Part III
Attachment III-E
Appendix III-E.1

REGIONAL GEOLOGY AND HYDROGEOLOGY

Pescadito Environmental Resource Center
MSW No. 2374
Webb County, Texas

PESCADITO
ENVIRONMENTAL RESOURCE CENTER

Initial Submittal March 2015
Revised September 2015

Prepared for:
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Laredo, TX 78041

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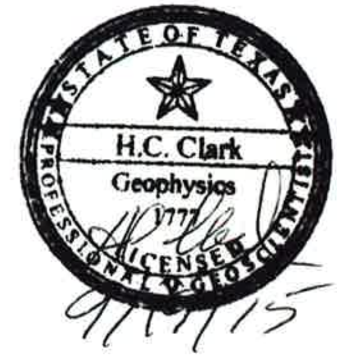

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STATE OF TEXAS
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Geophysics
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Table 2 - Hydrogeologic Properties

Reg	Aquifer		Carrizo-Wilcox	Queen City-Bigford	El Pico	Laredo	Yegua Jackson
	Function		Aquifer west Webb	Local aquifer, west	Regional confining	Aquifer regional	TWDB minor aquifer
	Composition		coarse sands gas production site bookend confining	sands and clays bookend confining	clay, some sand upgrad	sand, clayey sand sandier near base	clay, claystone, more clay sand stringers, sandier near base
	formation w/in		Wilcox	Queen City-Bigford	El Pico	Laredo	Yegua and Jackson undifferentiated
	transmissivity	ft^2/day	115-350[1]	see (1)	↑ Confining [1]	85-2735(1),141-192[3]	J 225[1]
	SC	ft/day	6-33[1]	see (1)		4-711[1]	J 17[1]
	K		.3-1[7] map	.1-.3[7] map		631-809 md core[3]	upper Y .3-1ft/dayH[2,2.1.4] lower Y 1-3 ft/dayH[2,2.1.4]
	Recharge	inches	outcrop,	outcrop, .5-1[7]		5%*21=~1[1] 5%*20.4=~ 1[6]	<~1inch, see text
	Thickness site area, ft geophysical log		~1700'	~2000'	110	875	Y 440
	Thickness Laredo Sheet		not described	~650' outcrop	900-1150 **	620	Y 400
	Rainfall(mean)	in/year	outcrop 21.3[4]2014	21.3[4]2014		20.4[4]	20.4[4]
	Lake Evaporation (mean)	in/year	64.07[4]2014	64.07[4]2014		66.26[4]	66.26[4]
	water table/confined		confined by Reklaw	confined by El Pico		wt/confined downdip	wt/confined downdip
	recharge character		Carrizo outcrop	Bigford outcrop		Laredo outcrop	surface minor, Laredo major
	recharge w/in 5 miles		none, west edge cty	none, west county		none	surface minor
	depth groundwater, ft.		162-204[1]	125-268[1]		12-252[1]	94-292[1], ~200[6]
	elevation groundwater		few wells	few wells		few wells east of Laredo	few wells in region
	groundwater flow rate		isolated wells	isolated wells		isolated wells	~.5'/yr using dip gradient, seepage vel eqn*
	groundwater flow direction		east-southeast	east-southeast		downdip east-southeast	downdip east-southeast, south[1]
	formation dip direction		east	east	east-southeast	east-southeast	east-southeast
	formation dip	ft/mile	87'/mi[1]	66'/mile [5]	54[1]	72[1]	64[1]
	flow from wells	gpm	150-200[1]west	see (1)		5-170gpm[1], 60gpm av[3]	<15gpm[1]
	TDS range	mg/l	826-2220[1]west	1000-5000[7]		1226-2200[3] (east side Laredo)	3-4k(2,4-235, lower Y) 2.1k[6],4.47k[1]
	Chloride range	mg/l	120-630	see [1]		100-1030[1]	300-1k[2], 712[6], 1772[1]
	map ref gradient		isolated wells	isolated wells		isolated wells	Deeds, 2004
	water use		domestic, ranch	ranch		Laredo supply, Las Lomas(w/RO)	ranch (domestic, livestock), rig supply
	wells w/in 1 mile site		0	0		0	1
	wells w/in 5 miles		0	0	↓ Confining (1)	Las Lomas area	ANB, Weid, Hurd, Alarcon?

Note: While the Carrizo-Wilcox and the Bigford-Queen City are important regional aquifers in Webb County, in the site area both are greater than a thousand feet below and saline (1) and Winslow et al (1972)

References:

(1) Lambert, 2004, few Bigford Wells in Webb County, none sampled
(2) Deeds, 2003
(3) Ch2M Hill, 1999
(4) TWDB rainfall and evaporation website, quad = 1008, 2015
(5) oil and gas geophysical log site area, geophysical log cross section
(6) this study
(7) Kelley, 2004

*A flow rate depends on interconnected sands for both Laredo(1) and Yegua(see text) seepage eqn estimate is likely inappropriate
** Includes sands below

slight tilt that initiated the slides and directed them to the east and east-southeast. This phenomenon is shown in the inset Figure 1 (Long, 2010).

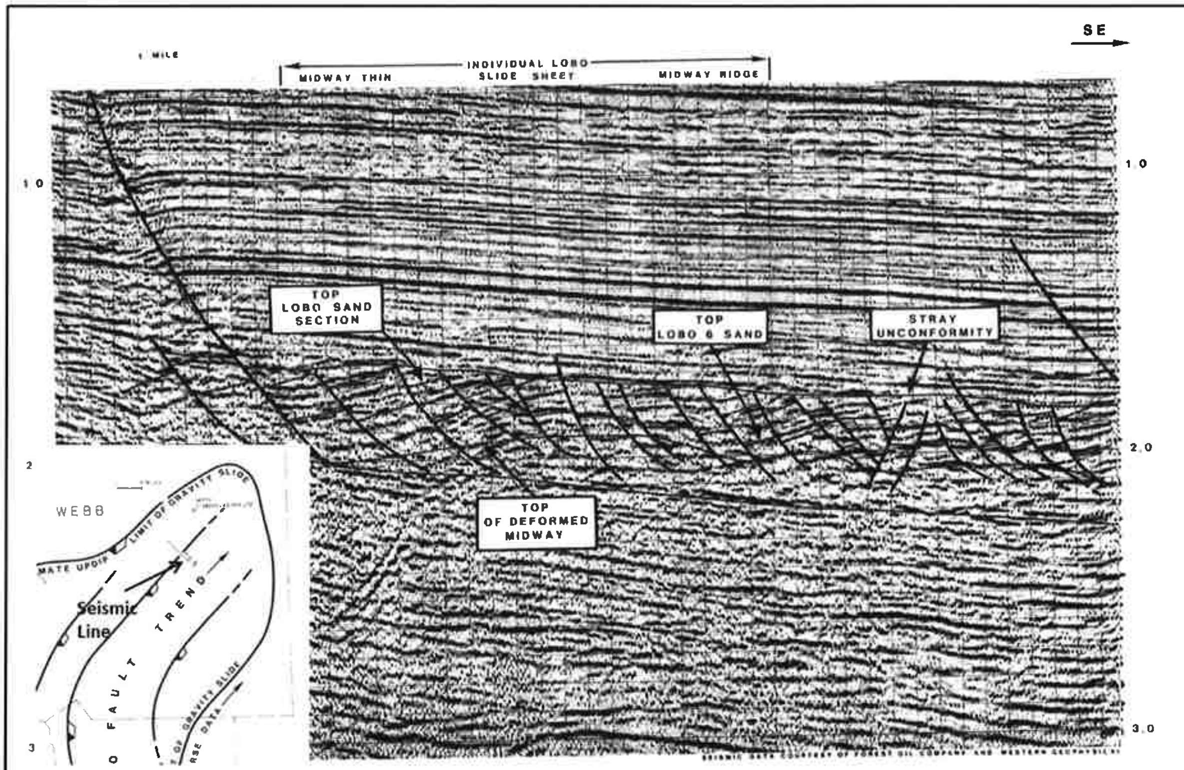


Figure 1 from Long, 1986. Seismic section in site region (note inset location map) illustrating the Eocene Lobo Slide.

This particular section is near the site and illustrates the Lobo slide "sandwich" as well as Wilcox regional listric faulting. Lobo production was discovered in the seventies, and these recent seismic sections tie together a picture of what must have been a difficult exploration task. Wells on the Yugo Ranch, the location of the proposed landfill, produce from these Lobo sands at depths of about 7000 to 10000 feet.

The remaining Wilcox deposition in the region is generally a combination of sands and muds of the Cotulla Barrier Bar system (Fisher and McGowen, 1967) and fine grained shelf system deposition in the landfill region. Overall, the Wilcox sands and clays are bound inland at the Cretaceous shelf edge, the Sligo and Stuart reef area, and the anticlinal Laramide structures to the south, and Wilcox deposition generally extended the continent by progradation accompanied by rapid subsidence.

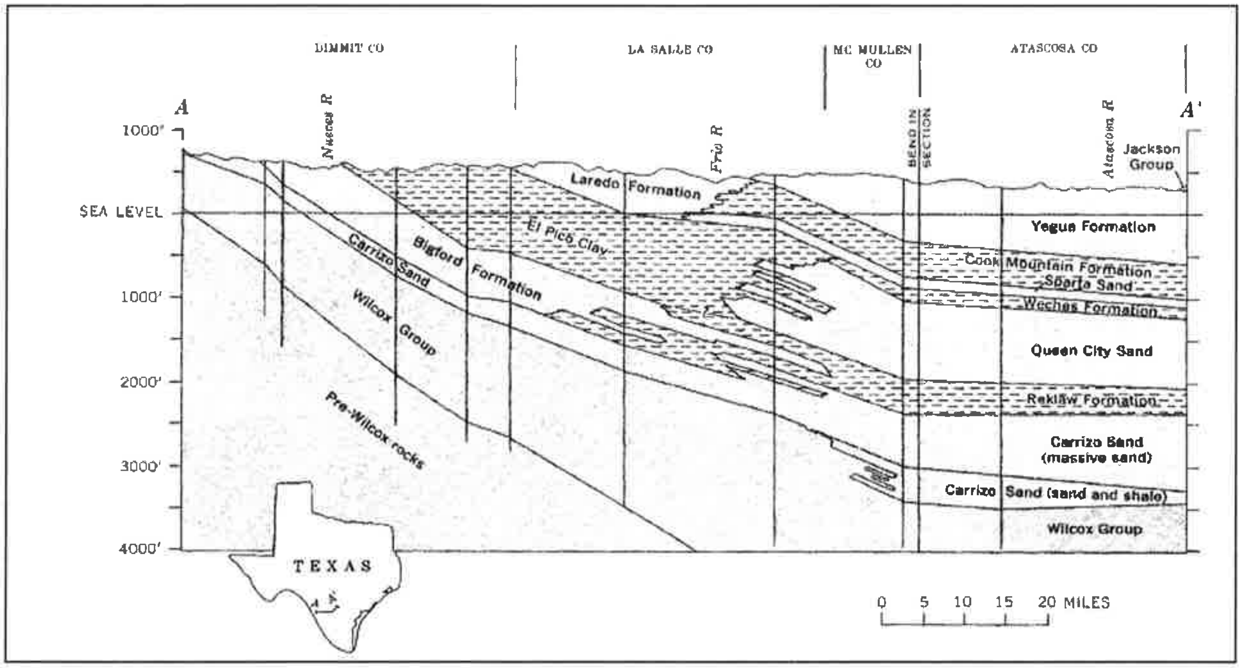
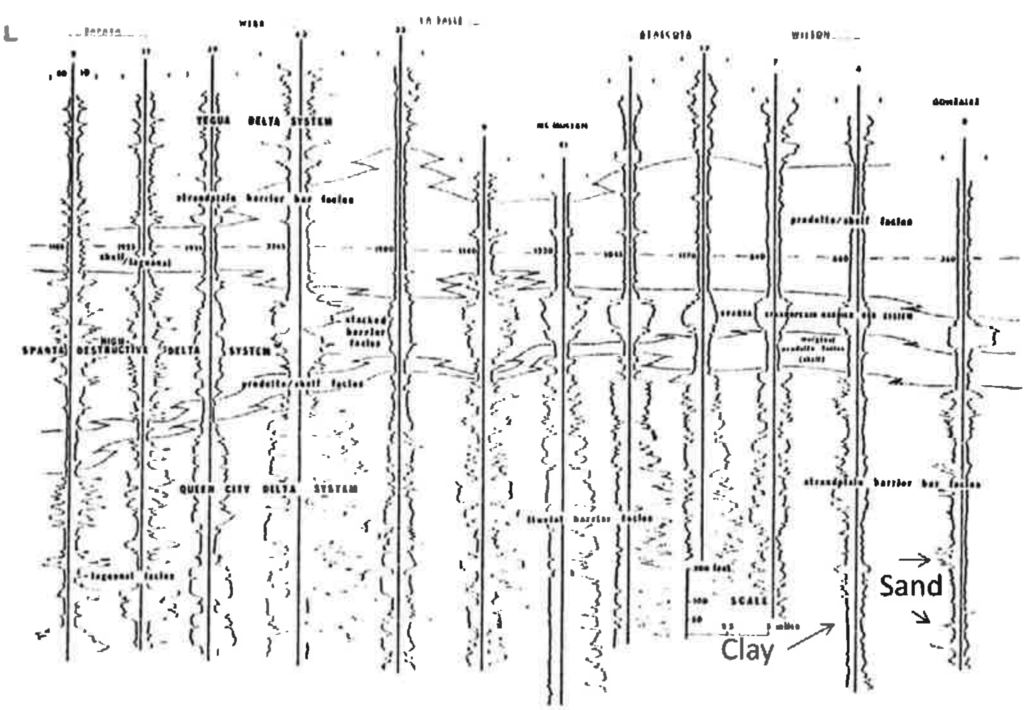


Figure 2 – Stratigraphic Dip Section Showing Equivalence of Formations Across the Region, Eargle, 1968

Here, dip and strike cross sections from the Ricoy study intersect near the landfill site, and while his study focused on the Sparta (think Laredo kind of equivalent), the sections are instructive in that they include the Queen City below and the Yegua above, together with depositional framework interpretations of each. Across Webb County and through the site region, the Queen City changes from lagoonal muds to a delta system (Ricoy, 1976) with stacked sand sequences. The Ricoy dip section and the strike section as well, show a continuous clay above the Queen City and below the sands above; this then is the Weches Formation, or the equivalent of the upper part of the El Pico Clay (Eargle, 1968). This clay is shown on the geophysical log section at the site as a continuous, uniform clay, about 110 feet thick and serves as the ultimate confining layer beneath the site.

Lonsdale (1937) found groundwater resources in the El Pico (then the Post-Bigford) to be "scanty and of poor quality" and that assessment holds true today (Lambert, 2004). The Queen City fares little better, the limited sands updip produce little water and the quality is marginal (Lambert, 2004), and while sands are plentiful downdip, they are also saline. (See Figures 3 and 4, Ricoy, 1976).



From Ricoy, 1976, Geophysical log strike section illustrating relationship of South to Central Texas facies.

Figure 3

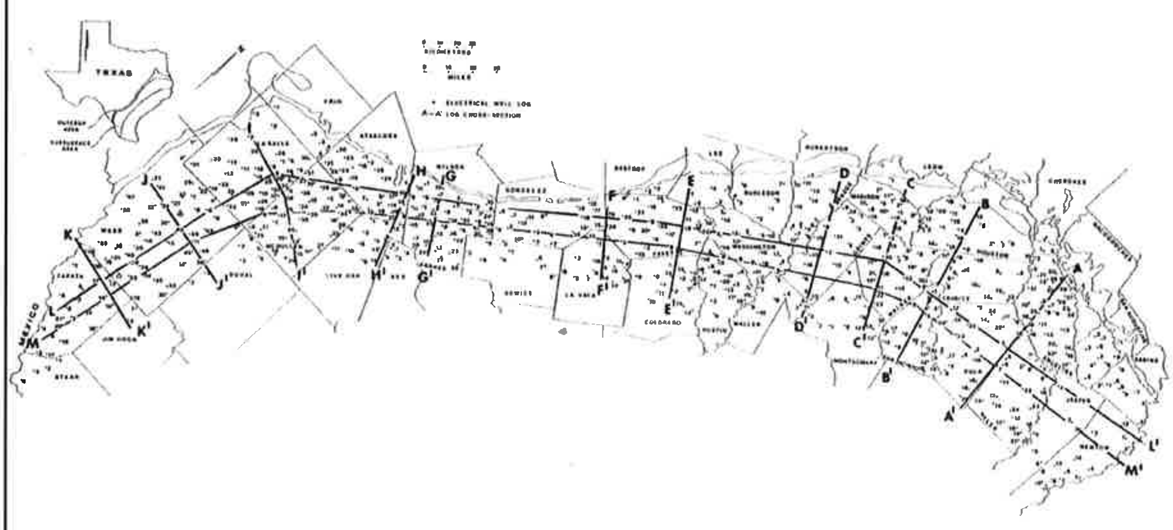


Figure 3a - Location Map for Section J-J' and L-L' – From Ricoy 1976

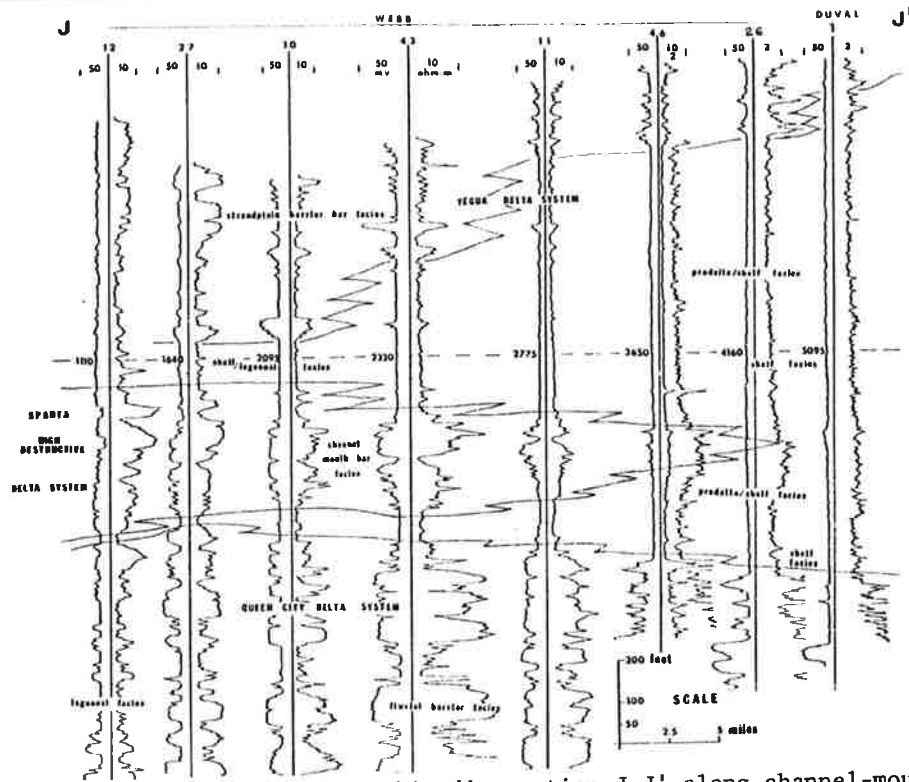


Figure 12. Stratigraphic dip section J-J' along channel-mouth bar facies, Sparta high-destructive delta system, south Texas.

51

Figure 4 – Stratigraphic Dip Section J-J' – From Ricoy, 1976

1.3.7 Laredo (elsewhere Sparta and Cook Mountain) with meaning for water

The Laredo Formation overlies the El Pico Clay (Weches) in the site region. It outcrops as sands and clays in the Laredo area (Plates 1 and 2), with cemented sands forming prominent ridges parallel to the strike. Its light color and dominant fine sands distinguish it from the El Pico Clay below and Yegua above. It was mapped and described in section by Trowbridge (Trowbridge, 1932) as part of a geologic reconnaissance along the Rio Grande, then by Lonsdale and Day (Lonsdale, 1937) looking more at groundwater resources in Webb County. Both designated the formation as Cook Mountain as had Duessen before them (1929), and then Darton and Gardner after (1937) when they published the Geologic Map of Texas. Then Gardner (1938), re-named their Cook Mountain equivalent the Laredo Formation. She formalized the long held view that in this southern part of Texas, "the middle Eocene section differed in lithologic composition and faunal assemblages" from the Cook Mountain elsewhere; and continued study "has made increasingly inept the inclusion of the heavy sandstone section of South Texas" under the Cook Mountain name. These geologists had little trouble identifying the Laredo at its base, where the sands contrast with the underlying and conformable El Pico clay; and they all chose as a few feet above its top, a readily identifiable oyster bed about 7.5 miles east of Laredo, a marker that they felt was near the base of the overlying Yegua Formation. Others have noted clays in the Laredo (Patterson, 1942, CH2M Hill, 1999) both downdip from Laredo. The sediments mapped by Trowbridge and Lonsdale and re-named by Gardner, are called the Sparta and Cook Mountain elsewhere in Texas (Eargle, 1968, Ewing, 1999) as a more detailed division of the Cook Mountain. The Laredo in the site region, with more sands near the base and fewer near the top, fits this picture. The Laredo sediments were likely deposited in a shallow, shoreline environment dominated by wave action carrying the sediments along the shoreline, because: the resistant beds of the Laredo outcrop form ridges generally parallel to the strike suggesting shoreline distribution, the subsurface geophysical logs depict relatively thick and correlable sands in the Laredo (CH2M Hill, 1999, and oil and gas geophysical logs for this study), and those observations fit with the several published geophysical log cross-sections that include, or pass close to the site (Ricoy, 1982, Baker, 1995, Bebout, 1976). Eargle's work (1968) and boundaries agree with the present mapping of the Laredo Formation on the Laredo Sheet (Plate 1 Barnes, 1976)

Lonsdale (1937) seemed relatively optimistic about the water resource potential of the Laredo (then known as the Cook Mountain), describing several wells with water adequate for irrigation all along the outcrop. However, he indicated that the quality varied and subsequent studies (CH2M Hill; Lambert, 2004) have concluded this as well and dimmed the prospects for abundant Laredo Formation water resources.

1.3.8 Yegua Formation (last of the Claiborne) and Jackson Group

Where light colored, fine and thick sands characterize the Laredo around and several miles east of the city, the Yegua is far more clay-rich with red, brown and purple muds along

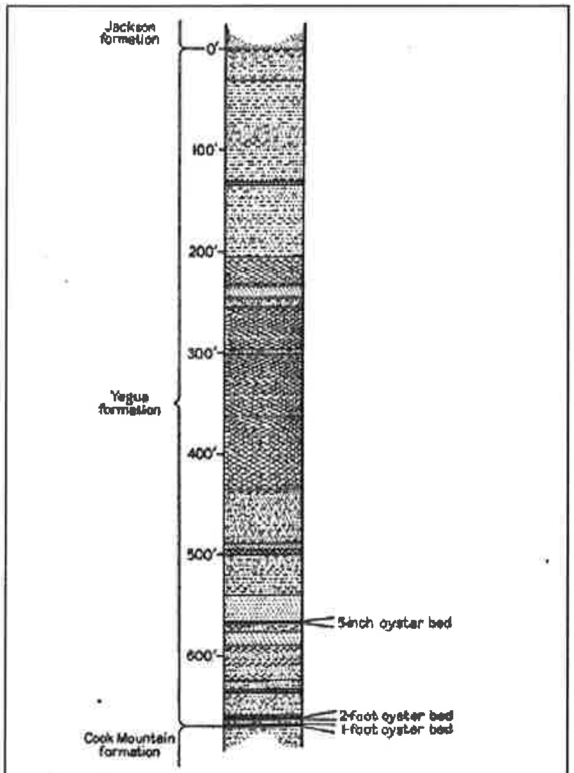


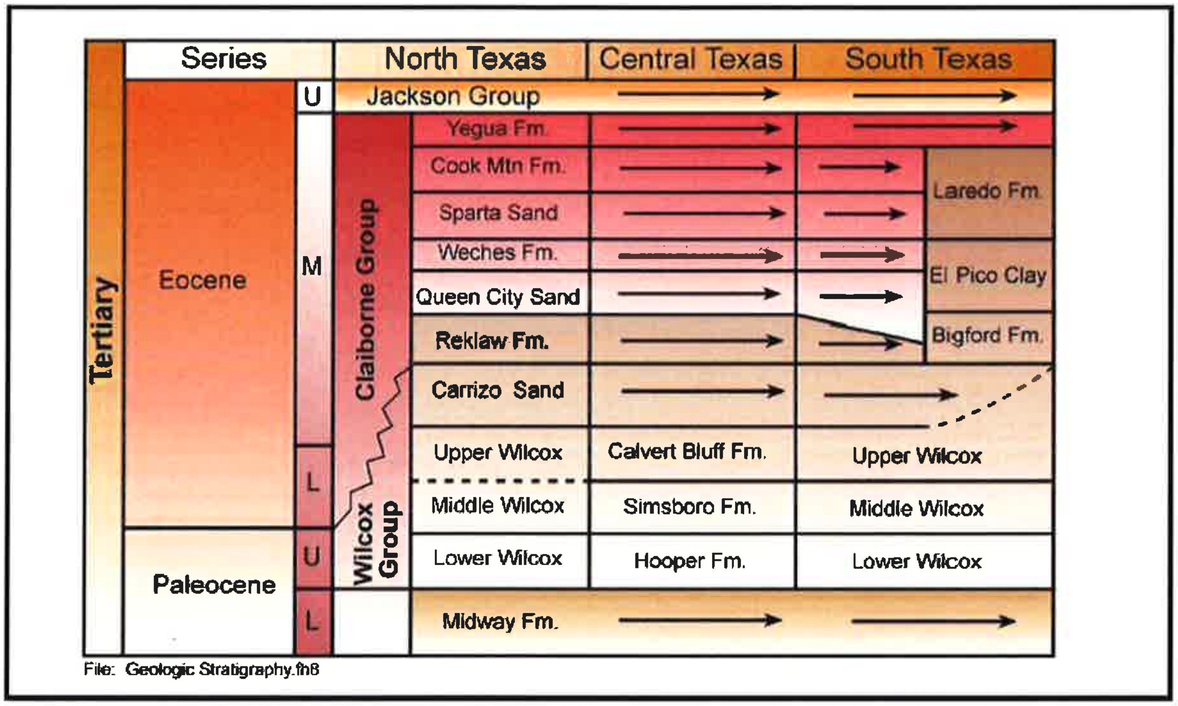
FIG 6.—Composite columnar section of the Yegua formation showing predominance of clay.

Figure 5 - Lonsdale, 1937 – Yegua Stratigraphic Section along US 59

Lonsdale (1937) found water production to be minimal and of poor quality, and thought better development in the area could be obtained by drilling through to the underlying Cook Mountain (now Laredo). A drilling log for a water well near the landfill site, the completion of the ranch well next to the site and a deep boring on the site indicate that more sand is found in the lower part of the Yegua here, and that is the source of water production. The thin, interbedded sands found in the Yegua at shallow depths may contain moisture and may be ultimately interconnected and serve as a sensor for groundwater monitoring purposes.

The base of the Jackson is frustratingly similar to what is found in Yegua outcrops, making its contact with the underlying Yegua difficult to distinguish in the surface and subsurface. Lonsdale (1937) marked the contact in measured section where he examined the sediments and found volcanic ash. There is a whitish sandstone that outcrops on US59 just east of the ranch entry road that may involve ash, but the evidence for that or any volcanic material nearby does not stand out. The Jackson (Lonsdale, 1937) includes clays, sandy clays and some sands that at least in part are arkosic and derived from volcanic activity to the west. Further north along strike, the Jackson includes extensive lignite (Ewing, 1999). Lonsdale estimated that the Jackson here is about 1500 feet thick and dips at about 80 feet per mile. He held the same view of water possibilities for the Jackson as the Yegua, few wells producing salty water, and where even in the outcrop, better water was available from roof catchment and surface ponds.

The question of the Yegua-Jackson boundary is particularly vexing because the Laredo Sheet (Barnes, 1976) depicts the contact passing virtually through the center of the site, from the ranch entrance at US59 and along a north-south strike. Trowbridge (1932) placed the contact



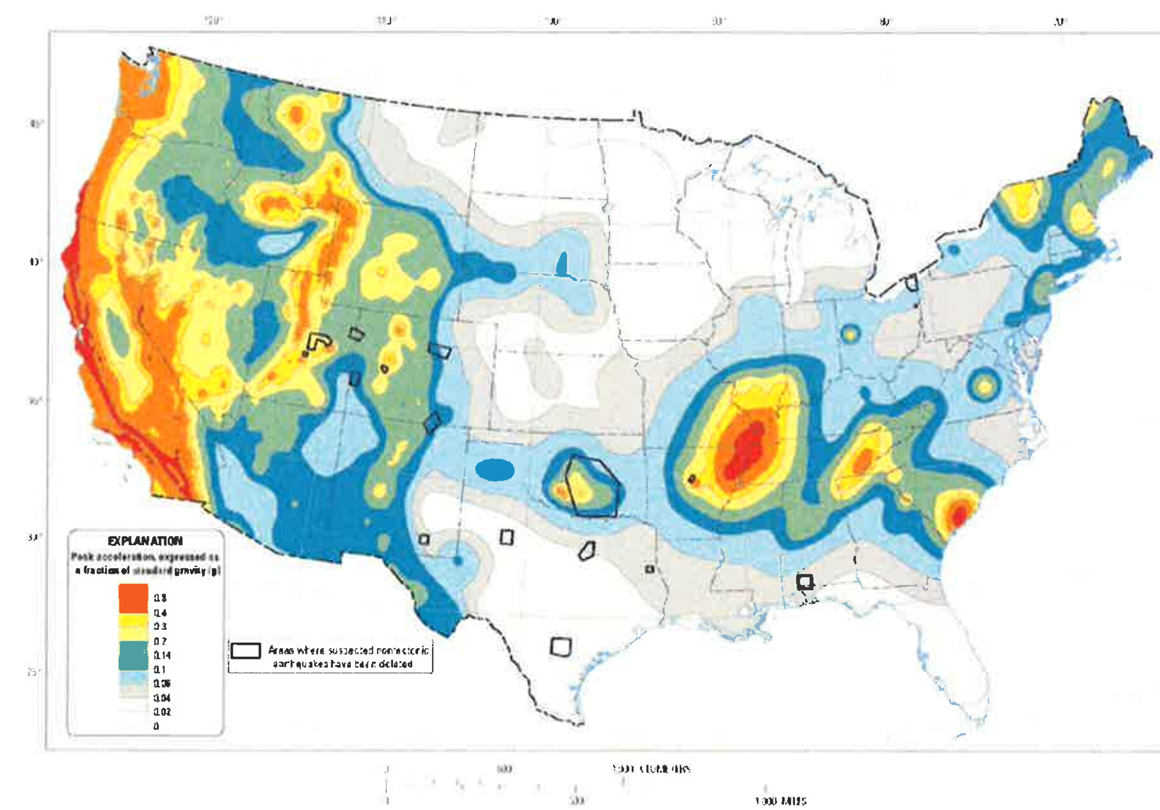
Generalized stratigraphic section for the Wilcox and Claiborne groups in Texas (after Ayers and Lewis, 1985; Hamlin, 1988; Kaiser, 1978; Ricoy and Brown, 1977; Guevara and Garcia, 1972; and Payne, 1968).

Figure 6 - From Kelley, et al, 2004 – Generalized Stratigraphic Section for the Wilcox and Claiborne Groups

Each of these aquifers reflects the effects of being at the southern end of basin-wide depositional systems, that is, the composition of the aquifer is not always the same as typical in the rest of Texas, and the semi-arid situation here has minimized the development of extensive groundwater resources in this area. The regional hydrogeology is discussed here, along with notes about differences from the broad regional systems designated as major and minor aquifers by the TWDB and included in the Groundwater Availability Models (GAMs).

2.3.1 Carrizo Aquifer

The aquifer with the greatest potential for future production in Webb County is the Carrizo; in this region, the sand-rich component of the Carrizo-Wilcox, a designated major aquifer in Texas. The Carrizo sands are the most lithologically uniform of all the Claiborne



Two-percent probability of exceedance in 50 years map of peak ground acceleration

Figure 8. (USGS, 2014) – National Seismic Hazard Map

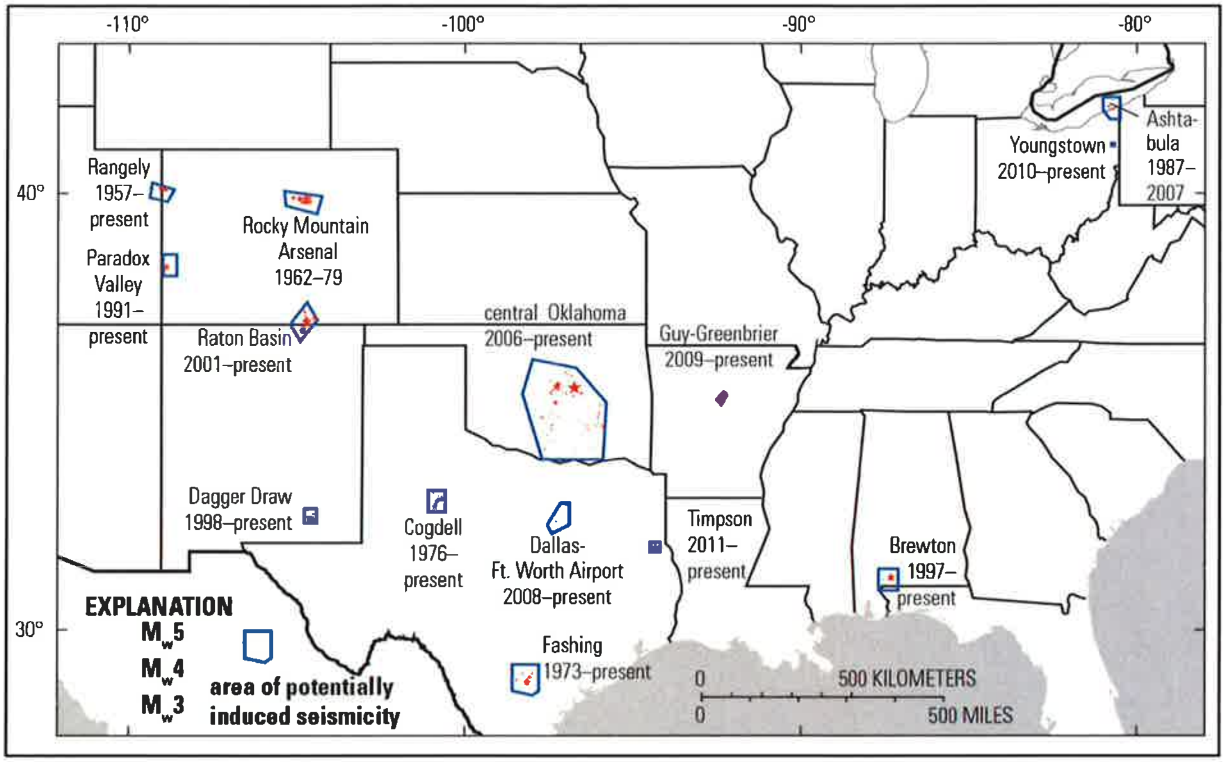


Figure 9 - Map showing areas of potentially induced seismicity in the Central and Eastern United States, USGS 2014

The gas field in the site area is a mature development and production from source rock is distant. There are no salt water disposal wells in the immediate area.

Ej

Jackson Group

Sandstone and clay; mostly sandstone, fine to coarse grained, friable to quartzitic, commonly laminated and crossbedded, white, gray, greenish brown, light brownish yellow, fossiliferous; clay, sandy, calcareous, greenish gray, pink, red, silicified wood abundant; some beds of white volcanic ash; large, dark limestone concretions composed of calcite crystals common; thickness about 360 feet

Ey

Yegua Formation

y and sandstone: mostly clay, lignitic, sandy, bentonitic, silty, mostly well laminated, chocolate brown to reddish brown, lighter colored upward, produces dark-gray soil; sandstone, mostly quartz, some chert, fine grained, indurated to friable, calcareous, glauconitic, massive, laminated, crossbedded, weathers to loose, ferruginous, yellow-orange and reddish-brown soil; some fossil wood; thickness about 400 feet

El

Laredo Formation

Sandstone and clay; thick sandstone members in upper and lower part, very fine to fine grained, in part glauconitic, micaceous, ferruginous, crossbedded, dominantly red and brown; clay in middle, weathers orange-yellow; dark-gray limestone concretions common, some fossiliferous; marine megafossils abundant; thickness about 620 feet

Epp

El Pico Clay

Clay, sandstone, and coal; mostly clay, in part gypsiferous, medium gray to brown; sandstone, mostly fine grained, some medium to coarse, argillaceous, silty, in part glauconitic, gray to brown, thin bedded to massive, friable to indurated; aphanitic septarian concretions common; thickness 900-1,150 feet

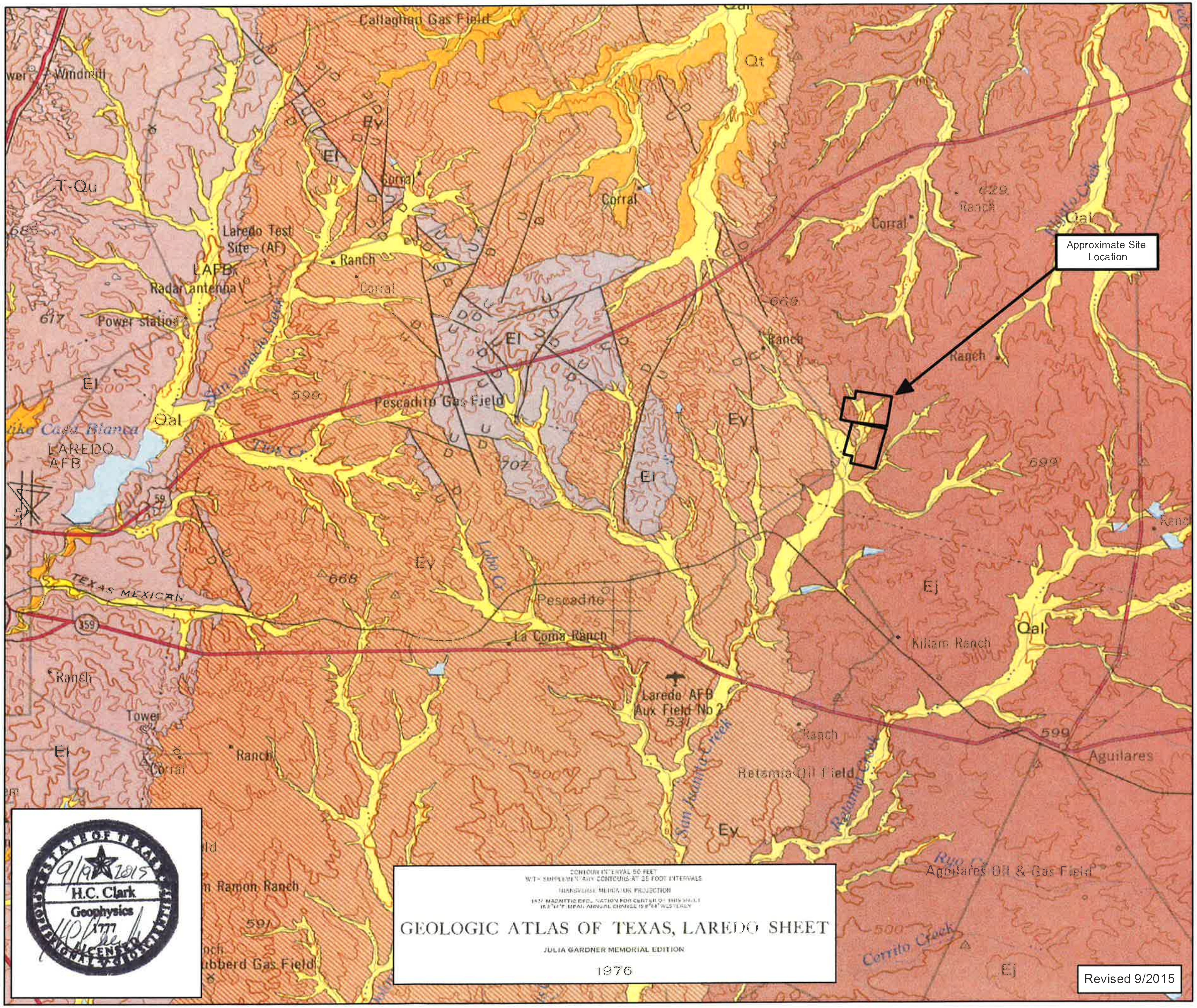
Plate 1 to Appendix III-E.1
Geologic Map of Region

N

2 1 0 2 4 6 8 Miles

Scale 1:150,000

Source: Geologic Atlas of Texas, Laredo Sheet (1976)



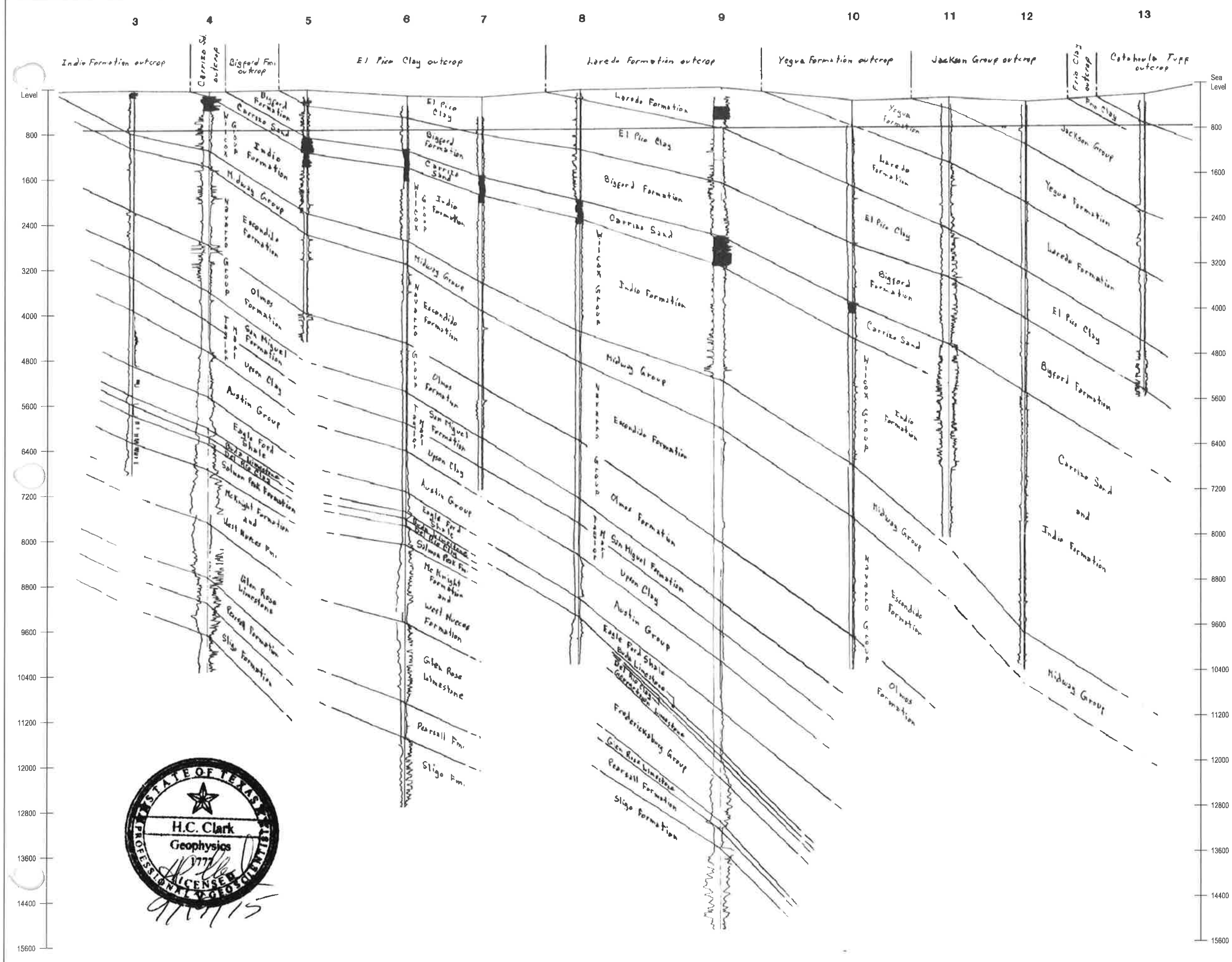
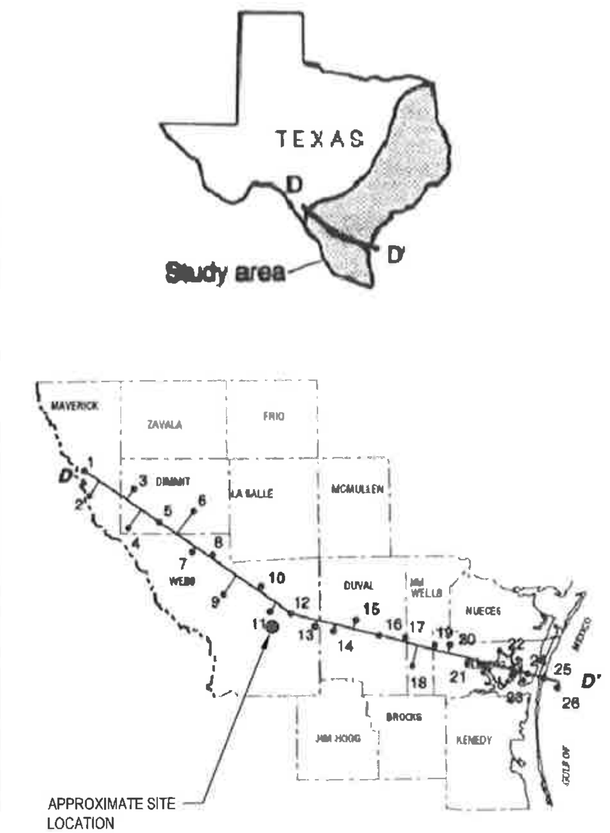
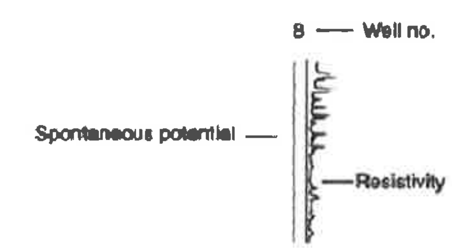


PLATE 2 TO APPENDIX III-E.1
HYDROSTRATIGRAPHIC SECTION ACROSS WEB COUNTY

GEOLOGIC SECTION D-D'

BY E.T. BAKER, JR (1995)





0 5 10 15 20 MILES
0 5 10 15 20 KILOMETERS
Vertical scale greatly exaggerated

EXPLANATION

INTERNAL CONTAINING WATER WITH LESS THAN 3,000 MILLIGRAMS PER LITER DISSOLVED-SOLIDS CONCENTRATION – Estimated from electric logs

DIAGNOSTIC MICROFOSSIL – Discorbis nomada

ABBREVIATION OF LITHOSTRATIGRAPHIC UNITS -- Gr., Group; Sd., Sand; Fm., Formation

OUTCROP GEOLOGY – From Brown and others (1975, 1976); modified from Brewton and others (1976)

NOTE: Although faulting is common regionally and is complex in some areas, all faults have been omitted from this geologic section to maintain unbroken continuity of the formation boundaries

REVISED 9/2015

Plate 3 to Appendix III-E.1
Area Water Wells

Note:
Submitted Driller Report Database (SDRDB) and Groundwater Well Database (GWDB) were obtained from the Texas Water Development Board. Topographic map provided by USGS and TNRIS as scanned Digital Raster Graphic of standard topographic map series (1980)

Revised 9/2015

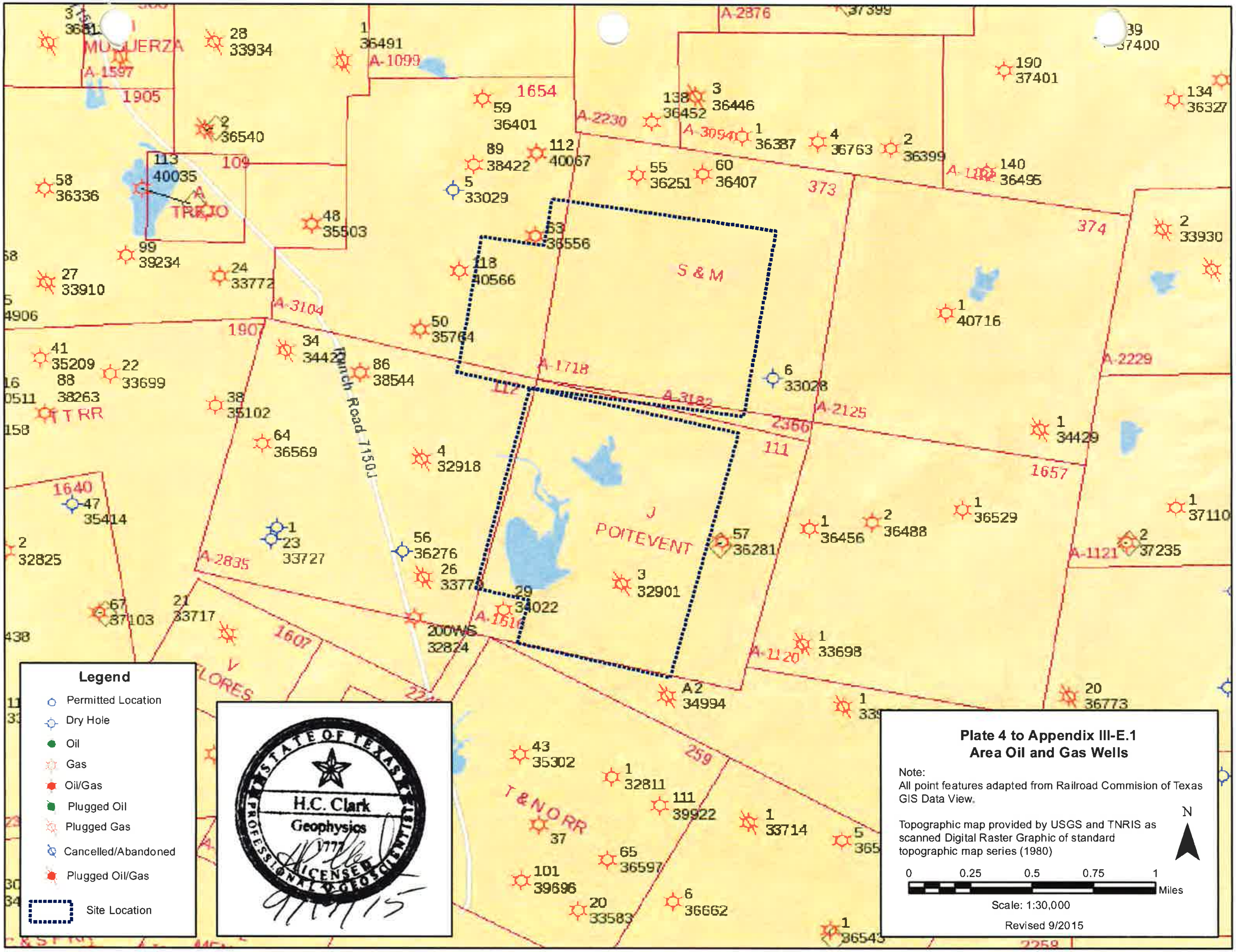


Plate 4 to Appendix III-E.1
Area Oil and Gas Wells
Note:
All point features adapted from Railroad Commision of Texas GIS Data View.
Topographic map provided by USGS and TNRIS as scanned Digital Raster Graphic of standard topographic map series (1980)
N
0 0.25 0.5 0.75 1 Miles
Scale: 1:30,000
Revised 9/2015
Legend
Permitted Location
Dry Hole
Oil
Gas
Oil/Gas
Plugged Oil
Plugged Gas
Cancelled/Abandoned
Plugged Oil/Gas
Site Location
STATE OF TEXAS
H.C. Clark
Geophysics
PROFESSIONAL GEOSCIENTIST
LICENSED
Ranch Road 7150J
S & M
J POITEVENT
T & N O RR
MUGUERZA
TREJO
V FLORES
T RR