SOUTH EAST
SAN JOAQUIN VALLEY FIELD TRIP,
KERN COUNTY, CALIFORNIA

PART II: Structure and Stratigraphy

April 18 & 19, 1986

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Introductory Remarks

The east side of the San Joaquin Valley has been the focus of oil exploration anc production for over 85 years yet it is still one of the most promising wildcatting areas in California. Recent discoveries in older and deeper Miocene sands have brought geologists back to the east side to search for the unmapped stratigraphic trap and the untested faul block.

This rekindled interest has created a need to review what is known about the stratigraphy and to discuss the structural setting in the southeastern corner of the valley. Part I of this review took place last year during the Spring Field Trip of the San Joaquin Geological Society when we visited outcrops north of the Kern River. The Guidebook for the field trip (Guidebook No. 56) includes maps illustrating production distributions anc cumulative production by formation, Olcese and Vedder descriptions from outcrops north of the river, core descriptions of Vedder and Freeman Silt/Jewet sands which do not crop out, and a listing of publications which conferred name designations and type localities for all of the east side formations.

The 1986 field trip will visit outcrops from just north of the Kern River south tc the Tejon embayment. This guidebook includes a paper summarizing the east side stratigraphy, numerous measured and stratigraphic sections, and two papers which present alternative views on the structural style in the southern part of the valley.

We hope this field trip will stimulate new ideas and generate discussions among its participants because it is through these exchanges that we all improve our understanding of this corner of the world that holds so much additional potential.

The field trip committee would like to thank the following companies for their clerical and drafting support in constructing this guidebook:

CHEVRON U.S.A.
Texaco, USA
Tenneco Oil Company
Santa Fe Energy Company
Evans, Carey and Crozier

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CONTENTS

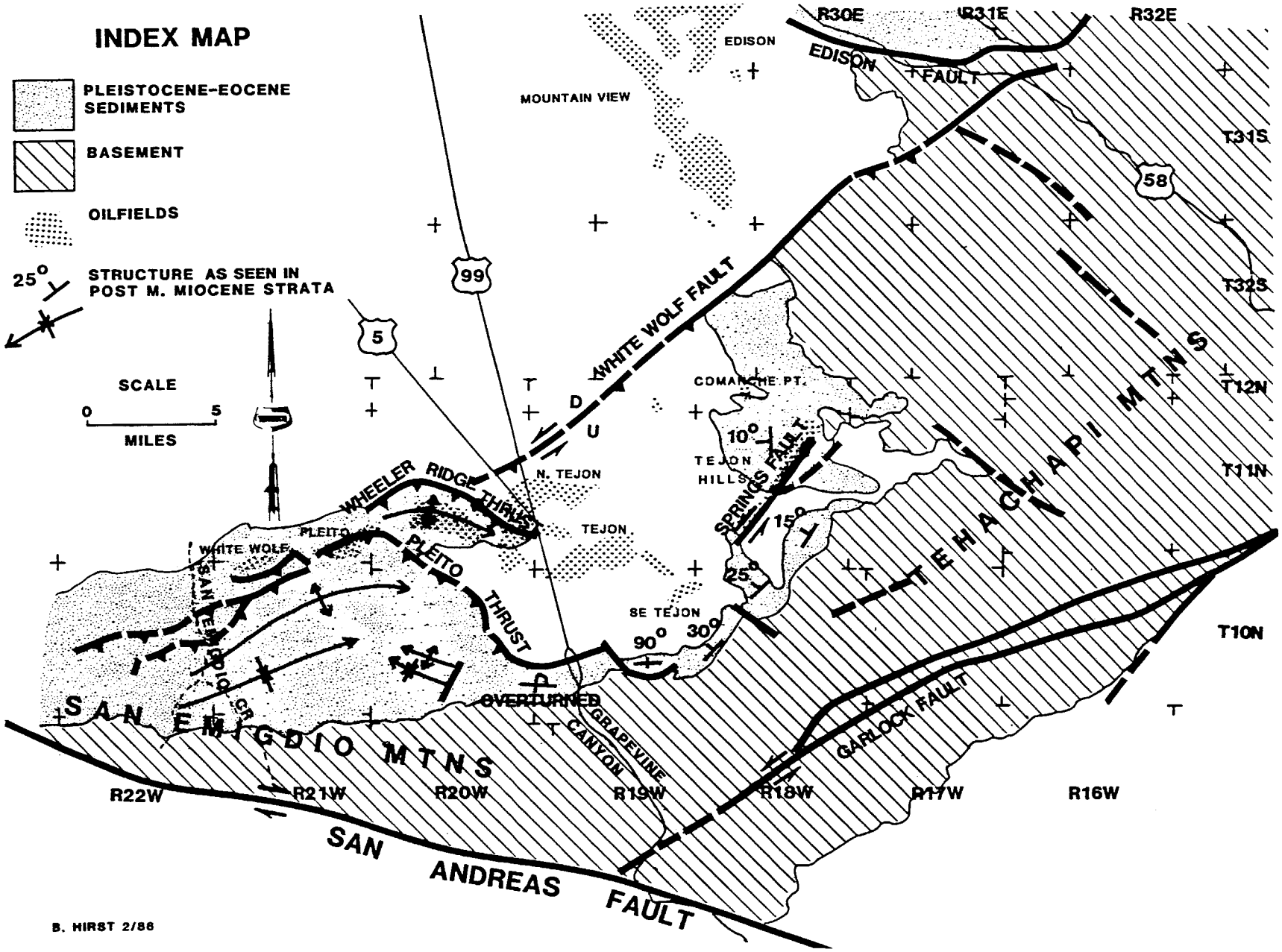

FIGURE 1: Index map of Tejon and adjacent areas showing basement and sediment outcrop, faults and structure developed by Pliocene to Recent tectonism as seen on post middle Miocene strata.

TECTONIC DEVELOPMENT OF THE TEJON AND ADJACENT AREAS, KERN COUNTY, CALIFORNIA

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INTRODUCTION

This paper is an informal overview of the tectonic development of the southeastern end of the San Joaquin Valley. Discussion will center on the Tejon "Embayment" area and adjacent physiographic terrains (Fig. 1). It is hoped that certain aspects of structural style and timing will be clarified. In particular discussion will center on evidence for a lower Miocene tensional tectonic event and the subsequent overprinting by Pliocene to Recent wrench and traspressional structuring.

The background for this paper was assembled while conducting petroleum exploration studies for Tenneco Oil Company. The opinions expressed here are based on subsurface, outcrop and literature studies as well as extensive seismic, magnetic, gravity and geochemical surveys.

A fair volume of published and unpublished work exists describing the structure and stratigraphy of the region. Notable are the mapping contributions by Dibblee (1973) and Bartow and Dibblee (1981). For a current in depth bibliography and structural investigation see Davis (1983).

PRE-MIOCENE STRUCTURE

The sedimentary record in the Tejon area begins in the Eocene. Pre-Eocene tectonic events are somewhat obscured. This paper will not speculate on these early events or their subsequent effect on later tectonic events.

The Eocene through Oligocene (Zemorrian) sediments do not generally indicate significant tectonism. These sediments were in general deposited in a shelf environment and are composed of sands, shales and nonmarine conglomerates (Fig. 2). There are some

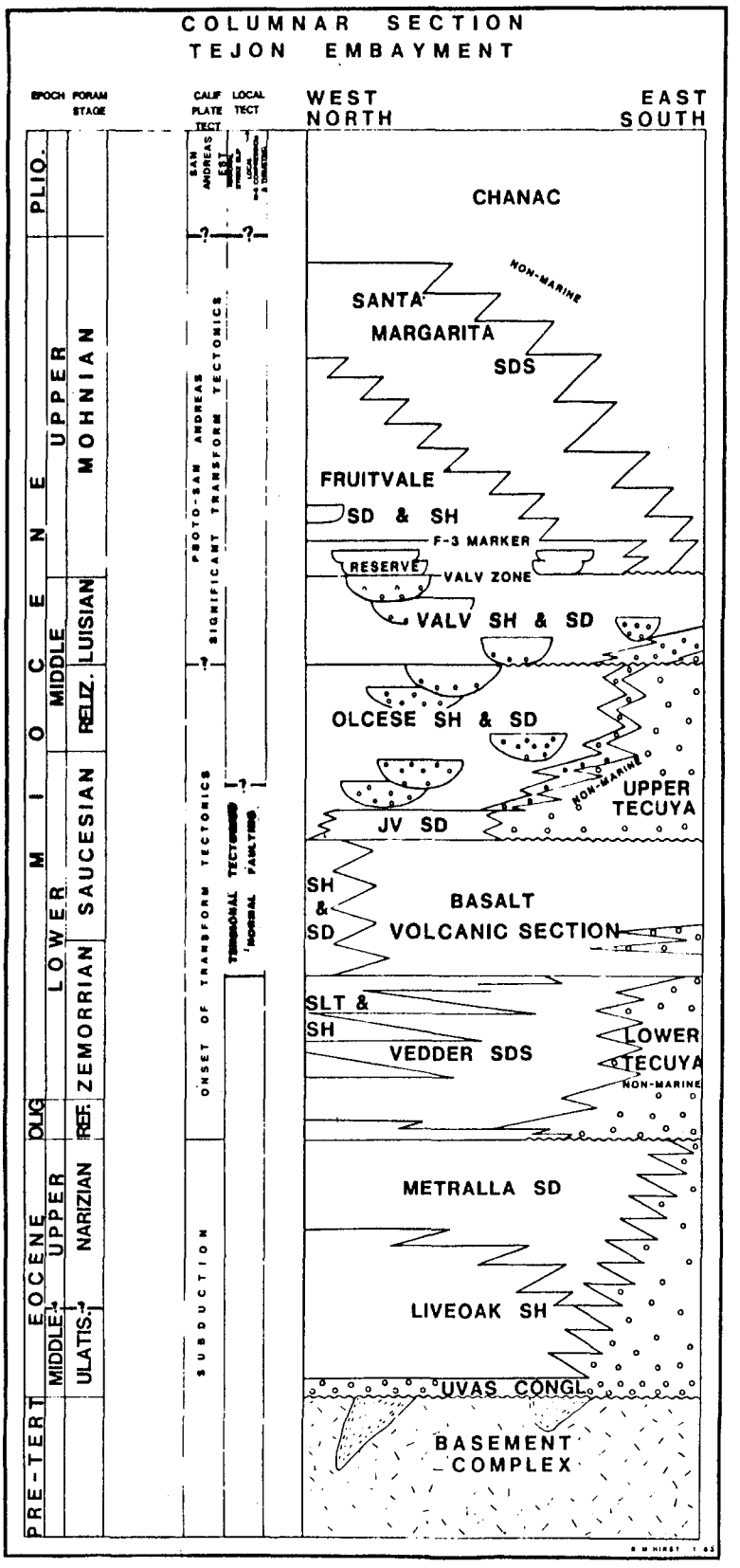

FIGURE 2: Columnar section for the Tejon "Embayment" showing expected facies changes from east and south to west and north.

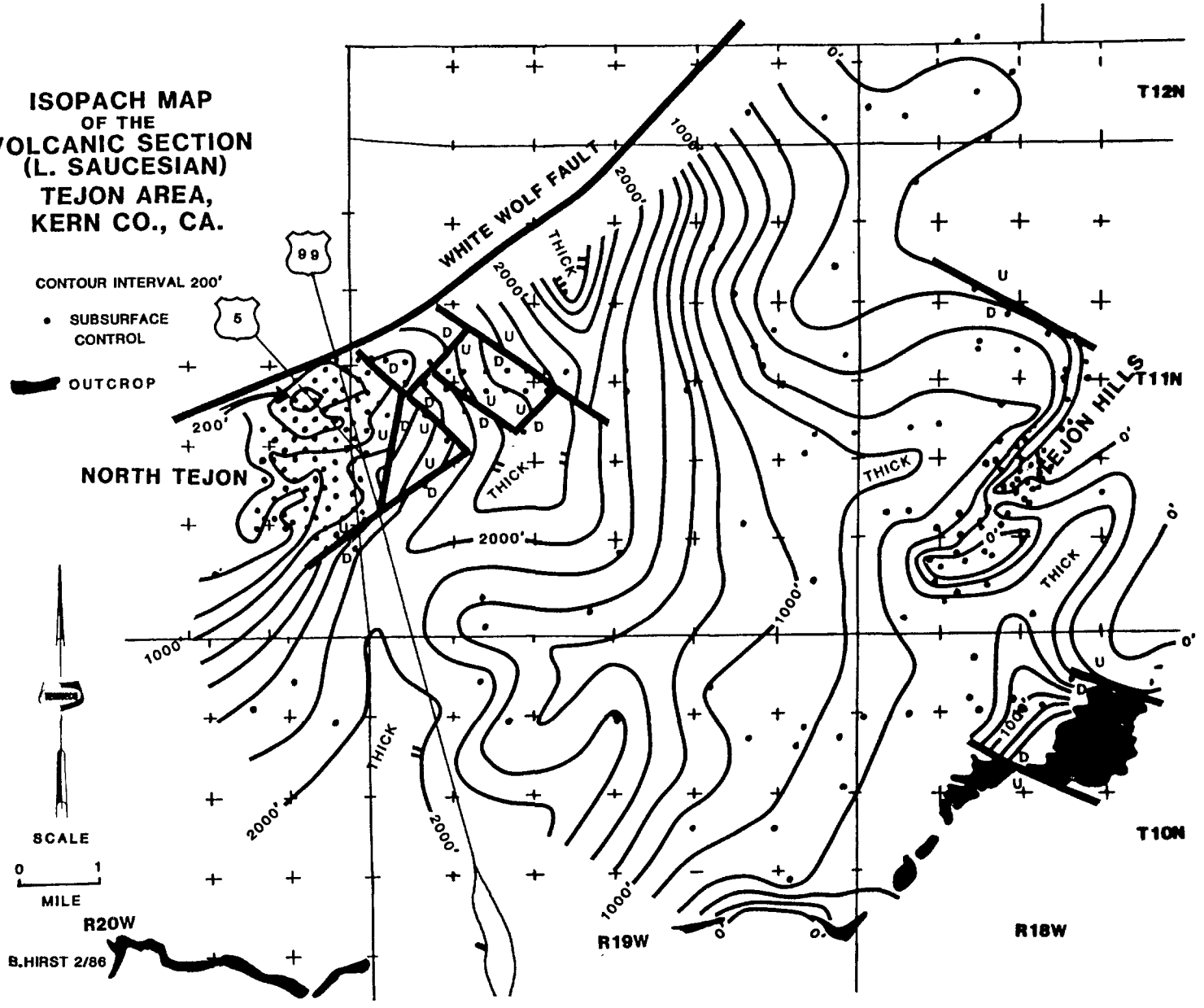

FIGURE 3: Isopach map of the "volcanic section" in the Tejon area. Small Saucesian age faults have been omitted for clarity in the North Tejon and Tejon Hills oilfield areas.

subsurface and outcrop indications of mild basinward downstepping during the deposition of these units. Further study may document this structuring.

LOWER MIOCENE TECTONISM

INTRODUCTION. The most significant and impressive paleo structuring recorded in the Tejon area is the tensional tectonism with associated volcanism seen in the lower Miocene. This event began as early as latest Zemorrian time but was mainly constrained to the lower Saucesian (22 myBP).

The most visible expression of the event is the volcanic section which lies immediately atop the Vedder-Tecuya sediments. It is the volcanic section which not only implies a tectonic event but serves as an excellent time correlation marker with which to study the event in the outcrop and subsurface.

The volcanic section includes both marine and nonmarine equivalents and is composed of varying proportions of volcanic rock types interbedded with sediments. The criteria used to define the section is the first and last occurrance of significant volcanic material in the section. The dominant volcanic rock type is basalt with lesser andesite, dacite, agglomerates and tuffs. The nonmarine facies is typified by flow basalts (vesicular and massive) with interbedded nonmarine conglomerates. The marine facies is typified by flow basalts and thick marine silt and clay sections with distinctive volcanic affinities (including bentonite beds). Definition and correlations of the volcanic section is generally easy and consistent.

Figure 3 is an isopach map of the volcanic section in the Tejon area. Not shown are numerous northeast and northwest trending faults which have been recognized in the Tejon Hills and North Tejon areas. The isopachs show that the volcanic section varies in thickness from 0' to 2700'. In general, it thickens westward into the basin to greater than 2000'. There are areas in which the section thins dramatically such as over the North Tejon and Tejon Hills oilfields. A close look at outcrop and subsurface control shows the dynamic nature of the volcanic deposition.

OUTCROP. The volcanic section crops out along the southern margin of the Tejon area. In T10N/R18W there is an excellent exposure which demonstrates both Saucesian age structuring and reactivation during the Pliocene to Recent (Fig. 4).

Outcrops of the volcanic section are unconformably overlain by nonmarine conglomerates of middle Miocene age in this area. These are labeled "Tnc" by Dibblee (1973). The section dips NW at 20 to 25 degrees. In and about sections 9 and 10 T10N/18W there is a volcanic section which is approximately 1400' thick. It is mainly composed of flow basalts with conglomeratic wedges near the base. A NW trending fault bounds this section to the SW. The fault has probable late movement as seen by changes in strike and dip of Quaternary beds in its vicinity.

Southwest of this fault the volcanic section is offset to the NW. Here the volcanic section averages 500' thick. This abrupt change in thickness across the fault existed prior to the deposition of the nonmarine conglomerates (Tnc). This would indicate the fault had significant activity in the middle Miocene or earlier.

Remnant magnetic field studies were conducted on these two outcrops by Tenneco Oil Company. Samples from the 500' thick volcanic section SW of the fault showed only normally polarized remnant magnetic fields. The 1400' thick section NE of the fault had normally polarized remnant magnetic fields in the upper part of the section and reversely polarized fields in the lower part of the section. This would suggest that the fault was active during the volcanic episode and that reversely polarized basalt flows filled the downthrown northeast side of the fault first. Subsequent normally polarized flows covered both sides of the fault. Based on the difference in thickness of the volcanic sections the fault ahd as much as 900' of offset prior to the deposition of the middle Miocene nonmarine conglomerates (Tnc).

Early structures of this magnitude can be seen in a number of the exposures of the volcanic section extending well into the San Emigdio Mountains. In some cases there is clear reactivation of these old fault trends by Pliocene to Recent movement.

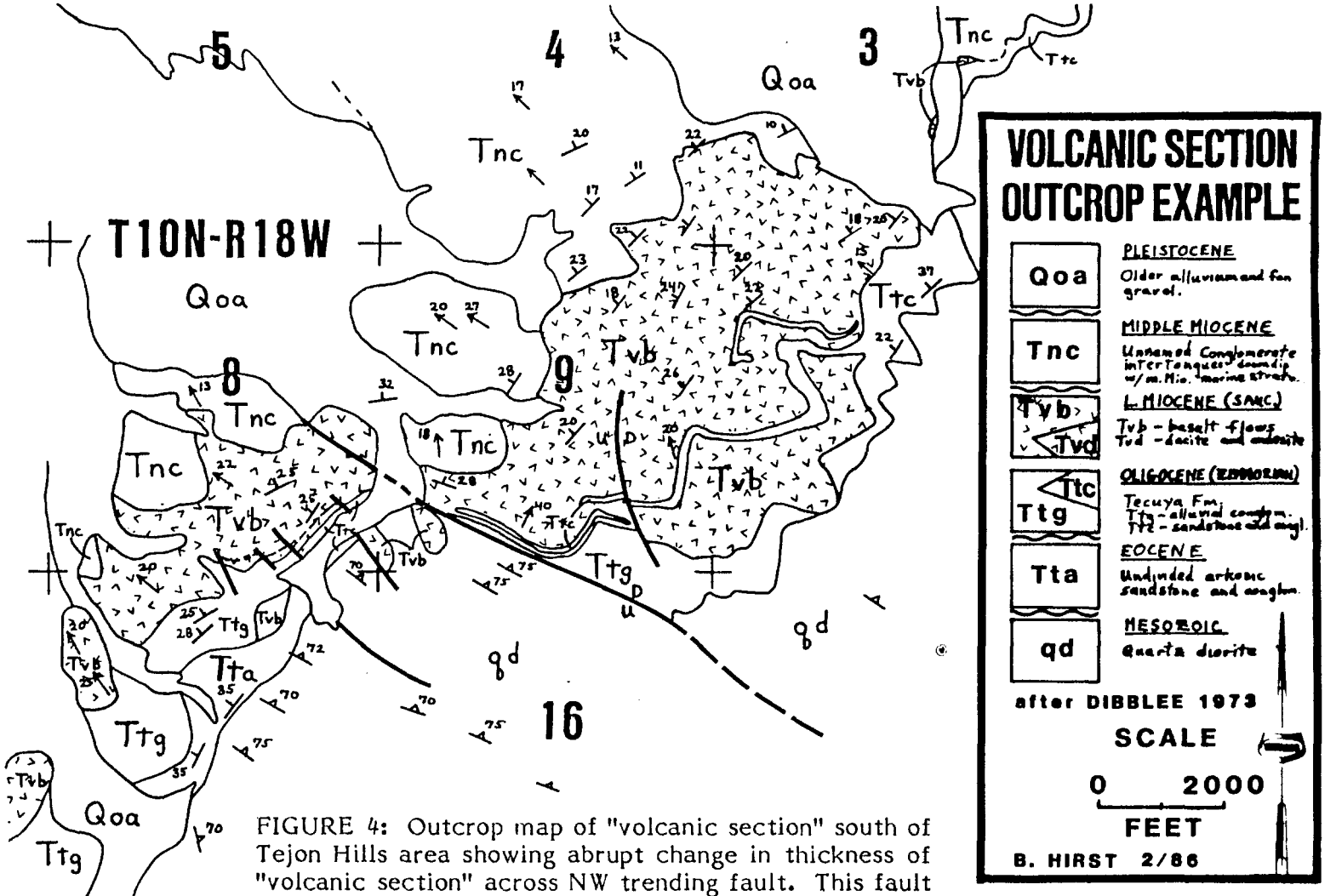

FIGURE 4: Outcrop map of "volcanic section" south of Tejon Hills area showing abrupt change in thickness of "volcanic section" across NW trending fault. This fault demonstrates both old and recent movement.

SUBSURFACE. The Tejon Hills and the North Tejon oilfields are ideal areas for subsurface study of the volcanic section due to numerous well penetrations of the section. Study of these fields has shown the following:

1. Both fields are located in areas of anomalously thin volcanic section.

2. Abrupt changes in thickness of volcanic section can be associated with faults of Saucesian age.

3. These faults are normal and generally have NE and NW trends.

4. Early structures can be significant hydrocarbon traps.

Most of the production at Tejon Hills is trapped along the Recent Springs fault. However, one pool within the field is trapped by earlier faulting. This is the Tunis Creek Pool in Section 29 T11N/R18W. This pool produces from Vedder sands which are trapped in a tilted horst block of Saucesian age. The horst block trap is a small scale version of North Tejon oilfield.

North Tejon oilfield is a large paleo feature as indicated by the thinning of the volcanic section in the isopach map. The field is located well out in the basin where the Eocene through Miocene sediments (including the volcanic section) were deposited in marine conditions. The thinning of the volcanic section occurs in step-like fashion from fault block to fault block. At least 1600' of thinning is indicated.

At the end of the volcanic episode, turbidite deposition dominated the Tejon area from late Saucesian to early Mohnian time. The Saucesian turbidites filled in the seafloor lows and eventually covered high blocks such as the North Tejon oilfield. Regional isopachs of the post volcanic Saucesian sediments shows that they thin more than 1000' up onto the North Tejon structure. This is in part due to faulting which extended into the late Saucesian as the basin continued tensional subsidence. Thus more than 2600' of paleo relief is indicated in the North Tejon area.

SUMMARY. From outcrop and subsurface study the Lower Miocene tectonic event can be reconstructed. It began in the latest Zemorrian or earliest Saucesian with volcanic extrusions which filled rapidly subsiding fault blocks. Following the volcanic episode, the area continued to subside through much of the Saucesian. The end result was the creation of a narrow shelf on the east which dropped off rapidly westward into a silled basin setting with local topographic expressions.

Turbidite sedimentation filled the basin and eventually covered the old seafloor topography. The structures created in the lower Miocene were natural traps for early hydrocarbon migration. The Vedder and Metralla sand reservoirs beneath the volcanic section probably began hydrocarbon charging as early as middle Miocene. The best Vedder and Metralla production at North Tejon oilfield is associated with old structural highs and not present day structural highs.

PLIOCENE TO RECENT TECTONISM

INTRODUCTION. Following lower Miocene tectonism Miocene deposition continued without indication of significant structuring. The Pliocene however marks the beginning of renewed tectonic activity in the Tejon and adjacent areas. This was set into motion with the development of the San Andreas fault system.

Much has been written concerning the San Andreas fault and the forces driving it. Likewise, there is considerable literature concerning the relationship of the San Andreas fault to the Garlock, Pleito and White Wolf faults the San Emigdio Mountains. This section briefly discusses some of the aspects of this Pliocene to Recent structure as it pertains to the Tejon and adjacent areas.

The southeastern San Joaquin Valley is composed of several structural domains of Pliocene to Recent age. The forces behind these domains are intimately related to the San Andreas fault and in particular the "Big Bend" developed in the fault.

COMPRESSIONAL UPLIFT. The first domain to consider is the compressional dominated uplifts which are typified by the San Emidgio mountains. A good place to begin the study of

this domain is in the sedimentary outcrops of the southern Tehachapi mountains immediately south of Tejon Hills oilfield (Fig. 1). Here the structural attitude of the middle Miocene and younger sediments give us a measure of compressional intensity since the Pliocene.

There are gentle NW dips in the outcrops south of Tejon Hills. Moving SW along the outcrop we come to the fault discussed earlier and note the recent reactivation with apparent right lateral and/or up-to-the SW motion. Several miles further SW along the outcrop there is an abrupt change in dip of the middle Miocene sediments from mild NW dips to vertical. At Grapevine Canyon there is the first scarp evidence of the Pleito thrust which is probably a reverse fault at this point. Immediately west of Grapevine Canyon the middle Miocene and younger sediments are overturned. A short distance westward the San Emigdio mountains are encountered and the Pleito fault is a major low angle thrust. These outcrops show the steady increase of the compressional domain westward towards the San Andreas fault.

There is evidence to suggest that pre-existing structures of Saucesian age play an important role in determining the location of the Pliocene to Recent thrust ramps. The two tectonic events should be considered together when unraveling the complexities of the San Emigdio mountains.

WRENCH BLOCK. The second structural domain to consider is the wrench dominated block. This is typified by the Tejon area proper which is bounded by the White Wolf on the north, the San Emigdios on the west and the Tehachapi mountains on the south and east. In general this area has undergone northward tilting with only minor compressional folding.

Subsurface and seismic studies have indicated that the most common structural features are strike-slip faults. An example is the NE trending, left lateral Springs fault. Offset along these faults is generally small. In most cases they are reactivated along earlier Saucesian age fault trends.

MARICOPA BASIN. The last domain to be considered is the Maricopa basin. For purposes of this paper it is defined as the youthful basin immediately north of the White Wolf fault. It extends from Comanche Point westward into the vicinity of Yowlumne oilfield. This area is undergoing extreme subsidence along with mild north-south compression. Since the beginning of the Pliocene the area as dropped 10,000' to 15,000' relative to the Tejon area. Virtually all of this offset is on the White Wolf fault.

WHITE WOLF FAULT. The White Wolf fault is probably the most controversial feature in the Tejon Area. This active reverse fault has developed more than 10,000' of vertical offset since the Pliocene. It is the opinion of the writer that the dominant offset on the fault is vertical with only minor left lateral offset.

The fault can be traced northeastward in outcrop as far as the Edison fault near Highway 58 and southwestward in the subsurface just west of Pleito Ranch oilfield. The westward limits of the fault are obscured beneath the thrusting of the San Emigdio mountains. It is likely that the fault eventually takes on a thrust like nature as it extends further into this highly compressive domain.

The apparent right lateral offset of the Southern Sierra Nevada mountains by the fault is best explained by vertical offset. If basement is assumed to dip eastward at 15 degrees and vertical displacement is 10,000' then the apparent displacement would be 7 miles. This agrees closely with the observed apparent right lateral offset.

Considering the extent of north-south compression in the San Emigdio mountains and the NE trend of the White Wolf fault it is difficult ot envision lateral motion other than left lateral. Distinctive turbidite channels of Saucesian through lower Mohnian age cross the fault in the Tejon area. These make excellent piercement points for offset studies as well as excellent exploratory objectives. Eventually drilling or seismic studies along the north side of the White Wolf fault will answer the lateral offset question by documenting the displacement of these channels.

SUMMARY

The Tejon and adjacent areas experienced a major tensional subsidence during the early

Saucesian. The volcanic rock types associated with this event extend westward into the San Emidgio mountains beyond San Emigdio creek and undoubtably northward across the White Wolf fault. The actual area covered by the tensional faulting extends much further and possibly as far north as the Bakersfield arch. The structures created in this event are excellent exploration targets which can be defined by Saucesian isopach maps or from seismic data. Early migration of hydrocarbons into these structures tends to preserve reservoir quality.

The area was apparently tectonically quiesent until the Pliocene. Early structures were overprinted by northward thrusting in the San Emigdio mountains and by strike-slip faulting in the Tejon area.

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_____ 1973, Geologic Map of the Grapevine Quadrangle, California: U.S.G.S. open file map #73-57.

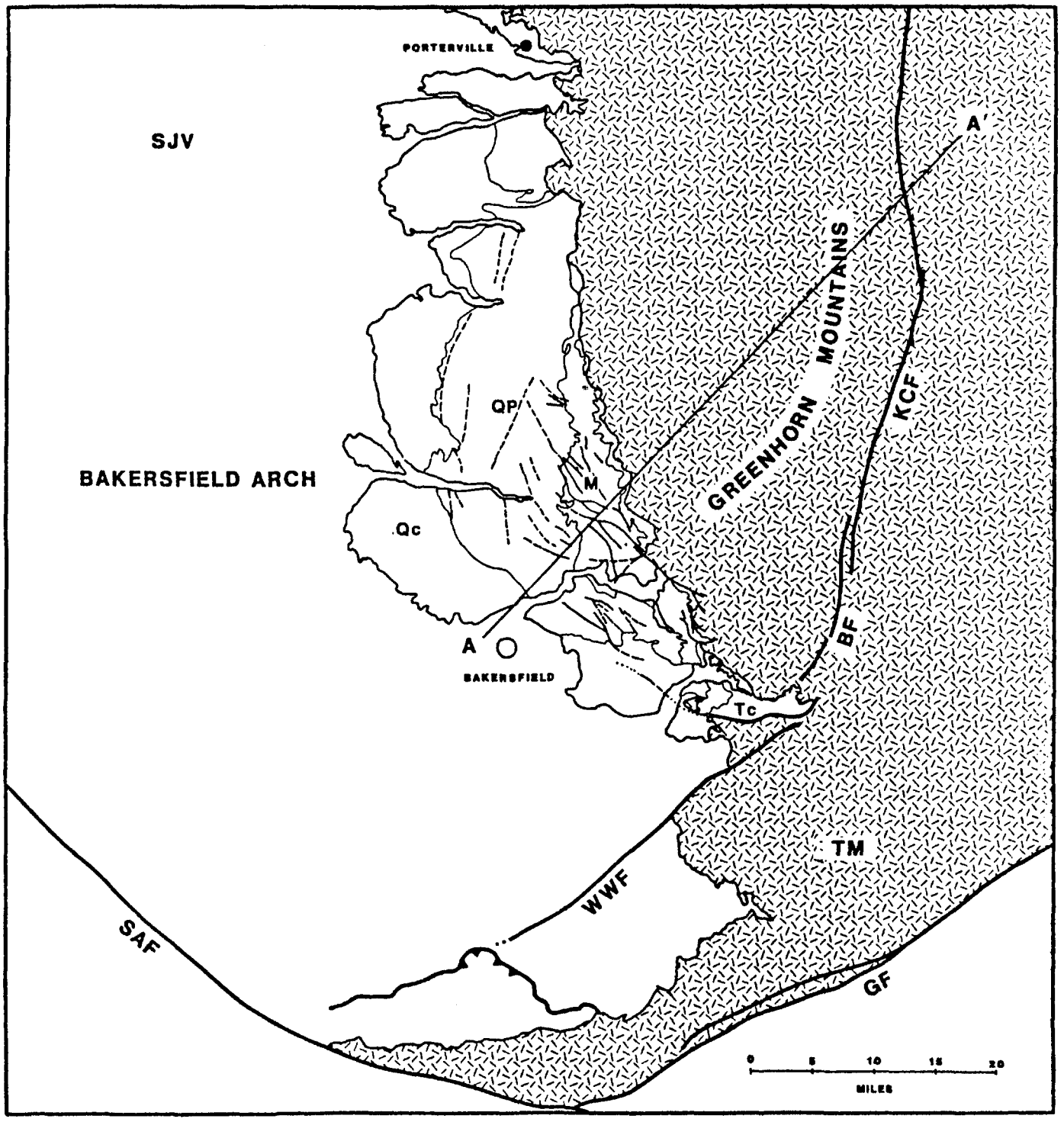

Fig. 1: General geology of the Bakersfield Arch area, southern San Joaquin Valley, California. Adjacent geologic structures include: WWF=White Wolf fault; BF=Breckenridge fault; KCF=Kern Canyon fault; TM=Tehachapi Mountains; GF=Garlock fault; SAF=San Andreas fault; SJV=San Joaquin Valley. Geologic symbols are: Qc=Pleistocene nonmarine sedimentary deposits; QP=Pliocene-Pleistocene nonmarine sedimentary deposits; M=Miocene marine sedimentary rocks, nonmarine in southern part; Tc=Tertiary nonmarine sedimentary rocks. Geology generalized from: Geologic Map of California, Olaf P. Jenkins Edition, Bakersfield (1964) and Los Angeles (1969) sheets.

TECTONIC EVOLUTION OF THE BAKERSFIELD ARCH, KERN COUNTY, CALIFORNIA

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ABSTRACT

The Bakersfield Arch is a major westward plunging structural bowing on the east side of the soutern San Joaquin Valley extending from Porterville, on the north, approximately 55 miles SSE to the vicinity of Bear Mountain. It plunges SSW into the San Joaquin Basin for approximately 20 miles. The Arch is the site of several major oil fields which produced approximately 66 MMBO during 1984. Oil production is from sandstone and siltstone of Tertiary age and younger, and from fractured basement rocks.

Structural evolution of the Bakersfield Arch began with the southwestward movement of the Western U.S. in response to plate tectonic forces. This movement resulted in westerly (clockwise) rotation of the southern part of the Sierra Nevada Batholith and the southwesterly projection of the Tehachapi Mountains granitic salient. The Tehachapi Mountains granitic is bounded on the south by the left-lateral Garlock fault and on the northwest by the right-lateral White Wolf and Kern Canyon faults. It is proposed that southwesterly pressure on the White Wolf-Kern Canyon fault has caused the Greenhorn Mountains block of the Sierra Nevada Batholith to be pushed (wedged) westward into the San Joaquin Basin. The Greenhorn Mountains are the core of the Bakersfield Arch. Movement on the Garlock fault to initiate the Bakersfield Arch growth probably began in the Middle Miocene.

INTRODUCTION

Prior to development of the Plate Tectonic theory, the origin of major geologic features such of basins and mountain ranges was attributed to "uplift" and "downwarp" of the feature in question. These terms did, indeed, indicate the obvious direction of movement of the geologic feature, but said little about the geologic processes by which the feature had evolved. Plate Tectonics has provided a mechanism to explain the development of pull-apart and rift basins. Plate Tectonics has also provided the large scale compressional forces necessary to initiate the "uplifts" that are encountered in regional geologic studies.

The origin of the Bakersfield Arch has generally not been examined in the literature beyond acknowledging its uplift and speculation as to the time of uplift (MacPherson, 1977; Webb, 1977). This paper proposes a model for the origin of the Bakersfield Arch related to local and regional tectonics. Such a model may help to explain some of the structural and stratigraphic features associated with the Bakersfield Arch and, at least, provoke some though as to the origin of "uplifts."

GENERAL GEOLOGY OF THE BAKERSFIELD ARCH

The Bakersfield Arch is the dominant structural feature on the east side of the San Joaquin Valley. The Arch extends along the east side of the southern San Joaquin Valley from the town of Porterville on the north to Bear Mountain on the south. The culmination of the arching occurs just north of the city of Bakersfield and the arch projects southwesterly into the subsurface approximately twenty miles (Fig. 1). The granitic rocks of the Greenhorn Mountains form the core of the Bakersfield Arch. These mountains rise to an elevation of over 8000 feet near the Kern River Canyon and slope gently westward beneath the Bakersfield Arch.

The oldest sedimentary rocks exposed at the surface at the crest of the Bakersfield Arch are fluviatile and shallow marine sands and silts of the Walker Formation of early Tertiary age (Metz, 1985). These rocks rest on Sierran granite basement of Cretaceous age. A fluviatile- to shallow-marine Oligocene and younger section overlies the Walker Formation rocks and gives way westward (basinward) to deeper water sediments. Depth to basement along the axis of the Arch at its southwest end is estimated to be over 13,000 feet. A generalized cross section along the axis is shown in Fig. 2.

The Bakersfield Arch is of great economic importance as it is the site of several major oil fields and many smaller ones. Estimated ultimate cumulative oil production from oil fields on the Bakersfield Arch is 3,083,226 MBO which is approximately 25% of the estimated ultimate

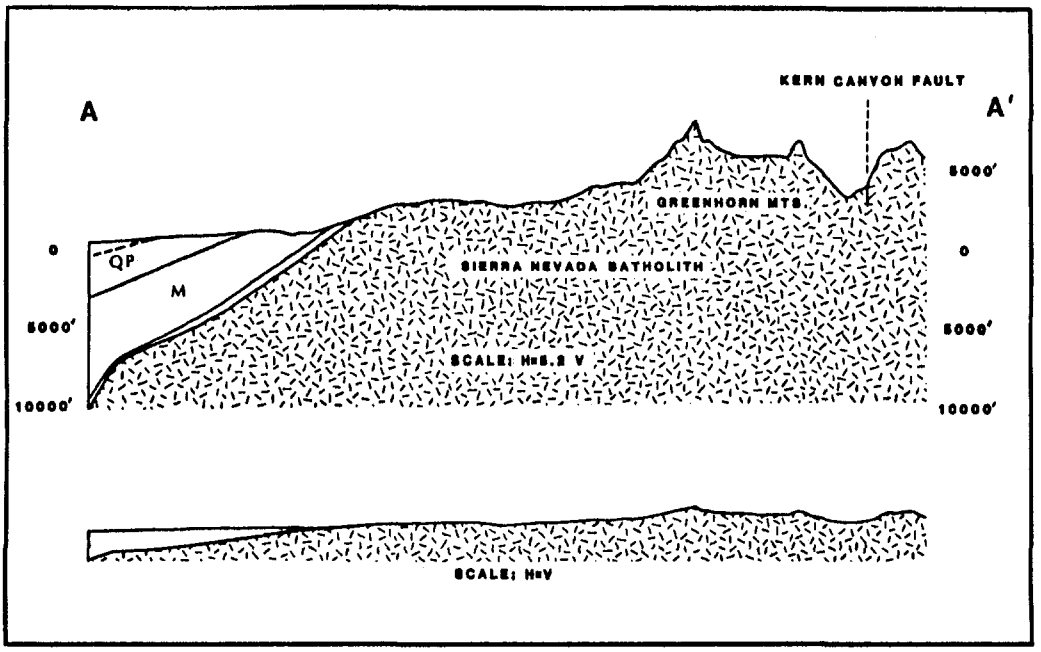

Fig. 2: Geologic cross-section A - A' from the Bakersfield Arch to the Kern River Canyon. Exaggerated and natural scale. Geologic symbols: QP=Pliocene-Pleistocene nonmarine sedimentary deposits; M=Miocene marine and nonmarine rocks.

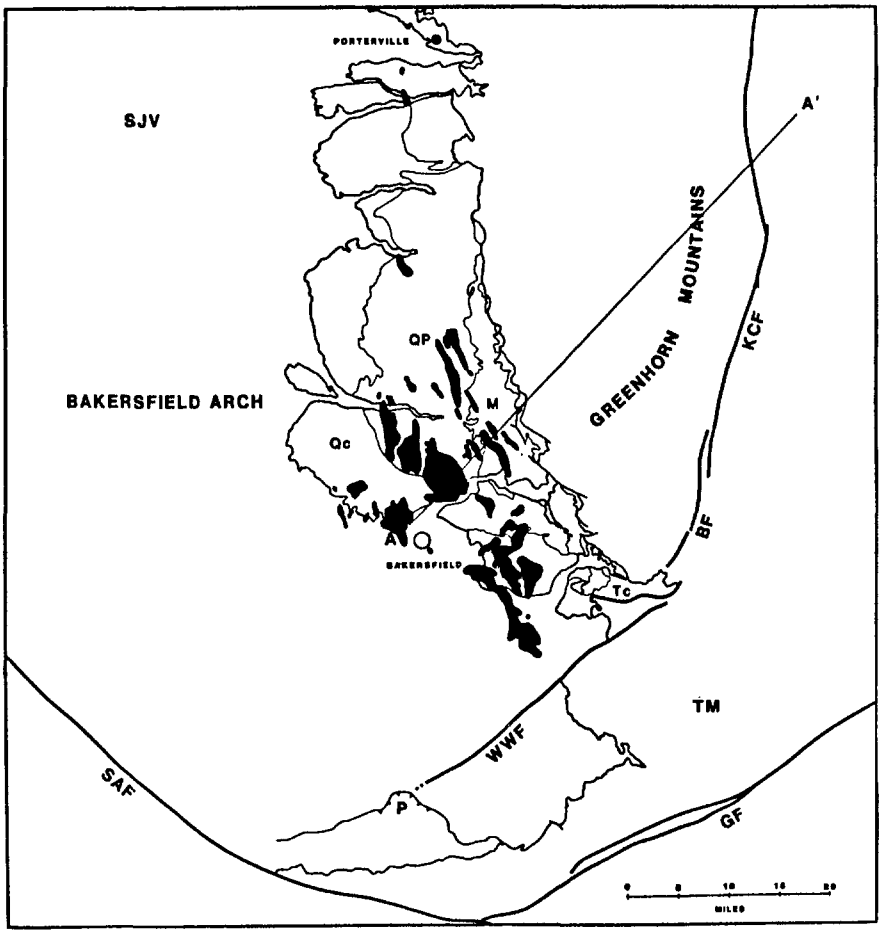

Fig.3: Oil fields on the Bakersfield Arch (shown in black). Explanation of symbols is the same as in Fig. 1.

recoverable oil in the San Joaquin Valley (Mefford, 1984). Figure 3 shows the distribution of known oil accumulations on the Bakersfield Arch. Oil production from these fields was approximately 66 million barrels of oil in 1984.

PLATE TECTONIC SETTING

The Bakersfield Arch is located in southern California near the western edge of the North American Plate (Fig. 4). Since Jurassic time, the North American Plate has been moving westward, away from the Mid-Atlantic Ridge. In the middle Tertiary about 29 my ago (Atwater, 1970), the westward-moving North American Plate collided with the East Pacific Rise spreading ridge and began to override it. At the present time, the East Pacific Rise has been overridden from the Queen Charlotte islands northward and from the Mendocino Fracture Zone southward to the southern tip of the Baja California Peninsula.

From the southern tip of Baja California northward, the East Pacific Rise exists as a series of short spreading-ridge segments separated by northwest-trending transform faults. Extensional pressures exerted by the spreading-ridge segments have opened the Gulf of California to its present form and extend into southern California where the northernmost spreading-ridge segment appears to be present at the southern end of the Salton Sea (Elders et al, 1972). The northernmost transform fault is the present San Andreas fault which extends from the southeast corner of the Salton Sea northwesterly to northern California. The San Andreas fault is a strike-slip fault with postulated right-lateral displacement of up to 300 km (Crowell, 1979). Rocks on the southwest side of the San Andreas fault are moving northwestward.

McKee (1971) proposed that the East Pacific Rise has been subducted by the North American Plate and presently lies beneath the Basin and Range Province where its presence is responsible for the extensional faulting and volcanism which are characteristic of the province.

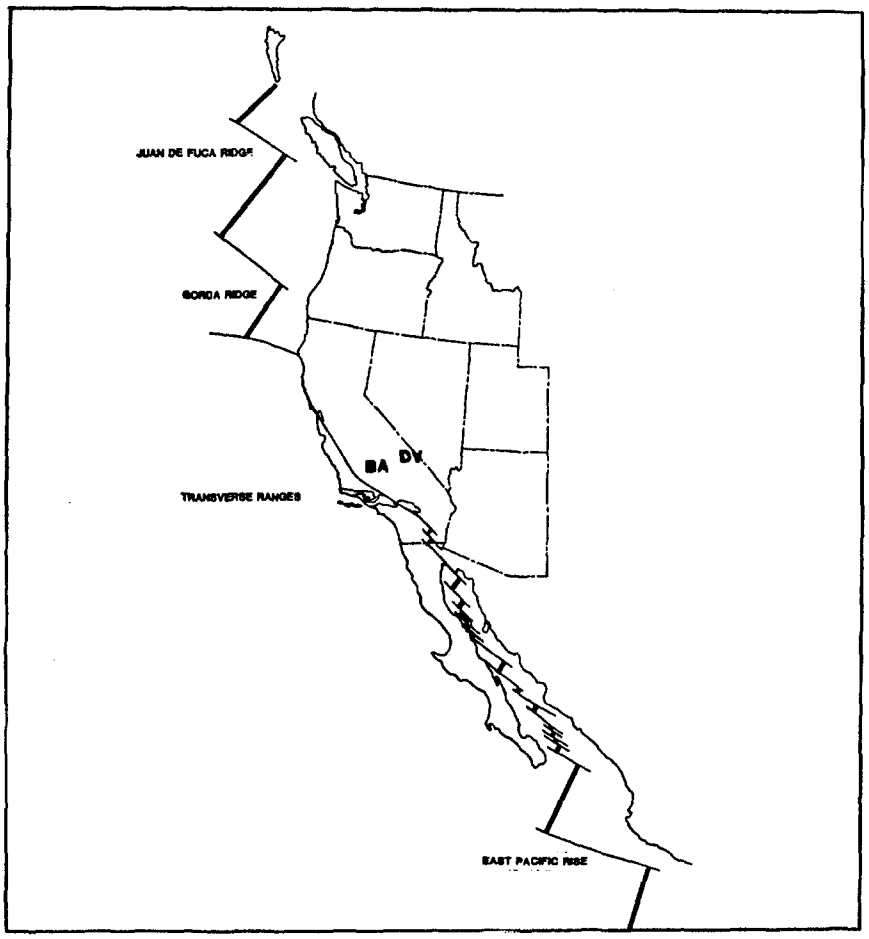

Fig. 4: Location of the Bakersfield Arch (BA) and Death Valley (DV) in the western United States, showing relationship to the East Pacific Rise and the spreading ridges offshore northern California, Oregon and Washington. Map modified from Elders, et al, 1972: Copyright 1972 by the American Association for the Advancement of Science.

If the East Pacific Rise is indeed buried beneath the Basin and Range Province, then a large part of California (including the Sierra Nevada) lies on the Pacific Plate, west of the East Pacific Rise. A logical surface extension of the East Pacific Rise into southern California would extend from the postulated spreading ridge at the south end of the Salton Sea northward through the Death Valley area where high heat flow and low topographic elevation may be a clue to incipient rifting (Fig. 4). Thus, the Bakersfield Arch is located in a tectonically active area subject to continental-scale forces involving seafloor spreading and subduction.

STRUCTURAL SETTING

The Bakersfield Arch is surrounded by a number of major structural elements which are closely linked to its geologic evolution (Fig. 5). A brief description of these elements is given below for reference in the discussion that follows.

Kern Canyon-Breckenridge-White Wolf Fault System

The Kern Canyon-Breckenridge-White Wolf fault system begins northwest of Mt. Whitney in the Sierra Nevada Range. The northernmost segment, the Kern Canyon fault, extends southerly from that point for approximately 83 miles to the Walker Basin southeast of the Bakersfield Arch. The Kern Canyon fault is a remarkably linear, north-south trending break separating the southern Sierra Nevada in two major blocks. Recent movement on the Kern Canyon fault is not noted on the Fault Map of California (Jennings, 1975), and relative movement across the fault is not known with certainty.

From the Walker Basin, the en-echelon Breckenridge Fault continues the trend southerly for 12 more miles to the vicinity of Bear Mountain. The location and direction of the Breckenridge fault suggests that it is probably a southerly continuation of the Kern Canyon fault. At its southern end the Breckenridge fault ends within a few miles of the northwestern end of the White

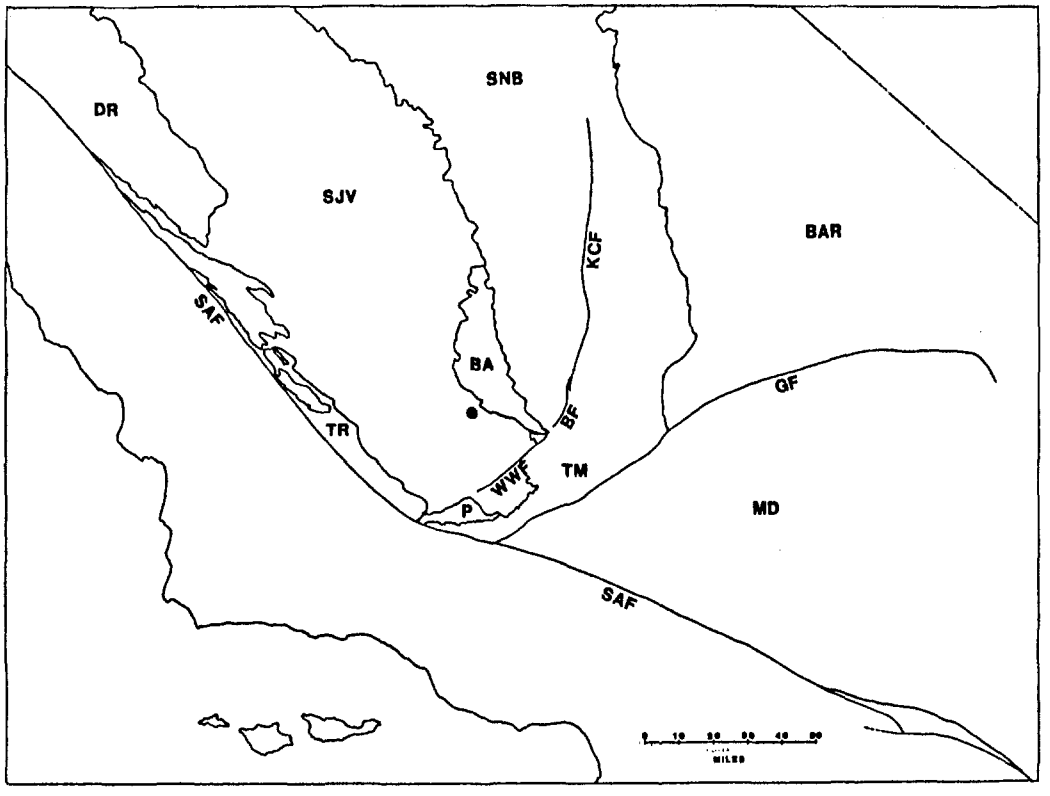

Fig. 5: Location of the Bakersfield Arch in Southern California, showing adjacent structural features: BA=Bakersfield Arch; SJV=San Joaquin Valley; SNB=Sierra Nevada Batholith; WWF= White Wolf fault; BF=Bakersfield fault; KCF=Kern Canyon fault; BAR=Basin and Range Province; TM=Tehachapi Mountains; GF=Garlock fault; MD=Mojave Desert; SAF=San Andreas fault; TR=Temblor Range; DR=Diablo Range.

Wolf fault. Warne (1977) notes a north-trending fracture zone that "might possibly" connect the Breckenridge and White Wolf faults.

The White Wolf fault, at the southern end of the system, trends southwesterly across the southern end of the San Joaquin Valley for 30 miles. In its northern part, the White Wolf fault separates Sierran basement on the southeast from San Joaquin Valley sediment and alluvium on the northwest. As the fault continues southwesterly, the trace is covered with young surficial deposits and its location is apparent only from recent earthquake features in those deposits. Well control and oil exploration seismic data define the White Wolf fault in the subsurface in this area. At its southwest end, the White Wolf fault is overridden by the north-verging, Pleito Thrust fault.

The White Wolf fault, as shown on the Geologic Map of California (Smith, 1964), is a left-lateral strike-slip fault parallel to and northwest of the Garlock fault. It is further described by Rogers (1979) as a high-angle reverse fault, dipping southeast, with the southern block moving up relative to the northern block. The total length of the Kern Canyon-Breckenridge-White Wolf fault system is over 125 miles.

Garlock Fault

The Garlock fault is a major, northeast-trending, strike-slip fault with an apparent left-lateral displacement of 38 to 64 kilometers (Smith, 1962). It extends southeasterly from the Death Valley area to its intersection with the San Andreas fault near Frazier Mountain and marks the southern boundary of the Sierra Nevada-Tehachapi Mountains block. The eastern termination of the Garlock fault is not clearly defined and left-lateral offset appears to die out in the vicinity of the Death Valley fault zone. Davis and Burchfiel (1973) have postulated that the Garlock fault may be an intra-continental transform fault, deriving its left-lateral offset from extensional tectonics on the north side of the fault in the basin and range province.

The age of the Garlock fault is related to the initial phase of the basin and range faulting which may be as old as 16 my (McKee, 1971). Rogers (1979) feels that there may be evidence from geodetic data and offset streams showing that the Garlock fault is currently active.

Tehachapi Mountains Granitic Salient

The Tehachapi Mountains granitic salient is a 22-mile wide block of granitic basement which separates the south end of the San Joaquin Valley from the Mojave Desert. It is bounded on the north by the White Wolf fault and on the south by the Garlock fault. The eastern end of the salient merges with the southern Sierra Nevada; the San Emigdio Mountains are included in the western part. The Tehachapi Mountains granitic salient extends from the south end of the Bakersfield Arch to the San Andreas fault and reaches an elevation of nearly 8000 feet at Double Mountain. Uplift of the Tehachapi-San Emigdio area apparently began in the early Miocene (Hackel, 1966).

San Joaquin Basin

The Bakersfield Arch lies on the east side of the southern San Joaquin Basin, a vestige of a large, marine forearc basin that developed during the late Mesozoic and early Cenozoic (Dickinson and Seeley, 1979). An estimated 35,000 feet of marine and non-marine sediments are present in the deeper parts of the basin (Hackel, 1966). These rocks thin toward the western and eastern boundaries of the basin and onto the Bakersfield Arch. At the south end of the basin a thick section of sediments is abruptly truncated at the White Wolf fault. The Bakersfield Arch, extending into the San Joaquin Basin, separates the Tulare sub-basin on the north from the Maricopa sub-basin on the south (MacPherson, 1977).

San Andreas Fault

The northwest-southeast trending San Andreas fault forms the western boundary of the southern San Joaquin Basin opposite the Bakersfield Arch. From there, to its beginning in the Salton Trough in southeastern California, the San Andreas fault marks the boundary between the northwesterly-moving margin of the North American Continent and the interior (Crowell, 1979). South of the "Big Bend" in the San Andreas fault, these northwest-moving rocks press obliquely against the San Andreas fault. The San Andreas fault also marks the western edge of the Tehachapi granitic salient and of the Mojave Desert.

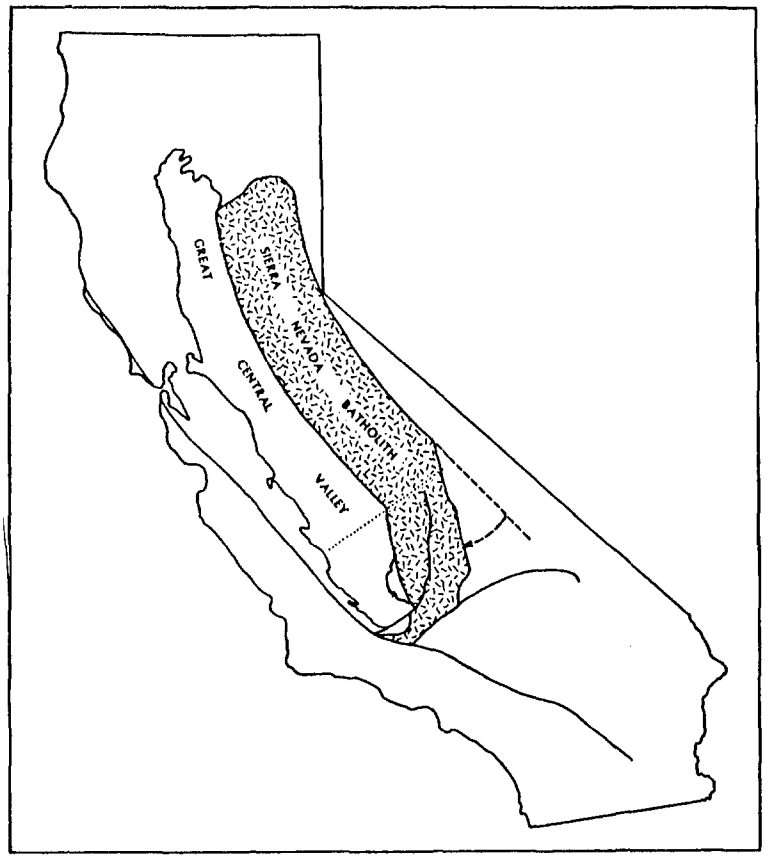

Fig. 6: Generalized geologic map of California showing westward (clockwise) deflection of the southern Sierra Nevada Batholith. Dotted line is the Kettleman-Kaweah-Independence Deflection.

DISCUSSION

The Bakersfield Arch is located in the "hook" of the Sierra Nevada Batholith (Locke, 1940) where the broadly convex, west-southwest-facing arc of the Sierra Nevada Range assumes a more north-south course (Fig. 6). This clockwise rotation of approximately 30 degrees is also evident in the San Joaquin Valley whose axis changes from a northwest-southeast trend to a more southerly course in its southern half. The change in direction of the axis of the San Joaquin Valley occurs across an imaginary line (here named the Kettleman-Kaweah-Independence Deflection) which extends from the Kettleman Hills on the west side of the San Joaquin Valley, through the mouth of the Kaweah River on the east side, to the town of Independence in the Owens Valley. The change in direction of the Kettleman Hills anticlinal trend, marked by the en-echelon offset between the north dome and the middle and south domes, is a measure of the deflection of the San Joaquin Valley and the southern Sierra Nevada and may be related to it. The eastern end of the Kettleman-Kaweah-Independence line marks the northern boundary of the "hook" in the Sierra Nevada Batholith and also the northern end of the Kern Canyon-Breckenridge-White Wolf fault system.

Tectonic evolution of the Bakersfield Arch is postulated to have begun with the initiation of crustal extension east of the south end of the Sierra Nevada Range. Westward extension in the Basin and Range Province (Davis and Burchfiel, 1973) caused left-lateral displacement on the Garlock fault and rotated the southern end of the Sierra Nevada Batholith in a clockwise (westerly) direction. The pivot point of the rotating block is in the Mt. Whitney area near the eastern end of the Kettleman-Kaweah-Independence line. As rotation continued and extension at the extreme southern end of the range increased, the southern Sierra Nevada block broke along the Kern Canyon-Breckenridge-White Wolf fault system and the Tehachapi Mountains granitic salient was shoved westward across the south end of the San Joaquin Valley. As this granitic block, bounded by the Kern Canyon-Breckenridge-White Wolf fault system on the north and the Garlock fault on the south, continued to move southwestward, the southern Sierra Nevada block west of the Kern Canyon-Breckenridge-White Wolf fault

system was wedged westward into the San Joaquin Valley, providing the tectonic "push" necessary to initiate the Bakersfield Arch.

Thus, the Bakersfield Arch is the result of a lateral tectonic movement whereby a passive granitic block, on which sedimentation has been taking place, is pushed westward into a sedimentary basin. In this case, the "uplift" for arch formation is provided by the initial elevation of the Sierra Nevada moving into the eastern margin of the San Joaquin Valley. Accurate faulting patterns define the shape and movement of the granitic block (Fig. 1).

It is postulated that the White Wolf fault, which has acted as the right-lateral counterpart to the left-lateral Garlock fault in projecting the Tehachapi granitic salient southwestward, has ceased its right-lateral movement and has been changed to a high-angle, reverse fault by pressure from the northwesterly-moving rocks south of the San Andreas fault. This same pressure may have formed the Pleito Thrust fault and related faults as it rotated the Tehachapi Mountains granitic salient in a clockwise direction. The apparent right-lateral offset of the Sierran basement/sediment contact near Bear Mountain may be an indication of this type of earlier movement on the Kern Canyon-Breckenridge-White Wolf fault system. Rotation of the Tehachapi granitic block began when the northwesterly-directed forces south of the San Andreas fault exceeded the southwesterly-directed forces of the Garlock fault.

Movement of the Bakersfield Arch westward into the San Joaquin Valley began with the extension related to initiation of movement on the Garlock fault. That movement has been dated in the area east of the Garlock fault at about 16 my ago (McKee, 1971), which is approximately the boundary between the Relizian and Saucesian microfaunal stages in California or lower Middle Miocene time (Pisciotto and Garrison, 1981).

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Stratigraphy, Paleoenvironment and Depositional Setting of Tertiary Sediments, Southeastern San Joaquin Basin

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ABSTRACT

The Tertiary stratigraphy of the southeastern San Joaquin Basin includes sediments of Eocene through Pliocene age. The Tertiary rests unconformably on Sierran basement rocks, which include pre-Upper Cretaceous granitic, mafic and metamorphic rocks.

The Walker Formation is a nonmarine unit ranging in age from Eocene to early Miocene. Depositional settings for the Walker vary from lahar and debris flows in older outcrops of Adobe Canyon, to braided stream deposits in the lower Miocene outcrops near Caliente Creek. The Walker is conformably overlain by the Vedder Sand, a Zemorrian age marine sandstone representing shelf and slope environments. Predominantly a subsurface unit, outcrops of the Vedder are confined to the Adobe Canyon area. The upper Oligocene-lower Miocene Bealville Fanglomerate represents debris flows, talus and colluvium derived from the Edison fault in the area of Caliente Creek, where it unconformably overlies basement and interfingers to the northwest with the Walker Formation.

The Zemorrian (lower Saucesian?) age Pyramid Hill Sand Member of the Jewett Sand represents a transgressive shelf sequence. Along the east side of the basin, the Pyramid Hill Sand lies unconformably on both the Vedder and the Walker. The upper Jewett Sand and overlying Freeman Silt indicate an increase in water depth during the Saucesian. Foraminifera from outcrops of the Jewett Sand indicate a lower bathyal water depth (2000m+). The Olcese interfingers with the underlying Freeman Silt and the overlying Round Mountain Silt. The Saucesian-Relizian age marine Olcese Sand contains evidence of a range of paleoenvironments including nonmarine, estuarine and outer shelf depositional settings.

The lower-upper Miocene Bena Gravel unconformably overlies the Bealville Fanglomerate. The Bena contains both an alluvial fan and a nearshore facies which form a fan-delta system with proximal parts of the Edison Shale (=Round Mountain Silt and Fruitvale Shale). The Upper Relizian (?) to Luisian Round Mountain Silt contains inner shelf faunas at the base, an outer shelf-upper bathyal diatomaceous interval assignable to the Denticulopsis lauta zone, and a tooth and bone bed near the top which is correlative with strata containing upper middle bathyal foraminifera (1000-1500m). The Round Mountain Silt is conformably overlain by the Mohnian Fruitvale Shale, representing a shelf-slope marine environment. Conformably and unconformably overlying the Fruitvale Shale, the upper Miocene "Santa Margarita" Formation is indicative of a regressive, littoral, upper Miocene sea.

Upper Miocene, nonmarine sands, clays and muds of the Chanac Formation interfinger with and conformably overlie the "Santa Margarita" Formation. The latest Miocene to Pleistocene(?) Kern River Formation unconformably overlies the nonmarine Chanac Formation and older units and interfingers with the marine Etchegoin Formation. The Kern River, a generally coarse grained fluvial unit, includes bar deposits, channel fill deposits and finer grained facies reflecting gradual channel abandonment. Cross-cutting channels with low depth-to-width ratios such as those represented by the Kern River are a result of variable flow and unstable banks.

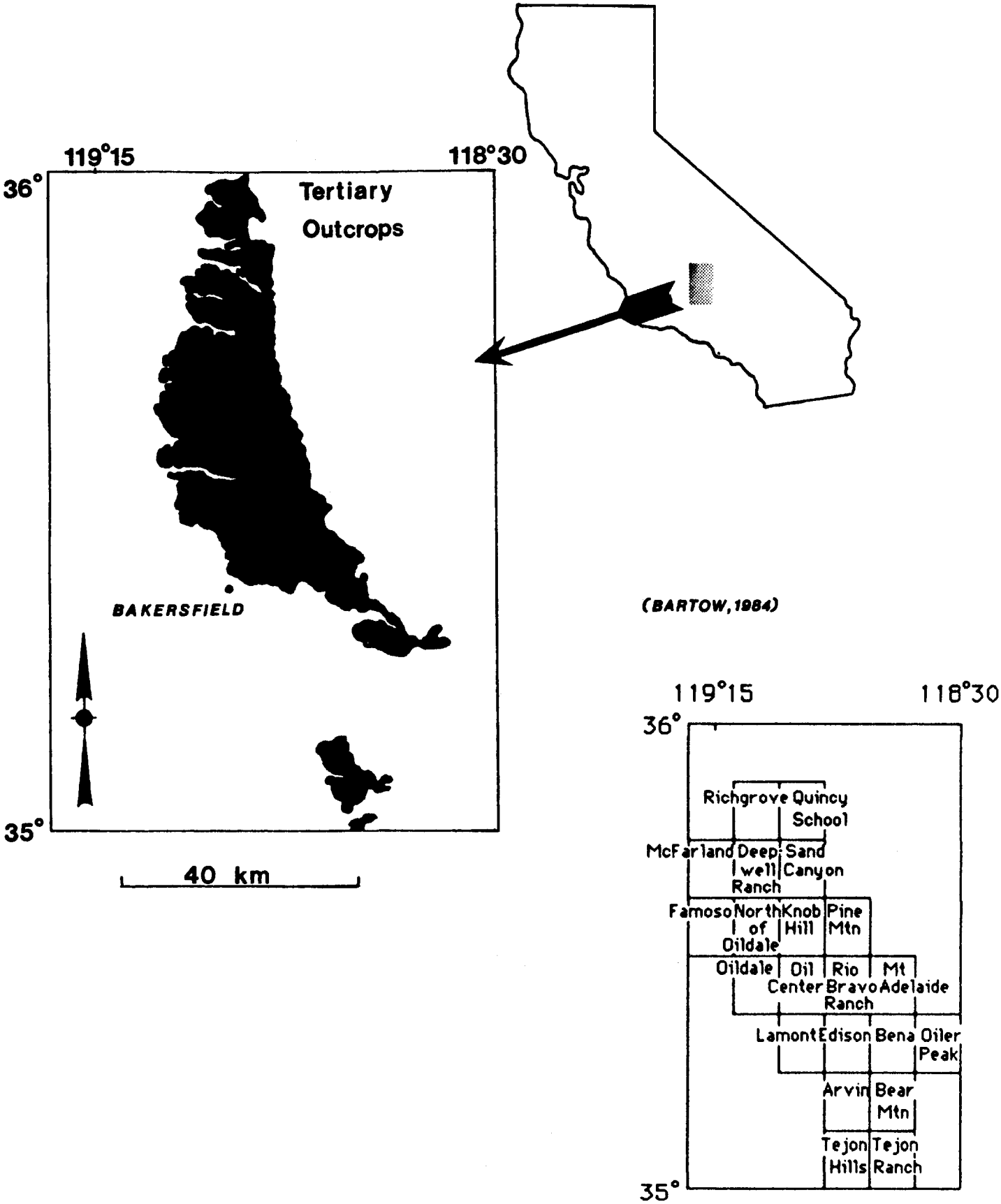


Figure 1 Outcrops of Tertiary sediments, southeastern San Joaquin Basin near Bakersfield, California.

INTRODUCTION

Tertiary sediments recording the development of the southeastern San Joaquin Basin are exposed in a NW-SE trending band of outcrops near Bakersfield, California (Figure 1). Several comprehensive stratigraphic studies have been completed on these Tertiary units (Addicott, 1956, 1970a; Bartow and McDougall, 1984). Figure 2 illustrates the stratigraphic relations of the southeastern San Joaquin Basin Tertiary units in the Bakersfield area. This paper incorporates stratigraphic information with a discussion of the paleoenvironments and depositional settings represented by these Tertiary units (Figure 3).

Much of this manuscript is the result of ongoing thesis research. Sampling of well-exposed outcrops has revealed very rich and extremely well preserved foraminiferal faunas. Benthic foraminifera are utilized for age control. The interpretation of paleobathymetry is also based on benthic foraminiferal faunas. This interpretation is based on the concept that faunas reflect water mass characteristics, which are in turn stratified and hence reflect bathymetry at the time of deposition (Figure 4) (Bandy, 1960; Ingle, 1980).

Methods for collecting data for depositional interpretation include detailed measuring of surface sections (Appendix 2), paleocurrent measurements (DeCelles, and others, 1983) and descriptions of lithology and sedimentary textures, sedimentary structures and geometries. Petrologic thin section analysis is based on the methods of Dickinson (1970).

The purpose of this report is to present new information on the Tertiary units of the San Joaquin Basin and incorporate them into the time framework of southeastern margin history. The following comments summarize key units of Eocene through Pliocene and earliest Pleistocene age.

TERTIARY STRATIGRAPHY

Walker Formation

The Walker Formation is a nonmarine unit ranging in age from Eocene to early Miocene. Wilhelm and Saunders (1927) proposed the name Walker for greenish sands and shales in wells of the Mount Poso field. Addicott (1956, 1970a) chose one of these wells, Shell Oi. Co. #1 Vedder, as the reference subsurface section. In this well, the Walker is 126m thick and is conformably overlain by the Vedder (evidenced by tongues of Vedder in the upper Walker). In outcrops north of Kern River, minor unconformities are present in the Walker and the contact with overlying units is unconformable with little or no angular discordance. At Pyramid Hill, the Walker is unconformably overlain by the Lower Miocene (Zemorrian) Pyramid Hill Sand Member of the Jewett Sand. Westward, the Walker thins and grades into marine Eocene Famoso and Oligocene Vedder sands.

Southeast of the Kern River, Dibblee and Chesterman (1953) designated a type section for the Walker Formation in Walker Basin Creek. Here, the Walker consists of 610m of nonmarine arkosic sandstone, conglomerate and minor gritty clay resting upon basement. The Walker may be continuous in the subsurface with the Tecuya Formation of the San Emigdio region to the south. A tuff bed from the near the top of the Walker has been radiometrically dated yielding a K-

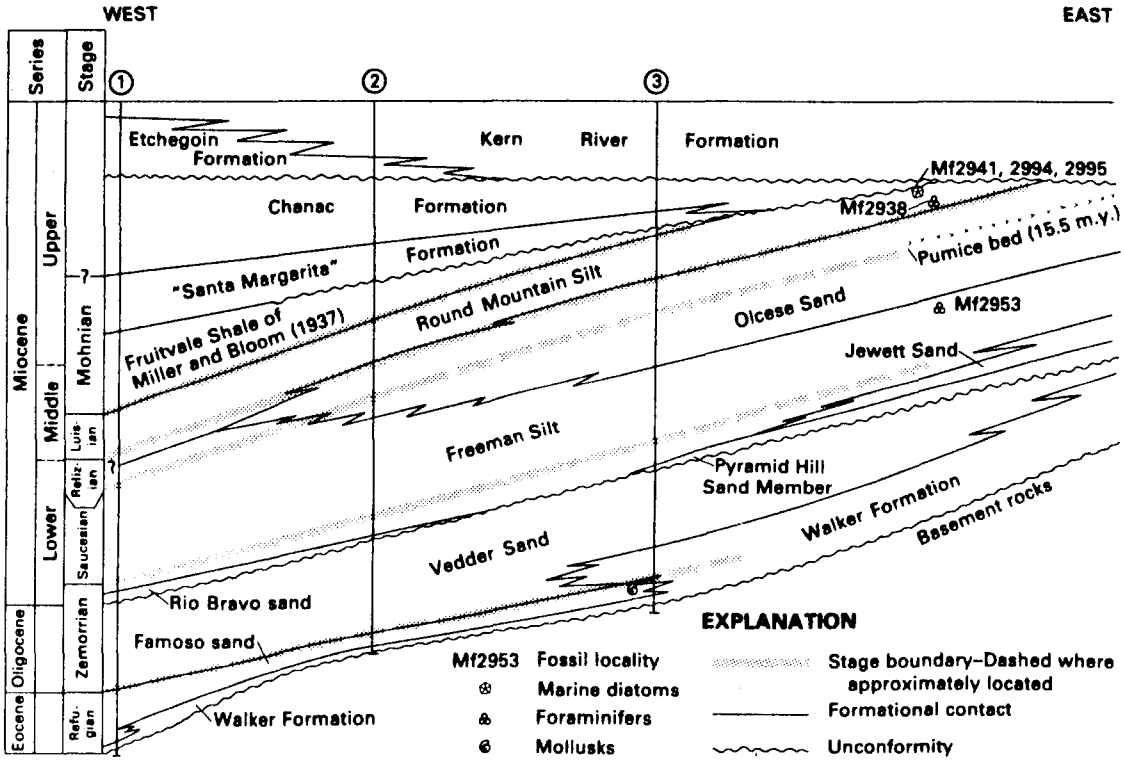


Figure 2 Stratigraphic relations of Tertiary sediments of the Bakersfield-Kern River area (Bartow and McDougall, 1984).

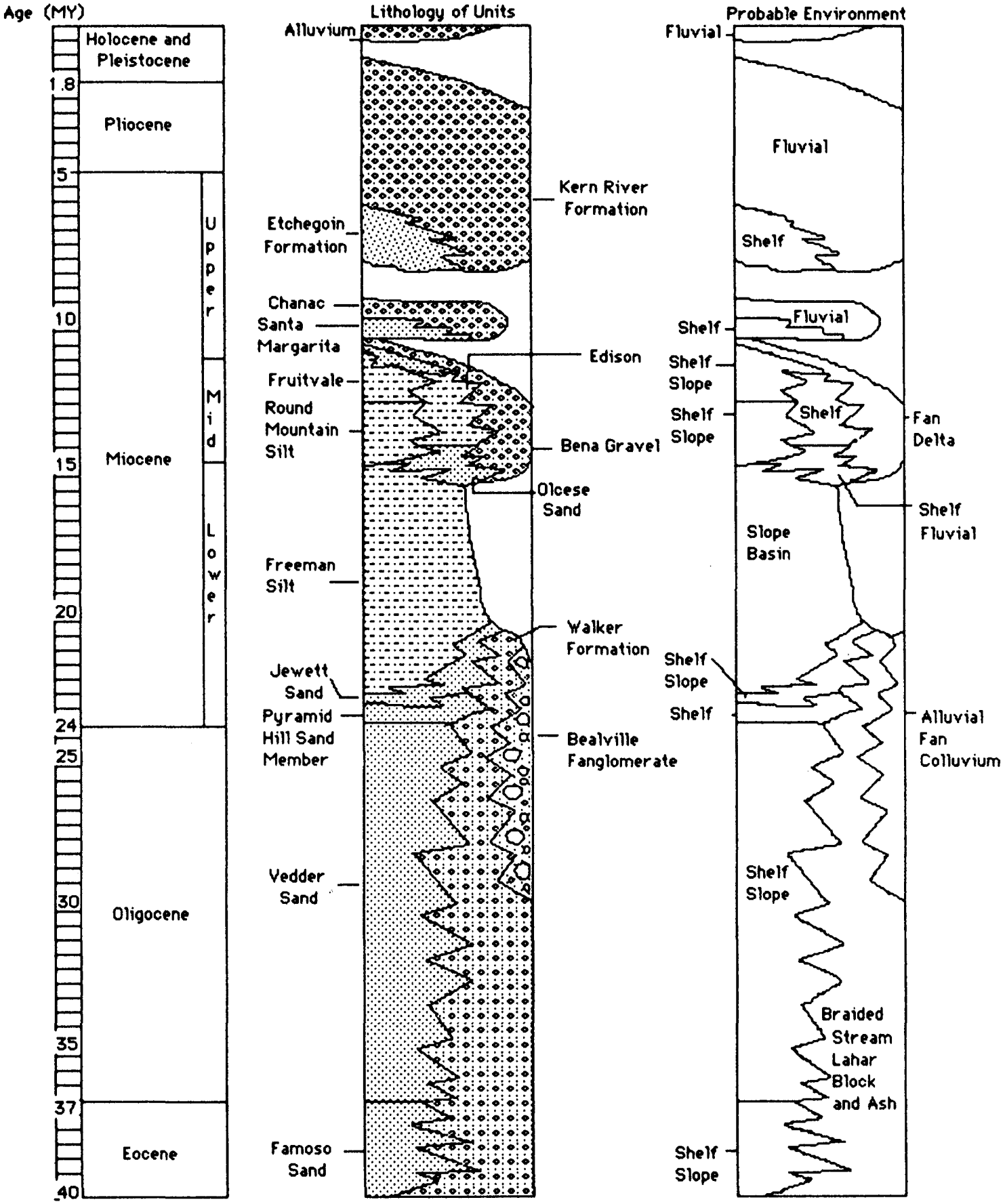


Figure 3 Stratigraphy, lithology and depositional environments for units in the Bakersfield area.

Ar age of 21.4 my (Bartow and McDougall, 1984). Hence, the Walker Formation is as young as lower Miocene south of the Kern River, but no younger than Oligocene north of the Kern River.

In the Adobe Canyon area (8,17-27S-29E), the Walker Formation lies unconformably on basement rocks of granodiorite composition (see Appendix 2). Common green-brown claystone with abundant quartz grit is exposed in a 35m section of the Walker at Chalk Cliff. Matrix supported and inversely graded beds indicate debris flows which are interbedded with clast supported beds composed of gravels, pebbles and cobbles. Many claystone beds contain abundant intraformational clasts and pumice lumps. Thin section analysis of the Walker Formation at this locality indicates a QFL composition of 75% quartz, 23% feldspar (16% plagioclase, 7% orthoclase) and 2% lithics (intraformational sedimentary). Detailed petrography of the Walker Formation north of the Kern River by Kiouses (1980) has shown that most of the monocrystalline quartz contained in this unit displays straight, unstrained extinction and embayed edges, typical of volcanic quartz ejecta. Many of the framework grains are floating in a matrix of altered volcanic glass, typical of ash fall tuffs. Both sedimentologic and petrographic evidence indicates that the Walker Formation exposed in Adobe Canyon, and probably much of the Walker Formation north of Kern River represents volcaniclastic sediments, many pyroclastic in origin, deposited by a lahar - block and ash system.

In the Walker Basin Creek area, the Walker Formation is well exposed in road cuts along Edison Highway. Sheet flood deposits, channel sands on the scale of 10m thick, and gravelly bar deposits are well exposed and indicate a braided stream environment. A few poorly exposed paleocurrent indicators give a general northwestward flow direction for this system.

The composition of the Walker Formation in this southern area is very different from that of the Walker north of the Kern River. In the type area, the Walker is composed of abundant feldspar and lithic fragments as opposed to the high percentage of monocrystalline quartz which is present in the northern area. Thin section analyses of the Walker in the type area indicate a change from a predominantly volcanic source to a solely granitic source after 21.4 my (K-Ar date from Bartow and McDougall, 1984).

Associated with and below the tuffaceous interval, the Walker Formation is mainly a mixture of material derived from both volcanic and igneous basement sources. Volcanic lithic fragments compose from 15-35% of the framework grains. Total quartz ranges from 15-30% and feldspar composes 30-40% of the framework grains. Microprobe analysis of the feldspar grains within volcanic lithic fragments (Figure 5) is compatible with an andesitic source; some rhyolitic glass is also present.

Above the tuffaceous interval, the Walker Formation drastically changes petrographic character (see Appendix 2). Sandstones are completely void of volcanic lithic fragments. Framework percentages are 21-49% quartz, 50-78% feldspar (almost exclusively plagioclase feldspars) and 1% sedimentary and metamorphic lithic fragments. Feldspars appear almost exclusively as detrital grains. Microprobe analysis of these feldspar grains indicates that they are compatible with a diorite source, most likely the surrounding basement rocks exposed in the area.

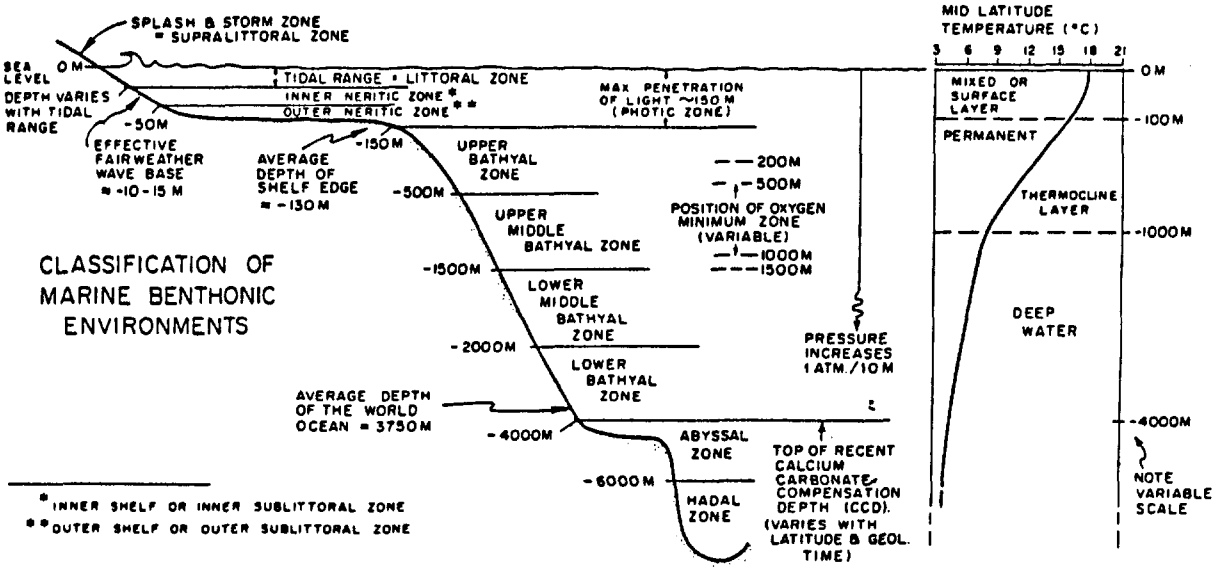


Figure 4 Classification of benthic marine environments in terms of depth and positions of critical oceanographic boundaries or transitional zones in the modern world ocean (Ingle, 1980).

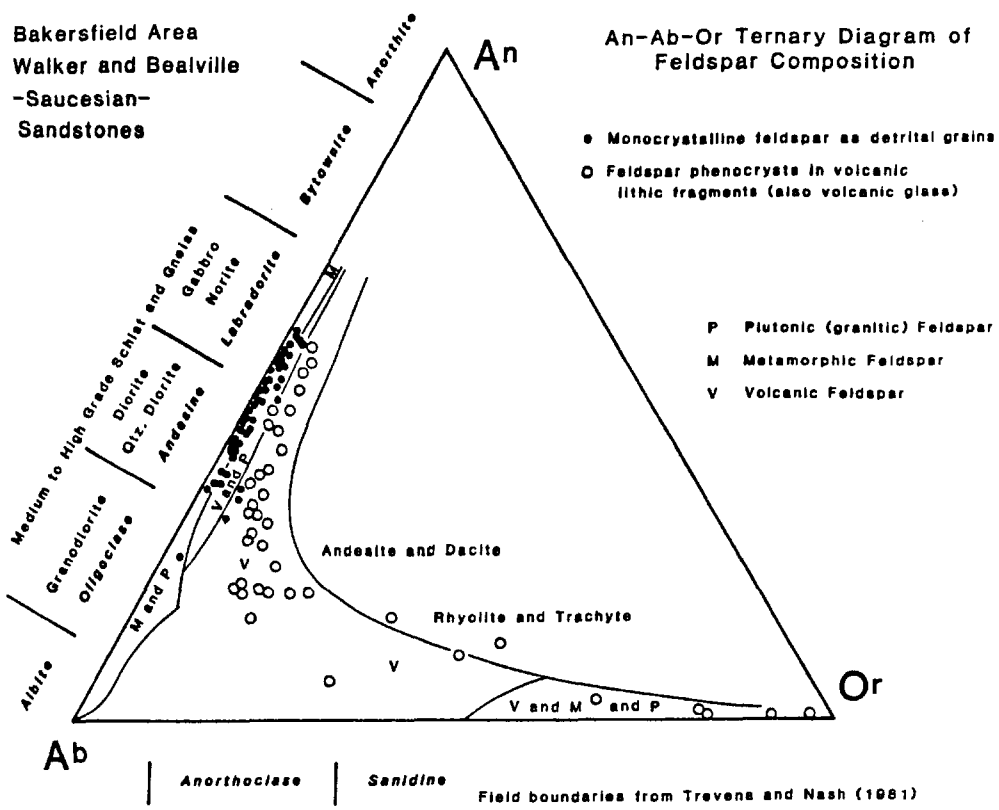


Figure 5 An-Ab-Or ternary diagram of feldspar composition, Walker and Bealville sandstones, south of the Kern River, Bakersfield, California.

This change from a predominantly andesitic source to a dioritic source after 21.4 my has also been emphasized by Bent (1985). His regional petrographic study of "Temblor" Sandstones of the San Joaquin Valley indicates a maximum plagioclase/total feldspar ratio centered near the middle of the Saucesian in the Bakersfield area (Figure 6). This ratio decreases both up and down section. This high ratio is probably related to the southern terminus of arc volcanism (approximately after 21.4 my) subsequent to the passage of the triple junction.

Vedder Sand

Addicott (1970a) chose the Shell Oil Co. #1 Vedder as the type section for the Oligocene Vedder Sand as well as for the Walker Formation. In this well, the Vedder is 229m thick with quartz sandstone predominating and a blue and green shale interval near the base of the unit. The Vedder is conformably overlain by the Freeman Silt towards the center of the basin, while the contact with the overlying Jewett Sand becomes unconformable toward the outcrop. Because the Vedder is principally a subsurface unit, no surface type section has been designated. In outcrop the Vedder is a light grey, well-sorted, fine-medium grained sandstone, locally cemented with silica. Microfossils from subsurface samples indicate a Zemorrian age for this unit (Bartow and McDougall, 1984).

Outcrops of the Vedder are limited to the Adobe Canyon area. A 73m section of the Vedder Sand was measured at Chalk Cliff (see Appendix 2). The contact between the Vedder and the underlying Walker is disconformable with medium grained, moderately well-sorted, quartzose sandstone overlying poorly sorted, knobby claystone with abundant gravels dispersed throughout. The petrographic change is quite distinct as orthoclase becomes the dominant feldspar. QFL compositions range from 60-69% quartz and 31-40% feldspar (19-21% orthoclase, 12-17% plagioclase and 2% microcline). Outcrops of the Vedder at this locality are massive to relatively poorly exposed. Laterally within Adobe Canyon, the Vedder is characterized by green, well sorted, very fine to medium-grained sandstone with low amplitude (6cm.) and short wavelength (12cm.) cross-cutting planar cross-beds. Migration directions for these cross-beds range from N80W to N65E and dips vary from 18-28 degrees. Although predominantly a subsurface unit and limited in surface exposures, evidence available from outcrops of the Vedder in the Adobe Canyon area lends support to a general interpretation of these sediments as deposited between low tide and fairweather wave base.

Subsurface work by Bloch (1986) supports a "ramp" geometry for the Vedder, a geometry of constant slope between nonmarine and deep-marine. Geohistory analysis of well data on the Bakersfield Arch suggests the Vedder was deposited following a period of rapid subsidence (ca. 50 cm/1000 years). The "ramp" geometry of the Vedder may have resulted from this rapid subsidence (Bloch, 1986).

Bealville Fanglomerate

The upper Oligocene-lower Miocene Bealville Fanglomerate unconformably overlies basement and interfingers northwestward with the Walker Formation. The Bealville includes more than 2100m of sediments in its type section near Caliente Creek, that consist of unsorted granitic blocks and debris

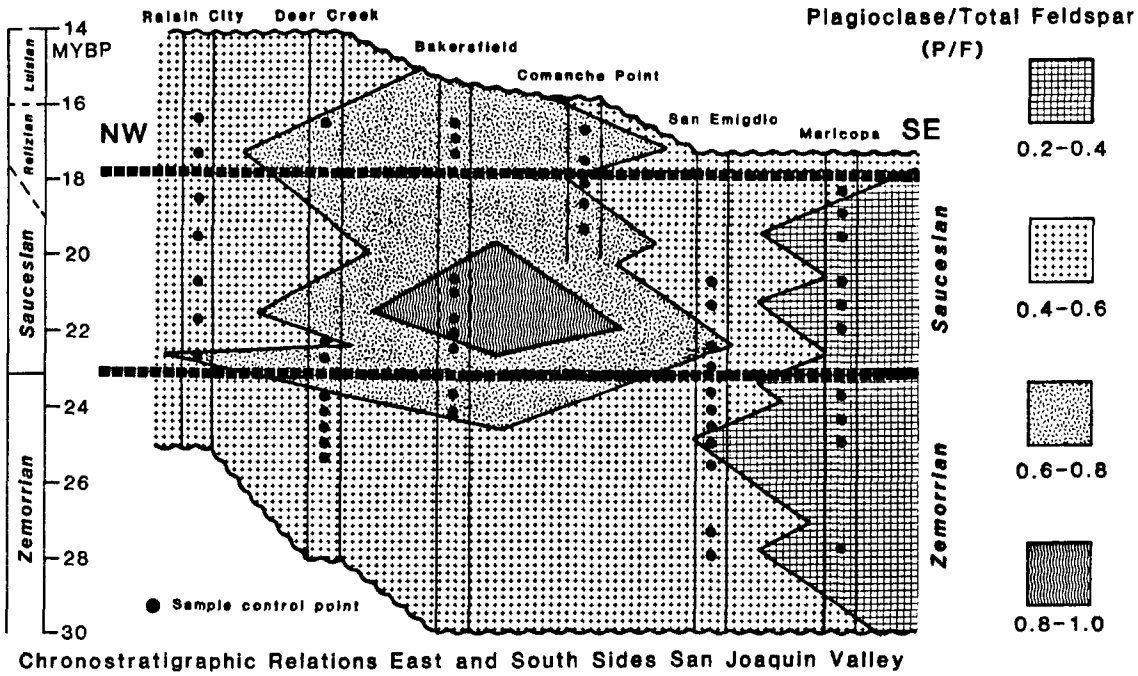


Figure 6 Plagioclase/total feldspar ratio for "Temblor" sandstones (Bent, 1985).

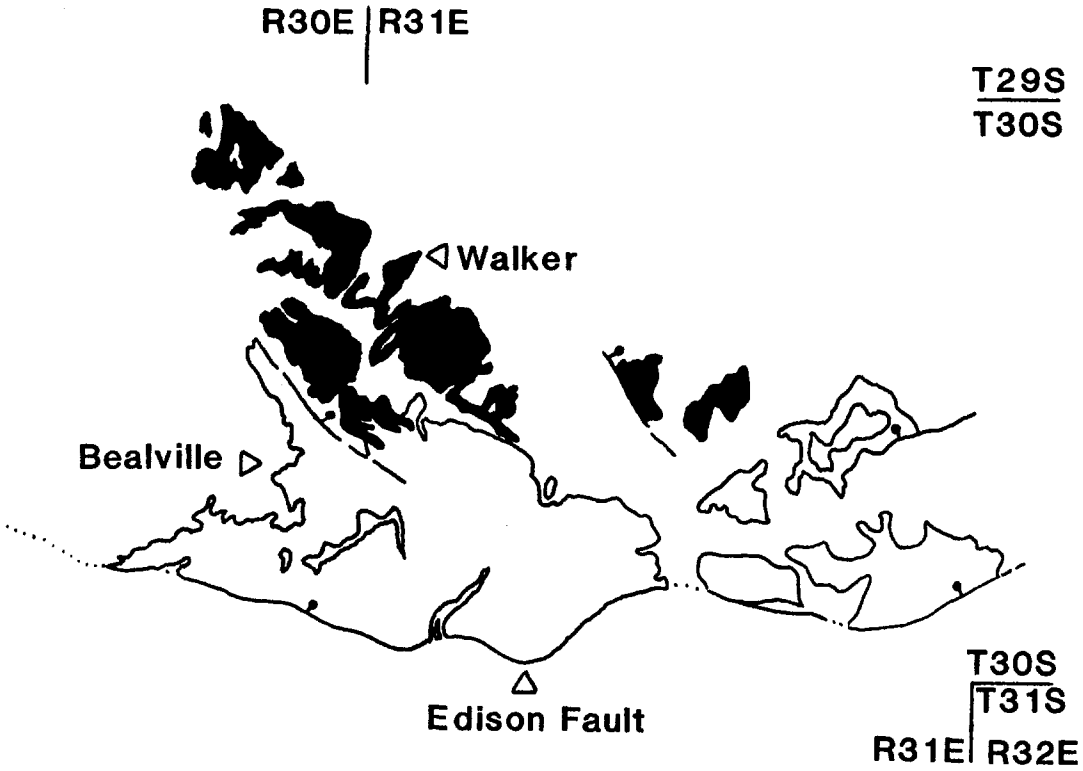


Figure 7 Relationship of Bealville Fanglomerate and Walker Formation to the Edison Fault.

flow material derived from upthrown basement rocks just south of the east-west trending Edison Fault (Figure 7). The Bealville is unconformably overlain by the lower-upper Miocene Bena Gravel.

Outcrops of the Bealville are well exposed along Edison Highway in the Bena quadrangle (Figure 8). Angular granitic blocks range in size up to 3m across. Several debris flow episodes are displayed with characteristic inverse grading followed by tractive flows filling in between large clasts at the surface. Much of the Bealville, however, does not clearly display inverse grading. The Bealville contains anywhere from 4-8% matrix. Abundant biotite grains are also present in the Bealville; in some cases biotite constitutes 20% of the framework grains. The large amount of biotite grains may possibly have enhanced the effects of the clay matrix present. An abundance of matrix in this unit could have lessened grain-to-grain interactions, resulting in less dispersive pressure and poor inverse grading. Petrographically the Bealville mirrors the composition of its source rocks, diorite basement rocks. QFL percents from thin section analysis range from 35-60% for quartz and 40-65% for feldspar (almost exclusively plagioclase).

Jewett Sand

The basal Pyramid Hill Sand Member of the upper Oligocene-lower Miocene Jewett Sand is well exposed at Pyramid Hill. A grey, poorly sorted, coarse-grained sandstone containing subangular quartz grains and black chert pebbles at the base of the Pyramid Hill Sand Member is known as the "grit zone." Basinward this "grit zone" hosts an assemblage of large pectens, pelecypods and scaphopods described by Addicott (1956, 1970a) as the *Lyropecten magnolia* faunal zone. The upper Jewett Sand is a massive, concretionary, silty sandstone and characterized by megafossils, sharkteeth and abundant marine mammal remains (Barnes, 1979; Welton, 1981). Kleinpell (1938) placed the basal Pyramid Hill Sand Member in the Zemorrian Stage, while in wells towards the basin, the upper Jewett Sand contains Saucesian foraminifera (Addicott, 1956, 1970a).

A 79m section of the Jewett is exposed at Chalk Cliff in the Adobe Canyon area (see Appendix 2). The Jewett Sand in this section is a predominantly massive, moderately well-sorted, fine-grained sandstone containing burrows, clam and pecten molds, wood fragments, and locally very abundant sharkteeth. Thin section analysis of the Jewett at Chalk Cliff demonstrates a QFL composition ranging from 69-75% quartz, 25-31% feldspar (7-10% plagioclase and 15-24% orthoclase), and 0-1% lithics (sedimentary).

At Pyramid Hill in the Rio Bravo Ranch quadrangle, the basal member of the Jewett Sand, the Pyramid Hill Sand Member, is well exposed unconformably overlying the Walker Formation (Figure 9). Thin section analysis of the Pyramid Hill Member indicates QFL percents of quartz 44%, feldspar 52%, and lithics 4%. The shallow water fauna, abundance of wood and charcoal fragments, poor sorting, angular grains, and scouring of the Pyramid Hill into the underlying Walker suggest a littoral, transgressive sand.

Addicott (1956) reports three or more oyster biostromes near the top of the Jewett. These biostromes indicate brackish water conditions which existed due to slight oscillations in water depth. Cushman and Parker (1931) reported a foraminiferal fauna from outcrops of the uppermost Jewett Sand (Kleinpell, in Diepenbrock, 1933)

Figure 8 Outcrop of the Bealville Fanglomerate along the Edison Highway, Bena Quadrangle.

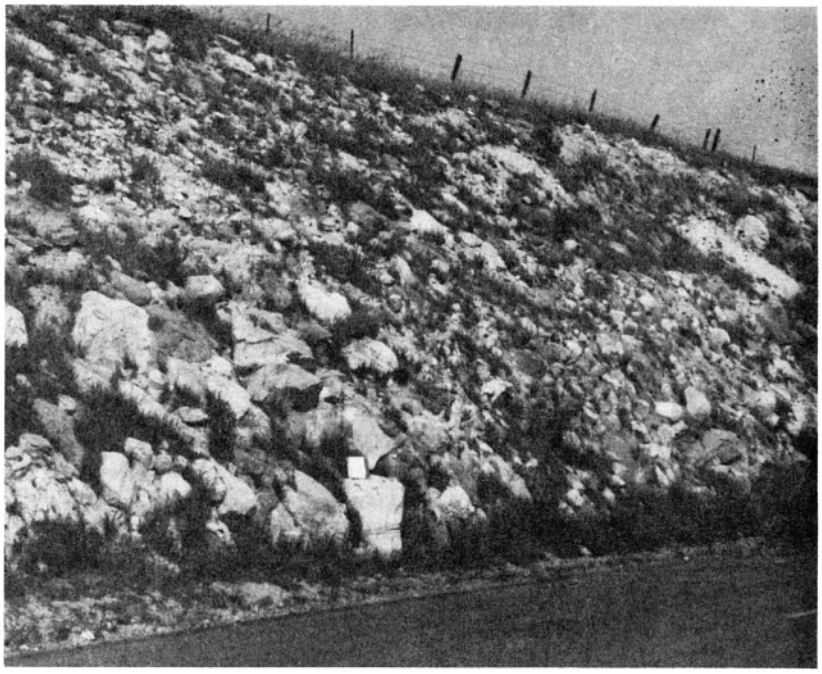


Figure 9 Pyramid Hill Sand Member of the Jewett Sand, Pyramid Hill, Rio Bravo Ranch Quadrangle.

Figure 10 Ophiomorpha nodosa burrows in the upper Olcese Sand, "Nickel Cliff" locality, Rio Bravo Ranch Quadrangle.

which is indicative of lower bathyal depths (2000m +) during the lower Saucesian.

Freeman Silt

The Freeman Silt is a grey-white, sandy to clayey, micaceous siltstone containing fairly abundant lower Miocene foraminifera. Subsurface foraminiferal faunas indicate lower middle bathyal water depths (1500-2000m) and a Saucesian age. The Freeman Silt overlies and intertongues updip with the Jewett Sand, and also intertongues with the overlying Olcese Sand (Bartow and McDougall, 1984). Addicott (1970a) designated a type well for the Jewett and Freeman, the Shell Oil Co. #1 Jewett in which the Jewett Sand is 206m thick, whereas the Freeman Silt is 100m thick.

Subsurface samples indicate foraminiferal faunas of Zemorrian and Saucesian age in the Freeman Silt. Foraminifera, notably Plectofrondicularia californica and Gyroidina soldanii, indicate water depths in excess of 2000m (lower bathyal).

Olcese Sand

The Olcese Sand interfingers basinward with the underlying Freeman Silt and the overlying Round Mountain Silt. In the type area of Round Mountain Field, the Olcese is between 300 and 360m thick. The Olcese is subdivided into three environmental facies. The lower Olcese is characterized by marine grey, very fine grained, silty sandstone with interbedded sandy and clayey siltstone. Scattered megafossils are generally found in calcareous sandstone concretions (Addicott, 1956, 1970a). Although predominantly a marine unit, the middle part of the Olcese is nonmarine with marine lenses of deposition. The middle Olcese is characterized by fine- to coarse-grained sandstone with occasional gravel lenses, strong cross-bedding and a blue-grey color. The upper Olcese is a very fine to fine-grained, marine sandstone which grades into a sandy siltstone in outcrop southward towards the Kern River and into a siltstone westward in the subsurface. Addicott's (1956, 1970a) Bruclarkia barkeriana zone (Barker's Ranch fauna) of the upper Olcese contains at least 116 different species of mollusks.

The Olcese is stratigraphically overlain by the Round Mountain Silt. South of the Kern River the Olcese unconformably overlies the Walker, and in the Tejon Hills area the Olcese rests directly on basement rocks (Bartow and McDougall, 1984). An unconformity within the Olcese encompassing the Saucesian-Relizian boundary has been suggested due to abrupt changes in benthic foraminiferal faunas (Bartow and McDougall, 1984). Addicott (1956) suspects that several unconformities are present near the basement outcrops where the middle Olcese is nonmarine in character. A pumice bed in the Olcese has been dated by fission track methods at 15.5 my (Bartow and McDougall, 1984), consistant with the presence of Saucesian and Relizian foraminifera.

In the Knob Hill quadrangle (7-28S-29E), the lower Olcese consists of: 1) thinly bedded to blocky, white, tuffaceous siltstone and sandstone and 2) planar cross-bedded, fine- to coarse-grained sandstone with pumice pebbles lining the bedding surfaces (see Appendix 2). Fossil mollusks, skate teeth and burrows from this unit indicate a marine environment. This 14m thick sequence represents a mid-shelf environment composed of water- laid tuffs and migrating offshore bars. QFL percents of

lower Olcese sands are 50% feldspar (27% plagioclase and 23% orthoclase), 49% quartz, and 1% lithics (sedimentary). The lower Olcese is overlain by strongly cross-bedded and generally coarser sandstone of the middle Olcese. Tangential cross-beds representing lateral accretion surfaces are oriented perpendicular (generally migrating N20W-N20E or S30W-S10E) to major channel systems defined by trough cross-beds (trough axis and paleoflow direction N80W-S70W). Large scale channeling, bedforms with migrating paleocurrent directions, and coarse channel fill represent variable fluvial systems debouching in this nearshore environment. Sandstone QFL compositions vary in the middle Olcese from 12-24% quartz, 54-45% feldspar (plagioclase 38-29%, orthoclase 17-14%, microcline <1%), and 16-31% lithics (volcanic lithics dominant). The 20m of middle Olcese exposed at this locality represent a nearshore marine environment with oscillating incursions from fluvial systems.

At Round Mountain both the middle and upper Olcese are well exposed (see Appendix 2). Here, the middle Olcese consists of 34.5m of nonmarine cobbles, sands and silts of a braided stream system. The overlying 28.5m of upper Olcese are composed of finer sands with frequent pebble stringers. Large scale (1.5m amplitude) cross-beds indicate a general NE-SW flow lineation and represent sand waves in a nearshore marine environment. At this locality the upper Olcese is overlain by mottled silts of the Round Mountain Silt.

At the "Olcese Creek" locality (28-28S-29E) the transition from nonmarine middle Olcese to marine Olcese is well displayed (see Appendix 2). Coarse sediments with abundant pebbles and cobbles of the middle Olcese are overlain and interfinger with finer grained sediments of the upper Olcese. Beach face sediments with herringbone cross-beds interfinger with fluvial sediments marking the transition from nonmarine to marine which defines the middle-upper Olcese contact. The beach facies of the upper Olcese is overlain by very fine grained sandstone and siltstone including several discontinuous biostromes of Ostrea titan. Mollusk fragments are common throughout the uppermost Olcese Sand. Other exposures of the uppermost Olcese in this area indicate an estuarine environment typified by foraminiferal faunas containing abundant Buccella oregonensis specimens.

The upper Olcese is well exposed at the Barker's Ranch Fauna locality (see Appendix 2). This faunal zone, the Bruclarkia barkeriana zone, contains at least 116 species of mollusks (Addicott, 1956). The Bruclarkia barkeriana zone extends upward into the lowermost Round Mountain Silt near the Kern River. Gastropod assemblages of this zone include outer shelf to slope species such as Trophon kernensis. The upper Olcese at this locality is composed of fine-grained sandstone to sandy siltstone, infrequently faintly cross-bedded, with interbeds of transported shells. This 43.5m of upper Olcese represents shelf deposits below normal wave base with frequent storm-induced wave-formed beds and concentrated shell lags. The upper Olcese at this locality is overlain by mottled siltstone of the Round Mountain Silt.

Excellent exposures of the upper Olcese are found at the "Nickel Cliff" locality (1-29S-29E). This 67m thick section displays the more silty facies of the upper Olcese (see Appendix 2). Abundant foraminifera, mollusks and burrows indicate an outer shelf environment. Foraminifera from

this outcrop such as Valvulineria depressa and Valvulineria miocenica indicate an upper Relizian age. The presence of Ophiomorpha nodosa as the dominant burrowing form is important as an indicator of a harsh environment (Figure 10). A high sedimentation rate on the outer shelf would inhibit many burrowing organisms, however, Ophiomorpha nodosa can reinforce its walls with pellets to protect against such a harsh environment. This upper Olcese sequence suggests an outer shelf environment (50-150m), probably with high sedimentation rates.

The same time equivalent strata which are present at the "Nickel Cliff" locality are also present just west of Rancheria Road at the "Nickel Creek" locality. These sandy siltstones indicate a shelf edge fauna (150m) characterized by species of Trifarina and Hanzawaia.

The varying environments in the Olcese Sand reflect slight but frequent changes in water depth most likely attributed to fluctuations in the eastern margin of the San Joaquin Basin.

Bena Gravel

Bartow and McDougall (1984) divide the lower to upper Miocene Bena Gravel into an alluvial fan facies of sandstone and cobble conglomerate, and a paralic facies containing plant material, fresh-water diatoms, foraminifers, rare oysters and marine mammal bones. The Bena Gravel was originally defined in lower Caliente Canyon by Dibblee and Chesterman (1953).

The alluvial fan facies, paralic facies and proximal parts of the Edison Shale (local name in the Edison field for the Round Mountain Silt and the Fruitvale Shale) form a fan-delta. The paralic facies of the Bena Gravel is equivalent to the deeper water marine facies represented by the uppermost part of the Freeman Silt, the Olcese Sand, the Round Mountain Silt, and the Fruitvale Shale in the deeper parts of the basin (Bartow and McDougall, 1984). The age of the Bena Gravel (from foraminifera, diatoms and terrestrial and marine mammals) is late early Miocene (?), middle Miocene, and late Miocene (Bartow and McDougall, 1984).

Round Mountain Silt

The middle Miocene Round Mountain Silt is a marine, greenish grey, micaceous, clayey-sandy siltstone with abundant foraminifera. Addicott (1970a) designated the type well, Ohio Oil Co. #1 Glide, in Mount Poso field. The Round Mountain Silt attains a thickness of 65m in the type well.

The lower part of the Round Mountain Silt is well exposed in canyons and bluffs north of Lake Ming (see Appendix 2). The lower part of this 30m thick section contains articulated specimens of the pelecypod Anadara osmonti in living position. This species prefers an environment ranging from intertidal to 130m. Foraminifera from this part of the section are characterized by Valvulineria miocenica and Valvulineria depressa and represent an upper Relizian/lower Luisian, outer shelf fauna. Slightly higher in the section, a transported shell bed contains gastropods typical of the Bruclarkia barkeriana zone. Foraminifera from silt in these gastropods indicate a lower Luisian, outer shelf fauna characterized by Gaudryina cf. collinsi and Valvulineria miocenica. Fossils are lacking in the upper part of this section. The lower Round Mountain Silt in the Kern River area is characterized by an abundance of mica. Thin section analysis of a

sandstone in the lower part of the Round Mountain Silt near Lake Ming indicates QFL percents of 33% quartz, 66% feldspar (48% plagioclase, 18% orthoclase) and 1% lithics (sedimentary).

Overlying the lower part of the Round Mountain Silt, a diatomaceous member is well exposed in outcrops of the study area. Diatoms from this member have been assigned to the Denticulopsis lauta zone, correlative with the flood of Valvulineria californica typical of the Round Mountain Silt and indicating a Luisian age (Barron, in press; Bartow and McDougall, 1984). The part of the Round Mountain Silt just above the diatomaceous member is characterized by a flood of Turritella ocoyana (Addicott's Amiantis mathewsonii zone) (Addicott, 1956).

A small 4.5m thick outcrop of the Round Mountain Silt is exposed along Highway 178 just west of Rancheria Road (Figure 12). Foraminifera from this section represent an upper middle bathyal (1000-1500m) fauna of upper Luisian age and include Uvigerina joaquinensis, Valvulineria californica, Bolivina advena and Bulimina inflata. Sharkteeth from this locality are probably biostratigraphically correlative with those from the tooth and bone bed (Bruce Welton, 1985 pers. comm.). The tooth and bone bed near the top of the Round Mountain Silt is well known for its contents of sharkteeth and various marine mammals. This correlation is important because no foraminifera have yet been reported associated with the tooth and bone bed. Above the tooth and bone bed, the Round Mountain Silt becomes a micaceous, sandy siltstone containing marine mollusks.

Beck (1952) assigned part of the Round Mountain Silt to the Relizian Stage. Foraminifera from outcrops of the lower part of the Round Mountain Silt indicate a lower Luisian to upper Relizian? age. Thus, the Round Mountain Silt ranges from upper Relizian (?) to Luisian. The Round Mountain Silt is conformably overlain by the Fruitvale Shale.

Fruitvale Shale

The middle to upper Miocene Fruitvale Shale of Miller and Bloom (1937) is a marine, grey-brown, poorly sorted, carbonaceous silt assignable to the Mohnian Stage (Bartow and McDougall, 1984). There is no satisfactory core or electric log contact between the Round Mountain Silt and the Fruitvale Shale, however, convention places the top of the Round Mountain Silt at the highest stratigraphic occurrence of Valvulineria californica (Addicott, 1956). Outcrops of the Fruitvale Shale at Comanche Point (Bartow and McDougall, 1984) have yielded upper middle bathyal (500-1500m) foraminifera such as Uvigerina hootsi and Bulimina pseudoaffinis. The Fruitvale Shale is conformably overlain in the Fruitvale oil field by the "Santa Margarita" Formation.

"Santa Margarita" Formation

The "Santa Margarita" is an upper Miocene marine, fine- to coarse-grained, grey-white sandstone. There is no detailed type description of this formation. Original usage of this name is due to the similarity of megafossils, in both the surface and subsurface, to the fauna of the type area near Santa Margarita, California. Because the formation cannot be accurately traced from the type area located more than 100 miles to the west, Addicott (1956) proposed replacing the name "Santa Margarita" with the Fruitvale Sand. "Santa Margarita," however, has

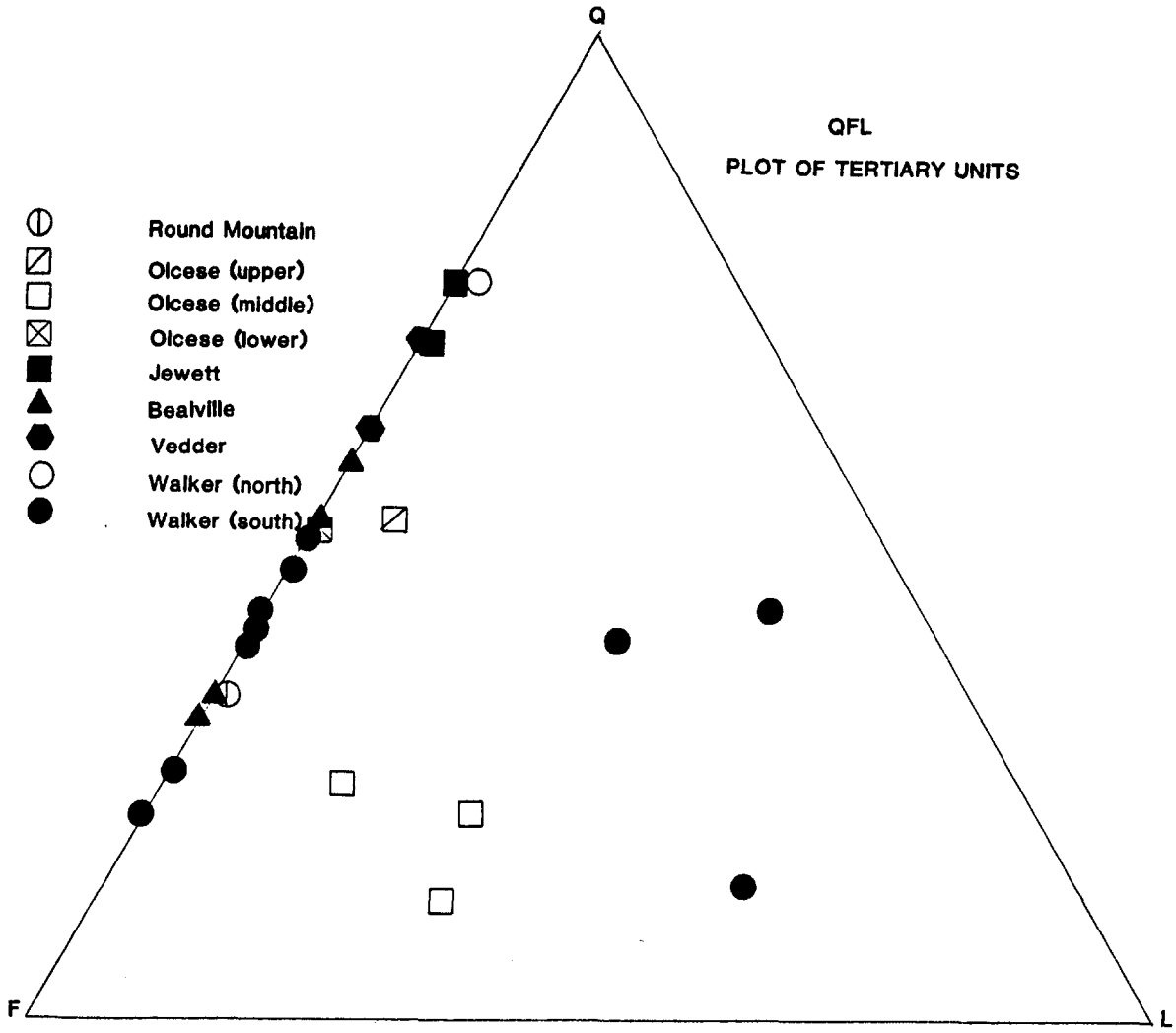


Figure 11 QFL plot of Tertiary unit, Bakersfield, California.

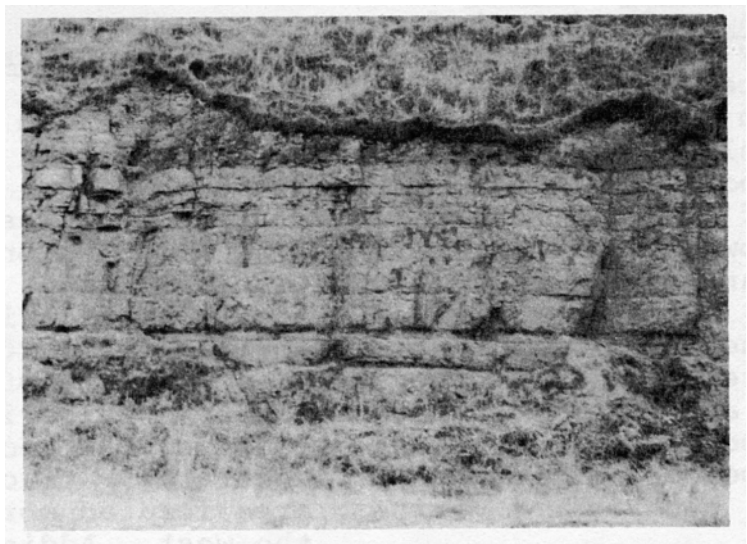


Figure 12 Outcrop of Round Mountain Silt along Highway 178 just west of Rancheria Road, Rio Bravo Ranch Quadrangle.

remained the commonly used name for this formation.

Megafossils recovered in the Fruitvale oil field were considered by Gale (1931) to indicate a regressive, littoral, upper Miocene sea. The "Santa Margarita" conformably overlies the Fruitvale Shale and, further to the east, unconformably overlies both the Fruitvale Shale and Round Mountain Silt. In the Tejon Hills area, the "Santa Margarita" unconformably overlies the Bena Gravel (Addicott, 1956, 1970a; Bartow and McDougall, 1984).

Chanac Formation

The Chanac Formation is the nonmarine equivalent of the "Santa Margarita" Formation and unconformably overlies the Round Mountain Silt in the easternmost part of the San Joaquin Basin. The generally fluviatile Chanac is believed to be of late Miocene age based on continental vertebrates found at the base of the formation in the Tejon Hills area. These fossils, known as the North Tejon Hills local fauna, include early single-toed grazing horses, medium sized three-toed grazing horses and hyaenoid dogs.

In the Tejon Hills up to 300m of Chanac are exposed as compared to no more than 30m in the Bakersfield-Kern River area. Lithofacies present in outcrop on Highway 178 about 12 miles east of Bakersfield include greenish gray trough cross-bedded very fine grained sandstone, laminated fine-grained sandstone, and cobble and boulder lags at channel bases with very coarse grained sandstone to granule conglomerate channel fill. At this same location the disconformable contact between the Chanac and overlying Kern River Formation is marked by a boulder lag with boulders up to 1.5m in diameter. The Kern River is readily distinguishable by its orangish brown color from the underlying greenish gray Chanac. Similar lithologic and electric log character make it difficult to differentiate between the two formations in the subsurface in areas where the upper Miocene marine Etchegoin Formation does not separate them. Farther west towards the center of the basin a tongue of Etchegoin unconformably overlies the Chanac and interfingers with the basal Kern River Formation.

Kern River Formation

The Kern River Formation, a generally coarse-grained fluviatile unit is the youngest Tertiary formation on the east side of the San Joaquin Basin. Its age, based on mammalian remains and interfingering relationships, is believed to be latest Miocene to Pleistocene(?).

Vertebrate fossils including an extinct honey badger, a ring-tailed cat, vultures, hawks, grazing horses, camels, rhinos, pronghorns, peccaries, mice, rabbits and ground squirrels have been found at the base of the formation near Bakersfield (Savage and others, 1954). This Kern River fauna is considered to be of early Hemphillian age (late Miocene to early Pliocene). A mastodon tusk, recently found in the same area, further suggests the base of the formation to be within the Miocene (Bruce Welton, pers. comm., 1985). No identifiable spores or pollen have been recovered.

The Kern River fauna is believed to correlate with an early Hemphillian fauna from the Mehrten Formation about 190 miles northwest of Bakersfield. The Mehrten fauna occurs within a few meters of a tuff dated at 8.2 m.y. (Bartow and Pittman, 1983). The basal Kern River interfingers to the west with

the marine Etchegoin Formation which is dated as latest Miocene on the basis of contained molluscan fauna and benthic foraminifers.

The Kern River unconformably overlies the nonmarine Chanac to the east (see figure 2 for stratigraphic relations). The Etchegoin, the basinward equivalent of the basal Kern River, is known to pinch out to the east at the eastern extreme of the Kern Front oil field approximately five miles northeast of Bakersfield. Still farther to the east, the Kern River unconformably overlies the Round Mountain Silt and laps onto pre-Tertiary basement rocks about 40 miles north of Bakersfield. Pleistocene alluvial gravels unconformably overlie the Kern River. The age of the youngest Kern River beds is presumed to be Pleistocene. Nonmarine beds of the Tulare Formation present on the west side of the San Joaquin Basin, dated as Pleistocene on the basis of mollusks, grade into the upper part of the Kern River Formation towards the east. The predominantly marine Pliocene San Joaquin Formation and marine Miocene and Pliocene Etchegoin Formation are both present in the central part of the San Joaquin Basin and grade into the Kern River Formation to the east.

The uppermost Kern River is possibly correlatable to the Pleistocene Turlock Lake Formation of the northeastern San Joaquin Basin. Other units in the northeastern portion of the basin which are possible equivalents of the Kern River are the Mehrten Formation, above the 9 m.y. old Table Mountain Latite and the Laguna Formation (Bartow and Pittman, 1983).

The name Kern River Formation was formally adopted by Bartow (1983) and a type well and composite reference section designated. The Kern River Formation crops out in a roughly crescent-shaped belt, about 12 miles wide at its widest point, from Caliente Creek on the south to the vicinity of Terra Bella on the north, a distance of about 50 miles. The best exposures are in the Bakersfield area along the bluffs just south of the Kern River. The composite reference section is located along these bluffs where maximum exposures of up to 60m occur (see figure 13 and 14 for the location and relative stratigraphic position of the composite reference section).

Measured section A of figure 13 corresponds to the measured section (Kern River Formation) with the location (6-29S-29E) in Appendix 2.

The type well, Getty Oil "Kern" 101 is located in the Kern River oil field in the SE1/4 SW1/4 (32-28S-28E). A section of Kern River Formation totalling eight hundred and sixty feet was cored from the type well, but none of the material was retained. Extensive coring in the Kern River field shows the character of the formation in the subsurface to be very similar to that in outcrop. The westward thickening Kern River reaches its maximum thickness of approximately 800m in the subsurface along a roughly north-south line about 3 miles northeast of Bakersfield.

Sediments of the Kern River Formation which are generally coarse-grained and poorly sorted reflect the high energy conditions expected in a braided stream environment. Poorly sorted, coarse-grained sand, granules and conglomerate predominate. The sands classified as lithic arkoses are immature and contain abundant subrounded grains of milky to clear quartz and white to pink feldspars commonly altered to clay. Biotite flakes are usually abundant and heavy minerals include hornblende,

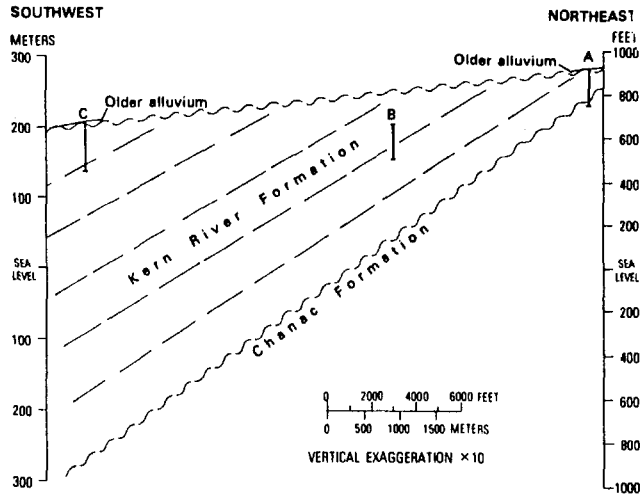


Figure 13 Diagramatic section showing the relative stratigraphic position of the composite reference section. Measured section A appears in Appendix 2. (Bartow and Pittman, 1983)

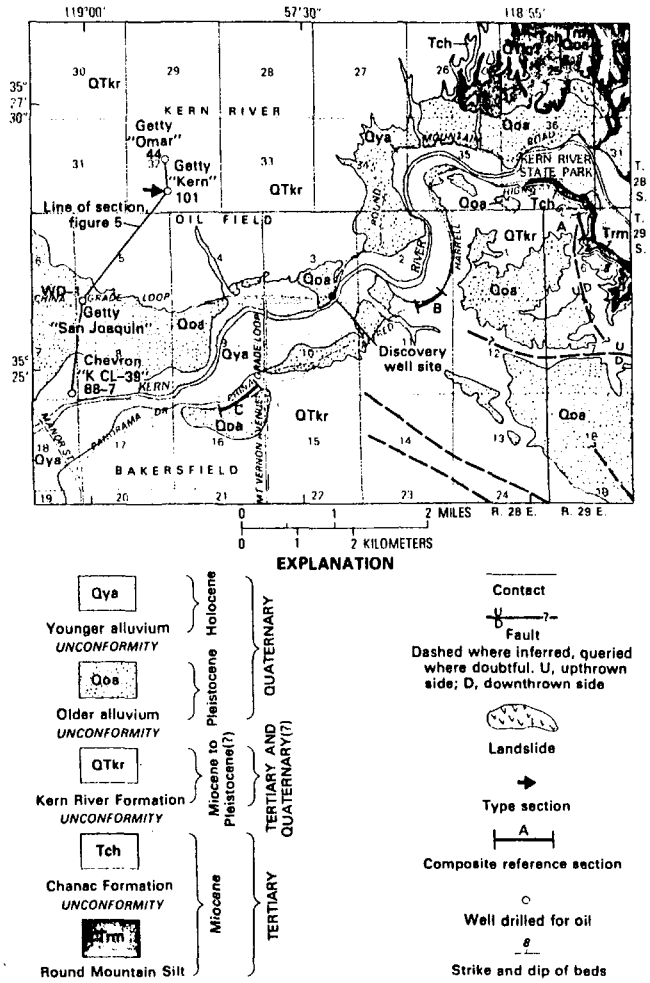


Figure 14 Geology of the Kern River area at Bakersfield, California, showing the location of the type section and reference section of the Kern River Formation. (Bartow and Pittman, 1983)

garnet and pyrite. Rock fragments present include granite, gabbro, gneiss, schist, quartzite, andesite and rhyolite. These compositions indicate the Kern River sediments to be the result of erosion of the Sierra Nevada. Clay types present at the base of the Kern River where it interfingers with the Etchegoin suggest a brackish water, estuarine environment (Nicholson, 1980).

Sands range from very fine to very coarse grained and are commonly pebbly. Conglomerates are usually very poorly sorted and contain clasts ranging from pebble to boulder size. Matrix material is commonly very coarse pebbly sand and granules. In outcrop, the sands and conglomerates are orangish brown to buff in color.

Siltstone and mudstone are not abundant in outcrop, but, when they do occur, they usually have a characteristic greenish gray color. They may be clayey and contain grains of up to coarse sand size dispersed throughout.

The Kern River Formation was deposited by a fluvial system characterized by channels with low depth to width ratios which are the result of highly variable flow and unstable banks. In outcrop, abundant channel lags, geometric relationships and abrupt changes in clast size suggest the unit is the result of many distinct flows in cross-cutting channels. Fining upward cycles on the order of 1 to 3m are the result of waning flow experienced by one flow event, and larger scale fining upward cycles are the result of gradual channel abandonment spanning many flows. This formation lends itself to using Miall's (1977, 1978) lithofacies classification of braided river deposits to gain insight into the depositional environment. These lithofacies assignments appear on the stratigraphic sections of the Kern River Formation in Appendix 2. The middle Olcese and Kern River formations are very similar in gross sedimentological character, suggesting similar depositional mechanisms. A brief description of each lithofacies and its interpretation as it applies to the Kern River Formation is given below.

Gm: MASSIVE OR CRUDELY BEDDED GRAVEL (HORIZONTAL)

Conglomerates present are usually clast supported indicating that the matrix material filtered into the interstices during waning flow after the initial deposition of the larger clasts. The base of these deposits is erosive and imbrication may be developed.

These deposits are interpreted as longitudinal bars which are elongate parallel to flow and form from clast by clast accretion onto an obstruction or lag. Avalanche faces are not developed, therefore cross-bedding is absent. Many of the conglomerates are amalgamated and individual units representing discrete bars can be identified only by abrupt changes in clast size.

Lithofacies Gm may also represent lag deposits which are very common, but lithofacies Gm was not assigned to each lag on the stratigraphic section in Appendix 2 to avoid confusion.

Sp: PLANAR CROSS-BEDDED SAND

Lithofacies Sp represents linguoid bar deposits which result from large scale migrating bedforms active during flood stage. Cross-bed heights range from 30cm to 130cm.

Ss: SCOUR FILL SAND, BROAD SHALLOW CROSS-BEDS

Typically large, assymetric scours (2-3m laterally, .3-.5m

vertically) are filled with fine- to very coarse-grained, commonly pebbly sandstone. Channel geometries in outcrop suggest flows to the northwest and southwest. The infilling beds may appear to conform to the shape of the scour, probably due to stratification being at a very low angle to the basal erosion surface. The cutting and filling of the channels are probably separate events. Cross-beds may be poorly defined due to poor sorting and a lack of fine material necessary to make the cross-beds evident. These deposits are interpreted as major and minor channel fill formed during high water stage.

Se: EROSIONAL SCOURS WITH LAG DEPOSITS OF SILT OR MUD INTRACLASTS

Sandstones vary from fine- to very coarse-grained and are commonly pebbly. The cross-beds present have sharp, flat or slightly scoured tops; set heights range from 30cm to 130cm. The foresets represent avalanche faces with dips ranging from 11 degrees to 27 degrees. These deposits are the result of sand waves migrating down channels. All of the planar cross-beds observed in outcrop dip to the southwest, suggesting flow in that direction.

Fl: VERY FINE SAND TO SILT, FINE LAMINATIONS

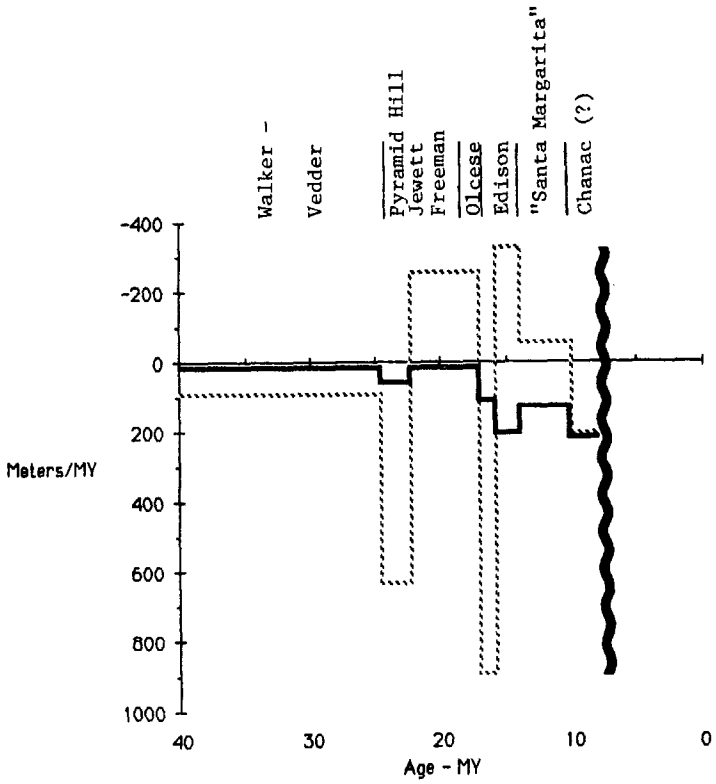
The siltstones present in outcrop are commonly structureless; fine laminations and root casts may also be present although they are uncommon. The lack of structures may be due to bioturbation or pedogenic processes. In outcrop this fine-grained facies is not abundant, but, in the subsurface in the Kern River oil field, siltstones and mudstones averaging 6m thick are fairly common. Fine-grained deposits are generally associated with flood plain or overbank areas and are probably more common in the distal parts of the braided stream environment. These deposits have a low preservation potential in active channel areas and their tops are always scoured.

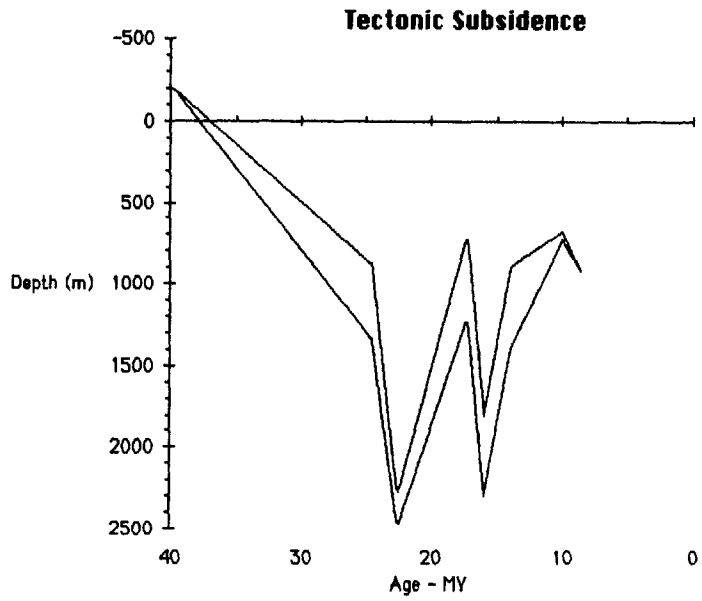
SUMMARY

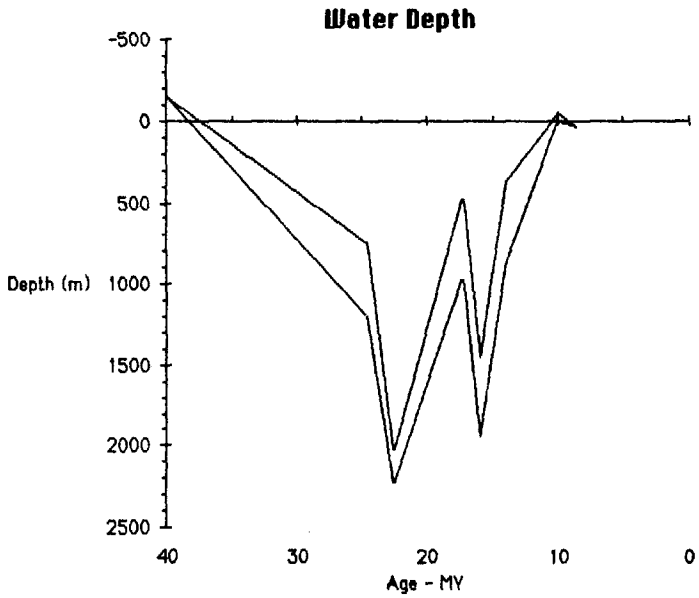
The stratigraphy of the east side of the San Joaquin Basin reflects a history of relative sea-level fluctuations. Nonmarine sediments of the Walker Formation were dominant throughout the Eocene and Oligocene epochs, interfingering with shelf deposits of the Vedder Sand during Oligocene time. A regressive-transgressive sequence followed and the transgressive Pyramid Hills Sand Member was deposited. Water depths increased during deposition of the Jewett Sand and Freeman Silt. Lower Saucesian paleobathymetry in excess of 2000m at the current basin margin raises the question of exactly how far the lower Miocene sea extended across the present Sierra Nevada Range. The Olcese represents a shoaling event around 15.5 my, followed by deepening into Round Mountain Silt time. Beginning in late Miocene time a relatively rapid regression began which continued into the Pleistocene. Shoaling once again dominated with deposition of the "Santa Margarita" Formation, the Chanac Formation and the late Miocene through Pleistocene(?) Kern River Formation. This regression was interrupted by a minor transgression in late late Miocene time resulting in the deposition of the tongue of marine Etchegoin Formation which separates the Chanac and Kern River Formations.

A preliminary geohistory diagram has been constructed by

Rate of Sediment Accumulation and
Total Subsidence







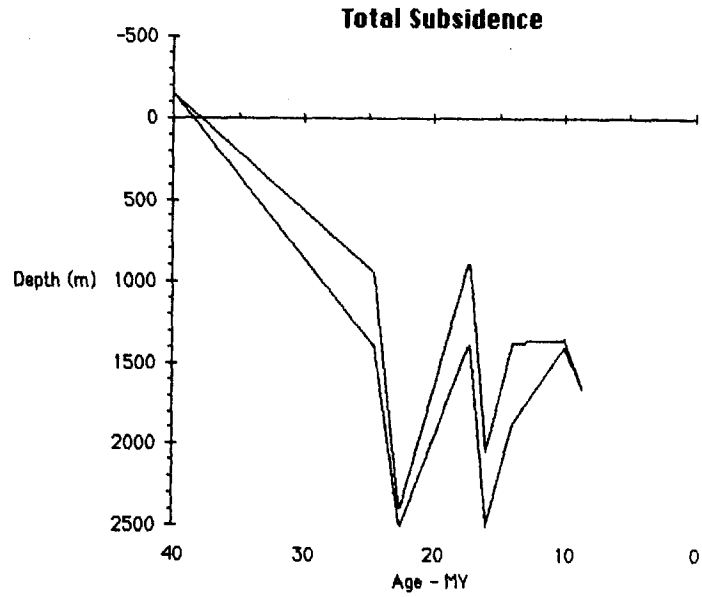


Figure 15 Geohistory diagrams and rates of sediment accumulation and total subsidence from Chevron #24-35. Paleo data for geohistory diagram is from data in Bartow and McDougall (1984). Subsidence and water depth diagrams show both minimum and maximum values.

Bloch and Olson (unpub.) of the Chevron #24 well (35-29S-29E) (Figure 15). This initial investigation indicates highest rates of sediment accumulation (200-210m/my) during deposition of the marine Edison Shale (Round Mountain Silt and Fruitvale Shale) and the nonmarine Chanac. The Olcese and "Santa Margarita" represent accumulation rates of 104m/my and 124m/my respectively. Lower sediment accumulation rates are indicated for the Walker, Vedder, Jewett and Freeman (8-53m/my). Between 40my and 22.5my the curves of total and tectonic subsidence in this part of the basin are compatible with the geohistory pattern of subsidence due to collision tectonics. These subsidence curve patterns preclude that subsidence was a result of thermal contraction (for example, subsidence associated with rifting).

With rapid rates of subsidence beginning at approximately the Oligocene-Miocene boundary, the transgressive Pyramid Hill San Member covered a large portion of the eastern margin. Sediment accumulation did not keep pace with subsidence and at about 24.6my the water depth of the eastern San Joaquin Basin rapidly deepened. Uplift followed and culminated during Olcese deposition (possibly marked by an unconformity in the middle Olcese). Uplift provided new sediment sources in the form of greater topographic relief. As a result, sedimentation rates greatly increased during the following period of subsidence, even at the middle bathyal depths of the Edison Shale. Sediment accumulation rates peaked during this time (14-15my).

Uplift provided shallowing of the basin for deposition of the marine "Santa Margarita" (13my). Uplift terminated with deposition of the nonmarine Chanac and subsidence ensued (at approximately 10my). The subsidence pattern of the geohistory diagram at this time is not clear (mainly due to a lack of data points and the possibility of an unconformity). Although further subsurface and surface studies will help refine these interpretations, this geohistory analysis gives a general concept of southeastern San Joaquin Basin margin evolution.

ACKNOWLEDGEMENTS

We appreciate suggestions, assistance and encouragement during this research from Jim Ingle, Steve Graham, Bruce Welton, Gardner Pittman, Pete DeCelles, Karen Provine, Jennifer Pence, Cecelia McCloy, Roger Bloch and Jon Olson. Field Research benefited from the generous hospitality of Mr. and Mrs. George Nickel. Sharksteeth were identified by Bruce Welton. Financial support for field work was provided to Greta Miller and Hilary Olson by a grant from Amoco Production Company. Financial support for thesis research has been generously provided by the participating companies in the San Joaquin Basin Industrial Associates Program at Stanford University: Amoco, Arco, British Petroleum, Champlin, Chevron, Conoco, Exxon, Husky, Marathon, Mobil, Occidental, Phillips, Santa Fe Energy, Shell, Sohio, Superior, Tenneco, Texaco and Union oil companies.

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APPENDIX I

FORAMINIFERA AND FISHES OF TERTIARY UNITS IN THE BAKERSFIELD, CALIFORNIA AREA

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94305

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Bakersfield, California
93302

NICKEL CLIFF LOCALITY

Foraminifera (i.d. Hilary Olson):

11-8-84-1
barren

11-8-84-2
barren

11-8-84-3
barren

11-8-84-5
barren

11-8-84-7
Elphidium sp.
Nonion costiferum
Valvulineria? sp.

11-8-84-8
barren

11-8-84-9
Bolivina advena striatella
Buccella tenerrima
Buliminella subfusiformis
Elphidium sp.
Lenticulina mayi
Lenticulina nikobarensis
Lenticulina sp.
Nonion costiferum
Nonion montereyanum
Nonionella miocenica
Valvulineria cf. casitasensis
Valvulineria miocenica?

11-9-94-2
barren

11-9-84-3
Buccella sp.
Bolivina pseudospissa?
Elphidium sp.
Lagena sp.
Nonion costiferum
Nonion montereyanum
Nonionella miocenica
Uvigerina sp.
Valvulineria depressa

11-9-84-5
barren

2-16-85-1
barren

2-16-85-2
Buccella sp.
Elphidium sp.
Globigerina bulloides
Nonion costiferum
Nonion montereyanum
Nonionella miocenica
Uvigerina sp.

2-16-85-4
Buccella oregonensis
Buccella tenerrima
Buliminella subfusiformis
Globigerina bulloides
Lagena sp.
Lenticulina sp.
Nonion montereyanum
Nonionella miocenica
Uvigerina sp.
Valvulineria miocenica
Valvulineria sp.

2-16-85-6
Bolivina sp.
Buccella sp.
Lagena sp.
Lenticulina sp.
Nonion montereyanum
Nonionella miocenica
Valvulineria miocenica
Valvulineria sp.

2-16-85-9
Buccella sp.
Elphidium sp.
Lagena melo
Lenticulina mayi
Nonion costiferum
Nonion montereyanum
Nonionella miocenica
Uvigerina sp.
Valvulineria depressa
Valvulineria miocenica

2-16-85-13
Buccella sp.
Lagena sp.
Nonion costiferum
Nonion montereyanum
Valvulineria depressa
Valvulineria sp.

2-16-85-14
Bolivina pseudospissa?
Buccella oregonensis
Buliminella subfusiformis
Gaudryina sp.
Globigerina bulloides
Lenticulina mayi
Lenticulina sp.
Nonion costiferum
Nonion montereyanum
Nonionella miocenica
Quinqueloculina sp.
Valvulineria miocenica
Valvulineria ornata?
Valvulineria sp.

2-16-85-15
Buccella sp.
Elphidium sp.
Globigerina sp.
Nonion costiferum
Nonion montereyanum
Nonionella miocenica

2-16-85-18
Buccella sp.
Nonion costiferum
Nonion montereyanum
Nonionella miocenica

2-16-85-22
barren

Fishes from the upper Olcese Sand (i.d. Bruce Welton):

Squalus occidentalis
Pristiophorus sp.
Heterodontus sp.
Carcharadon mexicanus
Cetorhinus sp.
Galeocerdo aduncas
Carcharhinus sp.
Mustelus sp.
Triakis sp.
Galeorhinus sp.
Myliobatis sp.
Dasystis sp.
Mobula sp.
Sciaenid otoliths

CHALK CLIFF LOCALITY

Fishes from the Jewett Sand (i.d. Bruce Welton):

Hexanchus sp.
Squalus cf. occidentalis
Pristiophorus sp.
Squatina sp.
Isurus sp.
Carcharhinus sp.
Galeocerdo aduncas
Myliobatis sp.
Raja sp.
Dasystis sp.
Gymnura sp.

BARKERS RANCH FAUNAL LOCALITY

Foraminifera (i.d. Hilary Olson):

11-23-85-5
barren

11-23-85-7
Buliminella elegantissima
Elphidium sp.
Nonionella miocenica

11-23-85-8
barren

11-23-85-9
barren

11-23-85-11
barren

Fishes from the upper Olcese Sand (i.d. Bruce Welton):

Squalus occidentalis
Echinorhinus blakei
Squatina lerichei
Heterodontus sp.
Isurus sp.
Alopias sp.
Cetorhinus sp.
Carcharhinus sp.
Triakis sp.
Hemipristis serra
Mustelus sp.
Pristiophorus sp.
Rhinobatis sp.
Myliobatis sp.
Mobula sp.
Dasystis sp.
Sciaenid otoliths
Bothid otoliths
Chimaeroid spine
Cetacea
Pinnipedia

LAKE MING LOCALITY

Foraminifera (i.d. Hilary Olson):

10-14-85-1
barren

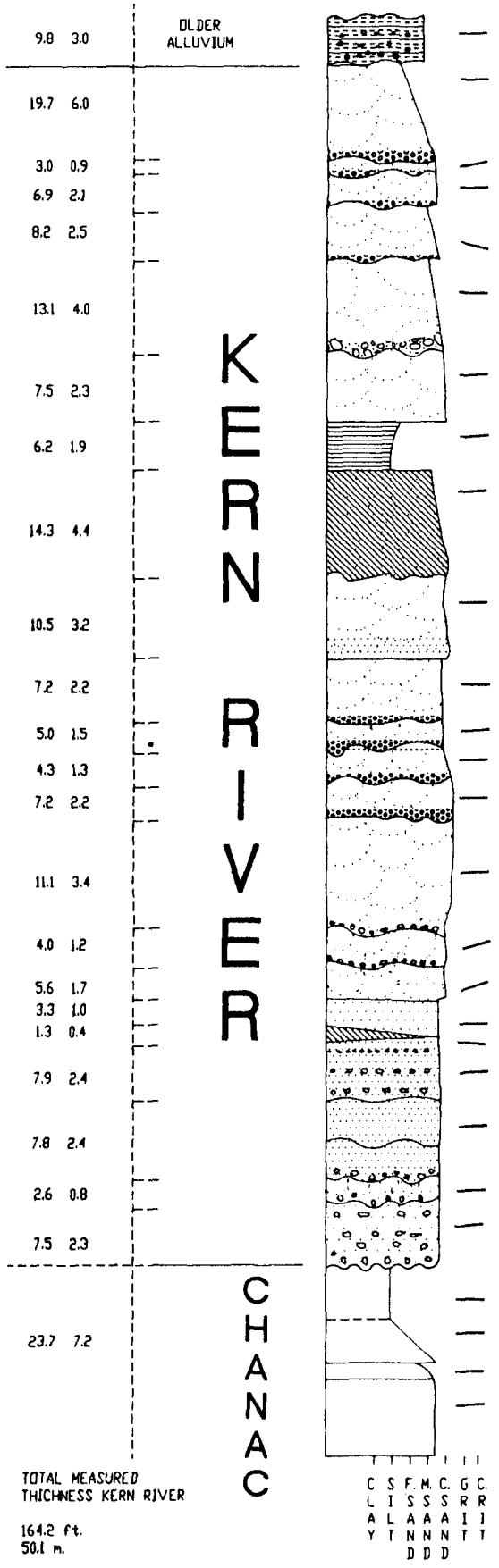
10-14-85-2
Buccella oregonensis
Buccella tenerrima
Bulimina sp.
Buliminella curta
Buliminella elegantissima
Elphidium sp.
Gaudryina cf. collinsi
Lenticulina smileyi
Nonion costiferum
Nonion cf. costiferum
Nonion montereyanum
Nonionella miocenica
Pullenia pedroana
Pullenia cf. salisburyi
Pullenia sp.
Quinqueloculina akneriana bellatula
Valvulineria cf. depressa
Valvulineria miocenica
Valvulineria sp.

10-14-85-3
Lenticulina mayi
Nonion costiferum
Nonion montereyanum
Valvulineria miocenica

10-14-85-4
barren

10-14-85-5
barren

10-14-85-6
Buccella tenerrima
Elphidium sp.
Globigerinoides quadrilobatus
Lenticulina mayi
Nonion costiferum
Nonion montereyanum
Nonionella miocenica
Valvulineria depressa
Valvulineria miocenica



Boulder conglomerate, clast supported, imbricated, mx. clast 16 in. (40 cm).	Gm-Massive or crudely bedded gravel
C. sand w/pebbles, pebbles follow trough cross-beds, set height varies 8 in. to 19 inches (.2-.5 cm), individual troughs commonly F.U. from pebbly grit to C. sand, scoured base w/cobble lag, max. clast 6 in. (15 cm).	Ss-Scour fill sand broad shallow cross-beds Se-Erosional scours with lag deposits or intraclasts
C. grit w/pebbles, scoured base w/cobble lag, max. clast 8 inc. (20 cm).	Se, Ss
C. grit w/pebbles, scoured base w/boulder lag, pebbles follow faint cross-beds, max. clast 10 in. (25 cm).	
Grit-C. sand w/pebbles, scoured base w/cobble lag, max. clast 6 in. (15 cm).	Se, Ss
C. grit - C. sand w/pebbles, very pebbly C. grit near base F.U. to C. sand near top, scoured base w/boulder lag, pebbles follow cross-beds, max. clast 12 in. (30 cm).	Se, Ss
C. grit - v. c. grit, poorly exposed, sed. structures obscured, abundant fine SS-siltstone intraclasts, max. clast 1 in. (3 cm).	Se, Ss
F. - med. sand, horizontal laminations 1.5 cm, biotite layers 2-3 cm.	Sh-Horizontally Bedded Sand
Grit - v.c. sand w/pebbles, planar cross-beds set height 47 in. - 28 in. (1.2-.7 m), 2D cross-beds measurement: 24° S35W, pebbles follow cross-beds, scoured base w/boulder lag, max. clast 10 in. (25 cm).	Sp-Planar cross-bedded sand
V.C. Grit, poorly exposed, scoured base w/pebble lag, scattered cobbles, max. clast 8 in. (20 cm).	Se, Ss
Grit, poorly exposed, scoured base w/cobble lag, max. clast 4 in. (10 cm).	Se, Ss
Grit, poorly exposed, scoured base, max. clast 12 inc. (30 cm).	Se, Ss
Grit, poorly exposed, scoured base, max clast 12 in. (30 cm).	Se, Ss
V.C. grit w/pebbles, pebbles follow low angle cross-beds, scoured base boulder lag, max. clast 12 in. (30 cm).	Se, Ss
V.C. grit w/pebbles, pebbled follow low angle cross-beds, scoured base w/cobble lag, max. clast 8 in. (20 cm).	Se, Ss
Grit w/pebbles, scoured base w/cobble lag, max. clast 6 in. (15 cm).	Se, Ss
Grit w/pebbles, pebbles follow crude cross-beds, max clast 2 in. (5 cm).	Se, Ss
Cobble conglomerate, max. clast 12 in. (30 cm).	Gm
V.C. Sand, planar cross-beds, 2D: 18° S45W	Sp
Cobble conglomerate, 3 cobble lags in unit: 31 in. (79 cm), vertical spacing, scoured base w/cobble lag, max. clast 16 in. (40 cm).	Gm
V.C. Sand w/pebbles, pebbles follow planar cross-beds, set height 52 in. (130 cm), 2D cross-bed measurement: 16° S40W, max. clast 16 in. (40 cm).	Sp
V.C. Sand, pebble lag at base.	Se, Ss
Boulder conglomerate, very poorly sorted, boulders follow crude bedding, max. clast 16 in. (40 cm).	Gm
Siltstone and Claystone	
Med. - C. Sand	
Med. - C. Sand, clayey	
Med. - C. Sand	

TOTAL MEASURED THICKNESS KERN RIVER

164.2 ft.
50.1 m.

MEASURED SECTION A

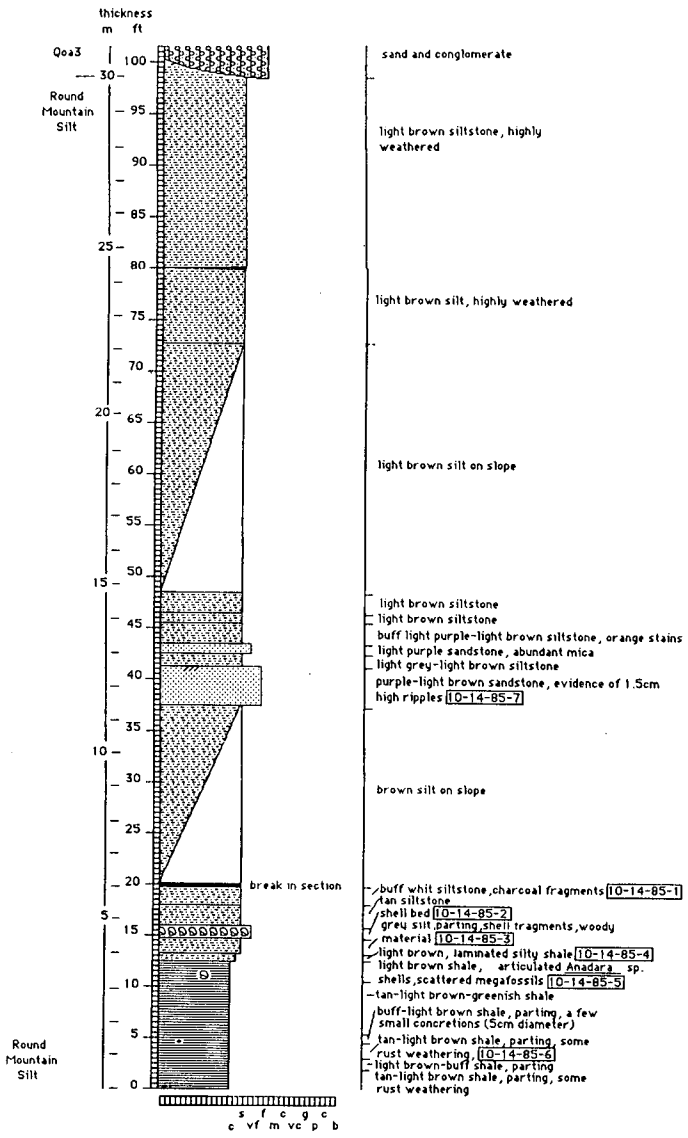
GRETA E. MILLER

* MIALL, A.D., 1977, A REVIEW OF THE BRAIDED-RIVER DEPOSITIONAL ENVIRONMENT : EARTH - SCIENCE REVIEWS, 18, 1-62.

CHANAC FROM BARTOW AND PITTMAN 1983

Lake Ming Locality

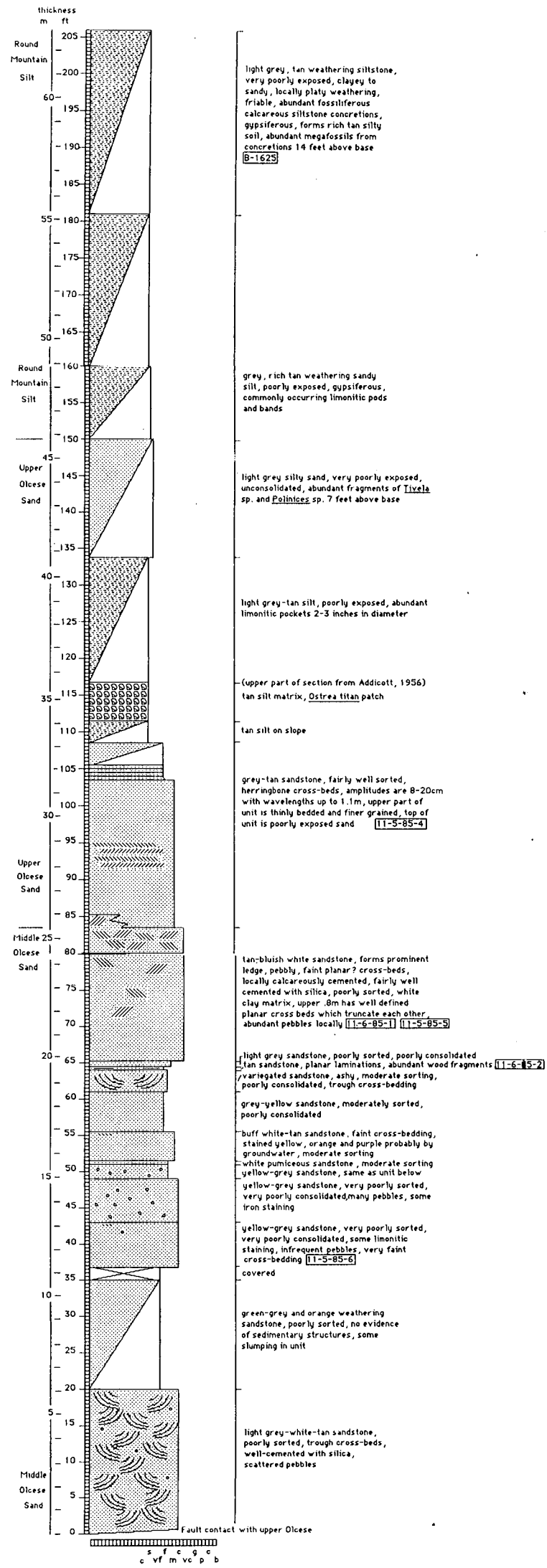
Rio Bravo Ranch Quadrangle
33-28S-29E



NO DIRECT CORRELATIONS IMPLIED

Olcese Creek (Upper) Locality

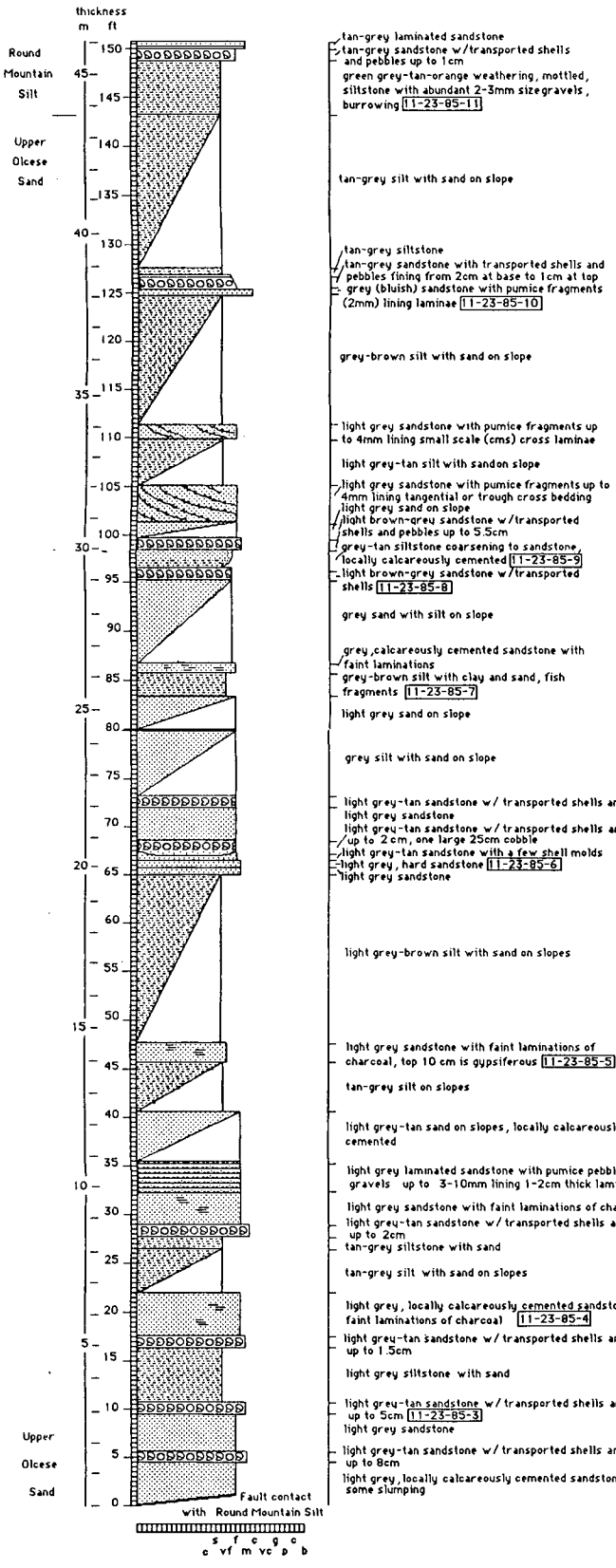
Rio Bravo Ranch Quadrangle
28-28S-29E



MEASURED SECTIONS B-C

Barker's Ranch Faunal Locality

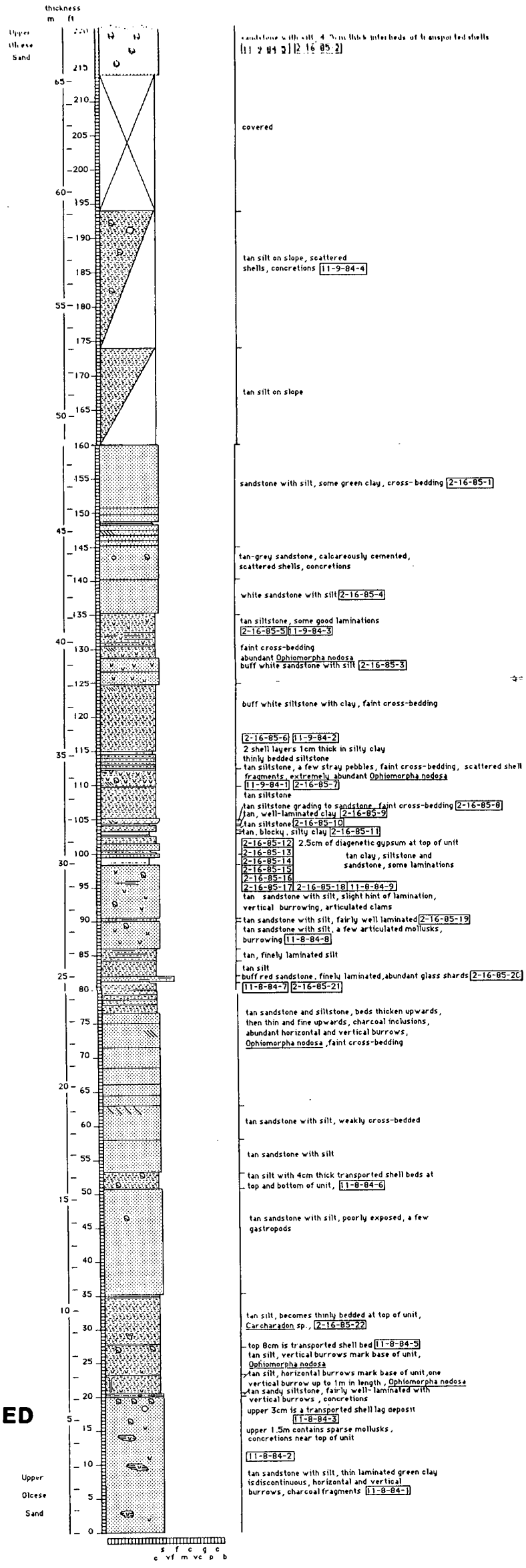
Rio Bravo Ranch Quadrangle
33,32,29-28S-29E



NO DIRECT CORRELATIONS IMPLIED

Nickel Cliff Locality

Rio Bravo Ranch Quadrangle
1-29S-29E

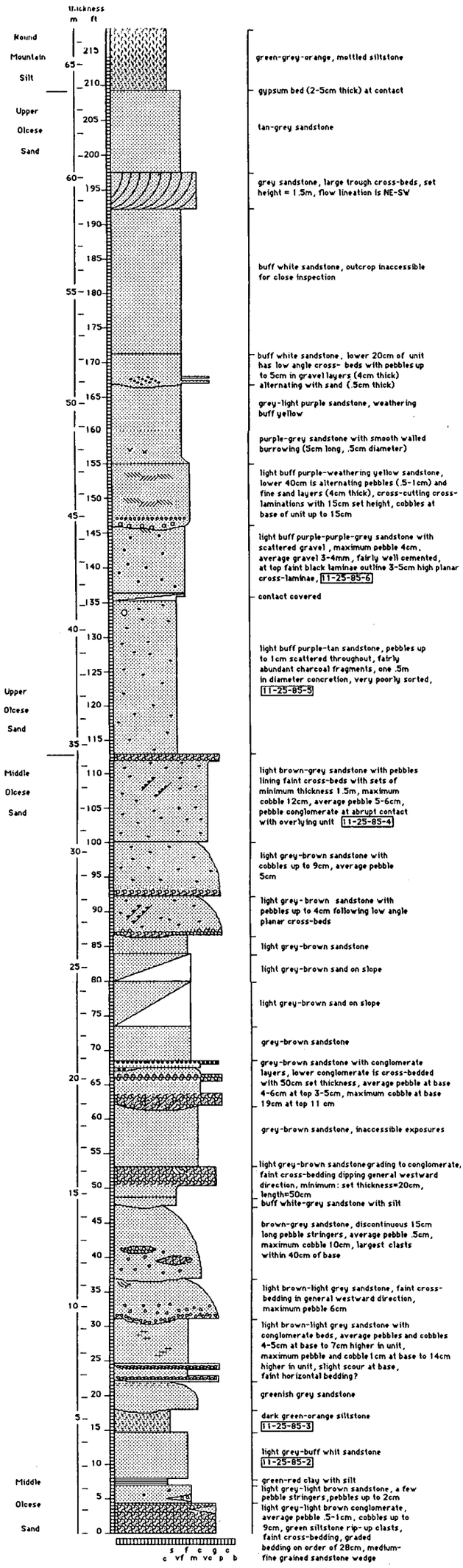


MEASURED SECTIONS D-E

Round Mountain Locality

Oil Center Quadrangle

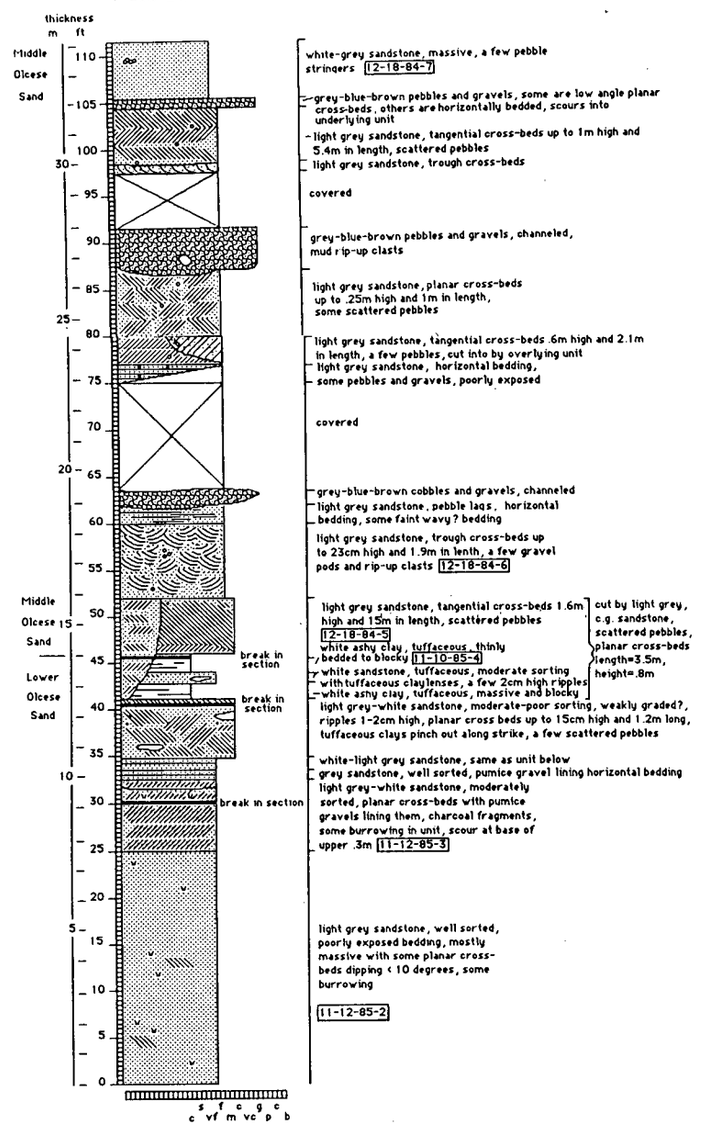
18,19-28S-29E



Round Mountain Road Locality

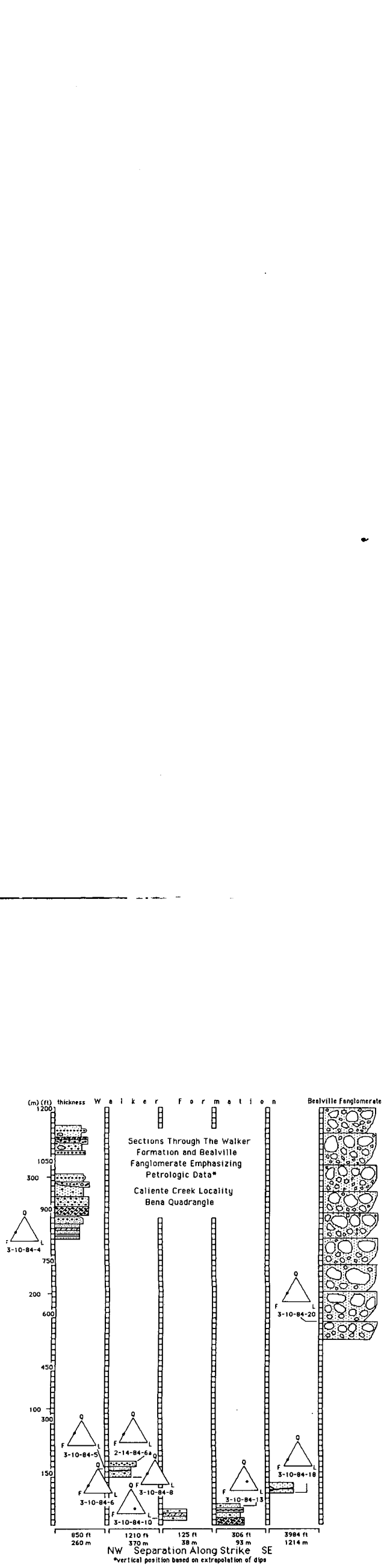
Knob Hill Quadrangle

7-28S-29E

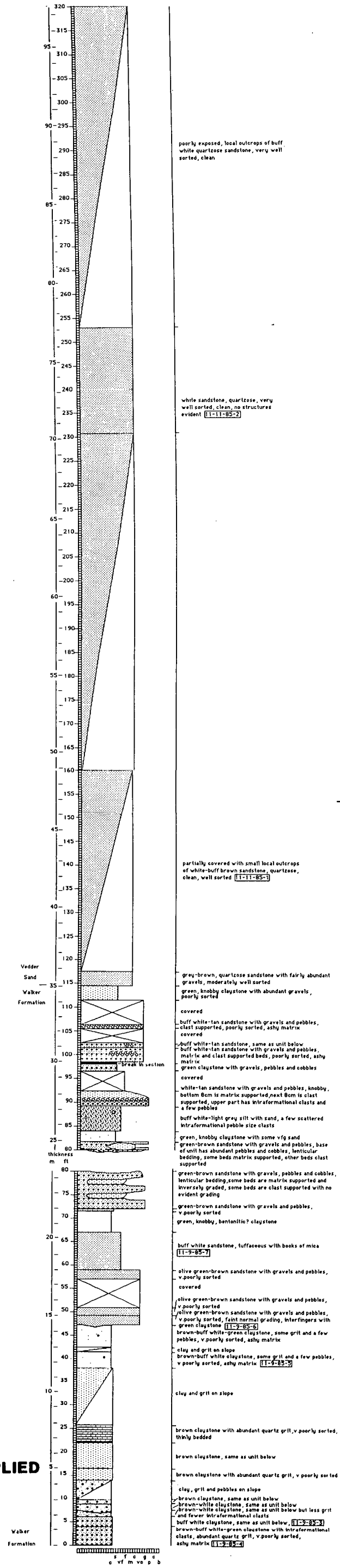


NO DIRECT CORRELATIONS IMPLIED

MEASURED SECTIONS F-G

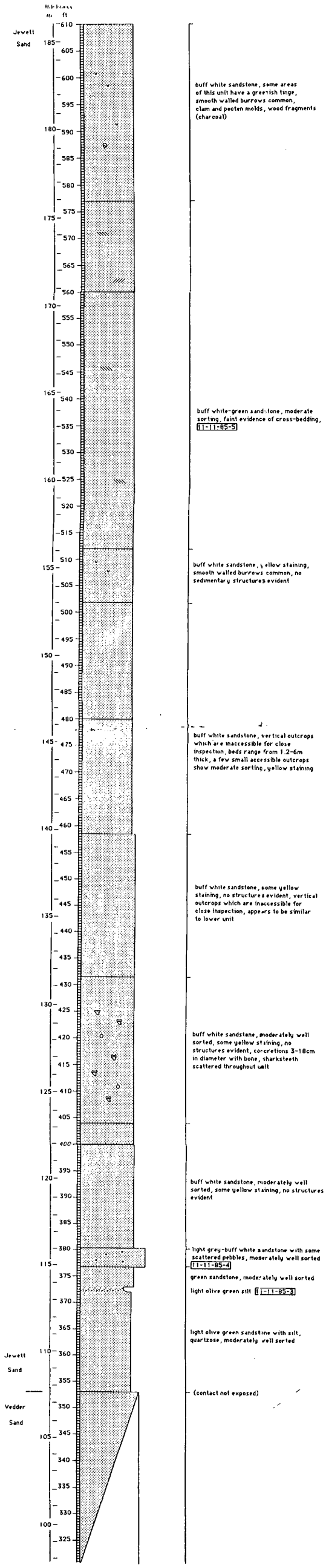


NO DIRECT CORRELATIONS IMPLIED

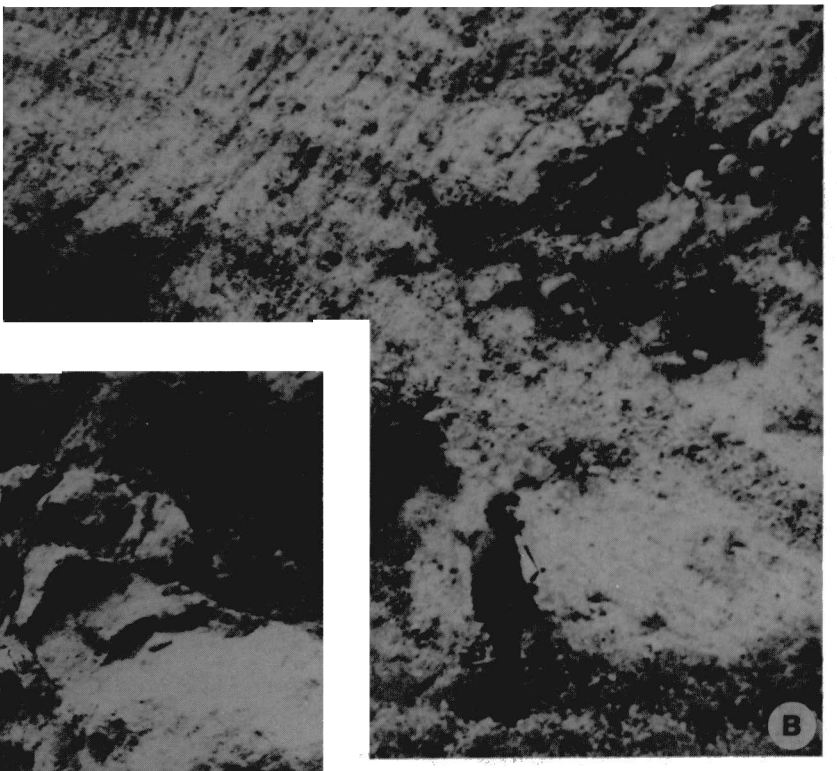


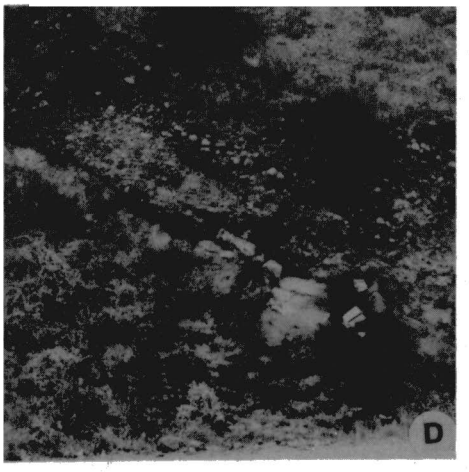
Chalk Cliff Locality
Adobe Canyon

Knob Hill Quadrangle
8,17-27S-29E



MEASURED SECTIONS H-I





WALKER FORMATION, CALIENTE CREEK AREA:

Fig. A. Pumice fragments in massive, very-fine-grained sand (facies Sh). Rare euhedral biotite crystals present in the sand with the pumice suggest deposition in lower flow regimes.

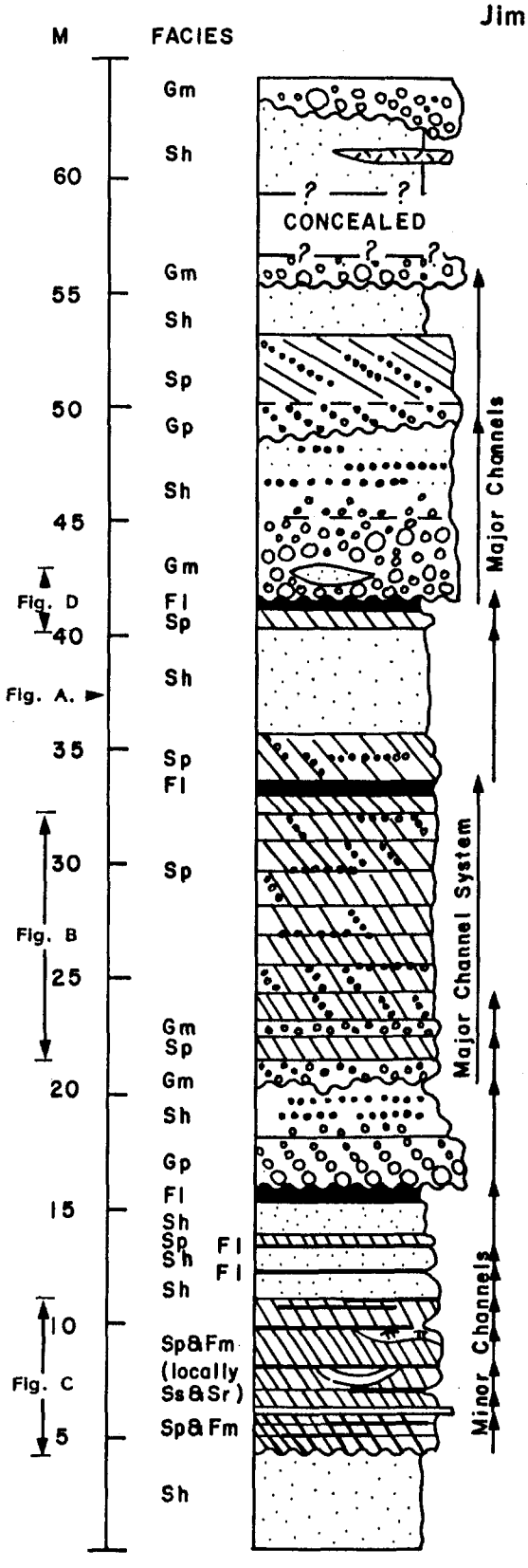
Fig. B. Planar crossbedded pebbly sand with gravel beds (facies Sp) deposited in a major channel system.

Fig C. Hydrothermally silicified planar-crossbedded sands with thin mud lenses (facies Sp and Fm). Underlying unit exhibits very similar lithology and sedimentary structures (also facies Sp and Fm) but is unsilicified. Sands probably deposited as linguoid bars in minor channels. Hydrothermal event perhaps related to waning stages of thermal event associated with the sill intrusion.

Fig D. Erosional contact between clast-supported conglomerate (facies Gm) and laminated silts (facies Fl) which overlie planar crossbedded sands (Sp). The conglomerate represents the base of a major channel.

MEASURED STRATIGRAPHIC SECTION WALKER FORMATION
CALIENTE CREEK AREA, NW¼ SECTION 13, T30S/R30E MDB&M

Stan Stearns, Evans, Carey & Crozier
Susan Chandler Kiser, Consultant
Jim Farris, Evans, Carey & Crozier



cobble, pebble congl.; contact w/underlying sits contorted due to sill intrusion

mafic sill; baked contact & chilled margin

fn. sd. & sits.; soft sed. deformation due to sill intrusion, including mudst. dike

pebbly, cobbly, cse. sd.; crudely bedded

v. fn. sd.; massive; well sorted; tuffaceous

med., cse. & pebbly sd. w/gravel lenses; planar crossbeds; sd. locally tuffaceous; cobble, pebble lenses locally imbricated

cobble, pebble, congl.; planar crossbeds

pebbly sd.; horizontally bedded

cobble congl.; crudely bedded; clast supported; locally imbricated; includes lenticular sand body

sits., fnly. laminated

med. & cse. sd.; planar crossbeds

fn. & v. fn. sd. & sits.; massive; tuffaceous

med. & cse. sd.; planar crossbeds; local pebble lenses

sits.; grades up to fnly. laminated mud

pebbly sd.; low angle planar crossbeds; includes several congl. bed w/crude bedding; horiz. bedded pebbly sd. near top

pebble, cobble congl.; massive; clast supported

med. sd.; planar crossbeds

pebble, cobble congl.; massive; clast supported

pebbly sd.; horiz. bedded; gradational lower contact; grades up to well sorted fn. sd.

pebble, cobble congl.; clast supported; poorly sorted, low angle planar crossbeds

sits. & dark-colored mud

fn. sd.; massive; loc. v. fn. lam.; tuffaceous

med. & cse. sd.; planar crossbeds

med. sd.; massive; overlain by fnly. lam. sit.

med. sd.; massive; overlain by fnly. lam. sit.

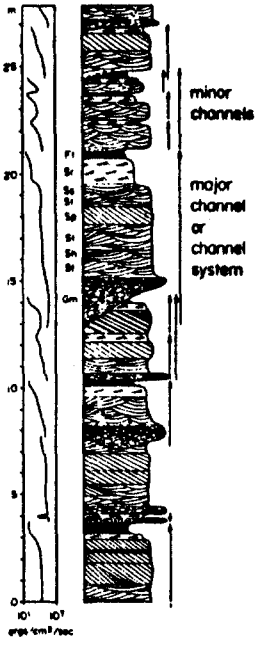
fn., med., & cse. sd. w/fnly. laminated mud lenses; planar crossbeds; local scour & fill; local climbing ripples; hydrothermal silicification present; degree of silicification varies laterally & vertical w/sed. texture locally destroyed

med. sd. w/dark-colored sit. & mud lenses; planar crossbeds

v. fn. sd., sit., & mudst.; massive, tuffaceous; fn. laminations locally in sandy portions; uppermost mudst. shows loading features

Walker section interpreted as a Donjek type braided-stream deposit. (Ref: Miall, Earth Sci. Rev., 13, 1977)

DONJEK TYPE



Facies Symbols	Interpretation
Gm	longitudinal bars, channel-lag deposits
Gp	linguoid bars or deltaic growths from older bar remnants
Sp	linguoid bars, sand waves (upper and lower flow regime)
Sr	ripples (lower flow regime)
Sh	planar bed flow (lower and upper flow regime)
Ss	minor channels or scour hollows
Fl	deposits of waning floods, overbank deposits
Fm	drape deposits formed in pools of standing water

East Side San Joaquin Valley Road Log

INTRODUCTION

This road log is provided to familiarize you in advance with the field trip route and will supplement the narratives of the field trip leaders on the buses. This road log may also at some future time serve as a guide to anyone who wishes to retrace our steps.

East side stratigraphy is summarized by Olson, Miller and Bartow in this Guidebook.

All cumulative production found in the field summaries are as of October 1, 1985. Production figures are from "The Annual Review of Oil and Gas Production" and "The California Production Record", Conservation Committee of California Oil Producers.

The numbers at the beginning of each commentary section are cumulative and incremental mileage figures (respectively).

Most of the stops on this field trip will be on private property. Please refrain from smoking while on private lands.

ACKNOWLEDGEMENTS

We would like to express our appreciation to those who have granted us access to their property, Mr. Mebane (Mebane Ranch) at Stop #1, Mr. George Nickel (Nickel Enterprises) at Stop #2, Mr. L. Hatchett (Steele Petroleum) at Stop #4, and Mr. Jack Park & Ms. Mildred Wiebe (Tejon Ranch) Stops #4 and #5.

0 0 Assembly Point

West parking lot at the Red Lion Inn, Junction 178 East (24th Street) and Highway 99. This trip will begin at 7:30 am and will return to the parking lot around 5 pm.

0.5 0.5 Kern River:

The Kern River was named for Edward M. Kern, topographer on the third Fremont Expedition. Due to water storage behind Lake Isabella Dam located 50 miles to the east and diversion of water into irrigation canals, the river at this point is often dry.

2.1 1.6 Union Avenue Exit:

Bear to the right on the Union Avenue off ramp and turn left (north) at the signal. You are now climbing upon a Plio-Pleistocene terrace of the Kern River. The deposits are non-marine sands, gravels and clays.

3.8 1.7 Junction of Union Avenue and Panorama Drive:

Bear to the right (east) and follow Panorama along the bluff.

The bluffs are formed by the Kern River Formation. To the north you can see the Kern River field, and in the distance to the northeast is the Round Mountain field.

KERN RIVER FIELD SUMMARY

In June of 1899 the Elwood brothers dug the first producing well with a hand auger. California Historical Landmark number 290 marks the location on the banks of the Kern River. The annual production reached an early peak of 17 MM bbls. per year of 10° to 16° gravity crude in 1904. Following the peak year the production declined as a result of falling prices and decreasing demand.

The introduction of enhanced recovery methods has had a dramatic effect on production rates and recoverable reserve estimates. In 1961 cyclic steam was initiated. In 1976 the first hot water flood began. The peak production was 49,200 MM bbls. in 1984. Peak gas production was 583 MMCF in 1930. Cumulative production for the Kern River field is 1,053 MM bbls. oil and 3,166 MMCF gas. A minor amount of this total is from a recently discovered Vedder sand reservoir.

The Kern River field is situated in a homocline where the main entrapment of hydrocarbons is by pinchouts and lenticularity of the reservoir sands.

ROUND MOUNTAIN FIELD SUMMARY

The Round Mountain field was discovered in 1927 with the Elbe Oil Land Development Company No. 2, Section 20, T.28S.-R.29E. The field produces primarily from the Vedder Formation but also from Freeman and Jewett sands in a

faulted homocline. Cumulative production in the Round Mountain field is 94.8 MM bbls oil and 5.5 MMCF gas.

6.2 2.4 Junction of Panorama Drive and Mt. Vernon Avenue (Alfred Harrell Highway):

Turn left (north) on Alfred Harrell Highway and proceed easterly as road curves to Hart Park.

As you drop down the bluff you can see the Kern River Formation on the roadcuts(Figure 1). The Kern River Formation is fluvial deposit discussed in much detail by Olson et al (this publication). Also refer to figure 13 and 14 in Olson et al for a geologic map and diagrammatic subsurface section of this part of the road log. The beds are dipping 4° to 5° westerly. In the roadcuts you can see cross-stratified trough bedding and thin beds of cross-laminated, fine-grained sand separated by mudstone.

As you drop down the bluff you are following the "China Grade" which was named for the Chinese encampment at the base of the bluffs during the late 1800's.

10.6 4.4 Entrance of Hart Memorial Park:

Continue east and keep to the right at each of the "Y's" in the road.

At this point you are traveling on a terrace of the Kern River. The bluffs to the south are Round Mountain Silt which is overlain by the Santa Margarita and Kern River/Chanac formations.

11.7 1.1 Leaving Hart Memorial Park:

Continue east on Alfred Harrell Highway.

You are still on the river terrace. The contacts between the formations on your right are difficult to see, except for an upper member of the Round Mountain Silt. This member is referred to as the "Sharktooth Bone Bed." Because of the abundance of fossils, the bone bed is a popular collecting locality. It can be followed for a great distance by tracing the digging sites.

A measured section from the Kern River Formation near the exit of Hart Park is identified as "6-29S/29E" in Olson et al (Appendix two (2), this publication).

To the northeast you can see Round Mountain and several tanks in the Round Mountain field.

13.1 1.4 Continue east on Alfred Harrell Highway:

To the left is the California Living Museum (CALM) which was opened in May, 1983. The museum presents exhibits of natural history both past and present. There are exhibits of reptiles, rodents, wild cats, foxes, coyote, water fowl, and birds of prey. They have one of the few bald eagle exhibits in California, as well as one of the largest aviaries. There is a petting zoo with domesticated farm animals, an educational auditorium, and fossil exhibits. With the opening of the DiGorgio House in the Spring of 1987, an exhibit of the "Minerals of Kern County and California" will be on display. The funding for CALM is through private donations, many of which are from petroleum companies.

14.1 1.0 Continue east on Alfred Harrell Highway:

To the left is the entrance to Ming Lake and the Kern River Golf Course. Across the lake are the outcrops of Olcese sand represented in the "Olcese Creek" measured section (identified as "28-28S-29E") discussed in Olson et al (this publication, Appendix 2).

Figure 1. Kern River Formation in the bluffs along Alfred Harrell Highway.

Figure 2. View of Pyramid Hill from turnaround point on Rancheria Road.

15.1 1.0 Continue east and south on Alfred Harrell Highway:

Outcrops of light colored sand along the crest of the hill to the right are the Santa Margarita Formation.

16.1 1.0 Junction Alfred Harrell Highway and Highway 178:

Turn left and follow Highway 178 to the east.

You are climbing onto a terrace of the Kern River. Note the river gravels in the road cut.

17.7 1.6 Continue east on 178:

Road cut on right is the Round Mountain Silt outcrop discussed in Olson et al (this publication) and illustrated in their figure 8.

17.9 .2 Junction Highway 178 and Rancheria Road:

Turn left (north) on Rancheria Road.

The road drops down through river deposits as it approaches the bridge crossing the Kern River.

20.5 2.6 Olcese in road cut:

Olcese sands are exposed along the road and they are overlain by Round Mountain Silt.

22.0 1.5 Turn buses around:

At this point, looking due north, at Pyramid Hill (Figure 2) exposures of Walker, Freeman and Jewett are seen. Refer to Olson et al (this publication) for a discussion of Pyramid Hill in the Jewett Sand section.

22.7 0.7 Junction Rancheria and PG&E Roads:

Turn left (east) on PG&E Road (through locked gate).

Near this point is the intersection of the Kern River Gorge and the Jewett faults. The Kern Gorge Fault follows along Rancheria Road to the north. You can trace the Jewett fault thought the saddle to the northwest. (see map in pocket). Round Mountain Silt and Olcese are exposed west of the Kern Gorge Fault.

23.6 0.9 "Y" in PG&E Road:

Keep to the left and proceed to the fence.

23.9 0.3 STOP #1: (At Fence)

From this vantage point you can see outcrops of many of the east side formations (Figure 3 & 4). As you look south across the Kern River and Hwy 178, the first valley and ridge west of the Kern River Canyon is Walker Formation. The westslope of the first ridge and second valley are Olcese, the second ridge to the west is Round Mountain Silt. To the far west you can observe the Kern River Formation in the road cut. Below is the modern Kern River and it's Holocene river deposits. To the southwest, the Olcese and Stop #2 are visible in the bluff this side of the river. Please refer to the map in the pocket of this guide book to orient yourself.

25.1 1.2 Return to Rancheria Road and turn left

28.2 3.1 Iron gate to Nickel property:

Turn left (east) through the locked gate. Follow the road to the left along the bluff.

29.5 1.3 STOP #2:

This cliff of Upper Olcese (Figure 5) is the silty facies identified as "Nickel Cliff" and as measured Section "6-29S-29E" in Olson et al (this publication).

30.8 1.3 Return to Rancheria Road and turn left (south).

31.8 1.0 Junction Rancheria Road and Highway 178:

Turn right (west).

33.7 1.9 Junction Highway 178 and Comanche Road:

Turn left (south).

You are traveling over Kern River gravels. Directly ahead is the Ant Hill Field.

LEGEND

Qac, Qt, Qya, Qoa_3, Qua_2	Alluvium (Pleist.-recent)
QTKr	Kern River Formation (U.Mio Pleist)
Tch	Chanac Formation (U.Mio)
Tba	Bena Gravel (Mio)
Trm	Round Mountain Silt (M&L Mio)
To	Olcese Sand (L.Mio)
Tfj	Freeman Jewett (L.Mio)
Tw	Walker Formation (EO-L.Mio)

Map adapted from Bartow, 1984

FIELD TRIP ROUTE

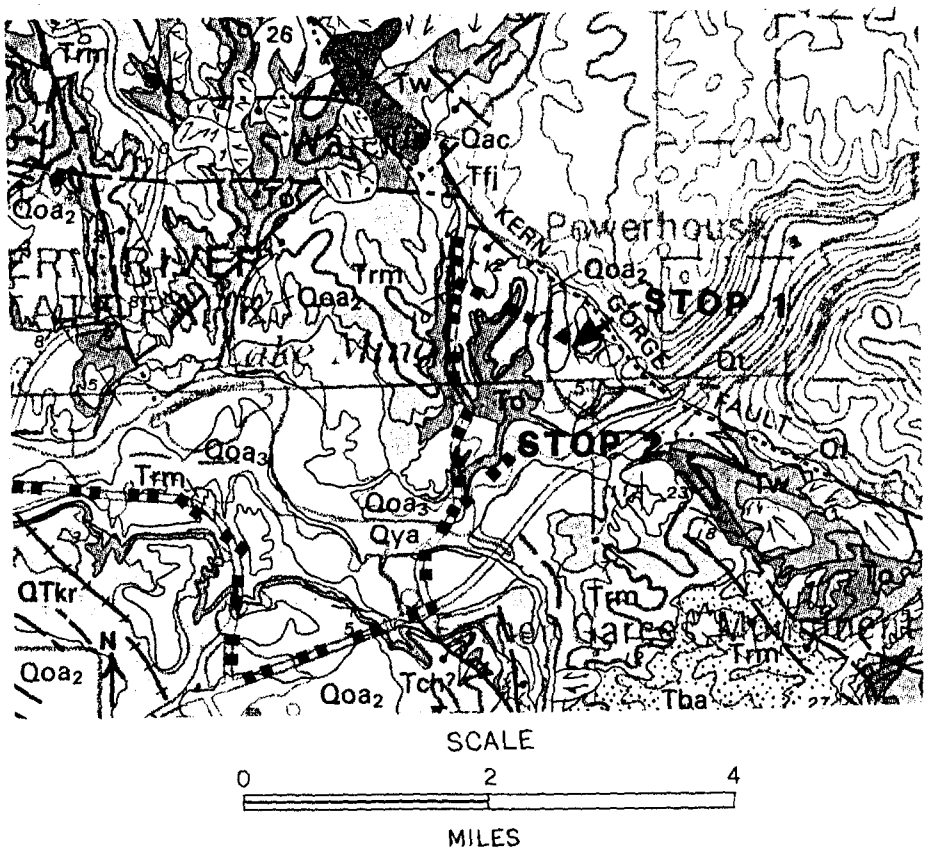


Figure 3. Geologic map of vicinity of Stops #1 and 2.

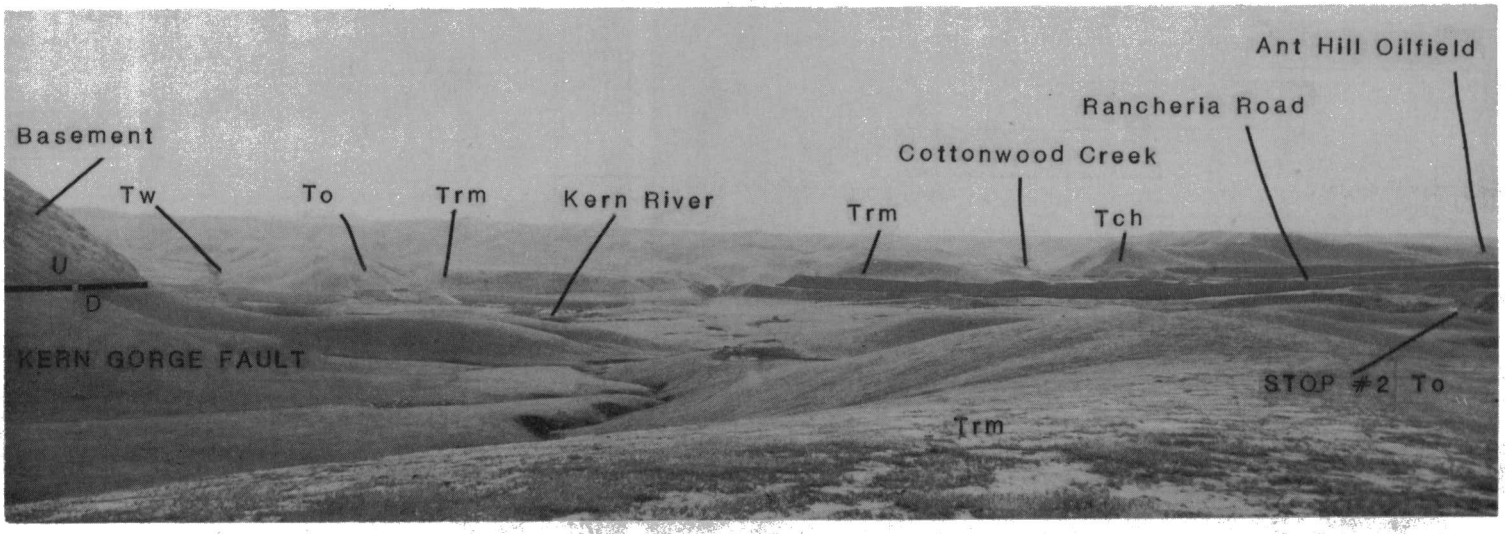


Figure 4. Panorama view from Stop #1.

ANT HILL FIELD SUMMARY

The Ant Hill Field was discovered in 1944 with the Amerada Petroleum Corp. "Southern Pacific" #36-15, Section 15, T.29S.-R.29E. The trap is a faulted anticline. The field produces from Olcese and Jewett sands.

The first well established production in the Olcese at a daily rate of 80 bbls. per day of 14° gravity oil with a 14% water cut. A second well drilled later in 1944 produced 182 bbls. per day of 40° gravity crude with a 1.7% water cut from the Jewett sand. Cumulative production from the field has been 7.2 MMbbls. oil and 232 MMCF gas.

35.7 2.0 Continue south on Comanche Road:

On your right (west) is Chevron's Section 27 Race Track Steam Generation Facility.

The Edison field covers an area of approximately 39 square miles and is divided into six main producing areas. You are passing through the Racetrack Hill area which is summarized below.

EDISON FIELD
RACETRACK HILL AREA SUMMARY

This field was discovered in 1944 with the British Petroleum and Capital Company "Portals" #53-3, Section 3, T.30S.-R.29E.

Oil accumulations are due to structural and stratigraphic entrapment. Oil is trapped in a highly faulted anticline within the lower Miocene sediments which drape over a basement high. Rapid stratigraphic variation is the trapping mechanism for middle and upper Miocene pools, particularly the Wicker and Nozu zones, and to a lesser extent the Jewett and Pyramid Hill zones. The structure at the top of the Santa Margarita is a moderately faulted, gentle southwest plunging nose. Trapping within the Santa Margarita is partially fault controlled.

Cumulative production for the Racetrack Hill area has been 20.8 MM bbls. oil and 37,900 MMCF gas. Total Edison Field cumulative recovery has been 129.2 MM bbls. oil and 69,600 MMCF gas.

38.6 2.9 Junction Comanche Road and Edison Hwy.:

Turn left (east)

43.1 4.5 Caliente Creek Terrace

You are passing through a cut in the upper portion of the Caliente Creek terrace (Figure 6). This terrace consists of fluvial sands and gravels laid down by Caliente Creek and its tributaries during Quaternary times. The deposit has been previously listed as a "Dune deposit" in CDMG County report 1 (1962, Table 24).

Three-quarters of a mile southwest of this point these Caliente Creek sands are quarried by the Edison Sand Company. With operations starting up in 1946, these quarries now average approximately 50,000 tons of sand a year.

44.7 1.6 Simplot Fertilizer Plant:

A large Quaternary landslide which was mapped by Dibblee and Chesterman (1953) is visible to the right (south) of the road

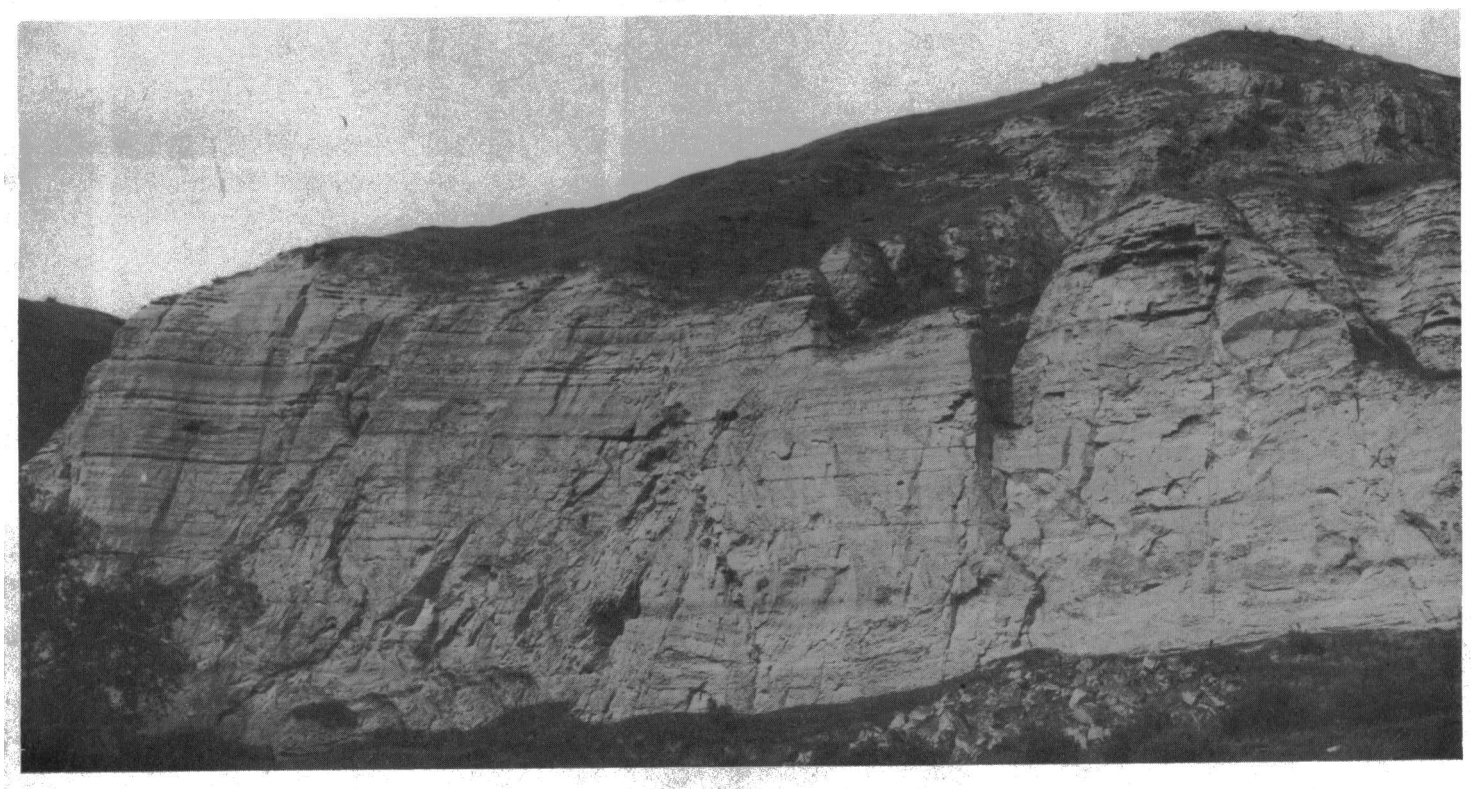


Figure 5. Olcese outcrop at Nickel Cliff, Stop #2.

of the road near the base of the hills (Figure 6). Much of the surface geology in the vicinity of this slide has been mapped as Bena gravels, with minor exposures of Walker and Bealville formations nearby.

45.5 0.8 CALIENTE CREEK OVERCROSSING

45.7 0.2 The angular unconformity of the Caliente Creek deposits unconformably on Bena Gravels is on your left.

45.9 0.2 STOP #3:

The Walker Fm is exposed in the roadcut on your right. These braided stream deposits are described in the measured stratigraphic section and annotated photograph by Stearns et al (this publication). Additional discussion of the Walker Formation is in Olson et al (this publication.

The westerly-dipping beds in the terrace cuts to the north across Caliente Creek are claystones, sandstones, and tuffaceous beds of the Walker formation.

To the west the Walker is seen to be concordantly overlain by the Ilmon basalt, which forms a recognizable dark-brown shoulder on the Caliente wash terrace (Figure 7). The Ilmon basalt has a very limited and discontinuous distribution in this area. This may be correlative with the Miocene andesities of Cache Creek Canyon northeast of Tehachapi or the basalt and dacite flows of the Tecuya formation at the south end of the San Joaquin Valley. Refer to Figure 8 for the geologic map of the vicinity of stop 3.

47.9 2.0 On the right (southwest) is the approximate contact between the Walker Formation and the Bealville fanglomerate. The linear exposure of coarse dioritic rubble on the hillslope is typical of the intertonguing contact between the Walker and Bealville. To the left (north) of the road and across Caliente Creek, terraces in Walker formation extend back to the break of slope in the dioritic basement.

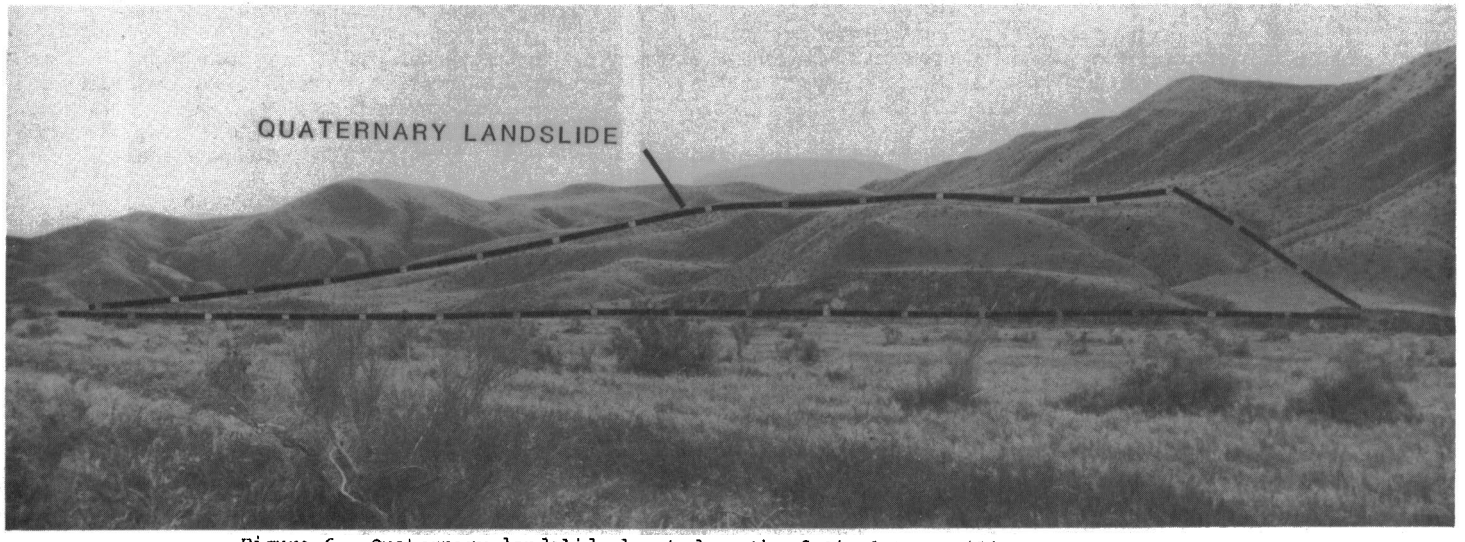
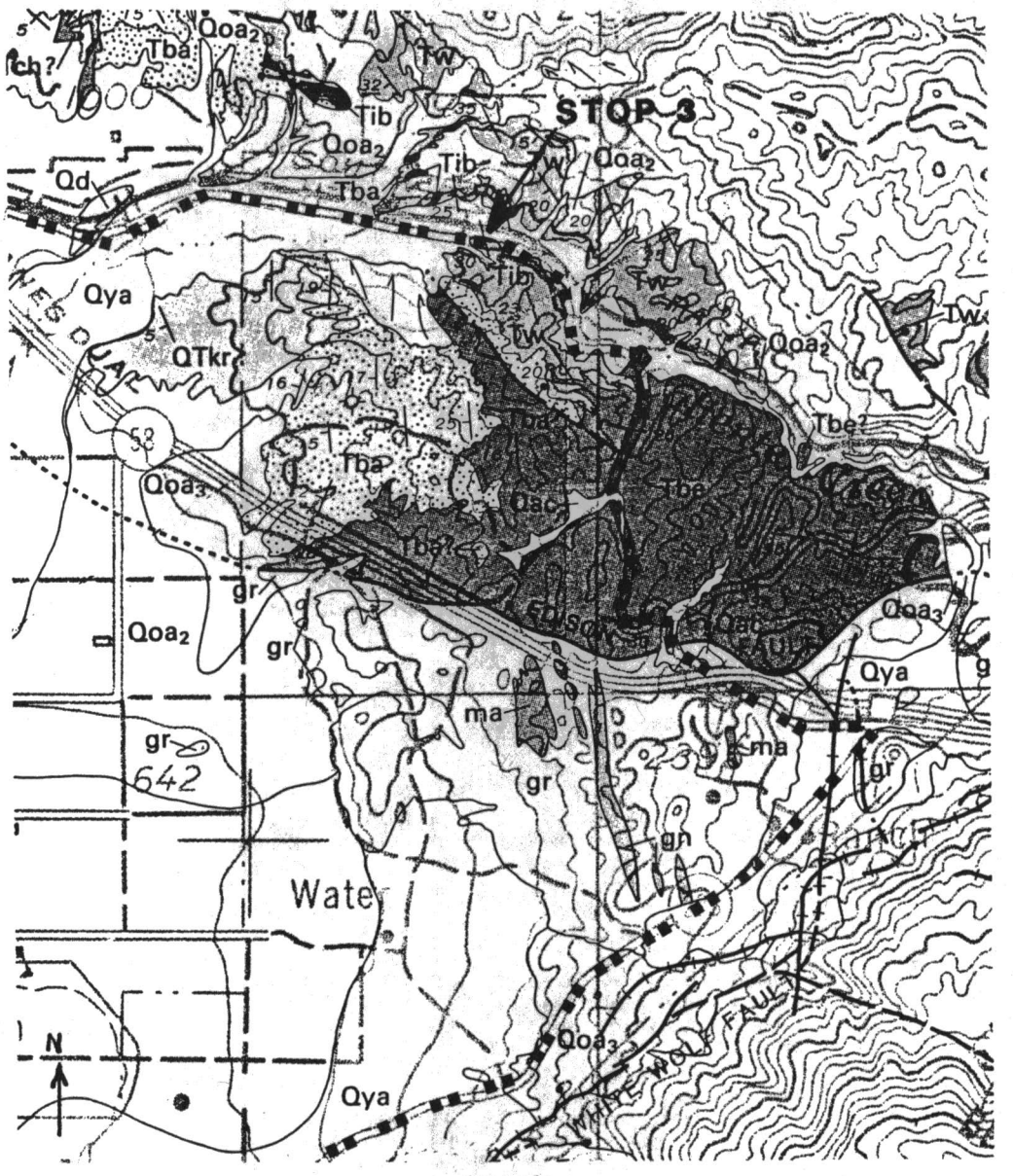


Figure 6. Quaternary landslide located south of Simplot Fertilizer plant along Bena road.

Figure 7. View looking northwest across Caliente Creek fromStop #4. Walker Formation crops out in bluffs dipping 20° westerly and is conformably overlain by Ilmon Basalt along the crest of the hill (arrow points to location). Unconformably overlying these Lower Miocene (?) rocks are the near horizontal quaternary Caliente Creek deposits seen to the west (left) of the Ilmon Basalt. Not visible from this vantage point, the Bena Gravel conformably overlies the Ilmon Basalt and is present between the unconformity and the Ilmon Basalt.



LEGEND

Qd, Qac, Qya, Qoa 3, Qoa 2	Alluvium
QTKr	Kern River Formation (U.Mio-Pleist)
Tch	Chanac Formation (U.Mio)
Tba	Bena Gravel (Mio)
Tib	Ilmon Basalt (L.Mio)
Tw	Walker Formation (EO.-L.Mio)
Tbe	Bealville Fanglomerate (Olig-L.Mio)
Gr, Ma, Gn	Pre-Upper Cretaceous Basement

Map Adapted from Bartow, 1984

■■ ■■ FIELD TRIP ROUTE

FIGURE 8

Figure 9. Surface expression of White Wolf Fault at the foot of Bear Mountain along Bear Mountain Boulevard.

In driving southward toward the head of Haypress Canyon, it will be seen that almost the full width of the exposed Bealville fanglomerate is now transversed and occasional olive to gray brown sandy clay beds offer a rare clue to its moderate (25%) southwesterly dip. After making the left turn in leaving the canyon the road passes through a deep cut which offers one of the best exposures of the content of this boulder-packed formation. A photograph of this outcrop is shown in Olson etal (this publication, Figure 8).

Here the road again turns south and we have a wide view of hills underlain by Bealville fanglomerate as it extends eastward and northward for several miles.

50.8 2.9 Passing the junction with Caliente Bodfish Road, we are facing Bear Mountain (elevation 6913') and the elevated roadway of Highway 58.

The Edison fault crosses the road we are following, approximatetly midway between the junction to Caliente and the point where our road passes southward beneath Highway 58. Eastward the fault is approximately located in the "V" where Hwy 58 cuts through the hills. This fault is well hidden, and is bounded on each side by little else than crystalline rocks.

The cut to the right (west) of the road here shown typical hornblende quartz diorite block south side of the Edison fault. Note the lenticular inclusion of an unassimilated metamorphic sliver. The high point on the ridge southeast of this loop of road is an amphibolite inclusion in the quartz diorite.

You are now traveling through the type section of the Bealville fanglomerate, which reaches a maximum thickness in the area of over 7000 feet. Lying unconformably on quartz diorite basement, the Bealville grades laterally to the west into its finer-grained Walker equivalent.

53.4 2.6 Junction of Bena Road and Bear Mountain Road:

Turn right on Bear Mountain Road southwest to Arvin.

At this point, you are in Holocene Alluvium. Looking directly south is Bear Mountain. Bear Mountain is composed of Mesozoic tonalite and diorite. At the base of the Bear Mountain trending southwest-northeast, is the White Wolf fault. Looking north across Hyw 58 is the Beaville Fanglomerate the surface trace of the Edison fault is located at the base of the hills in the valley north of Hwy 58. The trace of the fault to the west is located in the "V" where Hwy 58 cuts through the hills.

56.0 2.6 Continue Southwest

Bear Mountain Road is parallel to the White Wolf Fault which is located at the foot of the Tehachapi mountains on your left for the next several miles. The fault trace has been mapped all along the toes of the land slides located at the break in slope (Figure 9). As is evident in the Kern County epicenter density map, (Figure 10) this vicinity has historically been the most seismically active area in the county.

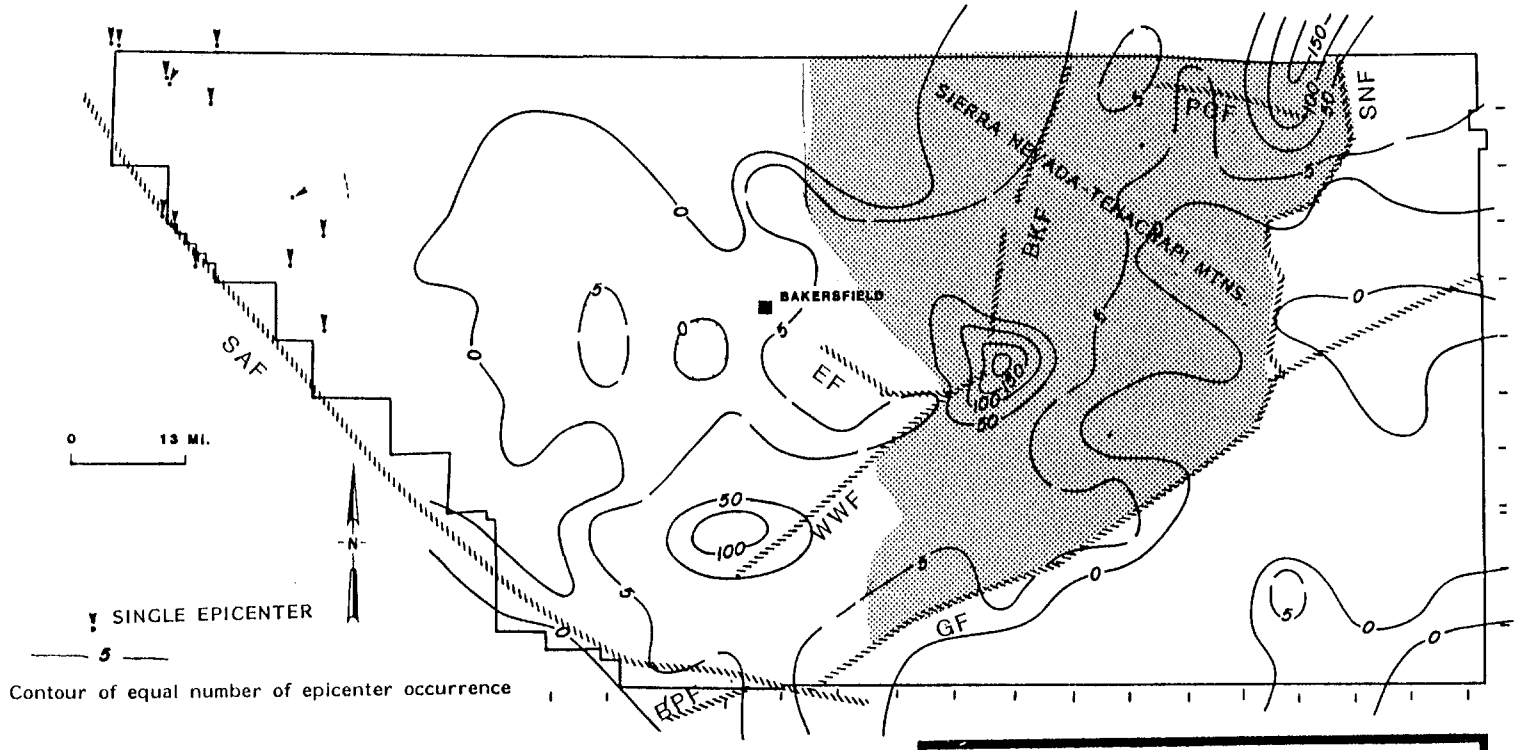
During the 1952 earthquake surface rupture was mapped along this stretch of the White Wolf fault. Remnants of fault scarpes and slumps may still be evident.

62.7 6.7 Entering Town of Arvin:

Oil wells to the right of the highway are part of the Arvin area of the Mountainview Field.

MOUNTAIN VIEW FIELD SUMMARY

The earliest discovery was made in 1933 when the Hogan Petroleum Company drilled "Wharton" #1 in Section 32, T.30S.-R.29E. Production was from the Santa Margarita sands above 6,000 feet. Additional producing zones were discovered in the mid to late 50's by various companies. Production in the Mountain View field is from metamorphic



ADAPTED FROM:
Kern County Seismic Hazard Atlas
Prepared by Kern County Planning Dept.
(updated by ECC 9/1/85)

SAF = San Andreas Fault
BPF = Big Pine Fault
GF = Garlock Fault
SNF = Sierra Nevada Fault
EF = Edison Fault
WWF = White Wolf Fault
BKF = Breckenridge - Kern Canyon Fault
PCF = Pinyon Canyon Fault

EVANS CAREY & CROZIER

EPICENTER DENSITY PER TOWNSHIP MAP 1932-1985

Kern County, California

FIGURE 10

rocks, Freeman-Jewett, Olcese, Round Mountain, Fruitvale, Santa Margarita, and Chanac formations.

The shallower traps in the field are formed by normal faulting on the southeast dipping homocline. Deeper traps are formed predominantly by basement onlap of the producing sands and local stratigraphic pinchouts.

Cumulative production through 1984 has been 85.1 MM bbls. oil and 87.6 MMCF gas.

ARVIN AREA SUMMARY-MOUNTAIN VIEW FIELD

The earliest production in the field was from the General Petroleum Corporation of California "Houchin #1, Section 27, T.31S, R.29E., just west of town. Production is from Freeman-Jewett, Olcese, Fruitvale, Santa Margarita and Chanac sands.

The structure is a faulted homocline, and traps are formed by stratigraphic variations and faulting. Cumulative production is 4.0 MBO and 14 MMCF gas.

63.2 0.5 Junction Bear Mountain Road and North Hill Street: Turn left (south).

Proceed to Di Giorgio County Park where lunch will be served. After lunch drive east on Sycamore Road.

63.7 0.5 Junction Sycamore Road and Tejon Road: Turn right (south).

You are passing through the east side of the southeast portion of the Mountain View Field.

67.1 3.4 Junction Tejon Road and Herring Road: Turn right (west).

(Note: If you turn left at this point, you can follow Comanche Point Road which climbs the west side of Bear Mountain. Following Comanche Road you climb the most northern section of Tejon Hills. The area is composed of Pliocene and Upper Miocene sediments. The rounded hills are composed mostly of Chanac sediments. Further up the grade are outcrops of Santa Margarita and Olcese).

68.4 1.3 Junction Herring Rd. and Rancho Rd.: Turn Left (south).

To the east you can see the terrace of the south bank of Tejon Creek. The hills behind are Upper Chanac, and the skyline ridge is granodiorite Basement.

COMANCHE POINT OIL FIELD

The field was discovered in October, 1947, by the Horace Steele and L. C. Gould "Gould" #2. The well was completed in the Santa Margarita sands for an initial production of 25 bbls/day 13° to 14° gravity oil. Peak production for the field was in 1951 with 10,687 bbls.

Structurally, the Comanche Point field is a faulted anticlinal nose with closure to the north and east bound by normal faults. The field is underlain with a granitic basement high. The basement complex is overlain unconformably by Middle Miocene Sands, including the Pulv Zone, and Valv Zone.
The middle Miocene is overlain by Santa Margarita and Chanac.

Cumulative production has been 231.7 MBO.

75.9 7.5 Junction Rancho and Sebastian Roads: Turn left (east).

You are approaching the Tejon Hills field.

TEJON HILLS FIELD SUMMARY

The discovery well, "Sunset-Tejon" #2, was drilled in August, 1948, by the Tejon Hills Company. Initial production from the well was 62 bbls. per day of 29° gravity oil. Cumulative production in the field from Vedder, Round Mountain, and Santa Margarita sands is 13.1 MM bbls. oil and 2.6 MMCF gas.

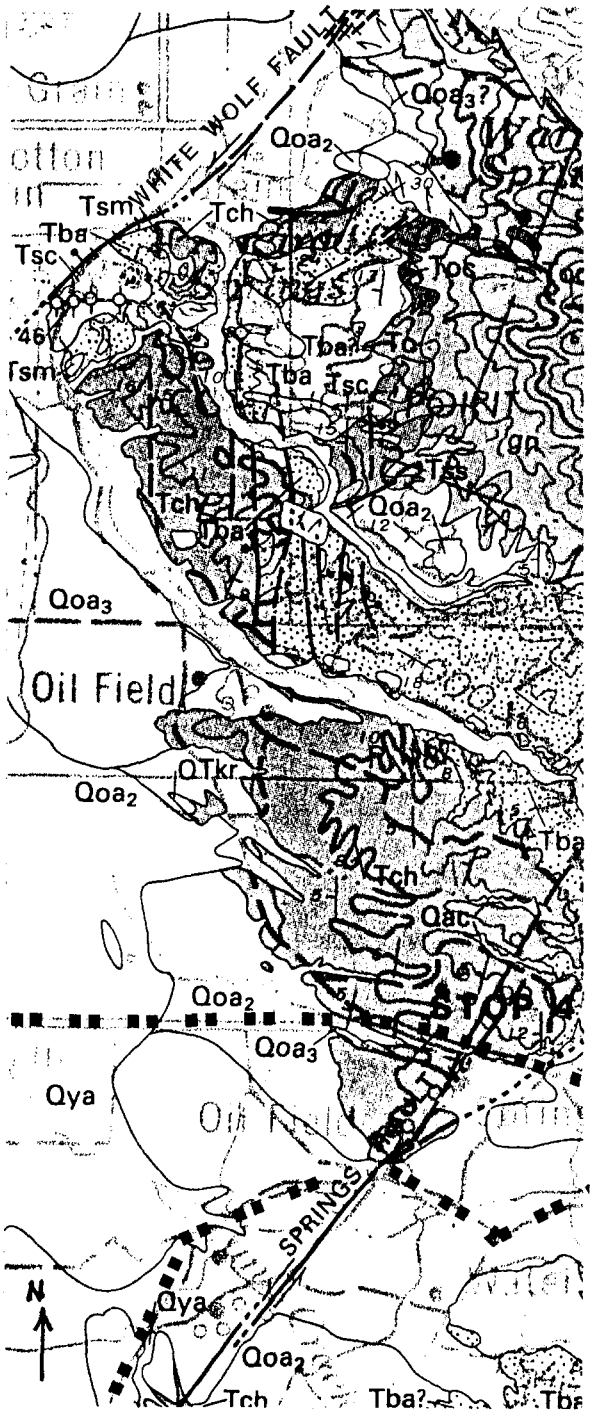
The reservoirs are found in blocks formed by normal and strike slop faulting associated with two distinct tectonic events in the Tejon Embayment. The Springs Fault is the easternmost trapping fault, and it forms the surface scarp which we will ascend for STOP #4. For a more complete description of this fault and its significance see the paper by Brian Hirst in this guide book.

78.4 2.5 Turn off to enter through the Tejon Ranch gate (locked): Turn right and enter through the gate. Proceed to the southeast along the gravel road.

79.7 1.3 Turn left at the road to the lease house: Turn left (northeast) and proceed past the lease house. Follow the road to the base of the nearest hill. We will leave the buses at the base of the hill and walk to the top to stretch our legs and enjoy STOP #4.

80.1 0.4 STOP #4

Looking north and then scanning in a clockwise direct you can follow the Tejon Hills from Comanche Point to the south terrace of Tejon Creek. The surface of these hills is the Chanac Formation. Directly across Sebastian road is the northern end of the Tejon Hills field. As you look east you can see the canyon formed by Tejon Creek, Mount Cummings, and the Chanac Creek canyon. To the southeast you see the alluvial fan systems of El Paso Creek and



SCALE

0 2 4

MILES

Qoa3, Qoa2, Qya2, Qac	Alluvium (Pleist-recent)
QTKr	Kern River Formation (U.Mio-Pleist)
Tch	Chanac Formation (U.Mio)
Tsm	Santa Margarita Formation (U.Mio)
Tsc, Tss	Unnamed miocene sds
Tba	Bena Ground (.Mio)
To	Olcese Sand (L.Mio)
gn	Basement (Pre-Upper Cretac.)

Map adapted from Bartow, 1984

■■ ■■ FIELD TRIP ROUTE

FIGURE 11

alluvial fan systems of El Paso Creek and Tejon Creek. The suture connecting the two fans is traced by the boulder field.

To the south and southwest, the Springs Fault is marked by the pumping units and the linear scarp. To the south also is the Tunis Creek Canyon and its alluvial fan. Directly above the fan in the basement is a popular mineral collecting locality which is famous for its garnets. Southwest of Tunis Creek Canyon is Pastoria Creek.

Looking west (if it's a clear day) you can see the San Emigdio Mountains. The northernmost promentory is Wheeler Ridge which was formed by a combination of thrusting along the Wheeler Ridge Thrust and movement along the White Wolf Fault. The White Wolf passes along the northern base of the ridge beneath the alluvial fan. Some researchers also believe that a splay of the White Wolf may also pass south of Wheeler Ridge.

Following Stop #4. Return to the Tejon Ranch gravel road and turn left (east). Proceed about 1.3 miles to a junction with another gravel road and turn right (south) across Chanac Creek. Proceed about 0.5 miles and turn right (west) on the orchard road which is the extension of Laval Road. After you have traveled about 1.3 miles you will re-enter the Tejon Hills field. Here the road descends down the scarp of the Springs Fault. Proceed along the road, through the locked Tejon Ranch gate, and onto Laval Road heading west.

103.6 6.3 Laval Road: Proceed west on Laval Road.

As you follow Laval Road you cross the center of the Eastern, Central, and West Areas of the Tejon Field.

TEJON FIELD SUMMARY

The first wells in the area known as the "Grapevine Field" were drilled in 1935. The field was abandoned in 1943 but was revived in late 1943 with production in shallow Chanac and Santa Margarita Transition sands. The field is divided into four separate areas: Southeastern, Eastern, Central, and Western.

The Southeastern area was discovered in 1935 with the Reserve Oil Company "Tejon Ranch" #1. The well IP'd at 55 bbls. of 16° gravity oil per day. The "Reserve" sand member of the Fruitvale Shale Formation is the producing horizon in the Southeastern area. Traps are formed by stratigraphic pinchouts in a faulted gently dipping homocline.

The discovery well of the Eastern area was Arco "Tejon A" #57-35 which was drilled in November of 1943. It produced 120 bbls. per day of 18° from the "Transition" zone (Santa Margarita) when it was first put on production. Northwest-southeast normal faults in a northwest dipping homocline form these reservoirs.

The Central area was discovered in 1944. The Reserve Oil Company "Pauley" #3-33 recovered 17° gravity oil from the "Transition" zone. Other zones in the Central area are the Santa Margarita, "Reserve", "Valv" (Round Mountain), Olcese, and "JV" (Freeman-Jewett). Traps in this area are formed by stratigraphic variations along an anticlinal nose and by faulting. The largest discrete accumulations are found in the Olcese and JV pools.

The Western area was proved in 1945 with the "Tejon Ranch" #41-5. Initial production was 144 bbls. per day of 16° gravity oil from the "Transition" zone of the Santa Margarita formation. This "Transition" zone is trapped by a large, nearly circular domal structure and accounts for most of the reserves in the western area. Other productive zones are the "Reserve" and "Valv" sands. As in the Central area these are trapped by stratigraphic pinchouts along an anticlinal nose and by faulting.

Cumulative production for the four areas is 30.7 MM bbls. oil and 59.2 MMCF gas.

92.7 6.3 Junction Laval Road and Highway 99 (which will merge into I-5):

Drive south.

Grapevine Offramp

Take the offramp and follow the road east to the Edmonston overlook (STOP #5).

You are crossing the Pastoria Creek alluvial fan. To your right (east) are hills of Bena Gravel underlain by Tecuya Formation and Oligocene basalts.

101.6 8.9 STOP #5: Turn right (south) through the gate and proceed up the hill to the overlook.

If the weather is clear you can see the entire Tejon Embayment from this vantage point. To the east is Comanche Point and the Tejon Hills. To the west are the an Emigdio Mountains and Wheeler Ridge. The northern boundary of this province is the White Wolf fault and the southern terminous is the Tehachapi Mountains. Within the Tejon Embayment are seven fields which have together produced over 120 million barrels of oil and 1.4 billion cubic feet of gas. Yet, the area still enjoys active exploration. Much of the potential lies below the thick layer of volcanic material which crops out beneath our feet.

110.5 8.9 Return to Highway 99: Proceed north on Highway 99 to Bakersfield.

140.5 30.0 Junction of 99 and 24th Street Offramp:

Take this offramp and go west (left) under the freeway to the Red Lion Inn. End of trip.

DIBBLEE, T. W., JR., and CHESTERMAN, C. W., 1953, Geology of the Breckenridge Mountain quadrangle, California: California Div. Mines Bull. 168, 56p. 3 pls.