San Joaquin Geological Society

Fieldtrip Guide
west side San Joaquin basin

December 1, 2000

Led by Dan Steward, Neal Livingston, Ryan Hull, and Mike Ponek

**Special Appreciation to
Russ Robinson (Secretary), Marianne Binkin (Treasurer), and Lisa Denke (Aera Energy)**

The Society is indebted to the companies who donated their time, material, and property access, to make this trip possible: Chevron, A&M Products, Texaco, Nuevo, and Aera Energy, who graciously donated four vans for the trip

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December 1st, 2000
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ROAD LOG

0.0: leave south parking lot of CSUB campus, near Well Sample Repository
0.2: turn right (west) onto Camino Media
0.7: turn left (south) onto Old River
1.2: turn right onto Ming Avenue
1.9: turn left (south) onto Buena Vista Road
3.4: Point of Interest: Canfield Ranch oil field, discovered in 1939 following the rash of discoveries made on the flat Valley floor after Ten Section (see below); pumping units and tanks are visible west of the road; Canfield Ranch produces high gravity oil from the late Miocene "Stevens" turbidite sand
5.0: turn right onto Panama Lane
9.8: Point of Interest: Ten Section oil field, first field discovered in California based solely on the reflection seismograph, June 1936. Wildcat "Stevens A No. 1" (later renamed "KCL A 1-29") was the discovery well. The well tested at 1,200 BOPD, 60.4-gravity condensate, 15-18 MMCFD gas. The "Stevens sand" reservoir took its name from the well, which took its name from a nearby planned development by the Southern Pacific Railroad called "Stevens Siding". Kern County Land Company originally leased Shell Oil Company 6,433 acres of land over ten sections, hence the field's name[1]. This discovery touched off an exploration boom across the San Joaquin Valley, which would discover a number of new fields
12.0: turn left onto Highway 43 (Enos Lane)
14.0: turn right (west) onto Highway 119 (Taft Highway)
16.0: Point of Interest: North Coles Levee oil field (on the north [right]), and the South Coles Levee retrograde condensate field (on the south [left]).

See attachment regarding the Coles Levee area (courtesy of Mike Clark)

17.2: Point of Interest: Tulare Formation outcrop is visible to the right of the road. Erosion by the Kern River has exposed this southeast flank of the Elk Hills and the Tulare. Prior to the Lake Isabella Dam and the California State Aqueduct installations, the Kern River used pass nearby and empty into the nearby Buena Vista Lake

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[1] Some of this material was derived from: Rintoul, William, 1990, Drilling Through Time: 75 Years with California's Division of Oil and Gas: Department of Conservation, Division of Oil and Gas, pp. 65-66.

21.5: Point of Interest: Hwy 119 is going downhill at this point, off the southwest flank of Elk Hills, and into the Buena Vista syncline. The Buena Vista Hills (and the Buena Vista oil field) are the next row of hills visible in the distance
25.3: Point of Interest: Buena Vista Front oil field marked by nearby pumping units; the Honolulu anticline (one of three on Buena Vista Hills) of the Buena Vista Hills in visible to the southwest
27.4: turn right onto Midway Road
28.1: turn left (south) onto North Lincoln Street
30.1: Points of Interest: The Taft Fort: A replica of 19th century Sutter's Fort, built by John Sutter near Sacramento. The original Sutter's Fort served as the centerpiece to a budding agricultural and trading center, pre-1849 California. It was a Sutter-commissioned party sent to build a lumber mill on the American River that first discovered gold and precipitated the California Gold Rush

11-C Camp, Standard Oil of California (Chevron): The abandoned 11C Camp is immediately north of the Fort –the old Camp entrance is framed by two rock pyramids. This Camp was for many years the operational headquarters of Standard Oil of California. In its heyday, the Camp comprised a huge complex of headquarters offices, laboratories, supply warehouses, recreation halls, meeting halls, employee housing, a credit union, equipment of all sorts, many recreation areas including a community swimming pool, and the largest machine shop in California. In those days, there were very few contractors, the thousands of Standard Oil Company employees did nearly 100% of the oilfield-related work. Taft was almost literally built by Standard.

The Camp was progressively dismantled starting in 1968, when Standard moved its accounting and finance division to Concord, California. The Camp was officially closed in 1992.

30.5: Kern Street (Highway 33) stoplight. Lincoln Street turns into 10th Street at this intersection. Go straight after the light (south), and continue south through the next two stop signs
31.4: Point of Interest: right bend in the road and the hill afterwards signals the northeast flank of the Spellacy anticline, road is now called "25 Hill Road". The Spellacy anticline apparently took its name from the Spellacy brothers (Tim, in particular), who operated the Mascot Oil Company, in the northeast quarter of section 26C (26 – 32S – 23E). The Mascot Oil Company drilled what was the world's deepest well on section 26C
32.2: Point of Interest: Tulare Formation outcrop is discreetly visible on the right side of the road, on the steep slopes outlined by motorcycle trails. The Pleistocene Tulare is notably dipping northeast, off the flank of the Spellacy anticline
32.7: Point of Interest: Wilbert lease (where 25 Hill Road takes right turn and ascends a steep hill. This crowded production area marks the downdip

production limit of the northeast flank of the Spellacy anticline. The production is from the late Miocene Monarch (a.k.a. "Spellacy") turbidite sands. The largest of several reservoirs on the Spellacy anticline, the Monarch originally contained in excess of 150,000,000 barrels of original oil-in-place. Drilling and production in this area dates back to 1900.

33.0: veer right off of 25 Hill Road onto a semi-paved oilfield road
33.3: veer right off oilfield road and negotiate a small maze of dirt roads, generally heading southwest, through the immediate small foothills, towards a barbed wire fence, a little more than 2 miles southwest of 25 Hill Road
34.5: cross cattle guard
34.9: park at 3-way intersection of narrow dirt roads, leave the canyon we drove in on and walk up the left-most of the dirt roads. Stop at the fire ring, the prominent cliff-like excavation of diatomaceous shale, and the lowest contact of the Williams sand on the diatomaceous shale

Stop #1: Williams sand (see handout by Dan Steward)

34.9: leave the 3-way intersection, head back down the canyon and out to 25 Hill Road
36.9: turn left onto 25 Hill Road
37.0: point of Interest: The A&M Products Quarry, our next stop, is clearly visible in the middle distance, on the left side of the road
38.7: stop sign at Pico Street. Go straight and prepare to turn left onto 'A' Street
38.8: turn left (west) onto 'A' Street
39.2: stop sign at 6th Avenue. Go straight
41.1: turn left onto A&M Quarry haul road. The road is wide and paved all the way up to the A&M Quarry gate. **<u>Watch for trucks</u>**.
42.6: A&M Quarry gate

Stops #2 (Williams Area overlook, see handout by Mark Mercer) and

Stop #3 (A&M Quarry diatomite exposure, Ryan Hull)

Leave A&M Quarry

Reset odometer as we pass by the A&M Quarry gate

0.0: A&M Quarry gate
0.1: take a sharp left off A&M Quarry haul road onto dirt road to Dan's Lunch Spot
0.7: take the left fork
0.8: nice diatomaceous shale outcrop on the left

1.6: old 3-axle trailer and mine workings mark the parking area for the lunch spot. Walk northwest towards the mine workings to see the oil-stained and slumped diatomite outcrop
1.6: leave lunch spot, head back to A&M Quarry haul road
2.5: take a right
3.1: A&M Quarry haul road, take a left, head down the road, **watch for trucks**
3.75: axis of the Spellacy anticline is exposed in the road cut, on the right side (if you want to get a closer look, park well off the road)
4.3: County Road, was called 'A' Street as we left Taft. The road is now called "Midoil Road". Take a left towards Fellows
7.9: stop sign at Midway Road. Town of Fellows, a former oilfield boom town with rail service to Bakersfield
8.1: stop sign at Broadway, which will change names to "Mocal Road". Take a left
8.4: Fellows Park and bathroom stop. Proceed on Mocal Road
8.5: Point of Interest: first gusher of the Midway field, well 2-6. The well and a historical marker are on the right side of the road
11.9: Point of Interest: oilfield development on a massive scale visible from here; marks the northern area of the Midway-Sunset field and north America's largest steamflood operation. Potter turbidite reservoir is the target of the development
12.3: turn left onto dirt road. A Texaco sign with an arrow indicate you are turning towards section 27 Government and section 28. Stop #4 is on section 28. **The road is heavily traveled by haul trucks coming in and out of the area. Drive carefully.**
13.1: cattle guard marks the entrance to the section 28 gravel pit
13.15: veer to the left behind surplus tanks, follow road up the hill
13.4: take left into flat area. Park and walk up jeep trail to east

Stop #4: Potter 'O' sand outcrop and 'O' sand gravel pit wall exposure (see handout by Mike Ponek)

13.4: leave Potter outcrop and head back down to Mocal Road
14.4: take a right onto Mocal Road
15.2: take a sharp right off Mocal Road onto oilfield road. Take the left-most semi-paved road that runs roughly parallel to the barbed-wire fence
15.4: take a sharp left towards the cattle guard at well 427-27F
15.41: after passing over the cattle guard, take the left fork
15.48: take left fork
15.55: take very sharp left
15.75: Stop #5

Stop #5: Potter 'K' sand outcrop (see handout by Mike Ponek)

15.75: return to Mocal Road
16.4: take a right onto Mocal Road, head towards Fellows and Highway 33.
20.6: stop sign at Highway 33. Go straight (east) down Midway Road, towards Highway 119
24.8: stop sign at Highway 119 (Taft Highway). Turn left, retrace our steps back to CSUB

Williams Sandstone[1]

Stop #1

The Williams sands outcrop about two miles southwest of the town of Taft, on the west side of Kern County. The outcrop trends northwest-southeast and is a little over four miles long and three-quarters of a mile wide at its widest point. Sections 28, 33, 34, and 35 of Township 32 South, Range 23 East contain most of the exposures. Other minor exposures can be found in section 32 of Township 12 North, 24 West, and section 4, 11 North, 24 West. The exposures vary from topographically prominent, very steep relief hilltops, to boulder-cobble rubble fields on gentle slopes. Good exposures are also found in the stream drainage walls and road [jeep trails] cuts.

The Williams sands are late Miocene, and are numbered among many other marine turbidites and gravity-flow deposits associated with the immense reservoirs of the Midway-Sunset field (e.g. Republic, Spellacy/Monarch, Sub-Lakeview, Potter [Pliocene]). Sedimentary structures such as normal-graded bedding, shale rip-up clasts, and ripple lamination; plus the lack of shoal indicators (e.g. filled mud cracks, root casts, paleosols, pervasive shallow marine invertebrates) support a turbidite depositional setting.

From a reservoir perspective, the vertical and lateral lithology changes at the Williams outcrop are particularly interesting. In the vertical direction, the sand is highly interbedded with thin diatomaceous shales. Laterally, the thin shales grade into sand, or are truncated by overlying sands. Grain-size distributions within the sands change rapidly, grading from conglomerate to very fine sands and back again within a few feet.

Thin-bedded shales can compartmentalize a reservoir into many separate "flow units", even if they have a low correlation length (<500 feet). The shale beds at the Williams outcrop subdivide the clean sands (i.e., reservoir compartmentalization), and would function as a vertical permeability barrier under reservoir conditions. In the heavy-oil enhanced oil recovery case, steam injectors that are not completed in a particular local flow unit will likely leave behind a significant amount of oil. In the light oil case, with high reservoir pressures and pressure communication between flow units, these thin shales would still function as vertical permeability barriers, but would slow the ultimate recovery process, rather than altogether halting recovery at the bed-scale.

At the Williams outcrop, these shales are observable at the outcrop scale (there is approximately 300 feet of gross sandstone at our stop), and at the bed-scale (inches to a few feet).

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[1] By Daniel C. Steward, December 12, 2000. Outcrop description and notes from the Williams outcrop stop (Stop #1), San Joaquin Geological Society fieldtrip, December 1, 2000.

Development of the Opal A Diatomite Facies in the Midway Sunset Field

(From Mercer 1996)

(distributed by Neal Livingston, Nuevo)

this handout covers Neal's description of the Williams Area of the Midway-Sunset Stop #2; Stop #3 is the diatomite outcrop

ABSTRACT

The upper Miocene Monterey shale units of the Midway-Sunset field and the San Joaquin basin are the main source rocks for many of the oil producing formations. The Monterey Formation is derived from diatom frustules making the rocks rich in biogenic silica. The four siliceous members of the Monterey Formation in Midway-Sunset are the McDonald, Antelope, Belridge, and Reef Ridge shales with the entire section being over 5000 feet thick and interbedded with the Williams, Republic, Spellacy, and Potter sandstones. These siliceous rocks are found as unaltered amorphous opal-A, and its diagenetic equivalents of opal-CT and quartz. The rock is characterized by porosities ranging from 70-10% and permeabilities less than 0.1 millidarcy. Since 1978, the members of the Monterey Formation have become major producing reservoirs on the west side of the San Joaquin basin as a result of hydraulic fracturing and/or cyclic steaming. Commercial production was established at Midway-Sunset by Santa Fe Energy Resources in 1984 and to date over 320 wells have been drilled to develop this reservoir. Current development centers along the NW portion of the spellacy anticline. At least seven areas in Midway-Sunset have had drilling and completion attempts aimed towards establishing commercial potential with mixed results to date.

REGIONAL OVERVIEW

The name Monterey Formation or Monterey Shale is used for marine sediments of middle to upper Miocene age, which are characterized by high percentages of biogenic silica present as diatomites and diagentically derived cherts and porcellanites. The depositional history of this Monterey section represents the confluence of tectonic, climatic, and oceanographic events which resulted in conditions favorable for the proliferation of the diatoms which are the source of the biogenic silica. The Monterey siliceous shales are important source beds and reservoirs in California, particularly along the west side of the San Joaquin Valley from Lost Hills Field south to Midway-Sunset Field.

The siliceous shale section has always been recognized as being oil bearing in the producing fields along the west side of the San Joaquin Valley, but due to the rock's inherent low permeability (less than 0.1 millidarcy), commercial production by conventional means had not been of any significance until 1978. In 1978, the first successful hydraulic sand fracture treatment established commercial production from the Belridge Diatomite and since that point in time there have been significant discoveries in and around these older producing fields on the west side through the use of modern reservoir stimulation techniques. Below is a table summarizing development of the siliceous Monterey since 1978.

Field	Discovery Date	Monterey Member	Development Date	Stimulation Technique	Initial Potential
South Belridge	1911	Reef Ridge	1978	SAND FRAC	375BOPD, 275MCF
		Antelope	1983	SAND FRAC	180BOPD, 1658MCF
		McDonald	1982	SAND FRAC	299BOPD, 675MCF
		Reef Ridge	1985	WATERFLOOD	
		Reef Ridge	1993	STEAMFLOOD	
North Belridge	1915	Reef Ridge	1978	SAND FRAC	226BOPD, 177MCF
Lost Hills (Main)	1915	Reef Ridge	1979	SAND FRAC	214BOPD, 289 MCF
Lost Hills (Cahn)	1980	Antelope/McDonald	1980	SAND FRAC	480BOPD, 6860MCF
Cymric – Welport	1980	Reef Ridge/McDonald	1980	SAND FRAC	70BOPD, 275MCF
Cymric 1-Y	1981	Reef Ridge/Antelope	1981	SAND FRAC/STEAM	178BOPD
Midway-Sunset	1890	Reef Ridge	1985	SAND FRAC	78BOPD, 15MCF
		Reef Ridge	1994	WATERFLOOD	
		Antelope	1992	STEAM FRAC	

The siliceous section of the Monterey consists of biogenic silica and its diagenetic equivalents. Three separate silica phases can exist: opal-A (Diatomite) the amorphous form of silica present as the unaltered diatom frustules, and the diagenetic equivalents opal-CT (low crystobalite/low tridymite) and Quartz (crypto-crystalline/microcrystalline). In the opal-A rock, remains of the diatom fragments are clearly visible where as the opal-CT rock shows a featureless fabric due to the diagenetic process. Each phase falls within a given porosity range:

opal-A	55-70%	Porosity
opal-CT	25-55%	Porosity
Quartz	10-25%	Porosity

Variations within the given porosity ranges are due mainly to compositional differences. As the diatoms died and settled to the ocean floor, increasing burial depths and associated temperatures allowed the characteristic changes of the diagenetic sequence from the opal-A to opal-CT to the Quartz phases. At each phase transformation there is a significant reduction in porosity and a gain in bulk grain density. The opal-A to opal-CT phase change results from diatom frustule solution and precipitation to the opal-CT phase. This is essentially a dewatering process which results in loss of porosity and gain in bulk grain density. The frustule framework collapses from the overburden which causes compaction. This diagenetic boundary can be abrupt or occur over an interval in excess of 400 ft thick depending upon the heterogeneity of the rock. With increasing clay percentages, greater pressure and temperature are required to cause the diagenetic change and the broader the interval boundary over which the phase change occurs. The opal-CT to quartz phase change is also considered a solution-precipitation process. The opal-CT phase is considered more stable and zones can be up to 4000 ft thick. The phase in which the rock is currently found by drilling is determined by the post depositional and tectonic history of an area. Any siliceous member of the Monterey can be found in any diagenetic phase depending upon post depositional history.

SILICEOUS SHALES AT MIDWAY-SUNSET

The siliceous section at Midway-Sunset field consists of four members: the McDonald Shale, the Antelope Shale, the Belridge Diatomite, and the Reef Ridge Shale. The Antelope Shale, Belridge Diatomite, and Reef Ridge Shale are interbedded with the Williams, Republic, Spellacy, and Potter sands. This upper Miocene siliceous section is composed primarily of biogenic silica. Generally the section becomes more silica rich the younger the section. The entire section is up to 5000 ft thick. Post depositional tectonics and structural growth dictate the diagenetic phase present in the field. The siliceous section is present from the surface to depths of 6000 ft. Produced oil gravities range from 10°-32° from depths of 300 ft to 5000 ft.

Structures associated with the oil bearing siliceous section are anticlines and truncated homoclines. The general structure is seen as a series of anticlines and synclines trending Northwest-southeast with general northeast dip basinward on the east flank of the Midway structure. Correlation log markers within the siliceous section can be mapped over large areas along strike.

Commercial Diatomite production was established by Santa Fe Energy Resources and CalResources in Sections 8, 9, and 16, T32S, R23E. Development of the Belridge Diatomite opal-A and opal-CT reservoir began in this area 1984 and continues to date with more than 150 wells drilled.

Commercial production from heavy oil diatomite reservoirs by thermal cyclic steaming was first realized in Nuevo's Keene #12 well. Approximately 160 wells have been drilled along the Spellacy Anticline into the opal-A facies of the heavy oil bearing Antelope Shale. This diatomite consists of approximately 300' of alternating cycles of diatomite claystone and dolomite beds. Reservoir properties within the producing horizon average 65% porosity and 65% oil saturation. Average drill depth is less than 2,000'.

Stop #4: Potter "O" Sand on Knoll West of Quarry in 28F
(Mike Ponek, Texaco)

This stop is located on a knoll just west of a large gravel quarry located in NE ¼ sec. 28, T.31S., R.22E. and provides an excellent overview location of the Midway-Sunset Oil Field. We will discuss depositional trends, subsurface patterns, and how the Potter Sands tie into the quarry outcrop. The following stop description is from Nilsen, T. H., Wylie, Jr., A. S., and Gregory, G., J., eds. 1996, Geology of the Midway-Sunset Oil Field: AAGP Field Trip Guidebook, p379-380:

"The walls along the northeastern flank of the quarry provide good exposures of relatively fine-grained pebble conglomerate, pebbly sandstone, and sandstone, arranged into a stack of fining-upward parasequences with erosive bases. Maximum clast size is about 30 cm. The angular unconformity at the base of and basal conglomerate of the Tulare Formation are exposed about 15 meters stratigraphically above the uppermost beds of the Santa Margarita Sandstone Member in the quarry.

From the knoll, one can observe to the southwest low ground that is underlain by the Belridge Diatomite Member, with higher ground to the northwest and southeast underlain mostly by clastic rocks of the Santa Margarita Member infilling submarine-canyon complexes. The sandstone and conglomeratic sandstone cropping out on the knoll form the basal beds of the Santa Margarita Sandstone Member; however, these beds are hundreds of meters higher stratigraphically the basal beds in the incised submarine-canyon complexes to the northwest and southeast.

The geometry of these basal beds is not straightforward, because although the regional dip is northeastward, the beds on the knoll have an apparent attitude of 175/61W. The underlying Belridge Diatomite Member and overlying sandstone beds of the Santa Margarita Sandstone Member dip northeastward, suggesting that (1) there is a tight anticline present at the knoll, (2) the basal west-dipping beds may be intrusive, thus cutting across the regional northeast-dipping succession, or (3) a minor fault may be present that has resulted in disruption of the basal strata. Based on surface mapping relationships, the second alternative appears to be the case. The basal Santa Margarita Sandstone Member is much finer grained here than it is within the fill of the submarine-canyon complexes, with a maximum clast size of about 40 cm."

Stop #5: Potter "K" sand near well 263-27F
(Mike Ponek, Texaco)

This stop is located at the padcut for Well 263-27 located in the center SE ¼ sec.27, T.31S., R22E., along the southwestern edge of the Midway-Sunset Oil Field. The productive Potter "K" Sand outcrops at this location and provides an opportunity for examination of younger, finer grained parasequences. The following stop description is from Nilsen, T. H., Wylie, Jr., A. S., and Gregory, G., J., eds. 1996, Geology of the Midway-Sunset Oil Field: AAGP Field Trip Guidebook, p. 365:

"The northeast-dipping succession of conglomerate and sandstone, with some thin interbeds of diatomite and a few thin interlaminae of micaceous clay, shale and siltstone near the top provides an excellent site for examination of the upper, finer grained units of the Santa Margarita Sandstone. The sandstones are moderately to heavily stained with oil. Samples collected at the surface yield porosities of 30 to 35 percent and permeabilities of 53 to 603 md. The samples are composed of 30-31% quartz, 32-40% plagioclase feldspar, and 13-16% potassium feldspar, with minor amounts of gypsum (probably from surface weathering), and 11-20 percent clay minerals.

The beds are broken by numerous joints and by one minor fault at the southern end of the outcrop that has an attitude of 95/83N. The succession consists mostly of amalgamated and scoured medium to thick beds of conglomerate, pebbly sandstone, and beds of Mutti and Ricci Lucchi facies B sandstone that are generally graded, massive to crudely parallel stratified. The complete section is organized into a stack of fining-upward parasequences. The conglomerates are mostly fine, with abundant small, well-rounded pebbles of almost 100% igneous and metamorphic basement rock types; however, several beds contain coarser cobbles and boulders as large as 35 cm in length."

rgstrat.gpf

<table>
<tr><th>SYSTEM</th><th>SERIES</th><th colspan="2">FORMATION</th><th>MEMBER</th><th>UNIT</th></tr>
<tr><td>QUATERNARY</td><td>PLEISTOCENE</td><td colspan="2">TULARE</td><td rowspan="3"></td><td rowspan="3"></td></tr>
<tr><td rowspan="4">TERTIARY</td><td rowspan="2">PLIOCENE</td><td colspan="2">SAN JOAQUIN</td></tr>
<tr><td colspan="2">ETCHEGOIN</td></tr>
<tr><td rowspan="2">MIOCENE</td><td rowspan="2">MONTEREY FORMATION</td><td>REEF RIDGE SHALE</td><td>POTTER SANDS</td><td>OLIG SAND
A SAND
B SAND
C SAND
D SAND
E SAND
F SAND
G SAND
H SANDS
J SANDS (1-8)
K SANDS (1-6)
L SANDS (1-8)
M SANDS (1-3)
N SANDS (1-8)
O SANDS (1-16)</td></tr>
<tr><td>BELRIDGE DIATOMITE</td><td>SPELLACY SANDS</td><td></td></tr>
</table>

Figure 2 - Stratigraphic Column Detailing Potter Sands.

from Mike Ponek, Texaco.

South Coles Levee field - summary

South Coles Levee is a unitized field that, since the field discovery in 1939, has produced almost 60 MMBO from the Stevens sandstone. Marathon, with a working interest of 34%, is the unit operator, whereas ARCO and Chevron, with equal interests of 33%, are unit partners. However, ARCO, through the purchase Tenneco assets, has royalties equal to half of all working interests in the unit. Thus, ARCO's effective interest is 66.5%, whereas Marathon's effective interest is only 17%.

A 1984 Marathon reservoir engineering study of the F-2 Stevens sandstone at South Coles Levee estimates the original oil in place at 107 MMBO (see pg. 1 of study). The predicted ultimate recovery of this oil is only 7.4% (see pg. 4 of study). Thus, almost 100 MMBO will be abandoned. A more recent analysis estimates that 80 of 90 MMBO of the original oil in place (i.e., an ultimate recovery of 11%) will be abandoned (Ron Ray, personal communication, 1991). In comparison, the oil recovery from the F-1 and 14-12 zones up to January 1, 1972 was 19% of the original oil in place (see conclusions of item B3). If similar recovery rates for the F-1/14-12 and F-2 zones are reasonable, then approximately 10 MMBO in the F-2 zone is not accounted for.

The geologic model of South Coles Levee assumes that reservoir sandstones in the F-2 zone are laterally and vertically connected. As a consequence, a single oil-water contact is assumed. However, the tilt of this oil-water contact (175 ft/mi) is higher than expected (<90 ft/mi). Also, sequence stratigraphic analysis indicates the presence of potential seals within the reservoir. Thus, several low-angle oil-water contacts may be present instead of a single high-angle contact. If so, some of the "missing" F-2 oil may reside in obscure areas of separate F-2 pools that will not be drained with the current well grid. Furthermore, undiscovered pools, in particular a lower F-2 pool, may exist within the F-2 zone. Thus, production is possible on the flanks of the structure below the previously presumed stratigraphic limit of F-2 production.

In addition to development possibilities within the F-2 zone, new pools below the F-2 zone are possible. The lower Stevens (i.e., the 68-29 sand or middle Coulter sandstone) produces at North Coles Levee, and the Middle Miocene (i.e., the Round Mountain silt and Nozu sandstone) produces at both North and South Coles Levee. Apparently, the North Coles Levee anticline has only 100 feet of closure at the "N marker", and the structure leaks westward into the Elk Hills anticline. In contrast, the South Coles Levee anticline has about 500 feet of four-way closure at the same horizon. Since more closure is present at South Coles Levee, economic lower Stevens and Middle Miocene production is likely at South Coles Levee.

Shallow Pliocene gas sands of the San Joaquin and Etchegoin Formations have produced over 41 BCF at South Coles Levee field. The productive sands, which include the Calitroleum, Gusher and 4th MYA sands, typically have initial production rates of 1.7 to 25 MMCFD. However, the reservoirs tend to be limited. Thus, these gas sands would be secondary objectives in any wells drilled at South Coles Levee.

South and North Coles Levee fields - production history

1936 - ***Discovery of the Stevens sandstone*** in the Ten Section field discovery well near Stevens Siding (16-30S-26E)

discovery well: Shell KCL-Stevens 1 (1-29)
location: 29-30S-26E (seismically-defined)
production depth: 7800-7900 ft

1938 - ***Discovery of Coles Levee field*** (future South Coles Levee)

Discovery well (F-1 reservoir)

discovery well: Ohio F-1 (Marathon SCLU 74-10)
location: 10-31S-25E
production depth (74-10): 9225-9364 ft
average reservoir thickness (DOG): 100 ft
average porosity (DOG): 18%
average permeability: ---------
average production (DOG): up to 900 BOPD
oil gravity (DOG): 32°-53° API

field statistics (Stevens at South Coles Levee)

cumulative production (1990): 57 MMBO & 396 BCF (51 yrs)
current status: 59 producers & 19 shut-in
current production (1990): 142 BOPD/well (63% wtr)
closure: 500-600 ft (4-way closure) at the N marker

1939 - Discovery of the Tupman area of Coles Levee field (future ***North Coles Levee field***)

Discovery well (Lower Western reservoir)

well: Richfield Tupman-Western 1 (ARCO CLA 32-32)
location: 32-30S-25E (seismically-defined)
production depth (32-32): 8396-8676 ft
average reservoir thickness (DOG): 550 ft
average porosity (DOG): 20%
permeability (DOG): 0-7,500 md
average production (DOG): 700-1,000 BOPD
oil gravity (DOG): 43°-60° API

field statistics (Stevens at North Coles Levee)

cumulative production (1990): 161 MMBO & 245 BCF (51 yrs)
current status: 73 producers & 66 shut-in
current production (1990): 14.3 BOPD/well (82% wtr)
closure: 100 ft at the N marker (leaks westward into the Elk Hills anticline)

1939 - Discovery of the ***F-2 reservoir*** at South Coles Levee

discovery well: Ohio KCL F-2 (Marathon SCLU 72-10)
location: 10-31S-25E
production depth (72-10): 9335-9650 ft
average reservoir thickness (DOG): 1000 ft w/ 500 ft of sand
average porosity (DOG): 18%
permeability (DOG): 0-1,000 md w/ average of 35 md
$\log K = .5238(\varnothing - 14.8807)$
oil gravity (DOG): 43°-60° API

1941 - Discovery of ***shallow Pliocene gas*** at South Coles Levee

discovery well: Standard KCL 20-9 (Marathon SCLU 52-9)
location: 9-31S-25E
reservoir: Calitroleum sand of the Etchegoin Formation
production depths (DOG): 5,000-7,000 ft
average reservoir thickness (DOG): 10-70 ft
average porosity (DOG): 25%
permeability (DOG): 400 md
average production (DOG): 1,750-26,000 MMCFD

cumulative production (1990): 41 BCF (29 yrs)
current status (1990): 6 producers & 3 shut-in in 1990 w/ only 1 well still producing in 1992

1943 - Coles Levee is separated into South and North Coles Levee.

1944 - South Coles Levee is unitized.

1945 - World record drilling depth (South Coles Levee)

well: Standard KCL 20-13 (13-5)
location: 5-31S-25E (west flank of anticline)
TD: 16,246 ft (TD in Middle Miocene)

1947 - Discovery of the ***68-29 reservoir*** (North Coles Levee)

discovery well: Richfield CLA 68-29
location: 29-30S-25E
production depth (68-29): 9650-9880 ft
average reservoir thickness (DOG): 225 ft
average porosity: ----------
average permeability: ----------
production (12/13/47): 213 BOPD (0.5% wtr) & 90 MCFD
oil gravity (DOG): 34.5° API

1952 - Discovery of the ***14-12 reservoir*** (South Coles Levee)

discovery well: Ohio (Marathon) SCLU 14-12
location: 12-31S-25E
production depth (14-12): 1952 deepening (9975-10065 ft) of an older well
average reservoir thickness: ------------
average porosity (DOG): 18%
average permeability (DOG): 45 md
initial production (32-12): 373 BOPD (35.7° w/ 0.4% wtr) & 788 MCFD

- Reevaluation indicates previous completions in the 14-12 reservoir. Apparently, the 32-12 well is the only 14-12 producer without commingled F-1 production.

1953 - Discovery of ***Eocene and Vedder reservoirs*** (North Coles Levee)

discovery well: Richfield "Coles Levee A" 67-29
location: 29-30S-25E

- TD in basement (17,895 ft) below Eocene strata

Eocene reservoir

production depth (67-29): 17,620-17,873 ft
reservoir thickness (67-29): 250 ft
average porosity (67-29): 12%
average permeability (67-29): 10 md
initial production (67-29): 61 BOPD (38° w/ 38% wtr) & 1,750 MCFD

- 1953 world record production depth

Vedder reservoir

production depth (67-29): 13,240-14,000 ft
reservoir thickness: -----------
average porosity (26-29 core): 5.1-14.5%
average permeability (26-29 core): 0.4-0.28 md
average production (67/29): 30 BOPD (54% wtr)
cumulative production (67-29): 3,534 BO (eight months)
oil gravity (26-29 core): 32°-38° API

1957 - Discovery of ***San Joaquin reservoir*** (South Coles Levee)

discovery well: Ohio (Marathon 71-10)
location: 10-31S-25E
reservoir: 4th MYA sand of the San Joaquin Formation
production depths: 4,200 ft
average reservoir thickness (DOG): 200 ft
average porosity (DOG): 29%
permeability (DOG): 1200 md
initial production (71-10): 3,380 MMCFD
cumulative production (1990): 76,046 MCF (one well)

1986 - Discovery of ***lower Coulter reservoir*** (South Coles Levee)

discovery well: Channel 12X-10
location: 10-31S-25E
production depth (12X-10): 10,768-11,109 ft
reservoir thickness (12X-10): 210 ft
porosity: ------------
permeability (12X-10): 0.5 md
production test (12X-10): 230 BOPD (36° w/ 3.0% wtr) & 400 MCFD on 2/11/86
average production (12X-10): 2-4 BOPD and 11-26 MCFD for 1-1/2 months with subsequent abandonment

1986 - Discovery of ***Middle Miocene (Nozu) reservoir*** (South Coles Levee)

discovery well: Channel 22X-10 (follow-up to 12X-10)
location: 10-31S-25E
production depth (22X-10): 11,392-13340 ft
reservoir thickness (22X-10): slotted liner over a gross interval
porosity & permeability: - **fractured shale?**
production test (22X-10)): 230 BOPD (3.0% wtr) & 400 MCFD on 2/11/86
cumulative production (22X-10): 4845 BO (39° w/ 50% wtr) & 18,626 MCF for 13 months with subsequent abandonment

1989 - Discovery of ***Middle Miocene reservoir*** (North Coles Levee)

discovery well: ARCO CLA 11-33 (1989 recompletion of an older well)
location: 33-30S-25E
production depth (11-33): approx. 11,000-12,000 ft w/ selected perfs over the gross interval
average porosity & permeability: - **fractured shale?**
production (11-33): 102 BOPD (0.9% wtr) & 225 MCFD in 1/7/89