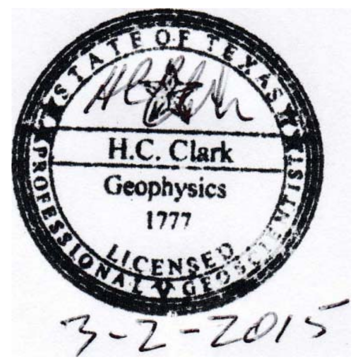
Part III
Attachment III-E
Appendix III-E.1

REGIONAL GEOLOGY AND HYDROGEOLOGY

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

PESCADITO
ENVIRONMENTAL RESOURCE CENTER

March 2015



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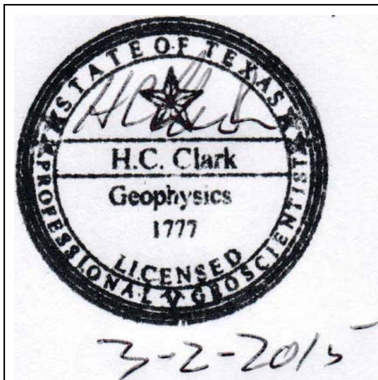

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1.0 Regional Geology and Hydrogeology [(330.57(f), 330.63(e)(1))]

The regional geology and hydrogeology sections of Attachment E have been prepared by H.C. Clark, P.G., PhD a qualified groundwater scientist, to meet the requirements of 330.57(f)(2) and 330.63(e)(1) and more generally, 330.63(e).

1.1 Introduction to Regional Geology

The geology in the landfill region is a stack of sediment layers dipping gently toward the coast, built first in the Mesozoic as flat platform limestones and muds accumulating at the edge of the then newly opened Gulf of Mexico; built next in the Tertiary, as rapidly accumulating sands, silts and muds vigorously prograded the continent out to the present coast. Adjustment and subsidence related to basin loading created Wilcox faulting in the site region, salt diapirism raised the nearby Pescadito dome; and Laramide tectonism just to the south in Mexico, provided much of the material that makes up the most recent several thousand feet of the geologic column. The hydrogeology of the region is a subset of this framework, where the limited water available is found in the more permeable sediments of upper reaches of the column; and, the quality and quantity of groundwater here reflects the limited recharge environment. The discussion here begins with a brief recount of the early geologic history and moves forward to describe the Wilcox Lobo that underlies the site and is the basis of gas production there; this is followed by a more comprehensive description of the geology immediately underlying the site and involved with the groundwater of the region.

1.2 Geomorphology

The land surface, or geomorphology of the site region is part of the Interior Coastal Plain of Texas (Wermund, 1996); it is generally a product of the geology immediately beneath, and since the whole geologic section is structurally tilted to the coast, the land surface is as well. Resistant sandstone ridges of more indurated Eocene sediments exposed at the surface in the site region generally parallel the strike, but the ridges are intermittent, overprinted by the effect of drainage to the south, eventually to the Rio Grande. The site area topographic map, the Burrito Tank quadrangle, describes the drainage that is characteristic of the region. The soils here are a relatively thin veneer in place, developed from weathering of the underlying formations and transported and developed in the drainage areas (Sanders, 1985). Scattered chert gravel much like the Leona and Uvalde residual gravels to the north overprints the surface. The topography is characterized by broad divides and equally broad alluvial washes and the soil borings at the site are a product of this development. In summary, the land surface in the site region reflects the underlying geology and is typical of the expected development in this arid environment.

1.3 Regional Geologic Framework [(330.63(e)(1))]

The surface geology in the Pescadito Landfill region is depicted on the Laredo Sheet of the Geologic Atlas of Texas (Plate 1 - Barnes, et al, 1976) [(330.63(e)(1)(A))]. Here, the outcrop bands parallel the coast as they do across the rest of the province, and then bend to a north-south strike indicating the role of uplift in Mexico, just south of the border—where the Laramide effectively bookends deposition typical of the Texas coast. A stratigraphic column (Table 1) outlines the geology of the site region and lists the downdip subsurface equivalent units [(330.63(e)(1)(B))]. The table also lists formation thicknesses in the subsurface interpreted from a site area geophysical log, along with notes about the approximate timing of regional events that influenced stratigraphy. Properties of the uppermost thousand foot plus section are summarized in Table 2 [(330.63(e)(1)(B))]. Together, these summaries form the framework of the discussion that follows here.

Table 1 - stratigraphic column

Era	System	Series	Group	Formation	Downdip subsurface	Thickness	Event
Cenozoic	Tertiary	Eocene	Jackson	Jackson Group undifferentiated		area geophysical log	
			Claiborne	Yegua		400	
				Laredo	Cook Mountain Sparta	620	dome
				El Pico	Weches, Queen City	900-1150	
				Bigford	Reklaw		
			Wilcox	Carrizo		2175	Faulting
				Wilcox	includes Lobo at site		
		Paleocene		Midway	includes Wills Point		
Mesozoic	Cretaceous			Navarro			Laramide
				Taylor			
				Austin			
				Eagle Ford	San Miguel, Anacacho		
				Hosston, Sligo			
				Cotton Valley			
	Jurrasic			Louann			

Table 2 - Hydrogeologic Properties					
Reg	**Aquifer**		**El Pico**	**Laredo**	**Yegua Jackson**
	Function		**Regional confining**	**Aquifer regional**	**TWDB minor aquifer**
	Composition		**clay, some sand upgrad**	**sand, clayey sand sandier near base**	**clay, claystone, more clay sand stringers, sandier near base**
	formation w/in		**El Pico**	**Laredo**	**Yegua and Jackson undifferentiated**
	transmissivity	**ft^2/day**		**85-2735(1),141-192[3]**	**J 225[1]**
	SC	**ft/day**		**4-711[1]**	**J 17[1]**
	K		**confining [1]**	**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**		**5%*21=~1[1] 5%*20.4=~ 1[6]**	**<~1inch, see text**
	Thickness site area, ft geophysical log		**110**	**875**	**Y 440**
	Thickness Laredo Sheet		**900-1150 inc. sediment below**	**620**	**Y 400**
	Rainfall(mean)	**in/year**		**20.4[4]**	**20.4[4]**
	Lake Evaporation (mean)	**in/year**		**66.26[4]**	**66.26[4]**
	water table/confined		**confining layer**	**wt/confined downdip**	**wt/confined downdip**
	depth groundwater, ft.			**12-252[1]**	**94-292[1], ~200[6]**
	elevation groundwater			**few wells east of Laredo**	**few wells in region**
	groundwater flow rate				**~.5'/yr using dip gradient, seepage vel eqn***
	groundwater flow direction			**downdip east-southeast**	**downdip east-southeast, south[1]**
	formation dip direction			**east-southeast**	**east-southeast**
	formation dip	**ft/mile**	**54[1]**	**72[1]**	**64[1]**
	flow from wells	**gpm**		**5-170gpm[1], 60gpm av[3]**	**<15gpm[1]**
	TDS range	**mg/l**		**1226-2200[3] (east side Laredo)**	**3-4k(2,4-235, lower Y) 2.1k[6],4.47k[1]**
	Chloride range	**mg/l**		**100-1030[1]**	**300-1k[2], 712[6], 1772[1]**
	map ref gradient				**Deeds, 2004**
	water use			**Laredo supp, Las Lomas(w/RO)**	**ranch (domestic, livestock), rig supply**
	wells w/in 1 mile site			**0**	**1**
	wells w/in 5 miles			**Las Lomas area**	**ANB, Weid, Hurd, Alarcon?**
References:					
	(1) Lambert,				
	(2) Deeds,				
	(3) Ch2MHill,				
	(4) TWDB rainfall and evaporation website,				
	(5) oil and gas geophysical log site area,				
	(6) this study				
***A flow rate depends on interconnected sands for both Laredo[1] and Yegua(see text) seepage eqn estimate is likely inappropriate**					

Geologic information about the site region includes geologic maps of the area, a number of papers describing and interpreting the geology of South Texas, site area oil and gas geophysical logs and a commercial structural contour map of the subsurface using those same wells and more, water well drillers' logs, field reconnaissance in the region including roadcuts north and south of the landfill site, and boring logs and test pits excavated on the site itself. The geology and hydrogeology of the Yegua-Jackson that makes up the first thousand feet beneath the landfill is also summarized in recent regional studies related to groundwater issues, particularly in the Groundwater Availability Model studies for the Yegua-Jackson (Deeds, et al, 2010) and Queen City-Sparta (Kelley, 2004) aquifers. Reconciling stratigraphy and formation names that have meaning over an entire depositional basin is always problematic, and doing so at the southern end of all these formations has been a special challenge for geologists since the 1930's, and before. It is difficult to describe geology in one place and have that description apply to all the rocks of about that same time all along a particular depositional framework that typically extends from Louisiana to Mexico. The differences derive in part because of particular interests of the researcher such as paleontology or sediment character, choices of boundaries, efforts to develop a broad, regional and correlable framework, and surface observations versus subsurface geophysical investigations. The site region, located near the southern edge of the Rio Grande Embayment is both especially interesting and frustrating because it has been subjected to an influx of terrigenous sediment that makes stratigraphic discrimination difficult and matching with the rest of the coast next to impossible. Examples in the site region include the designation of the Laredo Formation, the choice of the base of the Yegua Formation, the Yegua-Jackson contact—and the reconciliation of issues to fit all these formations with subsurface geophysical log information. The study for this landfill project necessarily involves surface and subsurface information directed to a regional geologic and hydrogeologic picture while considering the issues involved with landfill planning. The names and descriptions used here are chosen to fit with the surface geologic map and regional groundwater studies and then aligned with the subsurface geophysical log nomenclature using explanatory notes. In the end, the Yegua and Jackson sediments are similar and their properties for landfill purposes are effectively the same, but reconciliation of information remains. Inasmuch as the setting for the Paleocene and Eocene sediments that make up the upper reaches of the geology beneath the site [(330.63(e)(1)(B))] depends on the underlying framework, the discussion begins with a brief review of that framework, starting with the dawn of the Gulf basin.

1.3.1 Mesozoic Development and Site Region Structural Setting—the Rio Grande Embayment

The geology of the landfill region began with the opening of the Gulf of Mexico to a somewhat larger version of its present form in the Triassic. The oceanic crust spreading involved transfer faults (Huh, 1996; Knox, et al, 2007), along with interactions about the Laredo Triple Junction (Sams, 2010), leaving the early Gulf bordered by a set of alternating arches and embayments fanned about the basin, and also bound by remnants of the late Paleozoic overthrust, the Ouachitas (Cram, 1961). The site area is in the southern part of the Rio Grande Embayment, with the San Marcos Arch some distance to the north and a series of anticlines, the Zapata-Webb and Zavalla relics of Laramide activity to the almost immediate south (Long, 1985; Ewing 2010). This early basin geometry influenced the accumulation of the Jurassic Louann salt; thicker in the East Texas Salt Basin and Houston Embayment, thinner in the Rio Grande (Sams, 2010), but with some thicker occurrence in Webb County (Budd, 1981); thinner, if at all, over the intervening arches, and bounded by the southern edge of the embayment along the border with Mexico. The Louann salt's presence deep beneath the immediate area is evidenced by the Pescadito salt dome structure a few miles west of the site at US Highway 59 (US59) - (See Plate 1), and in a deep well in western Webb County, the PanAmerican #1 Rosa Benavides (Budd, 1981). The initial deposition in the area conformably on top of the salt was a thin tidal-flat mud, the Norphlet, followed by a thick progradational sequence of the Smackover then Buckner Formations (Budd, 1981), ranging from shallow basin limestones to reworked shoal muds; illustrated in cores and geophysical logs from two wells in Webb County, the Humble #1 Carlos Benavides in the site area and the PanAmerican #1 Rosa Benavides, to the west (Budd, 1981). The site region back in that time probably looked something like the Yucatan shelf today. The Cotton Valley ended the Jurrasic with another thick sequence, dominated by limestone, in the landfill region and all along the coast. The Cretaceous here was similar to the rest of the Texas shelf deposition, beginning with carbonate accumulations shelfward, from first the Sligo then the Stuart City reefs, found in the subsurface at the western edge of Webb County (Bebout, 1974). The Late Cretaceous here was a long episode of shelf development, with the Eagle Ford Shale (with new drilling in the western part of the county), then Austin Chalk followed by marls and muds of the Taylor and Navarro Formations ending the Mesozoic.

1.3.2 The Cenozoic and transgressive and regressive stratigraphy [(330.63(e)(1)(B))]

The Mesozoic was relatively quiet; but that time ended with the onset of Laramide activity, not only in the western part of the continent but reaching as far as and parallel to the Mexico border along the Rio Grande (Ewing, 2010), just south of the site region. As the Tertiary began, the uplifts to the south, as well as the continent to the west of the southern border, provided renewed sources of sediment and influenced input source flow from further west (Ambrose, 2007). The depositional framework and subsequent outcrop pattern in the site region bends to follow the Mexico border, marking the southern limit of the embayment. Information about these sediments in the site region comes from surface and subsurface data related to oil and gas, uranium, lignite, other minerals and groundwater and studies are directed to those exploration objectives.

The geology that characterizes the stratigraphic column immediately beneath the landfill region is recorded in the thousands of feet of muds, silts and sands that poured off the continent into the embayment during this last phase of development, from the Paleocene to the present. The processes involved in creating this record were the same as today: streams carrying sediment from the continent, changing course, flooding, changing course again, leaving behind overprinted and intertwined channel fill, splay and overbank floodplain deposits, and ending in sand-rich deltas at the Gulf edge; once there, the sands were spread along the shoreline and when those beaches became barrier islands, trapping bays and lagoons behind, all tidally affected. When the sands exceeded the wave energy available, the deltas dominated; more often in South Texas, the wave energy dominated and deltas were destroyed and distributed as bars, barrier islands and strandplains where they met the shoreline (Ricoy and Brown, 1977, Bebout, 1976). All this deposition took place at about sea level as the bowl of sediments subsided to accommodate each episode that brought new material. The Tertiary geologic history is punctuated by widespread marine shales, marking periodic and relatively brief returns of the sea (Ewing, 1999), as well as by salt domes and growth faulting, demonstrating the dynamic response of the section adjusting to the load. The geologic history here is the same as that all along the coast—the continent built outward through sequences of continental sediments punctuated by marine returns; the sum prograding in time and space, tilting and thickening toward the present Gulf, leaving the inward reaches of each formation exposed as north-northeast striking outcrop bands about parallel to the Tertiary and present coasts. During much of the time, a significant river system brought sediment in from and along the southern part of the Rio Grande Embayment as well as from regional river systems along the coast (Ambrose, 2007; Ricoy and Brown, 1977; Ewing, 1986). Other factors that influenced the depositional character were the arid climate and episodes of destructive wave energy that redistributed sands along the coast (Ricoy, 1976). This Tertiary phase of the site region geology is graphically illustrated in a cross-section typical of, and perpendicular to, the coast from Baker (1995) [(330.63(e)(1)(B))]. (Plate 2) While the Mesozoic was characterized by relatively quiet platform style deposition across broad shallow reaches with carbonate muds edged with reefs and shoals (Bebout, 1974), the Tertiary framework reflects the influences of renewed Laramide activity to the south in Mexico, and all across the Texas coast (Ewing, 1999).

The stratigraphy that developed during the Tertiary, summarized in the stratigraphic column and depicted on the regional geologic section, began as the Cretaceous ended with the depositon of Navarro (Cretaceous) and the Tertiary began with Midway (Tertiary Eocene), both shales laid out on a flat shelf, followed in Webb and Zapata Counties by a series of Lower Eocene Wilcox Lobo sediments, coarsening-upward sands. Sedimentary structures, created by attacking waves and then tidally dominated, along with trace fossil evidence of bioturbation indicate a shallow marine situation beneath the site region (Shultz, 2010). The Wilcox sands are extensive and interbedded with thick shales, likely developed as poorly lithified as those sediments beneath. Shortly after deposition, the entire Lobo section in this Webb and Zapata County region devolved into a series of gravity slides, more brittle sands riding over the shales beneath, leaving a complex of fault blocks where the later reaches often likely involved reworked earlier slide materials—all this a relatively sudden event in geologic time (Long, 2010). After that episode, the whole mass was then eroded, covered by middle Wilcox, Stray shales, leaving a sandwich of relatively undisturbed shales above and below the Lobo section—and trapping the hydrocarbons that are the subject of exploration in the landfill region today. The Lobo trend shows the effect of the uplift to the south and west in Mexico that provided the 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).

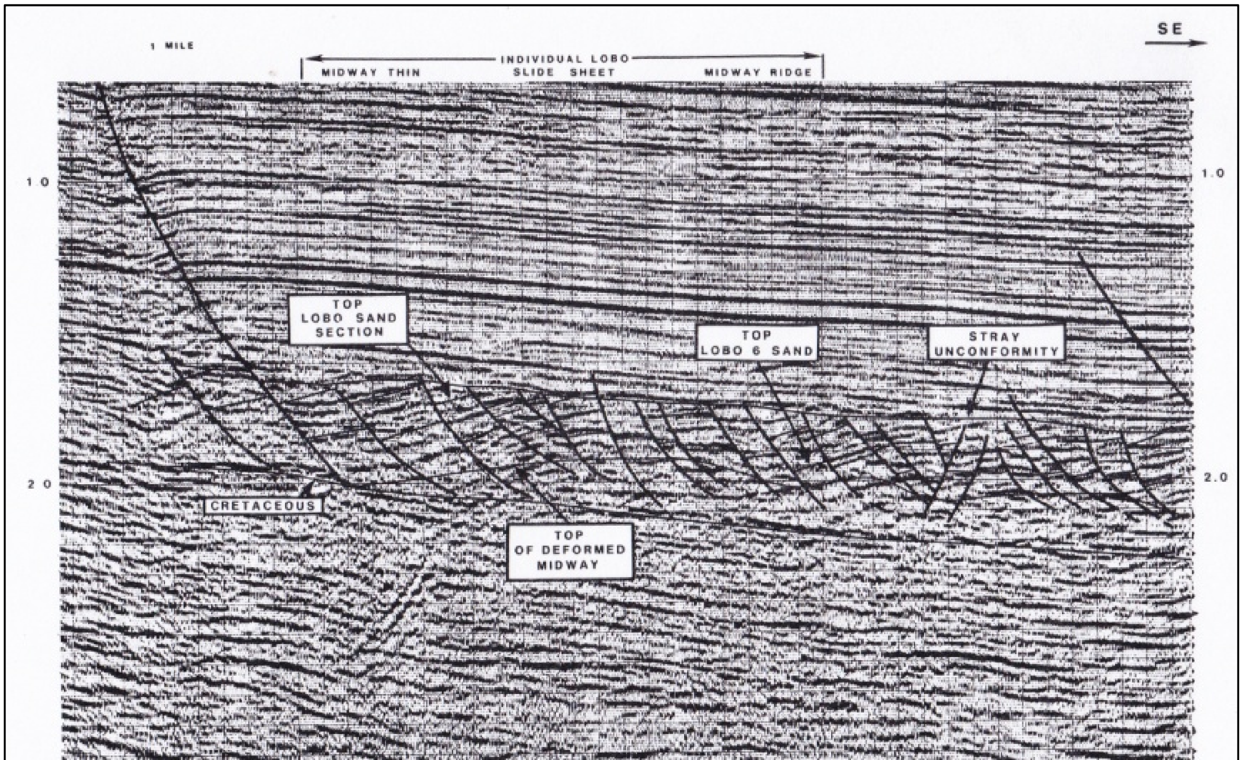


Figure 1 - From Long, 2010

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.

1.3.3 Wilcox Growth Faulting [330.63(e), 330.555(b) and 330.559]

Wilcox deposition led to faulting as a basin edge adjustment mechanism to accommodate the rapid influx of sediments. Faulting is discussed at this point as part of the regional geologic history and also as the analysis to address 330.63(e), 330.555(b) and 330.559 concerning processes in the site region. The basin edge adjustment became necessary when basin edge downwarp alone could not accommodate the incoming sediment load, something had to give, and at this point in the Eocene, the hingeline broke as a fault zone, a band of growth faults—syndepositional, listric, normal faults with attendant antithetic faults (Ewing, 1986, Fisher and McGowen, 1967). The faults generally floored, or became parallel to the bedding plane on the Midway shales below. The site area is at about the interior limit of this fault zone, with limited faulting to the west and increased faulting downdip to the east. The surface expression of the Wilcox fault zone is shown in the site region on the geologic map (Plate 1, Barnes, 1976) as a band of faults paralleling the coast. The faults cut sediments younger than the Eocene, indicating that Wilcox growth faulting continued. This surface mapping shows a fault at about US59 at Las Lomas, approximately two miles north of the site; it cuts Yegua and Jackson at the contact, so faulting extended at least to that time.

The Pescadito salt dome, pinned to the Jurassic Louann salt, is a surface manifestation of the inland limit of salt deposition and subsequent diapirism. Radial faulting accompanied this diapirism, or intrusion, and that faulting is limited to the area around the dome. The dome is about 5 miles west-northwest of the landfill site, and while the uplift mechanism remains, no evidence of recent activity was observed. In summary (330.63(e)(2)), there are Wilcox time related faults in the site region, but these faults have served their adjustment purpose and are quiescent; radial faults associated with the Pescadito dome are distant. In summary, faulting in the region related to basin adjustment is quiescent, and faulting related to salt diapirism is distant.

1.3.4 Carrizo, an aquifer in western Webb County

The Wilcox is followed by the Carrizo Formation, the beginning of the Eocene Claiborne Group. It crops out in a 2-3 mile wide band in the western part of Webb County and dips beneath the rest. The Carrizo in Webb County consists mostly of relatively coarse, often cross bedded sand, with some lenses of clay, and clay is often found in the sand matrix (Lonsdale, 1937). It is typically light brown and the sandy soils, with some indurated sandstone, create a rolling topography. Lonsdale found that estimations of thickness and dip were difficult because both varied across the region; he estimated a thickness of 125-250 feet and a dip of 108 feet per mile. The Carrizo, and the sands of the unconformably underlying Wilcox, to the extent those exist in this region, taken together are a significant freshwater aquifer in Webb County and along and downdip of the outcrop across Texas. The Carrizo-Wilcox combination is a Texas Water Development Board (TWDB) designated major aquifer, and the predictive groundwater availability model (GAM) for the southern region is important here, particularly for its meaning at the southern terminus of the model—where the sediments are limited and different, and where the water quantity and quality are not like that of the aquifer system's most productive parts. Lonsdale (1937) found a number of shallow wells on the outcrop and more producing good water from the Carrizo downdip of the outcrop. Yield was difficult for him to estimate, but depth to water was measured from 58 to 67 feet below ground surface (bgs). His writing about water supply and this formation was more positive than his words about other water resources in the county.

1.3.5 Bigford and Reklaw, equivalents

The Eocene continues upward with the Bigford Formation in this region conformably overlying the Carrizo. The Bigford was named by Trowbridge (1932), but tentatively placed differently than today, when he mapped the outcrop at the Bigford Ranch about 45 miles northwest of Laredo, and then followed the outcrop for several miles along the Rio Grande. The topography is rough, brushy and broken, with exposures in ravines (Lonsdale, 1937, placed Bigford differently, still). In western Webb County, the formation consists of sands, thin shales and coals (Eargle, 1968, who finalized the Bigford's formation rank and abandoned the Mt. Selmon nomenclature) and is about 650 feet thick. Lonsdale found few wells in the Bigford sands, and those produced fairly saline water fit only for livestock; and when allowed by multiple completion zones, Bigford water contaminated the Carrizo water below. However, today these Bigford sands are grouped with Queen City sands above in the west part of Webb County as an aquifer (Lambert, 2004). On the east side of the Rio Grande Embayment, the Bigford grades into the Reklaw, and it does so downdip in the subsurface as well (Eargle, 1968 and geophysical logs this study).

In the site region, the Reklaw is a uniform marine shale about 300 feet thick as shown on the site area geophysical log section and on regional geophysical log sections (Bebout, 1976). As a marine shale all along the Texas coast, the Reklaw marks a brief transgressive pause to the otherwise prograding activities. While the Carrizo-Wilcox, Queen City Sparta (CWQCSP) GAM refers to the Bigford not at all, and the Reklaw as “semi-confining” in the landfill site region, the Reklaw has the attributes to make it a confining unit. Here, the unit forms a confining unit for the Carrizo below and the Queen City sands above. The confusion about aquifer sands and confining layer is minimized by thinking about the Carrizo sand as an identifiable and continuous unit below, the Queen City sands above, with the Bigford sands and clays grading into the Reklaw as land meets sea, sandwiched in between.

1.3.6 Queen City and El Pico --downdip equivalent of Weches, an aquifer then a confining zone

The Queen City here is a series of sand and shale sequences about 2000 feet thick in the site region subsurface. It is correlable over the site region and along much of the Texas Coast. The Formation hasn’t always been called the Queen City, early field studies called the clays, few sands and coals of the rolling hills east of the Bigford outcrop, “post-Bigford” and made it an upper part of the then Mt. Selmon (Trowbridge, 1932, Lonsdale, 1937). Eargle (1968) changed Mt. Selmon member names to the Queen City and Weches Formations in Central and East Texas, and named the thick clay equivalent in the Rio Grande Embayment, the El Pico Clay (**Figure 2**), after the village on the Rio Grande where the outcrop typifies the section. There are few sands noted in the thick El Pico west of Laredo (Lonsdale, 1937), and one, but a widespread one, was correlated by Eargle (1968) in the subsurface in the Laredo Water Works and San Ygnacio School wells. Eargle’s interpretation was that the El Pico Clay graded to Queen City sands and the Weches clays above in the downdip section, and this is what is seen beneath the landfill site, where specific sequences and intervening shales can be correlated from log to log across the site region. The consistent character of the Queen City depositional framework is described along the coast in geophysical log sections that are part of a study of the overlying Sparta Formation (Ricoy, 1976, Ricoy and Brown, 1977) and these sections are a segue to the Sparta Formation, the next chapter in the site region stratigraphy.

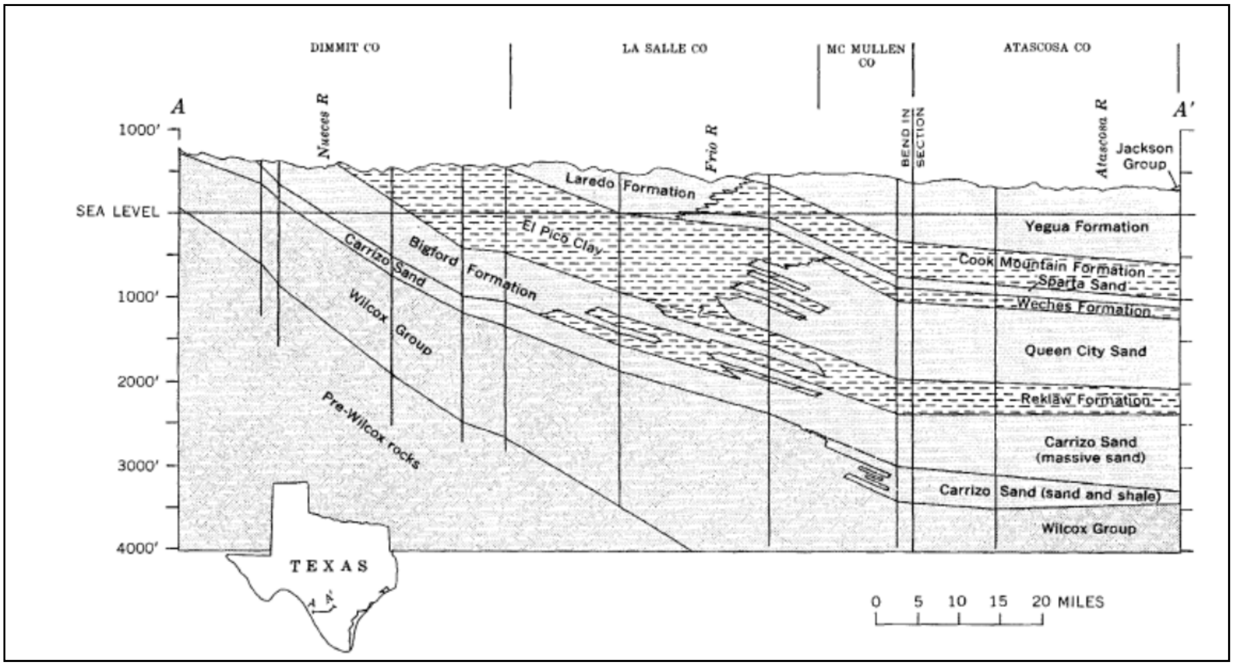


Figure 2 - Eargle, 1968

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).

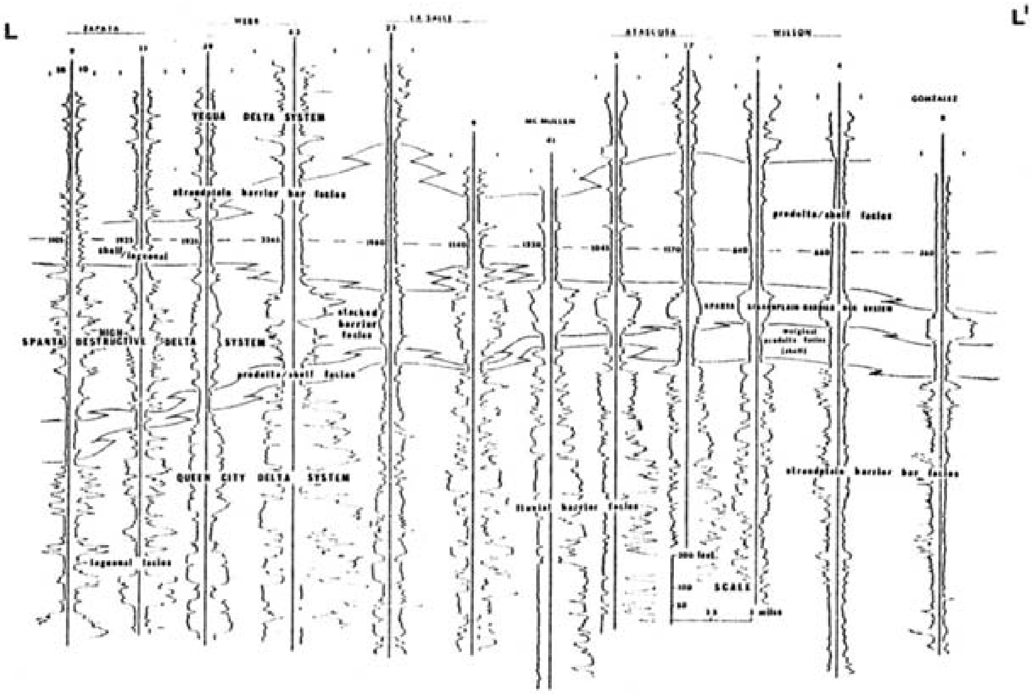


Figure 14a. Stratigraphic strike section L-L' across the high-destructive delta of south Texas and the strandplain/barrier-bar system of central Texas.

Figure 3 – From Ricoy, 1976

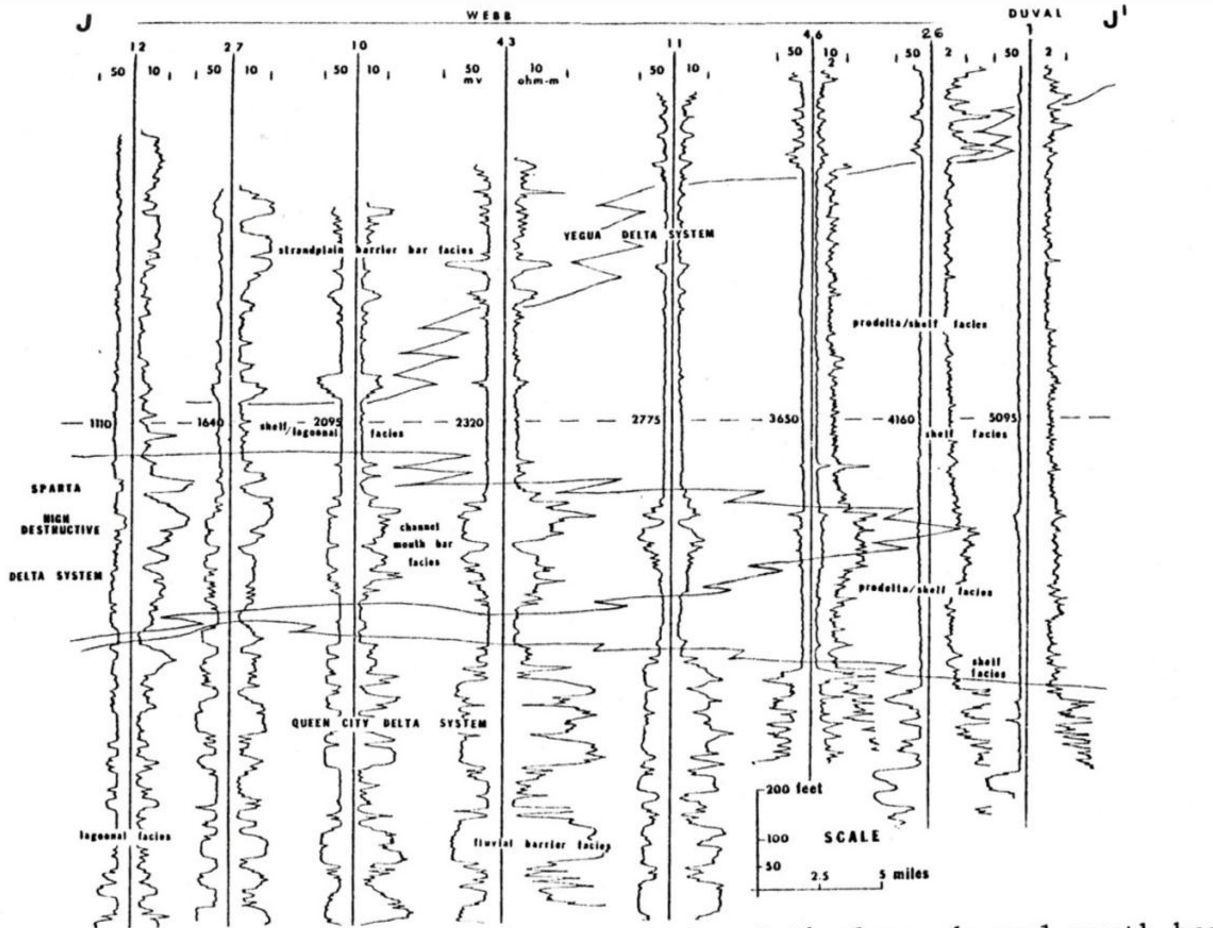


Figure 12. Stratigraphic dip section J-J' along channel-mouth bar facies, Sparta high-destructive delta system, south Texas.

Figure 4 – From Ricoy, 1976

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

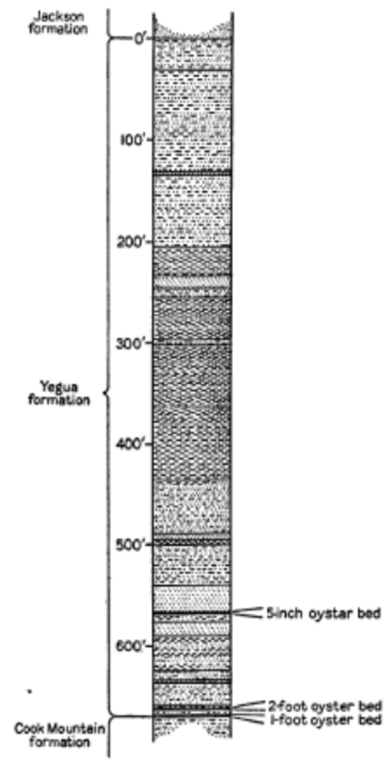
The Laredo Formation overlies the El Pico Clay (Weches) in the site region. It outcrops as sands and clays in the Laredo area (Plates 1 and 2), with cemented sands forming prominent ridges parallel to the strike. Its light color and dominant fine sands distinguish it from the El Pico Clay below and Yegua 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.

1.3.7 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 with sandy clays dominating the outcrop. The Jackson appears much the same as the Yegua, but includes more volcanic ash (Trowbridge, 1932; Lonsdale, 1937; Eargle, 1968; Barnes, 1976), though this is not immediately obvious in the outcrop, cores, or geophysical logs (Geocam gamma logs of soil borings, this study). This similarity between Yegua and Jackson makes it difficult to distinguish the contact between them. The Laredo-Yegua boundary at the base of the pair, as well as where the Jackson meets the Frio above are readily identifiable in the field and on geophysical logs; so the package of the two is bound and the pair is considered together as a designated minor aquifer, it's the boundary between that is elusive.

The Yegua begins slightly below a two foot thick prominent oyster bed that is found even today a few miles east of Laredo (Trowbridge, 1932, Lonsdale, 1937, Gardner, 1938), in a roadcut on US59 (and its predecessor roads). Like the Laredo, the Yegua includes resistant portions that parallel the regional strike forming gentle cuestas, evidence of the role that the shoreline orientation played in its development. This is a transition from much of the rest of the Yegua deposition, where sand bodies are found to be oriented normal to the shoreline, still in the form of the original fluvial and deltaic framework (Payne, 1970, Ricoy and Brown, 1977). The presence in the outcrop of the oyster beds, thin sandstones and occasional thicker sands indicate that the Yegua here was deposited close to, if not at the shoreline, in a bay or nearshore environment, often tidally controlled. The influx of muds, silts and sands from, or influenced by, the Laramide structures just to the south in Mexico created a high energy depositional environment, and this interpretation is supported by the character of the rock found in the test pits and in the outcrop of this study. This is affirmed by the Yegua geophysical log signatures and interpretation shown on the Ricoy (1976) sections. Lonsdale (1937) measured the Yegua in section in the vicinity of the present day US59 about 7.5 miles east of downtown Laredo, illustrated in his drawing where the Yegua totals about 670 feet thick. (See Figure 5) The thick oyster beds at the base are found today on US59, and the section in roadcuts shows the transition to dark brown, purple, greenish and yellow clays, thin sands and sandy clays he described. Trowbridge (1932) covered much of the same area and at the time, though recognizing the use of the term Yegua, continued an earlier designation, Cockfield, for these sediments.



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

Figure 5 - Lonsdale, 1937

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 further west of its position on the Laredo sheet of the Geologic Atlas of Texas (Barnes, 1976), and Lonsdale felt Trowbridge included lower Jackson and moved the contact east to its position on the Laredo sheet (Eargle,1968), (just not quite far enough). The demarcation between Yegua and Jackson is not evident in the core descriptions and was not found in the test pits, and evidence in the form of increased gamma log values on geophysical logs of boreholes in this study, expected if there were volcanic material, is not clear, if present at all. In addition, the geometric projection of related formation contacts from depth to the surface, and the position of the Yegua-Jackson contact shown on the Laredo Sheet are difficult to reconcile without forcing a steep dip, change in thickness, or other adjustment that would put this study in conflict with published good work about the surface and subsurface geology.

The difficulties posed by fluvial-deltaic, shoreline and near shore sediment interpretations, the combination of surface and subsurface measurements, extending correlations the length of the Texas coastline, and other efforts are well known. The Yegua, and its boundary with the Jackson above and along strike, is a type case of many of the difficulties outlined here, so much so that it was described in a classic paper, "The Yegua Problem" (Stenzel, 1940). The present study uses both the surface geology of the Laredo Sheet and the subsurface information from the geophysical log cross-section, with the exploratory core log descriptions from the subsurface study, along with the caveats described here to describe the geology of the site. That is, the location of the contact as shown on the Laredo Sheet of the Geologic Atlas of Texas (Barnes, 1976) is used here, but we have concluded that it is likely the contact in the site area is a little to the east meaning that the Yegua is the geology of the site surface and near subsurface, with the soils map suggesting the higher elevations may be more characteristic of Jackson. Inasmuch as the depositional environments and resulting clays are similar, the choice of contact location is not critical, but important in terms of a comprehensive evaluation of the site.

1.4 Regional Geology Summary

In summary, the geology of the site region is several thousand feet of sands, clays and gradations between. It has developed in a predictable fashion as the sedimentary section built out from the late Mesozoic beginning to the present coastline. The Yegua and Jackson, the immediate geology of the site vicinity, are similar, mostly clays deposited at or inland of the shoreline and typically massive and uniform. The aquifers of the landfill site region are a subset of, and incorporated in, the permeable portions of the geologic formations dipping toward the coast and they are generally bounded by those formations. The aquifers of the section are recharged by fresh water infiltrating their outcrop and flushing through the formations, generally in the downdip direction. In the site region, this process operates in a limited way because of the limited rainfall, net evapotranspiration and the limited outcrop and interconnected sands available. The hydrogeology here mirrors the properties of the geologic framework, and the aquifers here are named for those formations or their combinations. The formation combination that is a part of the landfill site itself is the Yegua-Jackson, designated a minor aquifer by the TWDB in 2002 (Kelley, 2004). Information about the aquifers in the region is derived from region-specific studies (Lambert, 2004, CH2M Hill, 1999, Lonsdale, 1937) and broader, coast-wide studies (Ricoy, 1976, Baker, 1995, Mace, 1999, Payne, 1970, 1972, 1975, Estaville, 2008, George, 2011) and regional Groundwater Availability Models (Deeds, 2010, Kelley, 2004).

2.0 Regional Hydrogeology

2.1 Groundwater Use in the Site Region

Groundwater is a critical resource in this semi-arid region. Laredo is one of the fastest growing and important commercial centers in the state, and the role of water here is critical to its sustainability. Presently, water for the City comes from the Rio Grande (a losing stream in this area (Kelley, 2004)), with some supplement from the Laredo Aquifer, and water from Lake Casa Blanca irrigates the local golf course and elsewhere (CH2M Hill, 1999). There are plans for the Carrizo Aquifer as a future municipal source (Deeds, 2003). The landfill site is several miles east of Laredo and downgradient of the principal groundwater resources in the region. The water wells in the site area produce from about a thousand feet, the more permeable portion of the Yegua, near its base.

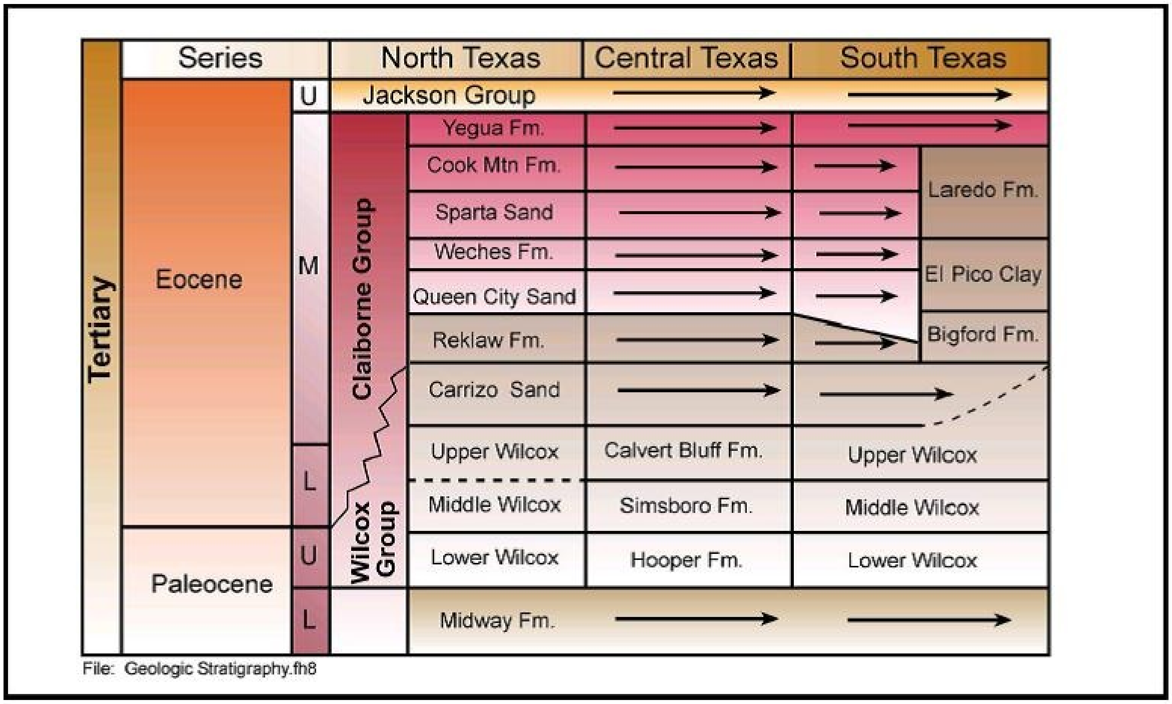
2.2 Precipitation, Evaporation and Recharge in the site region

Recharge is limited in this South Texas environment, where the site region annual mean rainfall is 20.4 inches, and the mean annual lake evaporation is 66.26 inches (TWDB, 2014). The values for precipitation depend on the timeframe involved in different studies and the location in the TWDB quadrangle (1008), but all illustrate that in the site area, evaporation exceeds precipitation by a large number. Not only is there little water available for flushing through the aquifers, but the nature of the slow, intermittent and poorly interconnected recharge process tends to clog and further diminish formation permeabilities. Salt tolerant (to the extent that it is), phreatophytic brush contributes to evapotranspiration. Conceptually, water infiltrating alluvium or entering desiccation cracks would stand a better chance of becoming recharge than that which spends any time on the surface. Coast-wide studies for Groundwater Availability Models estimate recharge in these sediments to be from about 0.27 to 0.3 inches per year (Deeds, 2010 for the Yegua Jackson Aquifer) to 1 inch or less per year (Kelley, 2004 for the Queen City-Sparta model which includes the Carrizo-Wilcox). The Texas Water Atlas (Estaville, 2008) shows that less than 0.1 to 0.25 inches of annual recharge is expected in the Webb County area. Lambert (2004), in a USGS study of Webb County aquifers used a 5% of rainfall value to estimate recharge; which would be at the upper end of that estimated here for the equivalent CWQCSP GAM. She then combined the recharge estimate with the measured outcrop area for an acre feet per year (afy) estimate for each aquifer in the county. This range of input estimates is summarized as part of the properties table for the Laredo and Yegua-Jackson Aquifers and also further described for the individual aquifers in the following paragraphs.

2.3 Regional Aquifers

The following discussion describes the aquifers of Webb County and the regional groundwater conditions [(330.63(e)(3))]. This section begins at the western edge of Webb County and moves east, downdip and through the hydrogeologic equivalent section, ending with a review of the Yegua-Jackson Aquifer immediately beneath the site. The aquifer equivalents are listed in the earlier stratigraphic table and data about the Laredo and Yegua-Jackson Aquifers together with the underlying confining zone, the El Pico, are summarized in Table 2.

The aquifers of Webb County, from its western border to the landfill site are the: Carrizo-Wilcox, Queen City-Bigford, Laredo, and Yegua-Jackson. These are shown on the regional hydrostratigraphic cross-section that passes to the north of the site (Plate 2, Baker, 1995) The relationship of the aquifers (formations) here to the rest of Texas is shown in this composite stratigraphic column from the Queen City-Sparta GAM (Kelley, 2004) (See Figure 6).



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

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 sediments (Payne, 1975) and this means that variability in aquifer properties like permeability is less than for other formations of the Claiborne. The Carrizo supplies water for irrigation in the Winter Garden area (McCoy, 1991), to the north of Webb County, and supplies a number of wells in Webb County. The Carrizo crops out in the western corner of the county and the productive part of the aquifer covers the northwest half of the county in the subsurface (Deeds, 2003). The Carrizo dips to the east, passing beneath the landfill site at about 4700 feet below the surface; there it is about 2100 feet thick according to oil and gas geophysical logs. While the Carrizo and Wilcox together are a designated major aquifer across Texas, confined below by Midway Formation marine shales over much of the state (Deeds, 2003), here beneath the site region the Wilcox is mostly shale, and acts effectively as the lower confining layer for the Carrizo above; significant groundwater production in Webb County is limited to the Carrizo. The formation in this region is made up of relatively coarse sands (Lambert, 2004) stacked as sets of cross-beds, interrupted by thin, extensive shales (as shown on geophysical logs, for example). Since the Carrizo outcrops in a limited part of the county, the direct recharge is only about 950 acre feet per year (afy) (Lambert, 2004); indirectly, recharge can and does also move across the county border in the subsurface, and also some recharge may also occur by infiltration through sands of the overlying Queen City Formation where those sands are interconnected. Wells in the Carrizo are typically found to the west and northwest of Laredo where they produce fresh to slightly saline water (Lambert, 2004) that then becomes more saline downdip. Water in the Carrizo downdip and beneath the landfill site is long past the drinkable stage as shown by the resistivity taper on geophysical logs in the area. That is, the geophysical logs shown on the regional cross-section (Plate 2, Baker, 1995) illustrate a progression from fresh to saline groundwater, moving from the west to the central part of Webb County. The fresh water in the Carrizo sands is there as a result of recharge flushing, but the process is incomplete and aquifer water quality is reduced in some locations by residual mineralization (Lonsdale, 1937; Lambert, 2004). As for the future, the region has recognized the vulnerability of the Rio Grande as a source of water and is researching the possibility of using the Carrizo as a secondary source for the Laredo area. Payne (1975) illustrates that transmissivity, total sand thickness and maximum individual sand thickness, as well as low TDS values converge in this area of Webb County. A water project for this purpose is part of Region M's plan for the area and the groundwater availability model for the southern Queen City-Sparta (which includes the Carrizo-Wilcox

GAM) considers this potential in its long term drawdown predictions for the southern part of the Carrizo.

2.3.2 Reklaw Confining Unit above the Carrizo

The Carrizo is topped by the Reklaw, a marine shale marking a broad transgressive event (Baker, 1995). The Reklaw is the downdip equivalent of the Bigford and it overlies the Carrizo updip at and near the outcrop (Eargle, 1968), with Reklaw being the term used in the subsurface. It serves as the upper confining unit for the Carrizo sands and the lower confining unit for the Queen City above (Lambert, 2004). The top of the Reklaw is at about 4300 feet beneath the site, where it is about 360 feet thick across the site area according to geophysical logs.

2.3.3 Queen City-Bigford

The Queen City sands beneath the western part of the Webb County region, together with the more limited sands of the Bigford there, make up this regional aquifer (Lambert, 2004). It may seem incongruous to call a formation a confining layer in one paragraph and an aquifer in the next, but Lambert makes it clear that the Bigford sands are few and the wells fewer and in the recharge zone. There are more sands in the Queen City Formation and they are more extensive as shown on geophysical log sections. In a coast-wide comparison of Queen City hydrology, Payne (1972) found that northeast of Gonzales County, where the sand fractions typically decrease downdip mirroring the depositional framework, salinity increases in an orderly way; but to the south in the region including Webb County, there is no consistency in the salinity pattern, with unexpected downdip occurrences of fresher water, perhaps due to opportunities for water in the underlying Carrizo to move upward (Payne, 1972).

In addition to upward movement from the Carizzo, the sands are recharged by infiltration of rainfall on the Bigford outcrop and by leakage through the overlying El Pico (Lonsdale, 1937, who called the El Pico the post-Bigford) to the Bigford and associated Queen City sands. Once infiltrated, the groundwater in this set of formations likely moves to the east, following dip (Lambert, 2004). Lambert (2004) estimated the Webb County recharge to this combination by adding the typically used 5% of rainfall times the outcrop area (140 mi^2) to half that assumption for leakage through the El Pico, downdip or above, to get about 45000 afy of recharge. This is an optimistic total for a set of sands that are not all that continuous, sands that derive some recharge from an effective confining layer, and produce limited water in any event. The little water that is produced in Webb County is somewhat mineralized and is used for livestock (Lonsdale, 1937). Lambert (2004) found the few wells that produce from the Queen City-Bigford are on the Queen City outcrop or just downdip, through the El Pico and there water depth ranges from 125 to 268 feet below the surface.

2.3.4 El Pico Confining Unit

The El Pico Formation in the region involves mostly clays, along with some sands and coals in the western part of the county. Lonsdale (1937) noted that the El Pico appeared to grade into interbedded sandstones and clays downdip to the east, and Lambert (2004) uses that interpretation to make the El Pico a part of the Queen City-Bigford aquifer downdip. That might be true where parts grade to sand, but in much of the region, including the landfill site, geophysical log sections (Ricoy, 1976, Baker, 1995) show a fairly uniform clay (termed the Weches in the subsurface). In the site region, the top of the El Pico (Weches) is about 2300 feet below the surface and it is uniformly about 110 feet thick according to geophysical logs. While there are a number of clays beneath the landfill that are widespread, continuous and thick, making them likely confining units, the El Pico is the lower confining unit beneath the Laredo.

2.3.5 Laredo

The Laredo Aquifer is equivalent to the Laredo Formation, cropping out in a north-south striking band across central Webb County and to the north. Since the lower part is more sandy and the upper more clayey, there is the expectation of greater water productivity from the lower part, and this is true in practice (Lambert, 2004; Lonsdale; 1937; Kelley, 2004). The Laredo Aquifer is utilized for limited applications in the Webb County region, but managing quality is a challenge (CH2M-Hill, 1999). The aquifer is limited to the formation as mapped in the Laredo region and is not a TWDB designated aquifer, though the Sparta portion of the CWQCSP GAM provides a coast-wide relationship perspective (Kelley, 2004). The Laredo and the clays in its upper reaches are now considered equivalent to the Sparta and Cook Mountain combination elsewhere (Ewing, 1999, Kelley, 2004) and treated as such in the Queen City Sparta groundwater availability model (southern portion) where the authors observed that neither the Sparta, or its Laredo equivalent produce much water. However, the Laredo area is at the southern end of the modeled area, and future conditions about the Laredo Aquifer are difficult to address and are not addressed to any extent in the model. The Laredo is treated as a separate entity from its along-strike counterpart for several reasons: it is lithologically different in makeup and origin reflecting the influence of uplift in Mexico, and its fossils don't match well with time equivalent sediments along the coast (Gardner, 1938). This has importance for local groundwater considerations. While the downdip portion of the Laredo that includes the site area has the thick sand and "rounded shoulder" geophysical log signature characteristic of the Sparta (Ricoy, 1982), the updip, water productive portion is made up of individual sands divided by clays. The Laredo is about 630 feet thick, dips to the east at about 85 feet per mile (Lonsdale, 1937) and the groundwater flows to the east (Lambert, 2004). The outcrop area for the total Laredo section is about 620 mi^2 in Webb County; if the recharge rate is the oft-assumed 5% of rainfall, which averages 20.1 inches there, then the annual recharge is 33000 afy (Lambert, 2004). Again, this is likely a liberal figure, considering for one thing that the upper part contains more clay than the lower part that it overlies, making actual water movement to the sands difficult. Wells yield from 5 to 170 gallons per minute (gpm) (Lambert (using TWDB database),2004); measured specific capacities ranged from 4 to 711 square feet per day (ft^2/d) and transmissivities estimated from this data ranged from 85 to 2735 ft^2/d. Looking to the future, while the Laredo is not the best groundwater source, but it is there and so it is important to those who depend on it. The Las Lomas community is now using a reverse osmosis plant to treat the water from their Laredo well. As part of an aquifer storage and recovery (ASR) feasibility study, CH2M-Hill (1999) drilled 4 wells focusing on correlative sand layers in the Laredo northeast of town. The work included pump tests and an injection experiment. The tests on selected sands of the Laredo showed a yield of about 60 gpm (somewhat more than typically reported, e.g. Lambert, 2004), an average storage coefficient of $9x10^{-5}$ and corresponding transmissivity of 168 ft^2/day. The formation compatibility test results (CH2M Hill, 1999) indicated that a mix of ASR storage candidate water and in-situ groundwater may develop mineral and biological aquifer plugging, but an operation to move the injected-insitu interface far away from the wellbore may be appropriate. In summary, the Laredo Aquifer is limited by several factors but serves as the aquifer for a considerable part of the county. It dips beneath the site area and is generally separated from any sands above by clays in the upper part of the Laredo Formation.

2.3.6 Yegua and Jackson Aquifer(s)

The Yegua-Jackson combination is designated a minor aquifer in Texas, and it is productive in the vicinity of its outcrop along strike across the state, particularly in the central and eastern parts of Texas; but like the several other aquifers in the section in the site region, its productivity is limited in quality and quantity here. The ability of the Yegua and other shoreline controlled sediments to act as an effective aquifer is strongly influenced by the character of that deposition. In the central and eastern part of Texas, the Yegua's sand bodies are oriented parallel to the downdip direction of groundwater flow and groundwater moves relatively unimpeded in the gradient direction (Payne, 1970); in South Texas, however, the sand bodies are re-distributed along Yegua (and Jackson) shoreline, and movement of groundwater downdip is thwarted as groundwater meets one boundary after another. In this situation, it's reasonable that groundwater would percolate downward, recharging a sand below, or into the sands of the formation above, if that route offered a more efficient pathway (Payne, 1970). Information about the Yegua and Jackson as aquifers in the site region is derived from the outcrop (Lonsdale, 1937), and regional groundwater studies (Lambert, 2004, Knox, 2007, Deeds, 2010).

The Yegua Aquifer is the formation equivalent and aquifer values such as recharge estimates and specific capacities are based on general observations in the region. The Yegua's function as an aquifer, as with the Laredo below, depends on the presence of productive sands. These are generally found nearer the base of the section (Ricoy, 1976, this study's deep boring, and area water well driller's logs), are not continuous and produce the most saline water in the region (Lonsdale, 1937; Lambert, 2004). Recharge across the outcrop is estimated by multiplying several factors: assuming a 5% recharge rate, knowing an average rainfall of 20.1 inches, and measuring the Webb County Yegua outcrop area, the recharge is 36000 afy (Lambert, 2004). Again, this concept of recharge is likely not really very effective recharge, since water moving from the surface through the formation has probably concentrated mineralization, rather than dissolved and removed it. The limit of any recharge mechanism in the site area is illustrated in the test pit photograph (Figure 7) (the huisache roots suddenly make a right angle turn at the base of the near surface soil zone). The regional groundwater flow appears to be to the east and south, but there are few wells to make this case. Conceptually, water entering the formation's sandier lower portion travels a circuitous route downdip where interconnected sands permit. It is also likely that the Rio Grande influences the gradient in its vicinity. Wells in the Yegua yield less than 15 gpm (Lambert, 2004). Depth to water in the few Yegua wells for the Lambert study, ranged from 94 to 292 feet below the ground surface and no Yegua wells were found with specific capacity tests; and the one well that met the sampling requirements measured a Total Dissolved Solids (TDS) value of 4470 mg/l (Lambert, 2004). The groundwater availability model work (Deeds, 2010) counted 9 wells in the Yegua in Webb County with water elevations ranging from 360 to 413 feet National Geodetic Vertical Datum (ngvd), while Lambert (2004) found water depths of 94 to 292 below the surface.

Figure 7 - Site Test Pit

The Jackson Aquifer, if the Jackson exists at the site, is the top of the regional hydrogeologic section. There are few water wells in the region, and none in the Jackson are reported for the Yegua-Jackson groundwater availability model (Deeds, 2010). Downdip, on the eastern edge of the county, the Jackson sands are the basis of the Miranda oil field. Lambert (2004) could locate only one well in the Webb County Jackson with test data; there the specific capacity was 17 ft^2/d and the corresponding transmissivity was 225 ft^2/d; and only one well was sampled, there the TDS was 1480 mg/l. Using the factors applied to the rest of the aquifers in Webb County, Lambert calculated a recharge to the Jackson of 45000 afy, again likely a high value. That study also suggests that the regional groundwater flow in the Jackson is to the east and south (Lambert, 2004).

2.4 Regional Hydrogeology Summary

In summary, the hydrogeology in the landfill site vicinity follows the depositional system; rainfall (mean 20.4 inches/year) falls on the outcrop, infiltrates to depth and recharges an incorporated aquifer or evaporates or is taken up by plants. The less than ideal aquifer qualities of the formations here, combined with the little rainfall that flushes through, are a harsh environment and the resulting groundwater tends to have a high salinity. The aquifer with the best prospects for future development is the Carrizo in the northwestern part of the County. The Laredo is next, particularly if technology, both chemical and physical, can be developed to make aquifer storage viable. Reverse osmosis is used to prepare the nearest community water pumped from the Laredo. The Queen City-Bigford is limited as an aquifer resource as are the Yegua and Jackson Aquifers.

3.0 Additional Geology Related Information

3.1 Area Water Wells

There are few water wells in the area around the site. The closest is the ranch well, the only well within one mile of the site. The attached map (Plate 3) is from the TWDB online groundwater database (update December 20, 2014) and includes water wells from the TWDB files (blue dots with numbers) and more recently submitted driller's reports (red dots with numbers). An additional windmill was found during the site study. Table 3 summarizes information for the ranch well and wells beyond the one mile perimeter [(330.63(e)(3)(J)].

Table 3 - Water Wells within One Mile of Site and additional area water wells (see Plate 3)

Grid	Number	Depth	Completion Date	Static water level	Screened Formation	Screen/Perf Depth	Well Use, Owner	
85-31-5	8531501	1166	orig. rig supply	**16.22, 222*	?Yegua Fm**	1025-1060	S, D	Yugo Ranch
85-31-2	251166	1058	3/16/2011	250	Y-J	645-1058	S, D	ANB
85-31-2		shallow		~pond	Y-J		S, D	ANB windmill at pond
85-31-9	286326	1023	3/10/2012	44	Y-J	310-1023	D?	Wied
85-31-7	328900	1025	7/7/2013	193	Y-J	492-1025	?	Martinez
85-31-7	279439	1210	1/17/2012	265	Y-J	168-1210	?	Alarcon
85-31-1	8531101	1235	6/16/1998	213	L	770-882	P	Webb County
85-38-3	312183	1116	2/11/2013	210	L?	1030-1072	?	Ponderosa Landfill

where:
S=stock water
D=domestic
P=public
* geophysical log run, this study
** TWDB data

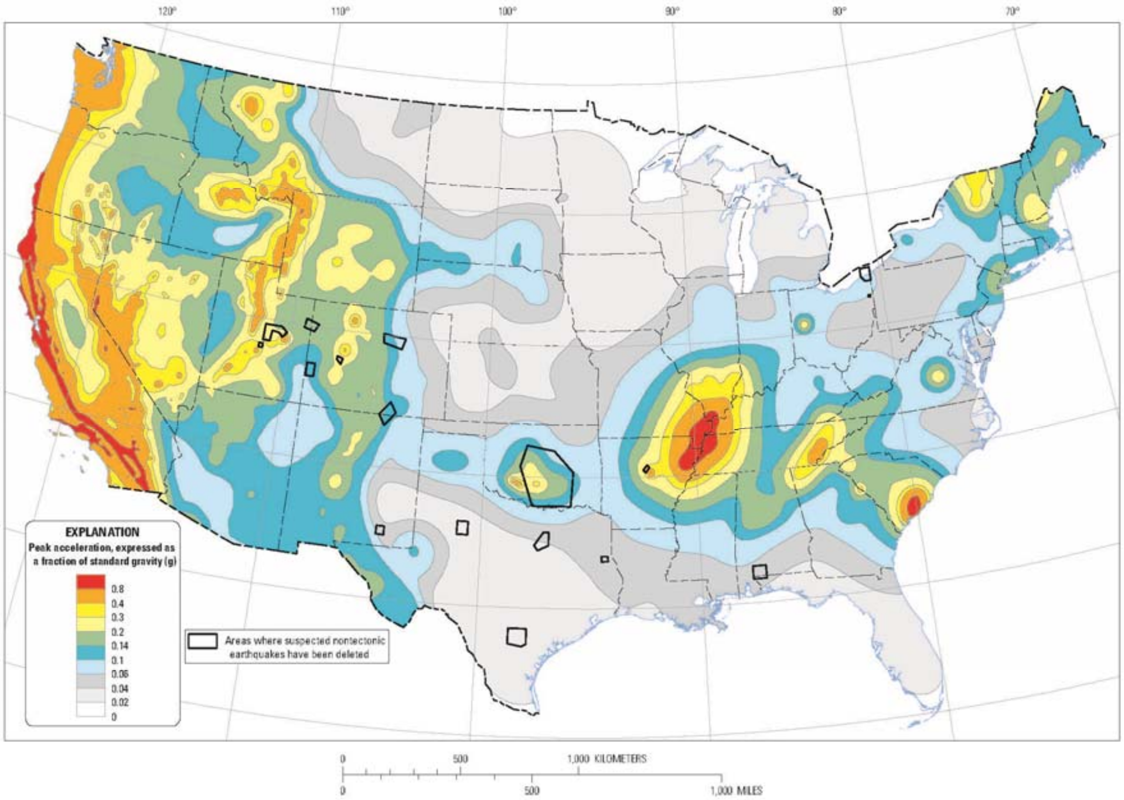
3.2 Area Oil and Gas Wells

A number of gas wells have been drilled in the vicinity of the landfill site. The attached map (Plate 4) is from the Texas Railroad Commission online oil and gas well related database (Texas RRC, update December 21, 2014) and shows the locations of these wells along with their identifying API numbers. These wells produce from the Lobo sands of the Wilcox Group, discussed earlier. The production interval is generally in the 7,000 to 10,000 foot depth range.

Hydraulic fracturing stimulation prior to production was a typical procedure. The field is active and several of the wells on the map are also shown on cross-sections referenced in the regional geology section.

3.3 Regional Seismicity and Induced Earthquakes

The 2014 USGS National Seismic Hazard Maps (USGS, 2014) show (Figure 8) that the site region is well below the concern threshold described in the location restrictions; however, this USGS 2014 edition includes an interest in induced earthquake activity. Induced seismicity (Figure 9 from the USGS, 2014 update), or an earthquake created by manmade activity, has always been an interesting subject and recent source rock related oil and gas exploration and related hydraulic fracturing have heightened the interest. The Fashing area in South Texas is one area with historic induced small earthquakes, and the Dallas-Fort Worth area earthquakes (Frolich, 2010) are a more recent phenomenon. Much of the recent induced seismicity seems to be related to disposal injection well activity, but also the Texas and Oklahoma recent seismicity is coincident with Paleozoic tectonic features. The Eagle Ford shale is the subject of current exploration and development near the site region and micro and small magnitude macro seismicity may be associated with hydraulic fracturing and disposal wells there.



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

Figure 8. (USGS, 2014)

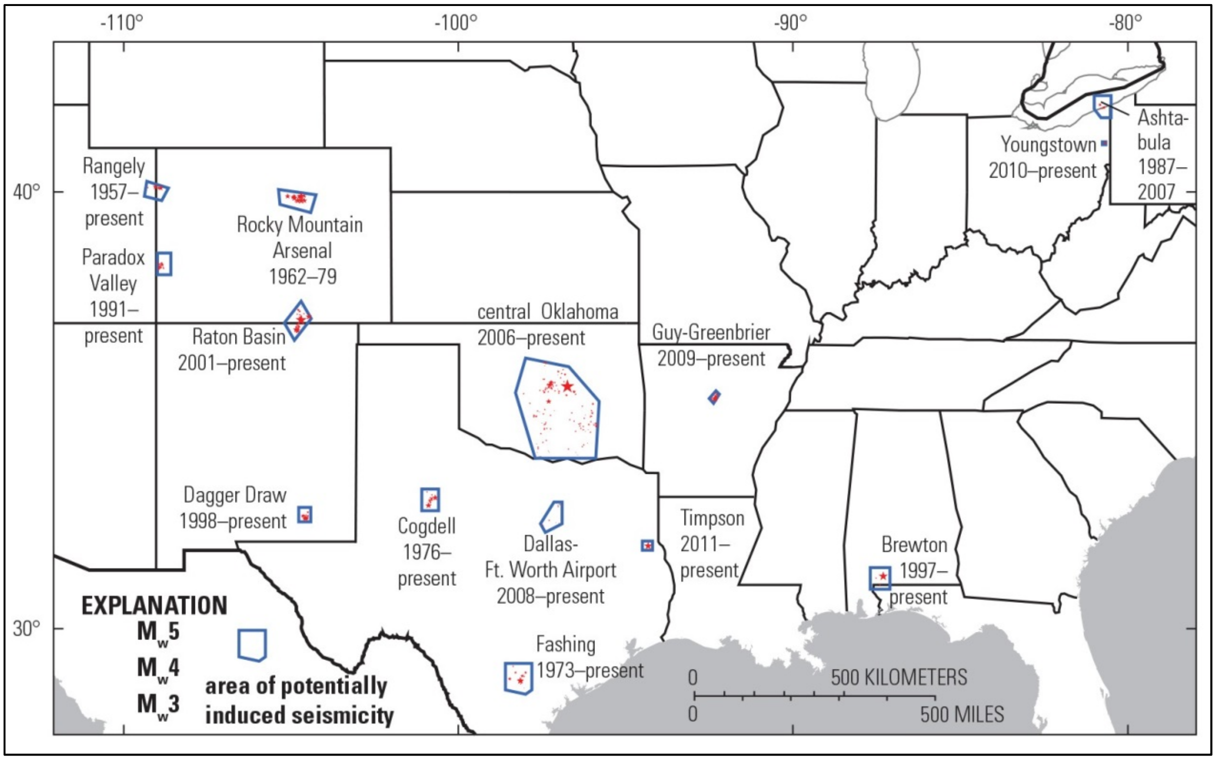


Figure 9 - Map showing areas of potentially induced seismicity in the Central and Eastern United States

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.

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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

Clay 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

Eep

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

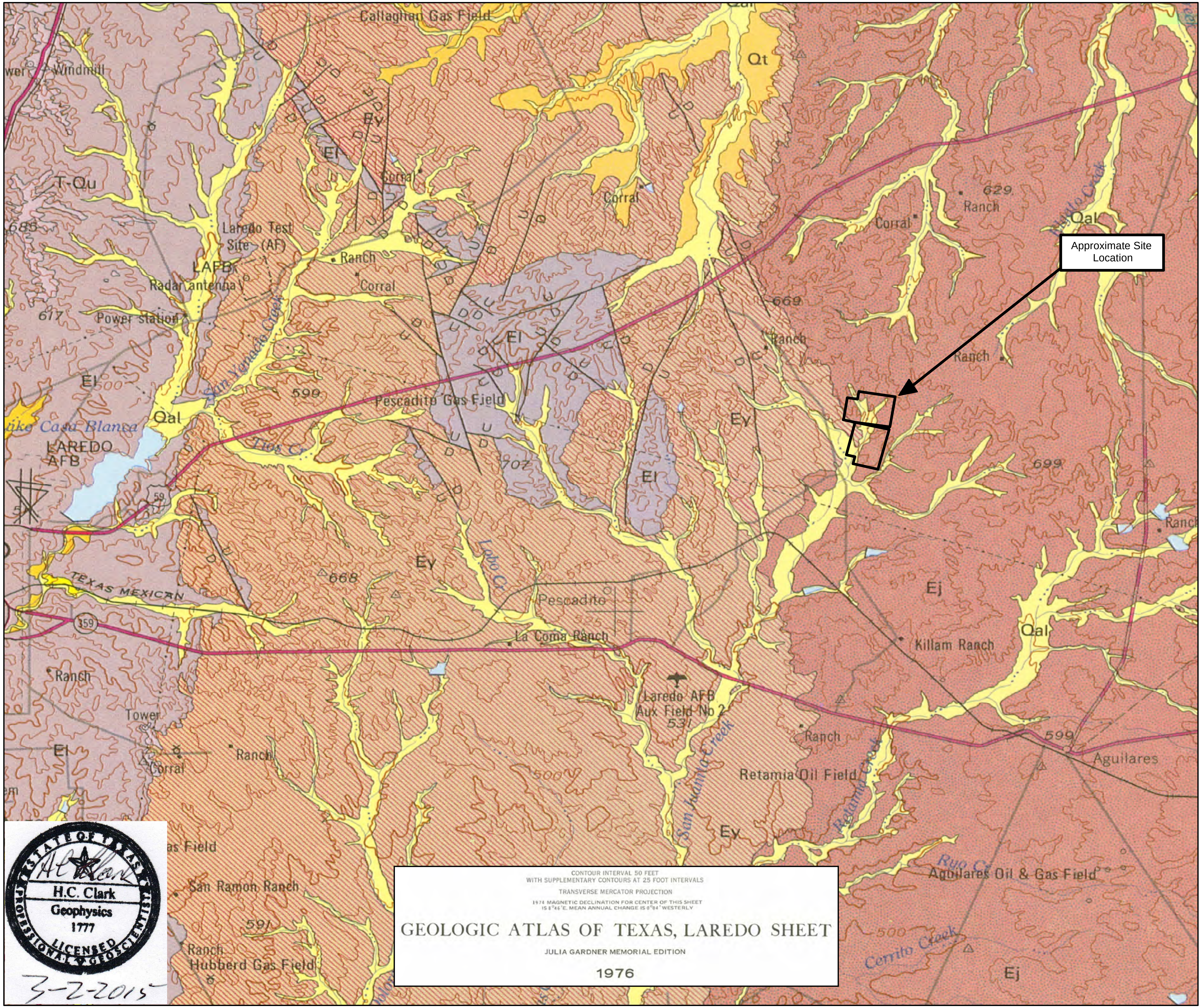
Plate 1 to Appendix III-E.1

N

2 1 0 2 4 6 8 Miles

Scale 1:150,000

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



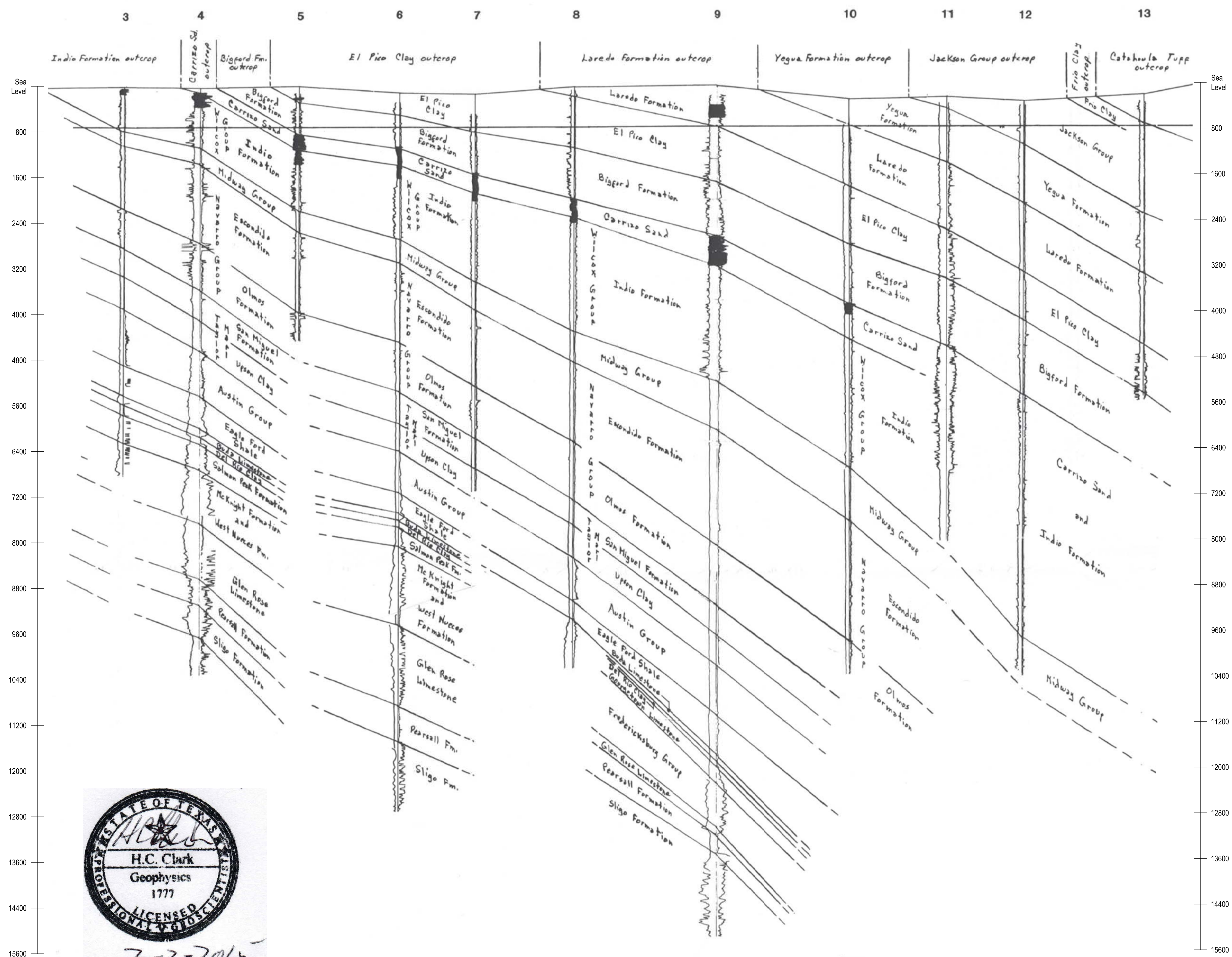


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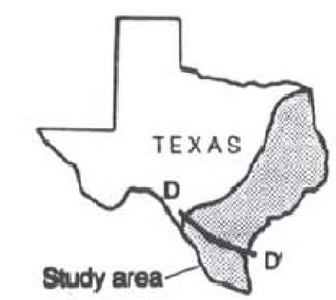
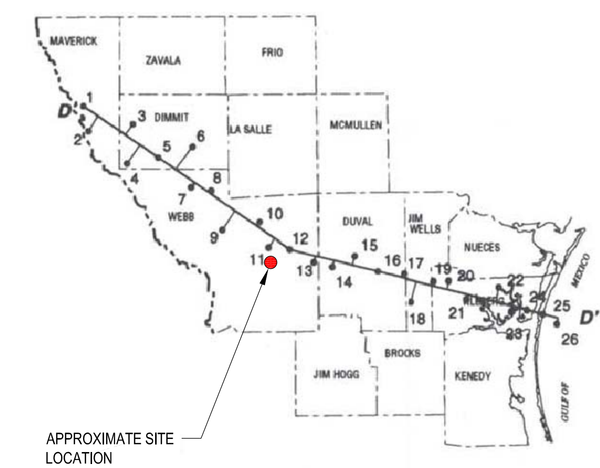
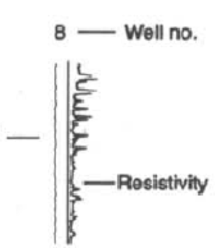
PLATE 2 TO APPENDIX III-E.1

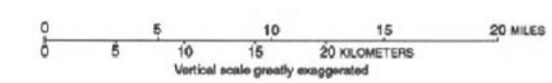
GEOLOGIC SECTION D-D'

BY E.T. BAKER, JR (1995)









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

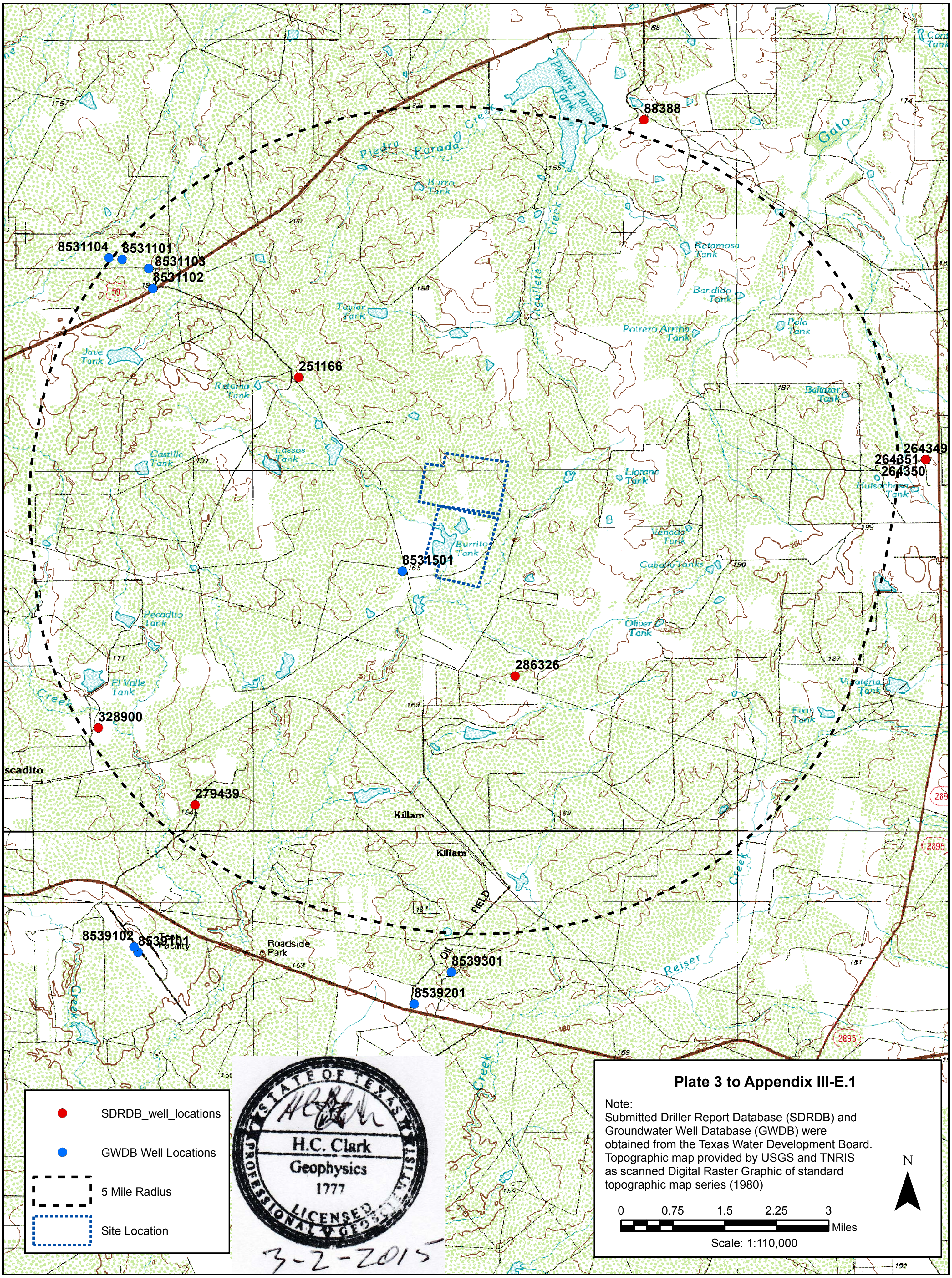
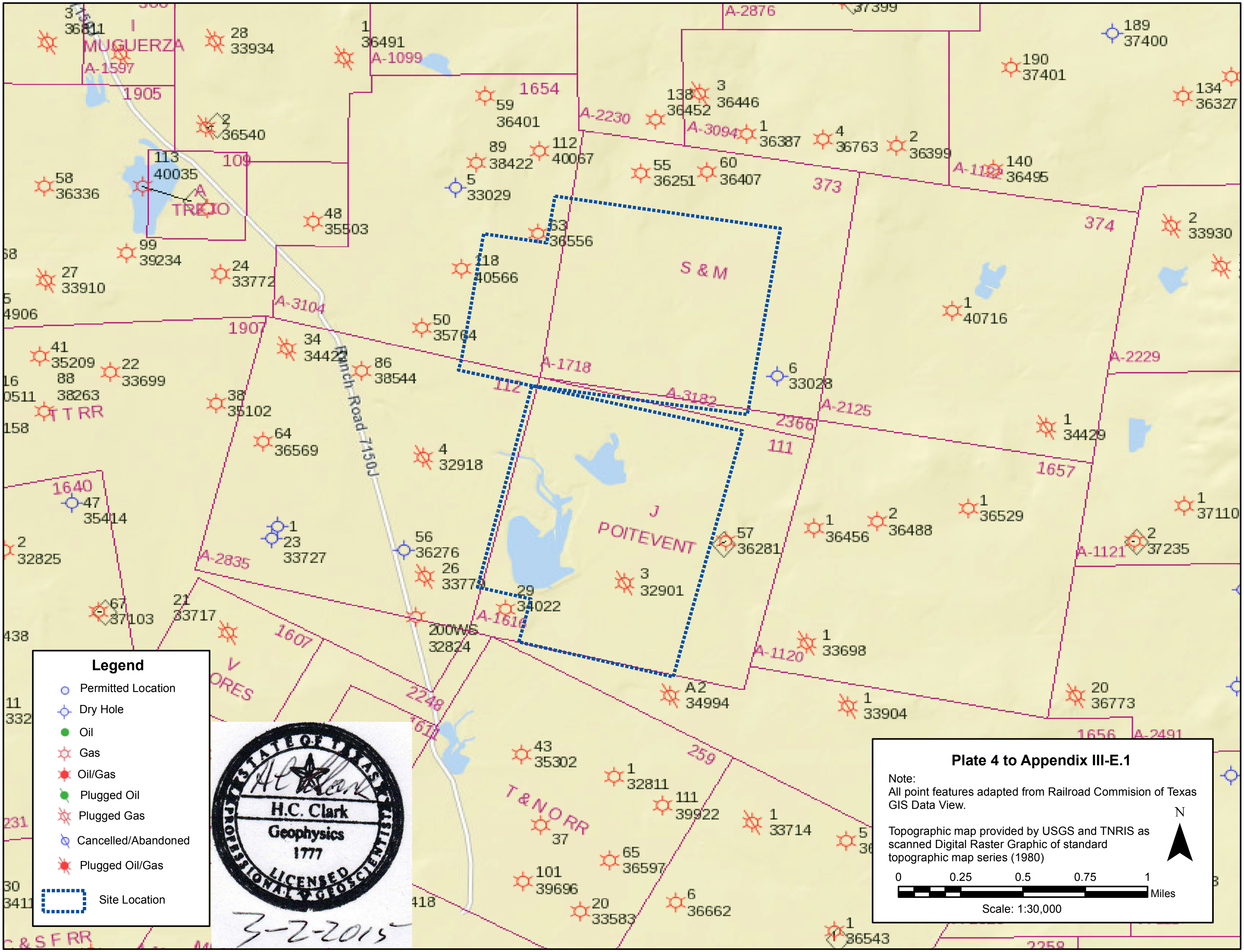


Plate 3 to Appendix III-E.1

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)


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
1777
LICENSED
PROFESSIONAL GEOSCIENTIST
3-2-2015
Plate 4 to Appendix III-E.1
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
S & M
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Ranch Road 7150J