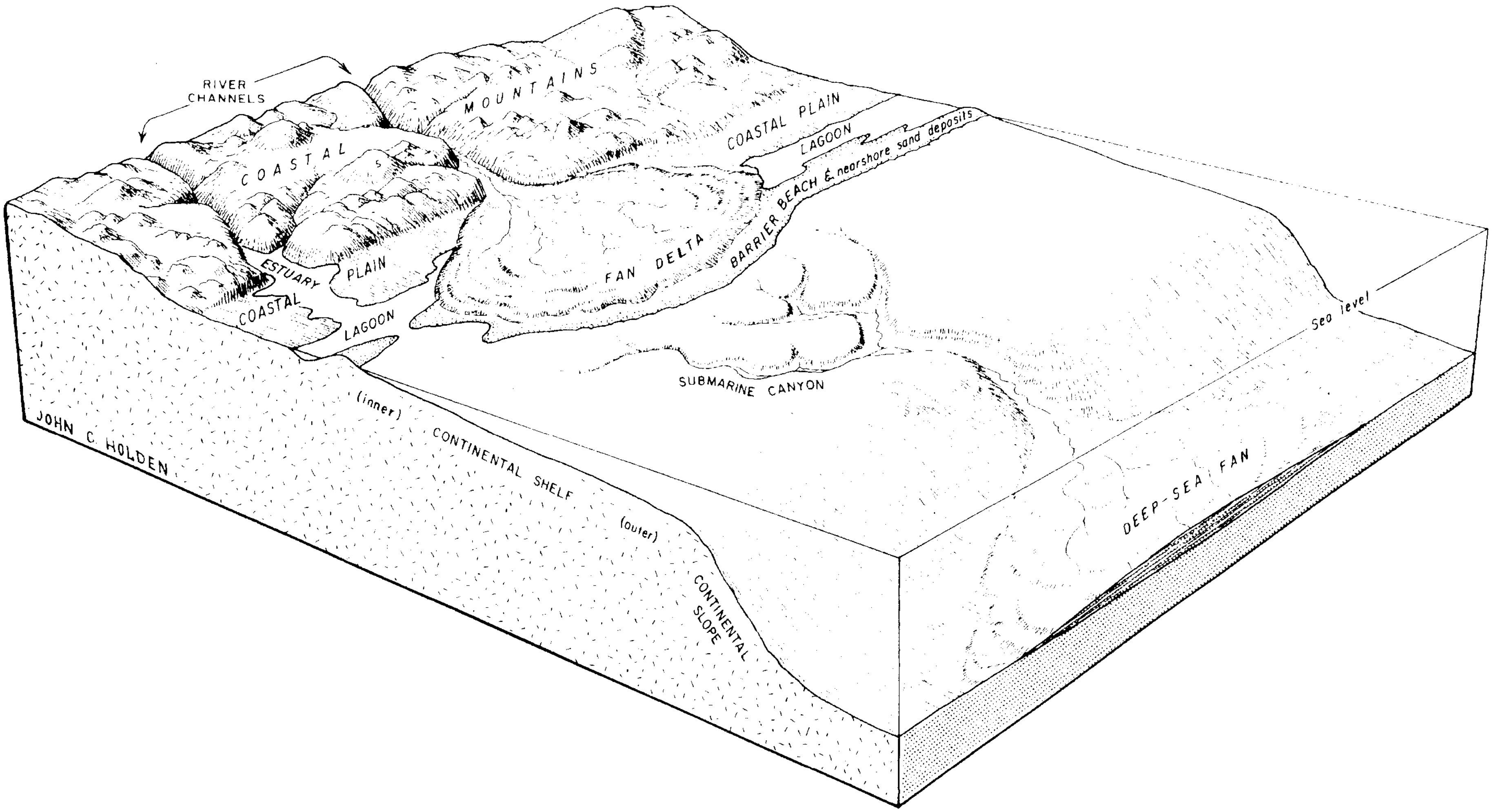


Fig. 4: Depositional Environments of The San Diego Coastal Region in Eocene Time (John Holden© 1986)

The Mt. Soledad Fm. was laid down in the submarine canyon system; it was buried by Ardath Shale continental shelf mudstones, at the same time that lagoonal muds were collecting as the Del Mar Shale, and the Torrey Sandstone barrier beach sands were being deposited. Slightly later in the Eocene, the fan delta crept seaward, contributing sand to the offshore site of the Scripps Fm., while the nonmarine Friars Fm. encroached westward over older units. The great wedges of Stadium and Pomerado deltaic conglomerates and sandstones represent two more seaward growth pulses of the fan delta, separated by a sinking episode which allowed the finer clastics of the Mission Valley marine and nonmarine facies to extend into lower-lying areas.

No record of the *Paleocene or early Eocene* has been found in San Diego, so we don't know whether rocks of this age were created and subsequently eroded, or were never deposited at all. But in the *middle Eocene*, about 50 Ma, a large, well-established fluvial (river) system began flushing coarse clastic debris (cobbles and sand) into the western county (**Fig. 4**). A broad coastal plain was crossed by seasonally torrential river systems which delivered sediment to form the Rose Canyon and Poway groups (**Fig. 3**).

In some coastal regions of southern California, masses of low grade metamorphic schists created by shallow subduction of the Farallon Plate were uplifted in the *Miocene* to create offshore highlands which shed masses of the San Onofre Breccia back toward the continent (part of **Suite A.)** above).

Slightly *later in the Miocene*, the Monterey Shale, in **Suite A.),** was deposited in a shallow continental shelf environment when volcanic ash falling into sea water collected as fine mud layers, and also promoted blooms of planktonic microorganisms which used silica from the dissolving ash for their microscopic shells.

The youngest marine unit in the coastal plain sequence in this Field Guide is the *upper Miocene-lower Pliocene* San Mateo Fm., a coarse, poorly sorted sandstone which poured through steep stream channels into a marine basin created on the downthrown side of the Cristianitos Fault.

In the southern part of San Diego County and Imperial County, tectonic activity relocated in *latest Miocene* time from the coastal region inland, as the San Andreas fault transform plate boundary was born. The Farallon Plate was now completely subducted at this latitude. This allowed the Pacific Plate to come in contact with the North American Plate, capture the Baja California-southern California slice of continent, and drag it to the northwest. This action created the San Andreas and related fault zones, and ripped open the Gulf of California. This movement continues to the present time, the *Holocene*. The other three major fault zones in the region are smaller sister systems to the San Andreas.

Sediments poured into the Salton Trough as it was rending apart, forming alluvial fan deposits, soft lake bed muds, evaporite beds, and occasional catastrophic landslide units. These *Miocene*, *Pliocene*, *Pleistocene* and *Holocene* units are grouped as **Suite F** in **Fig. 1**. They contain many spectacular fossil localities, due to rapid deposition and burial of organic remains, and are dramatically twisted and broken by active tectonism.

During *Pliocene-Holocene* time, geologic activity west of the Elsinore fault was relatively sedate, except for the Rose Canyon fault (below). Some gentle vertical uplift and sinking of coastal regions occurred, along with sea level oscillations controlled by Pleistocene ice sheet growth and decay. These actions caused the shoreline to migrate landward (crustal sinking, glacial melting) or further offshore (crustal uplift, glacial growth).

Thus some stream-eroded features, such as Scripps submarine canyon, extend into the marine realm. *Pliocene* conglomerates and sandstones of the San Diego Fm. (part of **Suite A** coastal plain sedimentary rocks) were deposited in sea level deltas and shallow marine bay settings similar to the modern San Diego River delta and related bay deposits in San Diego and Mission Bays. *Pliocene* streams extending over the coastal plain deposited the reddish brown sandstone and conglomerate of the Lindavista Fm. and other terrace units (Qt), all of **Suite A**, over coastal terraces. A 'bathtub ring' of marine sedimentary rocks, the *Pleistocene* Bay Point Fm., may be found several miles up western river drainages, marking minor periods of incursions of the sea.

The one western structural feature active onshore during *Pliocene?-Holocene* time is the Rose Canyon fault, a small sister fault to the San Andreas. It has been suggested (Kennedy, 1975, and others) that areas west of the fault, including Point Loma and La Jolla, have moved about 2.5 miles north relative to land on the east side of the fault. Squeezing of the land where the fault bends westward at Ardath Road has rotated and uplifted Mount Soledad.

Topographic relief along the fault, earthquake epicenters in San Diego Bay within the last three decades, and what appear to be offset *Holocene* bay sediments, strongly indicate that the Rose Canyon fault zone is still active.

Several investigations in recent years support this idea. Rockwell et al (1991) dug a trench across the major trace of the RCFZ (**Fig. 5**) in the south end of Rose Canyon and determined, via detailed stratigraphic analysis, that at this locality the fault had a minimum of 8.7 meters (+28 ft) of horizontal offset, and a couple of feet of vertical offset, within early Holocene deposits .

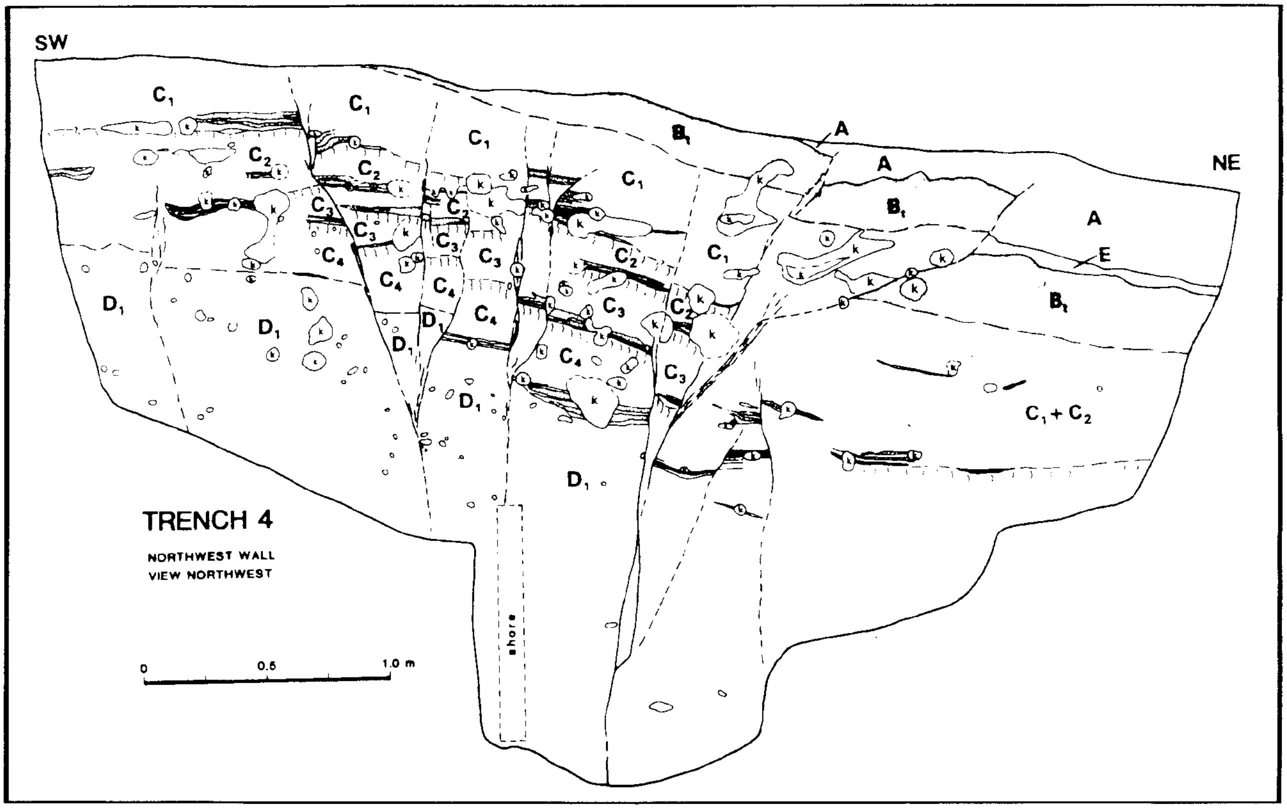


Fig. 5: Detailed Trench Log (note scale) Showing Multiple Fault Offsets, RCFZ

References

Abbott, Patrick L., 1997, *Miocene and Pliocene Sedimentation History, Split Mountain, Anza-Borrego Desert State Park, California*; in *Geology and Paleontology of the Anza-Borrego Region, California*, Field Trip Guidebook, Far Western Section, National Association of Geologists.

Holden, John, 1988, selected drawings relating to San Diego geology, for an unpublished manuscript; © John Holden, all rights reserved. May not be reproduced in any form for any purpose.

Kennedy, Michael P., 1975, *California Division of Mines and Geology Bulletin 200, Geology of the San Diego Metropolitan Area, California*, 56 pages and 6 geologic maps.

Rockwell, Thomas K., et al, 1991, *Minimum Holocene Slip Rate for the Rose Canyon Fault Zone in San Diego, California*, in Environmental Perils, San Diego Region, San Diego Association of Geologists, pp. 37-46.

B) PLATE TECTONIC EVOLUTION OF SOUTHERN CALIFORNIA

On the profiles that follow:

1. Color the rock types as you did on the rock cycle using **red** for igneous, **blue** for metamorphic and **yellow** for sedimentary. The key below will help you determine which color to use for each pattern in the profiles. You may have to do a little research if you don't know what type of rock these are.

	Sandstone, shale, conglomerate		Volcanic
	Limestone		Granite, diorite, and gabbro
	Silty limestone		Basalt and gabbro
	Mostly turbidite		Schist
	Shale		Marble

2. Fill in all the blanks with the information required. (Use the Geologic Time Scale on page 13 and the paleotectonic maps on page 16.)

ERA	PERIOD	EPOCH	IMPORTANT LIFE FORMS	TYPICAL FOSSIL
CENOZOIC	Quaternary Q	Holocene	Existing life forms; man dominates.	
		Pleistocene	Modern man, giant land mammals.	
	Tertiary T	Pliocene	Tool-using primate; mastodons, rhinos, camels.	
		Miocene	Furred marine and grazing mammals, *Homo* ancestors.	
		Oligocene	Primates diversify; terrestrial mammals expand.	
		Eocene	Whales, bats, horses appear; fish, insects common.	
		Paleocene	Large flightless birds, small mammals, corals.	
MESOZOIC	Cretaceous K	66	Abundant gastropods. Dinosaurs climax and become extinct, as do almost all shelled cephalopods. Modern fish expand. Modern echinoderms. First deciduous trees and flowering plants. Terrestrial snails appear. Insects flourish. Calcareous plankton abundant. Placental mammals diversify.	
	Jurassic J	135	Abundant pelecypods, cephalopods, echinoderms. Massive herbivorous dinosaurs on land; carnivorous forms in all environments. Birds debut. Freshwater snails appear.	
	Triassic TR	180	Shelled cephalopods expand and diversify; modern corals and echinoderms develop. Many small, bipedal terrestrial reptiles, including the first dinosaurs. Rodent-like true mammals appear. Coniferous land plants.	
PALEOZOIC	Permian PM or P	230	Diverse reptile popula[illegible]ons develop; amphibians also common. Shallow ma[illegible]ne animals experience many extinctions, including all the trilobites and most molluscs and brachiopods.	
	Pennsylvanian IP	280	Insect populations expand as wetland forests (coal swamps) spread over low-lying areas. Rapid plant evolution; some trees grow to 30 m tall. Coniferous plants appear. Earliest reptile fossils.	
	Mississippian M	310	The "Age of Sea Lilies." Other calcium carbonate secreting organisms abundant, such as planktonic protozoa, brachiopods, corals.	
	Devonian D	345	Corals, fish, cephalopods, brachiopods, trilobites, and gastropods are dominant marine fauna. Diverse land plants; terrestrial arthropods, amphibian vertebrates. Pelecypods enter fresh water.	
	Silurian S	405	Massive coral reefs, large (to 8 feet) arthropod predators, explosive evolution of the fishes. Brachiopods, echinoderms, trilobites, silica sponges are common marine invertebrates. Simple plants invade the land; possible terrestrial arthropods.	
	Ordovician O	425	Trilobites, brachiopods, solitary and colonial corals are common. Cephalopod molluscs become diversified and large (to 20 feet); pelecypod and gastropod molluscs present, but less abundant. Clear evidence of primitive fish in Colorado.	
	Cambrian €	500	All major phyla are represented. All are aquatic organisms. Trilobites, worms, sponges, bachiopods, and corals are common. Possible vertebrate remains from Wyoming.	
PROTEROZOIC — ARCHEOZOIC (4500 million years)	Precambrian p€	600 Million years	Fossils rare; include bacteria, blue-green algae, green algae, and organisms of unknown affinities. All marine, mostly microscopic free-floating organisms. Calcareous algal reefs present in Grand Canyon rocks.	

GEOLOGIC TIME SCALE (O'Dunn and Sill, 1986)

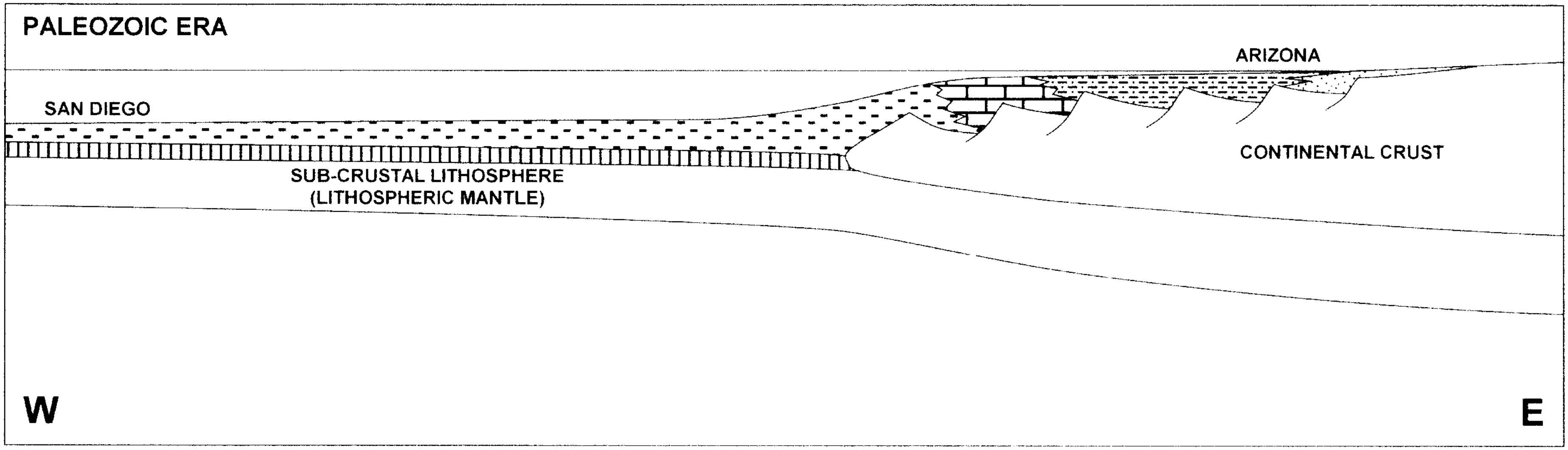
Numbers are in Millions of Years Before the Present (Mya)

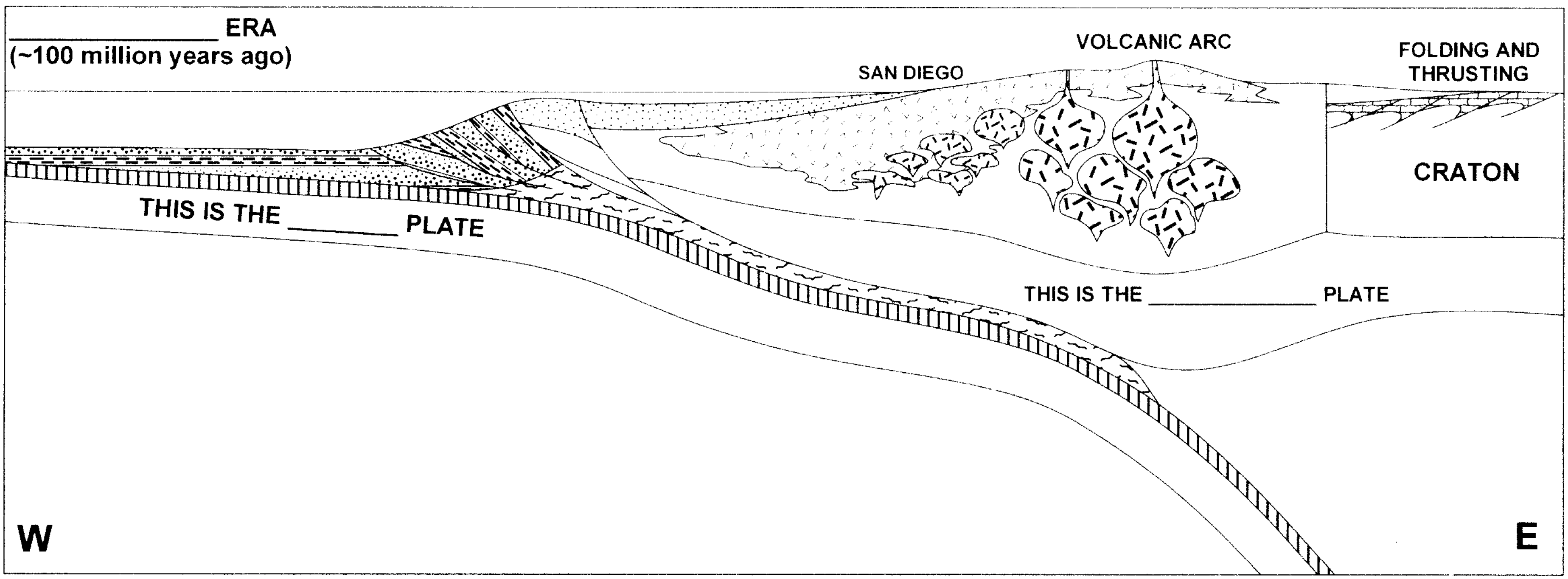
PURE SMUT

The (Geological) History of Southern California

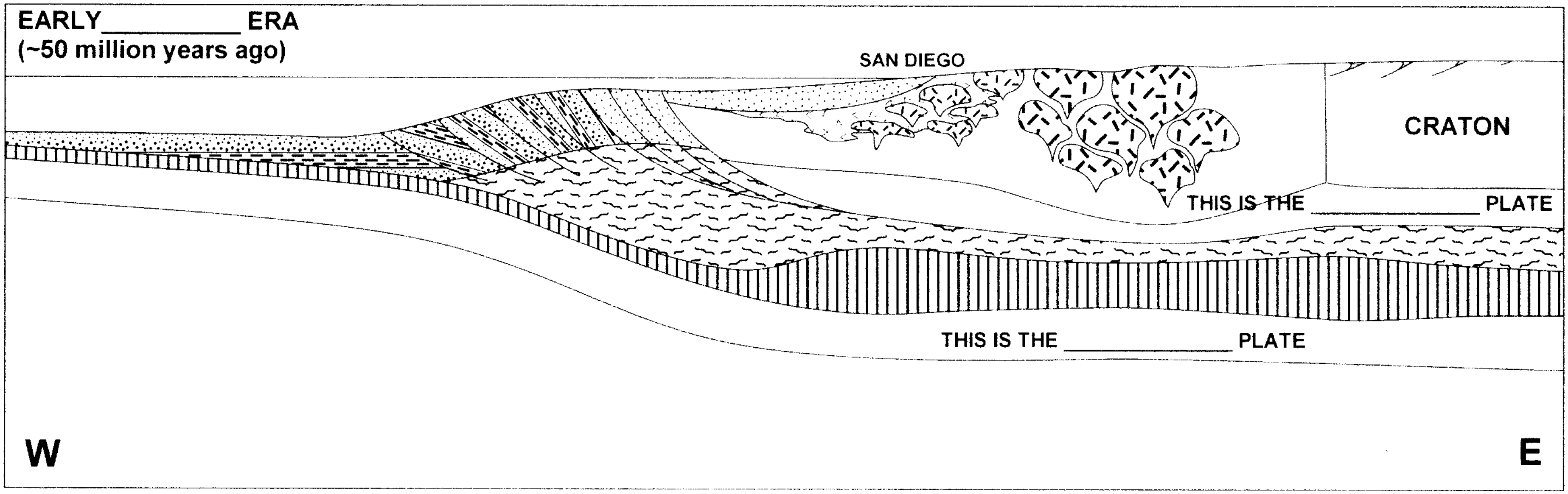
	EVENTS	ERA
T	**T**ermination (of subduction and ocean crust formation), **T**hermal expansion, **T**ilting, **T**ranslation, **T**ranstension, **T**ranspression, **T**erracing	**LATE CENOZOIC**
U	**U**nderplating **U**nusually thick crust, **U**plift, **U**n-roofing, **U**ndulating peneplain	**EARLY CENOZOIC**
M	**M**agmatic **M**adness, **M**etamorphism	**MESOZOIC**
S	**S**table **S**helf **S**edimentation	**PALEOZOIC**

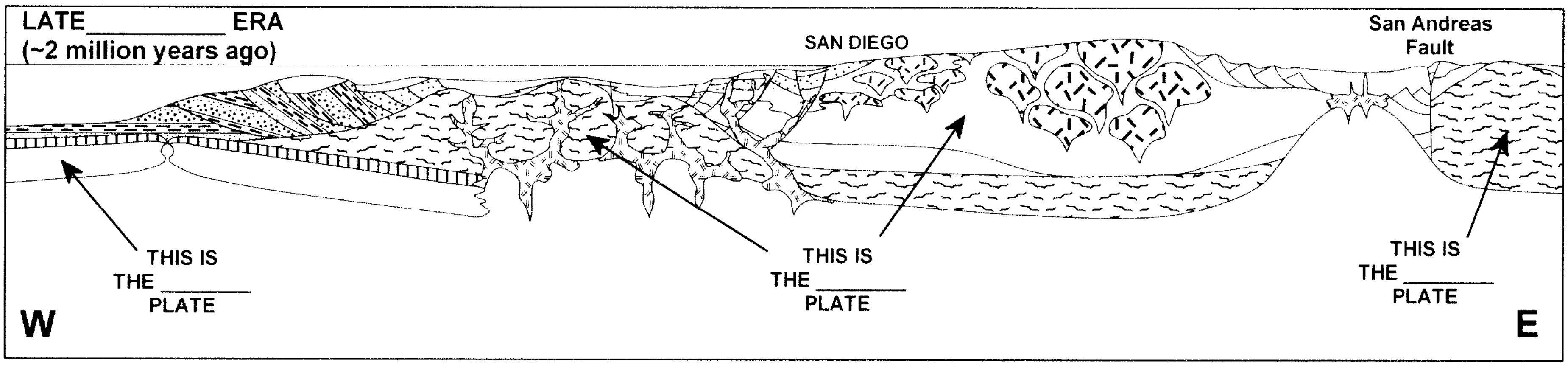
p15a.


PALEOZOIC ERA
ARIZONA
SAN DIEGO
CONTINENTAL CRUST
SUB-CRUSTAL LITHOSPHERE
(LITHOSPHERIC MANTLE)
W
E

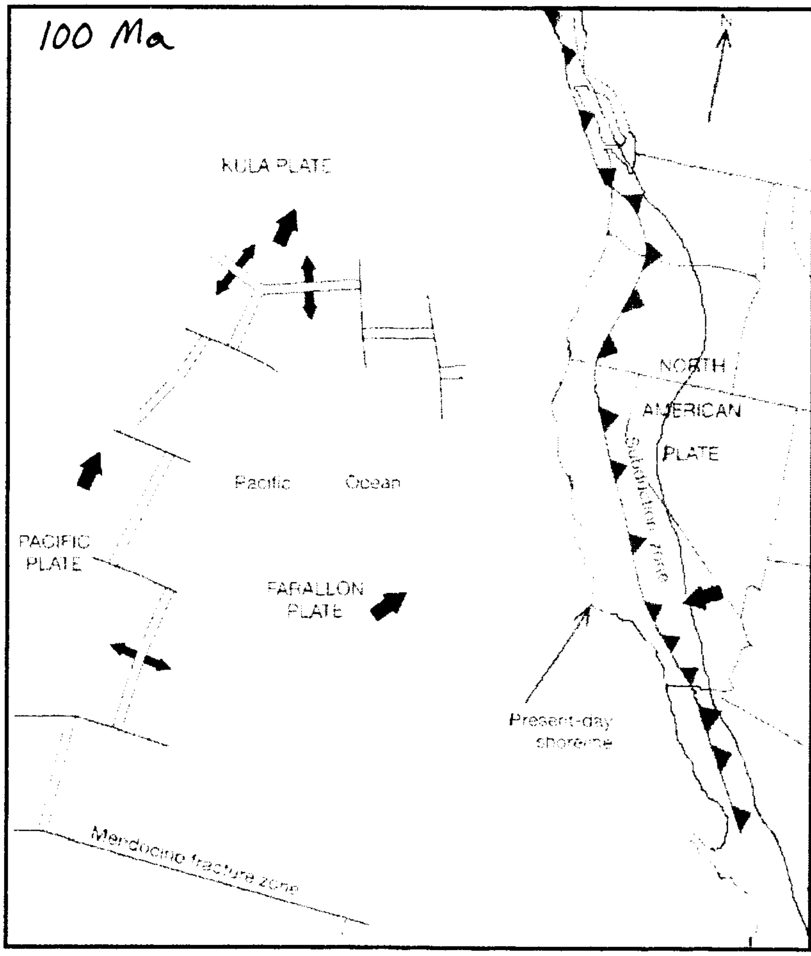

_______________ ERA
(~100 million years ago)
VOLCANIC ARC
SAN DIEGO
FOLDING AND
THRUSTING
CRATON
THIS IS THE ________ PLATE
THIS IS THE _____________ PLATE
W
E

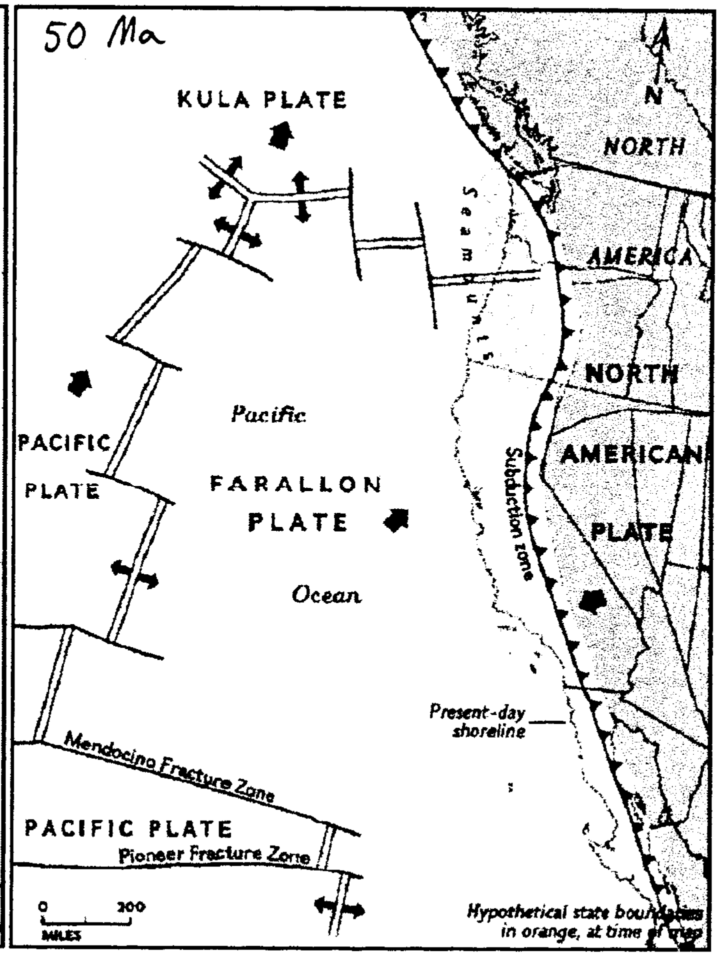
p.15b.


EARLY__________ ERA
(~50 million years ago)
SAN DIEGO
CRATON
THIS IS THE ____________ PLATE
THIS IS THE ____________ PLATE
W
E

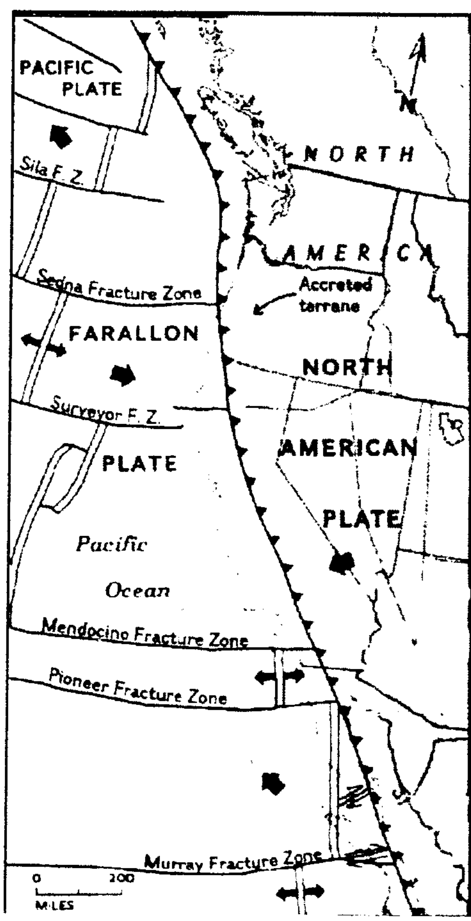

LATE__________ ERA
(~2 million years ago)
SAN DIEGO
San Andreas
Fault
THIS IS
THE ________
PLATE
THIS IS
THE ________
PLATE
THIS IS
THE ________
PLATE
W
E

PALEOTECTONIC MAPS

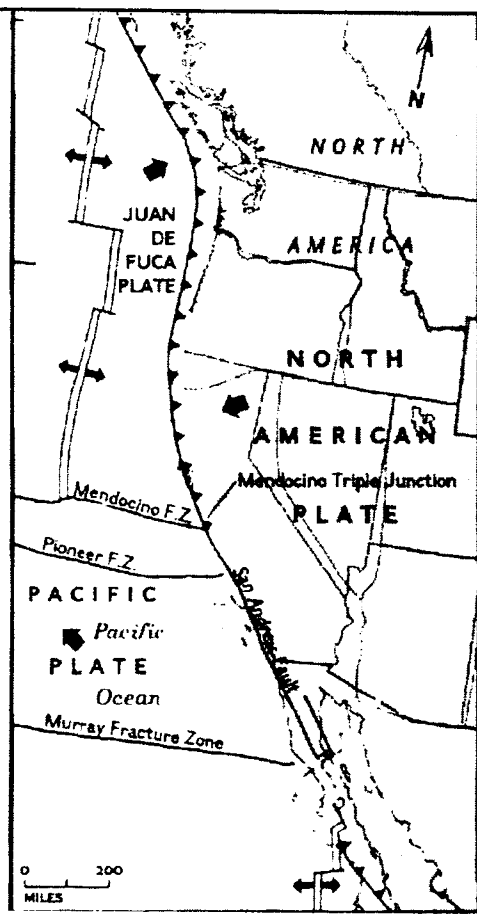




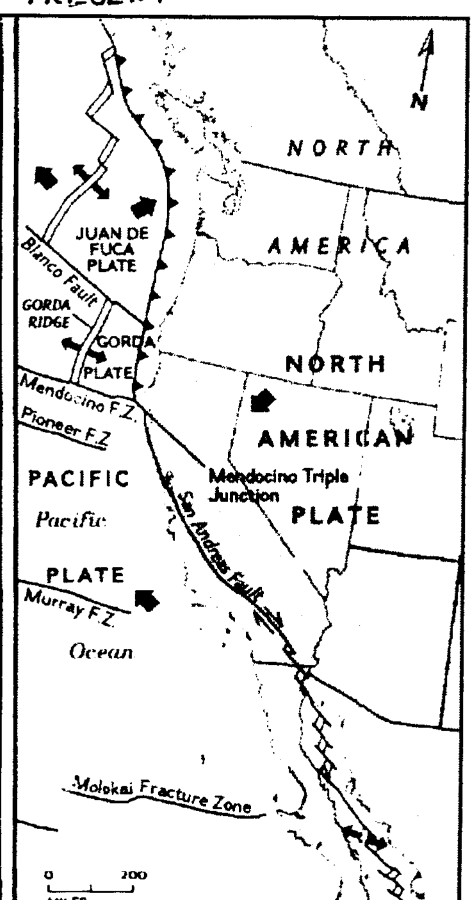
30 Ma



15 Ma



PRESENT



C) *GEOLOGY OF THE MECCA HILLS*

(Read and highlight and/or make margin notations.)

Rifting, Transpression, and Neotectonics in the Central Mecca Hills, Salton Trough, California

by Arthur Gibbs Sylvester

Introduction

Salton Trough is the northern, landward extension of the Gulf of California, which is over 1000 km long and up to 225 km wide (Fig. 1). The Colorado River enters the Gulf from its eastern side near Yuma, Arizona, forming a large delta cone that subdivides the trough into the nonmarine part to the north and the tidal-influenced delta and salinas in Mexico to the south. The delta blocks entry of marine waters of the Gulf into Salton Trough. In fact throughout its history, Salton Trough has experienced only one marine incursion - in late Miocene/early Pliocene time - all other sediment in the basin is lacustrine, fluvial, and alluvial.

The Salton Trough was known as the Salton Sink before the Colorado River flowed uncontrolled into it in 1905 and formed the Salton Sea. Most of it was desolate, especially in hot, dry summers. It is still desolate today, but certainly not desolated, it is still miserably hot in summer, but much more humid. On some summer days its towns are the hottest in the nation, even hotter than Death Valley.

Physiographically the Salton Trough is separated into the Coachella and Imperial valleys (Figs. 2, 3). Coachella Valley is only 10-15 km wide, bounded by high, northwest-trending mountains of crystalline bedrock. Low hills of deformed Neogene strata are aligned along active faults in the basin. Both valleys are important agricultural areas that require abundant irrigation water supplied mostly by aqueduct from the Colorado River. Aligned clumps of vegetation, especially native palm trees, mark traces of the San Andreas fault in Coachella Valley.

The second lowest point (- 72.3 m) in the United States is in the trough, beneath the Salton Sea; at its north end are the two highest mountain peaks in southern

(19)

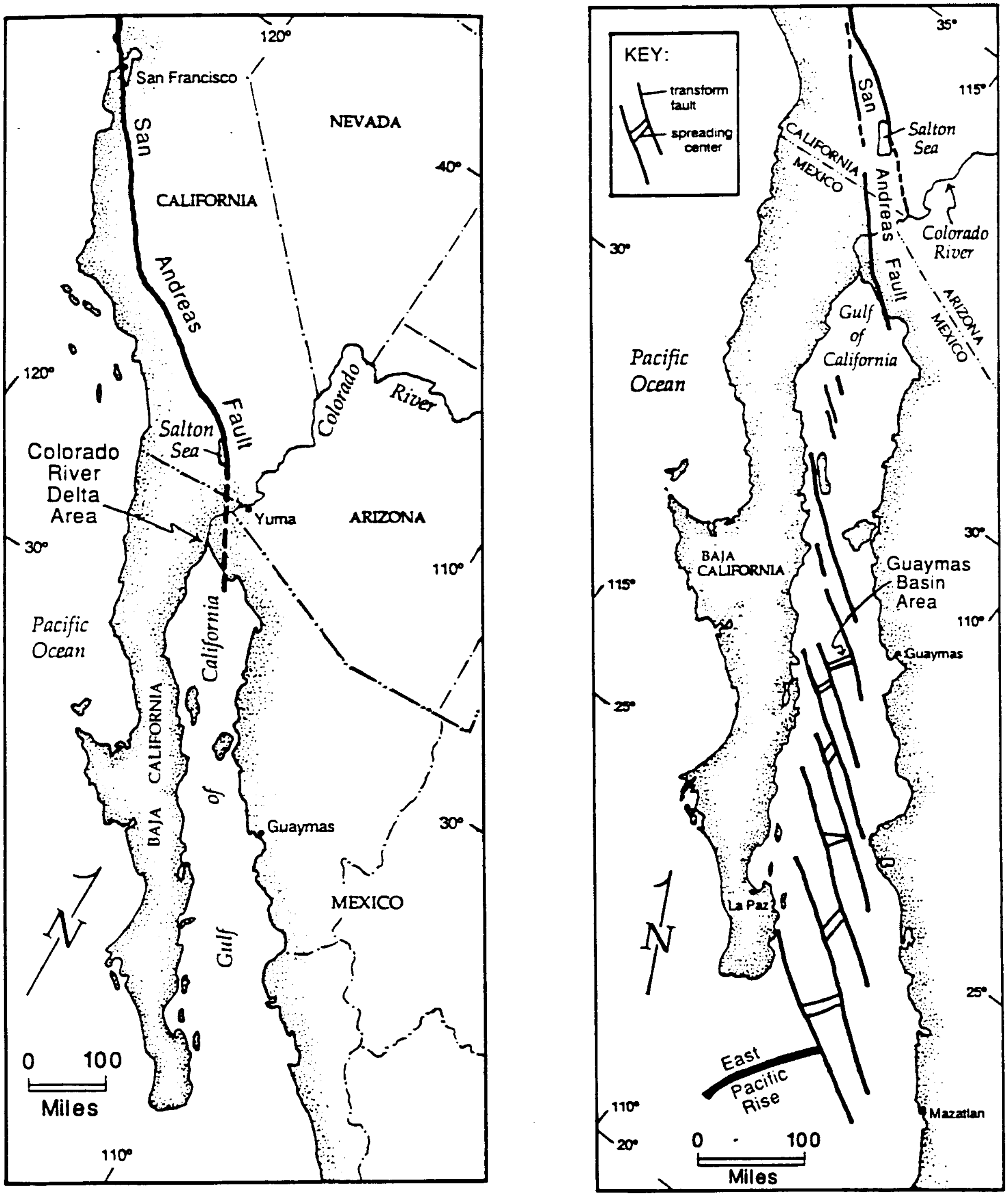


Fig. 1. Location of Gulf of California, Salton Sea, San Andreas fault zone, Colorado River, Colorado River delta, and Gulf of California spreading centers (From Schmidt, 1990).

(20)

Fig. 2. Oblique satellite image toward northeast of Salton Trough with Coachella and Imperial Valleys, Salton Sea, Mecca Hills, Joshua Tree National Park, and the Colorado River.

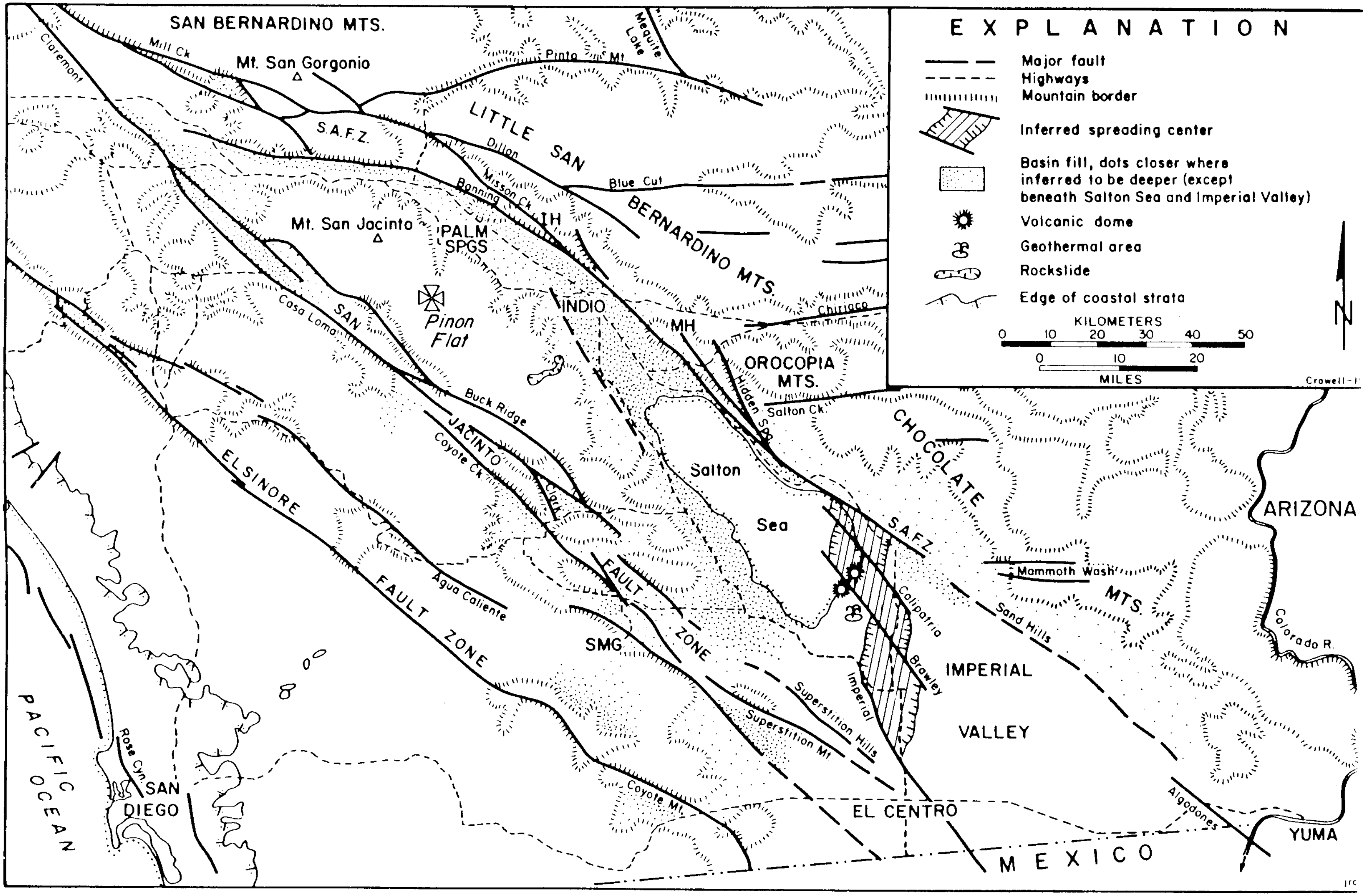


Fig. 3. Diagrammatic fault map of central Peninsular Ranges and Salton Trough region, with major faults of San Andreas system near their juncture with the divergent plate boundary in Salton Trough. Basin fill is stippled; line pattern southeast of Salton Sea is inferred active spreading centers in the Brawley seismic zone. Abbreviations: IH, Indio Hills; MH, Mecca Hills; SMG, Split Mountain Gorge (From Crowell and Sylvester, 1979).

California: Mt. San Jacinto (3324 m) and Mt. San Gorgonio (3539 m). The Whitewater River, which drains a large part of the San Bernardino Mountains, enters the north end of the basin in San Gorgonio Pass near Palm Springs. Strong winds blow through the pass across the Whitewater River alluvial fan at the head of Coachella Valley, and picking up sand and dust into the trough that are deposited in dunes mainly in the North Palm Spring area between Cabazon and Indio. The Algodones dunes are another extensive dune field in Salton Trough near Yuma.

Hydrocarbons have not been found in Salton Trough owing primarily to the lack of source rocks, but the Salton Sea geothermal field at the south end of the Salton Sea supplies about ten percent of San Diego's cravings for electric power. Wind machines at the north end of the trough produce adequate energy to satisfy the electric power demands of all the communities and casinos in the trough.

Plate Tectonic Overview

Salton Trough is the youngest of California's several Tertiary basins. It began to form about 16 my ago in mid Miocene time by crustal extension when the Pacific plate began its attempt to chip off and kidnap a long slice of the North American plate. Before the Pacific plate accomplished that dastardly deed, however, the North American crust above it extended greatly along high-angle normal faults and low-angle detachment faults, baring the top of the subducted Farallon plate beneath in tectonic windows, and giving rise to the proto Salton basin. Fragments of those faults are locally exposed in the bounding mountains as are scraps of 15 Ma- old andesite flows and interstratified alluvial and fluvial strata deposited during that extension.

Between 5 my and 4 my, the Pacific plate succeeded in its capture of a great sliver of the North American plate, consisting of all of continental Alta and Baja California that now lies between San Francisco and La Paz, and west of the present San Andreas fault (Fig. 1). South of the Transverse Ranges the plate boundary jumped eastward into the proto Salton Trough and Gulf of California where it found thinned crust and some major, high-angle faults that it could usurp east of the tough crustal slab consisting of Mesozoic magmatic arc rocks of the southern California batholith. In the Gulf the new boundary was a series of spreading ridges and transforms that connected the East Pacific Rise at the mouth of the Gulf to the San Andreas transform that extended southward from central California (Fig. 1).

Judging from seismic refraction data (Fuis et al., 1982), Salton Trough was an asymmetric basin with deep accumulation centers in its southwest corner near El Centro and its northeast margin beneath the present hamlet of Mecca. Judging from interpretations of gravity data, depth to basement beneath the trough varies greatly from 2150 m in northern Coachella Valley to 6800 m near the Mexican border. Stepover basins formed above spreading ridge segments between short transform faults in the Gulf in right shear.

The single marine incursion occurred in late Miocene - early Pliocene time, when the Imperial Shale and related turbidite and shallow marine and beach facies strata were deposited (Fig. 4). The presence of battered Cretaceous forams prove that the bulk of the basin's sediment was derived from the Mancos Shale in Utah and Colorado and carried to the basin by the Colorado River during Pliocene and Pleistocene time. At that time it flowed directly into the basin, forming thereby fresh or brackish lakes even larger and deeper than the present Salton Sea. During the past 1000 years, ancient lakes repeatedly filled Salton Trough to a highstand level of about 12 to 13 m above mean sea level. The most recent highstand was in 1663 ± 22 A.D. (Waters, 1983; Sieh and Williams, 1990); the highest shoreline is well preserved like a bathtub ring near sea level around the basin, and is reckoned to be 37,000 yrs old. The Holocene lakes are known collectively as Lake Cahuilla.

Around the margin of the basin, the lacustrine strata interfinger with alluvial fan, fluvial, braided stream, fan delta, landslide, and eolian deposits derived from the bounding mountains.

The Bounding Mountain Ranges

Salton Trough separates two physiographic provinces that differ greatly in age and rock types. Along the northeast side are the Little San Bernardino, Orocopia, and Chocolate Mountains. Rocks in the Little San Bernardino and Chocolate Mountains represent the North American plate and consist of Late Proterozoic gneiss, migmatite, anorthosite and granitic intrusions, Mesozoic granitic rocks of Sierra Nevada batholithic kindred, and Miocene (27-23 my) rhyolitic hypabyssal

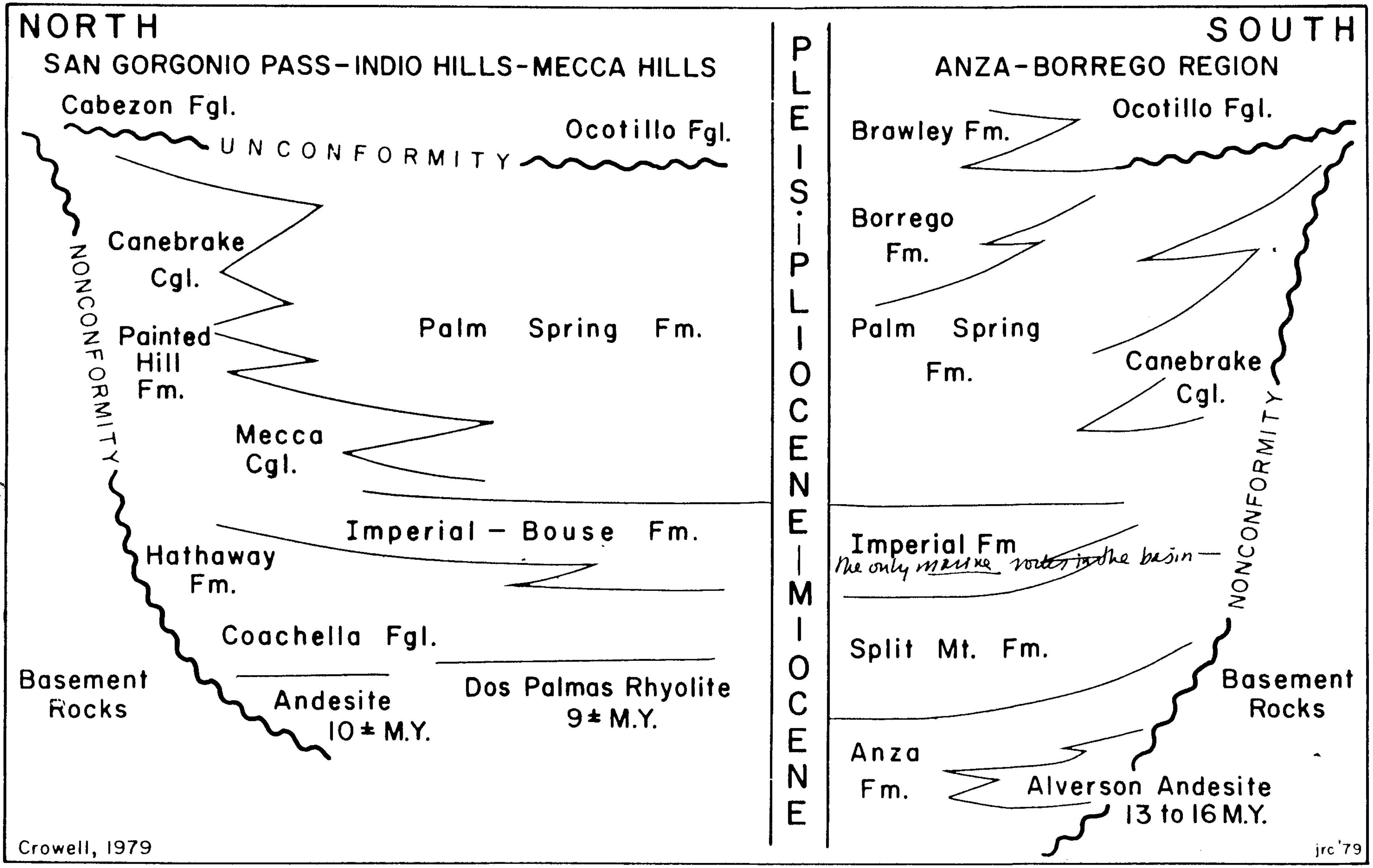


Fig. 4. Stratigraphic diagrams for late Cenozoic strata in Salton Trough for northern and southern parts of the basin (From Crowell and Baca, 1979).

intrusions. The Orocopia Mountains represent a tectonic window through North America plate to the top the ancient, subducted Farallon plate that became exposed when part of the North American plate slid off by detachment faulting in Miocene time. The mountain mass consists almost entirely of gray and green schist virtually identical in composition and origin to divers large schist bodies elsewhere in southern California, particularly its offset equivalent, the Pelona Schist in the San Gabriel Mountains.

The mountains southwest of the Salton Trough represent part of the great southern California batholith that stretches uninterruptedly from Los Angeles southward to La Paz in Baja California. Jurassic plutonic rocks range from gabbro to granite, but the average rock is tonalite, whereas that in the Sierra Nevada is granodiorite and quartz monzonite. The country rocks for the southern California batholith are Paleozoic miogeoclinal sedimentary rocks of the Winchester Series, now contact metamorphosed to argillite, mica schist, marble, and quartzite. Much of the mountain mass west of the Salton Sea was strongly mylonitized during Miocene detachment faulting and extension.

Faults and Active Tectonics

The rift and transform system of Gulf of California extends beneath the thick sedimentary cover of Imperial Valley where it spawned local rhyolitic volcanism, formation of stepover basins, and a system of strike slip faults whose frequent earthquakes make the region the most seismically active in California (Fig. 5). The main strike-slip faults, San Andreas and San Jacinto, bound the Salton Trough as a right-shear couple, between which left-slip cross faults bound a series of thin crustal slabs that rotate clockwise in the shear couple (Figs. 6A and B). These slabs rotate upon subducted Farallon plate, now captured by and moving northwestward as part of the Pacific plate. In at least one instance, the 1987 Superstition Hill earthquake, an M6.2 earthquake on one of the cross faults triggered a M6.6 earthquake 11 hours later on the San Jacinto fault system (Fig. 7).

There can be no doubt of the high level of late Pleistocene and Holocene activity of the faults in Salton Trough judging from abundant physiographic and geomorphic features, including faulted landslide deposits, faulted alluvial fans and terraces, truncated spurs, deflected drainages, sags, scarps, shutter ridges, aligned

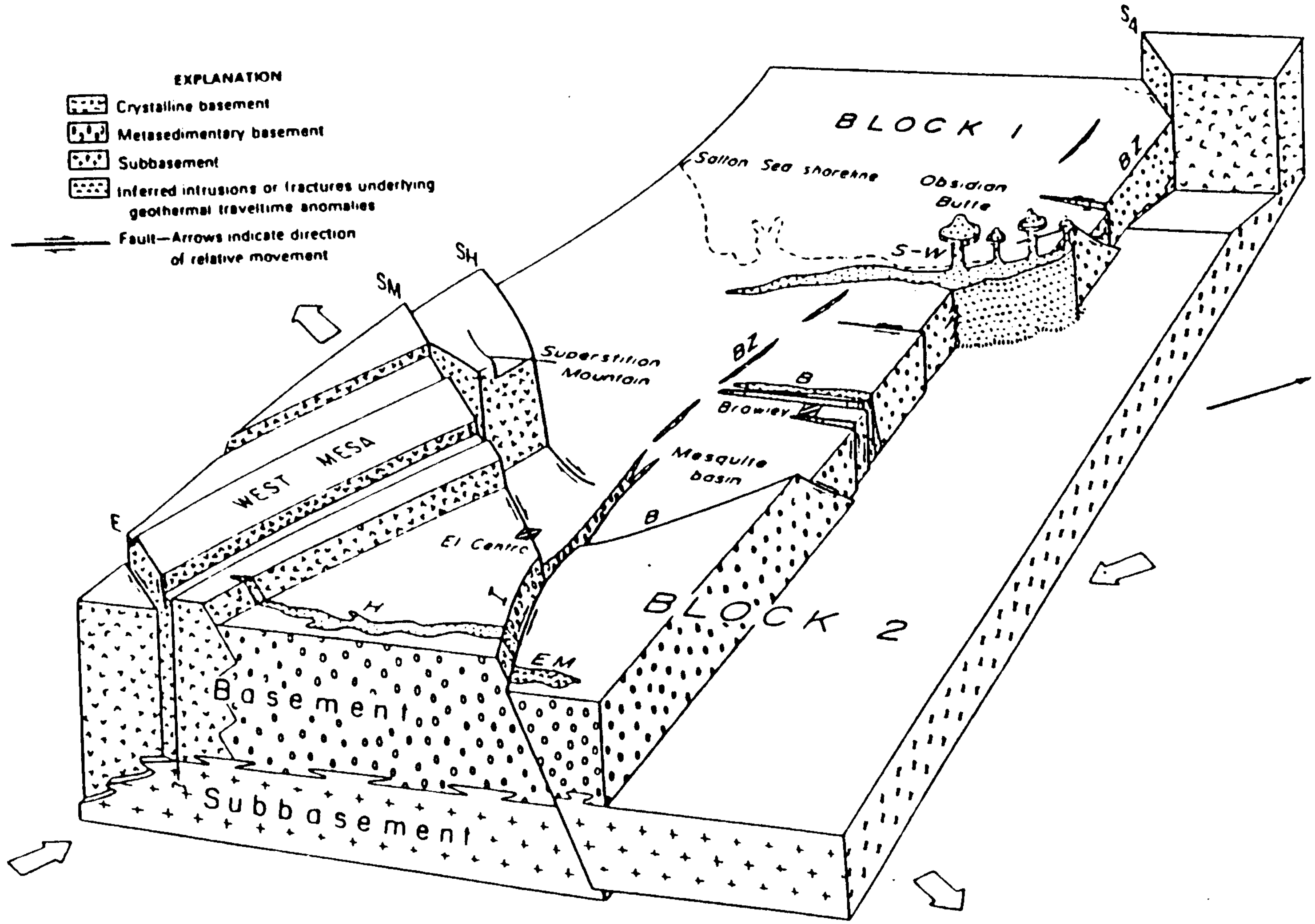
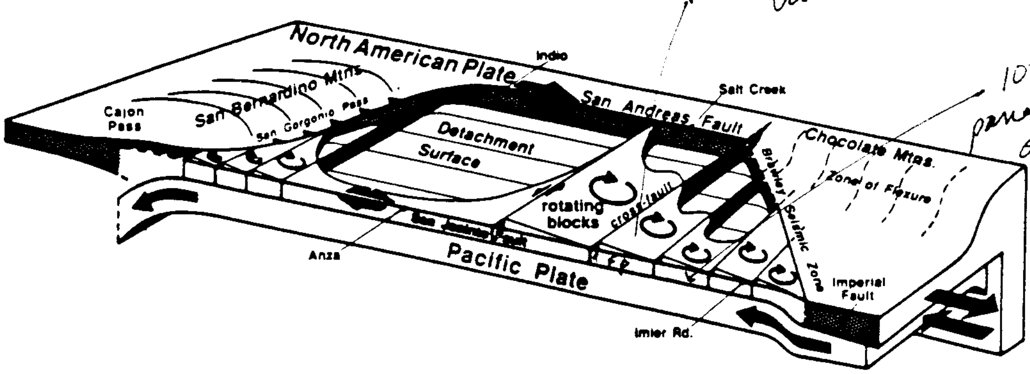


Fig. 5. Schematic block diagram of Imperial Valley region, with sedimentary rocks removed and basement cut away along a line roughly parallel to Brawley seismic zone. Geographic names are projected downward onto basement for reference. Abbreviations: B, Brawley fault zone; BZ, Brawley seismic zone; E, Elsinore fault; I, Imperial fault; SA, San Andreas fault; SH, Superstition Hills fault; SM, Superstition Mountain fault. Geothermal areas: B, Brawley; EM, East Mesa; H, Heber; S, Salton Sea; W, Westmorland. Shaded arrows indicate dominant extension and contraction directions for recent geologic past. Blocks 1 and 2 move away from Brawley seismic zone - and from inferred spreading center - in direction parallel to southern section of Imperial fault. Stepover basins form at Mesquite basin and Salton Sink which is presently occupied by Salton Sea. (From Fuis et al 1982; Fuis and Kohler, 1984).

(27)

panel
cross faults are LLSS
10-15 km thick panels are rotating on top of old Farallon Plate

A.



B.

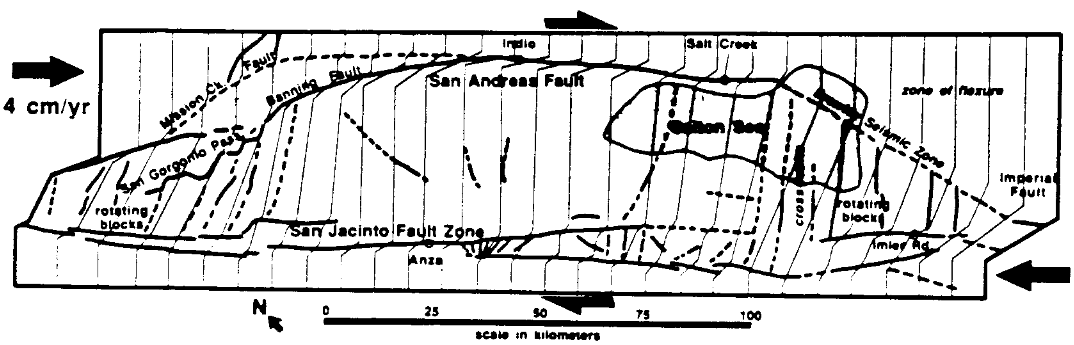


Fig. 6A. Hypothetical model of major detachment beneath Salton Trough from Brawley seismic zone to San Gorgonio Pass. Deformation in upper plate is partly the result of traction across this detachment. Slip on the detachment causes lithospheric thinning at the Brawley seismic zone, and thickening at San Gorgonio Pass. Higher long-term slip rates at Indio than at Salt Creek on San Andreas fault, and at Anza than at Imler Road on the San Jacinto fault, are explained by redistribution of displacement into block rotation and slip across the width of the zone from the San Jacinto to the San Andreas. (From Hudnut et al, 1989).

Fig. 6B. Strain distribution across the San Andreas and San Jacinto fault zones, consistent with the hypothetical model (6A). Displacement lines are rotated across areas where crustal blocks, bounded by left-lateral cross faults, are rotated due to right lateral plate boundary shear across the entire zone, in particular near San Gorgonio Pass and the Brawley seismic zone. Strain is partitioned into translational and rotational components. (From Hudnut et al., 1989).

(28)

valleys, and linear ground water barriers. Paleoseismologic investigations have given some insights about the pre-historic activity of some of the faults.

The largest historic shaker was the 1940 El Centro earthquake (M7.1) on the Imperial fault. That earthquake displaced the U.S. - Mexico boundary 5.8 m right laterally. A M6.6 earthquake occurred on the same fault in 1979, but all of the displacement was on the U.S. side of the border, and maximum right lateral displacement was only 1.5 m. Other notable right-slip earthquakes have occurred on the Mission Creek fault (1948, M6.4), southern San Jacinto fault (1968, M6.8), the Banning fault (1986, M6.2), and the Superstition Hills fault (1987, M6.6).

The fault segment from San Gorgonio Pass to Durmid Hill (Fig. 3) is one of the most seismically inactive stretches of the San Andreas fault along its entire 1000 km length. Significantly, no major earthquakes have been recorded along that segment in the last 350 years by historic or paleoseismic studies, although the geomorphic evidence is clear that the fault has been very active in Holocene time. With so much historic activity at each end of this segment of the fault, as well as along much its remaining length in California, however, seismologists are understandably concerned that the probability of a major earthquake here is quite high - perhaps as high as 50 percent in the next 30 years.

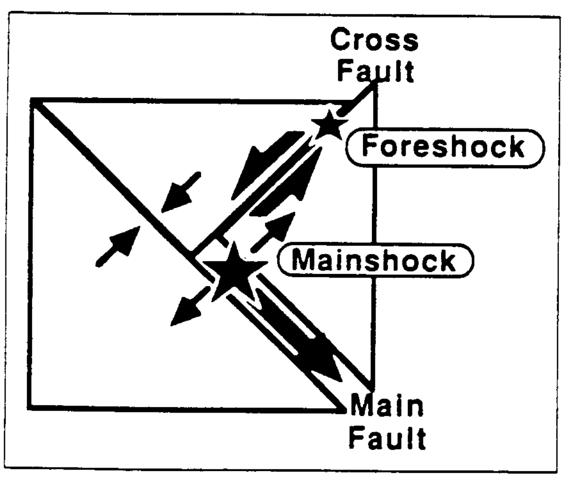


Fig. 7. Diagram of cross-fault triggering mechanism. Rupture of cross fault compresses and decompresses adjacent segments of main fault, strengthening and weakening the fault. After a delay, rupture starts on main fault in area of decompression. Rupture then propagates away from the intersection. This model works for the November 1987 Superstition Hills earthquake sequence and (by mirror symmetry) predicts that future rupture on cross faults farther northwest may trigger a great earthquake on the southern San Andreas fault. (From Hudnut et al., 1989).