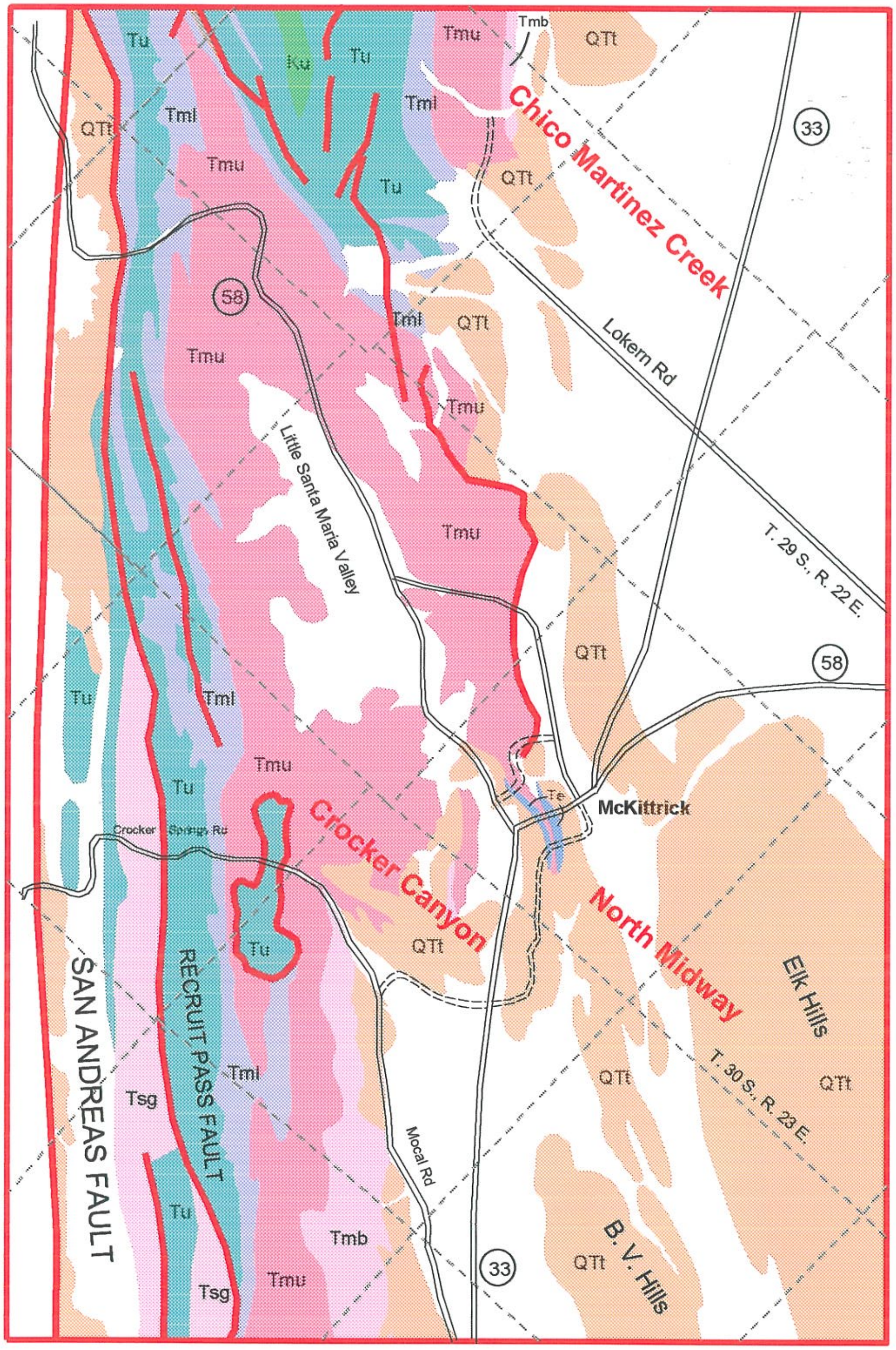
Classic Outcrops on the West Side of the San Joaquin Valley



San Joaquin Geological Society
Spring Field Trip, 1998

Field Trip to

Classic Outcrops on the West Side of the San Joaquin Valley

Volume I

San Joaquin Geological Society
Spring Field Trip, 1998

FIELD TRIP LEADERS

Tony Reid .... Occidental of Elk Hills
Mike Ponek .... Texaco North America
Frank Charron .... Texaco North America
Neil Livingston .... Nuevo Energy
Jack Carter .... Exxon USA

EDITORS

Michael S. Clark .... ARCO Western Energy
S. A. Reid .... Occidental of Elk Hills

OFFICERS OF THE SAN JOAQUIN GEOLOGICAL SOCIETY (1997-1998)

Field Trip Itinerary

We have a long day ahead of us. If we can leave the outcrops on schedule, it will help us to see everything we have planned. Thanks for your cooperation.

8:00 Meet at Well Sample Repository

8:15 Leave for Crocker Canyon (allow 60 minutes driving time)

9:15 Arrive at Crocker Canyon

- Spend **45 minutes** on the outcrop (stop 1)

10:00 Start return hike to cars

10:15 Leave for North Midway (allow 15 minutes driving time)

10:30 Arrive at North Midway

- Spend **1-1/2 hours** at stops 2 and 3

12:00 Leave for the Diatomite Mine at McKittrick (allow 15 minutes driving time)

- RESTROOM STOP AT McKITTRICK

12:15 Arrive at Diatomite Mine

- Spend **30 minutes** at the overlook (stop 4)

12:45 Leave Highway 58 oil seep (allow 15 minutes driving time)

1:00 Arrive at Highway 58 oil seep

- Spend **30 minutes** at the seep (stop 5)
- LUNCH STOP

1:30 Leave for Chico-Martinez Creek (allow 30 minutes driving time)

2:00 Arrive at Chico Martinez Creek

- Spend **3-1/2 hours** walking the section (stops 6, 7 and 8)

5:30 Leave for Well Sample Repository (allow 60 minutes driving time)

6:30 Arrive at Well Sample Repository for barbecue and core display

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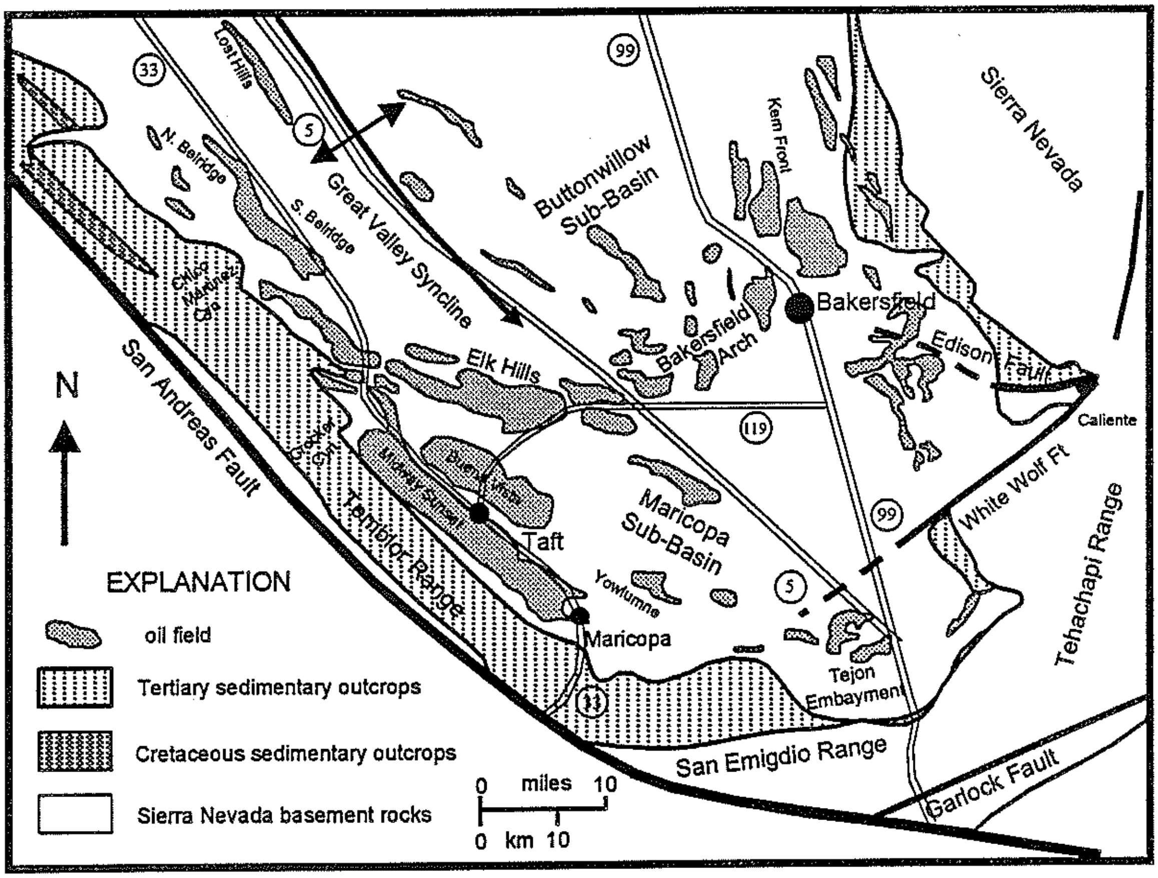

Lost Hills
N. Belridge
S. Belridge
Great Valley Syncline
Buttonwillow
Sub-Basin
Kern Front
Sierra Nevada
Bakersfield
Bakersfield
Arch
Edison Fault
Caliente
Elk Hills
Chico
Martinez
Ck
San Andreas Fault
Temblor Range
Midway Sunset
Buena Vista
Taft
Maricopa
Sub-Basin
Yowlumne
Maricopa
Tejon
Embayment
White Wolf Ft
Tehachapi Range
San Emigdio Range
Garlock Fault
N
EXPLANATION
oil field
Tertiary sedimentary outcrops
Cretaceous sedimentary outcrops
Sierra Nevada basement rocks
0 miles 10
0 km 10

INTRODUCTION

Miocene Depositional Systems of the Southern San Joaquin Basin

S. A. Reid

(Article excerpted by Permission of Pacific Section — SEPM)

Introduction

The Miocene and Pliocene stratigraphic section at Elk Hills contains a continuous record of deposition at the center of the southern San Joaquin basin. Although the section consists of mostly claystone and mudstone, five distinct sandy intervals are present which form the petroleum reservoirs of the Elk Hills field (Figure 1).

Major factors which influenced sand sedimentation in the basin center are local and regional uplift, San Andreas fault offset chronology, location of fluvial sediment discharge points, degree of tidal range, and eustatic sea level changes. Significant Miocene tectonic events included termination of subduction and establishment of the San Andreas strike-slip system and clockwise rotation of the Tehachapi and San Emigdio Ranges. Pliocene Basin and Range uplift in addition to compression on the San Andreas fault caused uplift of all ranges surrounding the southern basin.

Tectonic events in and around the basin had the most impact on development of depositional systems. Tectonics controlled the shape of the basin, the location of seaways and basin circulation patterns. The degree of restriction influenced the generation and preservation of diatoms and their associated organic material. Tectonics controlled the timing of uplift, and the location of provenance areas such as the Gabilan highland and highlands adjacent to the La Honda basin. The shape of western Stevens sand units (late Miocene) was controlled by San Andreas fault compression which created intraslope basins.

Effects of eustatic sea-level changes on the southern San Joaquin basin are more difficult to assess. One significant event most likely related to an eustatic sea-level change was the 10.5 Ma lowstand, which resulted in deposition of the Kern River-fed eastern Stevens submarine fan on the Bakersfield arch. Middle Miocene Olcese sequences, early Pliocene episodes of Etchegoin delta front progradation, and late Pliocene *Mya* sand depositional cycles are other examples of probable sea-level-controlled deposition.

Carneros Sandstone Paleogeography (19 Ma)

Uplift and erosion of northern portions of the Temblor Range and highlands bordering the adjacent La Honda basin continued through the early Miocene (Graham and others, 1989)and initiated deposition of the Carneros submarine fan (Figure 2). A thin Carneros section deposited on an unconformity indicates localized uplift in the northern Temblor Range (Pence, 1985). This uplift event caused a local, relative drop in sea level which forced sediment to bypass the shelf and to be deposited basinward. A major submarine fan sourced from the northern Temblor Range and north of the La Honda basin prograded east and southeast onto the central San Joaquin basin floor. Although a significant global sea level change is interpreted at 21 Ma (Haq and others, 1987), and initial Carneros sedimentation may have coincided with this lowstand, Carneros sedimentation continued through 19 Ma, well into an inferred global sea level highstand. Shelf sedimentation continued in westside areas less affected by the uplift (Pence, 1985). Coarse grained, shallow marine sedimentation also continued on the east side of the basin on a broad shelf adjacent to the low, eroding western slope of the Sierra Nevada. Although sea-level lowstands (including the 21 Ma lowstand) may have resulted in sequence boundaries (Bloch and Olson, 1990), sediments continued to stay on the shelf.

Gould Shale and Button Bed Paleogeography (16.5 Ma)

The paleogeography at 16.5 Ma is representative of much of the medial and early late Miocene, a time when the basin experienced the mildest tectonic activity of the Miocene-Pliocene interval (Figure 3). Movement of the San Andreas fault progressed with little associated uplift, resulting in few highlands to restrict marine circulation between the basin and the Pacific (Bartow, 1991). In the southern basin, rotation of the Tehachapi and San Emigdio Ranges was nearly complete (Goodman and Malin, 1992).

On the stable Sierra Nevada shelf, the effects of eustatic sea level changes should be the most apparent. Bloch and Olson (1990) correlate unconformities within the Olcese to sea level lowstands, and correlate the transgression of each Olcese sequence to relative rises in sea level. Bartow (1991) also documents the effects of sea level changes, and interprets widespread eastside shoaling at 16.5 Ma coincident with a major lowstand. No deep sea fan system development is associated with the 16.5 Ma lowstand, indicating all sandy sediments were contained on the broad shelf. In addition, the development of a very thick interval of shale throughout much of the basin center indicates coarse sediments seldom passed beyond the shelf edge, even at times of low relative sea level. In the Tejon area, localized deposition in nonmarine, shallow marine and turbidite facies indicates the continuing effects of an uplifted, nearby source area.

Monterey Formation and Stevens sandstone Paleogeography (10 Ma)

Discussion: Three contemporaneous events in the late Miocene at 10 Ma radically altered the paleogeography of the basin: (1) partial blockage of the basin along the west side by granitic blocks moved by the San Andreas fault, (2) formation of a drainage system and Sierran discharge point similar to the modern Kern River, and (3) a major sea level lowstand (Figure 4). These events resulted in formation of major petroleum reservoir rocks and the principle petroleum source rocks of the San Joaquin basin.

After removing about 250 km (155 mi) of post-medial Miocene San Andreas fault offset, granitic highlands of the Gabilan Range in the late Miocene lay west of the southern San Joaquin basin (Graham and others, 1989). Numerous streams drained east across the fault escarpment, forming an apron of fan deltas and a narrow northwest-trending band of shelf sediments (Santa Margarita Formation) in the area of the southern Temblor Range (Ryder and Thomson, 1989). Sand spilled across this narrow shelf onto the slope, creating small depositional lobes and channel-fill turbidite systems of the Williams, Republic, and Webster sand units of the western Stevens (Link and Hall, 1990). The Gabilan highland restricted ocean access of the basin on the western side, although seaways to the Pacific existed to the north and south (Bartow, 1991). Throughout the central and western areas, the basin geometry favored diatom blooms and preservation of their organic-rich tests in Antelope Shale (Graham and Williams, 1985).

Redirection of the Kern River through stream capture, as outlined by MacPherson (1978), resulted in a major shift in the terminus of southern Sierra Nevada drainage in the late Miocene. Sierra-derived detritus transported along the new drainage exited the Sierra Nevada highlands northeast of Bakersfield. As a result of this drainage shift, much higher volumes of sand entered the basin, resulting in extensive shelf deposits (Santa Margarita) and a large river floodplain (Chanac).

Eastern Stevens submarine fan deposition and the creation of the Rosedale and Fruitvale canyons are interpreted to have been the result of sea-level changes (MacPherson, 1978; Hewett and Jordan, 1993). Three upper Mohnian sea-level lowstands are interpreted as marking the beginning of the Coulter, Gosford, and Bellevue fan sequences (Hewett and Jordan, 1993). A precise tie of sea-level lowstands to eustatic sea-level changes, uplift of shelf areas, or other factors is difficult because of the poor age control in the subsurface. However, the most significant eustatic sea-level lowstand of the Miocene occurred at 10.5 to 10.0 Ma (Haq and others, 1987) and was contemporaneous with Stevens deposition in the eastern part of the basin.

Monterey Formation and western Stevens sandstone Paleogeography (8.5 Ma)

Discussion: Continued northward progression of the Gabilan granitic source area by the San Andreas fault moved the site of Santa Margarita sand deposition on the western side of the basin to the central Temblor Range (Ryder and Thomson, 1989)(Figure 5). Seaways continued to connect the San Joaquin basin to the Pacific Ocean north and south of the Gabilan highland (Bartow, 1991). Changes in plate motion (summarized by Bartow, 1991) or activation of eastern-directed thrust wedges of Franciscan rocks (Imperato, 1993) may have triggered a brief but important west side tectonic event, which resulted in a broad slope as far east as Elk Hills punctuated by several small anticlines and synclines. Western Stevens turbidites, originating from the Gabilan highland west of the North Midway-McKittrick area, prograded across the synclinal basins and around anticlinal ridges and onto the Buttonwillow basin floor southeast of Lost Hills.

By 8.5 Ma, sea level was once again at a global highstand (Haq and others, 1987; Bartow, 1991). Although the Kern River continued to supply abundant sediments, indicated by widespread Chanac and Santa Margarita subsurface deposits, no Sierra Nevada-derived sediments spilled across the shelf break to form submarine fans. However, San Emigdio highlands to the south continued to contribute clastics across a narrow shelf to feed smaller submarine fan systems in the Maricopa subbasin (Quinn, 1990). North of the Bakersfield arch, conditions continued to favor diatom generation and preservation (Graham and Williams, 1985).

Reef Ridge Shale Paleogeography (7 Ma)

Discussion: The end of the Miocene along the western San Joaquin basin was relatively stable (Figure 6). Reef Ridge deposits tend to fill the intraslope basins and cover the anticlinal structures of the west side. Although the Gabilan block continued moving northwest opposite the southern basin, the block no longer contributed a sufficient volume of sediments into the basin to reach the base of the western slope. Seaways north and south of the Gabilan block continued to connect the San Joaquin basin to the open ocean (Bartow, 1991). The end of the Miocene also brought further reductions in diatom sedimentation. A shallowing of the basin, shifting ocean circulation patterns, and/or temperature changes may be responsible for reduced diatom production. Sediments derived from the Sierra Nevada continued to be restricted to the eastern shelf areas. Increases in clay sedimentation across the central and southern basin may indicate (1) more clay available from the Kern and other drainage systems, (2) clay sedimentation no longer diluted by diatom contribution, and/or (3) development of tidal currents with reworking of nearshore deposits and shifting clay deposition to deeper areas of the basin. Whatever the cause, a thick clay layer covered nearly all western and eastern Stevens turbidites in the San Joaquin basin.

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This article by Tony Reid is excerpted from pages 131-150 of the following publication by the Pacific Section—SEPM (Society for Sedimentary Geology)

Fritsche, A. E., 1995, Cenozoic Paleogeography of the Western United States - II: Pacific Section—SEPM, Book 75, 309 p.

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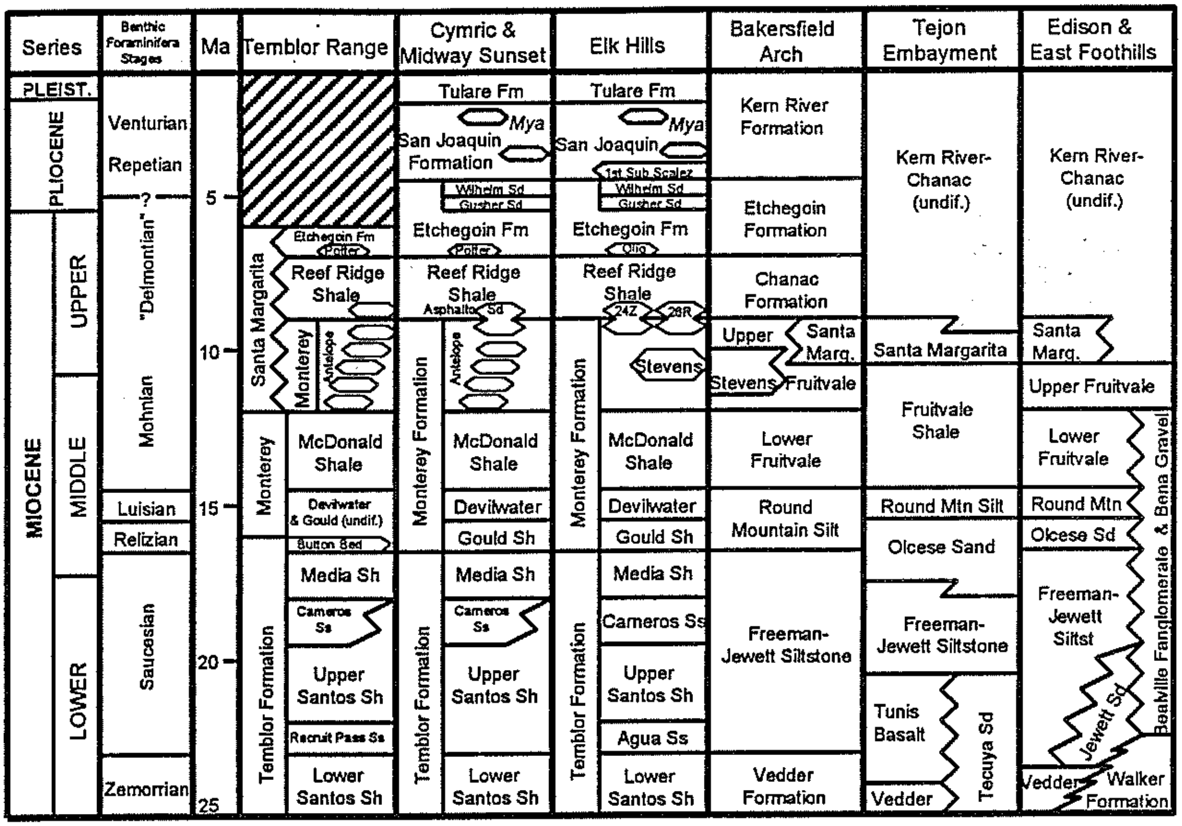

Figure 1. Correlation chart of Miocene and Pliocene stratigraphic units of the southern San Joaquin basin. Correlations are generally based on COSUNA (1984), with the following modifications: in the Temblor Range, Santa Margarita-Monterey relationship is from Ryder and Thomson (1989); at Elk Hills, ages of Miocene turbidites are from Reid (1990); Miocene Tejon correlations are from Hirst (1988); Edison area age distribution of the Bealville Fanglomerate and Bena Gravel is from Dibblee and Warne (1988).

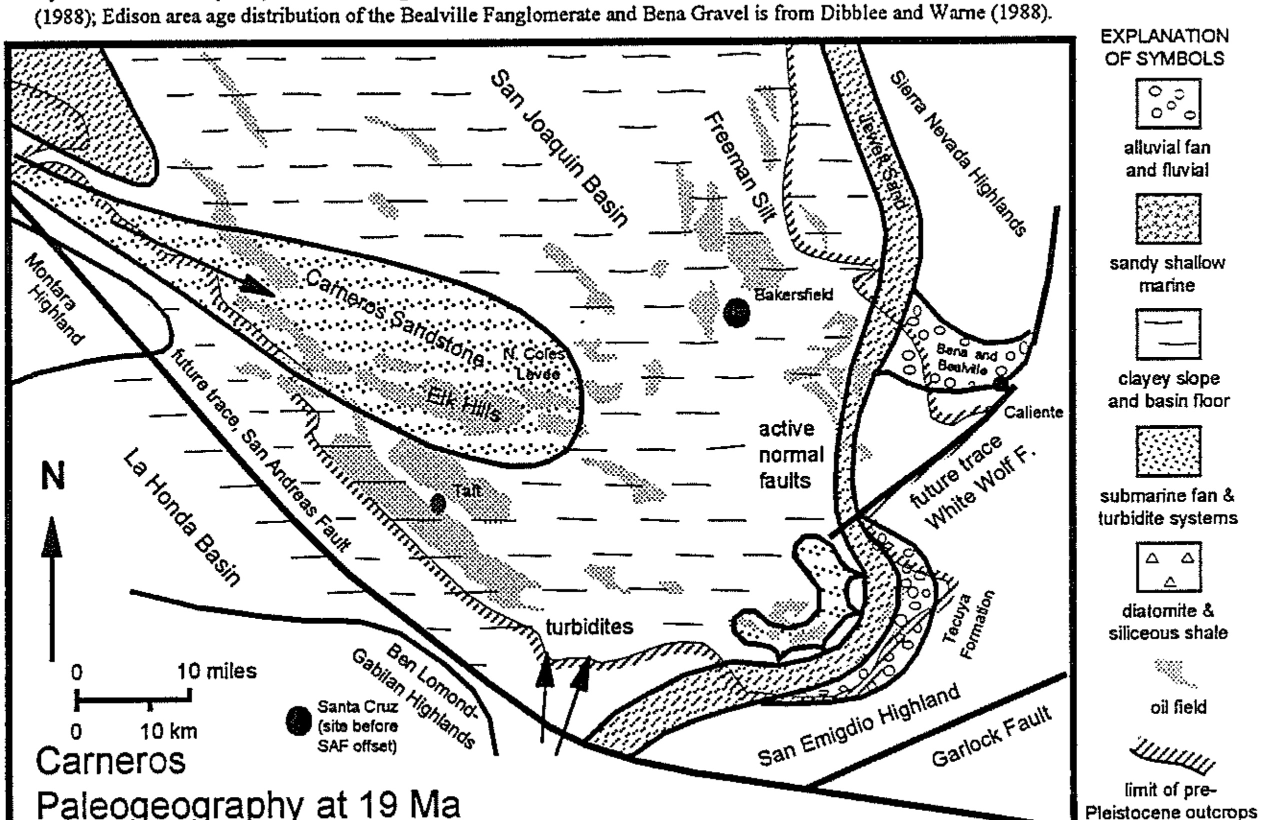

Figure 2. Paleogeography of the San Joaquin basin at 19 Ma, early Miocene, showing the depositional environments represented by the Carneros Sandstone and correlative units. Restoration of 315 to 320 km of San Andreas fault offset, La Honda basin paleogeography and western Carneros fan location are from Graham and others (1989). Northern Temblor shelf is based on Pence (1985). Nonmarine deposits of the Caliente area are from Dibblee and Warne (1988). Tejon embayment paleogeography is from Hirst (1988). The eastern limit of the Carneros is based on subsurface data from Elk Hills and North Coles Levee fields (Dunwoody, 1986).

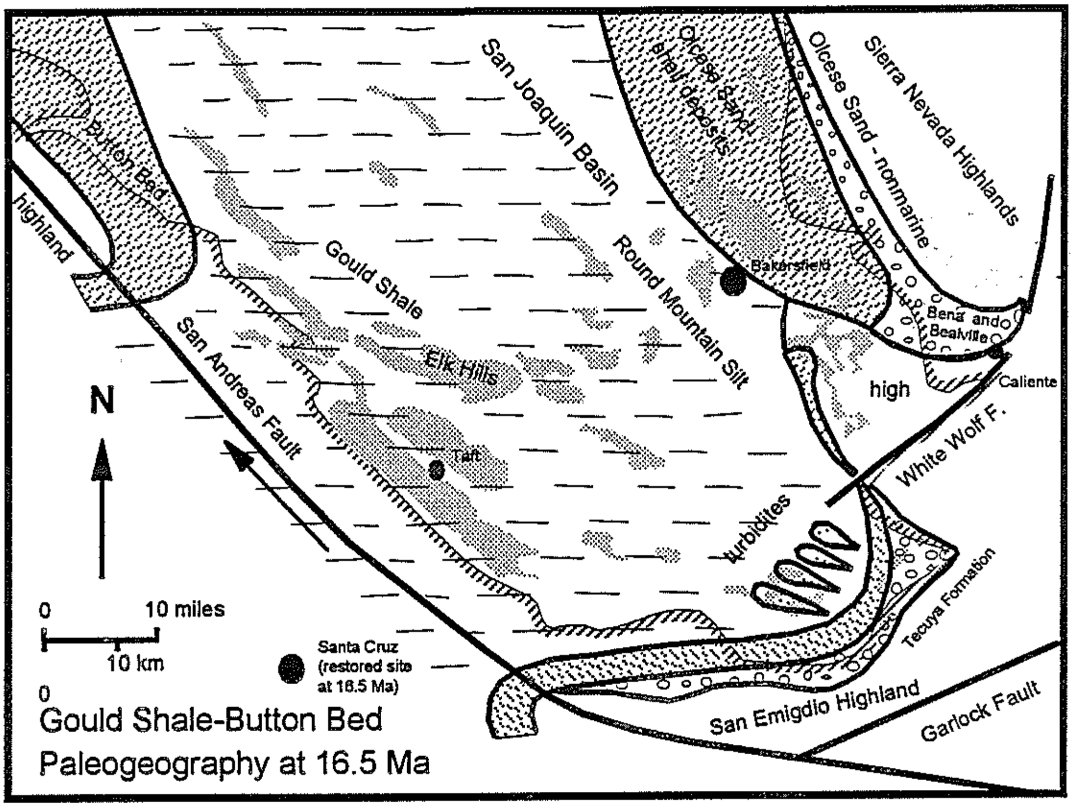

Figure 3. Paleogeography of the San Joaquin basin at 16.5 Ma, medial Miocene, showing the depositional environments represented by the Gould Shale and correlative units. See Figure 2 for explanation of symbols. Northern Temblor Button bed paleogeography is based on Carter (1985). Nonmarine deposits of the Caliente area are from Dibblee and Warne (1988). Tejon embayment paleogeography is from Hirst (1988).

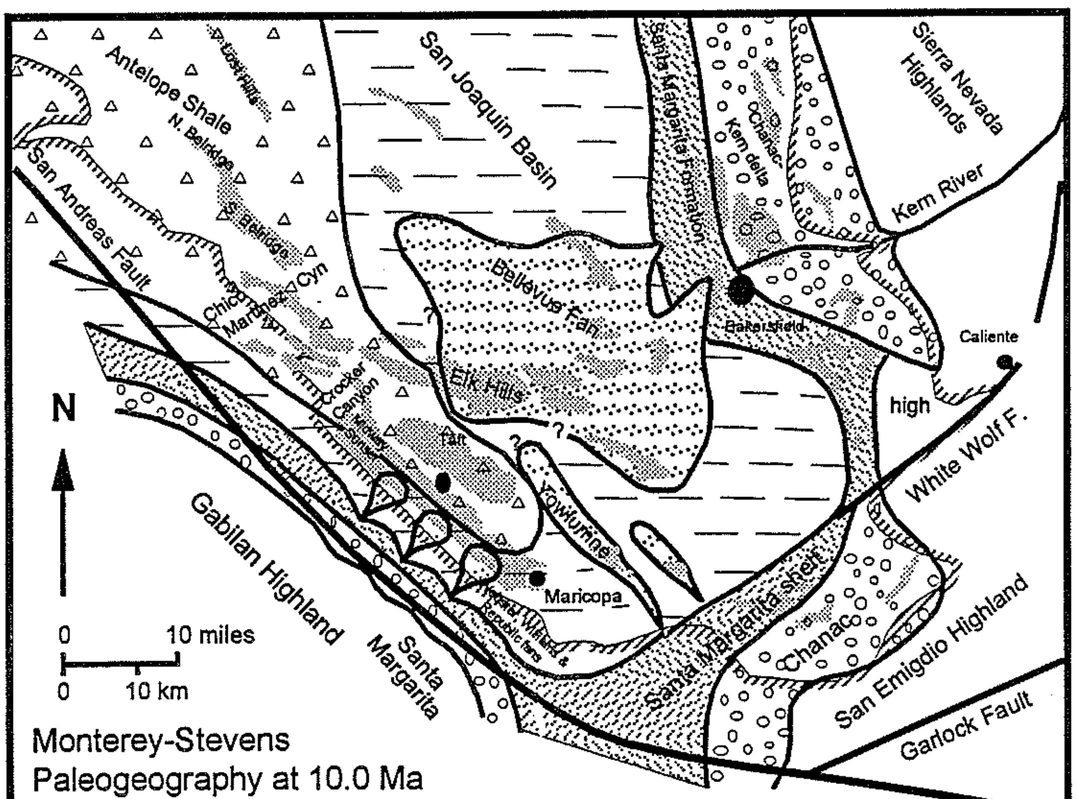

Figure 4. Paleogeography of the San Joaquin basin at 10 Ma, late Miocene, showing the location of Stevens sand turbidite complexes and correlative units. See Figure 2 for explanation of symbols. Location of the Gabilan highland is from Graham (1978). Distribution of western Santa margarita depositional environments is from Ryder and Thomson (1989). Subsurface distribution of eastern and western Stevens sand units are from MacPherson (1978), Webb (1981), and Quinn (1990). Subsurface occurrence of Antelope Shale is from Graham and Williams (1985).

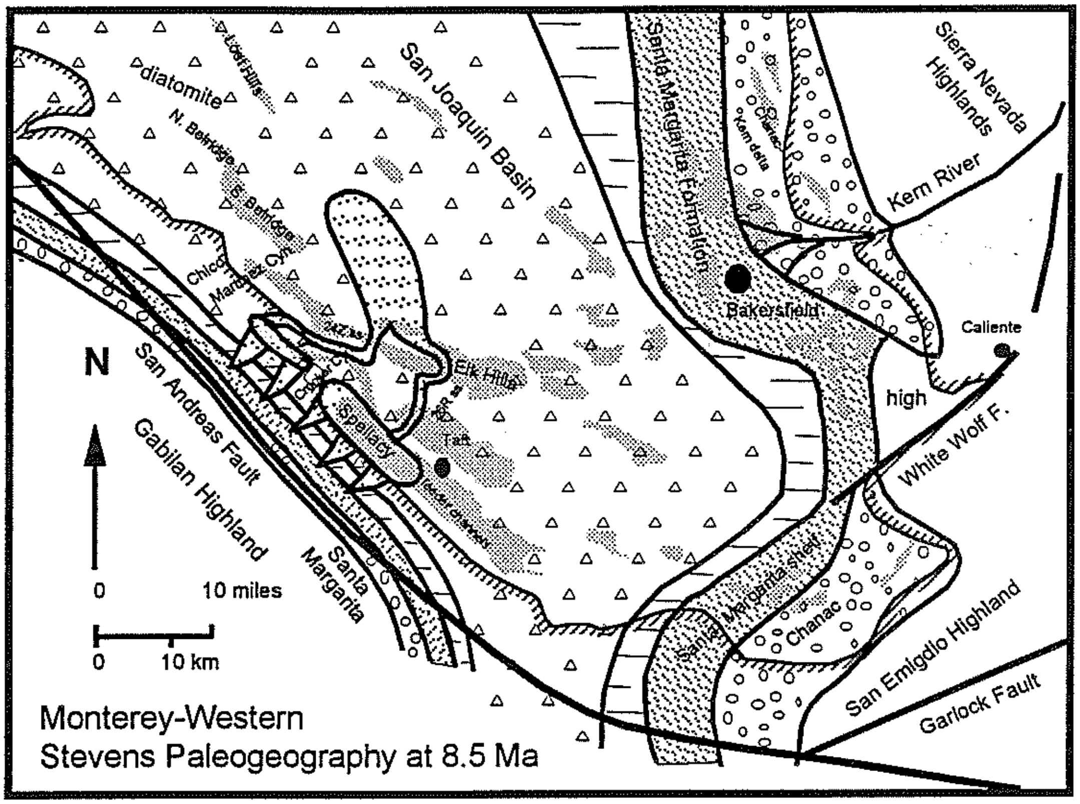

Figure 5. Paleogeography of the San Joaquin basin at 8.5 Ma, late Miocene (approximate N Point of Graham and Williams, 1985), showing location of western Stevens turbidite complexes and correlative units. See Figure 2 for explanation of symbols. Location of the Gabilan highland is from Graham (1978). Distribution of western Santa Margarita depositional environments is from Ryder and Thomson (1989). Subsurface distribution of western Stevens sand units is from Webb (1981) and Reid (1990). Subsurface occurrence of diatomite and siliceous shale is from Graham and Williams (1985).

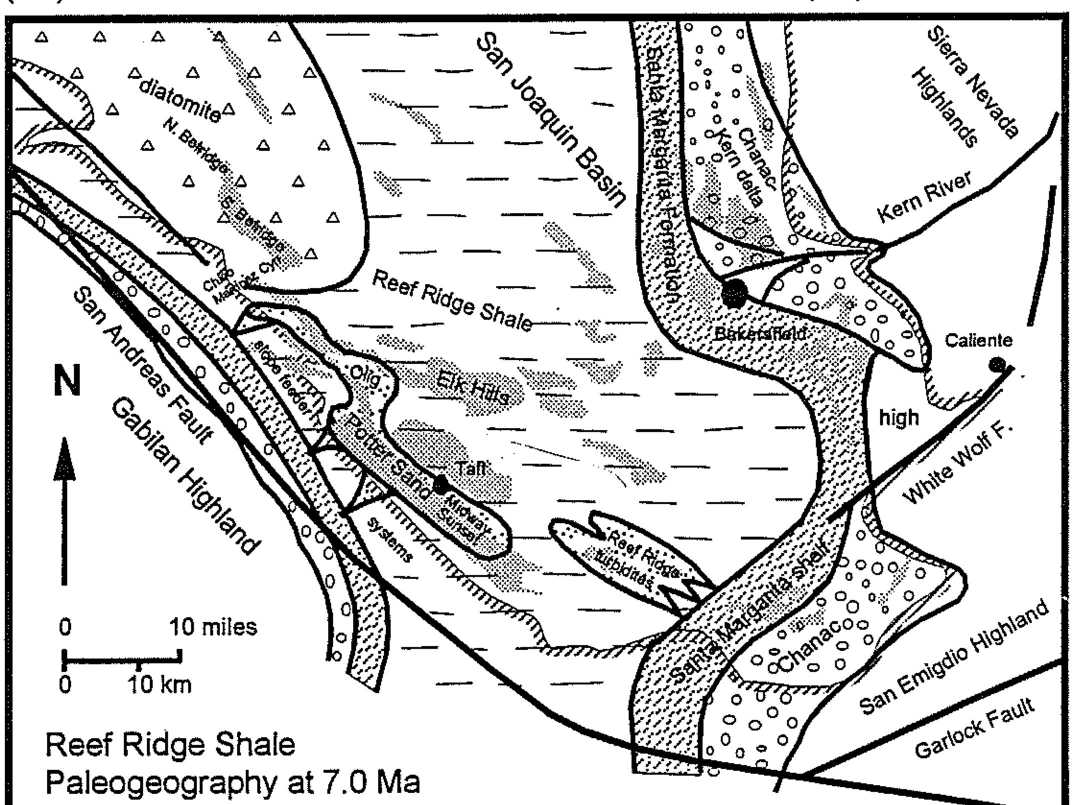

Figure 6. Paleogeography of the San Joaquin basin at 7 Ma, late Miocene, showing the depositional environments represented by the Reef Ridge Shale and correlative units. See Figure 2 for explanation of symbols. Location of the Gabilan highland is from Graham (1978). Distribution of western Santa Margarita depositional environments is from Ryder and Thomson (1989). Subsurface distribution of westerly-sourced turbidites is based on Schwartz (1988).

FIELD TRIP STOP 1

Stevens Sandstone at Crocker Canyon

Field Trip Leader: Tony Reid
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Tupman, CA 93276-1001

The accompanying article for Stop 1 by Tor Nilsen is excerpted from pages 391-395 of the following publication by the Pacific Section—AAPG:

Nilsen, T. H., Wylie, A.S. and Gregory, G. J., 1996, Geology of the Midway-Sunset Oil Field and Adjacent Temblor Range, San Joaquin Basin, California: Pacific Section—AAPG, Fieldtrip Guidebook GB75, 428 p.

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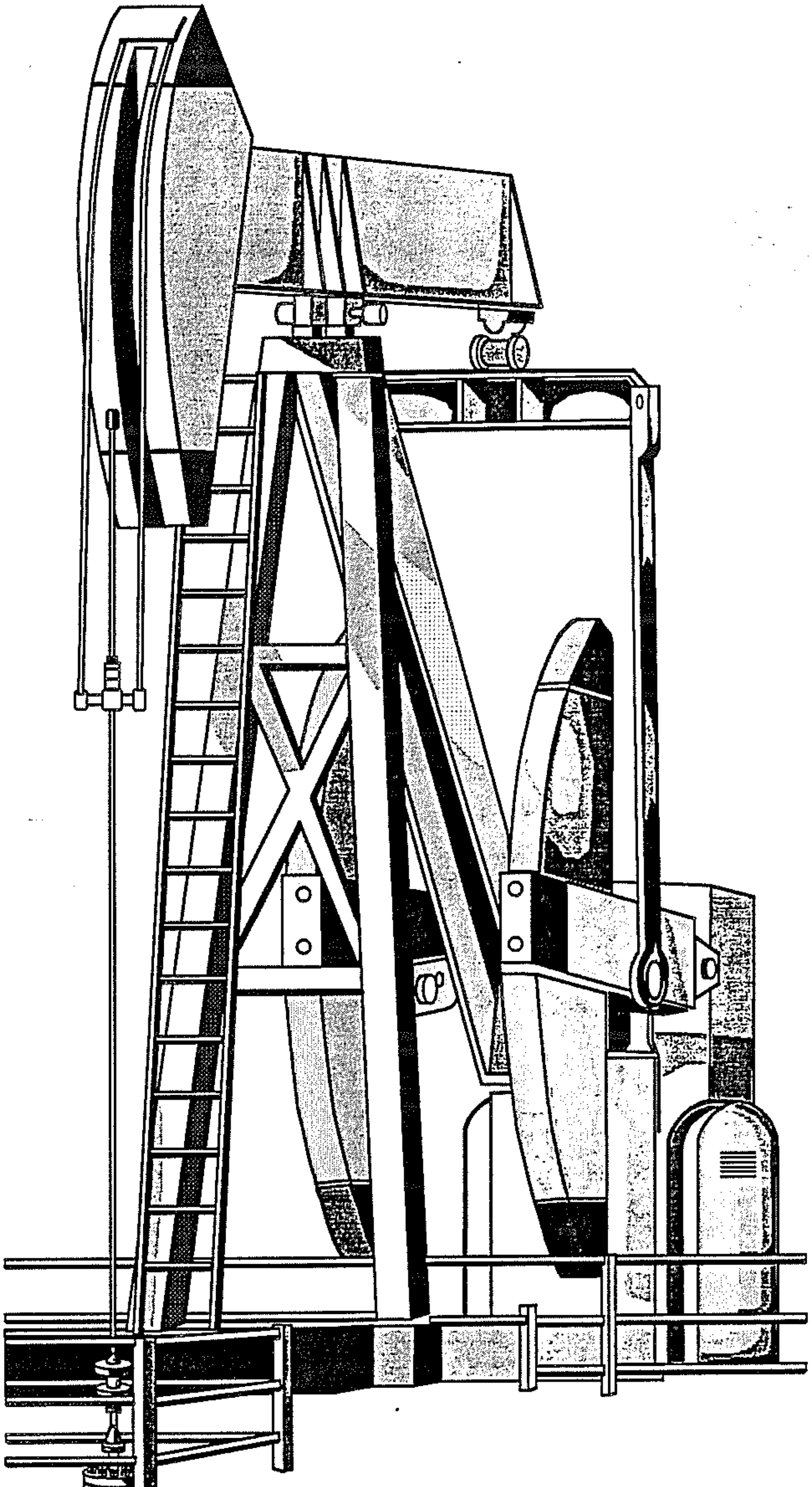

Crocker Canyon Sandstone Member and the Antelope Shale Member of the Monterey Formation

By Tor Nilsen

Excellent exposures of deep-marine sandstone of the Crocker Sandstone Member and siliceous shale of the Antelope Shale Member are present in the canyon, primarily along the south side, but also locally along the north side (Figure 1). These outcrops form the type section of the Crocker Sandstone Member as redefined in this guidebook by Nilsen (1995). The outcrop has been previously described in some detail by Kiser and others (1988) and McCullough and others (1990); the latter measured a section through the sandstone member and prepared a schematic line drawing of the uppermost beds of sandstone, reproduced herein as Figure 2. McCullough and others (1990) measured 313 m of strata, which they divided into six distinct lithofacies:

1. Diatomaceous laminated siltstone and shale, with interbedded chert and sand lenses, inferred to be Facies G of Mutti and Ricci Lucchi (1972), consisting of pelagic and hemipelagic fines.
2. Sandstone that is poorly sorted and contains abundant rip-up clasts of siliceous shale, inferred to be Facies F of Mutti and Ricci Lucchi (1972), consisting of submarine slump deposits.
3. Interbedded coarse-grained sandstone and silty shale. The sandstone beds are described as being laterally continuous, regularly bedded, and having sharp flat bases; they are inferred to be Facies C of Mutti and Ricci Lucchi (1972), deposits typical of nonchannelized sedimentation.
4. Sandstone that is massive, poorly graded and sorted, medium to coarse grained, as thick as 2 m, and with common scour marks and convoluted lamination along bedding surfaces; these beds are inferred to be Mutti and Ricci Lucchi (1972, 1975) Facies B2, typically deposited in channelized deep-sea settings.
5. Sandstone that is very coarse grained and very poorly sorted, contains abundant granitic pebbles, and is generally normally graded and amalgamated; it is inferred to be conglomeratic Facies A4 of Mutti and Ricci Lucchi (1972, 1975), typically deposited in submarine channels.
6. Pebbly sandstone that is very coarse grained, very poorly sorted, ungraded, and contains abundant small and large rip-up clasts of silty shale and slump features; it is inferred to be conglomeratic Facies A4 of Mutti and Ricci Lucchi (1972, 1975), typical of unstable submarine channel deposits.

These lithofacies are stacked in a generally coarsening-upward parasequence in which the coarser grained sandstones of lithofacies 4, 5 and 6 are most abundant at the top of the sandstone body. The entire sequence was interpreted by Kiser and others (1988) and McCullough and others (1990) to be in inner-fan channel complex in a sandy submarine fan system, with the distal fan deposits located in the subsurface to the east, where they form prominent reservoirs. McCullough and others (1990) infer the diatomaceous pelagic and hemipelagic units of lithofacies 1 below the sandstone body to consist of overbank and slope deposits, and the interbedded sandstone and mudstone deposits of lithofacies 3 to have been deposited as channel-margin or crevasse-splay deposits, possibly from adjacent channel systems.

The regional mapping of the Crocker Sandstone Member by Nilsen (1995) provides additional information and a different basis for a paleoenvironmental interpretation of the succession at this outcrop. Interpretation of the succession as an inner-fan channel system by Kiser and others (1988), Ryder and Thomson (1989), and McCullough and others (1990) is also somewhat inconsistent with published examples of modern and ancient inner-fan systems. Firstly, the succession exposed coarsens upward and is abruptly terminated at its top by overlying pelagic and hemipelagic siliceous shales; classic inner-fan channels fine and thin upward, leaving a record of gradual abandonment and overlying finer grained and thinner bedded levee/channel margin deposits. Secondly, the succession contains no easily documented channeling or incision that should mark both the base of the channel and the walls of either the main channel or of the thalweg channel; although there is abundant evidence of scour and amalgamation, as well as incorporation of blocks of silceous shale within the sandstone body, no clear incisions deeper than the thickness of a single bed can be observed, and no coarse-grained channel lag is present at the base of the putative channel system. Thirdly, the measured

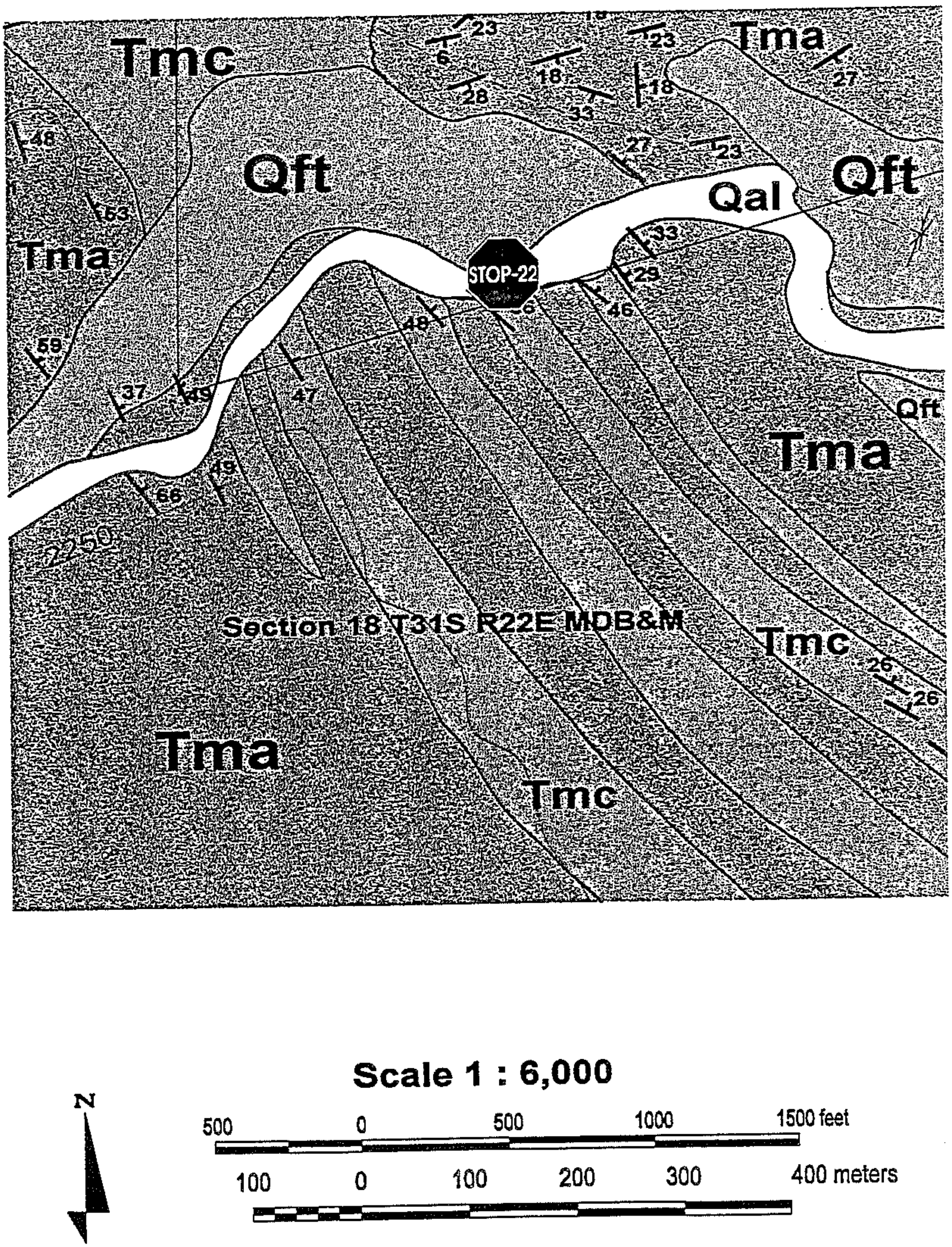

FIGURE 1: Simplified geologic map showing the locatior of Field Trip Stop 1 (modified from Nilsen, 1995).

section of McCullough and others (1990) clearly shows a succession of sandstone beds or bodies separated by thick intervals of siliceous shale of lithofacies 1; rather than a simple channel complex, the succession appears to consist of at least four separate sandstone bodies, the bases of which are at 87 m above the base of the section for the lowest, 127 m for the second 220 m for the third, and 270 m for the fourth and uppermost body (Figure 2A).

Nilsen's (1995) regional mapping clearly shows that four distinctive sandstone bodies make up the Crocker Sandstone Member in the area of secs. 18 and 19 (Figure 1, Pl. 1 in Nilsen and others, 1996); these bodies have been mapped for a distance of more than a mile northward to the Crocker Canyon exposures. A fifth and lowest sandstone body crops out in the canyon and appears to thicken northward of the canyon, where the mapping indicates the presence of multiple sandstone bodies wrapping around the Crocker Canyon syncline and related folds. The Crocker Sandstone Member pinches out in the central part of sec. 8, T.31S., R.22E. to the northeast of the type section, thus defining a lens-shaped cross-sectional area about 3-4 mi wide when unfolded, a geometry similar to that of the partly correlative Williams and Republic Sandstone Members to the southeast, which also lie within the Antelope Shale Member of the Monterey Formation.

The Crocker Sandstone member in outcrop appears to consist of an entire sand-rich submarine fan system, deposited during at least five distinctive pulses separated by hemipelagic shale intervals. The succession coarsens upward because the entire Crocker submarine fan has prograded into the Midway basin, with each successive pulse or parasequence representing a more proximal and thus coarser-grained and thicker-bedded part of the fan. The pulses are probably controlled by the mixed effect of tectonic uplift/subsidence and regional sea-level fluctuations, with the latter probably having a more profound effect. The lack of channeling at the base of the succession indicates that the deposits do not fill an erosive channel. Instead, the entire fan system appears to infill a tectonically generated synclinal axis within the Antelope Shale Member, with the successive sandstone bodies onlapping against the synclinal basin walls, rather than erosively cutting down into them (see Nilsen and others, 1996, for further discussion of the proposed depositional model). The onlap can be observed at several places within the outcropping section, but requires standing back from the outcrop and viewing it from a distance; different dips for the infilling sandstone bodies and the underlying folded siliceous shales are readily apparent.

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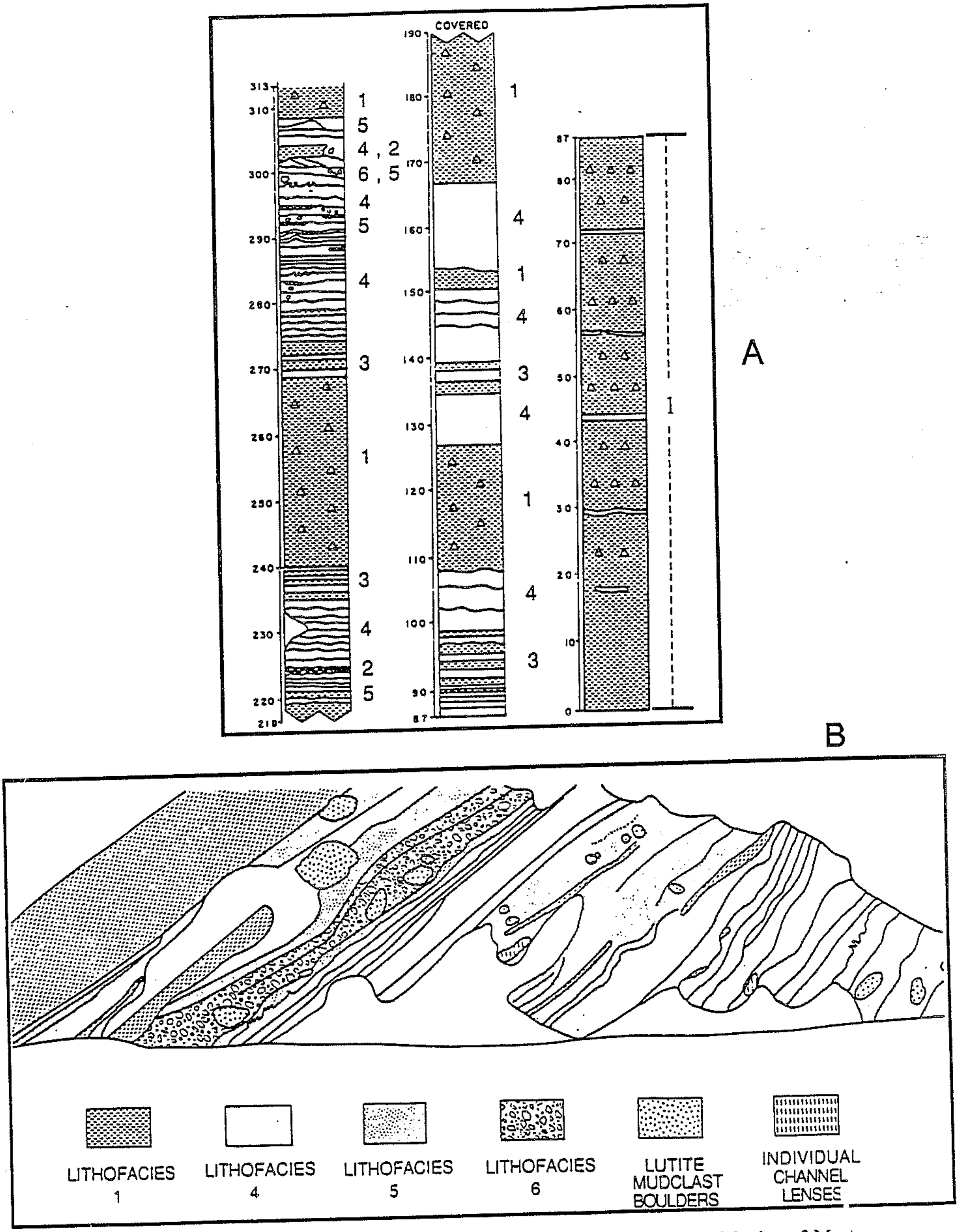

FIGURE 2: Measured section and schematic outcrop drawing of Crocker Sandstone Member of Monterey Formation in Crocker Canyon at Field Trip Stop 1 (from McCullough and others, 1990, Figures 5 and 6). Numbers to left of section (A) represent meters above base. Numbers on right represent lithofacies designations. Note that lithologic symbols in diagram (B) are different than those used in (A).

FIELD TRIP STOPS 2 & 3

Potter Sandstone at North Midway-Sunset Field

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Field History

The North Midway field is located southeast of the town of McKittrick, an oil field boomtown that developed with growth of westside oil fields. The north end of the field is approximately 1-1/2 miles southeast of the McKittrick Field and is a northern extension of the giant Midway Sunset Field.

The first test of the prospective area was drilled in May 1901 in the southeast quarter of section 34, T31S/R22E. This test hole was abandoned at 1060' with TD in the Tulare Formation. The next test well #92 was drilled in July, 1920 by the Associated Oil Company to a depth of 1794 feet. Well #92 penetrated the top of the Potter sand and was commercially productive. The locations for these early wells were staked on the basis of surface geology. During the 1920's only the southern portion of the North Midway Field was exploited.

The northern portion of the field, located in section 34, was later developed by Tidewater Oil Company during the mid-1940s. Tidewater's initial well #65 was drilled to a depth of 2880 feet, penetrating the Potter oil sand in what is now the main productive trend at North Midway Field. The Potter sands in this area are steeply dipping to overturned. This same Potter trend is being developed today in sections 27 and 28.

The Potter sands are usually encountered between 800 to 1600 feet deep and produce 20 to 60 barrels of oil per day, per well. Initially, the wells are cyclic steamed. Subsequent steam injection has aided in the recovery of the heavy oil from the Potter sands. The Tulare Formation is also productive in the North Midway Field, usually to a depth of 1000 feet, and produces 10 to 15 barrels of oil per day, per well. The Tulare wells are cyclic steamed.

Geologic History

Structural growth and uplift in the North Midway area resulted in many overlapping depositional relationships. The Potter sand member of the Reef Ridge Formation was deposited in Latest Delmontian time along the margin of a constricting and shallowing marine basin. The mode of deposition for the Potter sands is still under dispute. However, at North Midway, it appears that submarine canyons provided pathways for the lower siliciclastic units. The result was a series of interfingering conglomeratic sands interbedded with diatomaceous siltstones.

Displacement of the granitic highlands northwest along the San Andreas Fault and the structural development and uplift in the Temblor during Early Pliocene time resulted in a shallowing marine basin. This setting provided the site for deposition of the Etchegoin Formation. Severe structural deformation has uplifted and overturned the Pliocene and Miocene section. The Pleistocene Tulare Formation predominantly onlaps all older deposits. These structural complexities are evident in the outcrops and log data at North Midway Field in sections 27 and 28.

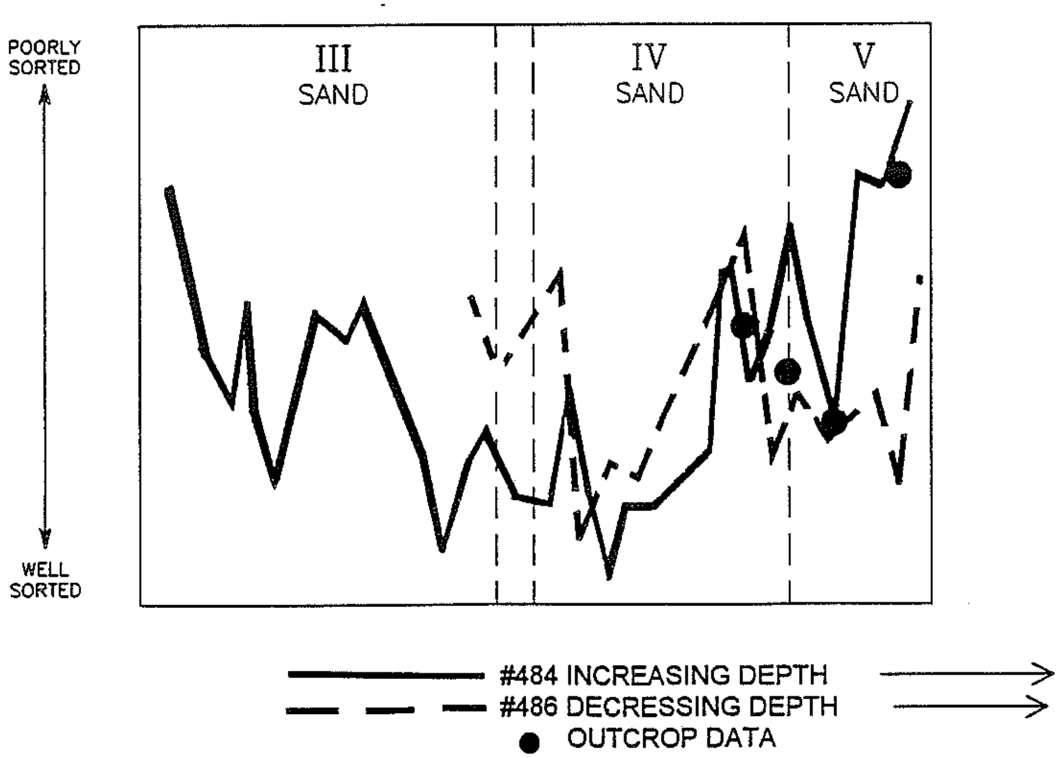
Stratigraphy

The Potter reservoir at North Midway consists of five sand units as shown on the typelog (Figure 1). Core from the lower IV and V sands are poorly sorted and usually conglomeratic, containing granitic cobbles, rounded chert and quartzite pebbles. This character is evident in outcrop. The upper I – III sand units of the Potter are moderately to well sorted and medium to coarse grained. Unfortunately the I - III sands do not outcrop at North Midway. At the North Midway field stops we will explore the various Potter and diatomaceous shale outcrops.

Below is a core summary for the Potter sands at North Midway:

Well	Zone	Perm (md)	Porosity (%)	clay (%)
T.O.3	I ss	1500-3500	30	1% ill, ch, sm, 3% fn/ mica
	II ss	2000-4000	34	1% ill, ch, sm; 4% fn/ mica
484	III ss	3321	31	5% ill, sm, heulandite
	IV diat slts	630	40	6% ill, sm
	IV ss	2388	37	5% ill, sm
	V ss	1151	33	5%
486	III ss	2000	35	Not complete
	IV diat slts	200	42	"
	IV ss	600-2000	36	"
	V diat slts	1-40	35-55	"
	V ss	620	35	"

COMPARISON OF CORE — SORTING PROFILES



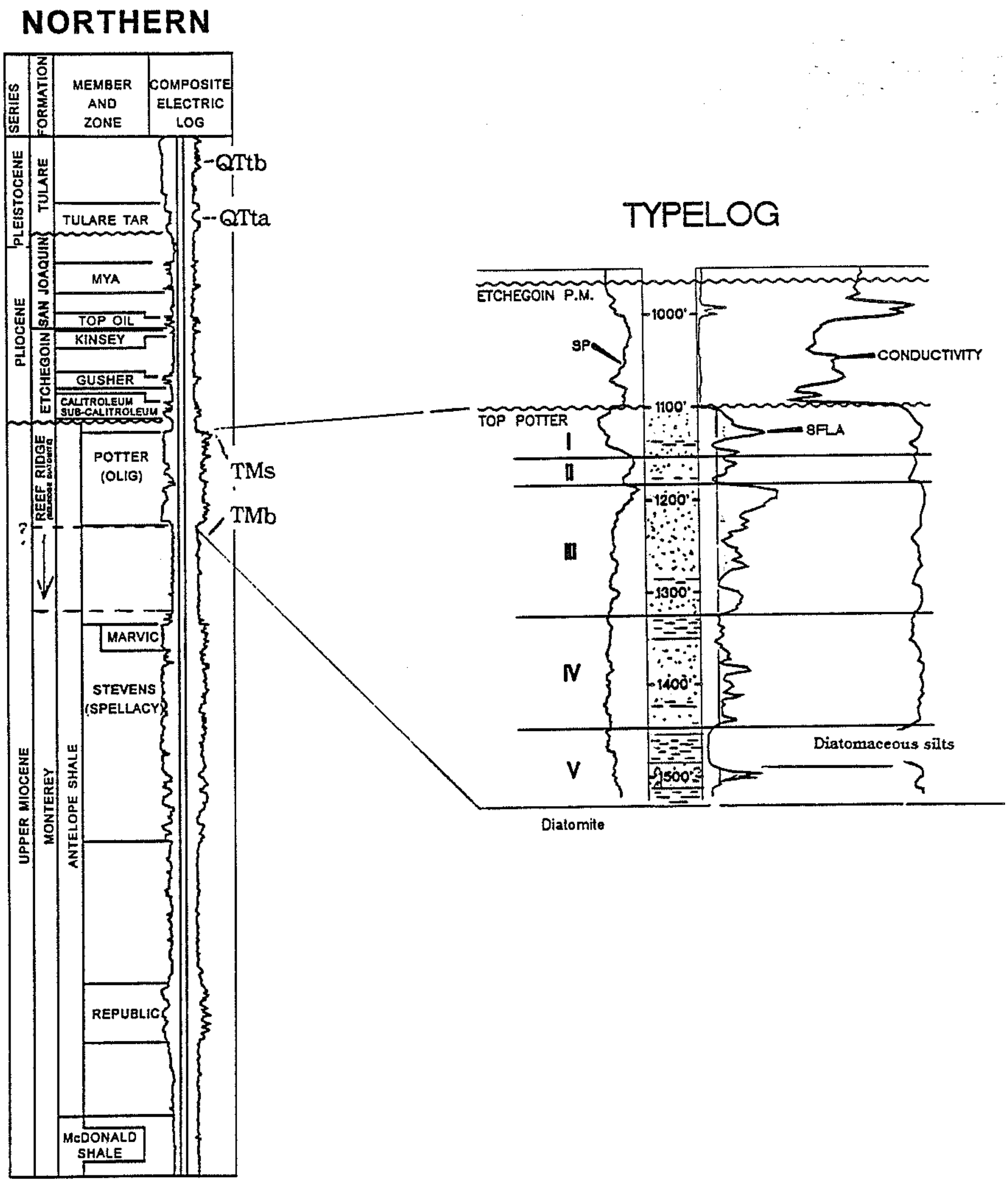


FIGURE 1: North Midway generalized stratigraphic columns and type logs (modified from D.O.G., 1985).

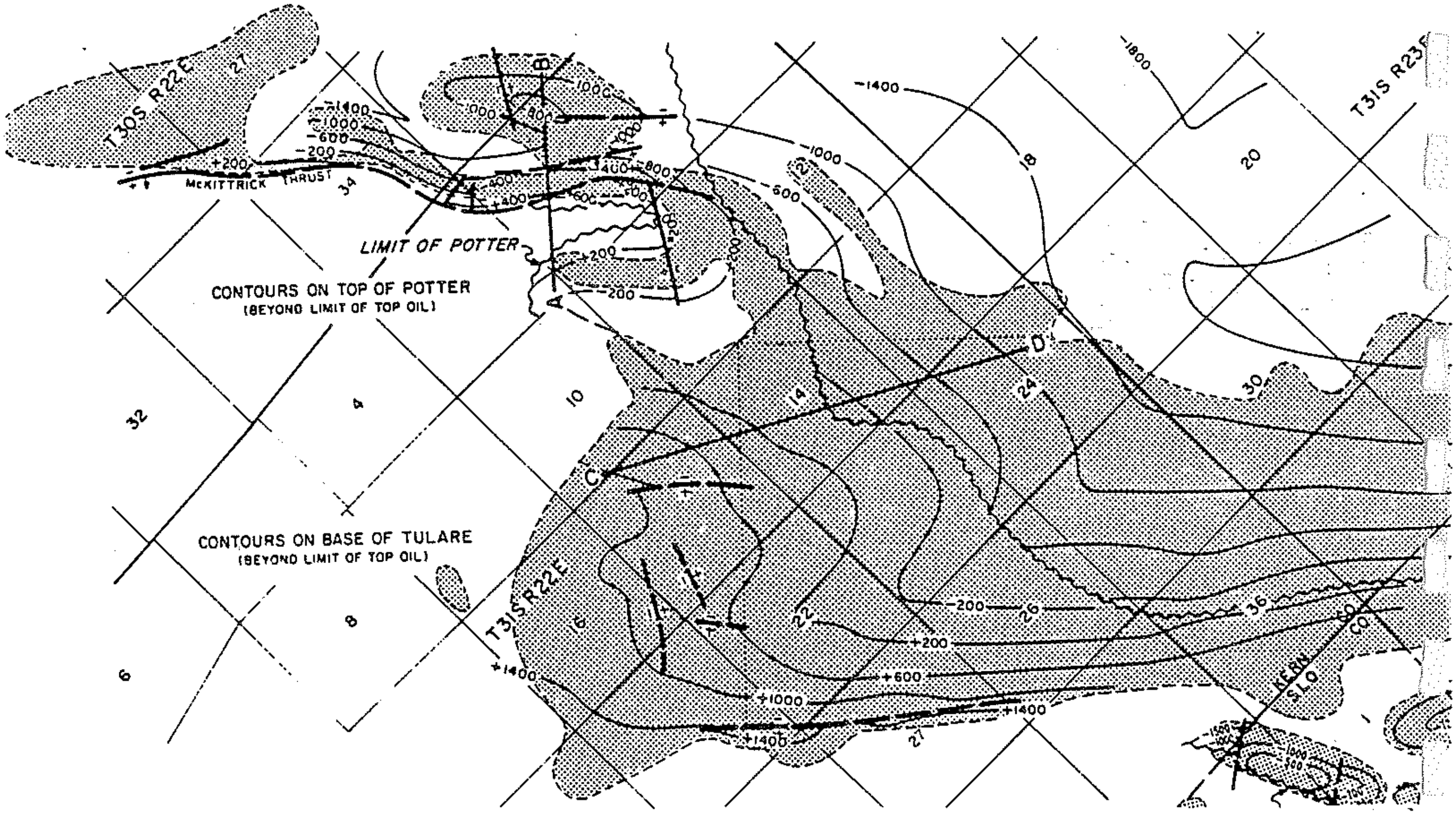


FIGURE 2: Midway-Sunset and North Midway generalized structure map (modified from D.O.G., 1985).

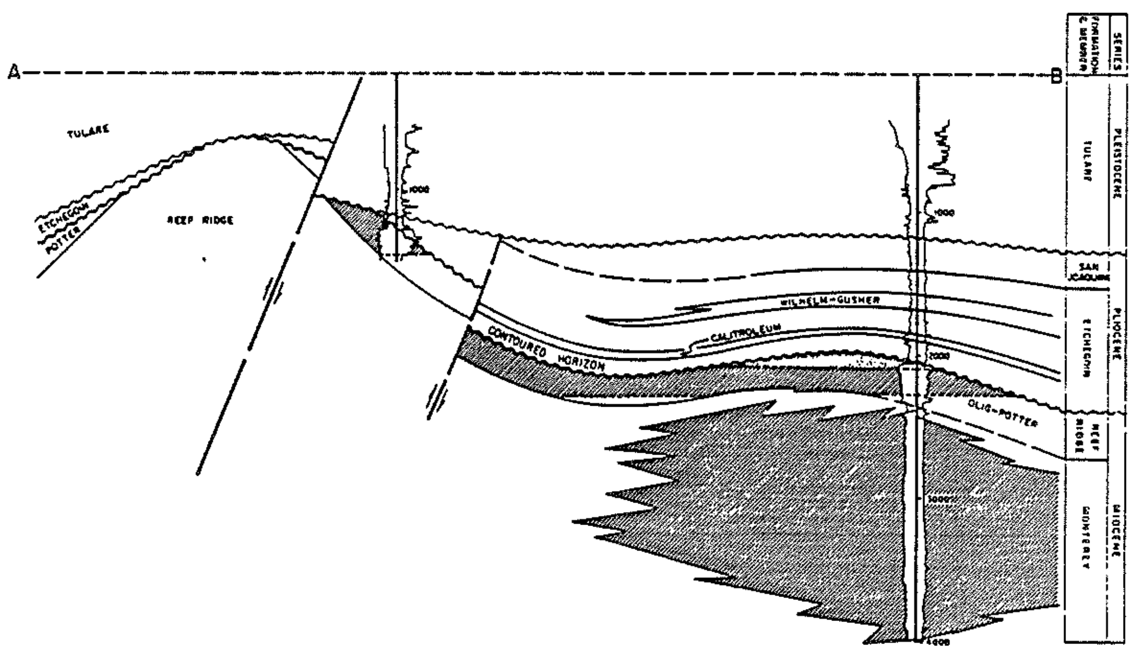


FIGURE 3: Midway-Sunset and North Midway gei eralized cross-section (modified from D.O.G., 1985).

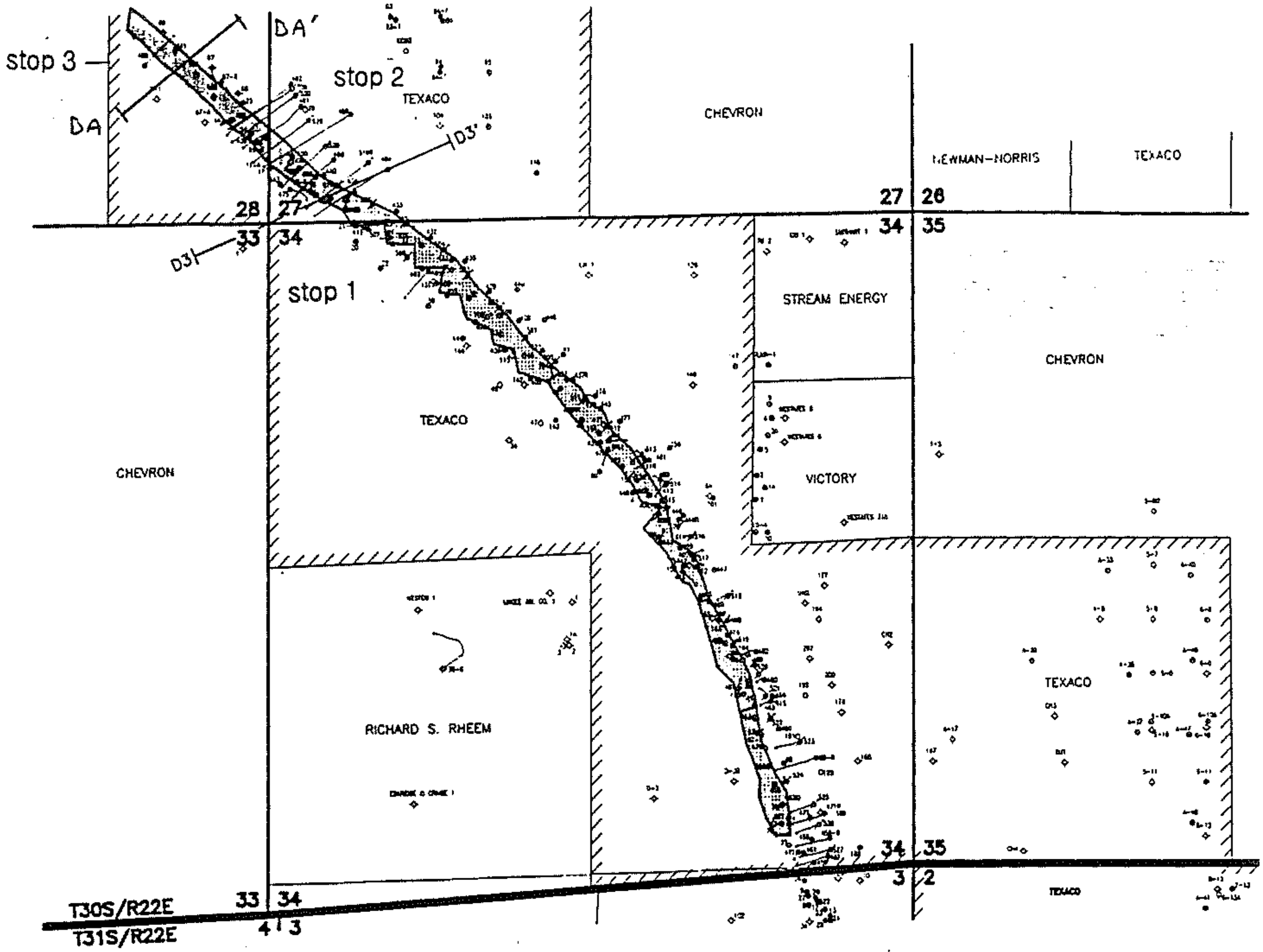


FIGURE 4: North Midway oil field map showing well locations.

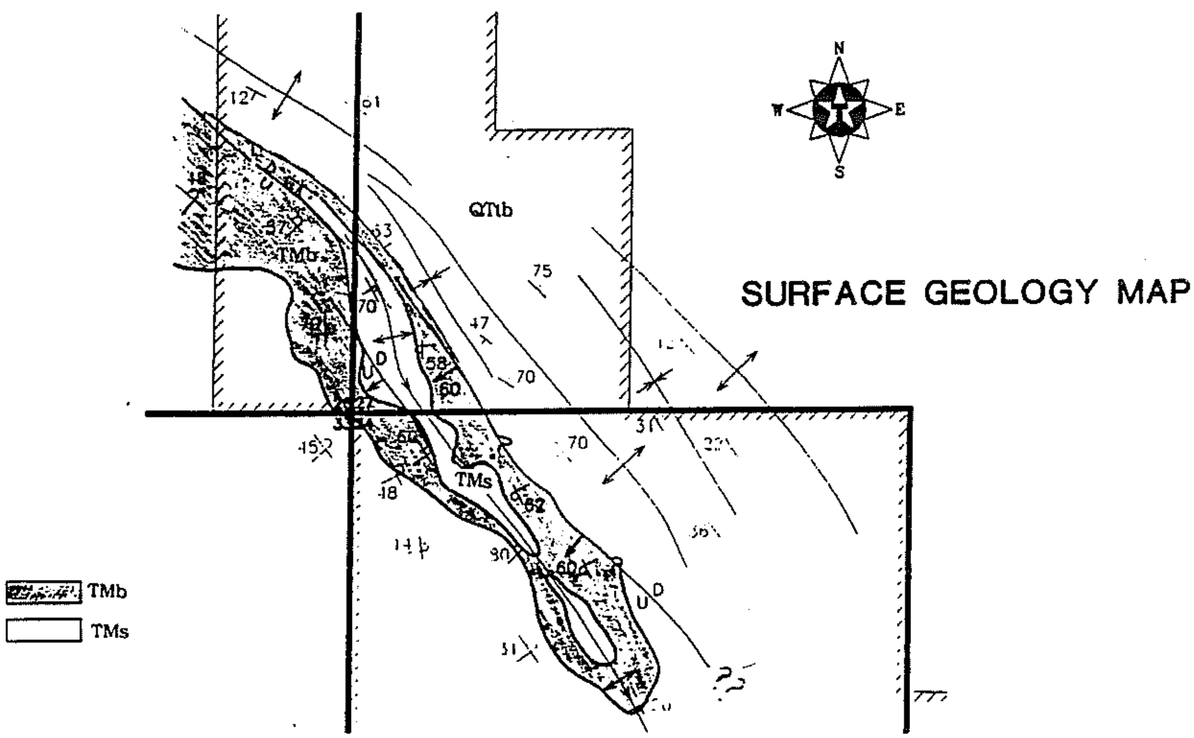
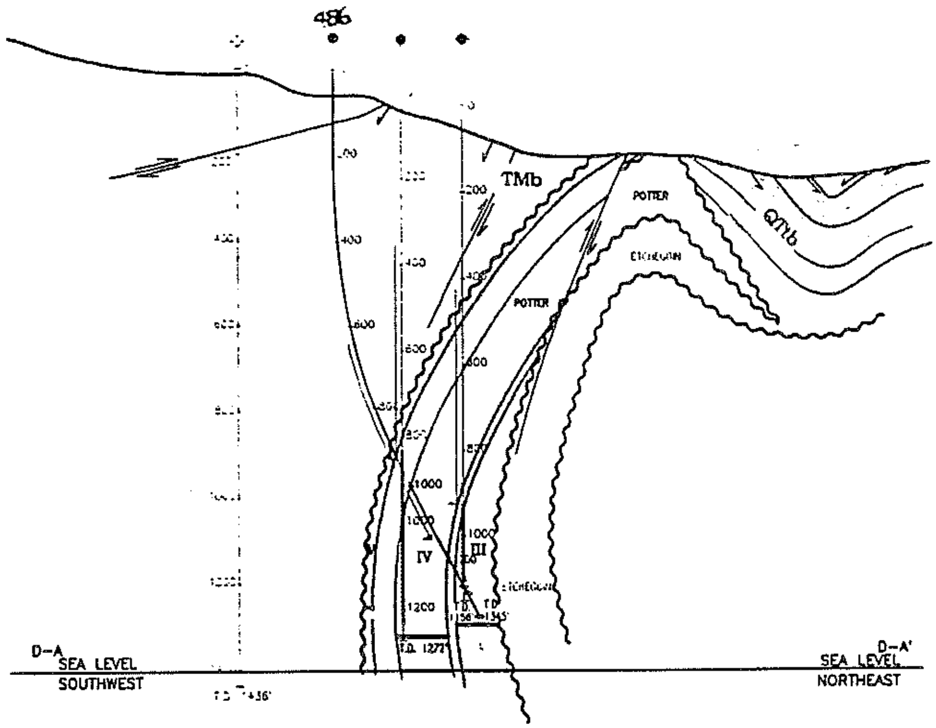
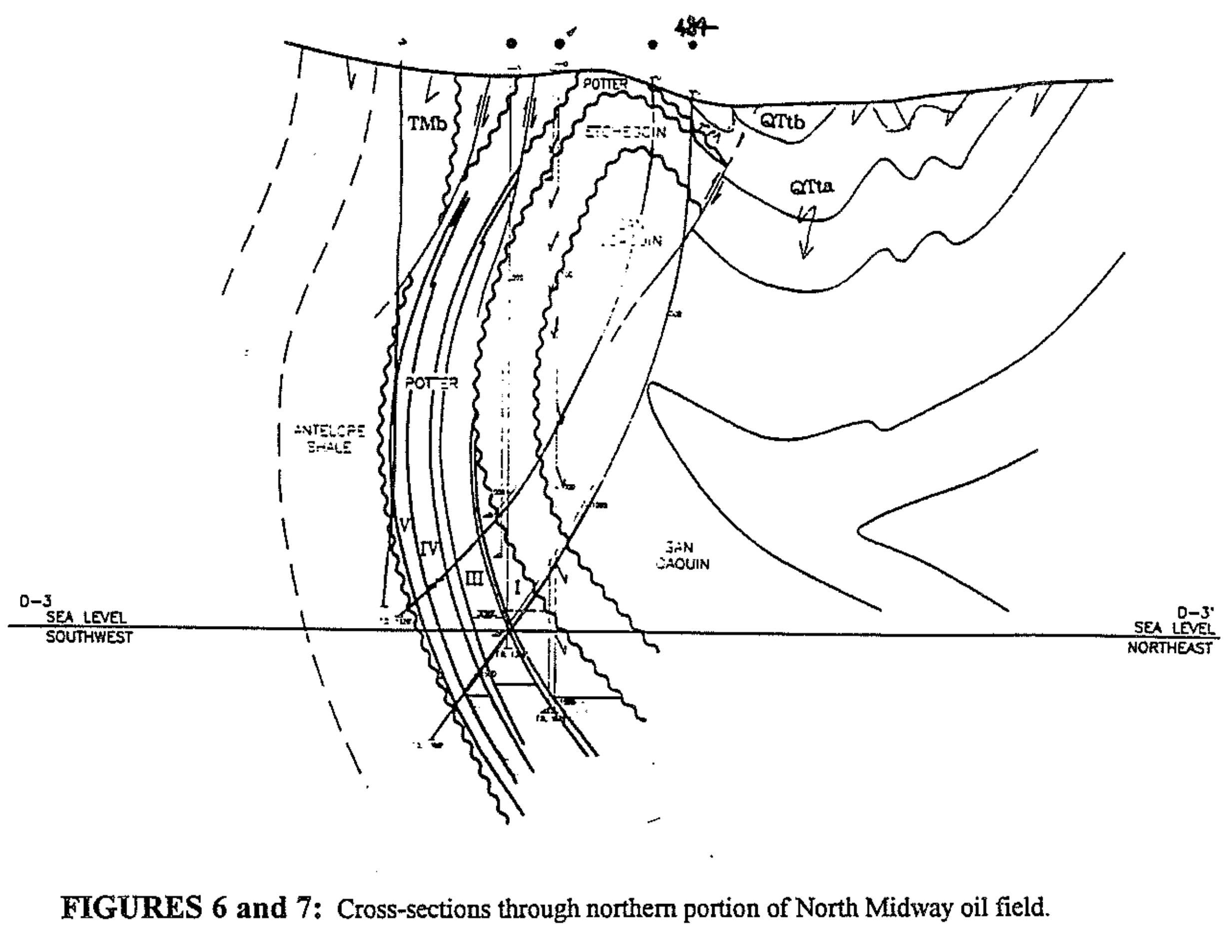


FIGURE 5: Surface geology of the northern portion of North Midway oil field.

CROSS-SECTION DA - DA'



CROSS-SECTION D3 - D3'



FIGURES 6 and 7: Cross-sections through northern portion of North Midway oil field.

FIELD TRIP STOPS 4 and 5

McKITTRICK DIATOMITE DEPOSIT

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Located just to the west of the town of McKittrick is a large, shallow deposit of oil-saturated diatomite estimated to contain up to 2 billion tons of ore at an average grade of 7% oil (by weight). This is equivalent to a geologic resource of over 800 million barrels of heavy crude oil. The significance of this large accumulation of oil was overlooked for many years, as numerous wells were drilled through the oil-rich diatomite into the deeper oil sands of the McKittrick Field. In the late 1960s Getty Oil Company began to recognize the potential of the shallow diatomite after analyzing core samples of the highly porous, soft, brown diatomaceous earth. Since that time the shallow diatomite has been extensively drilled and cored to define the limits of the deposit, while considerable time and effort have been spent to find a method to economically extract the oil from the tenacious grip of the diatomite.

McKittrick Diatomite Exploration History

1860s	Miners penetrate diatomite with shallow adits and shafts while mining asphalt veins.
1920s	Bulk sampling of diatomite by Associated Oil Company and W. H. Whittier Company.
1957	Excel Minerals samples diatomite, with primary interest in the solids, not the oil, and Getty geologists confirms high oil content with outcrop samples sent to Core Labs.
1966-67	Getty obtains cores from 3 oil development wells in the McKittrick Field and analyzes them using a solvent extraction method.
1972	Getty cores 3 holes specifically for diatomite samples in the southern end of the field.
1973-76	Getty conducts an extensive drilling program (138 holes) to evaluate the diatomite. Holes are logged using conventional logging methods and spot cores.
1981-82	Twin Hole Coring Program – Getty twins 4 older exploration holes with continuous cores. The drilling results show a significant lack of correlation between oil content based on core analyses and log interpretations.
1982-84	Getty continuously cores 300 + holes within the diatomite deposit (~50 miles of core).

Reserve Calculations and Mine Plans

Once it became apparent that the McKittrick diatomite deposit contained millions of barrels of oil but could not be produced by conventional methods, Getty began a systematic program to evaluate possible mining methods and to calculate the amount of recoverable oil in the deposit. Early site inspections by mining engineers concluded that the optimum ore recovery method would be open pit mining, due to the relatively small amount of overburden. the ease of excavation, and the general configuration of the ore body. Over the years there have been many mine designs and schedules, with the modifications and refinements resulting from new drilling data, fluctuations in oil price; anticipated changes to the planned mining rate, or other factors. Most of the mine planning has been done using MEDSystem, a mine-planning program developed by Mintec of Tucson, Arizona.

Data used in the reserve calculations and mine planning consist primarily of assay data obtained from the 300+ continuous cores taken by Getty in the early 1980s, density log data from those core holes, and detailed geologic core descriptions. All cores were analyzed using a Fischer assay to determine the oil weight percent in 10-foot composite samples. Each 10 foot interval was then assigned an oil content value (% by weight), a water content value (% by weight), density and rock type. This data used to construct a block model covering the entire diatomite deposit. The block model was then used in a

MEDSystem sub-routine to calculate the minable reserves based on various economic inputs and mine plan variables, such as pit slope and cut off grades. In most mine plans the minable reserves ranged from 300 million tons to 500 million tons, with an average grade of between 13% and 16% oil by weight. This is roughly equivalent to 30 or 40 gallons of oil per ton, or a little less than one barrel of oil per ton of ore.

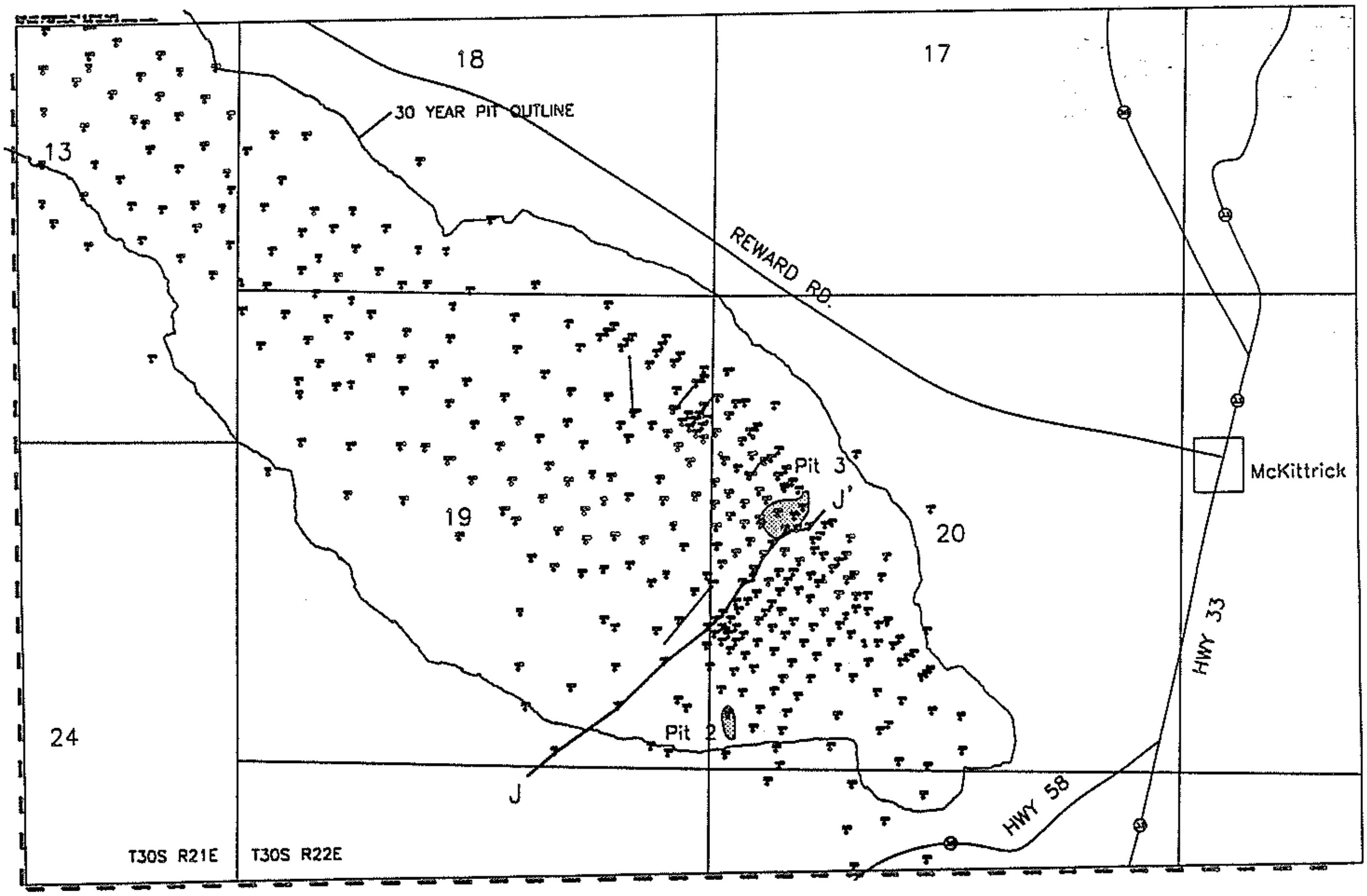


FIGURE 1: Location map showing collar locations of continuous cores and 30-year pit outline.

The most current mine plan was prepared late in 1996, with a total minable reserve of 328 million tons at an average grade of 16%. This plan was to supply ore to a solvent extraction processing plant at a rate of 33,000 tons per day. The total production mine life with this plan was 32 years, with 3 additional years for backfilling and reclamation. This plan required off-site storage of overburden and spent diatomite for a period of about 15 years, at which point the pit would be sufficiently large to allow backfilling in mined-out portions of the pit. Overall strip ratio for the mine is 2.5, with a total of 833 million tons of overburden and innerburden material removed. In general, mining would commence in the southeastern portion of the deposit and slowly proceed to the northwest. All mining would be done with 34 yd^3 hydraulic excavators and a fleet of 240 ton haul trucks. Conveyor belts would be used wherever possible to transport ore to the process plant and to send overburden and spent ore to the stockpiles. The ultimate pit will be approximately 3 miles long and 1 mile wide and an average depth of 600 or 700 feet. However, after about year 15 backfilling, recontouring, and reclamation would begin in the southern portion of the mined-out pit, so the entire 'ultimate" pit would never be open at any time. The outline of the "ultimate" 30 year pit is shown in Figure 1, as are the core hole collar locations and test pits 2 and 3.

Process Testing

The size and extent of the shallow, oil-saturated diatomite deposit at McKittrick has been well established, but it has proven to be a much more formidable task to find a method for extracting the oil from such a high porosity but low permeability (<2md) rock. Early on, Getty put one of the initial exploration wells (4DR) on pump to test primary oil potential. The well produced 1 bopd and 1 bwpd, but it was determined that all of that oil was coming from an isolated oil sand stringer within the diatomite. Other wells completed entirely in diatomite did not produce any fluids at all. These efforts were followed-up by attempts at steam injection, which only fractured the formations and opened fissures to the surface up to 200 feet from the well bore. Getty's production people then turned to their Research Lab and Minerals Department for assistance in finding a way to exploit the millions of barrels locked up in the McKittrick diatomite deposit. Ore samples were sent to Canadian tar sand miners, who determined that their extraction methods would not work on the diatomite ore, since the diatomite was "oil wet" as opposed to the "water wet" tar sand ore at their mines. Additional ore samples were then sent to labs all over the country and to Canadian and German facilities to look for a feasible extraction method. All in all, 15 different processes were studied, 10 were subjected to bench scale testing, and 3 of those were tested with small-scale pilot plants. Getty concluded that 2 methods held the most promise, a solvent extraction process proposed by Dravo Corporation and a retort method tested by the German company Lurgi. After 1976, Getty confined their process work to those 2 methods.

In the early 1980s, Getty built and operated 2 pilot plants at a site approximately 2 miles west of the town of McKittrick. This facility consisted of a centralized ore receiving/crushing/grinding circuit which fed ore onto conveyor belts leading to the Dravo solvent extraction plant and the Lurgi retort unit. The solvent extraction plant quickly encountered difficulties in separating the solids from the solvent and product oil. In spite of numerous additions and modifications to the Dravo plant, it was shut down and eventually dismantled. The Lurgi retort pilot plant yielded approximately 150 bopd and was the process of choice when Getty Oil Company was acquired by Texaco. The Lurgi plant continued to operate for about a year after the Texaco/Getty merger, but was eventually shut down in the mid-80s due to a steep drop in the price of crude oil.

Texaco began investigating enhancements to the Dravo solvent extraction process in the early 1990s, with the primary emphasis on sample preparation prior to putting the ore in contact with the solvents. Off-the-shelf technology such as pelletizing, a process common to the steel and fertilizer industry, and a Rotocel® solvent extraction process used for years by the seed oil industry were combined to design a promising method for the extraction of oil from the McKittrick diatomite deposit. This method was initially tested with a small Rotocel® in 1992 using high-grade ore. Following the success of the initial Rotocel® testing, Texaco has continued to refine the process, with substantial research programs carried out in 1996 and 1997.

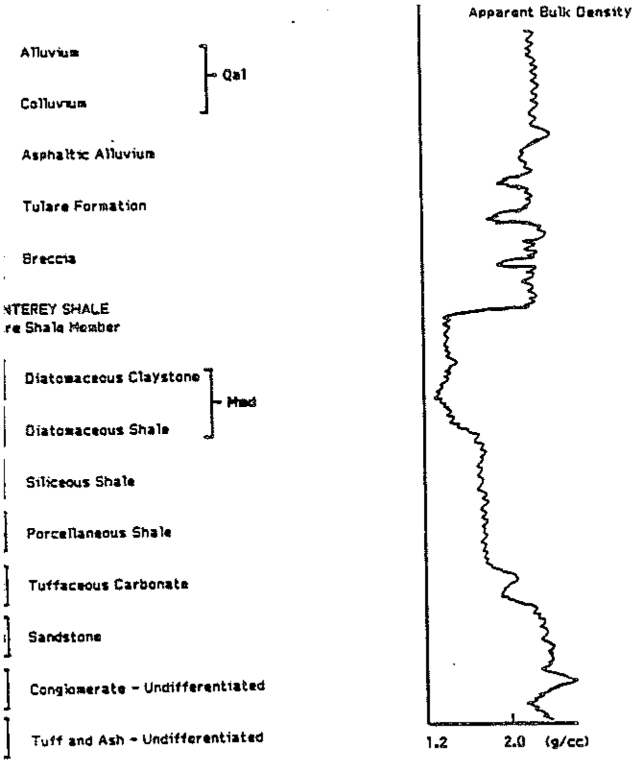
Geology of the Diatomite Deposit

The geology of the McKittrick diatomite deposit was described in detail by Mulhern, Eacmen and Lester in the 1983 SEPM Publication titled *Petroleum Generation and Occurrence in the Miocene Monterey Formation, California.* Much of the information presented here is excerpted from that paper.

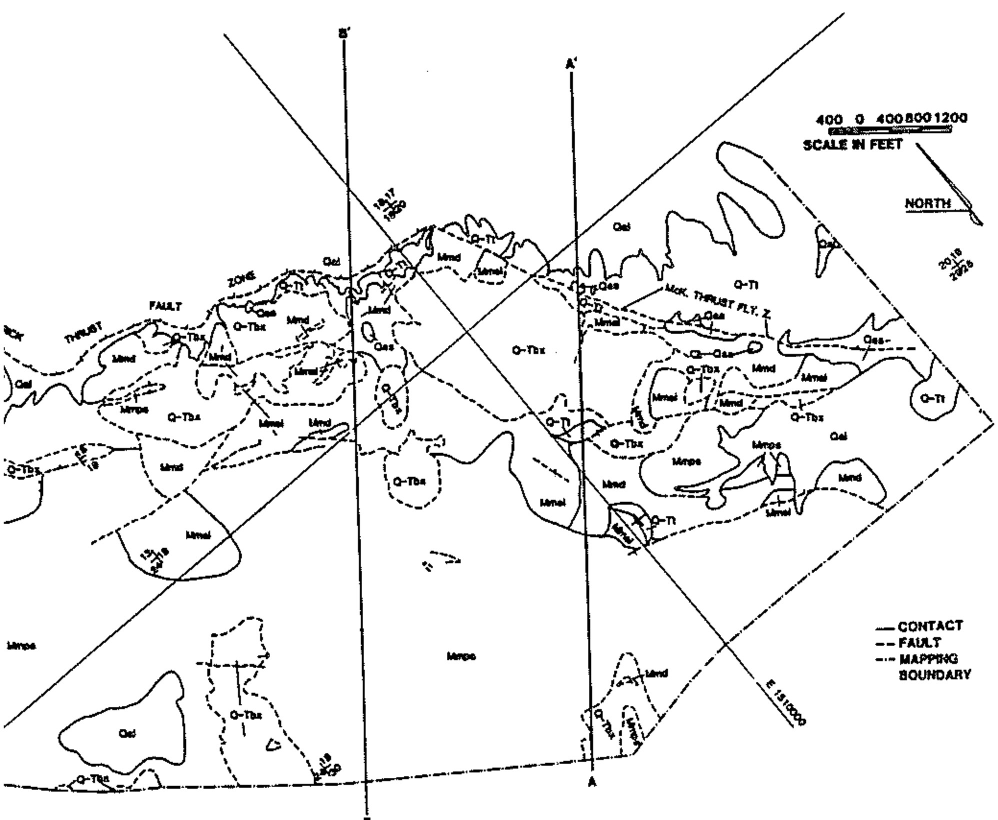
The oil-saturated diatomite at McKittrick is thought to be a facies of the Antelope Shale, a unit of the McClure Member of the Miocene Monterey Formation. The primary ore has been locally mapped as a diatomaceous shale, Mmds, described as "generally soft to medium, brown earthy diatomite or diatomaceous shale and mudstone displaying bedding and/or varve-like laminae with some degree of fissility. Other characteristics include an apparent log bulk density of 1.40-1.60 g/cc." The Mmds ore is composed almost entirely of whole and fragmental diatom frustules, with little or no cementation. The diatoms are primarily composed of opal-A, with porosities of 60% to 70% common.

The secondary ore at McKittrick was mapped locally as Mmsi, a silicious shale described as "light to dark brown, soft to hard, siliceous shale and mudstone" that is "somewhat brittle, generally thin-bedded or laminated with accented fissility." This unit has an apparent log bulk density of 1.60 –1.80 g/cc and is composed of diatom frustules that have been diagenetically altered to opal-CT. This unit has much less porosity than the opal-A diatomite and contains much less oil.

Overlying the diatomite ore are younger alluvium, asphaltic alluvium (including a scoriaceous slag of burned diatomite), colluvium, breccias and undifferentiated sands and clays. Underlying the diatomite deposit are oil sands of the Potter Formation, which is the primary reservoir for the conventional production in the McKittrick Field. Numerous natural tar seeps and springs are present along the trend of the diatomite deposit.



geologic map. No age relationships are implied for rocks within the Monterey Shale. A
onse of the various units is shown at right (from Mulhern, et. al.).



ieologic map referenced to CA Coordinate System (modified fro n Mul iern, et. al.).

The structural history of the McKittrick diatomite deposit is very complex and is still the subject of debate. Mulhern, et. al. summarize the structural setting as follows: "The diatomite was tectonically displaced over Plio-Pleistocene beds during the mid-Pleistocene by SW-dipping high-angle reverse and thrust faulting. The McKittrick thrust fault is the basal sole thrust associated with and locally offset by imbricate synthetic and a few antithetic secondary faults. Gravity sliding may have been involved, notably in the northern part of the field. Continuing, episodic compression has thickened the section and destroyed some bedding, formed extensive breccia and caused plastic deformation and rotation of large diatomite blocks." Getty geologists constructed 42 dip sections and 11 strike sections while attempting to describe the complex structure of the pit area. Cross-section J-J' is reproduced here as Figure 4, with the opal-A Mmds and opal-CT Mmsi diatomite ore shaded. This location of the dip section is shown in Figure 1, and was chosen because of its proximity to Pit 3, the largest of the test pits mined to provide ore to the Dravo and Lurgi pilot plants in the early 1980s. This cross-section shows that the thick accumulations of high-grade diatomite occur in two main lobes. The great thickness of those high-grade diatomite lobes is interpreted to be the result of the imbrication of several thinner slivers of diatomite along a series of low angle thrust faults. The northeasterly lobe has the thickest and highest-grade ore, with some core holes intercepting up to 500 feet of continuous high-grade (up to 35% oil by weight) ore. The southwesterly lobe is generally lower in grade (20% to 25%) and thinner, but has less overburden and would be mined first.

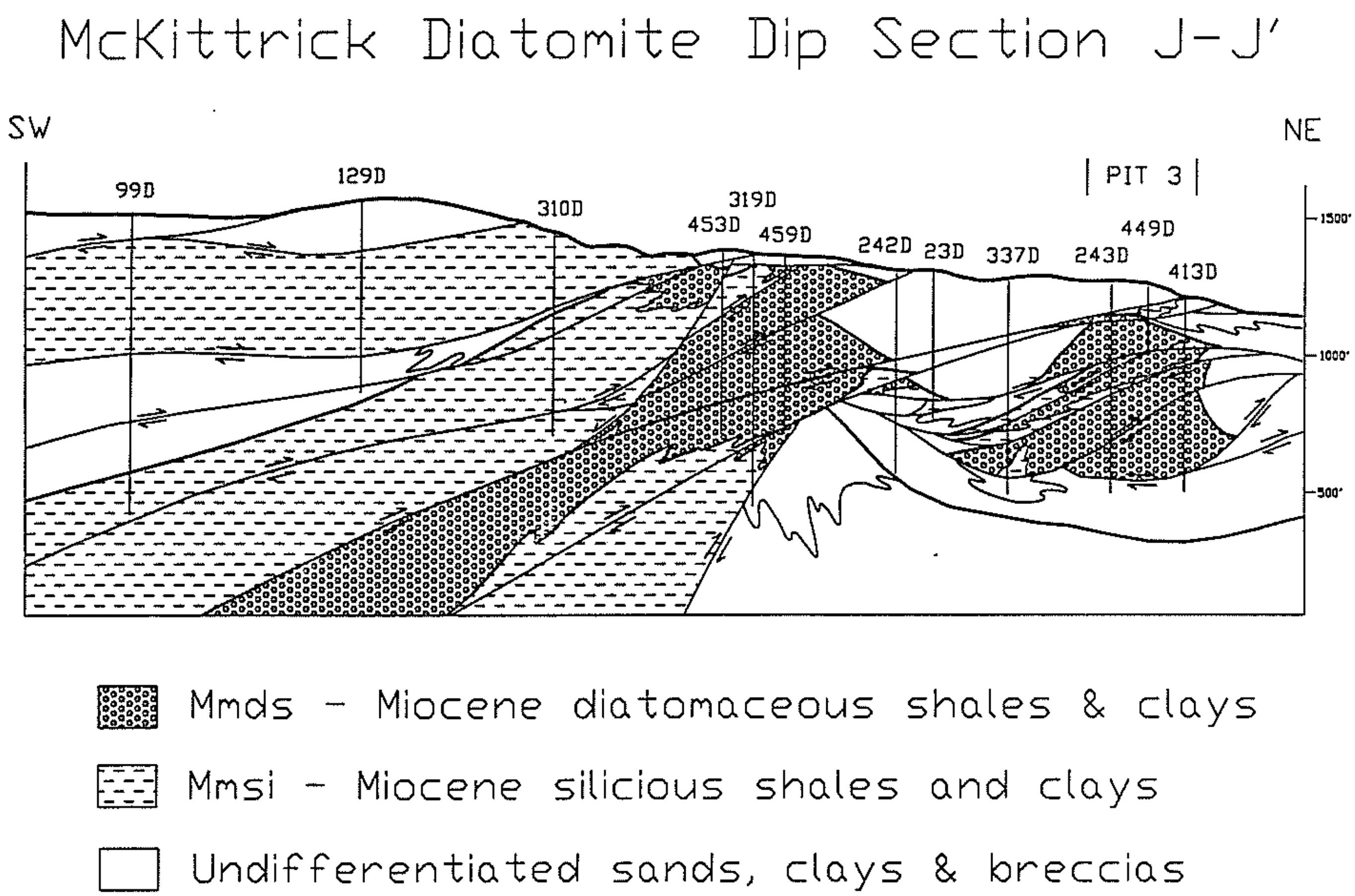
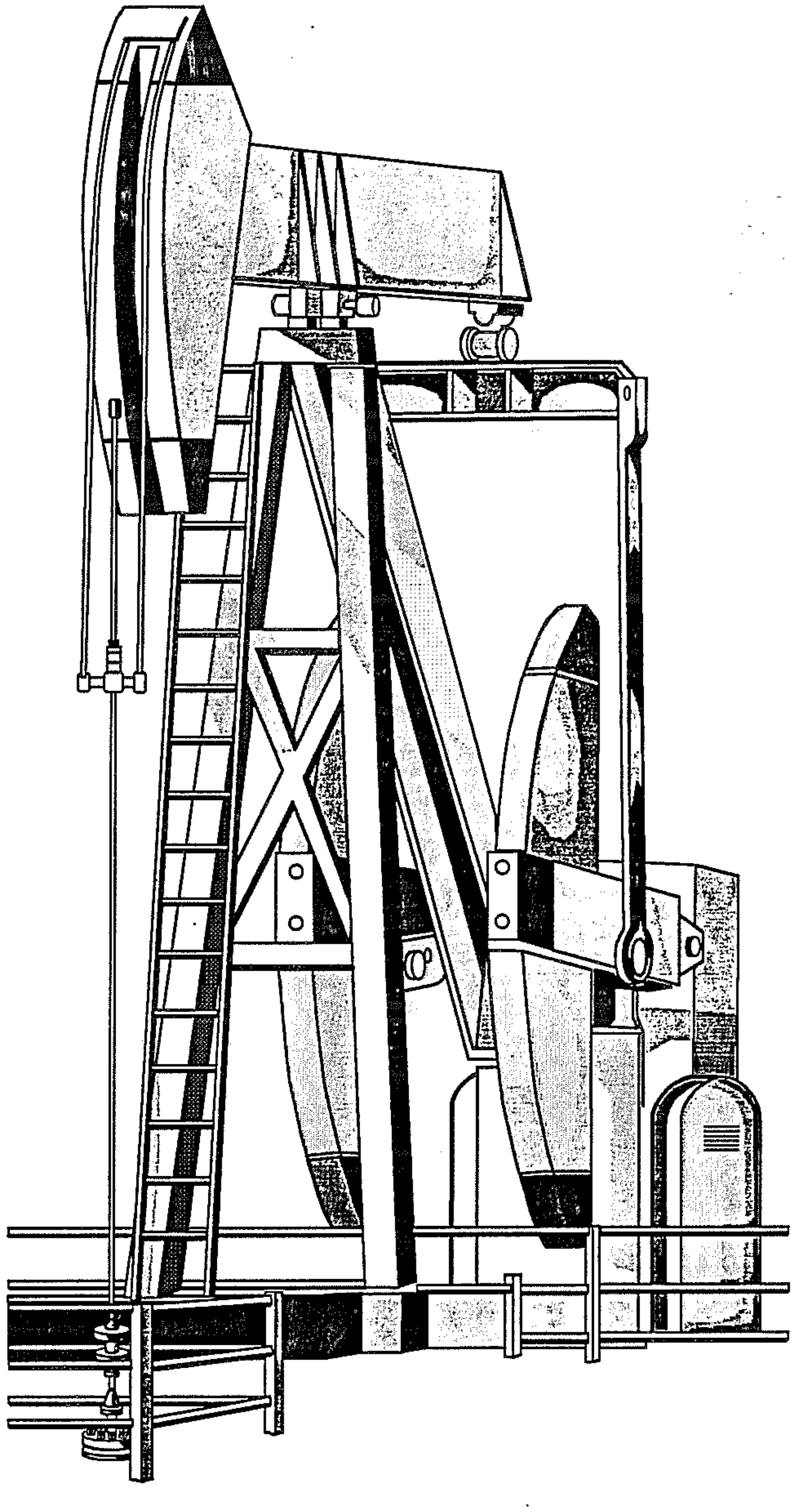


FIGURE 4: Cross-section J-J' highlighting Mmds (opal-A) and Mmsi (opal-CT) ore bodies.

Texaco continues to evaluate the geology and mining potential of this large and valuable resource and expects to produce the oil locked up in the McKittrick diatomite deposit at some point in the future. Research continues on process improvements for surface processing of the diatomite, as well as novel mining techniques and unconventional well bore problem. bore production.



History of the Tar Pits and Tar Mines of McKittrick and Asphalto

Michael S. Clark

(reprinted from the Web Site of the San Joaquin Geological Society)

Spanish explorers traveling through California in the 1700s observed Indians using asphalt for many purposes. In particular, Yokuts Indians of the southern San Joaquin Valley collected asphaltum from natural seeps near the Yokuts village of Wogitu on the west side of the valley. This asphalt was molded into fist-sized tar balls used for trading, waterproofing, and as an adhesive. Decorating was accomplished by inlaying bits of abalone shell into tar stuck on pottery, knives, masks, and clothes.

When Pahmit, a member of the Dumna Yokuts tribe, was about 105 years old, he remembered watching San Joaquin Valley pioneers collect tar from the same seeps he and his family once mined. These pioneers used the tar primarily for waterproofing roofs and to grease wagon wheels.

Inevitably, the Wogitu tar seeps attracted the attention of entrepreneurs who sought to capitalize on this unusual resource. The most successful were John Hambleton and Judge Lovejoy who in 1864 dug shallow pits, 8 to 10 feet deep, near active seeps in what became known as the Asphalto area. They built a small still and refined the tar they collected into lamp kerosene which was shipped by wagon to their agents in Stockton.

Working the asphalt pits was difficult and dangerous. Valley temperatures often hovered around 120° F, reaching as high as 140° F in the pits. Consequently, work was limited to twenty-minute shifts, lest the workers become debilitated by the heat or overcome by noxious fumes rising from the seeps.

By 1891, several 5-foot by 6-foot foot shafts, many lined with railroad ties for stability, were sunk up to one-hundred feet deep into the McKittrick tar seeps. Because the miners working these shafts quickly became covered with asphalt, they usually worked naked. At days end, they cleaned themselves with case knives or wooden scrapers made for race horses, then washed with distillate. Because it was impractical to clean up at noon, they ate lunch 'au naturale' sitting on newspapers at the camp mess.

Rather than dig pits, some prospectors, many of them former Mother Lode miners, dug tunnels in search of the "black gold" of the San Joaquin. These mines were located just outside of McKittrick, a pioneer town that sprang up near the old Asphalto tar pits.

The mines, some up to 300 feet in length, yielded a high-quality asphalt, as much as 90-percent pure, that was better quality than asphalt produced on the island of Trinidad, then the world's main supplier for this resource. Generally, McKittrick asphalt was used to pave streets and sidewalks in San Francisco or to grease log skids in the timber country. Apparently, this commodity was valuable enough to command $30 a ton in the days when a nickel might buy a decent meal.

Gradually, the tar mines were replaced by wells that drilled for the same oil which sourced the tar seeps. A new chapter in the story of the tar mines began in 1896 when the Shamrock gusher blew in at McKittrick field flowing 1,300 barrels of oil per day. Additional discoveries gave rise to nearby Midway-Sunset field, which today is one of the giant oil fields of the United States. Ultimately, the McKittrick and Midway-Sunset areas are expected to produce 3 billion barrels of oil over the lives of the fields.

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For more information on the McKittrick Tar Pits visit the San Joaquin Geological Society Web Site at http://www.sjgs.com.mckittrick.html

Field Trip Stop 6

Antelope Shale at Cymric East Welport Field

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Abstract

This article summarizes the development of the Antelope Shale in the Cymric-East Welport field. The Cymric-East Welport area was obtained by Nuevo Energy in their acquisition of Unocal's California properties. Production from this field has increased from 300 BOPD in January 1997 to 2150 BOPD I December 1997. A team of engineers and geo-scientist representing the operator and service company worked together to maximize the productivity of this field.

Introduction

Horizontal well MJH-1 is officially recognized as the discovery well for the East Welport area of the Cymric Field. The well was drilled in 1992 by Union Oil Company of California (Unocal). Unocal followed up this discovery well with two marginal horizontal wells MJH-2 and MJH-3. The first of these marginal wells was later re-drilled as a vertical producer and hydraulically fracture stimulated. In 1996 Nuevo Energy purchased the East Welport area from Unocal. Three-D seismic and well data from the existing horizontal wells provided enough control for Nuevo to begin drilling in September of 1996. The first Nuevo well, Twisselman 1-14, had a prorated IP of 535 BOPD, which provided enough encouragement to start a continuous drilling program. The operator and service contractor comprised a team to work on the development of this field. The primary focus of this team was to improve upon the results realized from the initial wells. Sixteen wells had been drilled by January 1998. The average IP is 350 BOPD and 200 mcfd of 26-degree gravity oil and 1200 BTU gas.

Geology

Structure

The East Welport area overlies a tight anticlinal fold in the heart of the sycline between the Belridge field and the Cymric field. The area is bounded by a large reverse fault to the northeast and an antithetic reverse fault to the southwest. The northwest limb of the structure dips at about 70 degrees and the southwest limb approximately 50 degrees. Structure on the crest is relatively broad and gentle with many of the wells having dips of less than 10 degrees. The anticlinal nose plunges about 5 degrees. The productive area to date is 1¼ miles long by 1000 feet wide (Figure 1).

Reservoir

Fractured Antelope shale forms the productive formation in the East Welport area. Average drill depth to the Antelope is 6200 feet. The Antelope Shale is composed of claystones, porcelanites, cherts, porcelaneous claystone, mudstone, and minor amounts of dolostone. The average reservoir parameters from core data are 1.2 md of permeability, 29% porosity and 52% oil saturation. Deposition of the Antelope Shale occurred during a time period when deep marine conditions existed within the San Joaquin valley. Deep water coupled with a cool climate represented unique conditions for sedimentation and preservation of diatoms and their siliceous frustrules. Periods of high diatom proliferation alternating with periods of greater detrital sediment influx formed a series of cycles averaging 10' in thickness of alternating siliceous rich sediments and low-permeable mudstones. Subsequent burial and diagenetic conversion to the more brittle siliceous quartz phase porcelanites and cherts crated the current reservoir conditions.

Field History

Bent #1 was the first well drilled in the area that targeted the Antelope Shale. The Antelope Shale was tested with promising oil shows but soon watered out. Bent #1 was subsequently re-completed in the up hole bent gas sand.

The next three wells drilled in the field were horizontal wells MJH #1, #2 and #3. It was reasoned that a horizontal well bore would increase oil production by increasing reservoir contact with the well bore, intersecting natural fractures, and reducing the amount of water production. The average cumulative production from these wells after one year was 39.267 BOE. MJH #1 had the highest cumulative production of 65,500 BOE and MJH #2 had the lowest cumulative production of 18,500 BOE. An acid stimulation treatment was performed on MJH #2 in an attempt to improve production after the well had been produced for sixty days. The initial production after the acid treatment improved from 35 BOPD to 100 BOPD. However the production declined back to the pre treatment levels within sixty days of the acid treatment. The decision was made to abandon the horizontal section of the well and to redrill the well vertically. The well was fracture stimulated immediately after the re-drill was completed. Production increased from 20 BOPD to over 160 BOPD. The cumulative production from the well after being fracture stimulated was 45,500 BOE over the first year.

The favorable production response from the fracture stimulated vertical well as compared to the production of the initial horizontal completion was attributed to a scarcity of natural fractures in the Antelope Shale and to the highly laminated 100 ft. thick section of pay interval. Subsequent testing with the Formation Micro Imaging logging tool confirmed that the productive interval of the Antelope Shale was not as extensively fractured as was originally thought.

The vertical to horizontal permeability anisotropy in this field was unfavorable due to the scarcity of natural fractures and the highly laminated pay interval. Hydraulically fractured vertical wells may out perform horizontal wells in cases of high permeability anisotropy or thick reservoirs.

Vertical Redrill

Nuevo Energy decided to drill additional vertical wells and complete them with hydraulic fractures after the successful vertical re-drill and fracture stimulation of MJH #2. Creating an effective hydraulic fracture in this field proved to be a challenging undertaking. Some of the obstacles which complicate the fracturing process include a complex geology in a tectonically active area, substantial near well bore fracture complexity, and high net fracture pressures. A methodology was adopted for subsequent treatments. This methodology can be summarized as follows:

1. Reservoir Description – Logging tools such as the FMI, DSI and CMR were used to evaluate the formation.
2. Perforation Strategy – The perforating scheme used can have an effect upon fracture geometry and should be considered on a case by case basis.
3. Fracture Modeling – A 2D multi layered model was used to determine the effectiveness of fracture fluid flow in limited entry perforated wells. A pseudo 3D model coupled with a net present value model was used to determine fracture geometry.
4. Treatment Execution – Calibration and step rate tests were used to calculate fluid efficiencies and near well bore pressures.
5. Post Treatment Evaluation – Net pressure matches were used to determine fracture geometry.

Results

The production from the vertical hydraulically fractured wells in this field has been very encouraging. The production from three vertical hydraulically fractured wells outperformed the production of the initial horizontal well in the same area of the reservoir. These four wells are situated in the best portion of the reservoir as of this date. The cumulative production after one year for the vertical fractured wells averaged 118,000 BOE compared to 65,500 BOE for the horizontal well. The average net present value after one year for the fractured wells was a positive $938,000 compared to a negative $290,000 for the horizontal well.

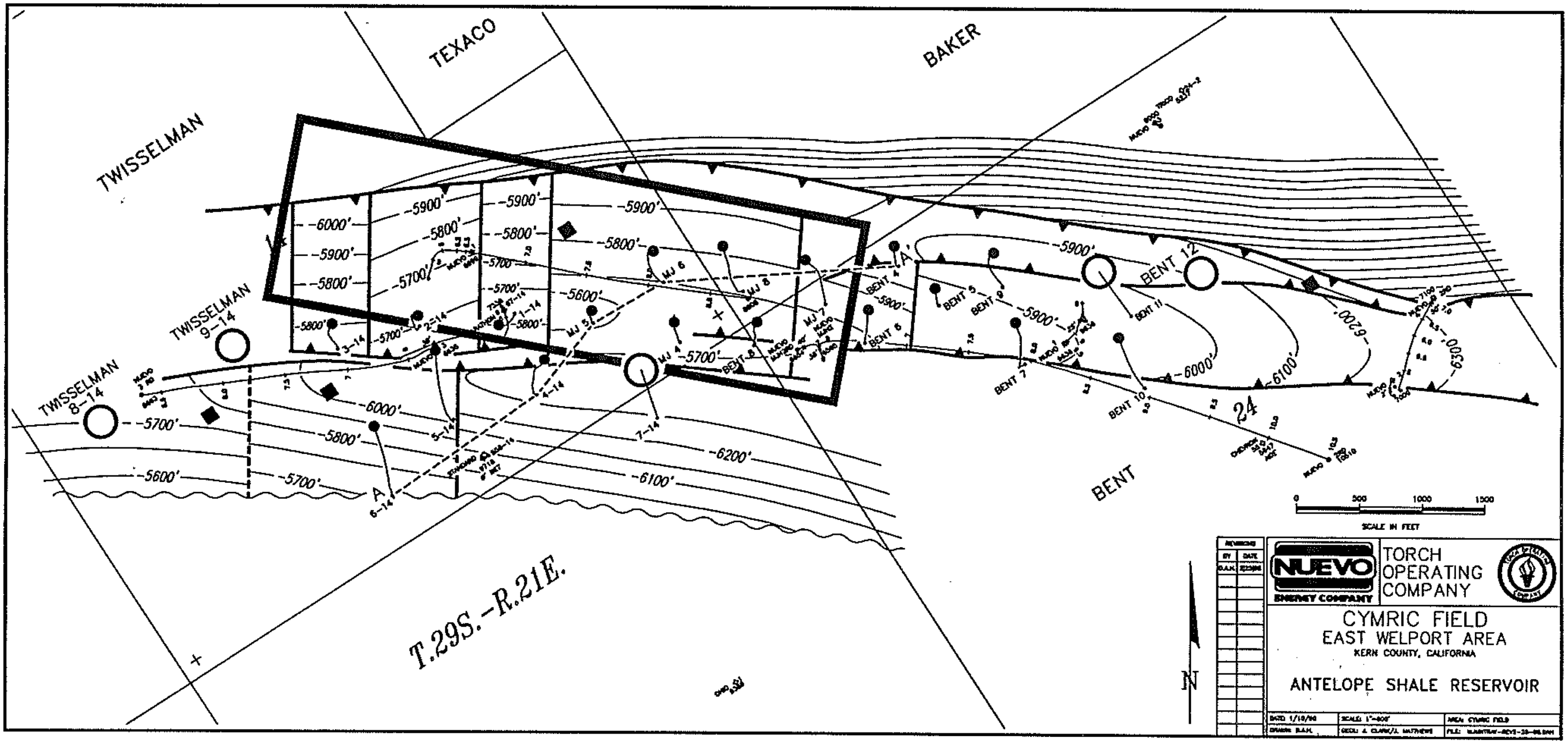

FIGURE 1: Structure map of East Welport area of Cymric field. Contours are drawn on top of the Antelope Shale Reservoir

FIELD TRIP STOP 7

Buttonbed Sandstone at Chico-Martinez Creek

and

FIELD TRIP STOP 8

Upper Monterey Formation at Chico-Martinez Creek

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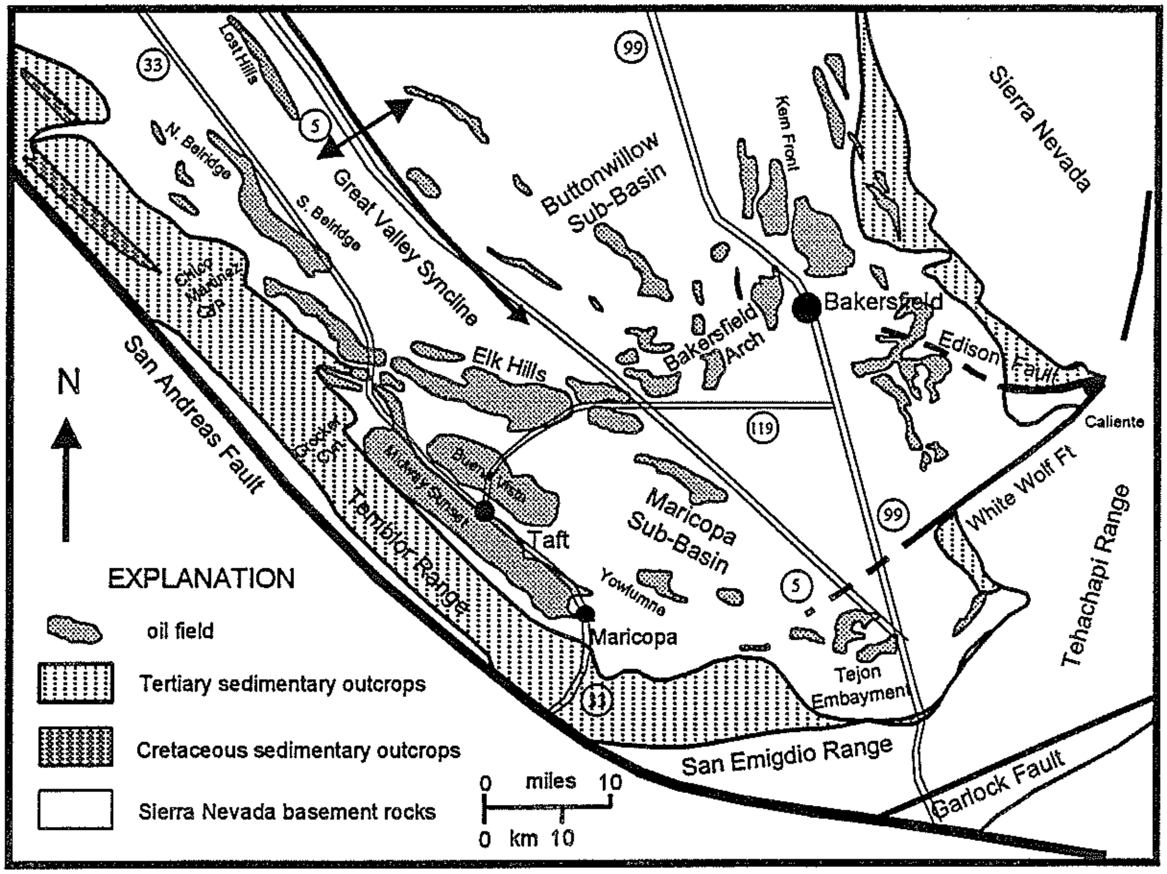
The accompanying articles by Jack Carter and Loretta Williams are excerpted from pages 339-346 and 347-356 of the following publication by the Pacific Section—AAPG:

Kuespert, J. G. and Reid, S. A. eds., 1990, Structure, Stratigraphy and Hydrocarbon Occurrences of the San Joaquin Basin, California: Pacific Section—SEPM and Pacific Section—AAPG, Fieldtrip Guidebook GB65, 366 p.

The San Joaquin Geological Society gratefully acknowledges the Pacific Section—AAPG for permission to reprint these articles



Lost Hills
N. Belridge
S. Belridge
Great Valley Syncline
Buttonwillow Sub-Basin
Kern Front
Sierra Nevada
Bakersfield
Bakersfield Arch
Edison Fault
Caliente
Elk Hills
White Wolf Ft
Tehachapi Range
Maricopa Sub-Basin
Taft
Maricopa
Yowlumne
Tejon Embayment
San Andreas Fault
Temblor Range
San Emigdio Range
Garlock Fault
N
EXPLANATION
oil field
Tertiary sedimentary outcrops
Cretaceous sedimentary outcrops
Sierra Nevada basement rocks
0 miles 10
0 km 10

FIELD TRIP GUIDE TO DEPOSITIONAL ENVIRONMENTS OF THE BUTTONBED SANDSTONE MEMBER OF THE TYPE TEMBLOR FORMATION, CHICO MARTINEZ CREEK, CALIFORNIA

Jack B. Carter
Exxon Company, U.S.A.
Houston, Texas

INTRODUCTION

The Buttonbed Sandstone is a member of the Temblor Formation, a complex assemblage of Oligo-Miocene strata that crops out for over 160 km (100 mi) along the western margin of the San Joaquin Valley. The Temblor comprises several major depositional sequences, a broad range of facies, and varies widely in age along the outcrop belt (Figure 2). No truly representative section of the formation as a whole exists, although Dibblee (1973) proposed a type section in the vicinity of Chico Martinez Creek, the location of this field stop. The type Temblor is significantly older and represents a greater diversity of marine environments than does the Temblor Formation to the north (Graham, 1985). Stratigraphically, the type Temblor is quite complex; it includes three significant unconformities and several depositional sequences (Fig. 3). Unfortunately, the stratigraphic expedient of including all these sequences in the Temblor Formation has obscured a complex middle Tertiary tectonic and sedimentary record, which includes four partial and complete cycles of deposition. These are the lower Zemorrian Cymric Shale sequence; the lower and upper Zemorrian Wygal Sandstone and lower Santos Shale sequence; the Saucesian sequence, including the Agua Sandstone (actually reported to be late Zemorrian), the upper Santos Shale, Carneros Sandstone, and Media Shale; and finally, the basal part of the Monterey depositional sequence, represented by the Relizian Buttonbed Sandstone. All of these, with the probable exception of the Cymric sequence, were preceded by tectonic uplifts and at least local emergence, followed by abrupt subsidence and a return to bathyal depths. Figure 3 diagramatically illustrates these sharp oscillations in paleobathymetry. This pattern is typical of many Tertiary basins in California and reflects the rapidly changing dynamics of a convergent, and later a transform, continental margin. Proximity to the San Andreas fault, a major basement boundary even before the onset of wrench tectonism, makes the type Temblor a particularly sensitive record of active margin tectonics. The fault was a locus of uplift three and possibly four times in the course of Temblor deposition.

The fourth depositional cycle included in the type Temblor is represented only by its basal transgressive sand -- the Relizian Buttonbed Sandstone, which is conformably overlain by bathyal shales of the Monterey Formation. Deposition of the shallow-marine Buttonbed followed the late Saucesian-early Relizian onset of wrench tectonism that was accompanied by regional uplift and locally intense structural deformation (Harding, 1976). The Buttonbed is highly lenticular in its distribution, due in part to residual fault- and fold-related paleotopography.

A diverse assemblage of primarily molluscan Temblor-stage fauna has been collected from several Buttonbed localities in the Temblor Range. Taken as a whole, the fauna corroborates a general shallow-marine interpretation (Carter, 1985). In the vicinity of Chico Martinez Creek the Buttonbed comprises three distinct lithofacies: a lower bioturbated fine-grained sandstone, a thick interval of sandwave cross-stratified sandstone, and an upper, trough cross-stratified coquinoid sandstone. These lithofacies are impressively displayed on Buttonbed Hill, the location of this field trip stop (Figs. 1 and 4).

LITHOFACIES AND OUTCROP DESCRIPTION

The Lower Bioturbated Lithofacies

The basal division of the Buttonbed consists of very fine- to fine-grained, poorly sorted sandstone. Essentially all bedding and other primary sedimentary structures have been destroyed by bioturbation, which is so pervasive that few individual burrows are recognizable. In the better-exposed outcrop of this interval on "1800 Ridge" (Fig. 1), identifiable trace fossils include Chondrites and an obscure Ophiomorpha-like burrow. In the same section, approximately 12 m (40 ft) above the base, a series of pebbly, fossiliferous beds from 15-60 cm (6-24 in) thick extend along the outcrop for as much as 400 m (1300 ft) (Carter, 1985; Figs. 60, 64, 65). Basal contacts of the larger beds are mildly erosive. Clasts include granule-sized phosphatic nodules, pholad-bored dolomite and sandstone clasts, very large colonial barnacle fragments, pecten and oyster valves, and echinoids.

Depositional Environment

The fine grain size and poorly sorted texture of the sandstone coupled with intense bioturbation indicate an offshore setting below fair weather wave base. The pebble-rich beds with erosional bases reflect occasional periods of higher energy. The sandstone above and interbedded with the overall pebble-bed interval is essentially devoid of both pebbles and fossils. This complete lack of similar clasts suggests an allocthonous origin, as opposed to the concentration of in situ clasts in response to storm-current winnowing. Thus, the pebble beds probably represent sheet-like aprons of debris swept off nearby marine banks or flushed out of interbank channels into normally quiet waters by intense, storm-generated currents.

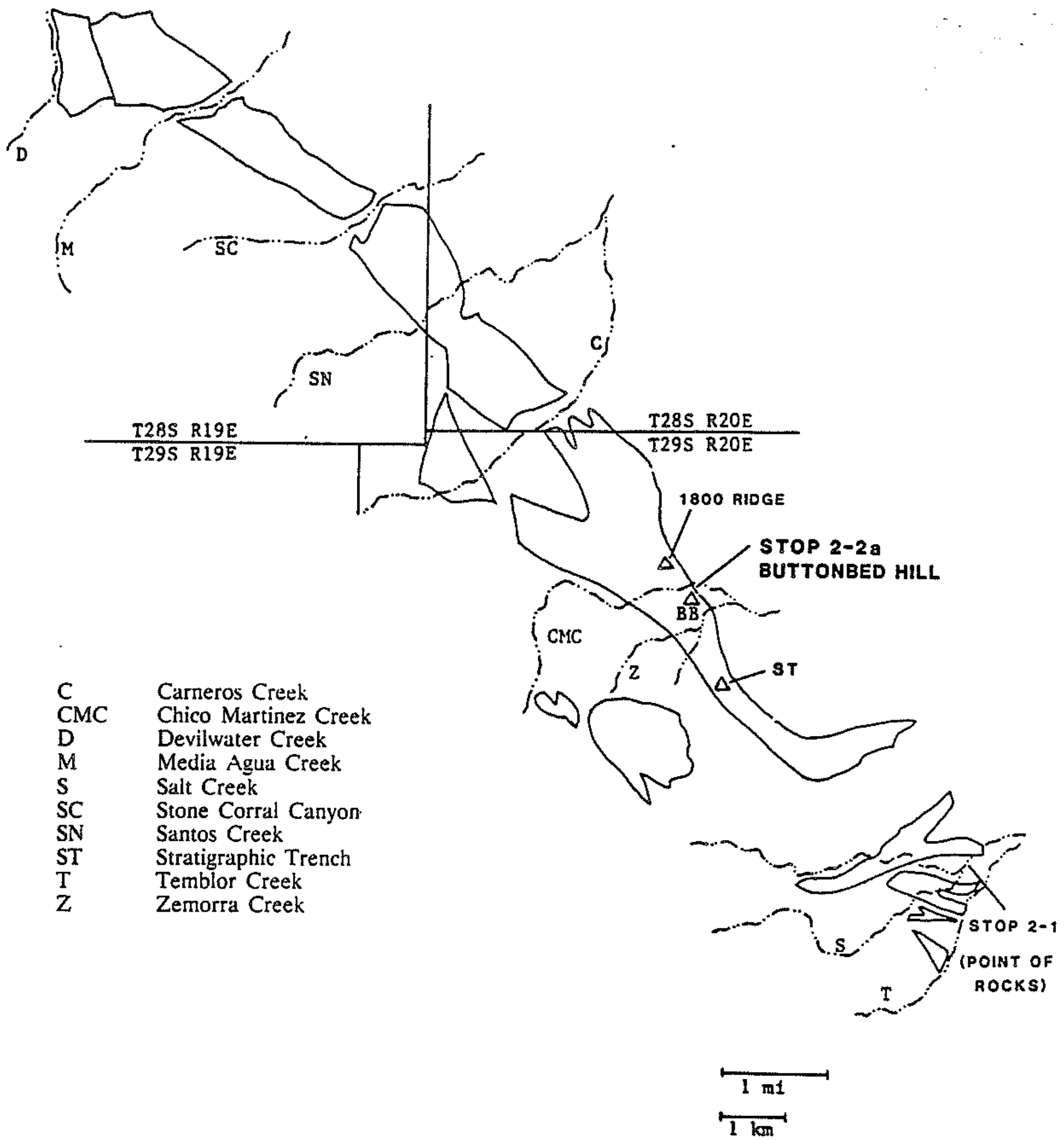


Figure 1. Outcrop of Temblor strata in vicinity of type area and location of field trip stop 2-2a (Buttonbed Hill). Geology from Dibblee, T. W., Jr., 1977, Geologic Map of the Carneros Rocks Quadrangle, Kern Co., California, U.S.G.S. Open-File Report 77-611.

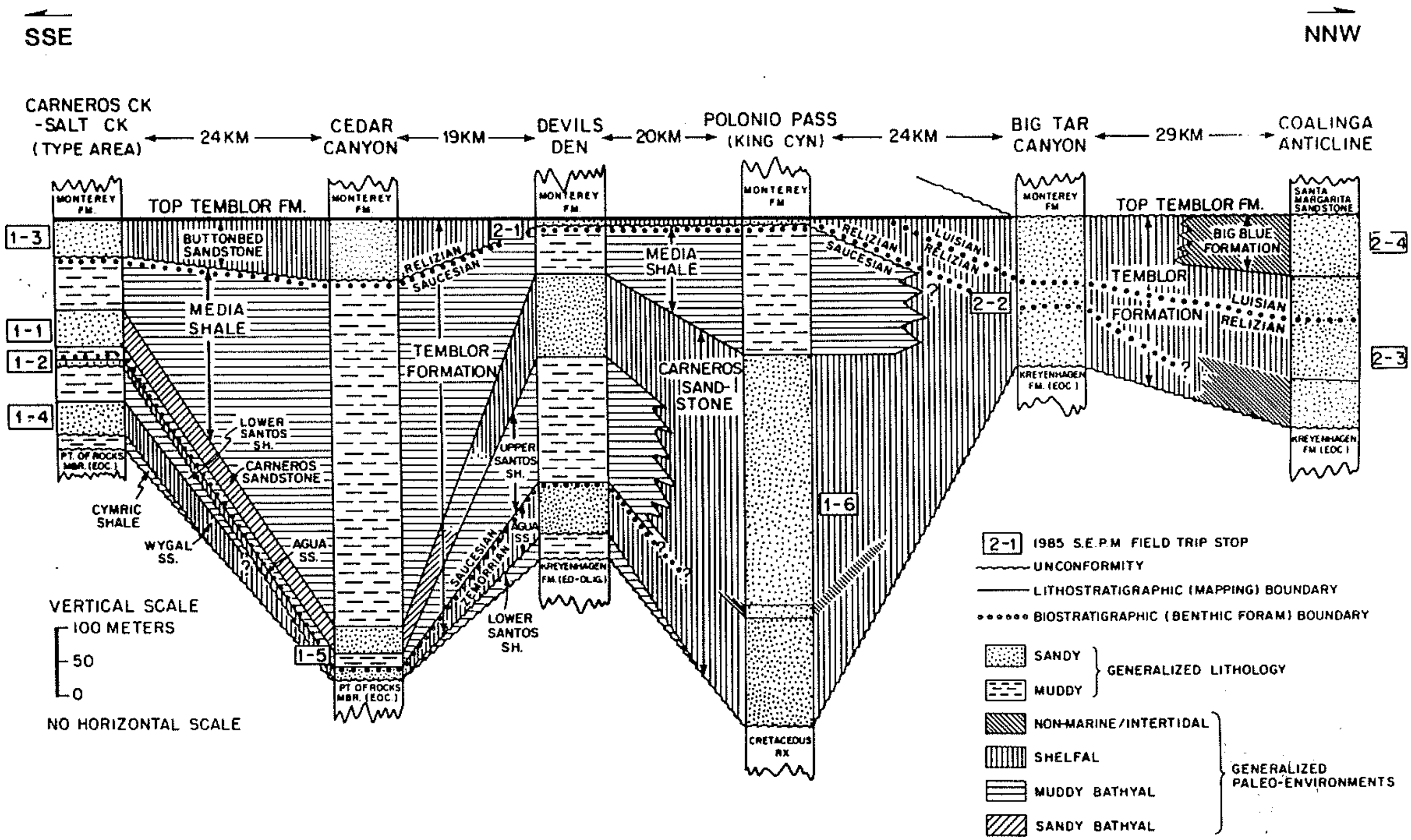


Figure 2. General stratigraphic and paleoenvironmental relations between sections of the Temblor Formation between the type area and Coalinga anticline. (From Graham, 1985, Figure 2.)

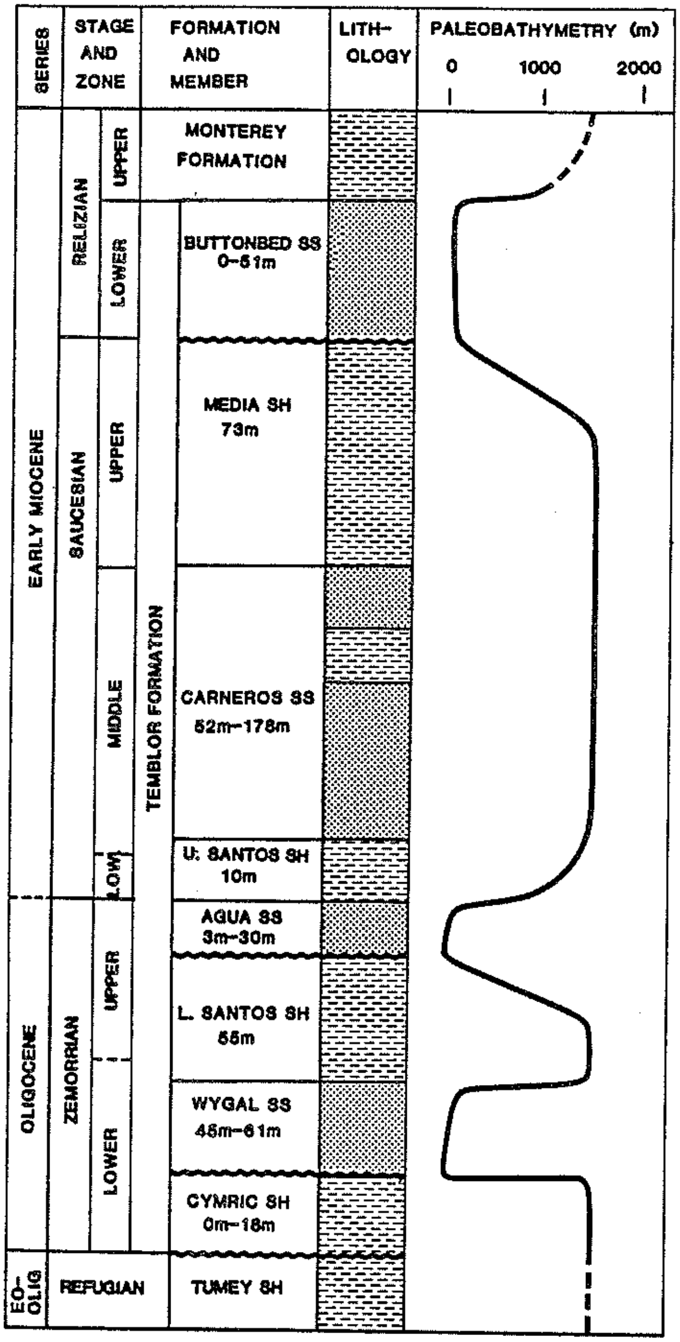


Figure 3. Stratigraphy and paleobathymetry of the type Temblor Formation. Age assignment from Kleinpell (1938) and Foss and Blaisdell (1968).

The Sandwave Lithofacies

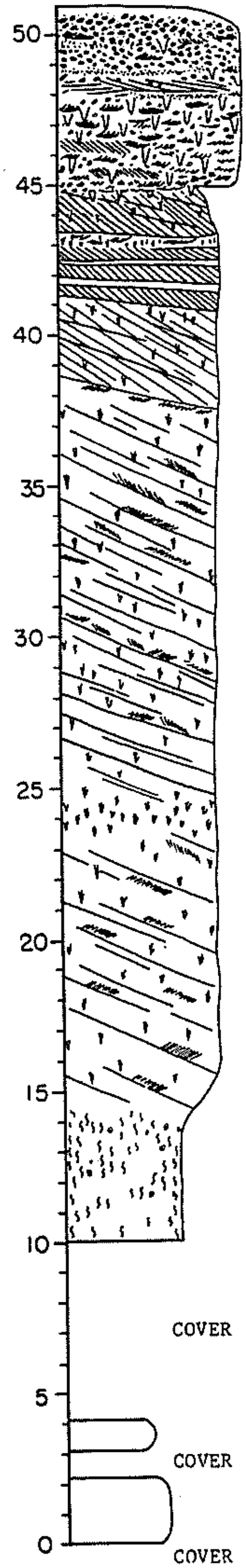
The lithofacies which succeeds the lower bioturbated interval is most notable for cosets of high amplitude, tabular cross-stratification (Fig. 4). This interval is lenticular in cross-sectional geometry, achieving a maximum thickness of 26 m (85 ft) on Buttonbed Hill and pinching out laterally to the northwest and southeast within 2 km (1.25 mi). The contact with the underlying bioturbated sandstone is relatively sharp, but there is no basal lag or other evidence of erosional scour. Throughout most of the interval, the sandstone is well sorted and medium- to coarse-grained. The scale of cross-stratification is impressive. Amplitudes approach 8 m (26 ft) in the lower part of the section on Buttonbed Hill (Fig. 5a). There is a decrease in amplitude higher in the same section to only 1-3 m (3-10 ft). Well-developed reactivation surfaces are common within the larger sets (Fig. 5b). Foresets dip at angles ranging from 18 to 32 degrees, and foreset contacts are generally not strongly tangential with underlying sets. Recognizable contrasts in grain size are rare, and silt or mud drapes are absent.

Paleocurrent directions of the larger sets are unimodal to the south-southwest (Fig. 6; Carter, 1985, Appendix 2). In many of the larger sets a much smaller sandwave cross-stratification is well developed along the foreset surfaces of the larger sets. Both tabular and trough sets are common, and amplitudes range from 10-80 cm (4-32 in). Paleocurrent directions of the smaller, superimposed sets are much more variable than in the larger sets. Essentially all possible current directions are present, but there is a strong cluster to the north. This is particularly true in the lower 7 m (23 ft), where 85% of the smaller sets climb back up the avalanche faces of the larger sets in a true bipolar direction (Fig. 7).

Depositional Environment

The very high amplitude, tabular cross-stratification in this interval was produced by a series of south-southwestward migrating sandwaves. The largest sandwaves exceeded 8 m (26 ft) in height. An empirical estimate of the maximum ratio of sandwave height to water depth is 1:3 (Belderson et al., 1982). Sandwave heights exceeding 8 m (26 ft) thus indicate a minimum water depth of about 25 m (82 ft). A very small spread in foreset attitudes indicates straight to mildly sinuous crests. Much smaller trough and tabular sandwaves climbed up, down, and along the lee slopes (and probably the unpreserved stoss slopes) of the larger sandwaves. These smaller bedforms record erratic and frequently reversing secondary currents. In unidirectional flows, separation eddies can produce a backflow (i.e., a reversing current) and regressive ripples in the troughs and on the lower slopes of encroaching sandwaves. This mechanism cannot account for much of the regressive cross-stratification in this section, however, because many sets occur on the upper slopes of the larger sandwaves. The common reactivation surfaces may also indicate erosion by reversing currents and are considered by some workers to be indicative of a tidal regime (Bridges, 1982), although similar features have been produced randomly in unidirectional flume studies (Allen, 1973).

In modern seas, large sandwave fields are particularly abundant on tide- and storm-swept shelves. The best known examples occur in the shallow seas surrounding the British Isles (Belderson et al., 1982). In most cases the bedforms occur in association with strongly asymmetric tidal currents whose mean spring tide near-surface velocities exceed 65 cm/s (26 in/s). Although less common, sandwaves are also found on shelves with tidal currents normally below this threshold. In these cases, they can generally be related to short-lived currents produced by wind-shear during intense storms (Johnson, 1978). In the absence of unequivocal evidence for tidal currents, such as cyclic spring/neap variations in foreset thickness, it is not possible to determine with certainty the relative importance of tide versus storm currents in Buttonbed deposition. The bipolar cross-stratification in the lower part of the section suggests some tidal influence. On the other hand, the thin, highly biotur-



Crs-v crs coquinoid ss w/ abund. echinoids & shell hash, rare barnacles & pectens. Several thin (10-25 cm) horizons w/ concentrations (2-10%) of granule-sized phosphatic nodules. Traces of trough & tabular x-strat. (ampl. <20 cm). Intensely bioturbated.

Crs, bioclastic ss. Abund. small-scale trough x-strat. w/ ampl. of 5-18 cm. A few larger tabular sets (ampl. 30-76 cm). Paleocurrents mainly to SW. Echinoids and conical burrows 15-25 cm deep & 6-10 cm in dia. are common.

Locally erosional contact.

Med-crs, well-sorted ss. Tabular to slightly wedge-shaped sets of x-strat. dipping S-SW. Ampl. 30 cm - 2 m. Common reactivation surfaces within the larger sets. Smaller trough & tabular sets (ampl. <20 cm) are common between the larger sets. Bioturbation is present throughout the interval but concentrated between the larger sets. Some foreset laminations are more crs than surrounding ss, while others contain sporbo & glauconite in concentrations of 5-20%.

<u>14.5-38.5 m</u>: Med & crs, well-sorted, hash-rich ss. S-SW dipping foreset lamination throughout interval. Set boundaries obscure but set thicknesses probably from 4-8 m. Smaller trough & tabular x-strat. sets (ampl. 8-60 cm) are developed along foreset laminae of the large sets. Paleocurrents indicated by the smaller sets are highly variable, but concentrated to the north.

Probable set boundary.

Med-crs, hash-rich ss w/ a few echinoids. Intensely bioturbated.

F ss. Intensely bioturbated.

Massive, vf ss. Poorly exposed.

Figure 4. Measured section of the Buttonbed on Buttonbed Hill near Chico Martinez and Zemorra Creeks (1750 ft south, 1500 ft west of NE corner of section 9, T29S, R20E). Scale in meters.

Figure 5a. Giant sandwave cross-stratification on Buttonbed Hill. Gray sagebrush (average height 0.3 m; 1 ft) for scale.

Figure 5b. Slightly wedge-shaped set of cross-strata with well-developed reactivation surface (directly above hammer). The set amplitude is approximately 3 m (10 ft).

bated intervals between some sets of cross-strata may reflect the more "normal" mode of sedimentation in which long periods of low-energy conditions were interrupted only briefly by intense storms. One conclusion is certain: strong currents operated in this locality for a significant period of time in a remarkably unidirectional pattern. It seems unlikely that several discrete storm events produced the same predominantly unidirectional current pattern without the aid of consistent, if subordinate, tidal currents, or, alternatively, constraints imposed by coastlines or other physiographic features. A related consideration is the probability that seafloor relief, related to the pre-Relizian deformational event, influenced sandwave development. On modern shelves, pre-Holocene topographic features, submerged (or isolated as islands) by the Holocene transgression, influence the distribution of sandwave fields and locally constrain and intensify regional current patterns (Caston and Stride, 1973). The distribution of the Buttonbed around the partially truncated fold-crest in Antelope Hills Oil Field (Carter, 1985, Fig. 57) is one example of the influence of topography on Buttonbed deposition. Similarly, the absence of the Buttonbed near Temblor Creek, where approximately 300 m (1000 ft) of underlying section are missing, is probably also related to fault or fold-induced relief. These structural features created shoals or small islands that may have played an important role in producing the strong currents recorded in this lithofacies.

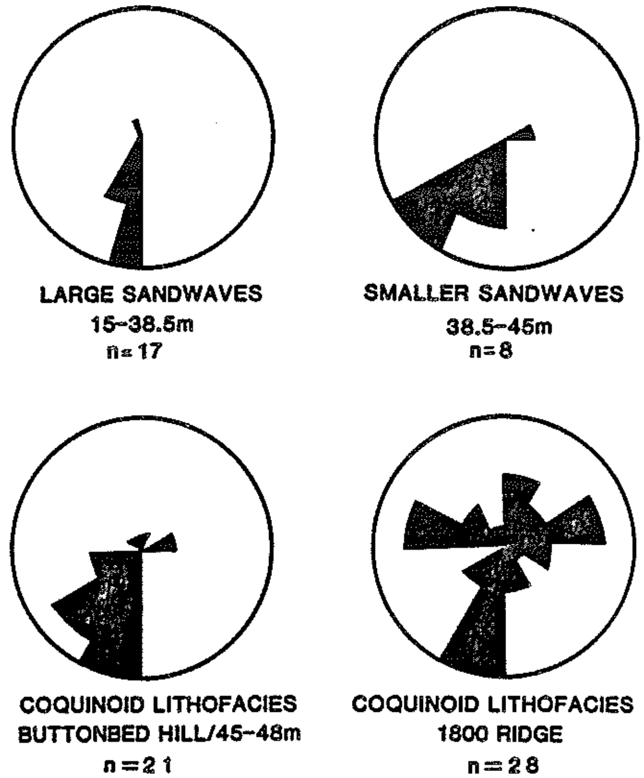


Figure 6. Paleocurrent patterns in the Buttonbed Sandstone. Numbered intervals (45-48 m, etc.) refer to the measured section of Figure 4.

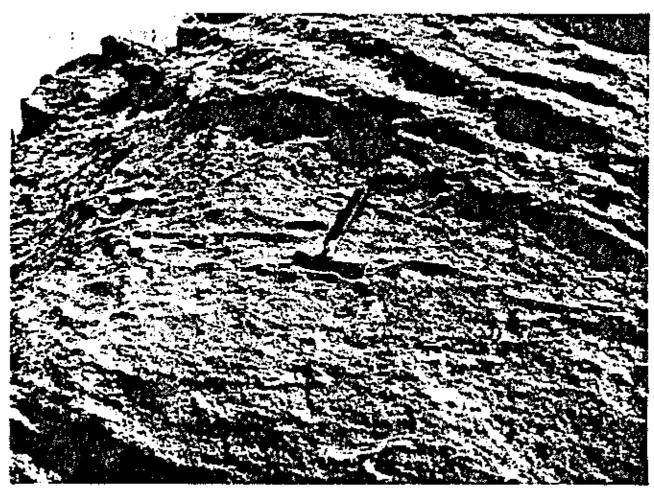


Figure 7. Regressive cross-strata (dipping to the left, parallel to the hammer head), climbing up the foreset bedding (the larger ledges dipping to the right) of a much larger sandwave.

The "Coquinoid" Lithofacies

The sandwave lithofacies is succeeded by a thinner interval of coarse, highly fossiliferous and trough cross-stratified sandstone. The base of the unit is erosional, while the upper contact is sharply gradational with the bathyal shales of the Monterey Formation. Over an interval of 1-2 m (3.3 - 6.6 ft), the coarse sandstone fines rapidly upward into silty Monterey Shale, with abundant foraminiferal tests and pelletal phosphorite. The following features distinguish the coquinoid lithofacies from the sandwave interval:

(1) A more complex and much smaller-scale mode of cross-stratification. Trough sets (Fig. 8) with amplitudes of 5-20 cm (2-8 in) and less common tabular to slightly wedge-shaped sets with amplitudes of 20-40 cm (8-16 in) are common throughout the interval. Paleocurrents exhibit a wider scatter (Fig. 8), particularly on "1800" ridge.

(2) A coarser, bioclastic texture, locally approaching that of a true coquina.

(3) A much greater abundance of the button-like echinoids. They occur scattered throughout the interval and in beds where they comprise up to 70% of the rock. These "button beds" are probably lag deposits resulting from storm-wave or current winnowing (Graham and others, 1982).

(4) More abundant bioturbation, including unidentified conical burrows 15-25 cm (6-10 in) deep and 5-10 cm (2-4 in) in diameter (Fig. 8). Poorly preserved Skolithos traces are also present.

Depositional Environment

Several features of this upper lithofacies strongly suggest a shallower environment than that for the sandwave interval. Erosional scour by wave and/or current action is indicated by the basal contact. Although not limited to shallow water, scour is certainly more common there. Coarse to very coarse grain size and abundant shell hash also characterize shallow-marine environments in which vigorous wave or current energy winnows finer sediment. The pervasive trough cross-stratification was produced by highly sinuous or lunate sandwaves with amplitudes of 5-25 cm (2-10 in). Lunate sandwaves of this size abound in many high-energy shallow-marine environments. Shoaling is also suggested by the decrease in sandwave size in the upper part of the subjacent sandwave interval on Buttonbed Hill (Fig. 4). Water depth is one of several limiting factors affecting sandwave size (Belderson et al., 1982). A minimum water depth of about 25 m (80 ft) was suggested for the larger sandwaves; by that empirical formula a minimum depth of only 6 m (20 ft) is obtained for the smaller sandwaves directly below this lithofacies.

If the coquinoid lithofacies was deposited above fair weather wave base, as appears likely, two possible mechanisms may account for the shoaling. The sand transported by the sandwaves may have accumulated over time and formed a positive feature on the sea floor. Longitudinal sand banks which form in this fashion are common on several modern shelves, including the southern bight of the North Sea. Tidal sand banks can exceed 40 m (131 ft) in height and frequently grow near enough to the sea surface for their crests to be strongly affected by wave action (Belderson et al., 1982). If the lower sandwaves on Buttonbed Hill were deposited in a water depth of 35-40 m (115-131 ft) and no subsidence, uplift, or eustatic sea-level changes occurred, then the thickness of the intervening section (30 m; 100 ft) dictates a paleobathymetry of only 5-10 m (16-33 ft) for the "coquinoid" lithofacies. A minor relative fall in sea level is a second possible cause. This could have resulted either from late-stage tectonic uplift or a minor eustatic event.

The increase in bioturbation, decrease in grain-size, and pelletal phosphorite of the upper few meters records a rapid transgression prior to deposition of the Monterey Shale. This interval represents a sediment-starved, organic-rich, outer shelf or upper slope setting transitional to the bathyal Monterey (Graham et al., 1982).

SUMMARY

The various lithofacies of the Buttonbed record a number of sub-environments on the early Relizian shelf. The lower part of the sandstone was deposited in quiet waters some distance from shore and well below fair weather wave base. Coarse sand, shell, and pebble lags record the passage of large storms which swept debris from nearby shoals. Sandwave fields appeared after this initial phase of low-energy deposition. Their presence may reflect continued shoaling in the early Relizian regression. Sandwaves migrated to the south-southwest in response to tide and/or storm currents and may have formed ridge-like accumulations on the sea floor. Pre-Relizian structural features produced shoals or small islands which influenced the direction and intensity of local current patterns. The sand thins, becomes patchy, and disappears altogether to the south and east, presumably towards the shelf break. Continued shoaling exposed a broad area to high-energy shallow marine processes, possibly above fair weather wave base. Vigorous currents or wave action produced local erosion and deposited a thin sheet of coarse, coquinoid, cross-stratified sandstone. Initial stages of the subsequent transgression are recorded in the thin interval which caps the Buttonbed. Coarse, inner-neritic sandstone fines upward into silty, bioturbated sandstone, phosphatic mudstone, and finally into bathyal shales of the lower Monterey. The Buttonbed is thus a basal transgressive sand of the Monterey depositional sequence, and a part of the fourth such sequence included within the type section of the Temblor Formation.

(Note: This article is largely reprinted from an article and field trip stop description by the author in: Graham, S. A., ed., 1985, Geology of the Temblor Formation, Western San Joaquin Basin, California: Society of Economic Paleontologists and Mineralogists, Pacific Section, vol. 44, p. 5-18 and 185-187.)

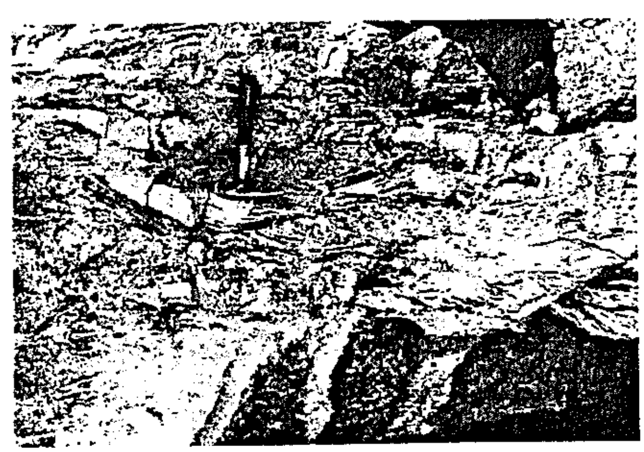


Figure 8. Coarse, trough cross-stratified sandstone typical of the coquinoid lithofacies. Note conical burrows on the right.

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DESCRIPTION OF THE MONTEREY FORMATION: CHICO MARTINEZ CREEK AREA, WESTERN KERN COUNTY, CALIFORNIA

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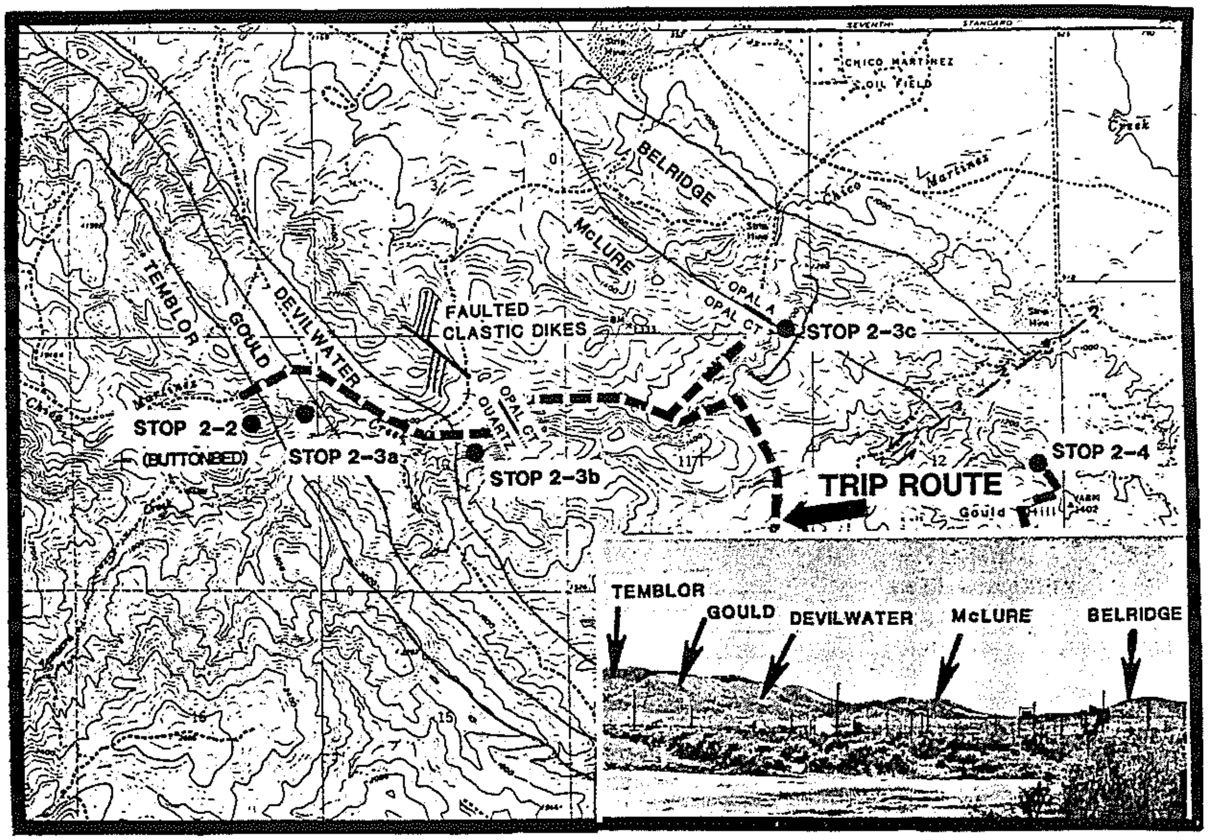

Figure 1. Portion of Dibblee map showing route on Twisselman Ranch property for day two field trip stops. Contacts of members of the Monterey are modified from Dibblee(1973). The Belridge Diatomite is considered a member by Dibblee; however we include it as a facies of the Reef Ridge member. Biogenic silica phase change boundaries from Murata and Larsen(1975). Photographic inset shows geomorphic expression of the four Monterey Formation Members as they occur here in a view looking WSW from Chico Martinez oil field.

CHICO MARTINEZ CREEK

The Chico Martinez Creek area is especially important to the history of geological thought in the San Joaquin Basin of California because it includes the type sections of Temblor and Monterey Formation members, as well as the type Zemorrian provincial benthic foraminiferal stage. In addition, the area provides the least structurally disturbed Temblor-Monterey section in the Temblor Range.

Drive 0.25 mile from Button Bed stop to right turn near the old corrugated pipe. Park on the alluvial plain for the first Monterey Formation stop.

MONTEREY FORMATION

As with most of the sedimentary units in the San Joaquin Basin, there is some controversy over the stratigraphic nomenclature of the Monterey Formation. There are even disagreements as to whether the term "Monterey" itself is appropriate, given the amount of fine-grained clastic dilution in the San Joaquin basin unit relative to the coastal Monterey Formation. The stratigraphy we will be using here is shown in Figure 2.

The thick marine basin fill known as the Monterey Formation crops out in the Temblor Range where it is generally divided into four members: Gould, Devilwater, McLure (subdivided informally into the Antelope Shale and MacDonald Shale), and Reef Ridge (locally including the Belridge Diatomite). The classic locality for examining these units is in the Chico Martinez Creek exposure, since this is the only place where all four members are exposed. We will be spending a fair amount of time examining this section to get a feeling for the Monterey Formation as it exists in the basinal portion of the Miocene basin.

Northward, in the Pyramid Hills/Reef Ridge area, the section thins to only two members: undifferentiated McLure Member and the overlying Reef Ridge Member. The classic locality for examining the Monterey Formation there is in Big Tar Canyon; we will be visiting this locality to compare the sedimentology of the shelf facies with the basinal facies we see here in Chico Martinez Creek.

The Monterey Formation is made up mostly of a few basic depositional and diagenetic components. Variations in relative concentrations of these components yield the different lithologies of the Monterey Formation.

Table I. Components of the Monterey Formation (Table Ia.) and the lithologies of the basic components (Table Ib.). Diatomites are made up mostly of diatoms, with lesser radiolaria, silicoflagellates and sponge spicules, which are also sources of biogenic silica. Diatomaceous shale contains more admixed detritals. Silica diagenesis changes diatomite to either chert or porcelanite, depending on original diatomite purity. Diatomaceous shale changes through diagenesis to siliceous shale. If there are abundant foraminifera and/or coccoliths in the rock, the prefix "calcareous" is appended to the lithology name. If detrital components dominate, the resulting rocks are called clay shales, siltstones, or sandstones, depending on grain size and mineralogy. Diagenesis may cause introduction of significant amounts of phosphate or replacement dolomite into the rock. If so, the term "phosphatic" or "dolomitic" is added to the rock name. If the rock is wholly replaced by dolomite, as commonly happens, it is simply referred to as a dolomite. Mat-laminated lithologies are rocks retaining fossil sulfur-oxidizing bacterial mats; these rocks retain a distinct thin wispy lamination and high organic carbon content.

A

BIOGENIC COMPONENTS

DIATOMS
FORAMINIFERA
COCCOLITHS
RADIOLARIA, SILICOFLAGELLATES, SPONGE SPICULES

DETRITAL COMPONENTS

CLAY
QUARTZ, FELDSPAR

DIAGENETIC COMPONENTS

OPAL-CT & QUARTZ
DOLOMITE
PHOSPHATE
CLAY

B

LITHOTYPES

DIATOMITE
DIATOMACEOUS SHALE — OPAL-A

CHERT
PORCELANITE
SILICEOUS SHALE — OPAL-CT/QUARTZ

DOLOMITIC LITHOLOGIES / DOLOMITE
MAT-LAMINATED LITHOLOGIES
PHOSPHATIC LITHOLOGIES

CLAY SHALE
SILTSTONE
SANDSTONE

While most Monterey Formation lithologies appear boringly similar to the untrained eye, the differences have very important effects on petroleum source and reservoir characteristics. We will talk a little about this as we go along.

Table II. Reservoir lithologies of the Monterey Formation. Diatomite, since it is made up mostly of microscopic fossils, typically has an extremely high porosity, but the pores are mostly microscopic and poorly connected, resulting in very low permeabilities. The brittle lithologies - chert, porcelanite, dolomite and to a lesser extent, calcareous chert and calcareous porcelanite - make up the Monterey Formation fractured reservoirs. Deepwater sandstones enclosed in the Monterey Formation fine-grained rocks are more conventional reservoirs, generally having matrix porosity and permeability, and a positive correlation between the values of the two.

LITHOLOGY	RESERVOIR TYPE
SANDSTONE	"CONVENTIONAL"
DIATOMITE	HIGH MX. Ø & LOW MX. PERM.
CHERT, PORCELANITE	FRACTURE
DOLOMITE	
CALCAREOUS CHERT	
CALC. PORCELANITE	

STOP 2-3a. TRANSITION FROM THE GOULD MEMBER TO THE DEVILWATER MEMBER

The members of the Monterey Formation can be distinguished from each other at Chico Martinez Creek partly on the basis of their geomorphic expression (Fig. 1). The Gould Member holds up the ridge which we followed as we drove upsection from the Button Bed stop. We are now below the low saddle which represents the less resistant Devilwater Member shales.

This outcrop demonstrates the transition from lithologies distinctive of the Gould Member to lithologies distinctive of the Devilwater Member (Fig. 3). The rocks in the creekbed 3 meters (24 feet) stratigraphically below this outcrop are thinly laminated calcareous porcelanites and calcareous siliceous shales typical of the Gould Member, the carbonate component is largely foraminiferal. Benthic foraminifera from these rocks were dated for us as Relizian by the Union Oil Paleo/Strat. Division laboratories in 1982 (see also Foss and Blaisdell, 1968).

The major outcrop of this stop is made up primarily of calcareous siliceous shales which are planar bedded, thinly laminated, and exceptionally rich in foraminifera. The roof of the small excavation in the outcrop (Fig. 3a) is made up of calcareous shales which contain articulated fish skeletons. These shales were also dated for us by Union Oil, and fall at the Relizian/Luisian boundary. Stratigraphically higher in the section, the beds become more fissile and less resistant to weathering, until we encounter the poorly exposed clay shales characteristic of the Devilwater Member (Fig. 3b). These have been dated by Foss and Blaisdell (1968) as Luisian.

Also note the dolomite concretions at this stop. The overlying and underlying strata bend around them due to differential compaction, indicating they were formed early in diagenesis. In some California oil fields these dolomites are important as fractured reservoirs for hydrocarbons.

Return to buses. Return to main road. Continue 0.15 mile to fork in road.

We are traveling along strike of the low-relief Devilwater Member saddle, looking toward the McLure Member in the next ridge. The striped appearance of that ridge is caused by exposures of regularly spaced dolomite concretionary beds (Fig. 4). Continue 0.4 mile. If you look to your left, you can begin to see two resistant features which cut perpendicular to bedding in the McLure Member ridge (Fig. 4). These are clastic dikes. They have been described and discussed by Peterson (1958).

We will continue for 0.3 mile, just beyond the old corral on the left, and pull over for Stop 2 in the Monterey Formation. Walk down to the creek.

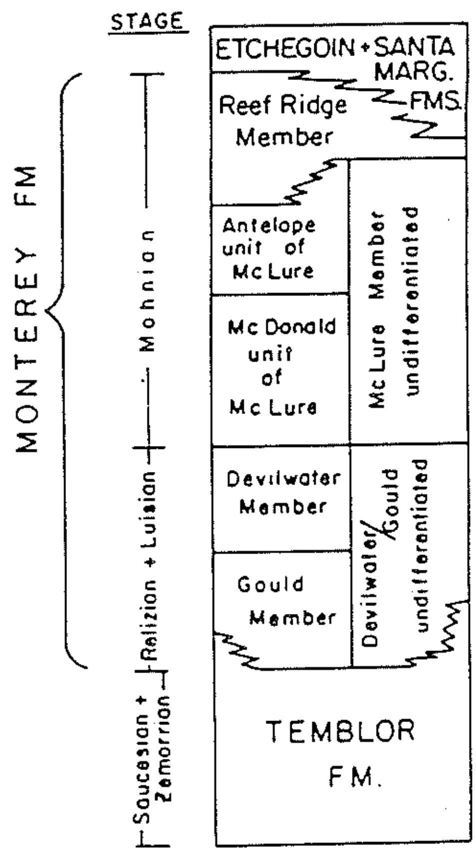

Figure 2. Stratigraphic nomenclature of the Monterey Formation in the San Joaquin Basin, from Graham and Williams(1985). The Belridge Diatomite, which we will examine on this trip, is considered a facies of the Reef Ridge Member.

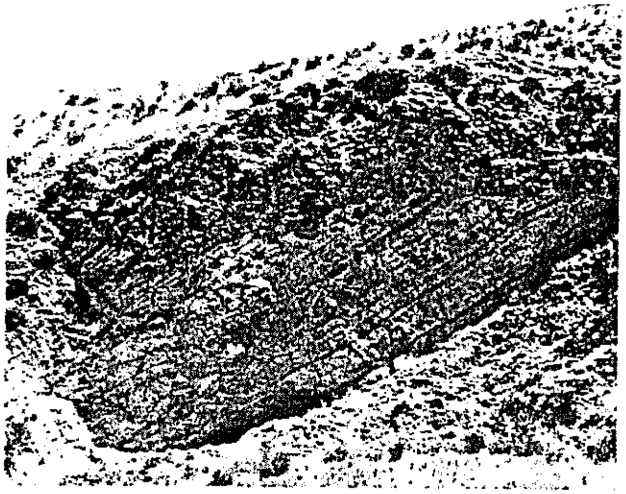

Figure 3a. Outcrop exposure of Gould Member/Devilwater Member transition in the Chico Martinez Creek bed. Biogenic silica is in the quartz phase.

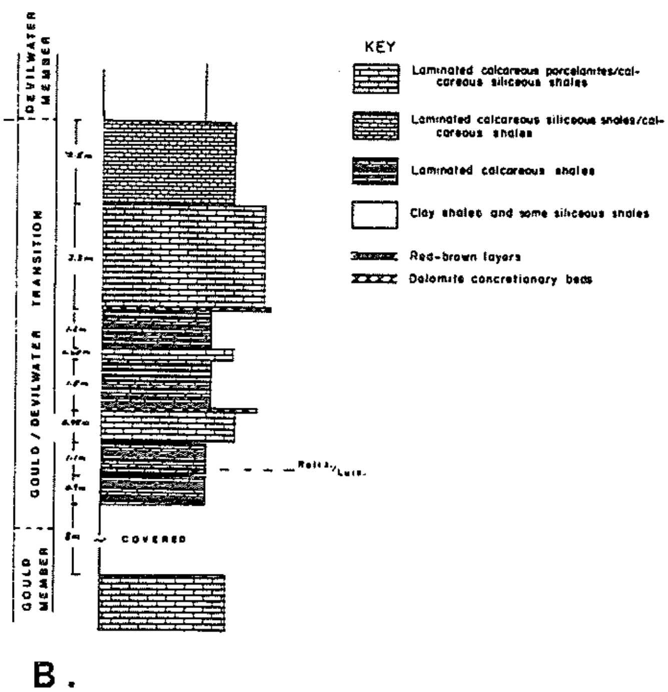

Figure 3b. Measured section of this locality.

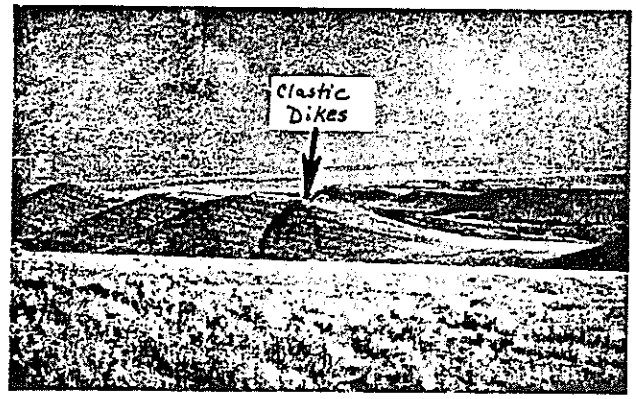

Figure 4. View looking eastward from Chico Martinez Creek. Ridge in foreground is held up by the McLure Member. Subhorizontal "stripes" are resistant dolomite beds. Vertical cross-cutting structures in ridge at center of photo are clastic dikes described by Peterson (1968).

STOP 2-3b. MCDONALD SHALE (LOWER UNIT OF THE MCLURE MEMBER)

We have moved from the clay shales of the Devilwater Formation into the siliceous shales (Fig. 5) of the lower part of the McLure Member. This lower portion is often designated as the McDonald Shale, however Dibblee (1973) claims that the Antelope and McDonald units cannot be differentiated in Temblor Range outcrops. Although the two are not easily geomorphically distinguished (one of Dibblee's main mapping criteria), they are nonetheless lithologically different. The lower part of the McLure Member McDonald Shale) is much less silica-rich, being dominantly made up of siliceous shale, whereas the upper part (Antelope Shale) is dominated by porcelanites with lesser siliceous shale.

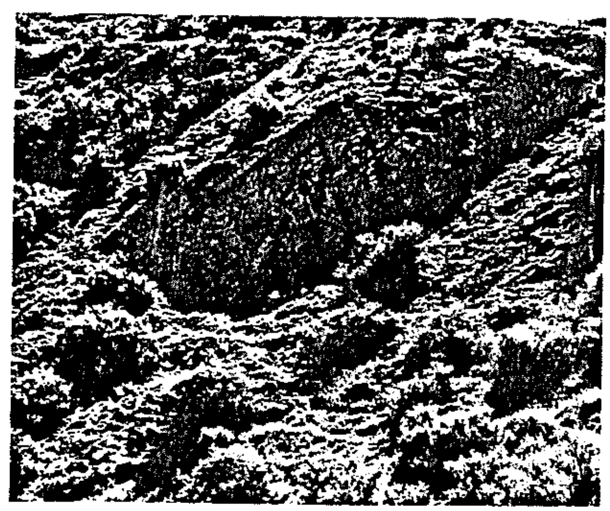

Figure 5. Outcrop exposure of siliceous shales of the lower McDonald Shale unit in Chico Martinez Creek bed. Biogenic silica is in the quartz phase.

Many of the siliceous shales and porcelanites of the outcrop at the first stop retain vestiges of bacterial mat lamination texture on freshly broken surfaces. These fossil organics are important as they add greatly to the kerogen content and petroleum source potential of the rocks (Williams, 1984; Graham and Williams, 1985). The siliceous shales are generally black in color on fresh surfaces, whereas interbedded porcelanites are usually brown. Some samples show an alternation of mat-laminated brown porcelanites and black siliceous shales - a very typical occurrence in core samples in siliceous zones (i.e., "high resistivity zones" - Graham and others, 1982; Graham and Williams, 1985) of the Monterey Formation. Unfortunately, both lithologies weather bluish here, and this alternation is not readily visible unless you break alot of rock.

The diagenetic silica in this section, as in that of the previous stop, is in the quartz phase.

Because the McLure Member is relatively barren of foraminifera and has lost its diatoms to diagenesis, it is difficult to date the section. Foss and Blaisdell (1983) assigned the McDonald Shale in Chico Martinez Creek to the upper Mohnian, and the Antelope Shale to the lower Mohnian. Dibblee (1973) assigned the McLure Member, undifferentiated, to the Mohnian Stage. Relizian/Luisian benthic foraminifera dates already referred to for the underlying members, and upper Mohnian diatom dates for the overlying Belridge Diatomite, suggest that the McLure Member is lower to mid-Mohnian in age in the Chico Martinez Creek section.

Return to buses. We will continue upsection along the McLure Member ridge.

The approximate location of the Antelope Shale/McDonald Shale contact lies 0.3 mile further on. The white, sparsely vegetated outcrop represents the more silica-rich Antelope Shale; the grass-covered slope stratigraphically below in the same ridge represents the less silica-rich McDonald Shale. Note the structural deformation in this ridge. The opal-CT/quartz diagenetic boundary occurs within the Antelope Shale 0.1 mile further on a dirt road that cuts left across the creek from the main road. We are looking ahead at the Antelope Shale of the McLure Member. Above this is a low saddle with a well-exposed white ridge above it. We will take the dirt road and travel east (upsection) for 3.5 mile below the Antelope Shale ridge. We will stop at the eastern drainage divide of this ridge and walk down section along it, highlighting interesting features along the way. The low ridge ahead of it represents the Belridge Diatomite (Reef Ridge Member). The point at which the ridge gives way to a low hill of diatomite and plains beyond marks the unconformable contact between the Monterey Formation and the Plio-Pleistocene Tulare Formation.

STOP 2-3c. <u>ANTELOPE SHALE/BELRIDGE DIATOMITE</u>

A few hundred feet of diatomites and diatomaceous shales of the Belridge Member mark the uppermost part of the Monterey Formation exposed at Chico Martinez Creek. The biogenic silica is largely opal-A and consists of recognizable diatoms; as a result the upper part of the section has been dated as middle upper Mohnian (Thalassiosira antiqua zone - see Keller and Barron, 1981, Fig. 2) by John Barron of the USGS. At the head of the ridge, we are roughly 61 meters (200 feet) below the dated horizon, and within the opal-A/opal-CT boundary zone. Note the change in properties of the rocks as we walk downsection, from extremely lightweight and porous, crumbly, dusty diatomite to denser, less porous, more brittle siliceous shales as the diagenetic silica changes, from opal-A diatoms to granular opal-CT. The rock luster also changes, from dull and earthy to a matte luster (particularly in porcelanites).Because of the porous, poorly indurated nature of diatomite, it is nonresistant to weathering, and thus is expressed geomorphically in lower, rounded hills.

Within the opal-A/Opal-CT boundary zone, you will see some diatomaceous shales (mostly opal-A) interbedded with siliceous shales (mostly opal-CT). The diatomaceous shales are often thinly laminated and often speckled with white speckles. These "speckles" are agglomerations of diatoms, which are probably fecal pellets (Fig. 6). Note also the fracture sets and small dewatering features in these shales.

Figure 6. Diatom aggregates (fecal pellets) on bedding plane of diatomaceous shale from Chico Martinez Creek outcrop of the Belridge Diatomite facies.

As you walk downsection, take note of the rocks along the way, especially changes in porosity and density (which implies changes in the relative amounts of opal-A and opal-CT, and in the crystallinity of the opal-CT). Note also changes in fissility and brittleness (which imply changes in biogenic silica content).

Basically, two things are happening:

1) The opal-A is almost totally converted to opal-CT and the crystal structure of the opal-CT is becoming more highly ordered, and

2) Biogenic silica content is increasing downward, away from the upper contact with the Etchegoin Formation clastics (which have since been eroded away in the Chico Martinez Creek section).

Walking around the next creek bend, we come to roughly 90 meters (297 feet) of excellent outcrop, which has been folded and faulted (Fig. 7). The rocks are better indurated and more siliceous. Porcelanites are mixed with the siliceous shales. These come to dominate the section about midway through the ridge. In some intervals the porcelanites have been heavily brecciated during deformation (Fig. 8) These porcelanites look black because of the fracture-filling tar. Is this tarry zone equivalent to the upper part of the oil-producing "fractured shales" of the Belridge, Buena Vista and Jerry Slough oil fields (Calif. Div. Oil and Gas, 1980)?

A careful examination of beds at this outcrop discloses syn- to early post-depositional soft sediment deformation features (Fig. 9). Dewatering fractures are common, becoming more so as we walk down section to the disconformity (Fig. 10). Thin very fine-grained ripple-laminated siltstones and sandstones are interbedded with the biogenic siliceous sedimentary rocks (Fig. 11). Some of these have loading features at their bases.

Figure 7. Folding and faulting in the Antelope Shale unit. Biogenic silica is mixed opal-A and opal-CT.

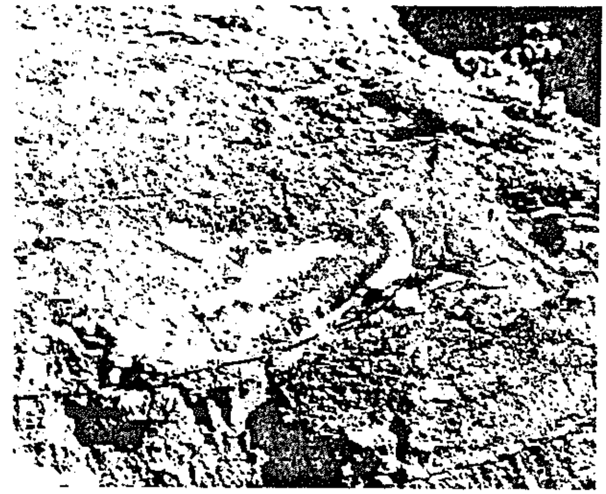

Figure 9. Soft sediment deformation in the Antelope Shale.

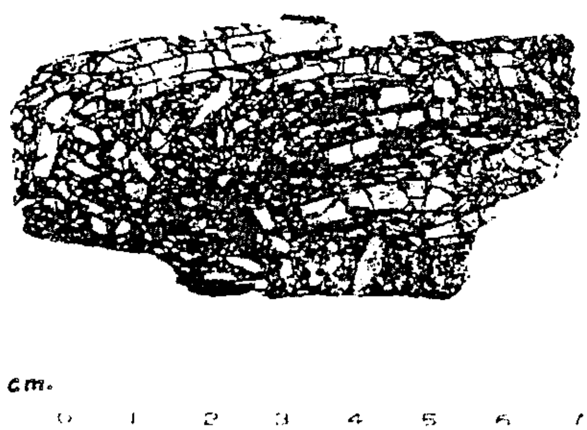

Figure 8. Tar-cemented porcelanite breccia from Antelope Shale in Chico Martinez Creek outcrop.

Beds of soft, brown, nonfissile siliceous shales are interbedded with the porcelanites. A significant portion of the silica in these beds is still opal-A indicating that we are still in the opal-A/opal-CT transition zone.

Around the next creek bend, we come to the last good exposure of this ridge. There is little deformation in this outcrop. The porcelanites are not brecciated and there is no tar. Groups of porcelanite beds alternate with groups of siliceous shale beds. We have passed through the transition zone and all the biogenic silica is opal-CT.

Halfway through the section is a zone in which fine-grained ripple-laminated sandstones are interbedded with siliceous shales. A current lineation pattern on the top of one of the sandstones yields a S85°W/N85°E direction. Transport was probably from the southwest, where the thick "Stevens" turbidites were being deposited. The thin sandstones here may be distal equivalents of some of those turbidites.

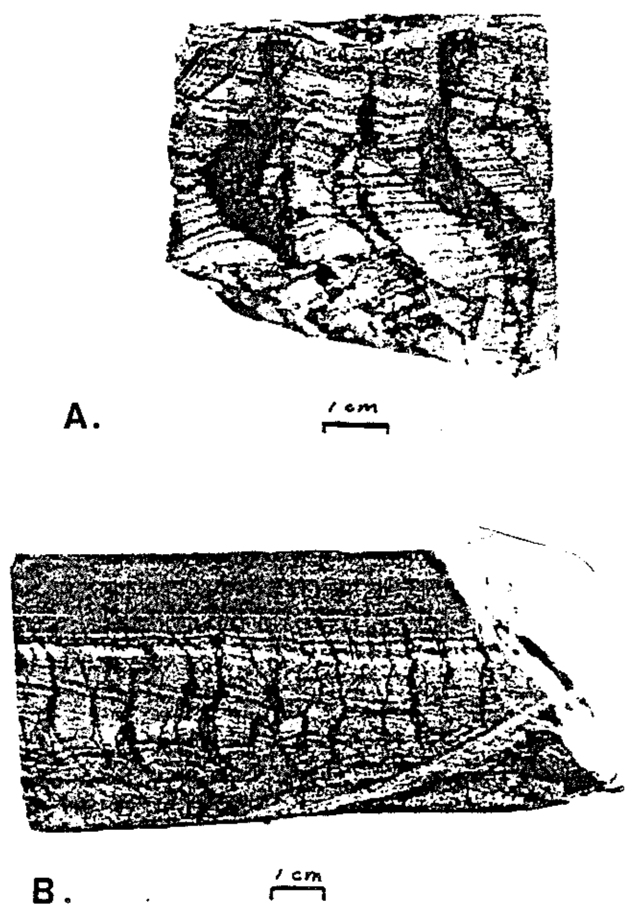

Figure 10 a & b. Dewatering fractures in thinly laminated porcelanites from the Antelope Shale unit in Chico Martinez Creek outcrop.

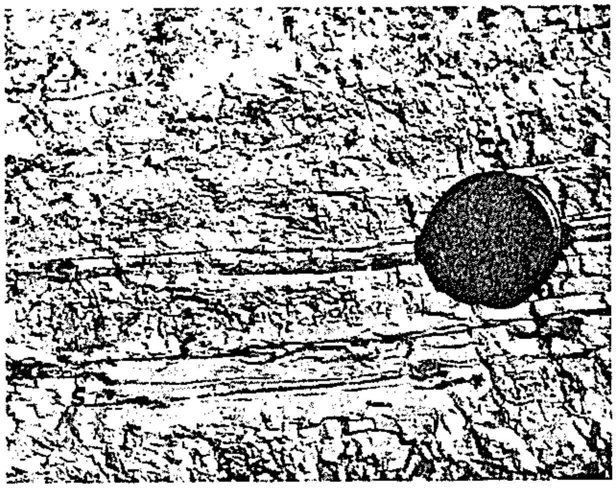

Figure 11. Fine-grained sandstones ("S") interbedded with porcelanites in the Antelope Shale unit on Chico Martinez Creek outcrop.

As we walk up toward the creek bank to return to the buses, stop and look back at the outcrop. You will discern an angular bedding relationship in the upper part of the section (Fig. 12). What is its origin?

1) Late tectonic thrust fault?

2) Syn-depositional disconformity caused by downslope slippage of upper section over lower section?

A thrust fault origin seems unlikely due to the lack of brittle deformation. Such disconformities are common in fine-grained basinal sedimentary rocks deposited on a slope. They have been frequently reported in fine-grained shelf/slope carbonate sequences (Wilson, 1959; Yuriewicz, 1977; Barthel, 1976; Williams, 1983). The theory that this feature is a soft sediment slump feature is also supported by the abundance of small-scale soft sediment deformation features seen within the "upper plate" rocks.

Figure 12. Angular bedding relationship within the Antelope Shale at Chico Martinez Creek outcrop. Biogenic silica is mostly in the opal-CT phase.

A last thing to consider here is the origin of the tar. Is it in situ, or has it migrated into its brecciated siliceous reservoir? The fact that the tar breccias are in the upper part of the opal-CT zone suggest that they never experienced temperatures much greater than 50°C (122°F), corresponding in this area to roughly 3462 feet of burial depth (calculated using geothermal gradient map of Graham and others, 1982). This is insufficient for extensive hydrocarbon generation (Graham and Williams, 1985; Kruge 1985); therefore this oil has probably migrated from elsewhere and then been degraded in situ to tar.

Return to buses. Return southward to the main road, through the gate, past barn and houses, to main road (Lokern Road). Continue across Lokern Road for 0.4 mile to a dirt road which forks to the left. Left on dirt road and up Gould Hill 0.8 mile to the bulldozer cut in the ridge (refer again to the map of Fig. 1).

STOP 2-4. GOULD HILL DIATOMITES (optional stop)

This artificial cut (Fig. 13) provides an unusually good exposure of opal-A rocks. Note the low density, high porosity and lack of cementation. Most of the biogenic silica in these rocks is present as diatom frustules. Although this section appears to be lithologically identical to the upper Mohnian Belridge Diatomite of Stop 2-3c, a sample has been dated by John Barron at the USGS as of the Denticulopsis hustedii- D. lauta zone - that is, lower to mid-Mohnian (Fig. 14). This outcrop is thus equivalent to the McDonald Shale of Stop 2-3b. The apparent differences in rock type are due to the fact that the rocks of this outcrop have not undergone diagenesis of the opal-A diatoms to quartz.

Note that dolomite concretionary beds, ubiquitous in the opal-CT and quartz diagenetic zones of the McLure Member we saw in Chico Martinez Creek, also are developed in these diatomites and diatomaceous shales. Although less indurated and dense than dolomites lower in the section, these beds are still more resistant than their non-dolomitized counterparts.

Figure 13. Diatomites and diatomaceous shales of Gould Hill exposed in bulldozer cuts. Although the biogenic silica here is mostly in the opal-A phase, this section is biostratigraphically equivalent to the McDonald Shale unit of the McLure Member at Chico Martinez Creek (whose biogenic silica is in the quartz phase), and not the equivalent of the opal-A diatomites and diatomaceous shales of the Belridge Diatomite facies Reef Ridge Member which we saw at Chico Martinez Creek.

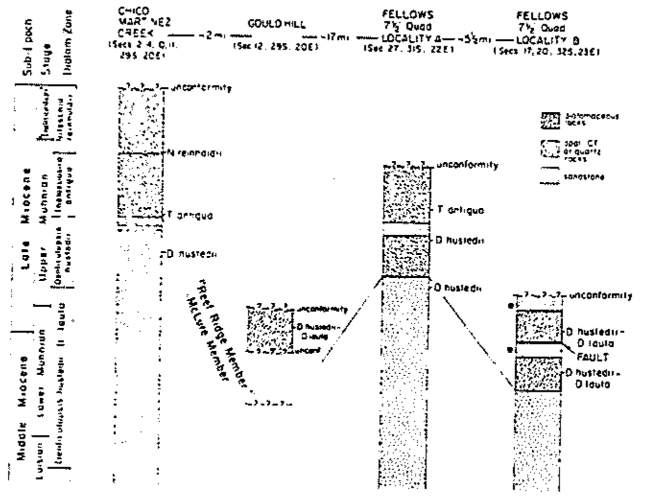

Figure 14. Biostratigraphic correlation of the upper Monterey Formation exposed in the Temblor Range, from northwest to southeast. The northernmost exposure is the Chico Martinez Creek section; the southernmost exposure of this diagram is near Fellows. Although all diatomaceous rocks of the Temblor Range have been previously mapped as upper Mohnian/"Delmontian" Belridge Diatomite (Dibblee, 1973), it is clear that there is actually no stratigraphic significance to this diagenetic boundary between opal-A and opal-CT. Lithologically, this outcrop is more readily assignable to the McDonald Shale unit of the McLure Member (i.e., both the Gould Hill diatomites and the McDonald Shale unit quartz rocks contain numerous dolomite beds and abundant bacterial mat lamination relative to the Belridge Diatomite at Chico Martinez Creek).

Although the rocks weather white, a little digging will reveal that the fresh rocks are actually brown and smell of hydrocarbons. Some of this organic richness is due to oil which has migrated into the diatomaceous reservoir. In addition, however, visual kerogen analyses on HF-treated samples reveal that this outcrop is extremely rich in amorphous algal/bacterial kerogen, some of which shows filamentous structure. The filamentous structures are believed to be remnants of sheaths of sulfur-oxidizing bacteria (Williams, 1984). A thinly laminated texture is typical of mat-laminated siliceous sediments. However, mats are often difficult to see in diatomaceous rocks because they have not undergone sufficient thermal or chemical alteration to darken organic pigments. At this outcrop, mat lamination shows up best in dolomitized beds. The common occurrence of bacterial mat lamination in the Gould Hill section is reminiscent of the Devilwater Member/ McDonald Shale unit lithology at Stop 2-3b.

Looking east down the hill (Fig. 15), we can see South Belridge oil field, in which a diatomaceous section like that we are standing on is a shallow oil objective(see Bowersox, this volume). Porosity at South Belridge is due in part to the diatom porosity, and also to fracture porosity and permeability. Diatomite is one of the main reservoir rock types of the Monterey Formation because of its high matrix porosity. The diatomite we are standing on also has the potential to be a good source rock, due to bacterial mat lamination and the resulting high kerogen content. However, since these diatomites never experienced temperatures above 50°C (and probably much below this value), the oil must have migrated in from elsewhere. Much greater temperatures would be needed to crack the indigenous kerogens to oil.

Return to buses. Retrace road down Gould Hill to Lokern Road, and east to Route 33.

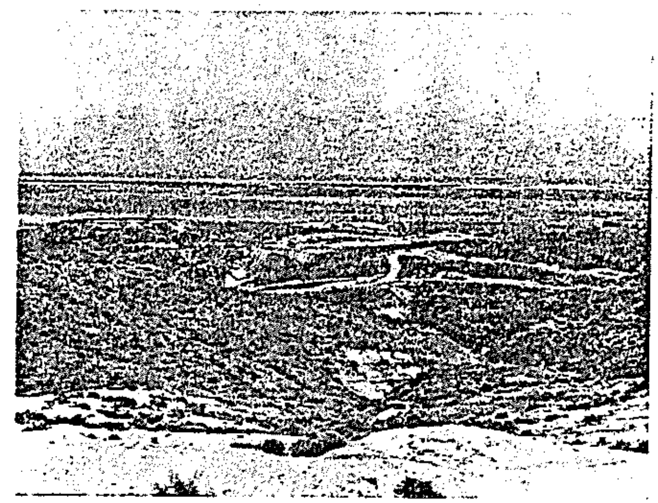

Figure 15. View eastward from Gould Hill past the small oil field to the huge South Belridge oil field barely visible on the horizon in this photo. Significant amounts of oil are produced from opal-A and mixed opal-A/opal-CT rocks of the Belridge Diatomite facies in South Belridge field.

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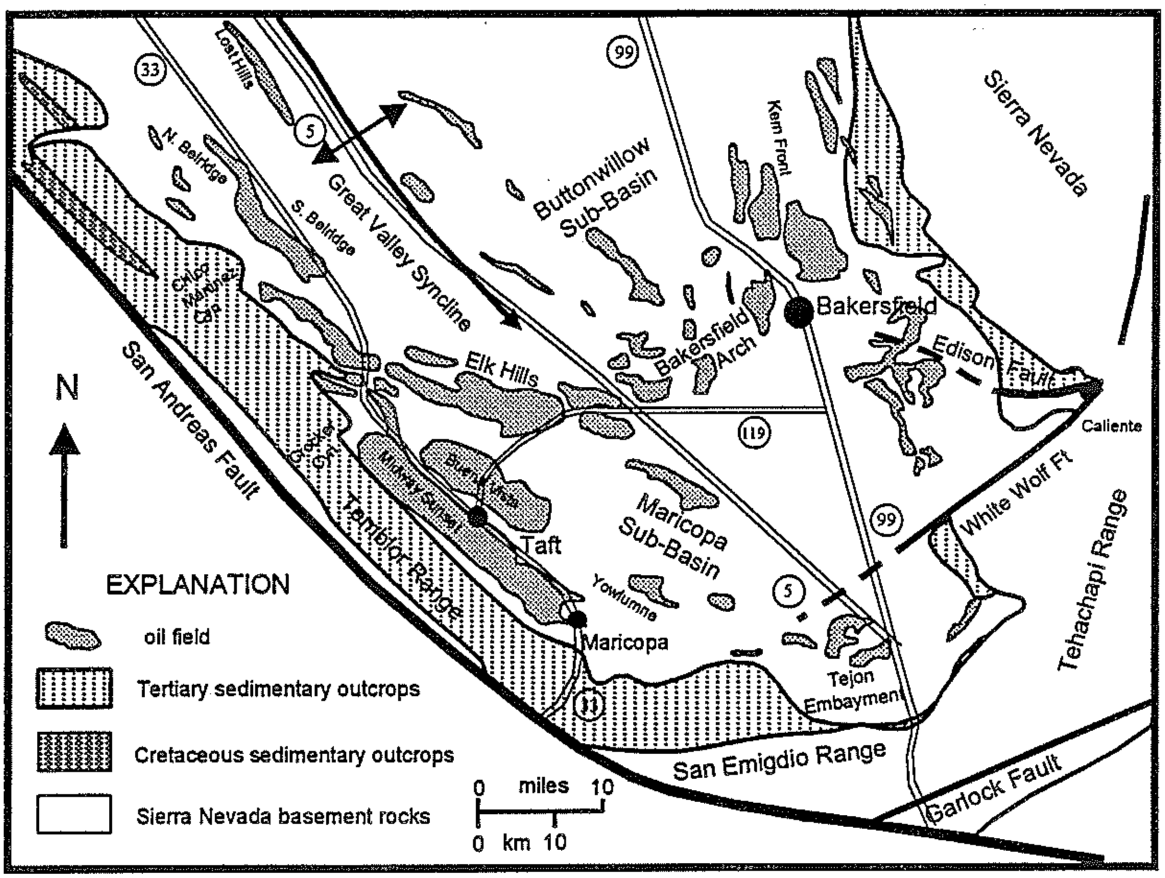
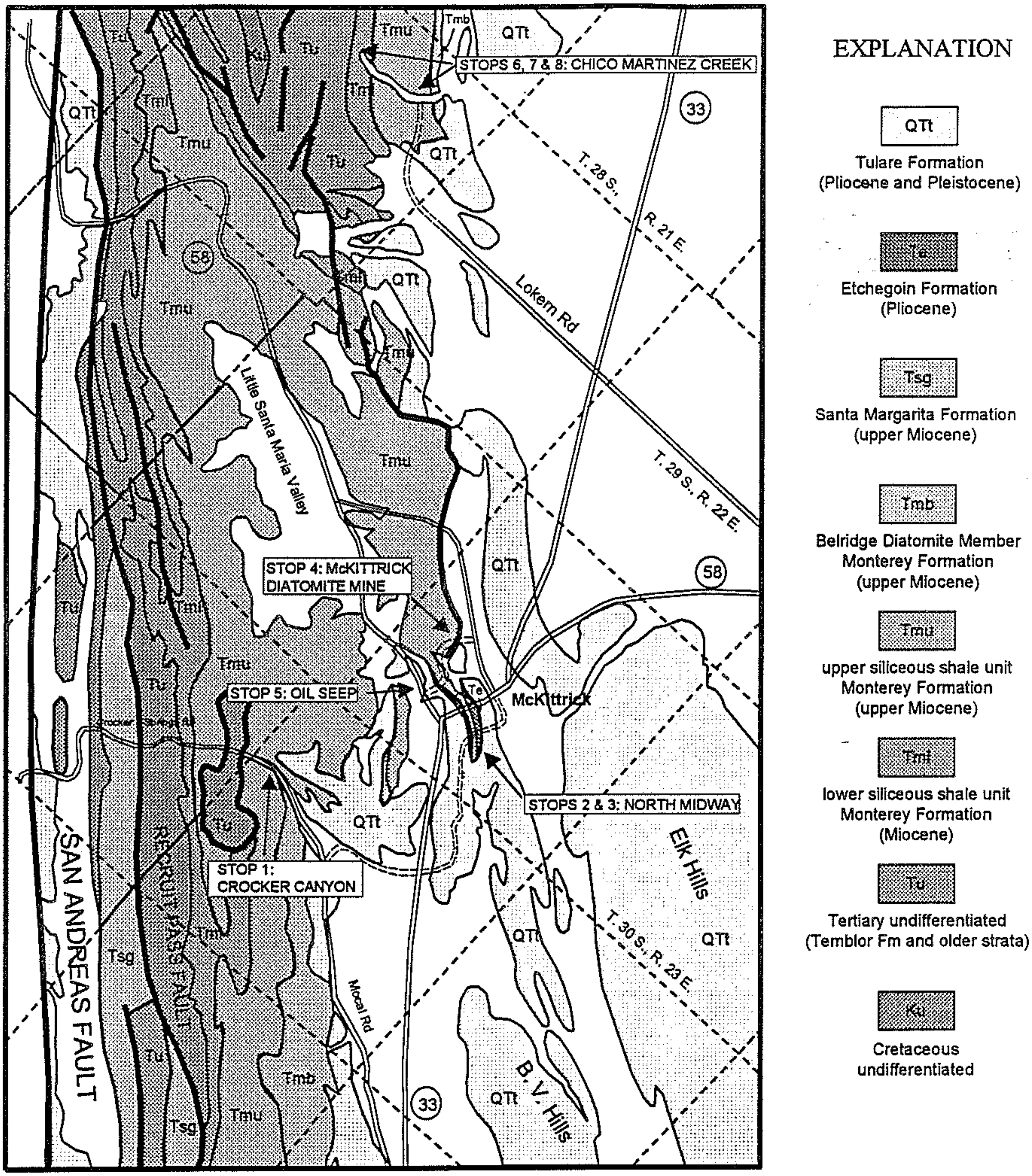


33
Lost Hills
5
N. Belridge
S. Belridge
Great Valley Syncline
99
Buttonwillow
Sub-Basin
Kern Front
Sierra Nevada
Bakersfield
Bakersfield
Arch
Edison Fault
Elk Hills
119
Caliente
San Andreas Fault
N
Midway Sunset
Buena Vista
Taft
White Wolf Ft
Maricopa
Sub-Basin
Temblor Range
Yowlumne
Tehachapi Range
EXPLANATION
oil field
Maricopa
Tejon
Embayment
Tertiary sedimentary outcrops
Cretaceous sedimentary outcrops
San Emigdio Range
Sierra Nevada basement rocks
0 miles 10
0 km 10
Garlock Fault

Road Log for field trip to classic outcrops on the West Side of the San Joaquin Valley

Michael S. Clark, S. A. Reid and Michael L. Simmons

Mileage	
0.0	Start at parking lot across the street from the California Well Sample Repository on the University of California campus.
	Turn right (west) on Camino Media.
	Turn left (south) on Old River Road.
1.8	Turn right (west) on Ming Avenue.
	Turn left (south) on Buena Vista.
3.2	CANFIELD RANCH OIL FIELD – The pumping jacks on the right (west) side of the road represent the East Gosford area of Canfield Ranch field, which produces from Miocene Stevens sandstones at depths of 7,000 to 8,000 feet. The field is primarily a stratigraphic trap controlled by the updip (eastward) lensing out of the oil-bearing sands. Also, several faults clearly influence the shape of the oil pool. Canfield Ranch is the first of several Stevens fields we will pass through that sit on the Bakersfield Arch, a regional northeast-to-southwest trending high that separates the southern San Joaquin Valley into the Tejon subbasin, on the south side of the Arch, from the Buttonwillow subbasin, on the north. The Arch continues through Ten Section and the Coles Levee fields before merging with the Elk Hills anticline.
4.8	Turn right (west) on Panama Lane.
9.5	TEN SECTION OIL FIELD – The tank farm and pumping jacks on the left (south) side of the road indicate Ten Section field, an anticline with no surface expression that was discovered in 1936 in the first application of seismic exploration in California. Production was established from a previously unknown, Miocene package of sandstones which was named the "Stevens" after the nearby Stevens Siding railroad stop. Today, the Stevens is one of the most important reservoirs in the basin, responsible for roughly 15% of the 12 billion barrels of oil that has been produced from the San Joaquin Valley since the turn of the century.
11.8	Turn left (south) on Enos Lane. The low hills visible in the foreground straight ahead are the Elk Hills anticline, better known as the former U. S. Naval Petroleum Reserve No. 1.
13.7	Turn right on the Taft Highway (Route 119).
15.7	COLES LEVEE OIL FIELDS – The tank farms and structures on either side of the road are facilities for North and South Coles Levee fields which sit in the middle of the Coles Levee Ecosystem Preserve. Both fields were discovered in 1938-1939, and North Coles Levee has the distinction of having supplied most of the crude oil used to make aviation fuel during World War II. North Coles Levee, with a cumulative production of over 160 MMBO, is also one of the giant oil fields of the San Joaquin Valley. Both fields are seismically defined anticlinal structures, with no surface expression, which produce from Stevens sandstones at depths of 7,500 to 10,000 feet. The Ecosystem Preserve is an award-winning project in which ARCO Western Energy dedicated the Coles Levee surface acreage as a wildlife sanctuary to be turned over the state when the fields are abandoned.
16.9	ELK HILLS ANTICLINE AND OIL FIELD – As we cross over the California Aqueduct, the Taft Highway (Route 119) climbs up into Elk Hills, one of the largest oil fields in the United States. Outcrops of the Tulare Formation mark the flanks of an enormous anticlinal dome, over 12 miles long and more than 4 miles wide. Beneath this anticline, at depths down to 10,000 feet, there are three major anticlinal structures that contain Miocene (Stevens sandstones and Monterey shales) and Pliocene (Etchegoin and San Joaquin Formation) reservoirs. The field has produced over 1 billion barrels of oil and currently produces 55,000 barrels of oil and 350 million cubic feet of gas per day.



Geologic map of the southern Temblor Range, showing location of the field trip stops (modified from Dibblee, 1973).

20.1 U.S. NAVAL PETROLEUM RESERVE No. 1 – A sign on the right (west) side of the road indicates the entrance to the Elk Hills field office, previous headquarters for U.S. Naval Petroleum Reserve No. 1. The Naval Petroleum Reserves were established early in the century to provide oil for the U.S. Navy in the event of a national emergency. With a strong upswing in oil prices in the mid-1970s, the Federal government decided to cash-in on the elevated oil revenues and open-up Elk Hills to full production. Pressure from corporations subsequently convinced the Government to sell their interest in the field. Occidental Petroleum successfully bid $3.65 billion in 1997 and recently assumed operation of the field.

23.7 BUENA VISTA SYNCLINE – At about this mileage, the highway passes through Buena Vista Valley, the axis of a giant syncline that separates Elk Hills (behind us) from the Buena Vista Hills anticline (in front of us).

BUENA VISTA HILLS ANTICLINE – The wooden derrick and pumping jack on the right (west) side of the road date to the early days of Buena Vista field. Since its 1909 discovery, the field has produced 660 million barrels of oil. The pumping jacks spreading from here south to Taft, on either side of the road, produce from Miocene and Pliocene reservoirs in the Buena Vista anticline, which corresponds to the hilltop west of the highway. Of particular interest is deeper production from both Stevens sandstones and fractured Antelope shale.

27.0 Turn right (west) on Midway Road.

29.7 MIDWAY SYNCLINE – The valley we are passing through represents the Midway Valley syncline, a trough separating the Buena Vista Hills anticline (in back of us) from the Temblor anticlinorium (in front of us). More important, the valley represents the separation between Buena Vista field and billion-barrel Midway-Sunset field. We immediately enter Midway-Sunset in an area of primarily Pliocene production, which has largely been abandoned. Here stratigraphic traps have formed on the east flank of the Temblor anticlinorium by the onlap of thin Pliocene sands onto a basal Pliocene unconformity.

31.1 Continue on Midway Road across the intersection with Highway 33.

31.5 Bear to the right, taking Mocal Road at the Y intersection.

32.0 Mocal Road changes to Broadway as it passes through the town of FELLOWS.

MIDWAY-SUNSET FIELD – The town of Fellows, which we are now passing through, is a company-owned community originally established as living quarters for employees working Midway-Sunset field. With a daily production of 160 to 170 thousand barrels, Midway is the largest oil field in the continental United States. The cumulative production currently stands at 2.3 billion barrels. As we continue driving northwest, we enter an area dominated by Miocene production resulting from the updip truncation of Potter sandstones (Reef Ridge equivalents) beneath the basal Pliocene unconformity.

32.4 MIDWAY GUSHER – The historical marker on the right side of the road commemorates the Chanslor-Canfield Midway No. 2-6, simply called the Midway Gusher, which blew out on November 27, 1909. Flowing at a rate of about 2,000 barrels of per day, this well foreshadowed development of Midway-Sunset field.

33.8 MIDWAY-SUNSET STEAM FLOOD – Most oil produced on the west side of the San Joaquin Valley is heavy crude, with an API gravity of 15 degrees or less, that flows with difficulty. Consequently, Midway-Sunset crude was sub-economic for many operators to produce until the advent of steam recovery in the 1960s. Today, steam injection into the subsurface, to increase mobility of the oil and facilitate its recovery, has made Midway-Sunset the most prolific oil field in the continental United States.

37.1 Turn left onto Crocker Springs Road.

38.9 COGENERATION PLANT – Unknown to many, most steam produced in the valley is first used to turn turbines and generate electricity before being injected into the ground. The steam plant on the right (north) side of the road, with three 78-megawatt turbines, is one of the larger cogeneration facilities in the valley. Although the electricity generated here exceeds the energy needs for all of Kern County, little is used locally and most is sent south to Los Angeles.

41.0 Turn left onto a dirt track just past the farmhouse and park.

STOP 1 **STEVENS SANDSTONE AT CROCKER CANYON** – see page 9 of field guide.

45.0 Retrace the route to the intersection of Crocker Springs and Mocal Road then take the left fork.

45.1 Bear to the left at the Y junction. The road curves around to the left (west) back the way we came and then curves back to the right (north).

45.5 Bear to the left at another Y junction. The main road winds through the fields, generally heading north, and then curves to the right (east) back towards Highway 33.

47.3 Cross Highway 33 and enter the Fairfield lease. The road immediately turns left (north) then right (east) passing a low warehouse on the right side (south).

48.1 Go right at a junction in the opposite direction indicated by a sign pointing the way to the Fairfield production office.

48.4 Go left (north) at a stop sign at a T junction.

49.6 Follow signs pointing to Texaco North Midway.

50.2 Bear to the right at a Y junction.

50.9 Bear to the left at a Y junction with a Texaco sign.

51.2 Bear to the right at a Y junction and head down the hill between the railings.

51.8 Pass a tank with STA 8 written on it.

51.9 Just pass the STA 8 tank, turn right (east) onto a dirt track that curves through pumping jacks steeply up and to the left to the top of a small hill.

52.1 Park on the hilltop. Notice the netting and grates covering the entrance of an asphalt mine on right-hand side of the gully that heads down to the left.

STOP 2 **STRUCTURE OVERVIEW OF NORTH MIDWAY** – see page 15 of field guide.

52.3 Retrace the route back to the oiled road and continue heading to the north (right).

52.6 Make a 90° turn onto a dirt track that heads down the hill.

52.7 Turn right and park in the flat excavated area beneath a dirt cliff.

STOP 3 **OUTCROPS OF POTTER SANDSTONE AND DIATOMITE** – see page 15 of field guide.

OPTIONAL STOP – OIL-STAINED TULARE SANDS AND HISTORIC TAR MINES – Gullies to the south of Stop 3 contain shafts and tunnels, dating to the 1880s, that were used to mine asphalt seams (see page 27 of the field guide). Dark, oil-stained rocks around the mine entrances are trough cross-stratified sandstones of the Pleistocene Tulare Formation that unconformably overlie Potter sandstones and diatomaceous shales. Oil-stained, flat-lying beds above the mines represent ancient tar seeps originally sourced by the asphalt seams.

52.8 Retrace the route back to the oiled road and continue to the north (right).

53.3 RECENT MUDSLIDE – Note where the side of hillside in front of us and to the left has failed and buckled the paved road.

53.4 Bear to the left at the intersection.

53.7 Bear to the right (north) at the intersection.

53.9 Turn left at the T intersection onto Reserve Road, which heads into the town of McKITTRICK.

54.9 Cross Highway 33 in the town of McKittrick and continue to the west. Note that the road changes to Reward Road on the other side of the Highway.

RESTROOM STOP AT McKITTRICK

55.4 When the Texaco production office appears on the right, turn left (south) onto the paved road and continue into the field. The road curves around to the right (west) and heads up the hill.

56.1 Turn right onto a dirt track.

McKITTRICK FIELD – Pumping jacks in this area are part of McKittrick field, which is one of the oldest fields in the San Joaquin Valley and dates back to the 1860s when commercial production was first established by collecting tar from the many seeps that characterize the area. Hand-dug pits and asphalt mines soon followed (see 27 of field guide). Modern production began in 1896 when the first genuine oil well in the area, the Shamrock gusher, blew out an estimated rate of 1,300 barrels of oil per day. Since then, the field has produced over 280 million barrels of oil to qualify it as one of the valley's giant oil fields.

56.2 Park and proceed to the mine overlook.

STOP 4 **DIATOMITE MINE** – see page 21 of field guide.

56.4 Return to the junction and turn left back onto the paved road.

56.6 Go left at the junction. The pavement ends near here.

56.7 After winding through the field turn right (west) onto Highway and head up the hill

56.9 Park on the right side of the road at the oil seeps.

STOP 5 **LUNCH STOP AT McKITTRICK OIL SEEPS**

57.3 Turn around and head back down the hill staying to the left of a junction at mile 57.3.

57.6 McKITTRICK TAR PITS – The historic marker on the right side of the road commemorates the McKittrick tar pits which have yielded a Pleistocene fossil fauna that rivals fossil finds of the better known La Brea Tar Pits in downtown Los Angeles.

57.7 Turn right (north) at the T intersection and continue on Highway 33.

58.6 Bear to the right, staying on Highway 33, at the Y intersection with Highway 58.

61.6 WELPORT AREA OF CYMRIC FIELD – The wells that have been appearing on the left (west) side of the highway since we left McKittrick, and which we will continue to see until we reach the entrance of Twissleman Ranch, produce from Cymric field. This complex accumulation, which has produced 280 million barrels of oil since its 1909 discovery, is characterized by several different types of traps and produces from reservoirs that range from Eocene sandstones to the Pleistocene Tulare Formation. Of particular interest is recent development of the fractured shale potential, which will be discussed at Stop 6.

65.2 Turn left (west) onto Lokern Road

66.4 Continue on Lokern Road across the intersection with Lost Hills Road.

69.8 SALT CREEK AREA OF CYMRIC FIELD – The pumping jacks to the left (south) side of the road produce from the Salt Creek area of Cymric which represents the easternmost production from the field. The East Welport area of Cymric, which will be discussed at Stop 6, sits to the southeast between this area and the entrance to Cymric field that we drove by at mile 61.6.

69.9 TWISSLEMAN RANCH – The paved road ends here and a dirt road continues on and enters the Twissleman Ranch . This roadlog ends where the pavement stops. Field Trip Stops 6, 7 and 8 are in Chico-Martinez Creek, which is located several miles up the road. Please respect the privacy of the Twissleman family and do not continue on the dirt road without their permission. Refer to pages 29, 339 and 347 of the field trip guide for the next three stops.

– DO NOT CONTINUE ON WITHOUT PERMISSION

STOP 6 – FRACTURED ANTELOPE SHALE AT CYMRIC FIELD – see page 29 of field guide.

STOP 7 – OUTCROP OF BUTTONBED SANDSTONE – see page 339 of field guide

STOP 8 – OUTCROPS OF MONTEREY FORMATION – see page 347 of field guide.

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Occidental of Elk Hills

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Texaco North America