A REVIEW OF FORMATION CHARACTERISTICS AND COMPLETION PRACTICES IN THE OLMOS SAND FORMATION OF SOUTH TEXAS

Eva S. Frazier, The Western Company of North America
Vithal J. Pai, The Western Company of North America
Sam J. Garbis, The Western Company of North America

ABSTRACT

The Olmos Sand formation in South Texas presents many completion problems which vary considerably depending on geographic location. Almost always, massive stimulation is required to bring the sand to economic levels of production. Factors which must be considered to develop the best completion methods include mineralogy, lithology, temperature and frac gradients, permeability and porosity data, and the nature of the produced fluids. The paper also discusses the relative merits of different stimulation techniques used by the operators in the area and describes some effective methods of perforating, breaking down and fracturing the Olmos Sand.

INTRODUCTION

The Olmos Sand Trend occupies a large area of South Texas southwest of San Antonio (see Figure #1). This area comprises Medina, Bexar, Frio, Atascosa, Dimmit, LaSalle, McMullen, Webb and Zapata counties. In these counties, the Olmos Sand varies in depth from 900' - 11,000'. The shallowest Olmos production occurs in Medina county, where the wells are 900' - 1100' deep. Medina, Atascosa (±1600' - 3500'), Bexar (1300' - 1500') and Dimmit counties possess the "shallow" Olmos Sand oil which is comparatively low gravity (27° - 40° API). Webb County Olmos produces gas and condensate, at depths ranging from 5000' - 7200'. McMullen and LaSalle counties have the deep Olmos (7700' - 11,000') producing a light oil that approaches condensate in API gravity, and gas.

The Olmos is considered a soft dirty sandstone formation which usually requires some type of stimulation in the completion program. Stimulation of the Olmos may be difficult in certain areas as a result of the lithology and the high temperature of the formation. A study of the lithology and stimulation history in the Olmos Trend may yield some insight into improving stimulation designs.

GEOLOGY

Stratigraphic Relations

The Olmos Sand is the lower member of the Navarro Formation. It has been dated to the Upper Cretaceous system of the Mesozoic era. It overlies the Upper Taylor member of the Anacacho Lime, and is overlain by the Escondido member of the Navarro Formation. The formation as a whole comprises 400' - 600' of non-marine, sandy, locally lignitic shales (see Figure #2).

Lithological Studies

The Olmos Sand is a medium to fine-grained, gray to brown, fairly well-sorted, extremely argillaleous feldspathic sandstone (feldspathic wacke). The sand grains are sub to non-rounded and angular in shape. The sand is consolidated but usually very friable. Some laminations are present, although generally these are not well developed. For the most part, quartz and feldspar grains are embedded within a continuous clay matrix. Clays are the primary cementing material, however, calcite, dolomite, and in some laminations secondary quartz may also cement the grains.

The clays are of both depositional and authigenic origin; some of the clays, perhaps the majority, were introduced into the sediment after deposition through precipitation. The clay minerals most often observed in the Olmos Sand include chlorite, kaolinite, and mixed layer illite-montmorillonite clays (see Figures 3-7 & Table #1). Petrographic studies have shown that mixed layer clays and kaolinite usually exist in the intergranular areas, whereas chlorite coats the grains. Since the clays line and occlude the pore spaces in an extensive and continuous network, they pose a potential threat for swelling and migrating fines in the formation.

In many areas in the Olmos Trend, then, when the rock is contacted by an acid or water-based fluid, a significant loss of permeability, and/or a loss of formation integrity, results.

MINERALOGY

The Olmos Sand is composed mostly of quartz, feldspar and clays (see Table #1). The quartz comprises 55-75%, feldspar 8-20%, and various clay minerals 10-20% of the rock. Various carbonate minerals, namely calcite, dolomite, and siderite, compose another 5-10%. Pyrite is locally quite prevalent in small percentages, sometimes comprising as much as 16% of the mineralogy (see Figure #5 and Table #1). Other minerals present in small-to-trace amounts include barite, anhydride, halite, ankerite, and carbon (locally, the Olmos is a coal-bearing zone). (see Table #1).

A wide variety of clay minerals are present in the matrix of the rock. Typically, mixed layer illite-montmorillonite clays are the most prevalent; concentrations range from 4-13%, followed by 4-6% kaolinite. Chlorite (important because of its iron content), is almost always present in concentrations of 6-8% (see Table #1).

Because of the pyrite, siderite and chlorite content, the Olmos Sand contains a large iron concentration that, together with the presence of mixed layer clays, is one of the reasons for the Olmos' sensitivity to aqueous fluids.

RESERVOIR CHARACTERISTICS

Formation characteristics not mentioned above, but which have considerable influence on the formation's productivity, include bottom hole pressure, porosity, permeability, temperature, and frac gradient (see Table #2).

The bottom hole static (reservoir) pressure varies from county to county. In the shallow Olmos, it ranges from 500 - 1000 psi. In Webb county, it generally measures about 1800 - 2500 psi; in LaSalle county, 3000 - 3200 psi; in McMullen county, 6000 - 6300 psi.

The porosity of the formation is relatively high (14-24%); although the intergranular porosity is quite low (1-2%). Generally, the intergranular porosity consists of micropores within the clay matrix and moldic pores formed by feldspar dissolution. Natural horizontal fractures and microfractures probably form the major portion of the porosity, as well as the permeability of the formation (see Figures 6,7). The permeability of the Olmos is very low (.05 - .6 md). Temperature gradients range from 1.1° F/100' to 1.81° F/100', but cluster at 1.4 - 1.6° F/1000'. This comparatively high temperature gradient is especially important in the deep Olmos in LaSalle and McMullen counties, where frac treatments must be designed with a BHT° about 250° F in mind. The fracture gradient is quite high in all of the counties that this paper is concerned with. In Webb county, the frac gradient averages .87 psi/ft. and ranges from .8 - .92 psi/ft. In LaSalle and McMullen counties, it ranges from .78 psi/ft. to .83 psi/ft. In shallow Olmos in Atascosa, Bexar and Medina counties, the frac gradient ranges from .83 to 1.02 and averages at .9 psi/ft. The Young's Modulus of the Olmos Sand is generally quite low (1.87 - 1.92 E6). This is consistent with the soft, friable nature of the rock.

PRODUCED FLUIDS

In the "shallow Olmos" the lower gravity 26 - 40° API is produced in Atascosa, Bexar, Medina, and Dimmit counties. In these counties, the oil contains a fairly high percentage of asphaltenes (3-6%) and paraffins (9-10%). In Webb county, the Olmos produces gas and a very high gravity condensate (50 - 53° API). Gas and high gravity crude (42 - 48° API) is produced out of the deep Olmos wells in McMullen and LaSalle counties (see Table #3).

COMPLETION TECHNIQUES

The vast majority of the Olmos requires some type of stimulation to make the sand a commercial producer. There is a wide range of treatments that have been successfully used to increase productivity. Hydrochloric acid (15% and 7-1/2%) and diesel with surfactants have been pumped to break down Olmos perforations, and in some of the shallow Olmos wells, no breakdown fluid is used at all.

The frac fluids include low gravity refined oil fracs in Medina county, 20 lb. cross-linked aqueous fluids in Atascosa, Dimmit, Medina, and Bexar counties, CO_2-commingled cross-linked 40 lb. 2% KCl water fracs in Webb county, and gelled diesel in McMullen, LaSalle, and Webb counties.

Most of the shallow Olmos wells are successfully propped with larger frac sand, such as 12-20, 16-30, and 8-12. In the deeper wells, 20-40 sand is pumped, but at concentrations approaching 15 ppg. The high sand concentration provides a higher sustained production due to increased fracture fill-up and a higher fracture flow capacity.

Much has been said about the influence of proppant embedment on the effectiveness of frac treatments in the Olmos. The results of embedment tests are shown in Table #4. They indicate that although some reduction in conductivity of the fracture due to embedment does occur, this reduction reaches (at most) 10% of conductivity with no embedment. The authors are of the opinion, then, that the Olmos sand benefits from larger sand concentrations in much the same way that any other low permeability formation would.

PERFORATION TECHNIQUES

Perforation and breakdown techniques in the Olmos sand vary greatly from county to county, well to well, and operator to operator. In Bexar, Atascosa, and Medina counties, the operators often simply perforate the Olmos zone, test to determine whether the well will flow and then proceed to the hydraulic fracturing part of the completion without benefit of a breakdown treatment.

The Olmos gas wells in Webb county are usually perforated through casing. The operators run tubing in the hole and spot 10% acetic acid or 7-1/2% HCl acid across the Olmos interval. The operator then pulls tubing out of the hole and perforates the well. Tubing and packer are then run back in the hole, and the well is swabbed and tested. The breakdown and cleanup which follows usually consists of 7-1/2% or 15% HCl acid with a clay stabilizer, an iron sequesterant, a corrosion inhibitor and ball sealers to ensure all perforations are opened.

In the deep Olmos in McMullen and LaSalle county, the wells are generally perforated through tubing; the operator runs tubing and packer in hole, and the hole is circulated with diesel or lease crude. The well is swabbed down and perforated under balanced. This technique minimizes formation damage because the pressure gradient goes from the formation toward the wellbore. In the past 7-1/2% HCl acid with clay stabilizers and citric acid had been used in perforation cleanup and breakdowns; however, acid used in breakdowns in LaSalle and McMullen counties resulted in sand production and unconsolidation of the zone. As a result, most operators at present break wells down with lease crude or diesel, "balling out" the zone to make sure of opening all perforations.

The perforation sizes and densities in the entire area vary greatly from operator to operator. In the thicker intervals, the zone is usually perforated with hydraulic fracturing in mind. To achieve limited entry, the operator must maintain 350 - 400 psi differential pressure across the perforations. The thinner sands are generally perforated with 2-4 SPF, depending on the experience in a given field.

In all areas, the use of "mud acid" as a breakdown acid in the Olmos sand should be avoided. The HF in this mixture breaks down the clay matrix in the formation, causing a great deal of sand production into the wellbore. Acid concentrations in any case should be kept quite low, because the formation contains siderite, chlorite and pyrite. All of these minerals, when acidized, release ferric hydroxide, a gelatinous material which can cause considerable formation damage. Although ferric hydroxide can be kept to a minimum by use of a chelator such as citric acid, it is best to keep acid concentration to a minimum.

Sidewall and whole-core flow-through studies were performed on the Olmos sand in McMullen and LaSalle counties. They have indicated that in this area the interval is extremely acid and water sensitive. In some of the tests, all completion fluids tested, except diesel with 10% mutual solvent, cause a complete dissection and breakdown of the framework structure of the rock.

FRACTURING

Two types of fracturing fluids are used in the stimulation of the shallow Olmos sand; refined 18° oil and 20 lb/m cross-linked fluid.

Some operators in Medina county (900 - 1100' wells) pump the local "somerset" refined oil, carrying up to 15 ppg. 8-12, 16-30, or 12-20 sand. Following the slightly higher breakdown pressure, the usual surface treating pressure measures at 1000 - 1250 psi, at 15-20 BPM down 4-1/2" casing. Usually about 15,000 gal. refined oil is pumped, carrying about 100,000 lbs. 8-12 or 16-30 sand (see Appendix A).

Cross-linked 20 lb/m water-based systems are also frequently utilized to fracture the Olmos in this "shallow" area (Atascosa and Bexar counties). This frac fluid should contain a surfactant, bactericide, a deemulsifier and a breaker. Quite often clay stabilizer is not included in the frac fluid. This is in the belief that the polymer-based chemical will "plug up" the permeability. In the authors' opinion, the damage likely to result from uninhibited clay swelling is probably far greater than any potential polymer plugging, expecially in the low concentrations that a clay stabilizer is usually pumped. Therefore, a clay stabilizer is recommended in aqueous frac fluids.

The 16,000 to 18,000 gal. cross-linked fluid usually carries up to 7 ppg. 12-20 sand for a total of 40,000 lbs. at 17-18 BPM and an STP of 700 - 1100 psi down 4-1/2" casing (see Appendix B).

In Webb county, the Olmos gas wells have responded favorably to fracturing with 2% KCl water-based, 40 lb/m cross-linked frac fluids. These frac fluids also contain 20-25% CO_2 to aid in load recovery. Often a prepad stage of gelled (un-crosslinked) water is pumped ahead of the treatment to cool down the formation and establish the fracture. The final sand concentrations on the surface usually range from 6-8 ppg., although some treatments have been pumped at 12 ppg. In addition to the CO_2, the frac fluids contain a polymer-based fluid loss additive, clay stabilizer, KCl (2%), surfactant and bactericide. The jobs are pumped at 8-15 BPM and 4500 - 5000 psi down 2-3/8" and 2-7/8" tubing, and 15-25 BPM and 2000 - 2500 psi down 4-1/2" or 5-1/2" casing. The treatment sizes vary from 30,000 - 100,000 gallons carrying 100,000 - 400,000 lbs. 20-40 Mesh Frac Sand (see Appendix C).

In recent years, Webb county operators have begun to frac the Olmos wells with complexed oil gels instead of water gels with excellent results.

In McMullen county, as mentioned above under "Breakdown Treatments", the use of hydrocarbon-based frac fluid minimizes formation damage. As a result, most operators pump complexed oil or diesel gels. No fluid loss additives are required or indeed recommended in this area; because the formation permeability is extremely low, additional lowering of fluid loss coefficient of the frac fluid would increase closure time beyond a tolerable level.

Because of the high bottom hole temperatures (about 250° F) and long pump times (6-8 hours), high temperature viscosity stabilizers are employed in these frac jobs. These stabilized fluids are better able to keep the sand in suspension until the fracture wall closes on it; again, because of the low formation permeability, these closure times tend to be relatively long (±24 hours).

The original gelled oil jobs in this area had been about 60,000 - 100,000 gallons in size, carrying 200,000 to 300,000 lbs. sand. Although the results of these jobs were much better than those of water-based jobs tried earlier, the maximum effectiveness was not reached until more recently when frac sizes were increased to ±150,000 gallons with as much as 1,000,000 lbs. 20-40 sand.

Rapid production declines following frac treatments resulting in conventional downhole and concentrations (1-2 lb/ft^2) were originally attributed to sand crushing and operators tried using bauxite (a high strength proppant) to forestall this possible problem. However, the closure pressure is not high enough in most of the Olmos Trend to significantly crush 20-40 sand. In addition, long closure times have led to sand falling out of the producing interval, thus decreasing the effectiveness of hydraulic fracturing treatments. Sand is now pumped at surface concentrations reaching 16 ppg, leading to downhole concentrations of 3 - 4-1/2 lb/ft^2. This achieves the double objective of increasing fracture flow capacity and reducing sand fall out from the zone of interest.

The optimum frac length at this time appears to range from 600' to 800'. At the usual rate of about 12 BPM, frac heights of about 100' result. At this rate, down 2-7/8" tubing, treating pressures average at about 7000 psi (see Appendix D).

CONCLUSIONS

Although the Olmos trend covers a large geographic area (and a huge range of depths), certain similarities exist that must be addressed in order to successfully complete the zone. Everywhere the Olmos is a clay-rich, water-sensitive formation. In some areas, such as Webb, Atascosa, Dimmit and Bexar counties, operators achieve successful completions with water-based frac fluids. However, in LaSalle and McMullen counties, the more costly oil-based fluids are employed. Future work in frac fluids should concentrate on the development of less expensive, perhaps aqueous, fluids to frac the Olmos in areas such as McMullen and LaSalle county.

Because the Olmos formation is a soft, friable sand, for years the difficulties with fracturing it had been blamed on embedment of the proppant. Operators responded by employing the larger 8-12 and 12-20 mesh sand in 6-15 ppg. concentrations in the shallow Olmos, and 20-40 sand, in maximum concentrations of 12-16 ppg, in the deeper zones. This had increased the success rate of completions; however, tests have indicated that even with strong formation damage and 5000 psi closure pressure, the decrease of fracture conductivity due to embedment is less than 10% (see Table #4). Figure #9 is a J/Jo curve which shows that this results in only minor differences in productivity. The Olmos sand, then, probably benefits from large downhole sand concentrations, because of increased fracture flow capacity and less sand fall out, not the lessening of embedment. It is possible that frac treatments with fluids of lower viscosity and at higher rates would produce more cost effective results. It might not be possible to pump as much proppant, but it is a question in the authors' minds whether sand concentrations that high are necessary. Perhaps treatments of equal fracture penetration and lower sand concentrations would achieve nearly the same results. Since lower viscosity frac fluids are less expensive, these jobs would almost certainly be more cost effective than those pumped at present. After all, in the medium-deep Olmos of Webb county, wells are completed successfully with maximum sand concentrations of 8 ppg. or less.

A third problem connected with the Olmos sand is the high temperature of the formation in the "deep" areas of production. Because in the present fracturing scheme very high downhole viscosities must be maintained for a comparatively long period. In many cases this means the special development of a frac fluid for this environment, which can be prohibitively expensive. In the future, then, either the fracturing theory regarding this formation should be scaled down to include lower viscosity fracturing fluids at higher rates, or new, less expensive downhole viscosity stabilizers must be developed.

REFERENCES

Sellards, E.H., Adkins, W.S., Plummer, F.B., "The Geology of Texas-Mesozoic Systems" The Geology of Texas Volume I The University of Texas Bulletin No. 3232; August 1932.

APPENDIX A

Typical Medina County Completion

1. Well is drilled with water (brine) based mud.

2. Following 4-1/2", 7.5# casing, perforate well via casing and test to determine whether it will flow.

3. Frac treatment: ±15,000 gal. refined 18° oil with ±100,000 lbs. 16-30 or 8-12 sand. Job pumped at 16-18 BPM and 1200 psi down casing. ISDP is ±600 psi. Maximum surface sand concentration is 15 ppg.

APPENDIX B

Typical Atascosa County or Bexar County Completion

1. Well is drilled with water (brine) based mud.

2. Following cementing 4-1/2", 9.5# or 12# casing, perforate well via casing and test to determine whether it will flow.

3. Frac treatment: ±16,000 gal. Mini Max III-20 (20 lb. cross-linked gel) with 40,000 lbs. 10-20 Mesh Sand. Job pumped 17-18 BPM and 800 psi down casing. ISDP is 500-900 psi. Maximum surface sand concentration is 7 ppg. Fracturing fluid contains 2% KCl, bacteriocide and nonemulsifier.

APPENDIX C

Typical Webb County Completion

1. Well is drilled and cased according to operator preference.

2. Spot 10% Acetic Acid or 7-1/2% HCl Acid across the Olmos interval.

3. Pull tubing out of hole; perforate through casing.

4. Run tubing and packer into the hole; swab and test.

5. Ball out with 1000-2500 gal. 7-1/2% - 15% HCl Acid containing fluorosurfactant, iron sequesterant, silt suspender and clay control agent.

6. Frac treatment: 70,000 gal. Water-based Frac Fluid; non-crosslinked prepad followed by Mini Max III-40 (cross-linked 40 lb. gel). Total volume is ±70,000 gal. carrying ±250,000 lbs. 20-40 Mesh Sand. Job is pumped at 18-20 BPM and 4500 psi down 2-3/8" tubing. Maximum sand concentration is 5 ppg. Fracturing fluid includes 20-25% CO_2, 2% KCl, biocide, fluorosurfactant and clay control agent.

APPENDIX D

Typical LaSalle and McMullen County Completion

1. Well is drilled and cased according to operator preference.

2. Tubing and packer run in hole.

3. Circulate lease oil or crude.

4. Perforate Olmos interval under balanced through tubing (pressure gradient going toward well bore).

5. Ball out with diesel (volume depends on size of zone).

6. Frac treatment: ±150,000 gal. cross-linked lease oil or diesel with close to 1,000,000 lbs. 20-40 Mesh Sand. Maximum sand concentration is ±15 ppg. Job is pumped at ±12 BPM and 7000 psi down 2-7/8" tubing. Fracturing fluid includes viscosity stabilizers and high temperature stabilizers.

Table 1
Mineralogy of Typical Wells by County Minerals by Percent

COUNTY	LaSalle	LaSalle	Webb	Webb	McMullen	McMullen	Atascosa	Atascosa	Dimmit	Frio
DEPTH	7500'	9000'	5200'	7100'	9600'	10,100'	3500'	4200'	4500'	3900'
FIELD	N/A	Wildcat	Dos Hermanos	Bien-audes	S.E. Tilden	N/A	Sutton	N/A	Catarina	Wildcat
QUARTZ	67	40	63	77	65	55	56	70	50	45
FELDSPAR	12	25	9	8	11	16	10	15	37	30
CALCITE	5	10		1	5	3	4		TR	TR
DOLOMITE	1				2	2	1			
SIDERITE					1					
ANHYDRIDE										
GYPSUM										
PYRITE	TR		13		TR		1			
BARITE					TR	1				
KAOLINITE	4	5	2		9	8	2	5	4	5
ILLITE										TR
CHLORITE	8	5		8		8	20		2	5
MONTMORILLONITE					1					15
MIXED LAYER ILL/MONT.	3	15	13	4	6	10	7	10	7	
HALITE					1					
15% HCL SOLUBLE	11	0.00	12.2	8.7	10	18	11.2	13.62		14.3
ACID SOLUBLE IRON	1.2	0.00	1.5	.92	.3	1.7	1.73	2.52		.65
CARBON										
ANKERITE				1						

Table 2
Reservoir Characteristics of Selected Wells by County

COUNTY	Atascosa	Webb	Webb	LaSalle	McMullen	Medina	Atascosa	Bexar
AVERAGE DEPTH	3600'	5200'	7-8000'	7500-9000'	9500-9800'	1100'	1500'	1500'
PERMEABILITY	1.04 md to kerosene	.5 md	.05-.1 md	.1-.5 md	.05-.6 md			
POROSITY		16%	14%	14-17%	19-24%			
BHP GRADIENT	.33-.4	.35	.33	.35	.44	.33-.4	.33-.4	.33-.4
FRAC GRADIENT	.9	.86	.83	.77-.85	.8	.89	.94	.91
T° GRADIENT	1.3	1.92	1.61		1.46			

Table 3
Oil Analyses of Selected Wells by County

COUNTY	Dimmit	Atascosa	Bexar	McMullen	Webb
DEPTH	2917'	1900'	1000'	10,000'	7114'
FIELD			Fairfield		
API GRAV.	33° @ 60°F	34.4°@ 60°F	26.8° @ 60°F	42.8° @ 60°F	45° @ 60°F
ASPHALTENES	3%	4.5%	.5%		
PARAFFINS	9.5%	10%	20%	6%	
POUR POINT	68°F	39°F	-22°F		

Table 4
Embedment Profile for Olmos Formation
(LaSalle County, 7470'-7506')

CLOSURE PRESSURE (PSI)	SATURATION FLUID	WIDTH BEFORE EMBEDMENT (INCHES)	WIDTH AFTER EMBEDMENT (INCHES)	% CHANGE IN WIDTH (INCHES)	CONDUCTIVITY BEFORE EMBEDMENT (DARCY FT)	CONDUCTIVITY AFTER EMBEDMENT DARCY FT)	% REDUCTION IN CONDUCTIVITY	SAND CONCENTRATION SIZE
3000	Dry	0.1165	0.1126	0.0039	1.685	1.629	3.3	1 lb/ft^2/ 20–40
3000	2% KCl	0.1165	0.1107	0.0058	1.685	1.601	4.9	1 lb/ft^2/ 20–40
3000	Kerosene	0.1165	0.1117	0.0048	1.685	1.617	4.1	1 lb/ft^2/ 20–40
5000	Dry	0.1105	0.1048	0.0057	0.835	0.792	5.1	1 lb/ft^2/ 20–40
5000	2% KCl	0.1105	0.1002	0.0103	0.835	0.758	9.2	1 lb/ft^2/ 20–40
5000	Kerosene	0.1105	0.1022	0.0083	0.835	0.772	7.5	1 lb/ft^2/ 20–40
3000	Dry	0.2061	0.2022	0.0039	2.981	2.925	1.9	4 lb/ft^2/ 20–40
3000	2% KCl	0.2061	0.2002	0.0059	2.981	2.897	2.8	4 lb/ft^2/ 20–40
3000	Kerosene	0.2061	0.2013	0.0048	2.981	2.913	2.3	4 lb/ft^2/ 20–40
5000	Dry	0.1963	0.1905	0.0058	1.484	1.440	2.9	4 lb/ft^2/ 20–40
5000	2% KCl	0.1963	0.1861	0.0102	1.484	1.407	5.2	4 lb/ft^2/ 20–40
5000	Kerosene	0.1963	0.1880	0.0083	1.484	1.421	4.2	4 lb/ft^2/ 20–40

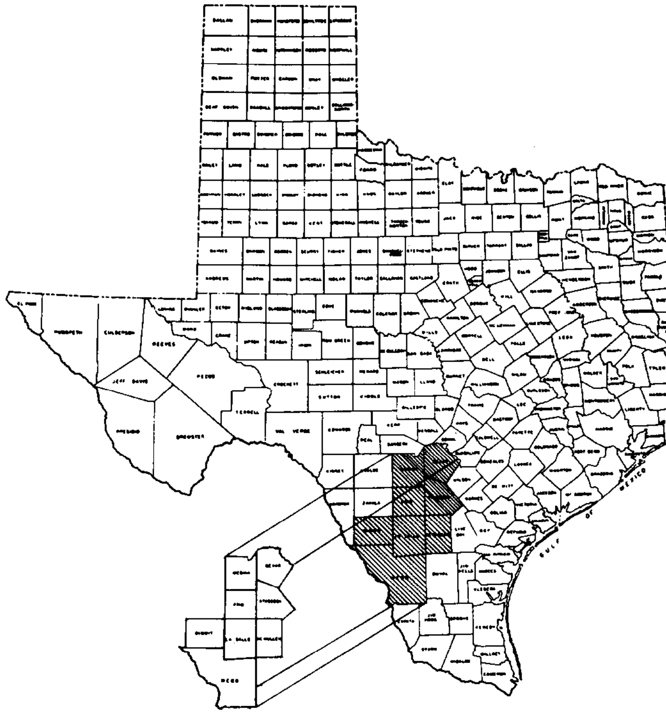

Figure 1

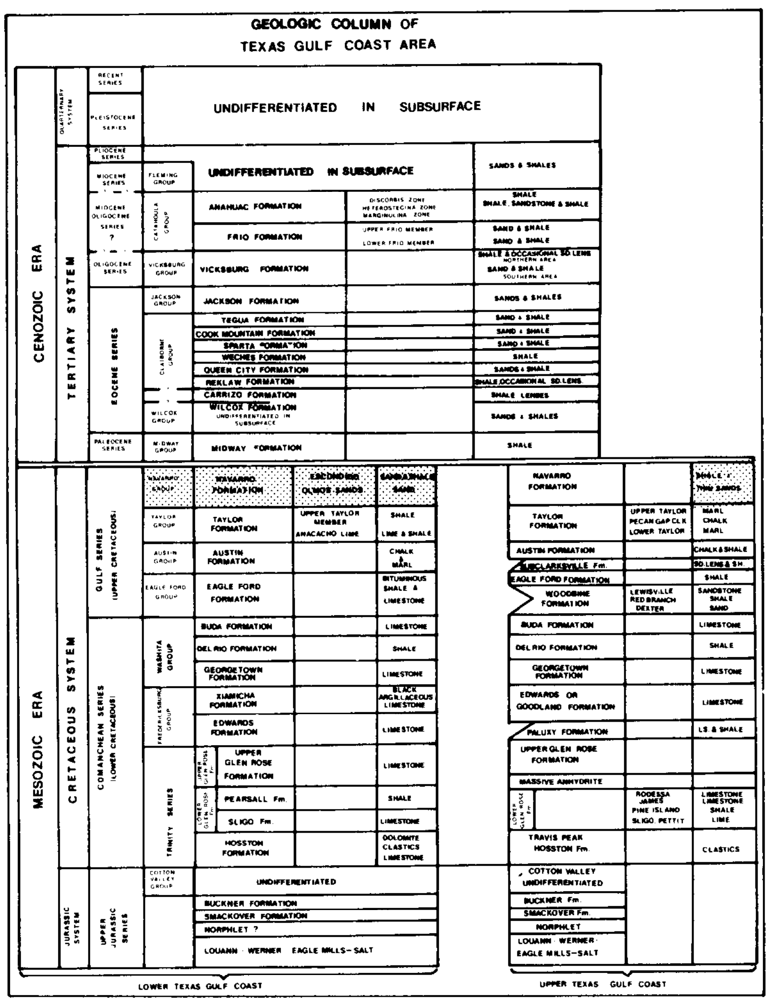

Figure 2

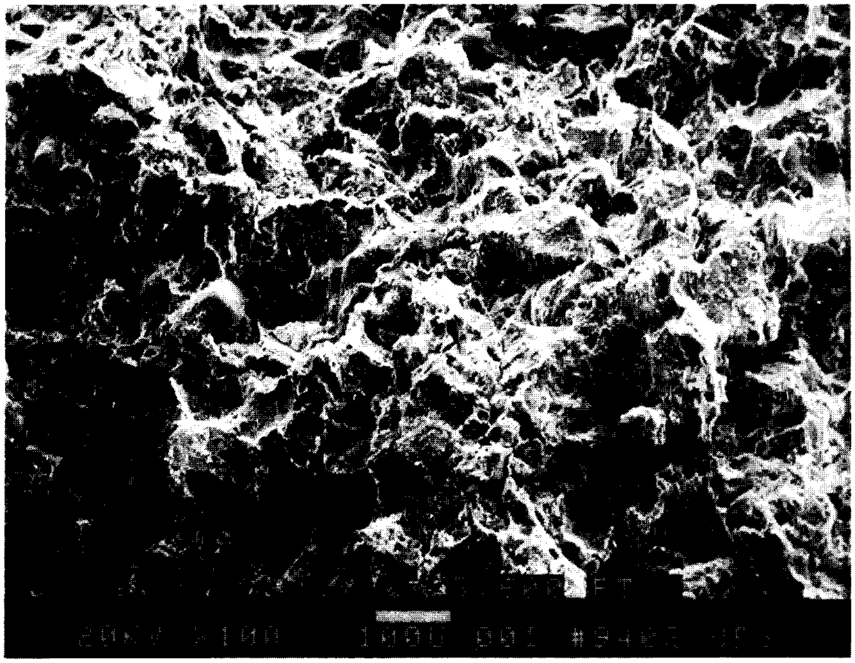

Figure 3 - In 100x magnification, individual framework grains are barely visible since most are coated with clay minerals. Atascosa County, 3600'.

Figure 4 - Under 2000x magnification, a small pore is shown between chlorite coated framework grains. The position of these clays with respect to the pore makes migration a distinct possibility. Atascosa County, 3600'.

Figure 5 - Under 2000x magnification, kaolinite and chlorite clays are shown along with a pyrite frameboid. A secondary quartz overgrowth indicates at least partial cementation by quartz. Atascosa County, 3600'.

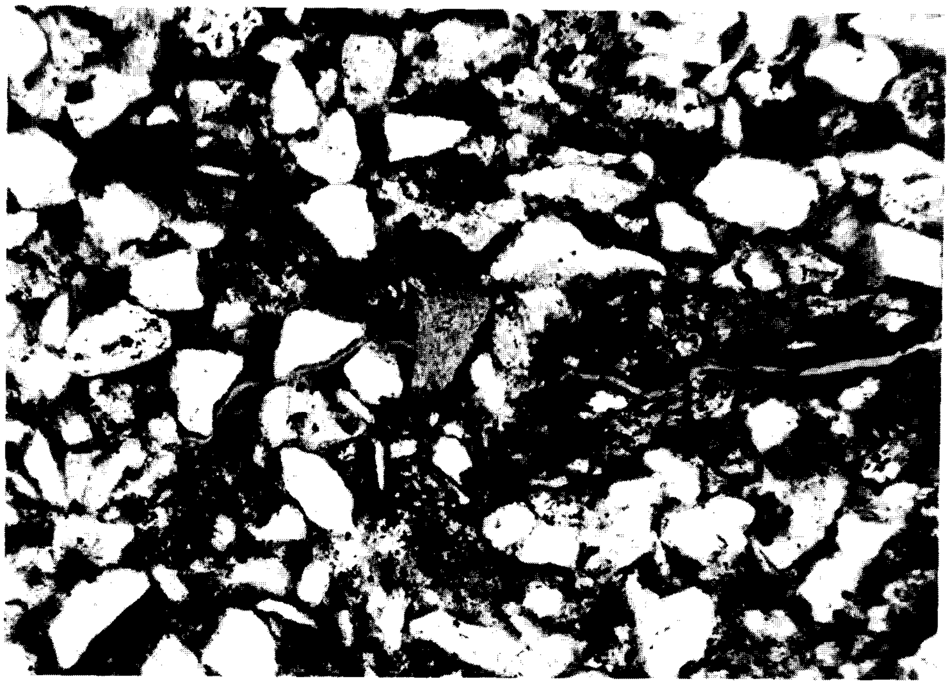

Figure 6 - Best porosity at this depth is due to horizontal fractures. Note oil residue (black) along right-hand portion of the fracture. LaSalle County, 7490'.

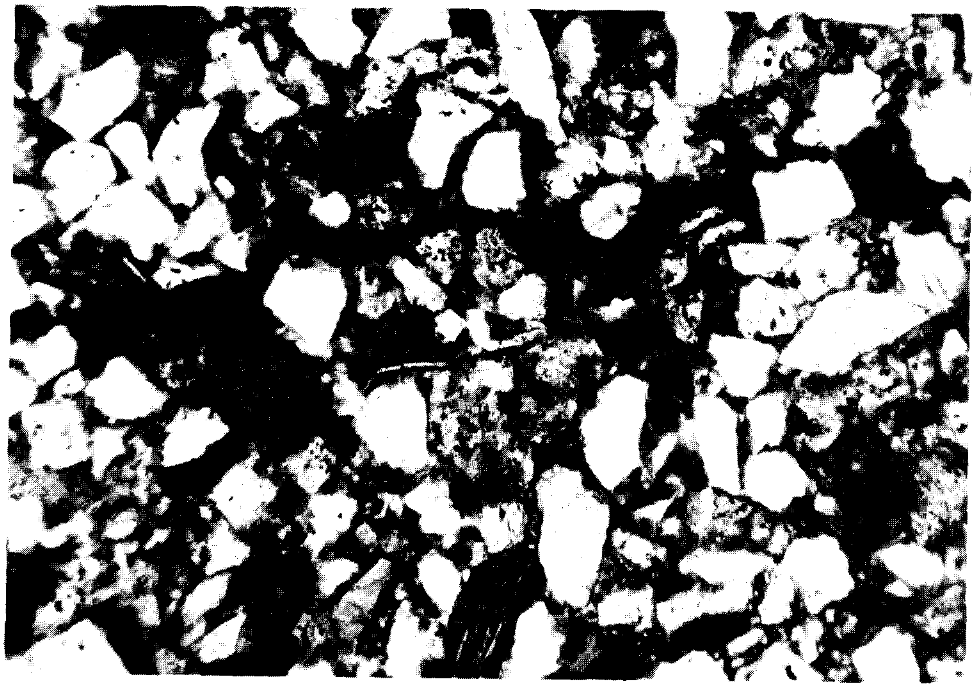

Figure 7 - This horizontal fracture is almost entirely filled with oil residues (black).
LaSalle County, 7490'.

MC MULLEN COUNTY, TEXAS

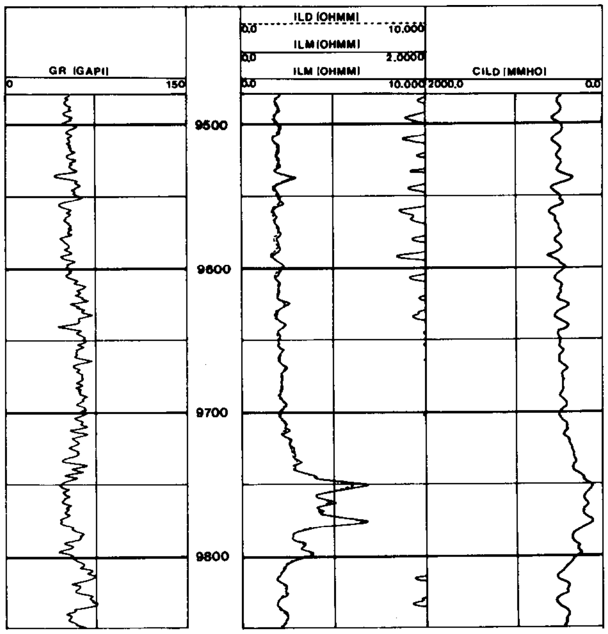

Figure 8A

MC MULLEN COUNTY, TEXAS

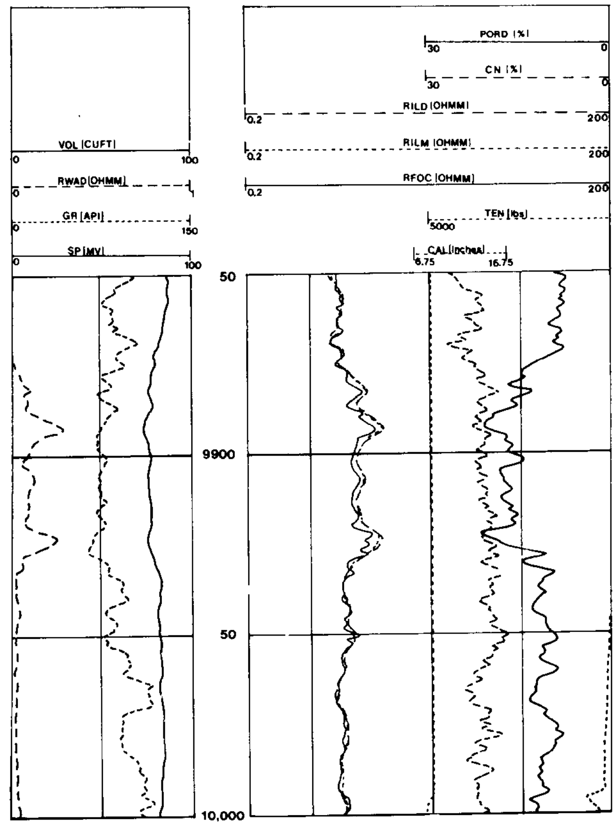

Figure 8B

FRIO COUNTY, TEXAS

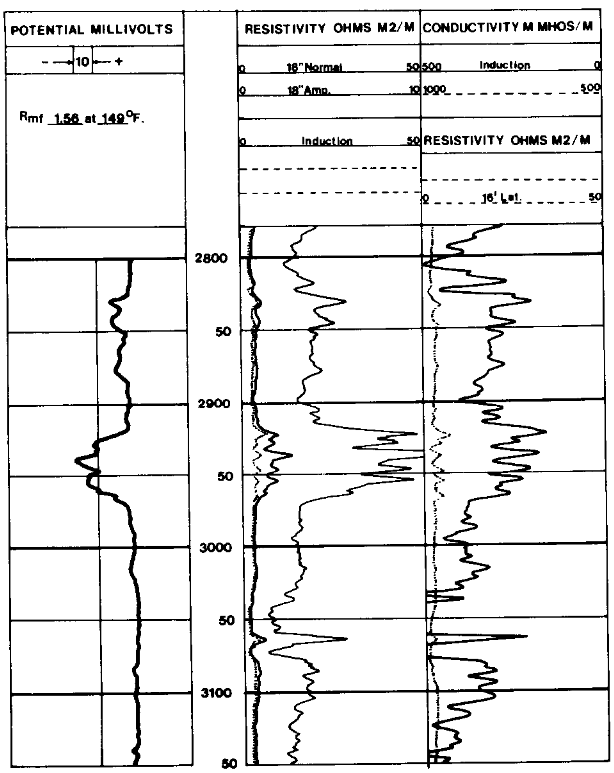

Figure 8C

CALCULATED PRODUCTIVITY INCREASE VS FRAC LENGTH

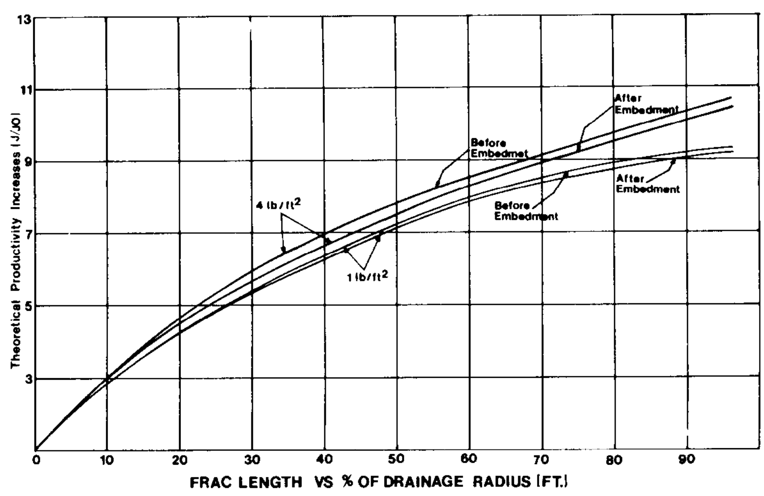

Figure 9