National City, Imperial Beach,
Otay Mesa, and Jamul
Mountains Quadrangles
Plates 1-4

GEOLOGY OF SOUTHWESTERN SAN DIEGO COUNTY, CALIFORNIA AND NORTHWESTERN BAJA CALIFORNIA

Edited By Gregory T. Farrand

1977

Scanned 06/02/22 - Missing pages are blank pages. The original black & white Plates 1-4 have been replaced with one original more detailed color map prepared by H.T. Kuper.

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Reconnaissance of the Marine Sedimentary Rocks of Southwestern San Diego County, California
By: H.T. Kuper

GEOLOGY OF SOUTHWESTERN SAN DIEGO COUNTY, CALIFORNIA AND NORTHWESTERN BAJA CALIFORNIA

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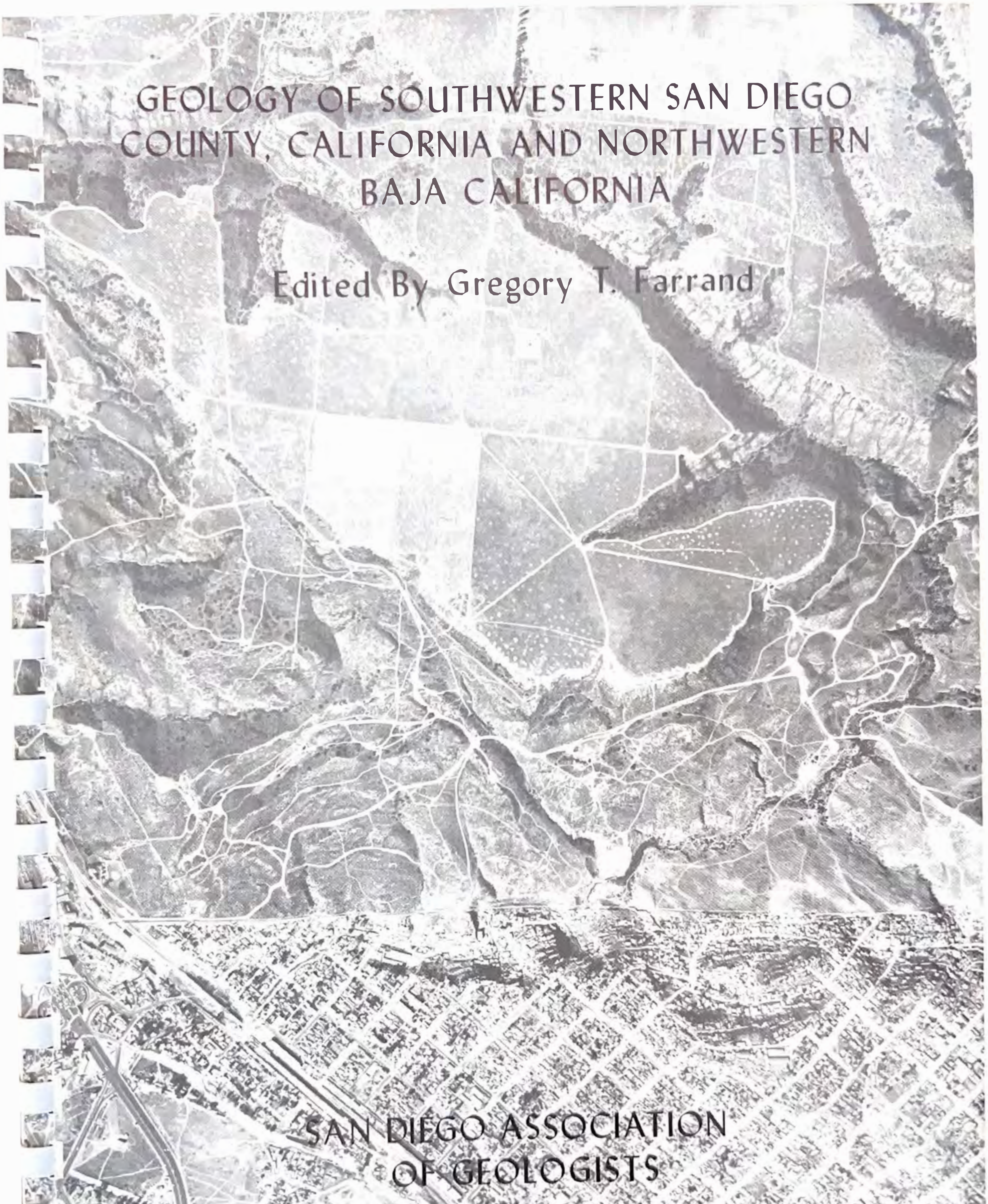

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Front Cover. Aerial photograph taken on October 12, 1969, from 11,000 feet of Otay Mesa-San Ysidro-Tijuana area. Large landslides are visible in center left and lower right portions of photo. Intensive land development south of the International Border has resulted in construction of residences over existing landslides (lower right). Photograph courtesy of Aerial Fotobank, San Diego, California.

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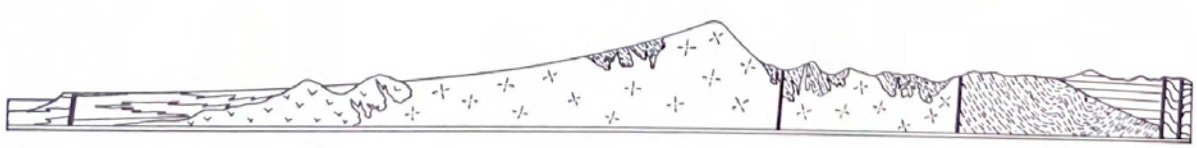

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CONTENTS

RECONNAISSANCE OF MARINE SEDIMENTARY ROCKS OF SOUTHWESTERN SAN DIEGO COUNTY

Herman T. Kuper
Soil Testers
La Mesa, California

Gordon Gastil
Department of Geological Sciences
San Diego State University

Seven mappable units are recognized in southeast San Diego County. The irregular basement contains Mesozoic age metamorphic and granitic rocks. Overlapping the basement, are six sedimentary units of Eocene to Pleistocene age: the Upper Eocene Stadium Conglomerate and Mission Valley, the Miocene Sweetwater and Otay, the Pliocene San Diego, and the Pleistocene terrace and channel deposits.

The sandstones of the Mission Valley Formation are unconformably overlain by locally derived, nonmarine, mudstones, sandstones, and conglomerates. These facies are in turn conformably overlain by sandstones and bentonitic clays correlatable with the Miocene Rosarito Beach Formation of Baja California.

The majority of exposures of both Miocene units are found east of the La Nacion fault from Lemon Grove to south of the International Border. Both constitute mappable units which should be recognized as the Sweetwater and Otay Members of the Rosarito Beach Formation. All formations of the area are overlapping and erosionally truncated by the marine San Diego Formation.

INTRODUCTION

The names Sweetwater and Otay "Formation" were proposed by Artim and Pinckney in 1973. Since then local geologists have tended to use the term "Otay" to represent all post-Eocene, pre-Pliocene strata in southwestern San Diego County without making the distinction between the Otay and Sweetwater.

Since 1973, student field classes at San Diego State University, Department of Geological Sciences, have mapped the entire area from the campus south of the International Border. H. T. Kuper began by compiling and rechecking all of the student work (Kuper, 1976), and has extended the work to the bedrock boundary on the east. The objective of this paper is to define the extent, stratigraphic sequence, and type sections for the Miocene units in southwestern San Diego County.

PREVIOUS WORK

Prior to the paper by Artim and Pinckney in 1973 it was believed that all post-Eocene strata in the eastern part of the coastal plain were part of the marine Pliocene San Diego Formation (Hertlein and Grant, 1944). George Cleveland (1960) reported on the Otay Valley bentonite, including it in the San Diego Formation. Artim and Pinckney showed the new "Formations" on a very generalized map at approximately four miles to the inch, and did not identify either type areas or type sections. Mandel (1974) described the "Otay Formation," but identified a type section for it which included the "Sweetwater Formation" of Artim and Pinckney in its lower part. The fossils attributed by Mandel to the "Otay Formation" are actually in the base of the unconformably overlying San Diego Formation.

Kennedy (1977) mapped units distinguished as "Otay Formation" and "unnamed fanglomerate deposits" stratigraphically between the Mission Valley and San Diego Formations, but does not assign an age to the "unnamed fanglomerate." His "Otay Formation" includes all of the "Otay Formation" of Artim and Pinckney, as well as most of the "Sweetwater Formation" to the south. However, from Otay Lakes Road north, Kennedy assigns most of the Sweetwater "Formation" to the Eocene Mission Valley Formation. Kennedy's "unnamed fanglomerate deposit" is essentially synonymous with the angular conglomerate facies of the Sweetwater Member as distinguished in this paper. The confusion between Sweetwater "Formation" and Mission Valley Formation arises in part from the fact that the map shown by Artim and Pinckney (1973) included considerable Mission Valley Formation within the boundary of what was designated as "Sweetwater Formation."

Just east of Rosarito Beach, Baja California, Minch (1967) recognized, described, subdivided, and formally named the volcanic and sedimentary rocks which overlay the Eocene unnamed sandstones and underlay the Pliocene San Diego Formation. He called this sequence the Rosarito Beach Formation and assigned a Miocene age on the basis of a meager marine megafossil fauna in the basal Mira al Mar Member. Hawkins (1970) dated a basalt (14.3±2.6 m.y. K/Ar) near the type locality of the Costa Azul Member. Flynn (1970) extended the Rosarito Beach Formation east and northeast to the Tijuana River Valley. Voorhees (1975) mapped and described both the Otay and Sweetwater "Formations" in the Presa Rodriguez area, immediately northeast of that mapped by Flynn. Scheidemann (1976) correlated the "Otay Formation" of southwestern San Diego County with the Rosarito Beach Formation as mapped by Flynn south of the Rio Tijuana. He recommended that the name "Otay Formation" be dropped in favor of the prior Rosarito Beach Formation.

LOCATION

Most of the area treated in this report lies within the cities of San Diego, Lemon Grove, Chula Vista, and National City, or immediately to the east thereof (Figure 1), and includes portions of the National City, Jamul Mountains, Imperial Beach, and Otay Mesa 7.5-minute quadrangles(Plates 1-4).The northernmost recognized exposures of these Miocene units are found just south of University Avenue in San Diego, Lemon Grove, and Casa de Oro. Because the Miocene units were erosionally truncated by sub-San Diego Formation erosion, it is probable that they once extended further to the north and northeast.

GEOLOGICAL SETTING

The basement underlying the continental margin of southern California is divided into two provinces: ophiolite to the west, Jurassic-Cretaceous metamorphic and granitic rocks to the east. The boundary between the two provinces is generally believed to be just west of the present coastline (Vedder and Howell, 1976).

During the Eocene, sediments derived far to the east were transported across parts of continental margin and deposited as deltas and deep water fans overlapping both basement provinces. During the Miocene, tectonic uplift elevated the offshore province, exposing the ophiolite basement rocks to erosion, and causing breccia flows which carried this debris eastward (e.g., San Onofre Breccia, parts of the Mira al Mar Member of the Rosarito Beach Formation).

At the same time, the granitic province to the east was uplifted which terminated the transport of exotic clasts from further east and provided an abundance of locally derived metamorphic and granitic clasts.

The San Diego trough was a north-northwest basin into which the contrasting rock types were deposited: ophiolite debris from the west, metavolcanic and granitic debris from the east.

CENOZOIC STRATIGRAPHY

Throughout southwestern San Diego County exposed Cenozoic rocks rest directly on the weakly metamorphosed volcanic-volcaniclastic rocks of Mesozoic age. The Cenozoic and Mesozoic rocks are separated by an extreme high relief unconformity with exposed hills of basement rock being in contact with Eocene to Pleistocene units.

STADIUM CONGLOMERATE

The Eocene Stadium Conglomerate (Moore and Kennedy, 1970) conformably underlies the Mission Valley Formation. In the area mapped, the majority of exposures consist of well-sorted, light brown cobble conglomerates with the distinctive "Poway" clasts. Lenses of sandstones are common. Exposures of the formation were not found south of the Encanto area.

MISSION VALLEY FORMATION

The Mission Valley Formation (Moore and Kennedy, 1970) contains pale grey marine sandstones of Upper Eocene age. Throughout the area, it displays a regional dip of about 3 to the southwest. Its most southerly exposures are at low elevations along the south margin of Bonita Valley (east of the La Nacion fault), and along the north margin of Otay Valley, north of the Bird Ranch.

The formation consists largely of medium to coarse sandstones, with local lenses of conglomerate and reddish mudstone. The lower portion is distinguished by flaggy bedding and calcareous concretions, some of which preserve casts and molds of marine mollusks. The upper portion tends to be more massive, more friable, coarser-grained, with thin but persistent cobble layers, and iron ore placers. The erosionally truncated top of the formation almost invariably displays one or two meters of iron-stained sandstone overlain by red mudstone. This altered horizon parallels the erosional contact, rather than the Mission Valley bedding, and appears to be paleosol feature.

SWEETWATER FORMATION

The Sweetwater "Formation" consists of four lithologic facies: angular conglomerates, gritstones, mudstones, and sandstones. The angular conglomerate facies ranges in size from pebble and sand matrix to giant boulders, angular to sub-rounded. The clasts consist largely of the weakly metamorphosed volcanic-volcaniclastic rocks of the adjacent Santiago Peak Formation, with lesser amounts of granodiorite and gabbro. Locally, as southeast of Jamul, the granodiorite boulders predominate. The matrix is poorly sorted, clay-rich, and in some places iron oxide stained. The most extensive exposures are found in Proctor and Otay Valleys. Local lenses occur within the gritstone facies further to the northwest. The most easterly exposures north of the International Border are found capping ridges 8 kilometers southeast of Jamul (approximately 350 to 400 meters above sea level). These deposits were first mapped by San Diego State field classes under the direction of Ellis Roberts during 1949-50.

The gritstone facies is found as lenses in the angular conglomerate and as massive beds up to 16 meters thick in the central part of the area, and as thin interbeds in the mudstone further west and north. It is the most distinctive facies and is second to the mudstone in abundance. The gritstone has been found in all localities of the Sweetwater with the exception of the furthest northwest exposures. The color ranges from bright white to tan. It is a lithic arkose in composition, with half-centimeter grains of quartz feldspar, and rock chips being the predominant components. Within the Paradise Valley area, this facies is in part well cemented with silica and forms resistant exposures. A particularly resistant exposure just north of Paradise Valley Road was pictured by Hertlein and Grant (1944). Sediments within this facies are massive and poorly sorted and resemble sheetflood deposits. The gritstone facies commonly overlies and interfingers with the mudstone facies.

The non-gritty, relatively well-sorted sandstones appear in the eastern and central areas as lenses near the base of the mudstone facies. To the northwest, muddy sandstones are gradationally interstratified with sandy mudstones. The appearance of the sandstone facies is in some places only a short stratigraphic distance above the Mission Valley Formation which adds to the confusion between the Mission Valley and Sweetwater units.

The mudstone facies varies from brown, brick-like mixtures of clay, sand, and grit to relatively clean pink, expansive claystones, resembling horizons in the overlying Otay. Massive mudstones units measure as much as 26 meters in thickness. Even the waxy, conchoidally fractured pink clays generally contain appreciable silt and are commonly studded with visible granules of quartz. Along the northern margin of the area, from 54th Street and Highway 94 on the west, to Casa de Oro on the east, the mudstone is the dominant facies.

The erosional beveling of pre-Pliocene strata along the sub-San Diego Formation erosional surface removed part to all of the Sweetwater "Formation" from Bonita north.

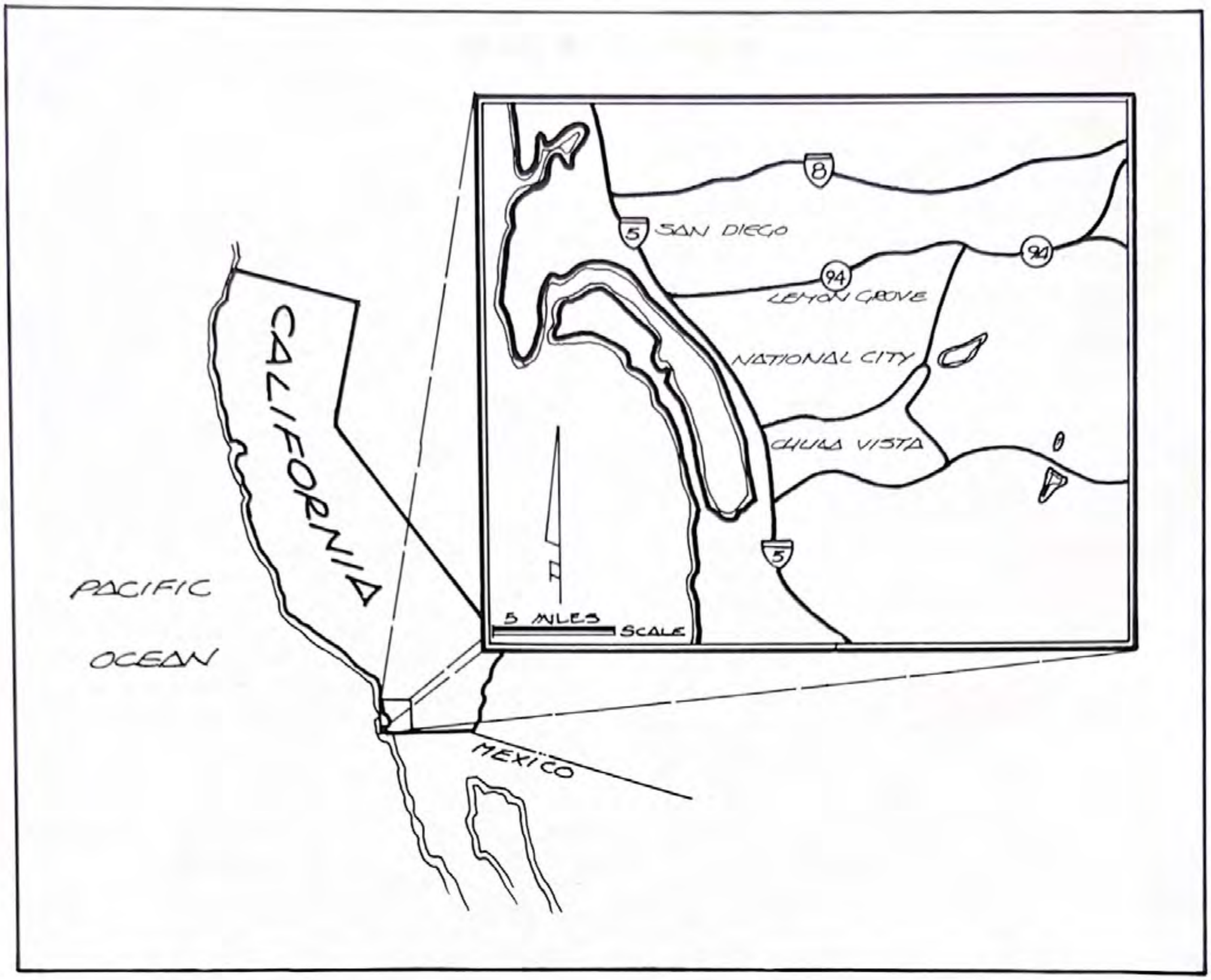

Figure 1. Site location map.

OTAY FORMATION

The unit which Artim and Pinckney (1973) named Otay "Formation" is essentially identical to that identified as Rosarito Beach Formation by Scheidemann (1976). It consists of very pale grey, massive to thin-bedded sandstone with beds of bentonite clay up to 2 meters in thickness (Cleveland, 1960). The sandstone varies from a gritty, angular, commonly cross-laminated, feldspathic litharenite in the lower portion to a well-sorted, fine-grained, lithic arkose in the upper portion.

Artim and Pinckney (1973) describe the Otay "Formation" as: "Predominately of...white, volcanically derived tuffaceous, fine sandstone with thin bentonite interbeds." Although the present authors have not done adequate petrographic work to confirm the volcanic derivation of the sandstone, volcanic lapillae and coarser volcanic clasts are found within the sandstones immediately south of the International Border. This, together with the ash-derived bentonite clay (Cleveland, 1960) gives credence to the belief that an appreciable contribution was from con-local Miocene volcanism.

From a distance, the contrasting pale tan and pale grey colors of the Sweetwater and Otay "Formations" clearly distinguishes their contact. Detailed examination, however, shows their lithology to be gradational, and a precise identification of the contact difficult. An excellent example of this gradation is found on the road which leads from Otay Valley Road north to the sanitary land fill area.

DISTINGUISHING FEATURES OF THE MIOCENE STRATA

The Mission Valley Formation can be distinguished from the Miocene units by the composition, rounding, and sorting of its cobbles and boulders. Conglomerates of the Mission Valley Formation, where adjacent to the basement rock contact, are predominantly composed of "Poway" type clasts (resistate, well-rounded, weakly metamorphosed siliceous volcanic rocks and quartzite). Commonly these occur in thin, persistent stringers only one or two clasts in thickness. Iron-ore placers, up to half a meter in thickness occur in the upper part of the Mission Valley Formation, but not in the Sweetwater or Otay units.

Clasts in the Sweetwater "Formation" are angular, poorly sorted, commonly in irregular lensoid beds, or scattered through the gritstone facies. Although the Sweetwater unconformably overlies the Mission Valley, reworked "Poway" type clasts are exceedingly rare. A few "Poway" clasts are intermixed with locally derived clasts by the old reservoir near the bottom of Chester Canyon.

The Otay "Formation" north of the International Border contains no conglomerate clasts of any type. Just south of the International Border, however, clasts of contemporary volcanic rock are included, and south of the Tijuana River Valley the reportedly equivalent Las Glorias Member of the Rosarito Formation (Scheidemann, 1976) contains clasts derived from the basement rocks to the east.

SAN DIEGO FORMATION

The marine San Diego Formation unconformably overlies all previously mentioned formations. The base of the San Diego Formation in the area of this study is marked by channels of discontinuous boulder conglomerates derived from both the basement rocks to the east and from the Eocene and Miocene formations. In the eastern part of the southern coastal plain, the San Diego Formation is composed of well-sorted, fine, white to yellow sandstones, with interbeds of well-rounded conglomerates.

PLEISTOCENE TERRACE AND CHANNEL DEPOSITS

Pleistocene channel and terrace deposits are found capping the previously mentioned formations throughout the area. The valley terraces are typically composed of coarse-grained, porous, rust-brown gritstone, resembling some exposures of the Sweetwater gritstone facies.

AGE OF THE SWEETWATER AND OTAY "FORMATIONS"

The Miocene age assigned by Artim and Pinckney (1973) and Scheidemann (1976) to the Otay "Formation" and by Kuper (1976) to the Sweetwater "Formation" is based upon correlation with the Rosarito Beach Formation. Minch (1967) reported a meager middle Miocene mollusk fauna for the lowest member and Hawkins (1970) reported a K/Ar age on basalt in the Costa Azul Member of 14.3 ± 2.6 m.y. The correlation is based upon mapping by Flynn (1970) and Scheidemann (1976). The extention of the Miocene age to the Sweetwater "Formation" is based upon the gradational contact between the two units.

Artim and Pinckney (1973) suggested that the Sweetwater "Formation" might be Eocene, and Kennedy (1977) places much of what they designated as Sweetwater "Formation" within the Eocene Mission Valley Formation. This is an unacceptable hypothesis, not only because it is hard to explain intergradation between Eocene and Middle Miocene units, but because of the radical contrast between Eocene and Miocene erosional environments. All Eocene formations in the San Diego area contain well-rounded, resistate conglomerates, composed largely of exotic siliceous porphyries and quartzite known as the "Poway" type clast population. Miocene conglomerates of the area (Rosarito Beach Formation and San Onofre Breccia) tend to be angular, poorly sorted, and of local provenance.
The coarse clastic facies of the Sweetwater "Formation" is totally dissimilar from those of Eocene age and entirely consistent with those of Miocene age.

NOMENCLATURE FOR THE MIOCENE UNITS

The names Sweetwater and Otay Formation introduced by Artim and Pinckney (1973) and used here in quotation marks are unsatisfactory because they ignore the adjacent Rosarito Beach Formation which includes similar rocks of similar age and has priority (Minch, 1967). Scheidemann (1976) correlates the Otay "Formation" with the upper portion of the Rosarito Beach Formation (probably the Las Glorias Member) and therefore assigns the name Rosarito Beach Formation (undifferentiated) to the Otay "Formation." Since the Sweetwater "Formation" is dissimilar to any unit described by either Minch or Flynn, Scheidemann retained that name as proposed by Artim and Pinckney. This solution may be technically correct, but is not entirely satisfactory because the Sweetwater and Otay units are as closely related to each other as the Otay is to the type of strata of the Rosarito Beach Formation.

We propose, therefore, that the names Sweetwater and Otay be given Member status in the Rosarito Beach Formation. Even if the Otay Member should prove to be the exact stratigraphic equivalent of the Las Glorias Member, relating the distinctive stratigraphy north of the Tijuana Valley to its own separate type section has practical advantages.

TYPE SECTION FOR THE SWEETWATER AND OTAY MEMBERS

We have not found a locality in which the contacts of both the Mission Valley Formation and Otay Member of the Rosarito Beach Formation can be seen in a single continuous section. An excellent area in which to see the Sweetwater Member lies between the South Bay Freeway and Paradise Valley Road; however, the Otay Member has been entirely removed by erosion below the San Diego Formation. The area adjacent to the north end of Proctor Valley includes all three formations, but the Mission Valley contact is poorly exposed. Perhaps the best complete section of the Sweetwater Member is found between Acacia Avenue and Otay Lakes Road in Bonita along the south side of Sweetwater Valley. The upper contact of the Mission Valley Formation can be seen near the valley floor at Bonita and the Otay Member is exposed in the hills between the two roads. Construction may soon destroy the usefulness of this type area.

The type section of the Otay Member of the Rosarito Beach Formation is designated the natural ampitheater on the northeast side of Chester Canyon, opposite the bentonite clay mine. At this locality the entire formation is exposed in a single natural cliff, with both the lower and upper contacts exposed.

INTERPRETATION AND CONCLUSIONS

The grain-size of the Sweetwater Member decreases and the thickness increases towards the west. These trends together with the exposed basement rock knobs and soil profile over the Mission Valley Formation suggest deposition as an alluvial fan or a group of coalescing fans from steep mountain ravines to the east, feeding desert playas to the west. The poorly stratified angular conglomerates and conglomeritic gritstones near the mountain front may represent lag deposits formed as the finer sediments were reworked toward the west.

The better rounded and sorted sandstones within the Sweetwater Member may have been deposited by stream channels which reworked the fan and playa deposits.

The gradational contact between the Sweetwater and Otay Members represents a difference in provenance and depositional process. Whether this change occurred simultaneously across the basin or is a time-transgressive contact has not been established. The Otay deposits appear to be lacustrine or playas with some channel sands. The bentonitized ash beds are believed to have fallen from eruptive centers located to the southwest. The Otay is not, however, simply a western volcanic facies contemporaneous with an eastern provenance Sweetwater facies. Near and south of the International Border it laps clear across the Sweetwater Member to the crystalline basement.

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View toward east of Otay Valley, Otay Mesa, Tijuana River Valley, and San Ysidro Mountains. International Border runs from lower right to upper left. Otay Mesa is capped primarily with Pleistocene terrace deposits and Pliocene San Diego Formation.

CORRELATION OF THE OTAY AND ROSARITO BEACH FORMATIONS

Robert C. Scheidemann, Jr.
Union Oil Company
Santa Paula, California

In 1973, Artim and Pinckney proposed two new formations in southwestern San Diego County, in strata that were previously thought to be part of the Pliocene San Diego Formation. The upper unit which they named the Otay Formation was believed to be comparable to the Miocene Rosarito Beach Formation in northwestern Baja California, Mexico.

In the area studied, a positive correlation was made between the Otay Formation of San Diego County and the tuffaceous, fine-grained sandstones and siltstones of the Las Glorias and Los Buenos Members of the Rosarito Beach Formation.

It is recommended that the Otay Formation be removed from the geologic literature in deference to the formation name, Rosarito Beach Formation, as established in 1970 by John Minch.

The Rosarito Beach Formation thins northward from 76(+) meters in the area mapped just east of Tijuana to zero meters just north of Sweetwater Valley in southwestern San Diego County, where it pinches out. In the area mapped, the horizontal strata of the Rosarito Beach Formation rests disconformably upon the Sweetwater Formation.

INTRODUCTION

The Sweetwater and Otay Formations were proposed by Artim and Pinckney (1973), but the authors failed to describe type sections or give type localities for their new stratigraphic units. Instead, they offered loose descriptions of the characteristic lithologies of their two formations. They believed the Sweetwater Formation was Eocene in age and the Otay Formation was correlatable with Rosarito Beach Formation (Minch, 1967) south of the United States-Mexico border, therefore assigning it a Miocene-Pliocene age.

The intent of this study is to see if a positive correlation can be established between the Otay Formation and Rosarito Beach Formation.

The area mapped is located approximately eight kilometers east of the Tijuana border crossing and is adjacent to the International Border that runs along Otay Mesa in northern Baja California, Mexico (Figure 1). Easy access to the area is gained by both dirt and paved roads leading from Mexican Highway 2.

Field work was accomplished in the fall of 1976. Mapping was done on a 1:50,000 (centimeter) scale Mexican Government 1973 preliminary topographic base map, code I-11-D-61, enlarged to a scale of 1:25,000 (cm) for the original map. An area of approximately 50 square kilometers was mapped (Figure 2).

PREVIOUS WORK

Prior geologic studies involving detailed mapping in the southwest portion of San Diego County have been made by Artim and Pinckney (1973), Mandel (1974), and Kuper (1976). Geologic mapping to the east, south, and west of the area currently studied in northern Baja California has been accomplished by Voorhees (1975), Flynn (1968), and Minch (1967), respectfully.

GEOLOGIC SETTING

In the mapped area east of Tijuana is an exposed succession of horizontal to very slightly dipping Miocene sedimentary strata unconformably overlain by Pleistocene terraces and channels. To the immediate east of the area are local Tertiary andesite plug domes (Strong, 1971) followed by the Miocene strata of low relief. Further to the east is the abrupt rise of the basement rocks composed of the Santiago Peak Volcanics and the plutonic batholithic rocks of late Jurassic and early Cretaceous age, respectively.

STRATIGRAPHY

Sweetwater Formation.---The Sweetwater Formation was first named by Artim and Pinckney (1973) to define the lower of

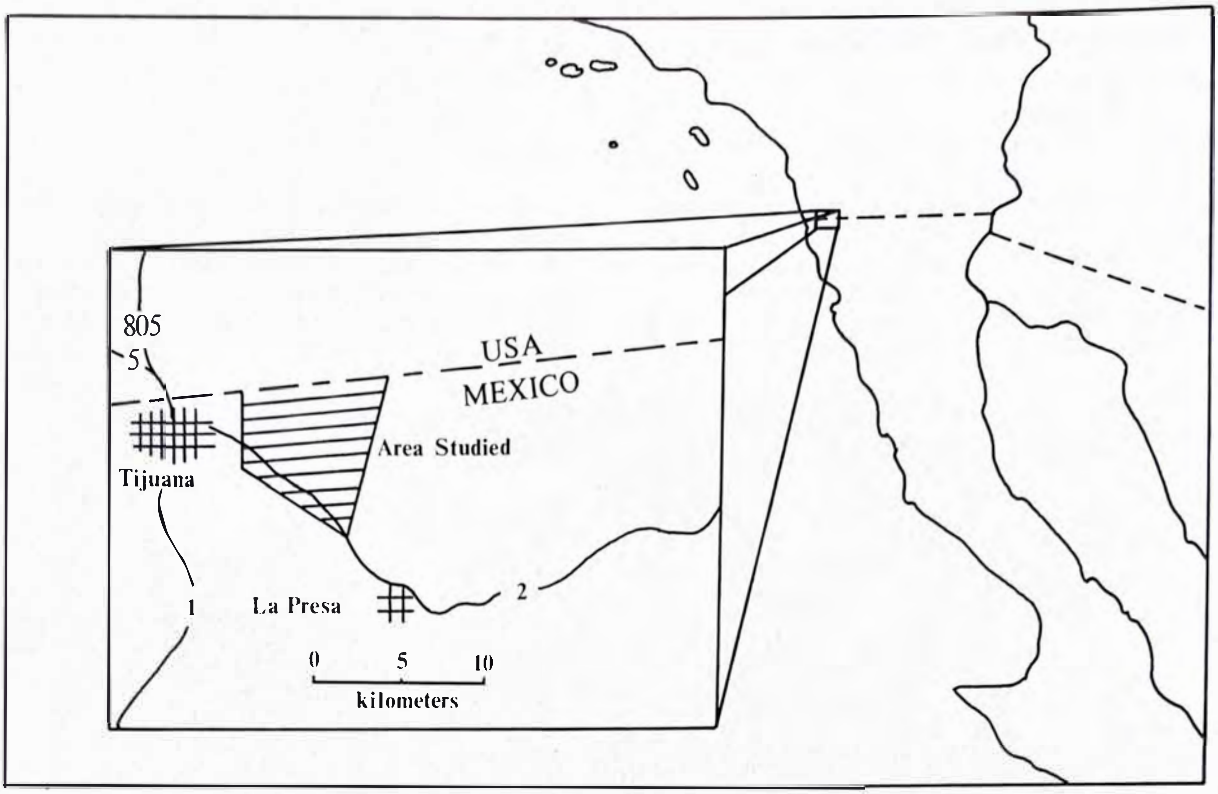

Figure 1. Location map.

the two formations previously classified as part of the San Diego Formation, resulting from their study of the La Nacion fault. In naming the Sweetwater Formation they neglected to measure a type section, but offered a brief lithologic description: "a lower gritty sandstone member overlain by a 35-meter-thick red claystone member." They assigned it an Eocene age on the basis that (in San Diego County) it was known to overlie an Eocene Formation and was overlain in turn by their Otay Formation which they believed was equivalent to Minch's (1967) Miocene Rosarito Beach Formation south of the border.

Kuper (1976) pursued the questioned Sweetwater Formation by compiling a general reconnaissance map that denoted the Sweetwater and Otay Formations. His main objective was to define their stratigraphic extent and to describe an accurate type section of the Sweetwater Formation. The Sweetwater Formation was found to be approximately 63 meters thick and has four distinct lithologic members. These members are gradational, varying from the boulder cobble breccia to the pebbly angular sandstones to the gritty mudstones to the upper sandstone. In southwestern San Diego County it was found to lie unconformably upon the Mission Valley Formation of Eocene age and to the south in northern Baja California it, in turn, is unconformably overlain by the Miocene Rosarito Beach Formation (Voorhees, 1975).

In the present area studied, the Sweetwater Formation has limited exposure, revealing only 45 meters of section. The Sweetwater Formation outcrops in the upper northwestern portion of the area in the steep cliffs adjacent to the Tijuana River on the southwestern extension of the Otay Mesa. Outcrops are best found along the road cuts and in the sparse gullies, as the steep slopes are covered by mass wasting and slumps. The lower 30 meters of the section consist of varying red-brown to yellow-brown to greenish siltstones, mudstones and claystones that are

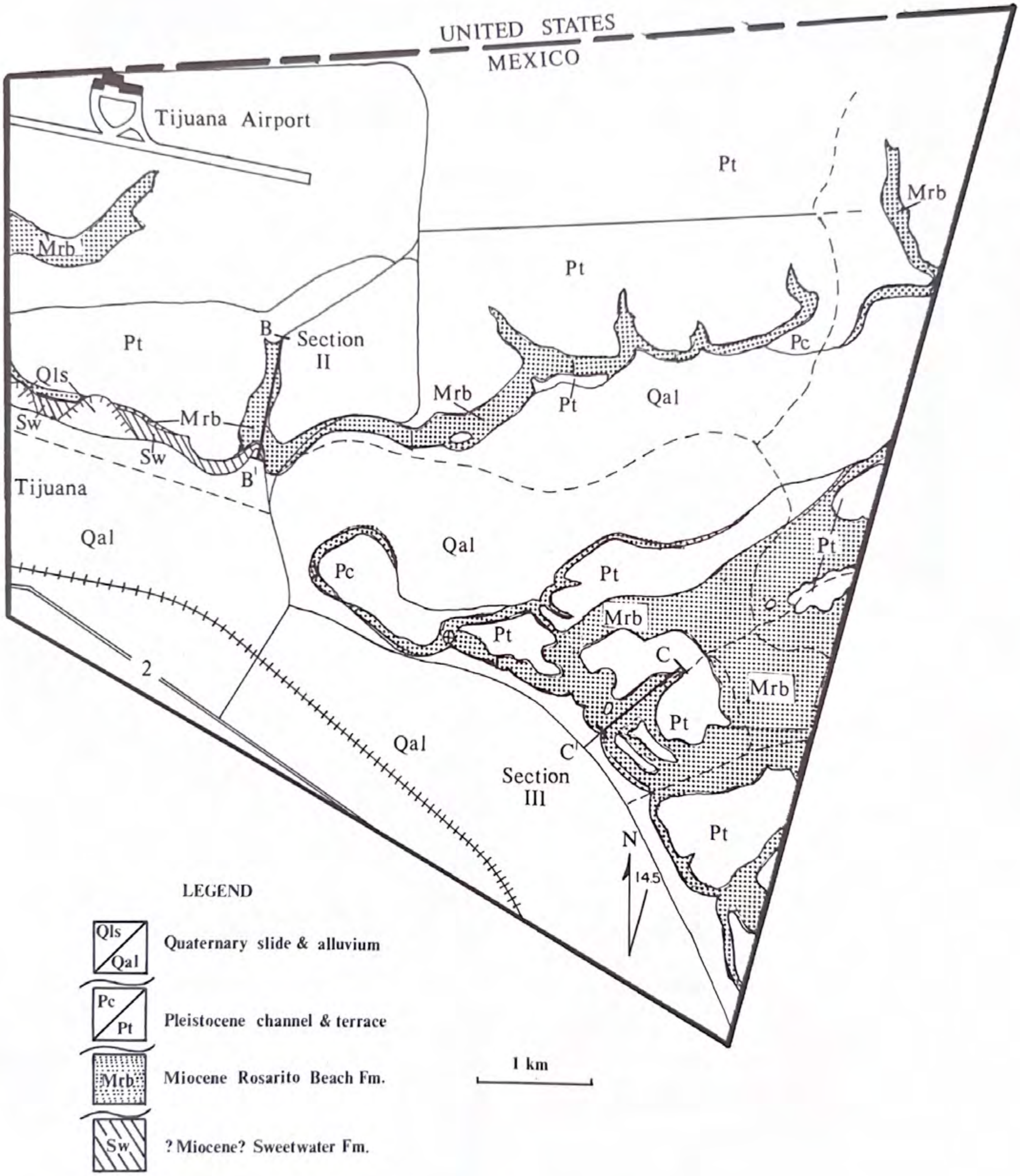

Figure 2. Geologic map of the eastern Tijuana area.

fractured and in places gritty. Above these argillaceous rocks is a 15-meter section of medium- to massive-bedded, pinkish-tan to gray-brown, medium- to coarse-grained arkosic sandstones that, in places, becomes grit and pebble rich. The individual grains range from angular to subrounded and commonly have a matrix

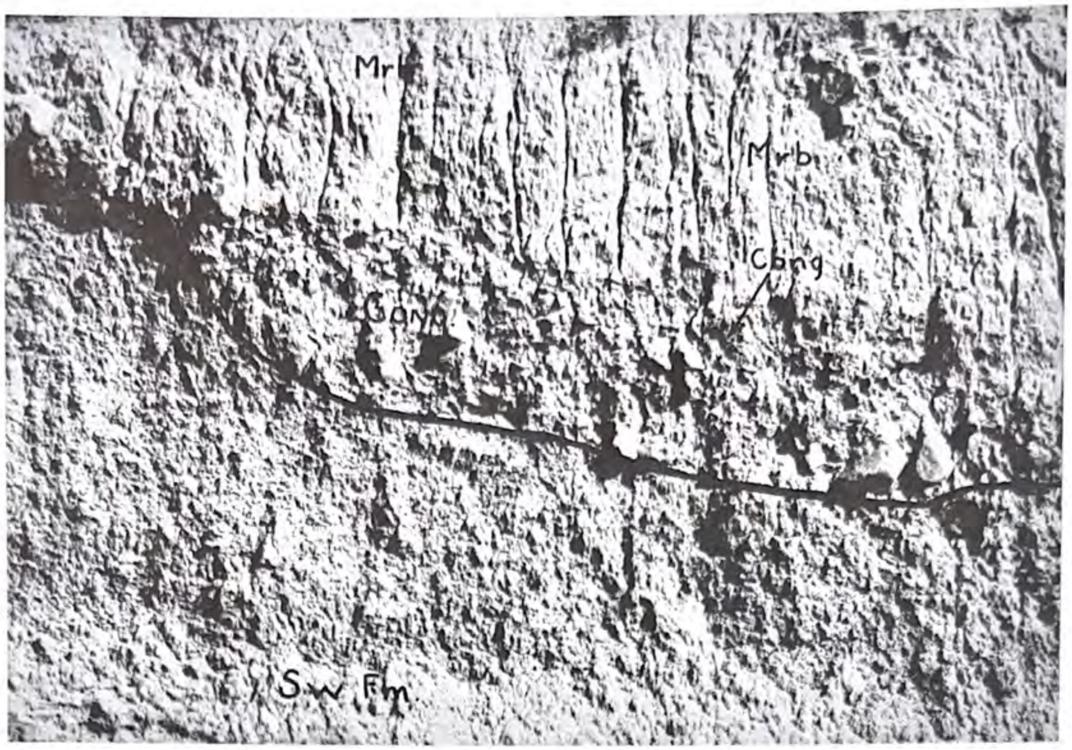

Figure 3. Rosarito Beach Formation unconformably overlying the Sweetwater Formation. Note the channel of conglomerate.

of fine sand and silt. It is poorly sorted and friable although locally indurated.

In the area mapped, it was found that the Rosarito Beach Formation disconformably overlies the Sweetwater Formation. This is well demonstrated at the valley junction of the main road that descends from the Tijuana Airport (Figure 3). Here the Sweetwater Formation has been stripped of the upper sandstone down to a mudstone of a few meters thickness, displaying a highly eroded surface covered by a thin veneer of a metavolcanic breccia thickening in a channel and subsequently overlain by a tuffaceous section of the Rosarito Beach Formation. This is the easternmost extent of the Sweetwater Formation in the area studied, although it is exposed in a similar disconformable relationship in Voorhees' area, located approximately 10 kilometers to the southeast. The Sweetwater Formation was not observed in Flynn's area to the direct south of the area mapped.

Both Voorhees (1975) and Kuper (1976) believe that the Sweetwater Formation represents an alluvial fan bajada environment extending westerly out of the eastern metavolcanic and plutonic mountains during the Miocene. The disconformity found in both Voorhees' area and the present area suggests a period of erosion at the base of the fans prior to the deposition of the Rosarito Beach Formation.

Rosarito Beach Formation.---The Rosarito Beach Formation is the predominant stratigraphic unit in the area. It was first mapped and described by Minch (1967) in the valleys and hills running south along the coast from Tijuana to Rosarito Beach. He divided the formation into five members: the basal Mira al Mar Member, a fossiliferous sandstone and breccia with some shale and limestone; the Costa Azul Member, basalt and tuff; the Amado Nervo Member, basalt; the Las Glorias Member, basalt and fine- to coarse-grained tuffaceous sandstones and siltstones; and the upper Los Buenos Member, primarily basalt with fine- to medium-grained tuffaceous sandstones and siltstones. Minch (1967) assigned a Miocene age to the formation based upon two independent lines of evidence. In his basal Mira al Mar Member, he found a collection of marine micro and megafossils that indicated a middle Miocene age. In this same basal member he also observed large clasts of Franciscan-type detritus, believing it reflected the Miocene offshore rise as described by Woodford (1925). Finally, a K/Ar age date of 14.3±2.6 million years was achieved by Hawkins (1970) on one of the basalts in the lower portion of the Rosarito Beach Formation, thus solidifying a middle Miocene age.

The area directly to the east of Minch's was mapped by Flynn in 1968. In the northern portion of his area he found that the basalts either pinched out

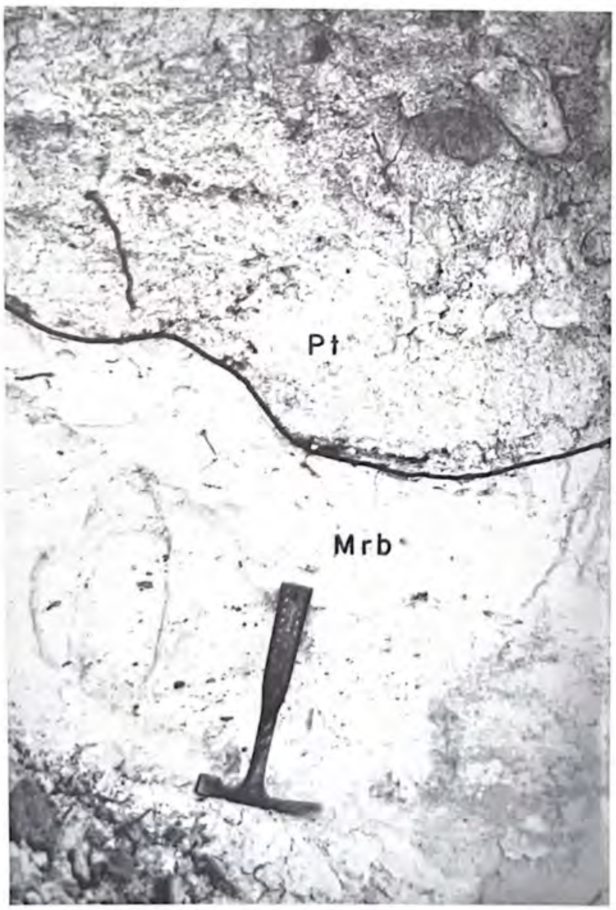

Figure 4. Pleistocene terrace overlying the Rosarito Beach Formation. Note the crossbedded shale ripup clasts in the Mrb.

or were removed by erosion. Here, the Rosarito Beach Formation is composed of the upper two sandstones of the Las Glorias Member and the lower sandstone of the overlying Los Buenos Member. The combined thickness of these northern tuffaceous sandstones, siltstones, and mudstones is 100(+) meters (Flynn, 1968).

In the area currently under study, these same dominant unfossiliferous tuffaceous sandstones and siltstones, as found in Flynn's adjacent area to the south, form the rolling hills and steep cliffs. The maximum thickness exposed is approximately 80 meters and is composed of predominantly white to light gray, very fine- to medium-grained tuffaceous sandstone that varies in composition from a lithic arkose to a feldspathic litharenite (Folk, 1968). Locally, it varies in grain size to a rare coarse sand and grit. Primary components are quartz, feldspar, hornblende, biotite, and polymineralic fragments of basalt, andesite, and tuff. The grains are angular to subangular and are locally cemented with calcite. The sandstone is poorly sorted with varying amounts of the tuffaceous clay matrix and is thin to massively bedded. Due to the poor cementation, the sandstone is friable although in places locally indurated and in many outcrops, displays a blocky or spheroidal weathering profile. Although the sandstones are not conglomeratic, there are erratic rounded cobbles and boulders of weathered basalt, andesite, metavolcanic, and granitic rocks in the southern part of the area (Figure 5, Sections II and III). In the south trough, lenticular and planar tabular crossbedding is also observed. Interbedded and commonly found as ripup clasts are the thin- to medium-bedded red-brown to light-brown to pinkish-gray siltstones, mudstones and claystones which are, in part, bentonitic (Figure 4). Where the waxy bentonite is concentrated, it commonly gives the sandstone the appearance of a popcorn texture which is due to weathering.

Pleistocene terraces, channels, and alluvium.---Throughout the area, Pleistocene sediment is deposited unconformably upon the Rosarito Beach Formation. It is expressed as both paired and unpaired alluvial terraces and channel fill.

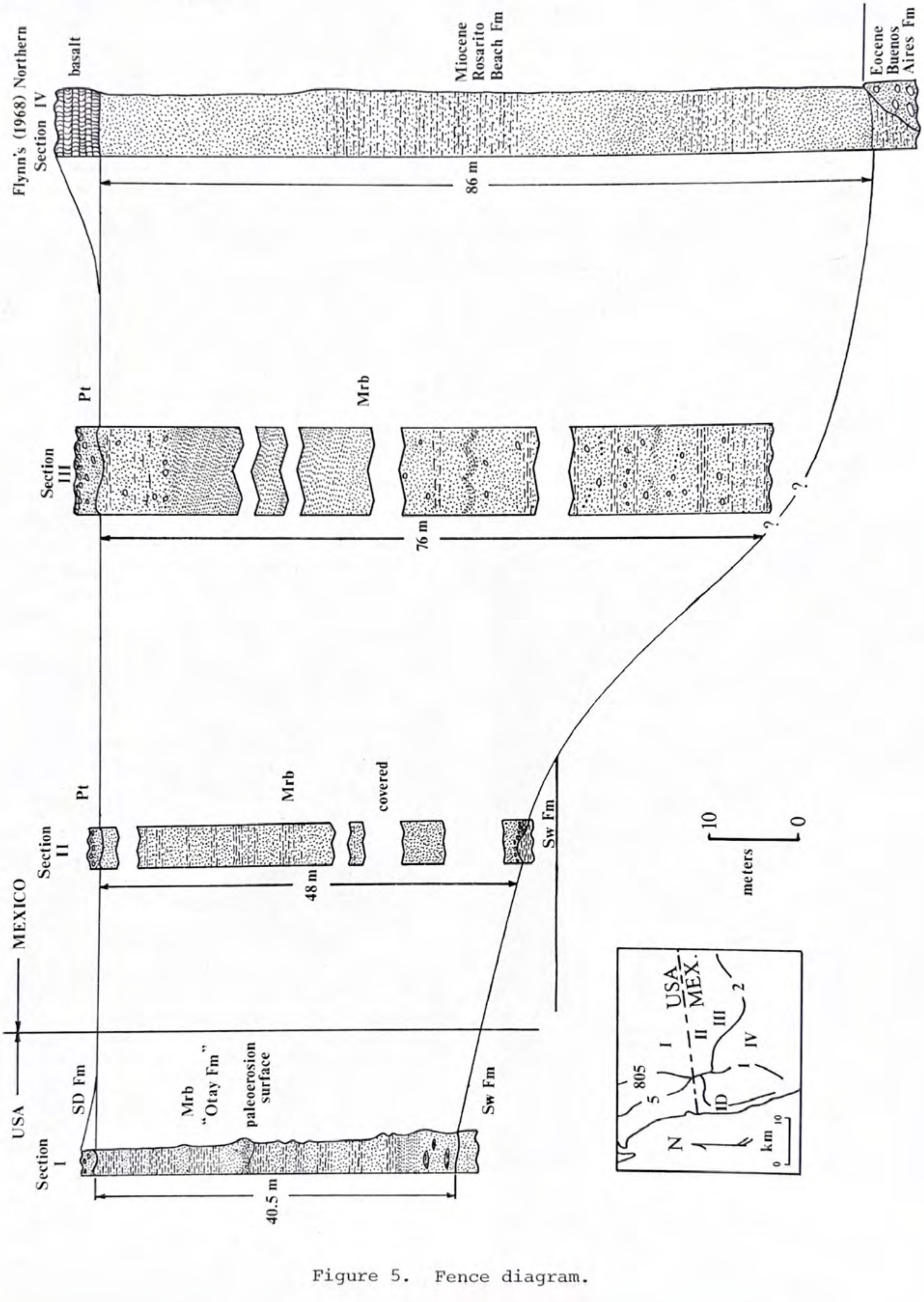

Figure 5. Fence diagram.

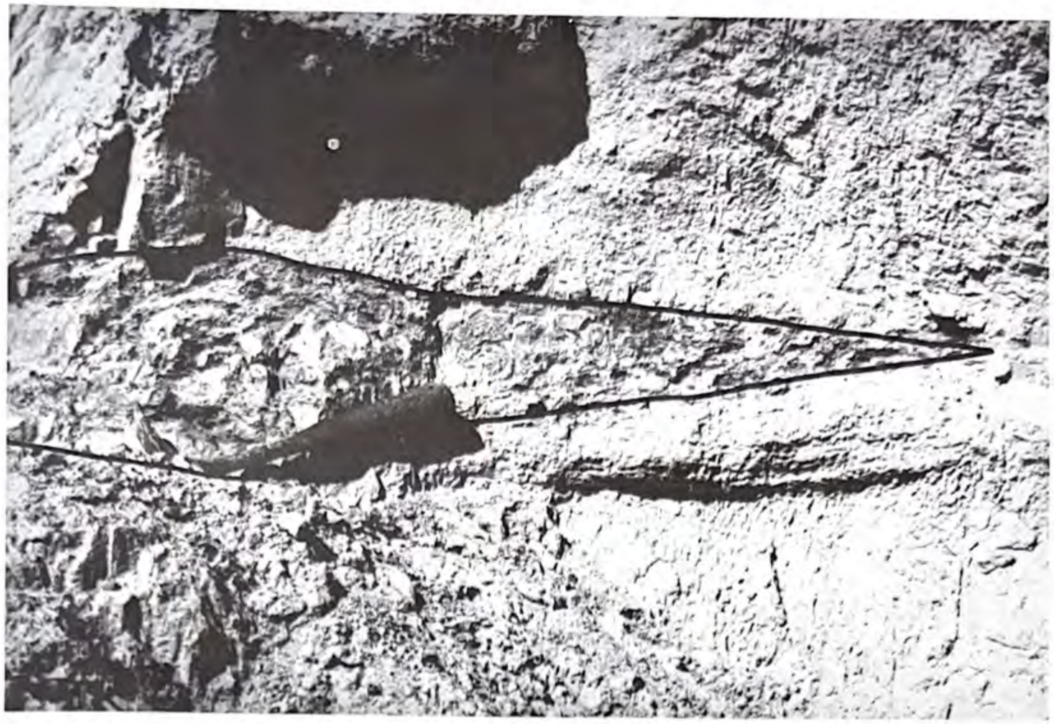

Figure 6. Lentil of bentonite in the Rosarito Beach Formation north of the International Border.

The deposits vary in thickness from less than three meters on the thinnest terrace to 40(+) meters in the channel deposits. The composition varies from terrace to channel, but it is basically a cobble to boulder conglomerate of granitic, metavolcanic, and quartzite clasts overlying and intermixed with a medium- to coarse-grained, gritty, poorly sorted sandstone. The sandstone varies in color from white to tan to red-brown and its subangular grains are predominantly quartz, feldspar, and large flakes of biotite. No fossils were found, but in a few places, rounded cobble- to boulder-size ripup clasts of the Rosarito Beach Formation are suspended in it.

It is hypothesized that these terraces were deposited by both marine and fluvial processes. The latter is confirmed by the presence of the nonpaired terraces and the large channels that must have resulted from a meandering river effected by a change in base level.

Currently the valleys are filled with alluvium typical of a coarse-grain meander belt. It consists of unconsolidated silt, sand, grit, and cobbles, presently being quarried for aggregate.

STRATIGRAPHIC IMPLICATIONS

In the course of this project, three columnar sections were measured: two from the study area and one north of the International Border. These were then drawn to scale along with a section measured by Flynn (1968) in the northern part of his area and displayed in a fence diagram (Figure 5). The columnar section measured north of the border (Figure 5, Section I) in Artim and Pinckney's (1973) Otay Formation displays a slight change in the lithology from the sections measured to the south (Figure 5, Sections II, III, and IV) of the Rosarito Beach Formation.

The measured section north of the border is located on Otay Mesa approximately 1.4 miles in a N40°W direction of the west end of the Brown Field Airport on the northeast side of Dennery Canyon, T. 18 S., R. 1 W., sec. 29, in the Imperial Beach 7.5-minute quadrangle. The boundary between the Sweetwater and Otay formations was picked according to Kuper's (1976) definition.

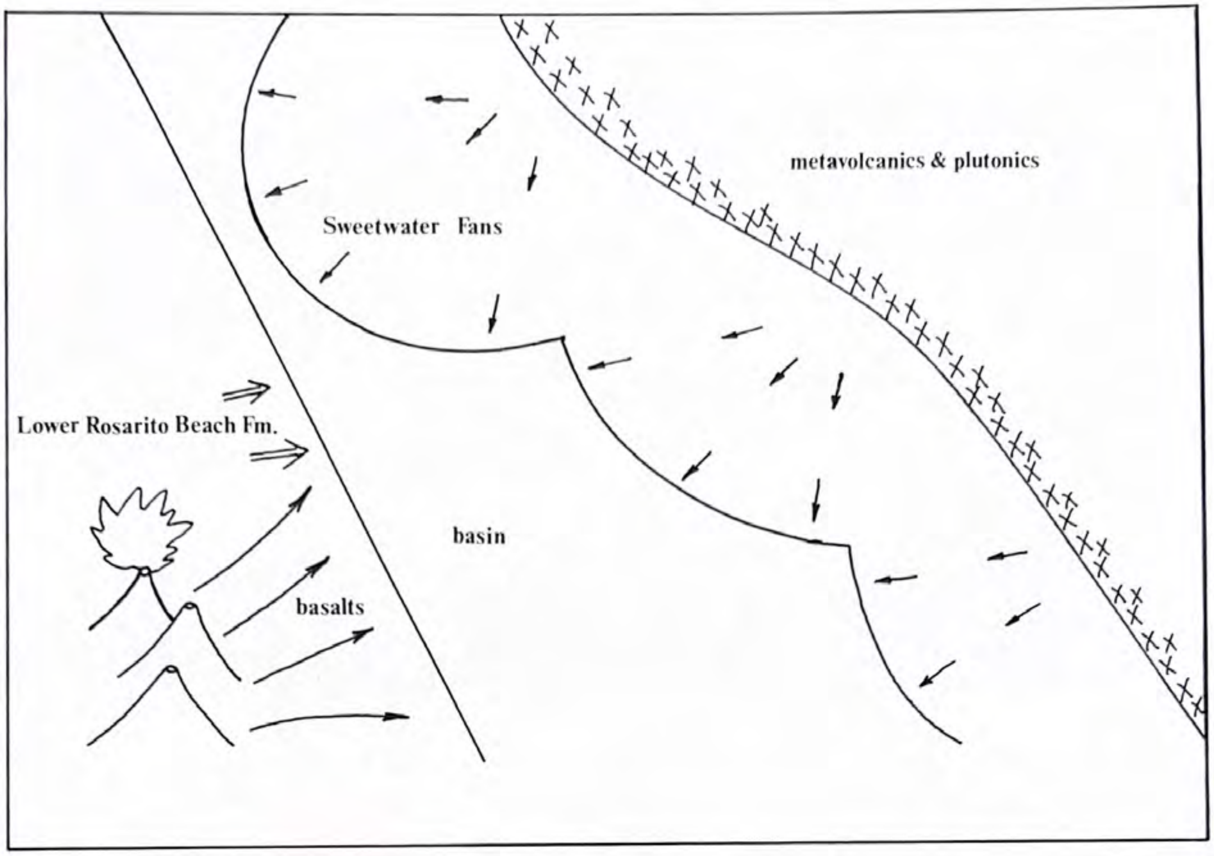

Figure 7. Depositional model during the Miocene.

The sandstones of this section are composed of a white to light grey, very fine- to medium-grained silty sandstone that is basically a lithic arkose (Folk, 1968). As compared to the Rosarito Beach Formation south of the border, the northern sandstone has a decreased amount of hornblende, rock fragments and a very sparse amount of tuff but contains an increased amount of biotite, calcite cement and small pieces of rounded red brown waxy bentonite.

Interbedded and comprising a greater percentage of this section than those measured to the south are the siltstones, mudstones and bentonitic claystones. Throughout the section are stringers, lentils, and beds of nearly pure to pure, red brown to white, bentonitic clays (Figure 6). The argillaceous rocks vary from thin to massive bedded and in color from light olive grey to light grey to red brown.

Near the middle of this northern section is a large channel believed to be evidence of a local erosional event not apparent in other outcrops of the formation. Above the channel the section is primarily siltstone with thin to medium interbeds of indurated fine-grained sandstone and two to six centimeter thick stringers of caliche due to weathering near the top.

These northern sandstones and siltstones of Artim and Pinckney's (1973) Otay Formation: "35 to 50 meters of white, volcanically derived tuffaceous fine sandstones with bentonitic interbeds, marked by a basal breccia conglomerate unit," as measured by the author on the north side of Otay Mesa are synonymous with the tuffaceous sandstones of the Rosarito Beach Formation as measured and described on the south side of Otay Mesa.

Comparison of the four columnar

sections indicates certain trends. The most obvious trend is the rapid thinning of the Rosarito Beach Formation as one moves from Flynn's section to the north (Figure 5). Flynn's (1968) northernmost section of the Rosarito Beach Formation displays 86(+) meters of the tuffaceous lithic sandstones and siltstones. The most southerly of the three most recently measured sections (Figure 5, Section III) is 76 meters thick where exposed, but is believed to extend below the valley floor. Moving to Section II on the south side of Otay Mesa, the Rosarito Beach Formation thins to 48 meters and finally to Section I on the north side of Otay Mesa the formation is reduced to 40.5 meters. As Kuper (1976) indicates, the formation pinches out just north of the Sweetwater Valley in southwestern San Diego County.

Along with the decrease in thickness, there is also a gradual change in the lithology. As one moves northward, there is a progressive decrease of the rock fragment and tuffaceous content of the sandstones with an increase in the amount of biotite, bentonitic clay, and calcite cement. These lithologic changes can be attributed to factors such as the distance from the source area and local variations in the environment of the deposition.

INTERPRETATION

Prior or during the early Miocene there was a westward progradation of detritus from the eastern plutonic and metavolcanic mountains forming a subaerial alluvial fan or bajada unconformably overlying the Eocene strata (Voorhees, 1975; Kuper, 1976). To the west in the Continental Borderland during the middle Miocene, was the offshore rise generating the Franciscan-type clasts into a marine basin followed by a period of volcanism also located to the west, being dispersed in an easterly direction on a subaerial surface (Minch, 1970). In between the basalt flows the volcanic ejecta mixed with the clastic debris from the sedimentary and igneous rocks in a fluvial, lacustrine environment forming the tuffaceous lithic sandstones and siltstones (Flynn, 1968). In the late Miocene and early Pliocene, there was a period of faulting in the south (Minch, 1970) although it is of a

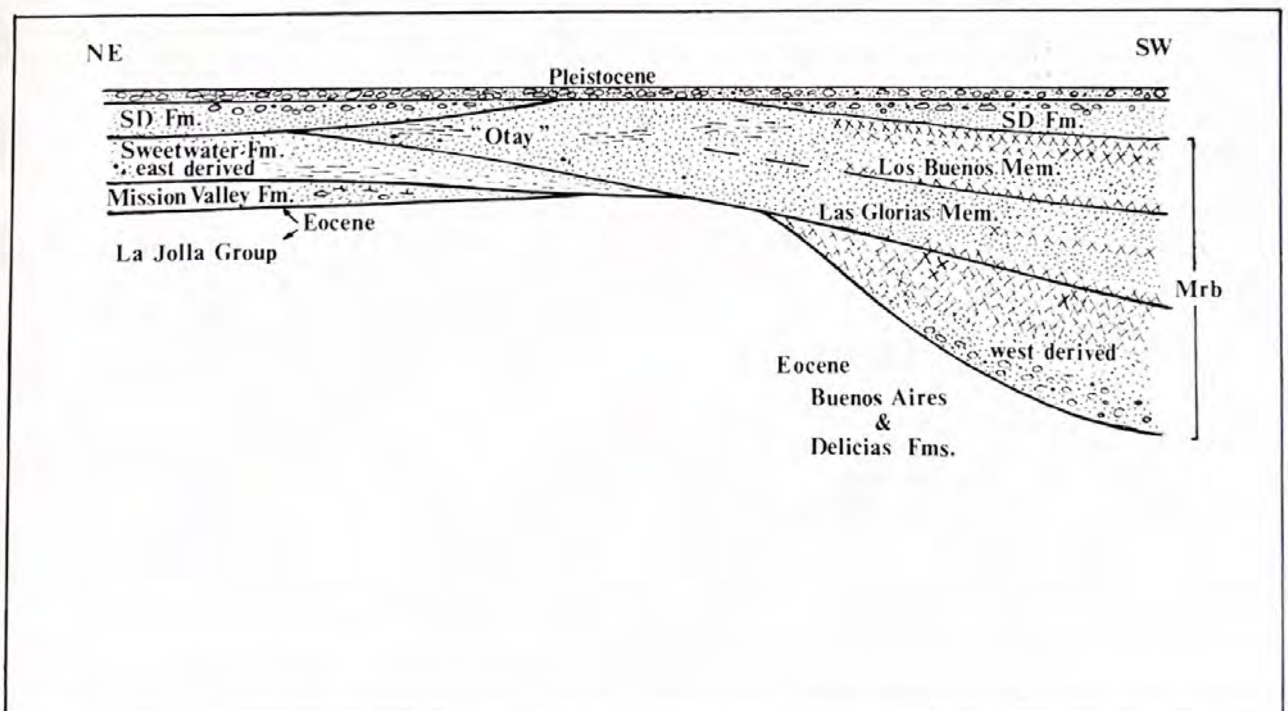

Figure 8. Stratigraphic relationships of the Tertiary formations.

very minor scale in the area presently studied. The fence diagram and the various geologic maps of the area suggest a modification of the depositional environment for the upper two members of the Rosarito Beach Formation.

Prior to the deposition of the Las Glorias and Los Buenos Members, a broad trough similar to that of Moore and Kennedy (1970) extended in a southeasterly direction from Sweetwater Valley into northwestern Baja California. The basalts and sediments formed an enclosure to the west, and the metavolcanics plus the plutonic mountains formed a wall to the east. To the north, the prograding Sweetwater fan complex formed an enclosure, creating a large-scale bolsun or bay to the south (Figure 7). A period of sparse sedimentation with erosion on the lower part of the fans as indicated by the disconformity south of the border was followed by the deposition of the upper members of the Rosarito Beach Formation in a subaqueous environment. Finally, erosion due to a regressing water level is evidenced by the pinching out of the Las Glorias and Los Buenos Members in the north.

The sampled sandstones of the Rosarito Beach Formation were found to have a mean grain size of 3.23ϕ, a very fine sand and were poorly sorted, 1.20ϕ, as they contained a high amount of clay matrix between the angular to subangular unfrosted grains. These characteristics were present even in areas of cross-bedding and tend to preclude an eolian environment (Selley, 1970). The planar tabular and trough lenticular crossbedding along with the abundant ripup clasts are common features associated with a fluvial medium. The angularity and poorly sorted nature of the sandstones along with the beds of siltstone suggest a body of water with little agitation. Such a body of water is necessary as pointed out by Cleveland (1960) to transform the volcanic ashes into the present form of bentonite as found north of the International Border.

CONCLUSION

Through the use of consistent, defined formational boundaries in the mapped areas and the measurement of a series of columnar sections exposed in strategic locations, it is concluded that Artim and Pinckney's Otay Formation (1973) correlates to Minch's (1970) Miocene Rosarito Beach Formation.

The Otay Formation as mapped north of the International Border (Kuper, 1976) is equivalent to the combined sedimentary lithologic bodies of the Las Glorias and Los Buenos members of the Rosarito Beach Formation (Figure 8). Furthermore, on the basis of this correlation, it is urged that the use of the Otay Formation be abandoned, simply to be replaced north of the border with the proper stratigraphic nomenclature as assigned by Minch (1970), the Rosarito Beach Formation.

This conclusion draws upon the rules as set up in the Code of Stratigraphic Nomenclature in the belief that this will eliminate an unnecessary term in the geologic literature while broadening the understanding of the local geologic history.

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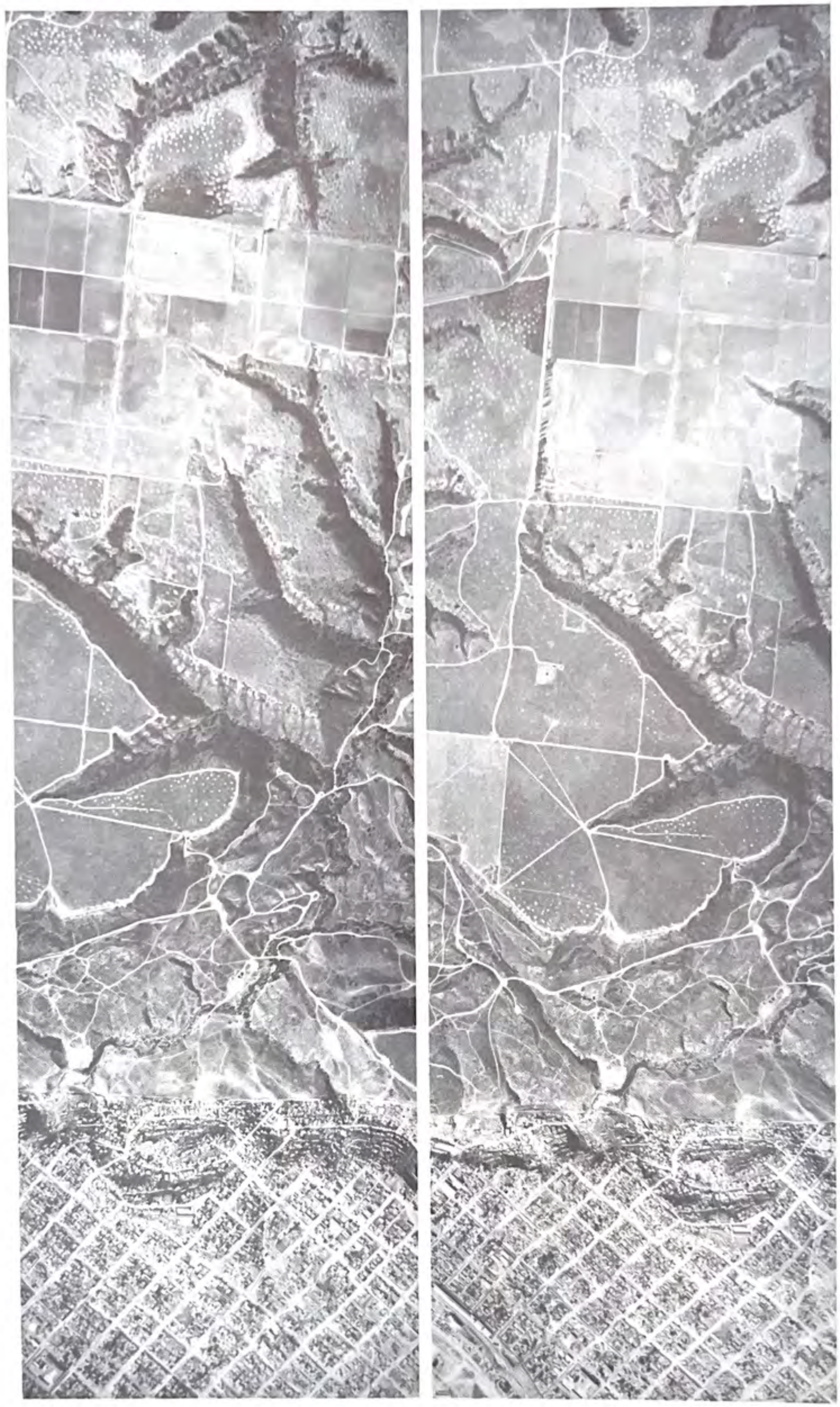

Stereogram of serial vertical photography looking down on Otay Mesa, San Ysidro, and the International Border in October, 1969. Altitude: 11,000 feet.

The San Ysidro landslide is visible in center of stereogram. White dots on mesa top are mima mounds. Photograph courtesy of Aerial Fotobank, San Diego, California.

SEMIARID PALEOCLIMATIC INDICATORS IN NONMARINE EOCENE FORMATIONS, SOUTHWESTERN CALIFORNIA

Gary L. Peterson and
Patrick L. Abbott
Department of Geological Sciences
San Diego State University

INTRODUCTION

In determining the depositional environments of any formation or group of formations one aspect of the ancient environment that sedimentary geologists tend to ignore or at least tend to relegate to minor significance is the effect of the ancient climate. However, the paleoclimate is in many cases of fundamental significance in determining the types of rocks that are deposited, the order and arrangement of rock units, and the quantity of sediments deposited. To cite an extreme example in the modern world, very different types of sediments are deposited in the humid, tropical equatorial regions than in the polar regions. Likewise, hot and humid regions are characterized by very different types of sediments than hot desert regions. Since all sediments are deposited in some type of climatic regime, a study of almost any stratigraphic unit should reveal at least something about the ancient climate that prevailed in the depositional area during the time of sedimentation.

In recent years, our attention has been increasingly focused on the types of paleoclimates that are revealed by the stratigraphic units of coastal southwestern California and northwestern Baja California and the results are somewhat startling. For example, although the region has no Paleocene through early mid-Eocene rock units, there is a wide spread deeply weathered zone (i.e., ancient soil) that was well developed across all Cretaceous and pre-Cretaceous rock units and overlain by mid-Eocene sedimentary rocks. This ancient soil (lateritic paleosol) indicates that a humid tropical paleoclimate comparable to that of the modern equatorial belt prevailed in this area in Paleocene and Early Eocene time (Peterson and Abbott, 1975; Abbott *et al.*, 1976).

More recently, our attention turned to the nonmarine Eocene stratigraphic units which overlie the deeply weathered lateritic paleosol (see Figure 1). Within these rock units, particularly within the Friars and Mission Valley formations, are well-developed beds of caliche which indicate a semiarid paleoclimate (Pierce, 1974; Pierce and Peterson, 1975). This initially seemed somewhat contradictory, considering the paleoclimate indicated by the underlying paleosol, but can be easily explained by a profound change in climate occurring at about mid-Eocene time (Peterson *et al.*, 1975). Interestingly, other completely different lines of evidence likewise indicate a mid-Eocene climatic change on a world-wide basis (Savin *et al.*, 1975).

In considering the semiarid paleoclimatic interpretation for the nonmarine Eocene rocks, we asked the question: what features other than the caliche beds might indicate the paleoclimate? Somewhat surprisingly, a variety of other characteristics seem best explained by deposition in a semiarid environment. The purpose of this article is to outline the nature of the semiarid paleoclimatic indicators. The article is based in part on a paper presented before the Society of Economic Paleontologists and Mineralogists Research Symposium "Paleoclimatic Indicators in Sediments" in New Orleans in May, 1976 (Peterson and Abbott, 1976).

LATER EOCENE DEPOSITIONAL ENVIRONMENTS

About 300 m of nearly flat-lying terrigenous sedimentary rocks of Middle and Late Eocene age overlie the lateritic paleosol (Kennedy and Moore, 1971; Flynn, 1970). The depositional environments recognized within the Eocene complex range from terrestrial to deep marine. For the purpose of our paleoclimatic interpretations, the nonmarine portion of the Eocene succession is most important. Consequently, our remarks will be confined to that portion (Figure 1). The Eocene stratigraphy north of the International Border has been extensively studied and has considerably better exposures because of abundant deep roadcuts and graded slopes in new housing developments. South of the border, although less thoroughly studied, the Eocene succession appears comparable (Flynn, 1970; Minch, 1970, 1972).

The nonmarine Eocene stratigraphy consists of two mutually intertongued bodies of rock (Peterson and Kennedy, 1974). An eastern predominantly cobble conglomerate rock unit intertongues toward the west with a body of rock that is predominantly finer grained and is dominated by sandstone (Figure 1). These Eocene rocks were for the most part deposited near sea level and at the interface between marine and nonmarine depositional environments. Most of the easterly conglomeratic rocks are nonmarine; portions of the finer grained western part of the section have yielded marine fossils (Kennedy and Moore 1971; Lillegraven, 1973; Kern, 1974; Golz, 1976; Novacek, 1976). Individual tongues of the principal rock units are mappable throughout much of the greater San Diego area and are further designated by formational names as indicated in Figure 1 (Kennedy and Moore, 1971; Peterson and Kennedy, 1974).

The cobble conglomerate body of rock (represented by the Stadium and Pomerado conglomerates in addition to numerous smaller conglomerate beds and lenses within the Friars and Mission Valley formations) represents deposition on a large low-slope alluvial fan and fan delta complex. The apex of this ancient alluvial fan is exposed in the Tri-Way Materials Co. quarry several miles north of Likeside along the Lakeside-Ramona highway. The apex occurs at a point where a large Late Eocene river system entered the San Diego embayment and deposited its coarse travelly bed load as a large alluvial fan spread out across the topographically low coastal plain (Minch, 1970, 1972).

The finer grained body of rock (represented by the Friars and Mission Valley formations together with finer grained tongues within the principal conglomerate units) in intricately interfingered with the conglomerates and are intrepreted as overbank accomulations along main channel systems and also as back-fillings of tributary stream valleys leading down to the mainriver system (Peterson, 1971; Peterson and Kennedy, 1974). In addition, the westernmost portions of the Friars and Mission Valley formations contain some nearshore marine rocks probably deposited in distal delta bar and strandplain environments.

The geometry of the coarse conglomeratic rock unit together with the manner in which it is intertongues with the finer rocks suggests two major pulses of gravelly debris that built two major alluvial fan complexes. The total character of this type of depositional environment strongly implies semiarid to arid paleoclimatic conditions during sedimentation.

SOME CHARACTERISTICS OF THE FLUVIAL CONGLOMERATES

Provenance of the cobble clasts (locally referred to as "Poway clasts") of the Eocene conglomerates has been controversial and has received considerable attention (Bellemin and Merriam, 1958; LeLisle *et al.*, 1965; Woodford *et al.*, 1968; Peterson, 1971; Minch, 1970, 1972; Abbott and Peterson, in press). The work of Minch (1972) has marshalled convincing evidence that the source of the highly distinctive Poway clasts lies in Sonora, Mexico. There are no local outcrops of bedrock resembling Poway clasts, and locally derived conglomerates within the Late Cretaceous succession contain no Poway-type clasts (Peterson and Nordstrom, 1970; Nordstrom, 1970; Peterson, 1971; Jones and Peterson, 1973). The point here is that a locally derived accumulation of conglomerate is mostly a function of relief and could occur in an any climatic regime. However, transportation of coarse detritus over a considerable distance is more likely in a fluvial system characterized by occasional extremely large discharges; this situation more commonly occurs in arid to semiarid climatic settings.

The fluvial conglomerates range in clast size from granules to boulders in excess of 60 cm diameter. In general, the conglomerates are moderately well sorted and dominated by cobble-sized (approximately 124 mm diameter) detritus. Clasts are typically rounded to well rounded. The conglomerates tend to be uniform in clast types and size distri-

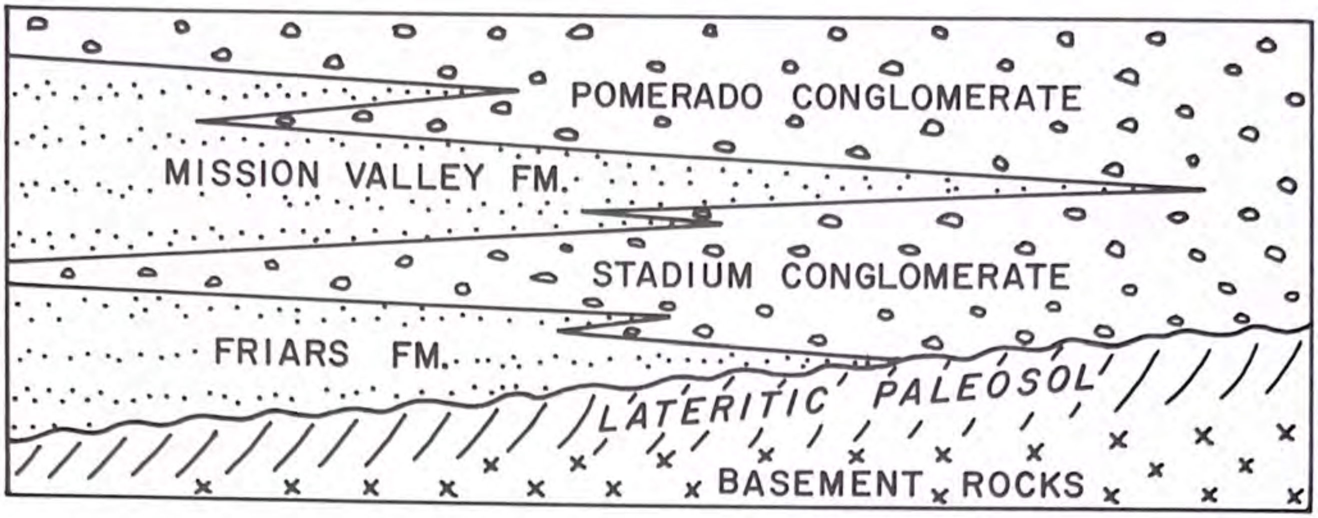

Figure 1. Generalized stratigraphic section for Later Eocene nonmarine units of the San Diego area (*after* Peterson and Kennedy, 1974).

bution at almost all localities; the Pomerado Conglomerate is distinguishable from the Stadium Conglomerate only by stratigraphic position.

The old river channel leading to the alluvial fan and fan delta complex in the San Diego area is referred to as the Ballena channel, and scattered outcrops of the channel fill perched among the batholithic rocks to the east of San Diego are referred to as the Ballena Gravels (Minch, 1970, 1972). These gravels and the associated channel can be traced east of San Diego to at least the Elsinore fault. A palinspastic reconstruction of southwestern California and Baja California to its geographic position in Late Eocene time removes the effects of the San Andreas and related faults and closes the later Cenozoic Gulf of California. This reconstruction indicates that the Ballena channel had its source area and headwaters in the Sonora, Mexico area (Minch, 1972).

The present western gradiant of the Ballena channel is 26 m/km. However, this gradient is not corrected for the late Cenozoic tectonic tilt of the Peninsular Ranges toward the west; thus, the original western gradient was considerably less (Minch, 1972, p. 62). Following the palinspastic reconstruction the distance from San Diego to the inferred source area is approximately 200-300 km. Minch (1972, p. 163) noted little or no downstream decrease in size or sorting of the clasts along the outcrops of channel remnants in the Peninsular Ranges, an observation we have likewise pointed out in the San Diego area.

We characterize the ancient Ballena fluvial system as a river with large fluctuations in discharge. The river transported a cobble-sized bed load ove: a long distance and down a low to moderate gradient. The necessary energy to transport such coarse detritus and transport it over such a long distance was probably gained from periodic large floods (flash floods). The insignificance of the clay fraction probably indicates that chemical weathering and rainfall were minimal in the source area or concentrated during certain times of the year. Thus, the river system probably was ephemeral or had greatly reduced flow during most of the year. The virtual absence of a clay fraction, and thus a suspended load, implies that the fluvial energy was concentrated on moving the gravel fraction.

A search for modern fluvial systems with dominantly cobble bedloads transported over long distances and analogous to the Ballena-Poway deposits turned up few possibilities. Examples where the steep slope and/or deep water occurred to generate the necessary high tractive forces include the White River on the flank of Mount Rainier (Fahnestock, 1963), the flood surge of the Rubicon River downstream from the Hell Hole dam following its failure (Scott and Gravlee, 1963), and the flood deposits of Arroyo Seco in the San Gabriel Mountains (Krumbein, 1942). Each of these channels, however, is developed on a high gradient surface (much higher than that of the Ballena channel). Each is subject to large discharges, but their gravelly deposits are not as well sorted and the gravel has not been transported over nearly as great a distance.

CALICHE-BEARING PALEOSOLS

The Upper Eocene nonmarine section contains numerous beds, lenses and nodules greatly enriched in calcium carbonate (Pierce and Peterson, 1975). These accumulations are absent in the marine Eocene formations. The carbonate rich layers and nodules contain up to 80% calcite; they characteristically also contain detrital sand grains and clay minerals scattered throughout the calcite. In outcrop the carbonate-rich layers typically are massive, soft, white and friable. They range in thickness from a few centimeters up to one meter. The calcium carbonate beds and nodules are interpreted as parts of differentially developed ancient soil horizons. These caliche-bearing paleosols are of the same age as the host formation inasmuch as they follow stratification. In contrast, Quaternary caliches in the San Diego area conform to the modern topography (Pierce, 1974; Pierce and Peterson, 1975).

Modern caliches, which are common throughout the southwestern United States, form as secondary accumulations of calcium carbonate. They are deposited characteristically in the upper part of soil profiles in arid and semiarid regions. According to Steel (1974) caliches will form in soils in areas receiving 63 cm or less of rainfall per year and having an average annual temperature greater than 5°C (usually considerably greater). Caliche layers are thicker and deeper near the upper rainfall limit and thinner and shallower as rainfall approaches zero. The caliche horizons in the Eocene succession are up to one meter thick and probably formed nearer to the upper rainfall limit.

Caliche is most common in the nonmarine sandstone-mudstone facies (Friars and Mission Valley formations), but occurs to a lesser extent in the conglomerate facies (Stadium Conglomerate). We interpret the caliche horizons as having formed in aggradational soil profiles developed on the Eocene alluvium. Each profile developed to a varying degree prior to interruption and deposition of the next layer of sediment whereupon the process was repeated. Thus, multiple layers of caliche were accumulated and developed to differing degrees paralleling the stratification of the Eocene formations. This interpretation implies an arid to semiarid climate in Late Eocene time.

INDICATIONS OF SALT WEATHERING

As many San Diego area geologists have undoubtedly noticed, some of the clasts within the nonmarine Eocene conglomerates are fractured *in situ*. That is to say, the entire cobble is present within the conglomerate but is broken into two or more pieces. Some cobbles have been observed having as many as five or six closely spaced parallel fractures. In other cobbles the fractures appear to be randomly oriented with respect to each other. Regardless of how the fractures are oriented within the clasts, the fractures are positioned without respect to the host formation. Thus, these fractures are positively not due to any type of structural deformation and, in fact, in many places where the fractured clasts occur the host formation is flat-lying and undeformed.

For the most part the fractures appear to be along rock cleavage planes within the clasts. These weakness planes were inherited from the original source terrane; however, the breakage did not occur along these incipient fracture planes until after the clast had been transported to the San Diego area and deposited. The question is then raised: what caused the clasts to break along the rock cleavage planes? We interpret the *in situ* breakage of the conglomerate clasts to be the results of salt weathering. This type of physical weathering occurs when small amounts of dissolved salts enter a porous medium and crystallize as minerals. If the minerals grow in a confined area the force of crystallization of the growing mineral may exceed the strength of the host resulting in fracturing of the host material. We feel that the incipient rock cleavage planes acted as very thin but permeable avenues along which salt-bearing solutions were able to penetrate. When the salts crystallized enough force was exerted to fracture the clast along the cleavage planes. A possible analogous example of this phenomenon was reported by Coleman *et al.* (1966) from the coastal area of Queensland, Australia, where coarse gravels were transported to high tidal flats. Upon wetting during high tides and subsequent drying and crystallization of salts, some of the clasts in the gravels fractured *in situ*. Whether this type of phenomenon took place on a high tidal flat or in a dry river channel, it would imply at least seasonal aridity.

CLAY MINERALOGY

Samples of clay were collected from the fine-grained beds of the Friars and Mission Valley formations and from a small clay-rich lens in the Stadium Conglomerate. After disaggregation of the fine material, the clay-sized fraction was subjected to X-ray diffractometer analysis in order to determine the types and relative abundances of clay minerals, and the results were compared with previous studies (Abbott and Fink, 1975; Kennedy and Peterson, 1975).

The most common clay minerals are vermiculite and smectite. These two minerals constitute up to 80% of the clays in some samples. The remainder of the clay minerals are chlorite and illite. Kaolinite was characteristically absent but was present in trace amounts in a few samples.

The occurrence and abundance of the chemically complex clay minerals together with the general absence of kaolinite indicate that chemical weathering of the sediments was weak. This is in very marked contrast to the underlying lateritic paleosol which is almost totally dominated by kaolinite.

We interpret the differing clay mineralogies of the Eocene rocks and of the underlying paleosol to have formed under markedly differing paleoclimates. The Paleocene and Early Eocene paleosol must of necessity have formed under humid tropical conditions. The immature clay mineral suite characteristic of the later Eocene formations, including the aggradational caliche-bearing paleosols, indicates weathering and deposition in a semiarid climate and continued exposure to arid and semiarid conditions.

SUMMARY

The total character of the nonmarine Eocene deposits of southwestern California and northwestern Baja California indicates a semiarid climate during deposition. Specifically, the caliche-bearing paleosols, the immature vermiculite-smectite-chlorite-illite clay mineral suite, the long-distance transport and ultradurable character of the coarse Eocene conglomerates, and the *in situ* salt-fractured clasts all imply conditions of aridity. Taken together, and coupled with the absence of humid paleoclimate indicators, the case for a semiarid paleoclimate becomes even stronger.

The caliche in particular is a good paleoclimate indicator inasmuch as modern caliche forms only in arid and semiarid climates (Leeder, 1975; Birkeland, 1974; Hunt, 1972). Steel (1974) concluded that caliche would not form in areas that have in excess of 63 cm of rainfall per year and that a strongly evaporative dry season would probably be essential. Based on the sea surface temperatures during Late Eocene time (Savin *et al.*, 1975), we estimate that the average annual Late Eocene temperature would probably be at least slightly higher than the present temperature (16°C); we estimate 18-20°C. This relatively high annual temperature suggests that the thick caliche beds formed under rainfall conditions nearer to the maximum for caliche formation. Our estimate of about 50-60 cm per year. The latitude (ancient or modern) implies that most of the rainfall occurred in the winter months, as at present.

The semiarid interpretation for the later Eocene deposits is not particularly surprising inasmuch as the Eocene paleogeography is much the same as the modern. Deposition occurred close to sea level, the mountains to the east were not very high, and to the west was the unobstructed Pacific Ocean (Clark *et al.*, 1975; Howell, 1975). The climate was warmer and probably had a higher annual rainfall but otherwise was much like the modern. However, the later Eocene climate contrasts markedly with the humid tropical climate present in the Paleocene-Early Eocene interval and indicates a pronounced climatic change occurred at about mid-Eocene time. We regard this event to be of global significance.

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LANDSLIDING, AN ALTERNATIVE TO FAULTING IN SAN YSIDRO, CALIFORNIA

Michael W. Hart
Geocon, Inc.
San Diego, California

Fifteen to 20 enthusiastic participants in the S.D.A.G.'s first field trip stood at the top of the steep slide scarp overlooking the community of San Ysidro while Dennis Hannan described his senior thesis area. Directly before us was what is now known informally as the San Ysidro slide, a spectacular example of an ancient landslide previously unknown to all of us. Equally spectacular, especially for San Diego-bred geologists, were two linear features located just south of the San Ysidro slide. Although only 1000-1500 feet in length, their discovery created considerable excitement because these apparent faults displaced Pleistocene marine terrace deposits and exhibited fresh-looking scarps on the order of 30-40 feet in height.

Such was the first introduction for most of us to the extremely interesting geologic features of the Otay Mesa area. Working more or less at the same time as Hannan in this area were Joseph P. Ziony of the United States Geological Survey, Ernest R. Artim of Woodward-Clyde Consultants, and later, Michael P. Kennedy of the California Division of Mines and Geology. All of these workers recognized several faults on the west and south rim of Otay Mesa. Artim and others (1971) and Artim and Pinckney (1973) continued the La Nacion fault south to the Mexican border beneath the San Ysidro slide as did Foster (1973). Later, Kennedy (1975, 1977) mapped a fault segment which he called the San Ysidro fault through the San Ysidro slide to Moody Canyon where he joined it with a longer segment of the La Nacion fault. All these workers were unanimous in mapping the two lineaments shown on Figures 1, 2, and 3 as faults. Kennedy (1975, 1977) and Foster (1973) extended the faults northward across the face of the San Ysidro slide scarp and through a landslide-filled canyon to a prominant topographic bench located just below a radar station.

The purpose of this brief paper is to examine the evidence used in mapping these "faults" and to determine if landsliding processes might provide a better explanation for these features.

The location of faults and landslides, as previously mapped by others, are shown on Figure 1. For the purposes of this discussion, the faults are identified as the San Ysidro fault (Kennedy, 1975) (the La Nacion fault of previous workers) and the South Rim lineaments of which there are two.

SAN YSIDRO FAULT

The primary evidence for the San Ysidro fault was discovered in a cut slope located in a borrow pit behind Beyer School in San Ysidro. Although the cut slope shown in Figure 4 has been obliterated by grading operations, the fault or shear surface is still well exposed as a result of scouring and gulleying by recent rains.

The borrow pit outcrop of the San Ysidro fault is located on the northern flank of a well-documented landslide that appears to be older than the San Ysidro slide of Hannan (1970). Evidence for sliding may be observed west of the "fault" outcrop and approximately two-thirds of the way up a cut slope behind Beyer School where a well-developed shear zone in a one- to two-foot thick claystone bed may be observed (Figure 5).

This shear zone, prior to the last stage of grading, could be traced for several hundred feet across the floor of the pit. Further evidence of sliding was obtained during a subsurface investigation for borrow material. During this investigation, several 30-inch diameter borings placed east and west of the fault outcrop encountered a nearly horizontal slip surface in bentonite at a depth of approximately 60 feet below the surface.

Further south, the San Ysidro fault has been mapped across several well-

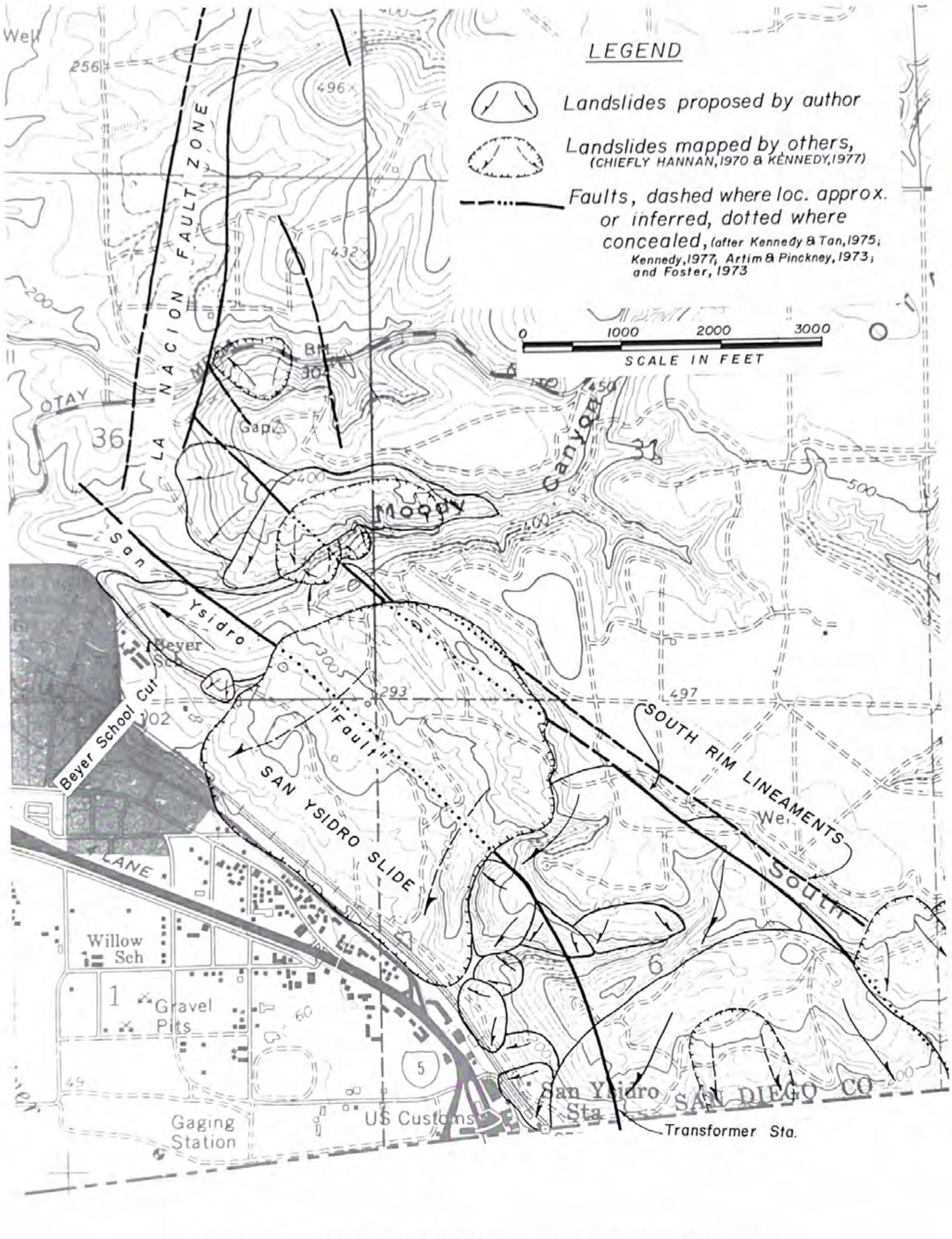

Figure 1. Fault and landslide map of San Ysidro area.

Figure 2. Oblique aerial photograph of southwestern Otay Mesa showing South Rim lineaments and the San Ysidro slide (view to south with Tijuana, Mexico in upper portion of photo).

developed topographic benches. These topographic benches need not to have originated as a result of faulting. Landsliding would seem to be a much better, even preferred, explanation in an area where massive landsliding is prevalent.

A shear zone exposed in a cut slope located behind an abandoned transformer station is Kennedy's evidence for extending the San Ysidro fault to the Mexican border (Kennedy, 1975, Figure 43). However, this outcrop, located approximately 100 feet north of the border, lies at the toe of one of the more spectacular landslides in the San Ysidro area. A close examination of the transformer station cut slope reveals that 20 to 30 feet west of the "fault outcrop" the San Diego Formation overlies ancient topsoils with a near horizontal contact. This is rather convincing evidence for a landslide origin of the shear zone. Based on the foregoing observations, it is believed that there is no direct evidence for a San Ysidro fault, at least in the location shown on previous geologic maps. It seems probable, however, that a fault does exist somewhere beneath the San Ysidro slide since the San Diego Formation underlies the landslide in the Beyer School cut slope. The minimum vertical separation on this postulated fault is approximately 200 feet based on the elevation of the contact between the San Diego and Otay formations on Otay Mesa.

SOUTH RIM LINEAMENTS

Two other features, herein referred to as the South Rim lineaments, have

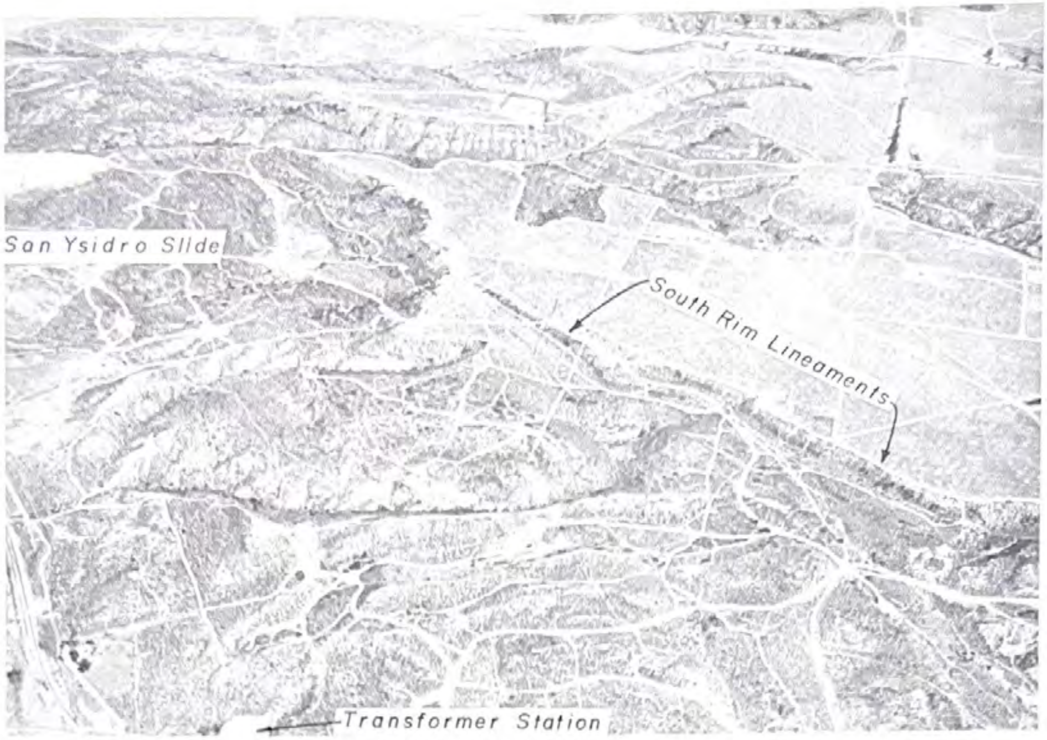

Figure 3. Oblique aerial photograph showing transformer station, South Rim lineaments and San Ysidro slide (view to northeast).

Figure 4. Cut slope in borrow pit located east of Beyer School. Conglomerates of the Lindavista Formation in left half of photograph, juxtaposed against sandstone of the Otay Formation on the right.

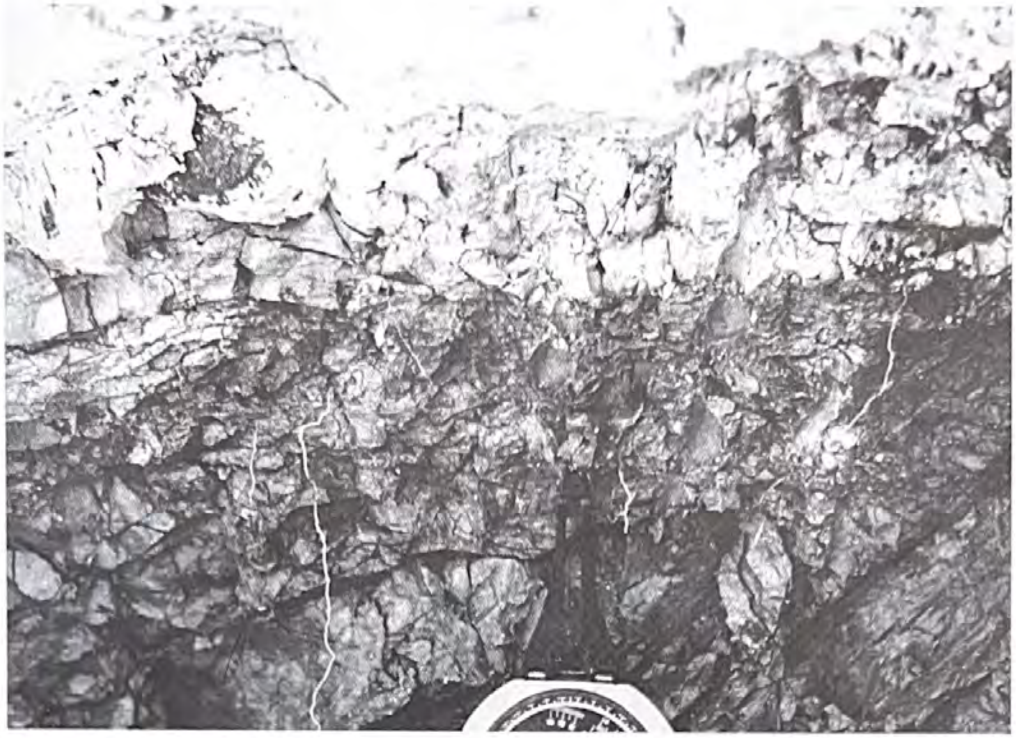

Figure 5. Exposure of sheared claystone bed in upper portion of the Beyer School cut slope. Light colored material near top of photograph is a well-cemented calcareous siltstone. The shear zone is approximately three inches thick and lies just above the Brunton compass.

appeared several times in recent geologic literature as faults (Ziony *et al.*, 1974; Artim and Pinckney, 1973; Foster, 1973; Kennedy, 1975, 1977). The South Rim lineaments (Figures 2 and 3) are prominant parallel scarps 1000 to 1500 feet in length. The nearly level surface of Otay Mesa is dropped down to the west along these very young-looking scarps by as much as 40 feet. Previous workers, not content to map these "faults" only as far as the well-defined scarp limits, have extended them to the north for a distance of nearly 1.5 miles based on evidence such as topographic benches and the somewhat linear nature of the scarp of the San Ysidro slide. No importance seems to be given the fact that both lineaments terminate prior to reaching the San Ysidro slide in what might be described as a "scissors-like" action. The observation that these lineaments terminate prior to reaching the San Ysidro slide and that they occur in a well-known landslide area suggests that they may be caused by landsliding. In this case, they may represent slide scarps of a possibly active landslide. In either case, there is no good reason to extend these features past their actual outcrops utilizing other landslide characteristics as justification.

Evidence suggesting the possibility of active landsliding in this area has been inadvertently gathered by the U.S. Border Patrol through their use of remote foot-traffic sensors. These devices are similar to standard geophones except that when activated they emit a radio signal that is received at Border Patrol Headquarters in San Ysidro. Weigand (1970) was the first to recognize the previously unexplained simultaneous triggering of five or six of these devices that were implanted just east of Beyer School. He attributed this behavior, which seemed to occur at intervals of three to four weeks, to microseismic activity occuring on local faults.

Further discussions with officials of the Border Patrol have revealed additional information. All of the sensors experiencing simultaneous triggering are located several hundred feet apart on the San Ysidro slide, suggesting that slide activity and not fault activity was the cause.

In order to test this theory, the five sensors located on the San Ysidro slide, as well as a "control" sensor, were monitored for several months. The control sensor was located in a canyon several thousand feet east of the San Ysidro slide in landslide-free terrain. During the short observation period, there were at least two occasions when the sensors located on the slide triggered simultaneously while the contol sensor remained inactive.

This relatively simple experiment strongly suggests that the San Ysidro slide is undergoing either internal adjustments or sporadic movement. During the coming year, survey monuments may be installed, which would provide further information on the slide's activity.

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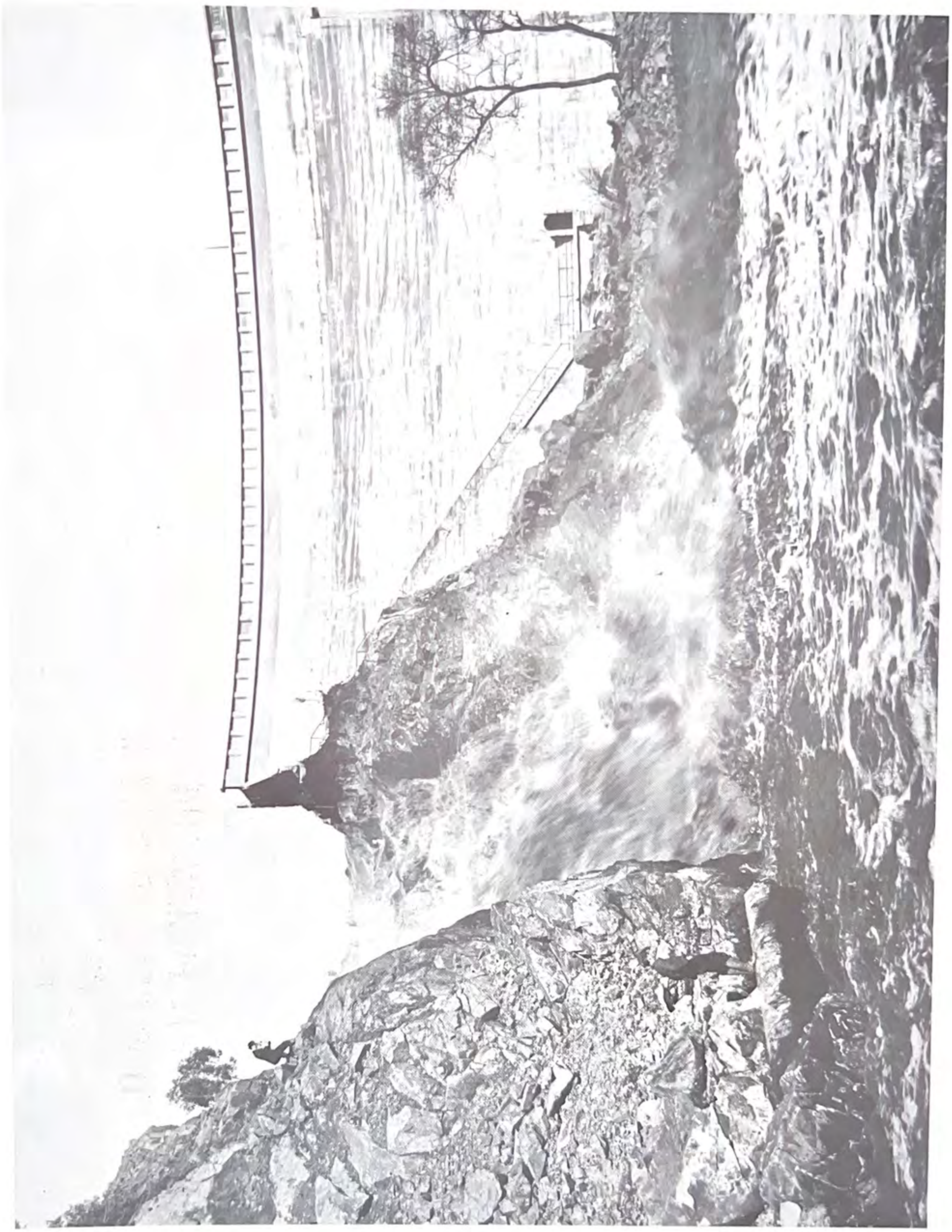

Failure of original Sweetwater Dam in Sweetwater Valley near La Presa, California. Dam failure occurred along spillway-bedrock contact on January 30, 1916, during a season of very high rainfall. Historical Collection, Title Insurance and Trust Company, San Diego, California.

U.S.D.A. Soil Conservation Service serial vertical photography looking down on Lower Otay Lake and Otay Valley in March, 1953.

The trim line (white eroded canyon slopes downstream from the Lower Otay Lake) was created during the failure of the original Lower Otay Lake Dam in January, 1919.

TEXAS STREET FAULT, SAN DIEGO, CALIFORNIA

Richard L. Threet
Department of Geological Sciences
San Diego State University

The Texas Street fault is a newly discovered extension of a fault that was originally shown near the northeast corner of Balboa Park by Goldstein (1956). The fault can be traced at least 12,000 feet (3.6 km), as a fault scarp 25 to 40 feet (8 to 12 m) high, across the mid-Pleistocene(?) Lindavista marine-cut terrace, from the center of the east boundary of Balboa Park to the east abutment of the Adams Avenue bridge across Texas Street. The fault trace can be extrapolated another 1,600 feet (0.5 km) farther north, to the mouth of Texas Street Canyon, where an abrupt disparity in elevation of the Stadium Conglomerate/ Mission Valley formational contact indicates 31 feet (10 m) of stratigraphic separation or throw. Similar separation of at least two other easily recognized stratigraphic marker beds within the Mission Valley Formation further confirms the suspected fault relationships. Nowhere is the actual fault surface exposed, and nowhere is the fault trace indicated clearly on aerial photographs, primarily because of the obscuring effects of intensive development on San Diego Mesa and because of heavy brush cover and local highway construction in Texas Street Canyon. Slip on the fault occurred only sometime during the past 10^6 years, as indicated by comparable amounts of separation of Eocene and Plio-Pleistocene stratigraphic units. The lack of topographic expression of the fault in areas of significant erosion and deposition suggests that the fault should be classified as inactive or only potentially active.

INTRODUCTION

Familiarity is said to breed contempt. I am embarrassed to recall how many times I had driven hurriedly through the canyon in which Texas Street connects with Mission Valley, contemptuous of the apparently simple structure of the Eocene strata which are exposed in road cuts along the lower canyon walls. Only after having the direction pointed, a couple of years ago, by reference to Goldstein's work on Balboa Park (1956) did I begin to suspect the presence of a northerly extension of the eastern fault of what might be called Morley Field Graben. No published works known to me recognize such a fault in Texas Street Canyon, and none of the local geologists to whom I have talked has known of the existence of that fault. Kennedy (1975*a*) shows a short trace of a fault in the south wall of Mission Valley, about 1,000 feet (300 m) west of the mouth of Texas Street Canyon, a fault that he carried over through the several versions of his mapping in the San Diego urban area. However, Kennedy did not choose to include the Balboa Park faults on his maps, although Lough (1973) and Ziony (1974) cited Goldstein's work.

Although the actual fault surface cannot be seen in Texas Street Canyon or elsewhere, the evidence near the mouth of Texas Street Canyon demands interpretation of a fault directly beneath Texas Street in that vicinity, with approximately 30 feet (10 m) downthrow to the west. The easily observed field evidence is discussed below, and a geologic map and cross section is shown in Figure 1.

The Stadium Conglomerate/Mission Valley formational contact and the strata within the lower part of the Mission Valley Formation strike east-northeasterly on both sides of the canyon, as indicated by apparently horizontal bedding in the portions of the grading cuts along the south wall of Mission Valley in that vicinity. The fairly regular top of the Stadium Conglomerate and the concretionary beds within the lower part of the Mission Valley Formation consistently dip 3% (about 2°) in a south-southeasterly direction, as measured in the grading cuts at the canyon mouth.

The closest approach of the exposed marker beds on opposite sides of Texas Street is about 800 feet (250 m). Even that relatively generous gap would require a drastic change in strike and dip of the strata, for which there is no evidence, to avoid the implications of faulting to account for the 31-foot (10-m) difference in elevation of at least three stratigraphic markers. The elevation differences

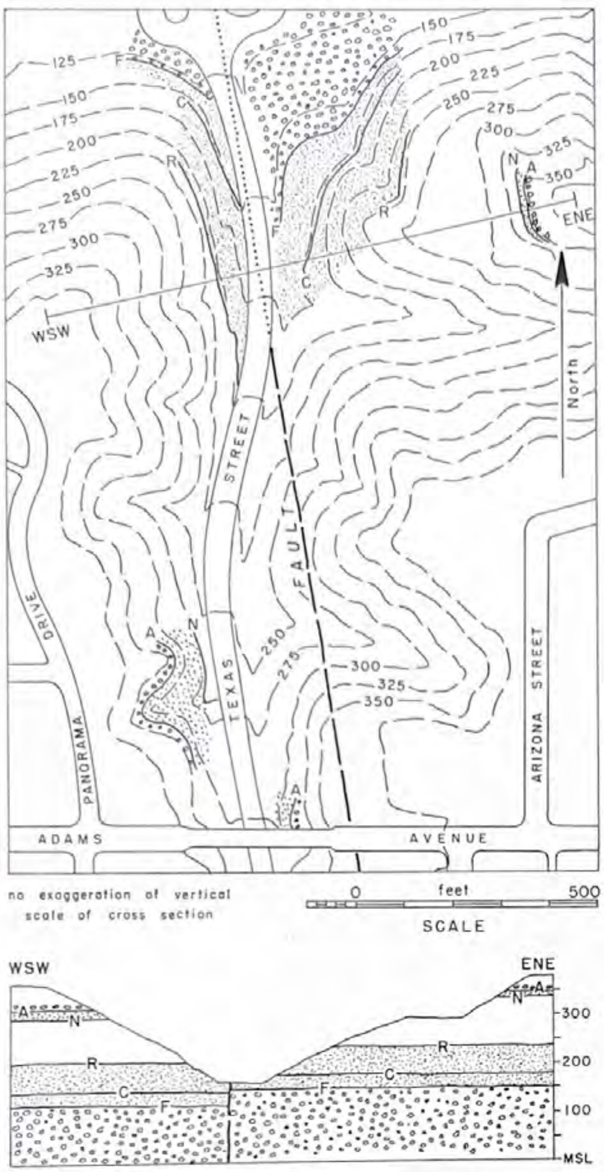

Figure 1. Geologic map and cross section of exposures in Texas Street Canyon between Adams Avenue and Camino del Rio South (base from City of San Diego topographic map 218-1725): A-slightly angular unconformity between Linda-vista Formation and San Diego Formation; N-late Neogene unconformity between San Diego Formation and Mission Valley Formation; R-red-stained marker bed in middle of Mission Valley Formation; C-especially conspicuous bed of large concretions in lower part of Mission Valley Formation; F-Stadium Conglomerate/Mission Valley formational contact.

can be hand leveled along the direction of regional strike or can be interpolated from the geologic map on the topographic base.

STRATIGRAPHY

Eocene strata.---The general lithology and stratigraphic relationships of the Eocene strata in the San Diego area are now generally well known (Kennedy and Moore, 1971). Although the Stadium Conglomerate regionally interfingers with the Mission Valley Formation, the contact locally is relatively abrupt and smooth--massive conglomerate composed of distinctive pebbles and cobbles overlain by laminated to massive, fine sandstone. The lower part of the Mission Valley Formation exhibits a predominantly pale yellow-gray color and contains discontinuous to nearly continuous concretions up to 2.5 feet (75 cm) in diameter, in beds that occur repeatedly at about 5-foot (1.6-m) intervals. A detailed measured section could be presented for each side of the Texas Street Canyon, to show the degree of persistence and correlation of such beds, but only the most conspicuous and most nearly continuous bed of large concretions is necessary here to document the stratigraphic separation of the Texas Street fault. That particular bed of large concretions occurs consistently at 25 feet (8 m) above the top of the Stadium Conglomerate, near the mouth of Texas Street Canyon.

There is one other noteworthy marker bed in the sandy Mission Valley Formation on both sides of lower Texas Street Canyon--a thin, red-stained zone about 85 feet (26 m) above the Stadium Conglomerate. The same zone is conspicuous also throughout the exposures of the Mission Valley Formation in the vicinity of the type section, where the red zone occurs about 85 to 90 feet above the Stadium Conglomerate (Threet, 1973). This red unit is included by Kennedy and Moore (1971) as part of the type section of the Mission Valley Formation, but the unit is emphasized here because of its possible relationships to definition of the Sweetwater and Otay Formations in southeast San Diego and Otay Mesa (Artim and Pinckney, 1973).

The upper part of the Mission Valley Formation in the type section and at Texas Street Canyon exhibits a predominantly light gray to white color which is accentuated by calichification in the shallow colluvial soil zone that is intersected near the daylight line of many cuts on the south wall of Mission Valley. For many years, the white color was mistakenly attributed to the San Diego Formation, and the nearly ubiquitous white soils in areas of poor exposures, throughout much of the area below the San Diego and Otay Mesas, still cause great difficulty in the identification and correlation of the Mission Valley, Sweetwater, Otay, and San Diego Formations (Gastil, pers. comm.). Perhaps the present field trip and guidebook will shed definitive light on the status of Eocene, Miocene, and Plio-Pleistocene stratigraphic units in the area south of Mission Valley.

Plio-Pleistocene strata.---Road cuts in Texas Street Canyon are less extensive and less informative in the upper part of the canyon; dense chaparral or brush and widespread slopewash cover the upper part of the Mission Valley Formation and the unconformably overlying San Diego Formation. I do not agree with Kennedy and Moore (1971) that the upper part of the 190-foot (58 m) type section of the Mission Valley Formation "contains several thin beds of pebble and cobble conglomerate.... At the type section, the Mission Valley Formation is overlain conformably by a non-marine cobble-conglomerate layer 10 m thick that belongs to an unnamed formation of the Poway Group" (Threet, 1973). It is my opinion that the overlying conglomerate, and probably also the sandy beds that contain pebble and cobble conglomerate, is a thin wedge remnant of the San Diego Formation that is disconformable on the Mission Valley Formation and is itself truncated by the marine-abrasion surface on which the rusty Lindavista conglomerate and sandstone formation lies.

A similar situation is present near the top of the high cut at the east end of the cross section shown on Figure 1, where nodular concretionary light-gray sandstone of the uppermost Mission Valley Formation is abruptly overlain by only 10 feet (3 m) of gritty fine sandstone and conglomeratic sandstone with a pale yellow-gray color that is usually associated with the genuine San Diego Formation, as recognized in the downtown San Diego area and in southern Balboa Park. That pale yellow grit and conglomerate is then abruptly overlain by the closely packed cobble conglomerate at the base of the Lindavista (formerly Sweitzer) Formation which forms a cap as much as 50 feet (16 m) thick on San Diego Mesa.

Similar relationships are exposed in a limited way, on the west side of Texas Street, in a small gully and adjacent cuts about 250 feet (80 m) north of the Adams Avenue bridge. There, the basal yellow grit of the San Diego Formation is somewhat thicker and more strongly cemented, so that it forms an overhanging ledge at the base of a 43-foot (13-m) section of light yellow-gray San Diego Formation, which is preserved here as a thicker part of the wedge of San Diego Formation that is truncated by the wave-abrasion surface on which the rusty cobble conglomerate of the basal Lindavista Formation lies. The disparity in thickness between the two portions of the San Diego Formation exposed in the upper walls of Texas Street Canyon probably reflects a component of regional tilting down to the west or southwest, prior to development of the Lindavista cut terrace. For that reason, the differences in elevation of that sub-San Diego unconformity cannot be used reliably to evaluate precisely the chronology and amount of stratigraphic separation on the Texas Street fault.

By contrast, the disparities in elevation of the sub-Lindavista wave-abrasion surface or of the tread of the Lindavista Terrace provide timely and accurate reference surfaces for evaluating throw of the Texas Street fault, once the effect of regional slope of the terrace is subtracted. Many measurements on the ground and on topographic maps can be used to establish that the Lindavista Terrace in the vicinity of Mission Valley has a regional slope somewhat less than 50 feet per mile (1% grade), toward the west-southwest. Thus, either the Lindavista Terrace tread or the base of the Lindavista Formation has an observed difference in elevation of 35 feet (11 m) between Arizona Street and Panorama Drive or 30 feet (10 m) between the two ends of the cross section shown in Figure 1, respectively. The corrected fault shift of 25 to 30 feet (8 to 10 m) is quite compatible with the values derived from disparities in elevations of Eocene marker beds, measured in a strike-parallel direction.

Thus, the stratigraphic and structural relationships exposed and easily mapped and measured in Texas Street Canyon provide a firm starting point to evaluate the throw of the fault which is measurable directly only in terms of elevation differences between the top and bottom of a fault scarp that crosses San Diego Mesa, in a direction only a few degrees east of south (Figure 2). Unfortunately, the fault scarp has been modified considerably by grading of streets and residential properties many years before detailed topographic maps and aerial photographs became available. To a much smaller extent, the fault scarp has been modified and obscured by erosion and mass wastage during later Pleistocene and Holocene time.

It might be supposed that the fault should be exposed also by the extensive road cuts along Friars Road and by the large quarrying operation for gravel in the north wall of Mission Valley between Stadium Way and Mission Center Road. However, if the N09°W inferred trend of the portion of the fault in Texas Street Canyon were extrapolated across Mission Valley, the fault should be present at the Stadium Way underpass for Friars Road, whereas only unbroken Stadium Conglomerate is exposed in the broad cuts in that vicinity. Either the Texas Street fault dies out northward somewhere beneath Mission Valley, or it curves somewhat more northwesterly and lies concealed beneath the vast stockpiles of gravel superimposed on the remnants of the former north wall of Mission Valley.

The fault scarp across San Diego Mesa is fairly consistently conspicuous as a block-long rise of about 25 to 40 feet (8 to 12 m) where it crosses: (1) Adams Avenue between the alley west of Arizona Street and the eastward-jogged Arizona Street north of Adams, (2) Meade Avenue between Arizona and Hamilton Streets, (3) El Cajon Boulevard at Lyon Van & Storage and the Church of Christ, (4) University Avenue between Oregon and Hamilton Streets, (5) Upas Street between Pershing and Arnold Avenues, and at many other intermediate localities on a northerly trend from Morley Field and the Muncipal Gold Course.

The Morley Field block appears to be downdropped between the Texas Street fault and another north-trending fault mostly along the bottom of Florida Canyon (Goldstein, 1956), although much more work must be done to establish a satisfactory evaluation of seismic risk for the proposed addition to the U. S. Naval Hospital in southern Florida Canyon (Threet, 1975, unpublished geological report in geotechnical report by Robert Prater Associates, for Halsey & Associates, landscape architects for City of San Diego plans to develop Florida Canyon). On the basis of very rough and tentative measurements, the Florida Canyon fault is essentially a mirror image of the Texas Street fault, except that it has not been traced northward as far as Mission Valley.

AGE OF FAULTING AND SEISMIC RISK

The Texas Street fault clearly displaces the Lindavista Terrace, and it displaces the Eocene marker beds a similar amount, thus establishing the fault as one without a long-term history of movement--sometime during the past 10^6 years, since the Lindavista Terrace was formed. As with practically all of the faults in the San Diego area, as noted by Ziony (1973), the Texas Street Fault lacks "topographic features commonly associated with Holocene faulting elsewhere in coastal California, such as sag depressions or well-defined scarps." Other criteria of recent or active faulting, especially displacement of Holocene deposits, are absent; however, a search should continue for additional evidence regarding age of faulting on the Texas Street fault. Also, the trace shown on Figure 2 is based on the assumption that it lies at the foot of the fault scarp, whereas future investigations may reveal that the trace should be mapped a bit farther east or west.

Because of its northerly trend, the Texas Street fault might be assigned to a broadly defined "La Nacion fault zone." However, Holocene activity of the La Nacion fault at its type locality has been discredited (Hart, 1974; Dowlen, *et al.*, 1975), and the La Nacion fault "zone" has been shown by Kennedy (1975*b*) to be a vaguely defined system of diversely

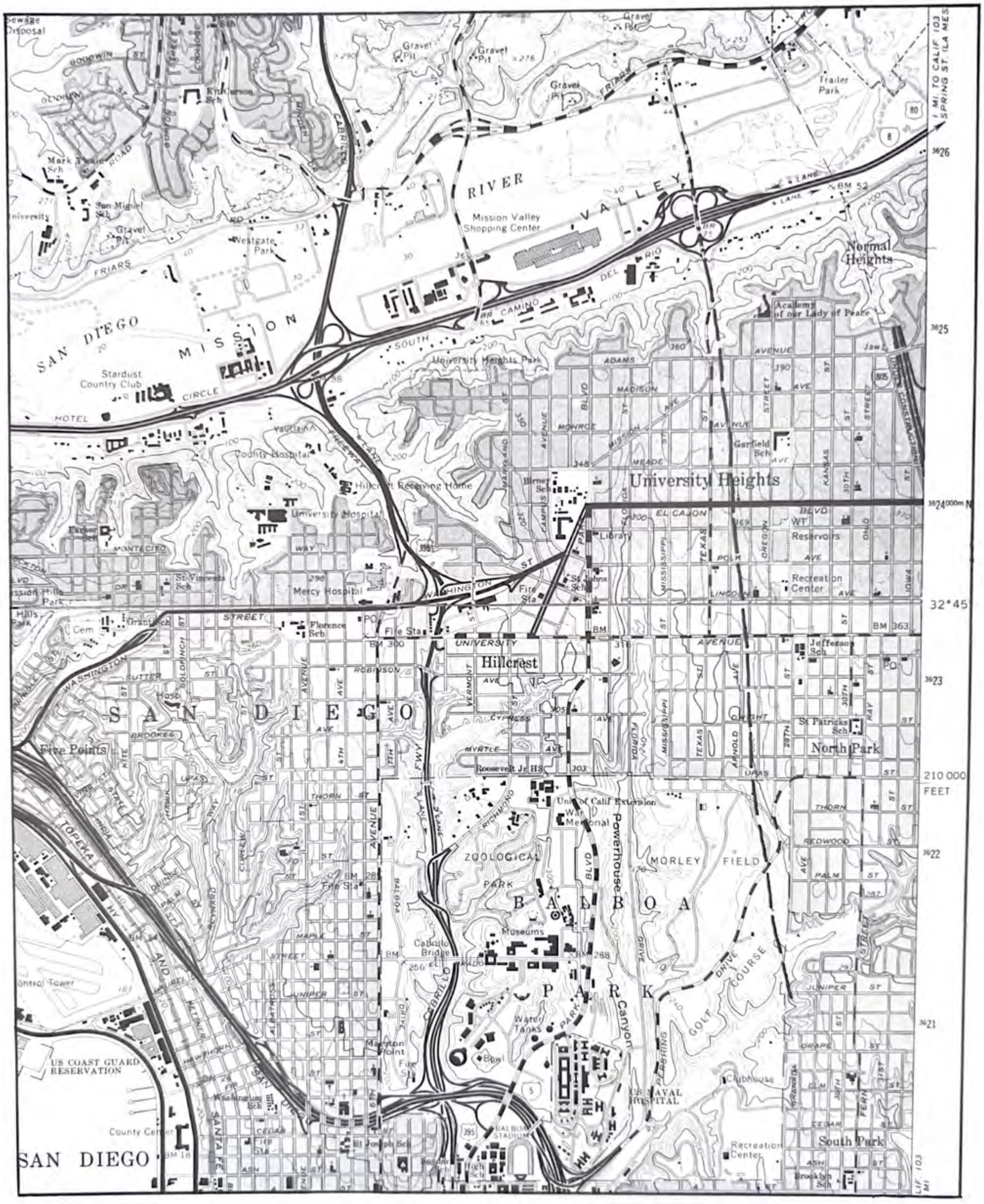

Figure 2. Southeast portion of La Jolla 7.5-minute quadrangle and northeast portion of Point Loma 7.5-minute quadrangle USGS topographic maps, showing inferred trace of Texas Street fault from Balboa Park to Mission Valley, a distance of at least 2.5 miles (4 km).

oriented and discontinuous faults with very short trace lengths, which may not merit serious consideration for most seismic risk evaluations. It is my opinion that nothing useful would be served by forcing the Texas Street fault into an already too loosely defined "La Nacion fault zone," nor into an equally poorly defined "Rose Canyon fault zone" adjacent to and beneath San Diego Bay (Moore and Kennedy, 1975; Kennedy, 1975*b*).

On the basis of the very limited trace length of the Texas Street fault and its erstwhile lack of evidence for recency of movement, it is my opinion that seismic risk from the Texas Street fault is low. In the event that a hospital or other very sensitive risk structure is to be sited on the fault trace, of course, trenching across the expected position of the fault trace would be justified to evaluate site-specific evidence of recency of fault movement. Because of the already completed development all along the trace of the Texas Street fault on San Diego Mesa, it is not likely that construction sites on the fault will be investigated in the near future. When such time comes, the fault probably should be considered only from the standpoint of slope stability, as with any other zone of weakness.

The only new construction on or very near the fault at this time is an apartment complex being built partly on cut and partly on filled ground just south of the east abutment of the Adams Avenue bridge over Texas Street. Unfortunately, I did not have an opportunity to examine the deeper cuts for foundations at the east side of the site. It is my opinion that no fault would have been exposed, because the fault trace probably lies a few tens of feet east of the apartment site.

CONCLUSIONS

The newly discovered and documented Texas Street fault is certainly not a major fault, but it deserves to take its place among the hundreds of faults already known in the San Diego metropolitan area. As with practically all those faults, except perhaps the main Rose Canyon fault along the northeast side of Mount Soledad, probably only their existence and magnitude of separation need to be noted routinely (together with any evidence of post-Lindavista or, rarely, more recent movement). Unless and until a case for "active" classification is unequivocally documented, seismic risk from such a fault should be played down. Assignment of such a fault to a "fault zone" alleged to have major importance should be avoided, especially when the definition of that fault zone is still extremely nebulous and the status of its activity extremely questionable.

A few years ago I recommended abortion of a very questionable fault along Mission Valley (Threet, 1973). Now I am a party to conception of a fault, on what I believe to be a firmly documented basis, near the junction of Texas Street and Camino del Rio South in Mission Valley. I hope that this inadvertent parity will be accepted for its primary purpose, a contribution to what must be a continuing evaluation and re-evaluation of the geology of the San Diego area.

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View north-northeast over Poggi and Telegraph canyons (right foreground) of area underlain by the San Diego Formation and Otay Member of the Rosarito Beach Formation. The Sweetwater Member of the Rosarito Beach Formation is exposed in lower and center left portions of photo. Photograph courtesy of Aerial Fotobank, San Diego, California.

NEW EVIDENCE CONCERNING AGE OF MOVEMENT OF THE LA NACION FAULT, SOUTHWESTERN SAN DIEGO COUNTY, CALIFORNIA

William J. Elliott
Fugro, Incorporated
Long Beach, California

Michael W. Hart
Geocon Incorporated
San Diego, California

The La Nacion fault was discovered in 1971 by Mr. Ernest R. Artim during soil and geologic investigations for urban development in the communities southeast of San Diego (Figure 1). Following the discovery, extensive investigations including field mapping, trenching and borings were conducted to delineate the nature and extent of the fault.

By 1972, sufficient data had been compiled by Ziony and Buchanan (1972) to show that the La Nacion fault extended for approximately 16 miles from near San Diego State University southerly to near San Ysidro. They concluded that the youngest geologic unit definitely displaced by the fault was the early Pleistocene Lindavista Formation, and that geomorphic features commonly associated with Holocene faulting elsewhere in coastal California, such as sag depressions and well-defined scarps, were not observed along the fault.

In 1973, Artim and Pinckney (1973*a*, 1973*b*) reported that the La Nacion fault offset Holocene alluvium at two localities a maximum of 1 meter and that the maximum age of offset was determined by a Carbon-14 date to be 10,190±190 years B.P. (before present). They further concluded that the fault should be considered a potentially active, if not an active, fault. No locality data for the offsets were given.

Later investigations along the La Nacion fault, however, failed to document conclusive evidence for Holocene activity (Dowlen *et al.*, 1975; Foster, 1973; Hart, 1974; Kennedy, 1977; Kennedy and Peterson, 1975; Kennedy *et al.*, 1975; Ziony, 1973; Ziony and Buchanan, 1972). In particular, Hart (1974) reported unfaulted Holocene alluvium overlying the fault in Poggi Canyon approximately

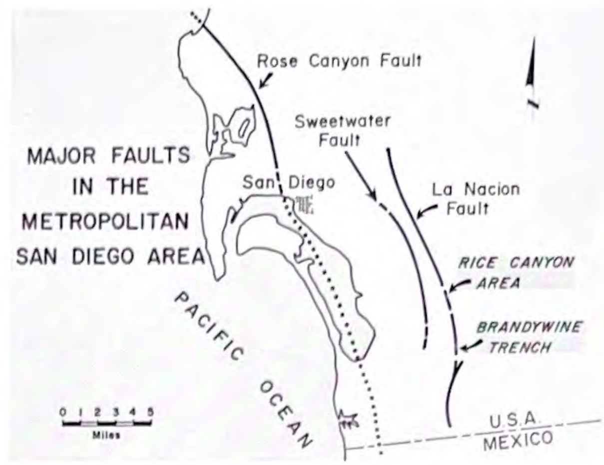

Figure 1. Location map showing principal faults in the San Diego area and the two locations of reported offset Holocene alluvium along the La Nacion fault at Rice Canyon area and Brandywine trench.

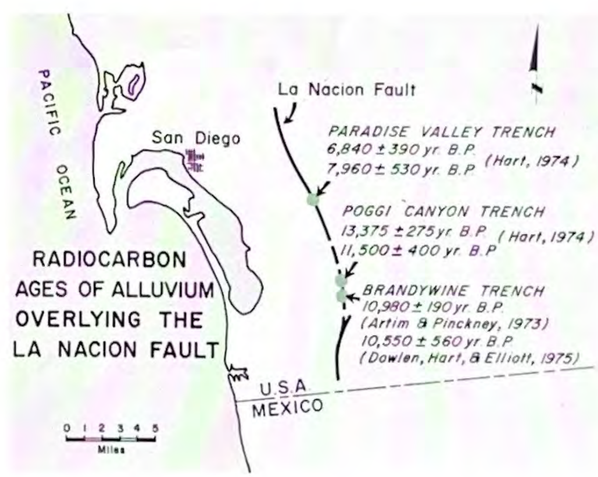

Figure 2. Locations of radiocarbon age dates of unfaulted alluvium overlying the La Nacion fault.

Figure 3. Topographic map showing location of Brandywine and Poggi Canyon trenches.

1 kilometer north of the Brandywine trench (Figures 2 and 3), and in an unnamed canyon in the Paradise Valley area, approximately 10 kilometers north of the Brandywine trench (Figure 2). Hart's radiocarbon ages on unfaulted alluvium overlying the La Nacion fault ranged from 6,840±390 to 13,375±275 years B.P. (Figure 2).

Because of these conflicting reports as to whether or not the La Nacion fault had offset Holocene deposits, it was decided to re-examine the evidence for Holocene activity reported by Artim and Pinckney (1973*a*, 1973*b*). Through oral and written communications with both Artim and Pinckney, it was determined that the offset Holocene alluvium they referred to had been observed in the south wall of the Brandywine trench (Figure 2).

In addition, another offset of alluvium had been reported in the Rice Canyon area (Figure 1) where boring data showed anomalous thicknesses of alluvium on opposite sides of the projected trace of the La Nacion fault. This anomalous condition, however, apparently had not been trenched or studied further.

An investigation of the possible alluvial offset in the Rice Canyon area (Figure 1) was not pursued because the boring logs and exact boring locations were unavailable for review. In addition, the owners of the property were unwilling to permit access. Since the exact location of the Brandywine trench was known, and a copy of the original trench log at a scale of 1 inch equals 10 feet had been obtained, it was decided to re-excavate the Brandywine trench in order to re-examine the reported 1 meter of alluvium offset, and to obtain a new soil sample for radiocarbon dating.

The original Brandywine trench location was relatively easy to find, as backfill material had settled and had the appearance of a sag pond. Being a non-profit venture, the 728th Transportation Company of the U.S. Army Reserve and the Larry Erb Drilling Company were contacted, and a bulldozer and a backhoe, respectively, were donated for the excavation (Figure 4). On July 19, 1975, approximately 19 interested local geologists (Figure 5) assembled at the site to re-log the south wall of the Brandywine trench and, specifically, to determine whether or not the Holocene alluvium was indeed displaced by faulting.

Figure 4. View easterly of Larry Erb's backhoe completing the Brandywine trench re-excavation.

Figure 5. Several of the geologists who participated in the Brandywine trench logging. Front: W. J. Elliott, D. Hannan; rear: M. Hart, L. Erb (L. Erb Drilling Co.), R. Dowlen, T. Liem, D. Stickney, L. Reed, F. Kingery, A. Mayo, W. Ganus. Not in protograph: G. Gastil, B. Smyllie, Sgt. C. Cook, Jr., M. Chapin, and W. Catlin.

As the new excavation was limited to removing backfill material, the new south wall exposure was within a foot or so of the original one. It was therefore relatively easy to pinpoint and correlate features illustrated on the original trench log with the bedrock and soil exposed along the south wall of the re-excavated trench.

The new Brandywine trench was logged in detail at a scale of 1 inch equals 5 feet and is shown diagramatically in Figure 6. Results of this logging showed that: (1) the La Nacion fault consists of several distinct slickensided shear zones, (2) there is a main shear zone which juxtaposes light gray clayey siltstones of the Eocene/Miocene Sweetwater Formation (Eocene Mission Valley Formation of Kennedy, 1977) on the east against yellow fine-grained sandstones of the Pliocene San Diego Formation on the west, (3) a dark gray-brown clayey Holocene paleosol and brown sandy Holocene alluvium were deposited over the La Nacion fault on an irregular erosion surface, (4) neither the Holocene paleosol nor the sandy alluvium are displaced by the La Nacion fault, and (5) the age of the paleosol based upon radiocarbon analysis was determined to be 10,550±560 years B.P. (R. Berger, 1975, written communication).

Figures 7 and 8 show the unfaulted Holocene paleosol overlying the main trace (trace No. 1 on Figure 6) of the

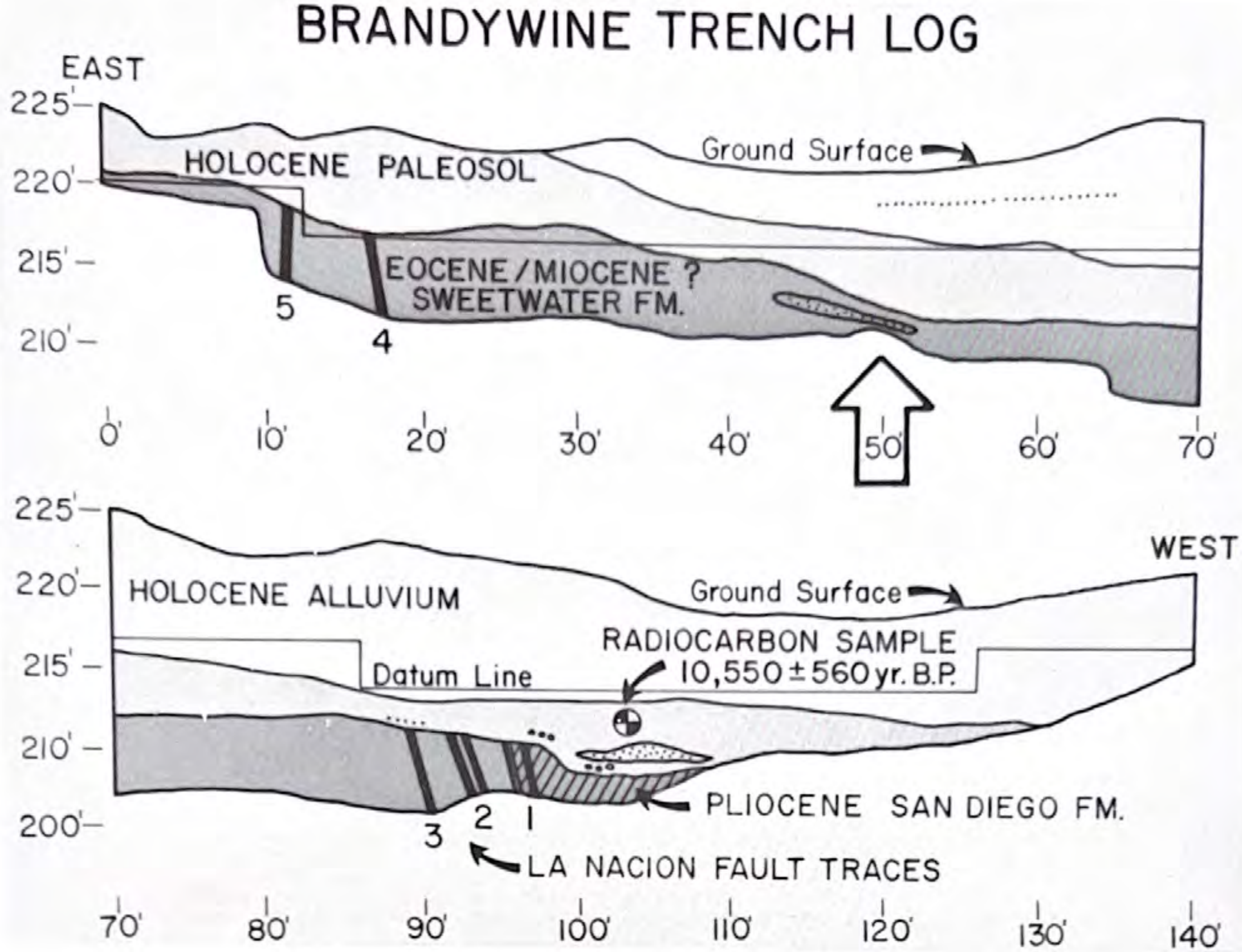

Figure 6. Simplified log of the south wall of the re-excavated Brandywine trench. The left member of trace no. 1 (the main trace) of the five La Nacion fault traces shown, separates the Eocene/Miocene? Sweetwater Formation from the Pliocene San Diego Formation. The location of the reported 1 meter (3 ft.) of offset of Holocene alluvium (Artim and Pinckney, 1973*a*, 1973*b*) is at station 50, indicated by the large open arrow. Neither the bedrock nor the overlying paleosol and alluvium are faulted at this location. None of the traces of the La Nacion shown offset is overlying Holocene paleosol or alluvium.

La Nacion fault. The head of the rock hammer in Figure 8 is approximately 2 inches to the left of the main trace.

The location of the reported offset Holocene alluvium, as shown on the original trench log, is approximately at station 50 (large open arrow on Figure 6). This portion of the trench was examined by each geologist present. The results of this investigation indicated that the there was no evidence of offset in the Holocene sediments or underlying bedrock at station 50. The irregular nature of the bedrock/paleosol surface at this location and elsewhere in the trench is best explained by scouring and channeling of the bedrock surface prior to deposition of the Holocene paleosol.

In conclusion, it has been determined that: (1) the La Nacion fault is overlain by unbroken Holocene deposits in the Brandywine trench, (2) the anomalous thicknesses of alluvium along the La Nacion fault trend reported in the Rice

Figure 7. R. Dowlen pointing out the main trace (trace no. 1 on Figure 6) of the La Nacion fault. Dark colored Holocene paleosol lies unbroken over the lighter-colored bedrock.

Figure 8. Closeup of Figure 7 showing dark colored Holocene paleosol lying unbroken over the main trace of the La Nacion fault. Rock hammer head is about 2 inches left of the main trace which separates light gray Sweetwater Formation on the left from yellow (medium gray in photo) San Diego Formation on the right (Figure 6).

Canyon area can be easily explained by non-tectonic processes (as opposed to Holocene movement on the La Nacion fault), and (3) Pleistocene age deposits (Lindavista Formation) have been offset by the fault, but Holocene deposits have not been offset. Therefore, the La Nacion fault should be considered potentially active (Assoc. Engineering Geologists, 1973).

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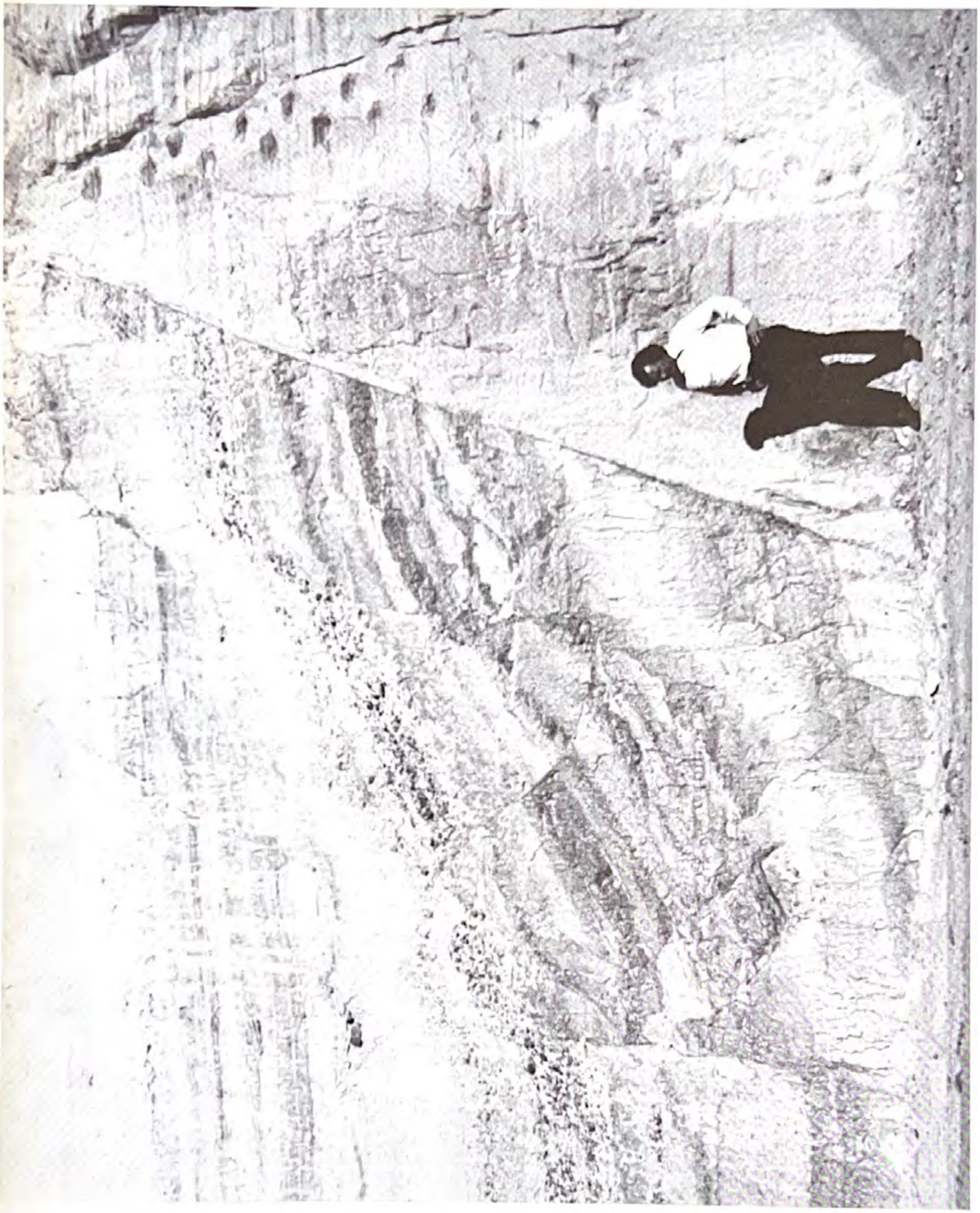

La Nacion fault exposed in road cut on north side of Sweetwater Road, approximately 1000 feet west of Cresta Bonita Drive, in Bonita, California. The unit exposed on the right (east) side of the main fault trace consists of yellow-tan, thin-bedded, silty fine sandstones of the San Diego Formation. Downdropped unit west of the fault trace is probably the San Diego Formation. C. W. La Monte in photograph.

LATE PLEISTOCENE MAXIMUM AGE OF FAULTING, SOUTHEAST MISSION BAY AREA, SAN DIEGO, CALIFORNIA

Tiong J. Liem

Alvarado Soils Engineering, Inc.
La Mesa, California 92041

A radiocarbon date of 28,700±1,500 years B.P. was obtained from faulted deltaic-type sediments in the southeast Mission Bay area, San Diego, California. This date represents the youngest date yet published for onshore tectonic activity which may be related to the Rose Canyon fault zone.

INTRODUCTION

The status of activity of the two prominent local fault zones in the San Diego metropolitan area, the Rose Canyon fault zone and the La Nacion fault zone, has been and remains a controversial yet popular topic of discussion among local geologists. Aside from being a matter of academic interest, this issue has become even more important since various municipalities, particularly those traversed by these general north-northwesterly striking structural features, adopted their respective Seismic Safety Element. Since late 1974, this legislative action indirectly resulted in a rising demand for engineering geological studies, especially on real properties located within a particular hazard zone, as defined in the Seismic Safety Element for that particular area. Needless to say, the economic implications of the findings and recommendations presented in geotechnical reports are of sufficient importance that extra caution is warranted in evaluating all available evidence with respect to potential geologic hazards that may exist or could occur as a result of the proposed site development.

A majority of local consulting geologists currently use the California Division of Mines and Geology criteria as a basis for classifying faults as active, potentially active or inactive. The following problems or factors are characteristic of the western San Diego region and should be included in any consideration of local fault activity:

1. Although the short period of recorded local seismic history cannot be ignored, it may not be a reliable basis for any quantitative estimate of seismic hazard.
2. Extensive urban development has altered much of the original topography, such that access is restricted and detailed field mapping becomes impractical in many areas.
3. Holocene tectonic activity has been suggested in previously published studies (Moore, 1972; Moore and Kennedy, 1975) on the basis of offsets interpreted from offshore subbottom profiles; yet no solid evidence of Holocene onshore fault activity has been discovered to date.
4. Geomorphic features normally associated with Holocene faulting such as sag depressions and/or well-defined fault scarps are absent.

Considering the above discussed criteria, it becomes readily apparent that, wherever possible, absolute age dating techniques should be used to determine the latest fault movement, at least where Late Quaternary faulting is suspected. However, even where absolute age data can be obtained, differences in the interpretation of field evidence could result in contradictory evaluations (Artim and Pinckney, 1973; Hart, 1974; Dowlen *et al.*, 1975).

The present paper presents a maximum age of faulting for a previously undiscovered local fault located near the southerly end of the Rose Canyon fault providing additional "fuel for discussion" which hopefully will contribute to a better understanding of tectonic activity in the western San Diego region. The radiocarbon date was determined by Geochron Laboratories of Cambridge, Massachusetts.

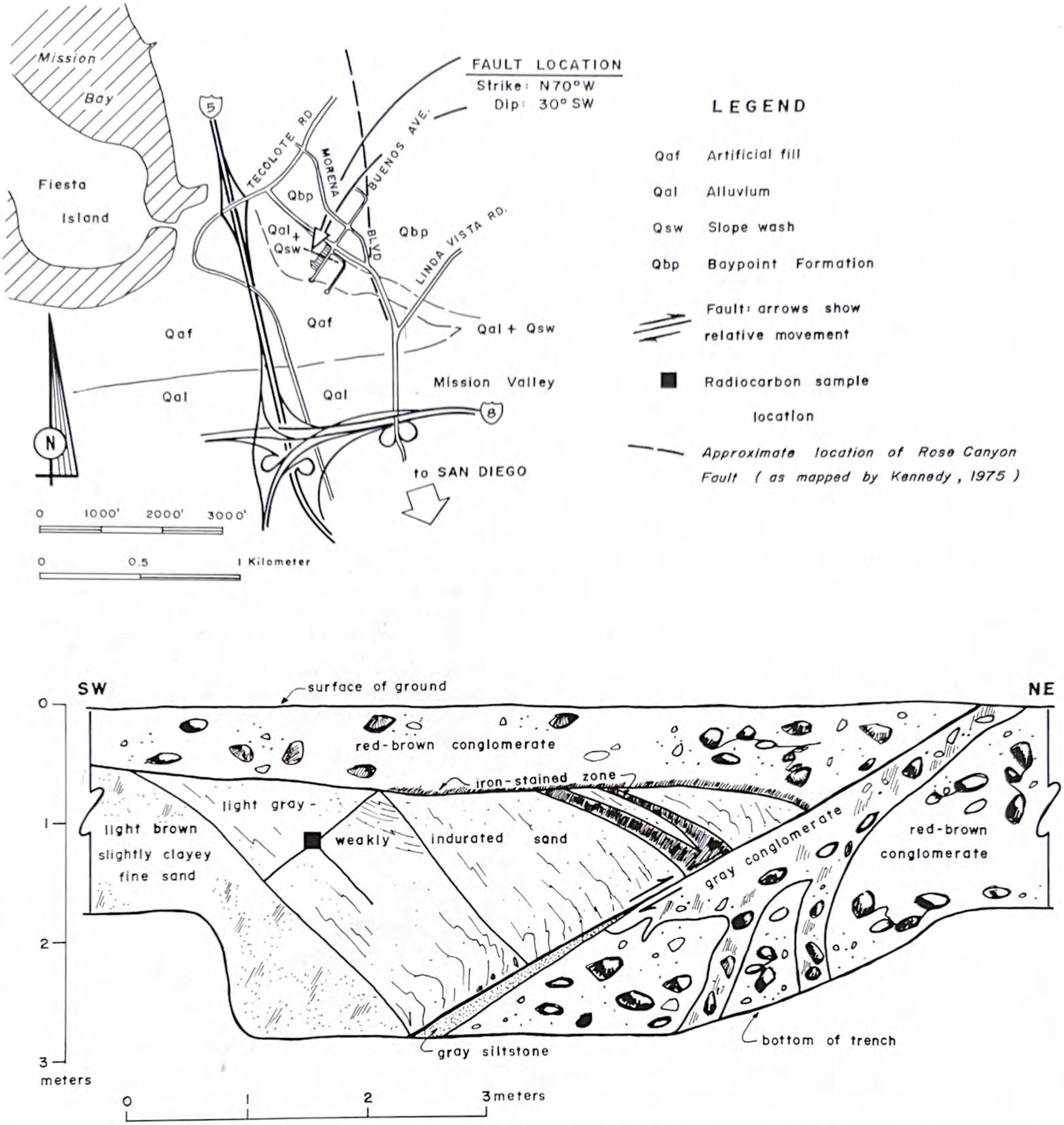

Figure 1. Location of subject fault and log of a portion of the main exploratory trench along Buenos Avenue.

Figure 2. View of the northerly exploratory excavation wall.

GEOLOGIC SETTING

The site is situated on relatively flat terrain at an average elevation between 4.5-10.7 m (15-35 feet) above mean sea level in the southeast Mission Bay area of San Diego, California (Figure 1). The general area is underlain by terrace deposits of the Late Pleistocene Baypoint Formation which grade upwards into younger deltaic-type sediments which mostly consist of weakly indurated cross-bedded sands, locally containing abundant flecks of carbonized organic matter.

During a routine exploratory soils and geologic investigation for a commercial development in July, 1975, a low-angle reverse fault was discovered striking N 70° W and dipping approximately 30° toward the southwest. Observations in the exploratory trenches indicate a minimum throw of 2.7 m (9 feet) and show the fault as a single, clean break that could be traced to the ground surface. Unfortunately, grading previously accomplished on the site had obliterated any evidence which could have been used to establish a minimum age for movement on this fault.

The relationship between this local fault and the Rose Canyon fault, as mapped by Kennedy (1975) and located less than 0.25 km east of the site, is not readily understood. Its west-northwesterly strike does not conform to the predominant north-northwesterly trend of the Rose Canyon fault. Furthermore, its reverse-style does not agree with the mostly dip-slip and strike-slip fault movements reported elsewhere by Kennedy (1975) within the Rose Canyon fault zone.

CONCLUSIONS

Considering that the throw of at least 2.7 m (9 feet), as observed in the exploratory trench, could not likely have been caused by a single seismic event, the Carbon-14 date presented in this paper suggests the possibility of relatively recent movement on this local fault. Unfortunately, no other supporting evidence could be obtained during the investigation to definitely establish its status of activity. Using the California Division of Mines and Geology criteria, the fault discussed herein is classified as potentially active. Additional data are needed to explain its relationship with the Rose Canyon fault zone.

ACKNOWLEDGMENTS

I thank Dale M. Stickney for his assistance in logging the exploratory trench and collecting samples for the radiocarbon analysis. Thanks are also due to Michael W. Hart and Richard L. Threet for their encouragement and critical comments in the preparation of this paper.

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View upstream of the original Lower Otay Dam in Otay Valley, San Diego County, California, February, 1916. Failure occurred during a season of very high rainfall. Historical Collection, Title Insurance and Trust Company, San Diego, California.

Flood damaged Otay Valley following failure of the Lower Otay Dam, February 1, 1916. View is toward the northwest from the Palm City area of San Diego, California. Historical Collection, Title Insurance and Trust Company, San Diego, California.

GROUNDWATER OCCURRENCE IN THE URBAN ENVIRONMENT: SAN DIEGO, CALIFORNIA

Donald R. Sorben
Kendall L. Sherrod
Shepardson Engineering Associates, Inc.
El Cajon, California

In recent years, groundwater seepage problems, occuring within the residential environment, have become a familiar subject to many local investigators. However, since most investigations have been limited by the usual time and budgetary restrictions, a thorough understanding of the nature and the potential extent of these problems has been somewhat inhibited.

The present discussion represents a summary of the observations and the data which have been collected by the authors over the past two and a half years and is based on a comprehensive review of several case histories.

Our findings, as well as the findings of others, indicate that most urban groundwater problems are directly related to the irrigation practices within residential developments, and that seepage conditions can develop wherever underlying lithological boundaries impede the normal downward percolation of groundwater. The evidence also indicates that a substantial groundwater impact may accompany many, if not most, residential developments.

Because this groundwater impact was not previously realized, most geologists and soil engineers have addressed only those groundwater problems which were known to exist at a site prior to construction. For this reason, subdivision grading designs have not normally taken into account the effects of substantially increased groundwater. In fact, grading operations have often contributed to the development of seepage conditions.

The factors which have led to the development of seepage problems at numerous locations in the past are probably present at many existing sites and have yet to develop into problem areas. For this reason, the number of these events may be expected to increase in the future.

It is estimated that as many as five hundred examples of "backyard" seepage exist at the present time within the County of San Diego. While most of these are quite small and are very localized, others involve numerous homes and many thousands of gallons of water per day.

GENERAL CASE

The typical seepage condition, which reaches the attention of a consultant, usually involves between 500 and 2000 gallons of water per day and is generally confined to a few homes. Normally, seepage conditions have developed within one to five years after the homes in the area were initially occupied. The first signs of the impending problem may be an area of ground which remains damp most of the time. During this period, plant consumption and evaporation can keep pace with the accumulating groundwater so that the problem may go unnoticed for some time. During this early phase, vegetation may flourish due to the availability of water. Other vegetation, particularly citrus, which is susceptible to the build-up of salts, may die.

This damp condition gradually gives way to a permanently waterlogged or swampy condition, usually within the following year. As water continues to accumulate, the affected area may become larger. Occasionally, some structural damage may be apparent in the form of settlement or shifting of structures. Paved areas may also show signs of weakening where water has saturated the subgrade material.

SOLUTIONS

The solution to these problems invariably calls for the installation of a subsurface drain system to remove the accumulating groundwater. Since these drains must be engineered specifically for each site, an understanding of the geological conditions which affect the flow and distribution of groundwater in the area is essential. The cost of performing these services can amount to several thousands of dollars, which in the past has been paid for by residential developers, home owners, and governmental agencies.

GROUNDWATER IMPACT

Considering the costs involved in even the most limited investigation, it is understandable why more detailed investigations to determine the source of water are not undertaken. The authors, however, have pursued the matter in some detail in an effort to determine the groundwater impact of residential developments. Furthermore, our findings may be applicable to other residential areas throughout southern California, whenever economic parameters, climate, and landscaping are equivalent.

As a result of our investigations, it was possible to conclude that the source of seepage water, in certain cases, was the result of irrigation. In each of these cases, subsurface drains had been installed to remove the excess water. The rate at which water was flowing from these drains was measured. By knowing the contributing lot space, it was then possible to use this measured flow of water to calculate an average amount of water contributed per square foot of irrigated lot space. The values thus obtained varied between 10.1 gallons (16.2 inches) and 11.2 gallons (18.0 inches) per year, per square foot of irrigated lot space.

Since these quantities represent excess water, above evapotranspiration losses, it is possible to compare a natural hydrological system with the hydrological system of an existing residential development.

One of the areas where flow rates of existing subdrains was measured was in the Vista Del Cerro area. Figure 1 is a plot of precipitation versus evapotranspiration for this area from 1958 to 1977. The potential evapotranspiration curve was plotted using the Thornthwaite potential evapotranspiration equation, corrected for latitude. Figure 1 represents the natural system which prevailed in the area prior to residential development. It can be seen that the only time excess water is available is during part of November, December, and January. During the rest of the year, potential evapotranspiration rates exceed available water. The area of overlap between the two curves is proportional to the amount of excess water and, in this case, that area represents only one-half inch of water. Since the moisture holding capacity of the soil is several times this amount, it can be safely concluded that no permanent groundwater recharge was taking place under the natural system.

Figure 2 is presented for comparison. The potential evapotranspiration is again poltted using the same data as in Figure 1. However, under the post-development system, we have a measured amount of excess groundwater occurring throughout the year. This amount represents the difference between applied water and the water lost through evapotranspiration. In fact, in any area where shallow plants are kept green year round, the amount of applied water must at least equal potential evapotranspiration rates. Therefore, the Vista Del Cerro area receives a total amount of water which is equal to the amount of evapotranspiration plus the amount of groundwater which is removed from the area by drains. In Figure 2, the dashed curve now represents the total water and is equal to precipitation plus irrigation.

An analysis of this graph reveals that this post-development system is equivalent to the same area, if undeveloped, receiving over 40 inches of precipitation per year. Or, stated differently, it would require over 40 inches of precipitation per year to equal the groundwater impact of this subdivision. Even this value is somewhat misleading in that it does not take into account runoff. Water applied for irrigation is usually controlled for maximum infiltration so that runoff is minimal. Precipitation, on the other hand, is more likely to occur as higher intensity showers with greater runoff. With these considerations in mind, an equivalent amount of precipitation might be closer to 50 or 60 inches

VISTA DEL CERRO
POTENTIAL EVAPOTRANSPIRATION vs. RAINFALL

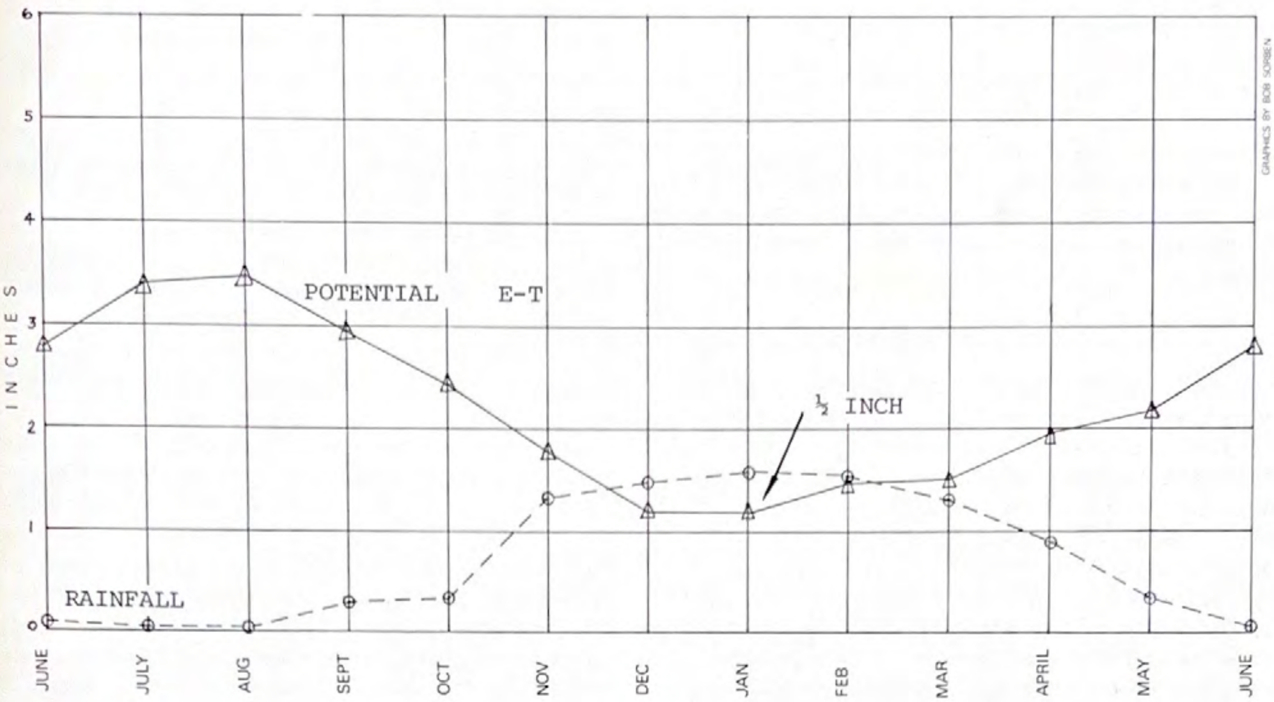

Figure 1. Natural system.

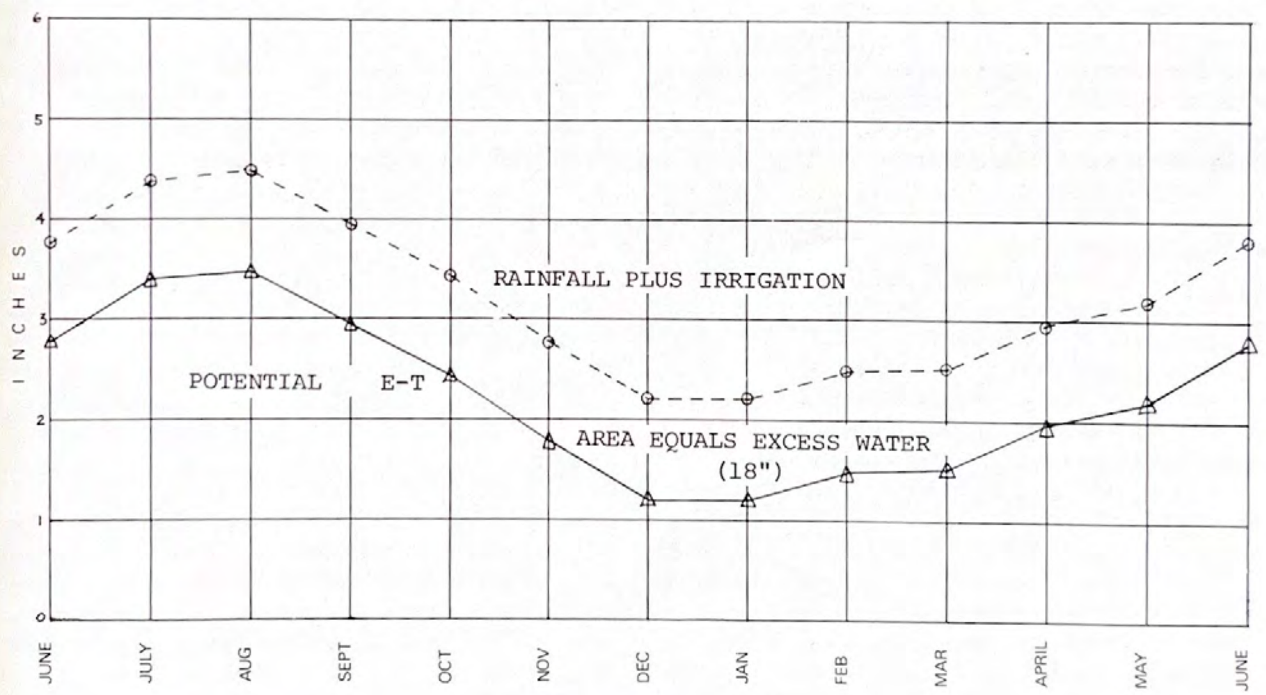

Figure 2. Post-development system.

per year. Certainly, if the San Diego area did receive this amount of rainfall, no one would be surprised to find that seepage conditions were a common occurrence.

It is believed that as soon as the homes in a particular subdivision are occupied, water begins to be applied at something close to the above rates. Due to the fact that new landscaping is being established over a broad area, it is conceivable that some subdivisions may even exceed these rates for a period of time.

CONTRIBUTING FACTORS

This excess water infiltrates to lower and lower levels within the subsurface. If the area is underlain by a porous permeable material, this groundwater may continue unimpeded to join the regional groundwater system at depth. If, on the other hand, the area is underlain by lithologies of contrasting permeability, this water may begin to accumulate at less permeable horizons. As groundwater continues to mound, it may migrate laterally, following whatever lithological conduits exist. These conduits may consist of buried stream channels, zones of low cementation, sandstone lenses, landslide debris, or even utility trenches. Often, seepage conditions develop where these conduits are intercepted by the ground surface, as in cut slopes, or where they are blocked by low permeability fill materials.

The placement of compacted fill material in swales is a common practice in most modern grading operations. The hydrological effects of these fills, however, range from one extreme to the other, depending on the permeability of the final compacted material. When fills are permeable, water may infiltrate to the original buried drainage channel, accumulate and flow "down swale," possibly causing problems at lower elevations.

An interesting example of this, taken from the Poway Mesa area, is illustrated in Figure 3. The natural landscape was modified by cut/fill operations, which resulted in the filling of a small swale with approximately 20 feet of decomposed granitic material. A small amount of sandy alluvium within this swale was covered over. When irrigation water was applied to the lots above, water was able to percolate through the fill to the original alluvium, resulting in a seepage condition with an estimated flow of 2000 gallons per day. Of course, if the condition could have been anticipated, a small inexpensive drain could have been placed in the swale during construction to prevent the problem from developing. The intentional placement of a subsurface drain in the bottom of swales, prior to their filling, has been used successfully at some locations. However, it should be noted that this is not always effective.

In the Vista Del Cerro subdivision, a major canyon was also filled. In this case, the fill material was very

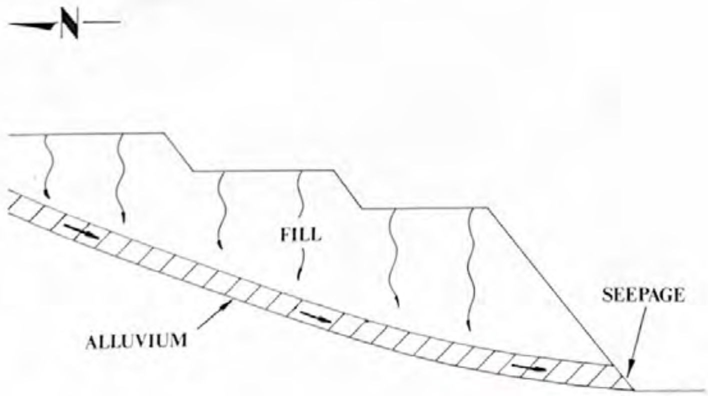

Figure 3. Cross section - Poway Mesa.

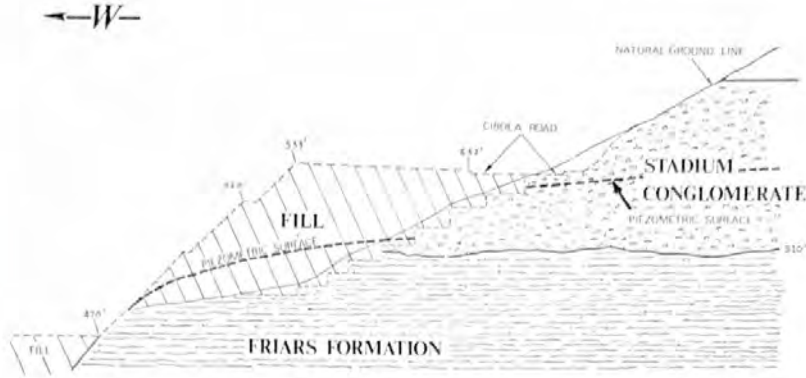

Figure 4. Cross section - Vista Del Cerro.

low in permeability and acted as a barrier to the flow of groundwater. The subsurface conditions through part of the seepage area are shown in Figure 4. Homes in this area have been built mostly on Stadium Conglomerate, which is underlain at a shallow depth by the Friars Formation. The Friars Formation, in this area, is composed of approximately 30% montmorillonitic clay and is virtually impermeable. However, the permeability of the Stadium Conglomerate in the area has been determined by a pump test to be approximately 70 gal/day/ft^2, and that of the fill material was measured at 7×10^{-2} gal/day/ft^2. It is our opinion that irrigation water was able to infiltrate to the Stadium/Friars contact where its normal downward percolation was stopped. As groundwater continued to accumulate, it also began to migrate down dip, eventually reaching the compacted fill barrier. This impounded groundwater ultimately saturated the fill, causing structural damage to the homes above, and waterlogging conditions to the lower lots.

In the Poway Mesa subdivision a similar situation developed where a thin alluvial aquifer had been partially removed during grading, and was subsequently replaced with compacted subgrade material for Betty Lee Way. As irrigation water became "dammed up" behind this obstruction, a seepage condition developed which was over one block long. Figure 5 is a groundwater contour map within the area and shows the restricted flow pattern. This map was constructed after installing perforated plastic pipe in shallow hand-augered holes throughout the area. By using these pipes as piezometers, it was possible to survey the groundwater surface directly, and then to use these elevations to plot the inferred groundwater surface.

As previously mentioned, accumulating groundwater may sometimes gain access to utility trenches and these trenches may then act as conduits. Observations indicate that many of these trenches, particularly those which have been backfilled with clean sand, have the capacity to collect groundwater over a broad area. As a result, groundwater may be concentrated at lower elevations where its accumulation may eventually lead to the development of seepage conditions. This phenomenon suggests the possibility of modifying the design of some utility trenches so that they might intentionally function as subsurface drains. With proper management, it appears likely that a relatively inexpensive means of controlling groundwater in some areas would thus be obtained.

Another somewhat dissimilar occurrence of groundwater seepage has been observed in areas which are underlain by particularly well-cemented Linda Vista terrace material. In the typical case, imported landscaping soil has been placed over this terrace "hard pan." Over-irrigation allows water to accumulate in the surface depressions of the underlying terrace, leading to local waterlogging. Since many of these depressions are not intercemented and the relief in these areas is generally low, these problems probably

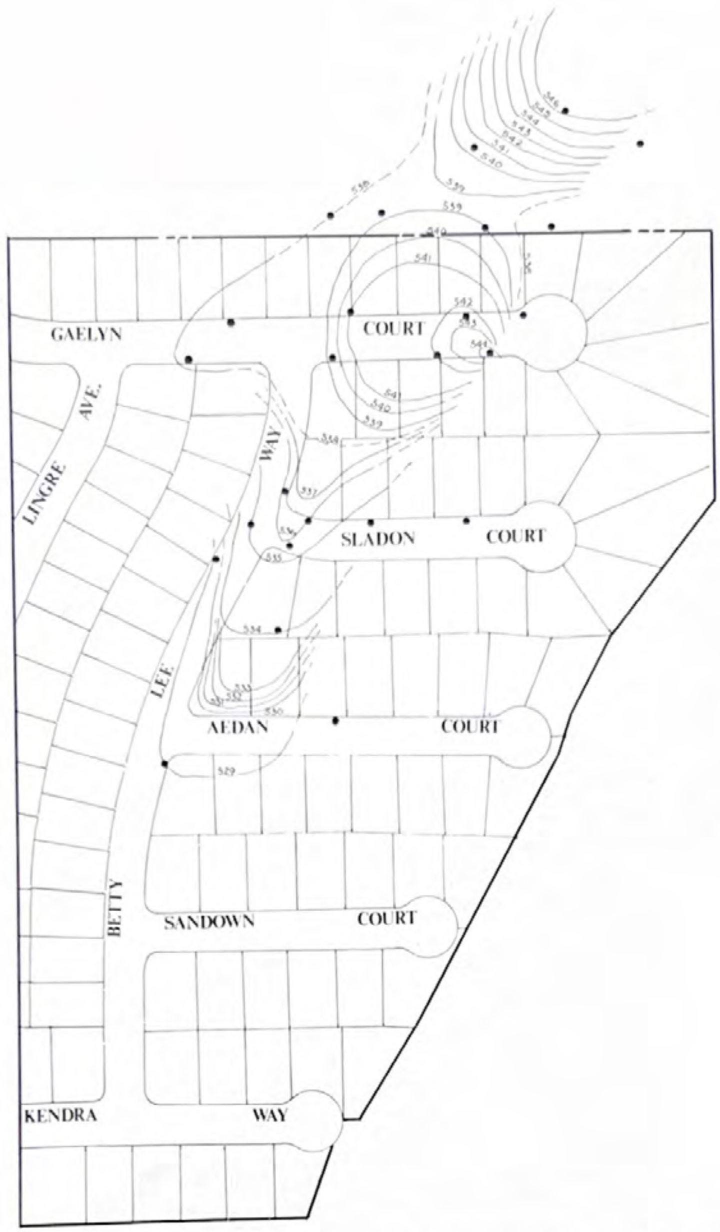

Figure 5. Groundwater contour map - Poway Mesa

do not have the potential to develop beyond the local ponding stage.

APPLICATIONS

Perhaps the most striking example of urban groundwater problems appears to be an area which is presently under investigation by the City of San Diego. The area extends from near Patrick Henry High School, southwest along Navajo Road and south along College Avenue. This area encompasses over 300 acres and includes at least 40 individual seepage sites. The entire area is underlain by the Santiago Peak Volcanics which are highly fractured and probably quite permeable.

The authors have investigated many of the groundwater problems in this area and have concluded that the most pro-

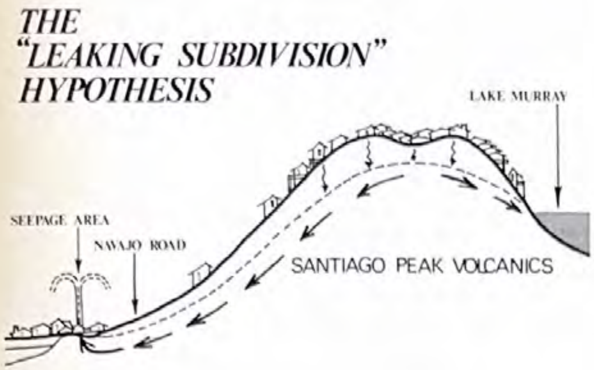

Figure 6.

bable source of this groundwater is irrigation with perhaps some initial contributions from Lake Murray. Figure 6, "The Leaking Subdivision Hypothesis," is presented as a model for the situation as it is believed to currently exist. This model proposes that Lake Murray, which was constructed in the early 1900's, has provided the area with a constant supply of groundwater, and that over the years this has resulted in raising the local groundwater table. Subsequently, imported irrigation water has been contributed by the residential developments in the area, so that at the present time water is being supplied faster than it can be removed from the area.

The fact that the number of groundwater problems in the San Diego area have actually increased during the past few years, while the San Diego area has, at the same time, had below normal precipitation (Figure 1), seems to preclude natural water as a probable source. Also, measurements for total dissolved solids, which can sometimes be indicative of this source, have generally been too high (2000+ppm) for natural groundwater flowing through fractured rock. Actually, a much better correlation can be made between both the poor quality and the increased quantity of groundwater in the area with the amount of development that has taken place on the surrounding hillsides.

The piezometric surface which could be expected to accompany this model is also shown on Figure 6. In fact, seepage sites, located well above the level of Lake Murray, have been observed in the field, and their existence tends to confirm the existence of a high pieszometric surface which could only be present it water is being supplied from above.

Since we have already assessed the groundwater impact of other similar subdivisions, it is possible to use these calculations as a check on the feasibility of this model. If an area of 3000 feet by 3000 feet is considered as being the potential contributing area, and if it is assumed that 50% of this area is regularly irrigated lot space, then the estimated amount of groundwater added per day can be calculated:

$$3000 \text{ ft} \times 3000 \text{ ft} = 9\text{x}10^6 \text{ ft}^2 \text{ (gross area)}$$

$$9\text{x}10^6 \text{ ft}^2 \times 50\% = 4.5\text{x}10^6 \text{ ft}^2 \text{ (irrigated area)}$$

$$4.5\text{x}10^6 \text{ ft}^2 \times \frac{10.1 \text{ gal/yr/ft}^2}{365 \text{ days/yr}} = 124{,}520 \text{ gal/day}$$

If these calculations are applicable, then the presence of groundwater at these seepage sites can easily be attributed to irrigation within the adjoining subdivisions.

CONCLUSION

In the foregoing discussion, we have attempted to present a broad outline of the physical occurrences of groundwater seepage in local urban environments. It would be nice to be able to conclude with a list of workable solutions which could be applied to the many ramifications associated with these problems. We cannot provide such a list, but we hope that the information we have presented may contribute to the understanding of the problem and thereby expedite the development of really workable solutions.

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View towards northwest of the International Border, Tijuana (lower left), San Ysidro, and Otay Mesa. Date of photograph is approximately 1940.

THE CASE OF THE BOOMERANG COBBLE

Patrick L. Abbott
Department of Geological Sciences
San Diego State University

In July of 1975, five Mexicali firemen enroute to Tijuana stopped at a well-frequented wide place in the road 13 km east of Tecate to avail themselves of the type of facilities well known to field geologists. While relieving themselves among the chaparral and spheroidally weathered granitic boulders, they smelled the stench of decaying human flesh. The firemen walked toward the locus of the odor and found a crudely dug, shallow grave.

The gruesome find was reported to authorities who returned to disinter the body which was partially covered by a plastic tarpaulin shroud. Unwrapping the shroud exposed not only a woman's body but also a well-rounded, durable cobble. The Tijuana policia perceptively noted that the stinking black cobble did not resemble the surrounding granitic terrane. The cobble apparently was of such significance to the murderer that it received the same efforts at concealment as the body. Obviously, it was hoped that neither of them would ever be seen again. The autopsy showed that death occurred as a result of a severe battering with a blunt instrument that included a blow along the right side of the head that impacted with enough force to knock a silver dollar-sized hole in the skull. Thus, it appeared that the rounded silicic cobble was the likely instrument of death.

Identification of the body was hindered by the absence of any personal effects such as identification cards and jewelry and especially by the cunning of the killer in removing the victim's full set of dentures. Burial had taken place during the warm and dry summer weather which retarded decomposition of all surfaces of the body. Specifically, the part of the body resting on the floor of the grave was severely rotted due to upward-rising capillary water trapped beneath the impermeable barrier created by the body. However, the side of the body facing upward was mummified due to the dry surface conditions which thus allowed a fingerprint make which idenfified a California school teacher. Cross-

Figure 1. Photo of grave east of Tecate.

checking revealed that the woman's husband had filed a missing person report near the end of June saying she had wandered away from their vacation residence in Rosarito Beach.

The presence of an apparent murder-weapon rock, and the question as to which country had jurisdiction over the case prompted the prosecutor from the District Attorney's office to call in geologists to see what information they could contribute regarding the cobble. Did the murder occur on impulse within Mexico using a handy rock found at or near the gravesite? Was the murder perpetrated some unknown distance away, possibly within the U.S.? The case presented an interesting chance to apply some knowledge of the provenance of cobbles.

The initial visit found the gravesite (Figure 1) located just over a low ridge near the highway. The shallow grave was dug only 30-45 cm deep before the digger

Figure 2. View from the gravesite toward the alluvial slope that would have been reached had the murderer continued a little further.

ran into indurated grus and granitic bedrock. Had the furtive murderer carried the petite body another couple hundred meters he would have reached an alluvium-covered slope (Figure 2) where a deep grave could have been easily dug. This unreasonable selection of a gravesite by a murderer thorough enough to remove dentures suggested that the burial occurred at night when the nearby terrane could not be readily evaluated. This lack of understanding of the terrane ruled out all SDAG members as murder suspects.

A careful search of the surrounding granitic slopes for conglomerate outcrops or lag gravels failed to yield any stones even remotely like the murder-weapon rock. Thus, the rock obviously was transported to the burial place, possible from the murder site. The lethal stone is a dense, silicified, lithic tuff breccia of apparent andesitic composition. It is crudely flow banded subparallel to the intermediate and short axes. Typical lithic fragments within the cobble are comprised of altered flow rock and relict pumiceous-textured fragments about 2 cm long and 0.5 cm thick; the largest fragment is a silicified phenocrystic aphanite about 4.3 cm long and 1.6 cm thick. The rock is a moderate greenish gray (5GY 5/1), well-rounded cobble with one rounded joint face; dimensions are 11.7 x 10.8 x 7.6 cm. The high degrees of sphericity and roundness suggest it was worked long and hard by vigorous currents.

The next phase of the investigation took us to Clairemont to visit the victim's home constructed upon the Linda Vista terrace. Inspection of the side and back yards revealed planter areas edged by well-rounded, oblate to spheroidal andesitic breccia cobbles, some of which were similar to the death instrument (Figure 3). Therefore, it seemed likely that the murder occurred with a rock from the homesite.

However, in the missing person report the husband stated that the wife disappeared from the family trailer home in Rosarito Beach. Was it possible that the

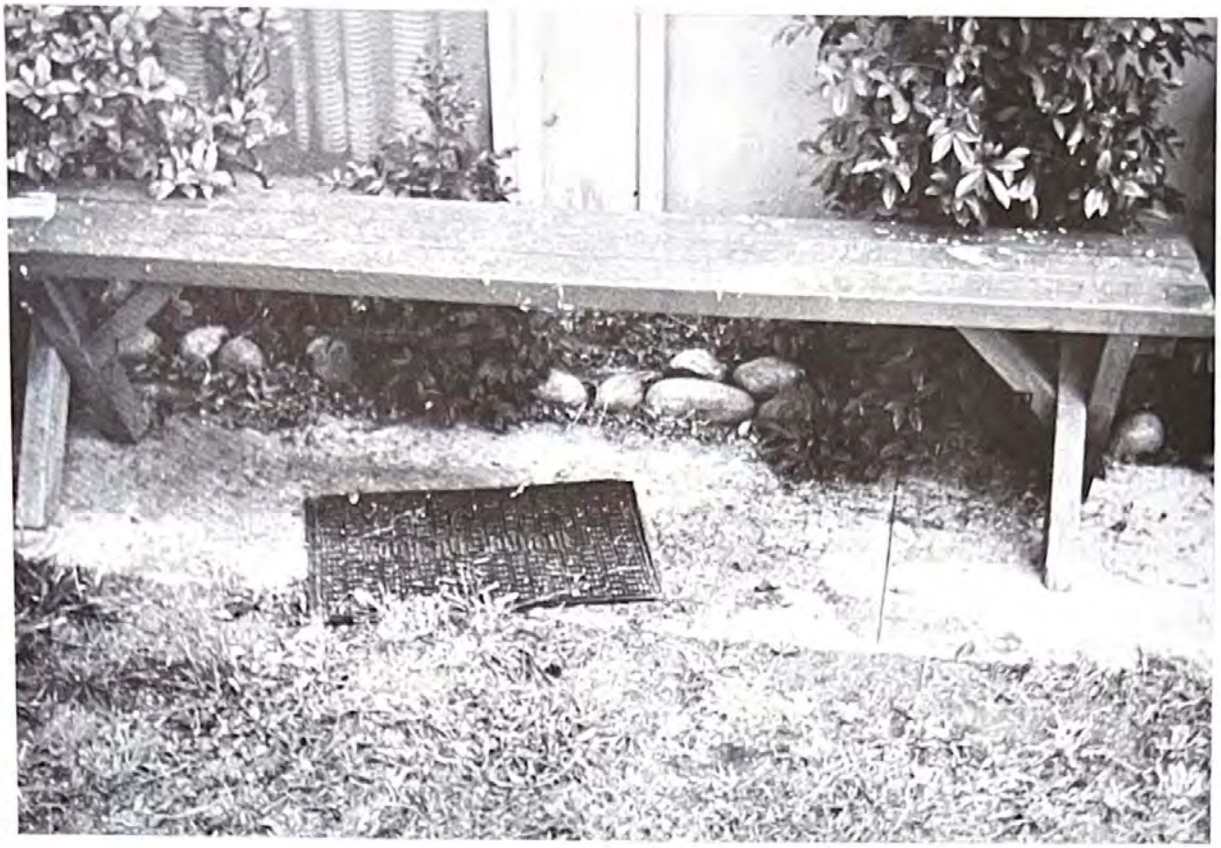


Figure 3. Volcanic breccia cobbles from the Lindavista Formation lining a planter area in the backyard of the murder victim.

lethal cobble came from Rosarito Beach and that the murder was committed there? The conglomerates at Rosarito Beach, and the gravels derived from them, contain andesitic breccia clasts with compositions and textures that overlap those found at the victim's homesite on the Lindavista Formation in Clairemont. Thus, it was not possible to say whether the death instrument came from Rosarito Beach or Clairemont.

Later the cobble in question was shown to a daughter of the deceased who recognized it as a rock she picked up at Rosarito Beach and brought back to the home in Clairemont. The geological inability to determine where the cobble was picked up was resolved by the daughter's memory. Discovery of blood spatters at the Clairemont home, together with the recollection of the cobble's recent migratory history, answered the question as to where the murder occurred.

After being confronted with the geologic and other evidence, the husband finally recanted his stories of innocence and pled guilty to a charge of voluntary manslaughter with this description of the murder: "In a moment of blind passion, I grabbed a rock that was on top of the refrigerator and struck her on the head. She fell and struck her head." The husband is presently serving a term of from six months to fifteen years. It would have been simpler to file for divorce, split the community property, and be done with it.

Postscript.---The geologic investigation established that the murder rock was not collected in the vicinity of the gravesite and hence the crime probably occurred elsewhere. However, the clast was not distinctive enough to pinpoint a Rosarito Beach or Clairemont source. Thus, the geologic contribution was not as great as it could have been if, for example, the murderer had been discriminating enough to select a Poway rhyolite clast.

GEOLOGY OF SOUTHWESTERN SAN DIEGO COUNTY, CALIFORNIA: FIELD TRIP

Annual Field Trip
San Diego Association of Geologists
October 8, 1977

Herman T. Kuper
Soil Testers
La Mesa, California

Gregory T. Farrand
Geocon, Incorporated
San Diego, California

ROAD LOG

Mileage

0.0 *Start of trip.* Parking lot south of the San Diego State University parking garage east side of College Avenue. Exit back of parking lot onto Montezuma Avenue (0.2). West on Montezuma Avenue to Montezuma Avenue-Collwood Boulevard intersection.

1.5 *STOP 1.* Exposure of the Mission Valley Formation on the northern side of the Montezuma Avenue-Collwood Boulevard intersection. These exposures are typical of the lower portion of the Mission Valley Formation in southwest San Diego County. Tan to grey, fine grained sandstones, fossiliferous concretionary beds, and cross-bedding are some of the more common features. Exposures of the Stadium Conglomerate are found down section, west on Montezuma Avenue. The conglomerate overlying the Mission Valley Formation is probably the Pomerado Conglomerate. The most northern traces of the La Nacion fault are exposed farther west in the same roadcut.

Proceed south on Collwood Boulevard to 54th Street (2.3), continue to Euclid Avenue (4.8), and proceed south.

4.1 Approximate location location of the Mission Valley Formation-San Diego Formation contact.

Turn east of Federal Boulevard (5.0). Proceed east to Bayview Heights Way (5.6), go south across Highway 94 (Bayview Heights Way turns into Kelton Road), and park opposite uphill roadcut on Kelton Road (5.8). Walk over Kelton Road and roadcut to the east. An old paved road should be visible in the canyon.

5.8 *STOP 2.* Walk to exposure of Mission Valley Formation farthest west down the old paved road. In this exposure are fossiliferous concretionary beds and grey, fine grained sandstones of the lower Mission Valley Formation. Notice the "flaggy" appearance of some areas of the exposure. Walk to exposures up the old paved road to the south. Visible in the section are iron placers, pebble stringers, and darker brown weathering colors of sandstones in the upper Mission Valley Formation. Continue back to roadcut exposed on Kelton Road. In the cut, the Mission Valley Formation in contact with the San Diego Formation is a pink colored sandstone. The overlying conglomerate is believed to be an incised channel of the San Diego Formation. A more typical exposure of the San Diego Formation is found at the top of the hill on the northeast corner of Kelton Road and Bethune Court.

Turn around at top of hill, proceed east on Highway 94 (6.0), exit a at Federal Boulevard (6.3). Follow Federal Boulevard northeast to Mallard Street (6.9). Turn east on Mallard Street, then south on Swan Street (7.0).

7.0 Exposures of Stadium Conglomerate.

Proceed up Swan Street.

7.1 *STOP 3.* Cuts on the east side of the road expose sediments of the Mission Valley Formation, the San Diego Formation, and Pleistocene terrace deposits. The Mission Valley Formation contains friable white sandstones with numerous caliche veins. The iron stained sandstones and pebble stringers of the San Diego Formation unconformably overlie the sandstones of the Mission Valley Formation. Upslope is the contact between the San Diego Formation and the reddish brown iron-cemented gritty sandstones of Pleistocene age.

Proceed back to Mallard Street (7.4) and continue east.

7.7 Exposure of the Mission Valley Formation.

Follow Mallard Street to 69th Street (8.1), south on 69th Street, then southwest on Madera Street (8.7).

9.2 The most southerly exposure of the Stadium Conglomerate known is exposed on the south side of road, east of the intersection of Madera Street and Wunderlin Avenue.

Proceed on Madera Street to Imperial Avenue (9.5), east on Imperial Avenue to Woodman Street (9.5, next street), then south on Woodman Street to Madrone Avenue (9.7).

9.7 *STOP 4.* Walk approximately 100 feet up Madrone Avenue passing through exposures of upper Mission Valley Formation. At top of cut are good exposures of the "redbed." Sweetwater mudstones (not exposed here) unconformably overlie the Mission Valley Formation in this area.

Continue south on Woodman Street to intersection with Skyline Drive (10.2).

10.2 *STOP 5.* Exposed in the road cut on the northwest corner of the intersection are the interbedded mudstones, gritstones, and sandstones of the Sweetwater Member of the Rosarito Beach Formation. Cleaner sandstones occur in the eastern portion of the exposure, halfway up the cut.

Continue west of Skyline Drive to 61st Street (10.9), then south on 61st Street to Division Street (11.3). Turn east on Division Street and then north on Theodore Drive (11.5), follow to the end.

11.6 *STOP 6.* Exposure showing unconformable relationship between the bright white gritstones of the Sweetwater Member and the tan to grey, medium grained sandstones of the San Diego Formation. The La Nacion fault passes through the housing tract and until recently houses were not constructed on the pads through which the fault passes.

Turn around and go back to Division Street (11.7), then east on Division Street to its end.

11.8 *STOP 7.* Outcrops of the silicified Sweetwater gritstone in this area were first described by Hertlein and Grant in 1944 as an unusual outcrop of the San Diego Formation. It is so well cemented that good thin sections of the rock are possible.

Turn around and proceed west on Division Street to Harbison Avenue (12.8). Turn south on Harbison Avenue and then turn east on 8th Street (13.3). Proceed on 8th Street to Plaza Boulevard (13.5).

13.5 Good exposure of the San Diego Formation across Plaza Boulevard.

Turn northeast onto Plaza Boulevard. Stay on the two-lane highway (becomes Paradise Valley Road). Continue east on Paradise Valley Road to Woodman Street (15.1). Turn south on Woodman Street and follow to Alta View Drive (16.1). Turn east on Alta View Drive to intersection with the street connecting Alta View Drive with the South Bay Freeway (16.3). Turn east on South Bay Freeway.

16.6 *STOP 8.* Road cut exposes the "redbed" of the upper Mission Valley Formation unconformably overlain by sandstones and mudstones of the Sweetwater Member. A good outcrop for showing the difficulty in distinguishing the Mission Valley Formation from the Sweetwater Member. The "redbed" is one of the distinguishing features.

Continue east on South Bay Freeway to second road cut east of Briarwood-South Bay Freeway intersection (17.2)

17.2 *STOP 9.* The roadcut on the north side displays the unconformable relationship between the Mission Valley Formation and the Sweetwater Member. Notice the iron placers, cobble stringers, and "redbed" which emphasize the angular unconformity. The Sweetwater mudstones overlie the sandstones and are found interbedding with the gritstones and sandstones of the Sweetwater Member farther up section.

Continue east on the South Bay Freeway.

17.7 Exposure of the Mission Valley Formation lapping onto metamorphic rocks of the Santiago Peak Volcanics.

Turn south on Sweetwater Road (17.8). Turn south-southwest on Bonita Road (18.8). Proceed south on Bonita Road, then turn southeast onto Acacia Avenue (19.9). Continue to end of paved road (21.0).

21.0 *STOP 10.* On the south side of Acacia Avenue, behind the houses, is a dirt road leading up the hill. Along this road are good exposures of the Sweetwater and Otay Members of the Rosarito Beach Formation. The Sweetwater-Otay contact is exposed in the cut across from the new housing development halfway up the hill. Farther up the hill are exposures of the San Diego Formation and Pleistocene terrace deposits.

Turn around and go back to Bonita Road (22.2). Proceed west on Bonita Road.

23.5 Brookside Winery.

Turn south onto Glen Abbey Boulevard (24.0)

24.4 *STOP 11.* Notice the vertical separation: to the east, exposures of the Otay Member at street level and the San Diego Formation near top of hill, and to the west, exposures of the San Diego Formation.

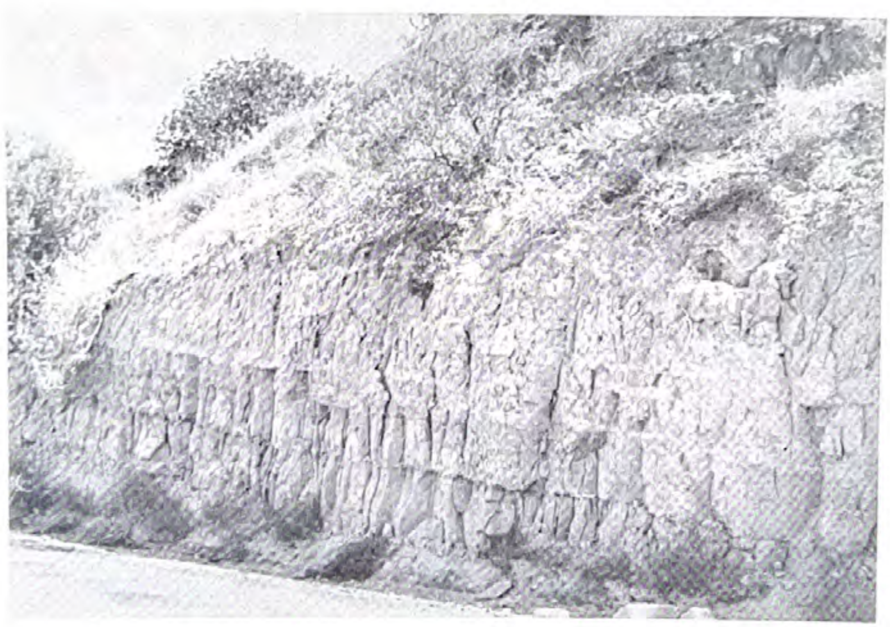
Continue on Glen Abbey Boulevard to Bonita Road (24.6, Glen Abbey Boulevard loops back to Bonita Road). Turn west on Bonita Road to Interstate 805 (24.9). South on Interstate 805.

26.6 *See Side Trip 1.* Exit Interstate 805 at Otay Valley Road (28.8). Go east on Otay Valley Road to Brandywine Avenue (29.5), turn north on Brandywine Avenue to the end of the pavement.

30.2 *STOP 12.* On the low hill to the northeast is a good exposure of the La Nacion fault and the contact between the Sweetwater and the Otay. This shows the gradational nature of the contact between the two members.

Turn around and go back to Otay Valley Road (31.0). Proceed east on Otay Valley Road, going uphill through exposures of Sweetwater Member, Otay Member, San Diego Formation, and Pleistocene terrace deposits.

33.3 Sweetwater-Otay contact.



Medium-bedded, light grey sandstones of the Otay Member of the Rosarito Beach Formation exposed along east side of Otay Valley Road in Chester Canyon, Otay Mesa, California.

33.7 Otay-San Diego Formation contact.

33.8 San Diego Formation-Pleistocene terrace deposits contact.

33.9 *See Side Trip 2.* Continue east on Otay Valley Road to Heritage Road (34.0). Turn south on Heritage Road to Otay Mesa Road (34.3). Turn west, then south (35.5) to stay on Otay Mesa Road.

36.0 *STOP 13.* Road cut on west side of road contains locally derived, boulder and cobble size clasts in San Diego Formation or Pleistocene terrace deposits.

36.2 *STOP 14.* In road cut on southeast side of the road is the San Diego Formation-Otay contact.

36.8 Approximate location of Otay-Sweetwater contact.

Continue south on Otay Mesa Road until it turns into East Beyer (37.3). Continue on East Beyer to Center Street (37.8), then west on Center Street to San Ysidro Boulevard. Turn north on San Ysidro Boulevard and then onto Interstate 805 back to San Diego State University. End of trip.

0.0 *Side Trip* 1 - *Otay Lakes.* Begin at intersection of Interstate 805 and Telegraph Canyon Road. Proceed east on Telegraph Canyon Road.

1.3 La Nacion fault crosses road and trends south through canyon.

2.3 Approximate location of Sweetwater-Otay contact.

7.3 Turn south on Wueste Road (lake perimeter road).

7.7 Exposures of Sweetwater gritstone with interbeds of angular conglomerate facies.

8.1 Roadcut exposing angular conglomerate facies.

8.9 More exposure of angular conglomerate.

10.6 Lower Otay Park. Location of contact of Sweetwater with basement rocks (granitics).

Return to intersection of Telegraph Canyon Road and Interstate 8. End of *Side Trip* 1.

0.0 *Side Trip* 2 - *Bentonite Mines.* Turn west off Otay Valley Road onto dirt road leading to Bates' Auto Dismantling. Circle around south side of Bates', then follow dirt road north along fence. Take most western road at junction of several dirt roads (0.6).

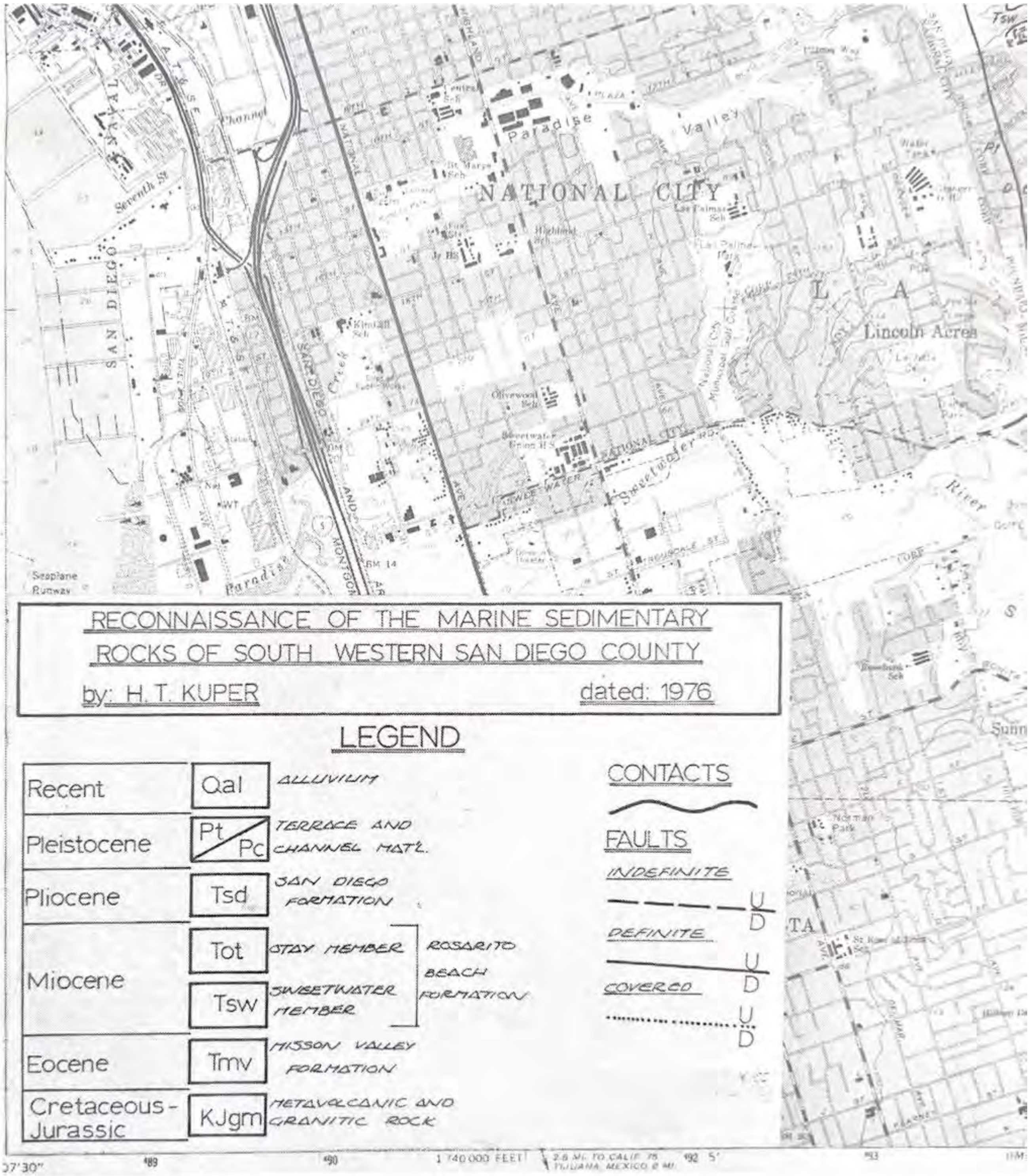
0.7 Mima mounds.

Continue on dirt road

1.1 On south side of hill are exposures of Sweetwater Member, Otay Member, and San Diego Formation. Cuts made by petroleum companies provide excellent exposures of the Sweetwater Member and of the bentonite beds within the Otay Member.

Return to Otay Valley Road. End of *Side Trip* 2.

Back Cover. Close-up photograph of landslide on front cover in Tijuana, Mexico. View is toward the west along the International Border.



Mapped, edited, and published by the Geological Survey

Control by USGS, USC&GS, and City of San Diego

Topography by photogrammetric methods from aerial photographs taken 1966. Field checked 1967
Supersedes map surveyed 1939, revised 1953

Selected hydrographic data compiled from USC&GS Chart 5107 (1967)
This information is not intended for navigational purposes

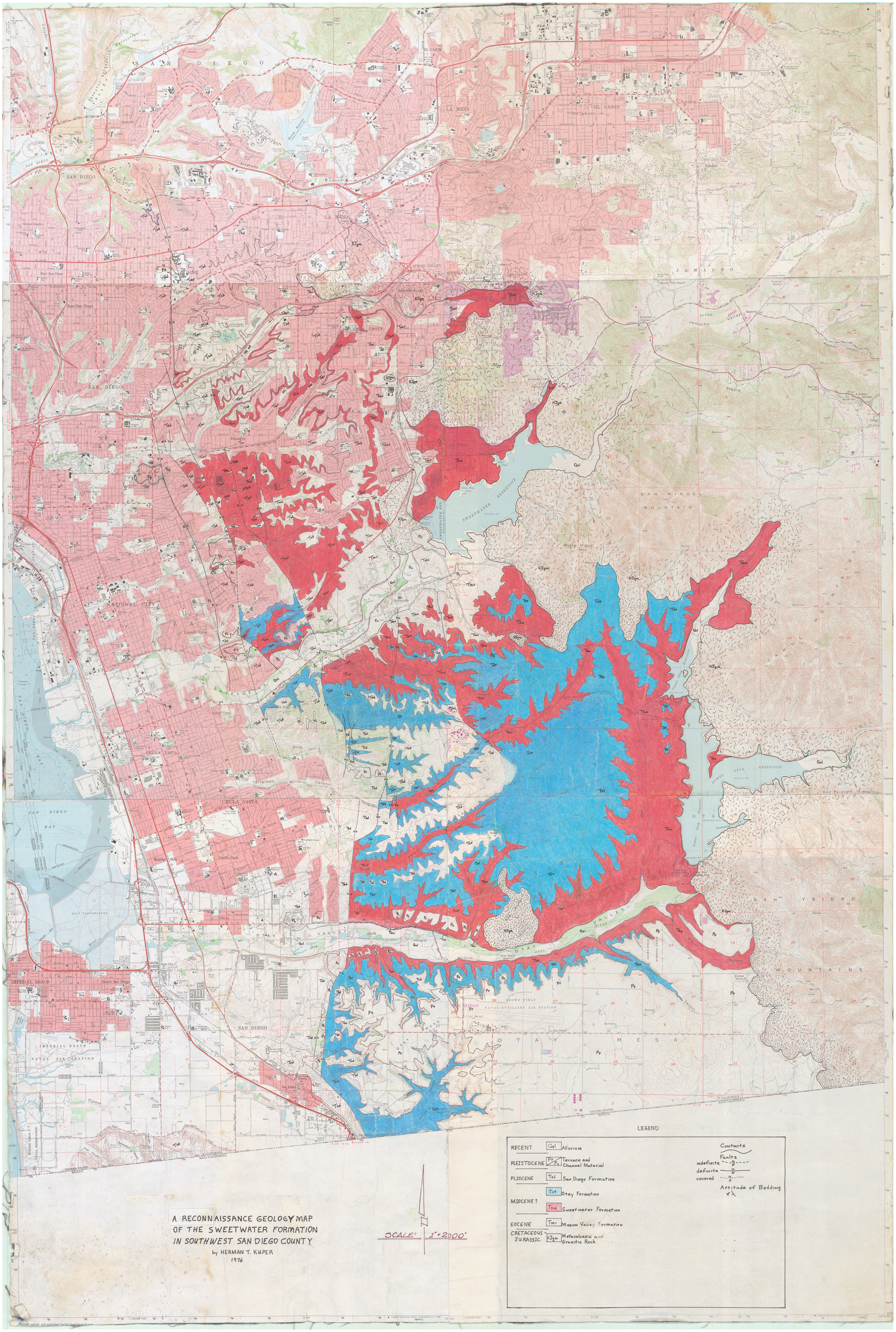
Polyconic projection. 1927 North American datum
10,000-foot grid based on California coordinate system, zone 6
1000-meter Universal Transverse Mercator grid ticks, zone 11, shown in blue

Red tint indicates areas in which only landmark buildings are shown

UTM GRID AND 1967 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

CONTOUR
DOTTED LINES RE
DATUM
DEPTH CURVES AND SOUNDINGS
SHORELINE SHOWN REPRESENT
THE MEAN RANGE

THIS MAP COMPLIES WITH
FOR SALE BY U. S. GEOLOGICAL SURVEY, D
A FOLDER DESCRIBING TOPOGRAPHIC



A RECONNAISSANCE GEOLOGY MAP
OF THE SWEETWATER FORMATION
IN SOUTHWEST SAN DIEGO COUNTY
by HERMAN T. KUPER
1976
SCALE: 1" = 2000'
LEGEND
RECENT
Qal Alluvium
PLEISTOCENE
Pt/Pc Terrace and Channel Material
PLIOCENE
Tsd San Diego Formation
MIOCENE ?
Tot Otay Formation
Tsw Sweetwater Formation
EOCENE
Tmv Mission Valley Formation
CRETACEOUS - JURASSIC
KJgm Metavolcanic and Granitic Rock
Contacts
Faults
indefinite
definite
covered
Attitude of Bedding
4°
SAN DIEGO
LA MESA
EL CAJON
SPRING VALLEY
JAMACHA
NATIONAL CITY
CHULA VISTA
SWEETWATER RESERVOIR
SAN MIGUEL MOUNTAIN
SAN DIEGO BAY
IMPERIAL BEACH
OTAY MESA
SAN YSIDRO
MOUNTAINS
UNITED STATES
MEXICO
CALIFORNIA
BAJA CALIFORNIA