AN INTEGRATED STUDY OF A PORTION OF THE FOSTER (GRAYBURG/SAN ANDRES) FIELD, ECTOR COUNTY, TEXAS

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Abstract

A cooperative two-phase study of the Grayburg/San Andres reservoir is being conducted in response to the United States Department of Energy's (DOE) Class II Oil Program. The study's purpose is to preserve access to existing wellbores by identifying additional reserves. Phase I was an integrated Geological, Geophysical, and Engineering study to determine if state-of-the art technologies, including 3D seismic and sequence stratigraphy, could be integrated into a reservoir simulation to enhance oil recoveries in this 66 year old field. At the end of Phase I, recommendations for new drills, deepenings, and workovers were made. Data gathering in Phase II included taking cores in three new drills to evaluate stratigraphy, running pressure buildup and production tests and injection profiles in existing wells, and RFT's and modern log suites in new drills and deepenings to evaluate reservoir conditions. Attribute analysis of the 3D data was integrated into the decision making process during Phase II. The results of three new drills, one deepening, four workovers, and two conversions to injection were to increase production by 50%. Injection water quality has been improved and a waterflood realignment implemented.

Introduction

The objective of this two-phase study is to demonstrate an integrated methodology for reservoir characterization of shallow shelf carbonate reservoirs which is feasible, and cost effective, for the independent operator. Furthermore, it will provide one of the first public demonstrations of the enhancement of reservoir characterization using high resolution three dimensional (3D) seismic data.

This particular project is evaluating the Grayburg and San Andres reservoirs in the Foster and South Cowden Fields of Ector County, Texas. The investigators are showcasing a multi-disciplinary approach to waterflood design and implementation, along with the addition of reserves by selective infill drilling. This approach in reservoir development will be applicable to a wide range of shallow shelf carbonate reservoirs throughout the United States. Technology transfer will take place through all phases of the project, and be available to the public. For a review of the results of Phase I of the project, see Smith, et al., 1995 and Reeves, et al., 1996.

Geology

The reservoir description is an integration of the 3D seismic interpretation with the geologic model derived from the core description, thin section study, log analysis and cross section work. Geological evaluation of the Grayburg/San Andres reservoirs (Fig. 1) has included work concentrated on completing the reservoir description in the WorkBench software program and preparing a data set to be used during the reservoir simulation. Although a single layer model for the Grayburg was used during the initial simulation, models using two layers (Grayburg and San Andres), five layers (A1, A2, B1, B2 and C zones), and seven layers (A1, A2, B1, B2, C, Lower Grayburg, and San Andres) were constructed for use in more advanced reservoir simulations.

A series of property maps, to be used in the simulation, were developed for each layer (Figs. 2A - 2D). The maps were based on normalized logs. There are twenty (20) wells for which modern full logging suites exist and forty nine (49) wells for which some logs exist. Average spacing in the project area is 14 acres/well, so the control is excellent.

Once the net feet of pay for each zone was determined, historic production allocation was undertaken. The completion records were evaluated to determine which zones had been in production in which years, when zones were added or deleted, and when a producer's status changed. The merging of the geologic zonation with production histories was completed - as was an effort to determine which zones were receiving flood support. Any and all injection profiles were collected and used to allocate injection to each zone.

Core K and ϕ for All Cores

During the simulation, a question arose regarding the permeability and porosity of the different layers used in the model. A closer examination of the ϕ vs. K was undertaken and a series of plots (Fig. 3) were generated from the existing core reports. Although six wells were cored (Fig. 4) in Sections 36, 31, and 32 (just to the east of Section 31), only the cores taken in the Sun #6 Witcher still exist. The Sun #6 Witcher was cored in the Upper Grayburg and San Andres. The Arco #10 Brock was cored in the San Andres. The Arco #3-X Foster-Pegues was cored in the Upper Grayburg. The General American #7 Maurice was cored in the Upper Grayburg. The Great Western #19 Johnson was cored in the Upper and Lower Grayburg. The Richmond Drilling #3-A Maurice was cored in the Upper Grayburg. A total of 950 ft. of Upper Grayburg, 40 ft. of Lower Grayburg, and 115 ft. of San Andres were recovered. Unfortunately, the #6 Witcher core is only Upper Grayburg and a portion of the San Andres and does not by itself provide enough information to adequately describe the entire reservoir. The recovery of cores in three new drills, the Foster-Pegues #11 (Lower Grayburg), Foster #11 (Lower Grayburg and San Andres), and the Witcher #12 (San Andres) will provide a framework to better describe the entire reservoir.

The All Wells All plot (Fig. 3A) of ϕ vs. K contains all the analyses from the six older wells. The wide scatter of data initially appears to show no distinct trend. However, with further evaluation, there appears to be three distinct populations: a high permeability/low porosity "fracture field", a low permeability/high porosity "secondary or vugular field", and a permeability/porosity field which exhibits a "normal" distribution for shallow shelf carbonates.

The fracture field is present in the Grayburg in the #6 Witcher, #19 Johnson, #7 Maurice, and #3-X Foster-Pegues. In each well, there are a limited number of values (2-3) indicating that fractures make only a minor contribution. In addition, there are two 4 to 5 ft. thick intervals in the core taken from the #11 Foster-Pegues with oil staining in fractures. The log analysis indicates these zones have less than 3% porosity and would not have been perforated without the core.

The "secondary" porosity field is composed of San Andres in the #10 Brock and #6 Witcher, and some of the Grayburg in the #7 Maurice. The San Andres in the #6 Witcher core is composed of clean, high energy grainstones and packstones with secondary inter-particle porosity.

Analyses from the #10 Brock and #6 Witcher indicate that the San Andres is a poor waterflood candidate. Although the logs and cores indicate zones with 12 to 14% porosity, the low permeability (averaging 1 mD at 10% ϕ) would preclude successful waterflooding on 20 acre spacing, and raise the risk of successfully waterflooding on 10 acres. This conclusion is supported by the marginal results of a San Andres-only flood west of the study area.

There are few Grayburg analyses which fall in the secondary range, leading to the conclusion that most of the Upper Grayburg reservoir is composed of connected inter-particle porosity with good permeability. When the cores taken in the three new drills are evaluated, there will be an adequate data set available to draw facies based conclusions for the Lower Grayburg. The analysis of the #11 Foster-Pegues, the first Lower Grayburg new drill, shows the cored, Lower Grayburg in this well to have a large component of primarily tight dolomite with less than 4% porosity and less than .2 mD of permeability, and a small component of "Secondary Porosity" with porosity 3 to 6% and permeabilities of .3 mD. The best log porosity, however, in the "G" and "H" zones was entirely below the cored interval. There is a significant component of fracture porosity (less than 3% porosity but up to 20 mD of permeability) in the "C" and "E" intervals. The fractures in the "C" are proposed as the explanation for the behavior of the Foster #1WI (Fig. 4) after clean out. The well had been injecting into the "A" zones only and was cleaned out through the Lower Grayburg. When injection resumed, the well took up to 400 BWPD on vacuum with 85% of the injection water entering the "C" zone.

Water Analyses

The pressure data collected during Phase II indicates that many of the producing wells are not "seeing" the flood. As part of the effort to determine which zones have received waterflood support, all water analyses were collected, and water samples from producing wells and injection stations collected and analyzed and entered into a spreadsheet. Analyses range from two partial analyses done in 1940 to a series of "base line" analyses completed in May of this year. A major question is: what did the virgin Grayburg and San Andres waters look like? By the 1970's when the first large scale water analysis program was undertaken, the waterflood had been ongoing for fifteen years. Although this had been primarily a water disposal program, breakthrough to producing wells had occurred as early as 1963. A "Typical Grayburg water analysis" recorded in 1963 represents our best guess as a base line Grayburg analysis. Water collected from the Witcher #2 and Foster #11 in July and August have provided a "Typical San Andres" for the Foster Field. It is now known that the San Andres water has significantly more Total Dissolved Solids than the Grayburg and that the ratios of cations and anions are different. This is a strong indication that the Grayburg and San Andres are NOT in communication and that they should be viewed as separate reservoirs.

Injection water has varied greatly through time. Every available water, from Canyon (very high TDS) to "Fresh Water" (shallow Santa Rosa and Hendricks Reef water), as well as Grayburg and San Andres, have been injected in Section 36. The compatibility problems resulting from this mixture have undoubtedly had an adverse effect on the reservoir (See Waterflood Section).

An example of how the water analyses can be used to increase the efficiency of the waterflood can be seen in the Brock #12. Water analyses for the Brock #12 are plotted in Fig. 5. This well was sampled, when it began producing from the Grayburg and San Andres in November 1994, when it began producing Holt water from below a leaking bridge plug (December 1995), and twice (March and May 1996) after a new bridge plug was set and Grayburg and San Andres production re-established. The plot of the Cations shows a change in water chemistry through time that reflects the different produced waters. It also demonstrates that the "Holt" influence lasted for at least two months (March thru May 1996), but less than five months, after bridge plug was set (by August 1996, the water analyses strongly resembled that from December 1994). This is an indication how deeply the Holt water had invaded, and possibly damaged, the lower pressure Grayburg. This is an indication of potential problems if different pressure zones were to be commingled.

Geophysics

See Reeves, et al. (1996) for a review of acquisition and processing. The sequence stratigraphic interpretation from well data is being integrated with the 3D seismic data to resolve complex stratigraphic relationships important for the reservoir characterization. This interpretation will continue to be refined as more data is acquired. Seismic attributes (such as horizon time, interval time, instantaneous amplitude, frequency, and phase) have been reviewed to help refine reservoir properties for the simulator. The first step was to review the seismic data to determine its characteristics of bandwidth and phase. Variables such as shoot geometry, fold, processing limitations, and objective depth affect the credibility of structure, reflection amplitude, and reflection shape. Credibility of near-edge data must be judged by relative appearance, ties to well data, and reasonable risk assessment. Because this 3D survey is relatively small, the data credibility must be continually considered. The half section eastern part of this survey is very noisy and is of limited stratigraphic value, although it is valuable for structural interpretation.

Data phase was determined by reflection comparison at well tie locations with synthetic seismograms made using available sonic log digits. A comparison is attached (Fig. 6). Synthetic seismograms were incorporated into a preliminary cross section and then a 2D forward model was created to show ties of log correlations with seismic (and synthetic) reflections and demonstrate visual changes across the interpolation model.

To better integrate the geophysics with the geology and engineering, the following topics were addressed: 1) relating the resolution of seismic reflection intervals compared to log fine-sequence resolution, 2) very preliminary map observations statistically compared to interval porosity measurements and a test of the mechanical interface between geophysical and engineering computer software packages, and 3) data resolution optimization. Preliminary correlations were made for seismic reflections, simple and complex geometries of the Grayburg and San Andres were debated, and an approximate vertical resolution of the seismic wavelet was estimated at 100 ft.

Seismic inversion modeling will be conducted as stratigraphic analyses on an inversion model data set has a higher degree of correlation than on seismic reflection (wiggle) data. The mapped parameters of inversion data will simply be more geologically intuitive and lead to valuable conclusions more quickly. Consideration has been given to the constraint horizons to be used in calculating the model(s). The geologic and seismic relationships need to be established first. Inversion modeling is not a trivial operation only because the input parameters must be well understood, complete, and be appropriate. The mechanics of inversion, however, are simple and the process runs fairly quickly.

Near-term Objectives

Resolution of the seismic data is being studied to further relate the seismic scale to the geologic (log) scale for the Grayburg and the San Andres formations. Additional simplified forward models will be built to demonstrate the effects on seismic response of porosity changes within several levels of the Grayburg sequence.

Engineering

Recovery Technology Identification and Analysis

A complete production history for the leases under study was obtained from the Railroad Commission of Texas, the Midland County Library, and former operators. Water injection rates, water cuts, and reservoir pressure measurements were obtained from various operators in the area. Reservoir properties, such as porosity, permeability, and PVT relationships for reservoir fluids, were obtained from core and fluid analyses done on samples from the reservoir.

Reservoir Simulation

Using the results of reservoir characterization developed using the Reservoir Description portion of the WORKBENCH portion of Scientific Software-Intercomp's (SSI) Workstation, a three dimensional model of the study area was developed. The study area was originally composed of Section 36, Blk 43, Twn 2S and 224 acres from the contiguous Section 31, Blk 42 Twn 2S. Phillips Petroleum sold the Section 31 lease in late 1995 and the purchaser declined to participate in Phase II. The model, therefore, was centered on Section 36 (Figs. 7A - D). Two vertical layers were used: the upper layer (layer 1) consisted of flow compartments contained in the Upper and Middle Grayburg Formation (A1, A2, B1, B2, and C). Layer 2 contained the Lower Grayburg (D, E, F, G, and H) and the San Andres Formations.

Several grid block sizes were tried in the initial simulation runs. Because of the very long history (55 years) and the large number of wells (58), and the speed of the machine available (50 MIPS), it was necessary to restrict the number of grid blocks. The final grid dimension selected was an 18 by 18 aerial grid for the full Section 36. Furthermore, it was evident from early runs that the zones contained in layer 2 would not support a waterflood due to the high water saturation already existing in these lower zones. It is also noteworthy that approximately 90% of the production originated from the Upper and Middle Grayburg zones. Accordingly, the final model developed for analyzing profitability of infill drilling and potential waterflood recoveries consisted of an 18 x 18 grid, single layer model.

Initially, the production and injection as recorded over the span of 55 years was simulated. This mainly involved achieving a match of pressures and water-cuts over the period of operations. An excellent match of both parameters was obtained after making several runs with the Workstation.

A "base case" prediction run was then made assuming operations would continue as in the past with no new wells drilled nor any remedial work of existing wells other than normal rod, tubing and pump repairs currently employed. The results showed a profitable recovery of an additional 389 MBSTO with abandonment occurring in approximately ten years.

The next prediction run was designed to obtain maximum waterflood recovery using a ten-acre well density. Twenty new wells were drilled and 20 existing wells were recompleted so as to expose all flow compartments delineated in the reservoir description portion of the study. This model was used to generate income expected from the increased production obtained by implementing infill drilling and full-scale water flood. The total expected recoverable oil is calculated to be 5,000 MBSTO, or approximately 4,611 MBSTO increase over the base case.

The model was then used to attempt to optimize profitability of the lease as opposed to optimizing oil recovery as examined in the previous case. In this effort, only five carefully selected new wells will be drilled and twelve existing wells recompleted for profit optimization purposes. In this instance, the most profitable venture shows an additional recovery of 4,000 MBSTO, or an increase of 3,611 MBSTO over the do-nothing case.

Summary of Reservoir Simulation

In Laguna's Section 36 property, forty six wells have produced from the Upper Grayburg, Lower Grayburg, and San Andres. Production from these zones has been commingled and wells have been recompleted over time. Hydraulic fracturing was effective and may have allowed the zones to communicate vertically. A number of layering strategies and areal grids were evaluated leading up to a five layer model using as layers the A, B, and C zones, the Lower Grayburg and the San Andres.

As a preliminary step, the Upper Grayburg was split into five layers (A1, A2, B1, B2, C) and modeled separately. The grid extended two locations past the edges of Section 36. The five layer model showed early migration in the A zone to the northwest due to the original four injectors (Figs. 7A -D). There are several good wells in the Amoco property to the northwest that probably benefited from the migration.

Understanding the vertical distribution of production was the next step. Detailed analysis of each well's production history was undertaken to allocate production to each zone. Open net thickness compared to total net, time of completion, and well tests were used to calculate each zone's contribution. The distribution of cumulative production is as follows: Upper Grayburg, 81%; Lower Grayburg, 5%; and San Andres, 14%.

Early 40-acre wells (pre 1970) of the north 320 acres produced from the A, B, and C zones only. Six of the eight 40-acre wells of the south 320 acres also produced from the Lower Grayburg and San Andres.

The 40-acre wells tended to be open hole, shot with nitroglycerine. Hydraulic fracturing of these wells in 1955 increased the Section 36 production from 150 to 450 STB/D. Subsequent frac jobs were also successful with some wells fraced three times. Water injection was initiated in 1962 by converting four old producers to injection. The injection was into the depleted upper zones on a vacuum. Thirteen injection profiles obtained from 1962 to 1980 were analyzed. These profiles showed that most of the injection water went into the A zone with a small amount into the B zone and almost nothing lower. Fill in the wells in the post 1980 period has probably insured that injection has not reached the deeper zones. The profiles also showed that in three original injectors, the Queen Sand was in the open hole section and took 15 to 35% of the water. In the model, the pre waterflood depletion was combined with these injection profiles. The model results showed that 71% of the cumulative injection went into the A zone, 20% into the B zone, 5% into the C zone, 4% into the Lower Grayburg and essentially no injection into the San Andres.

The model's response to the oil production increase observed after the frac jobs provides an insight into the production mechanisms observed in the field. With a horizontal permeability of 5 md in all layers, vertical permeability of zero and calculated completion kh, the model was unable to produce the reported production. This observation led to a series of sensitivity runs aimed at matching the frac oil production. It was hypothesized that the fracs established communication horizontally and vertically with natural fracture systems that did not contribute before. This was modeled by changing horizontal and vertical permeabilities to the levels shown below:

Layer	Horizontal Perm., md.	Vertical Perm., md.
A	10	10-5
B	5	10-5
C	5	10-5
LG	3	10-9
SA	10	10-9

In addition, completion kH was increased by a factor of ten and the wells were fully completed in the C zone even though they were partially penetrating. The effect of these changes was to produce about 400,000 STB of Lower Grayburg oil through the Upper Grayburg perfs.

Results of Workovers and New Drills

The results of the simulation led to recommendations of high priority workover candidates. Each well was chosen to test parts of the simulation results. The workovers completed in early 1996 were the Foster #3, Brock #12, and Brock #13 (Fig. 4). The Foster-Pegues #11, a new drill, was also recommended to test the potential primary reserves in the Lower Grayburg. The Foster #3 was chosen to determine if a gas cap, or isolated gas zone, existed in the A zone as postulated based on old drilling records. The Brock #12 workover tested for the presence of a highly permeable zone channeling water from an injection (Witcher #3-WI) to the producer. The Brock #13 was tested to determine if the simulation had correctly identified that the water being injected into the Upper Grayburg was sweeping oil into that area.

The Foster #3 tested two porous intervals that had not been included in the original completion in 1941. The original drilling report indicated that these zones produced gas during drilling at rates as high as 2MMCFGPD. These zones were not shot during the initial completion, nor at any later date. All 1940's vintage wells in the southwest part of the project area indicate gas present above about 900 ft. v.s.s., with the first show of oil below that depth. These wells, the Foster #3, Foster #4, and Brock #1, and wells to the west were not completed above -900' v.s.s. The Foster #3 was chosen to workover because of its accessibility. It was TA'd but re-enterable. The A2 zone was tested first and swabbed 100% flood water, most likely from the Foster #5 or the Brock #9. The A1 zone was tested next and swabbed oil, gas, and water. The Foster #3 is pumping 27 BO, 182 BW, 14 MCFPD. These results indicate that the waterflood is pushing water into areas that had not previously been considered to have potential. This will necessitate a change in the simulation, adding pay in the A1 and A2 zones in the Brock and Foster leases.

The Brock #12 was chosen for workover because it had gone from making 27 BO and 230 BW to 0 BO, and 400 BW in five months at the end of 1995. Upon entering the well, it was determined that the water was not flood water entering from the Grayburg but was, instead, coming from the deeper Holt (1,500 ft. below the Grayburg) past a leaking bridge plug. After the bridge plug was cemented in, the Grayburg began making oil and water. It is believed that the Holt water was entering the lower pressure Grayburg and some formation damage (scaling) may have occurred. The Brock #12 is pumping 8 BO, 202 BW, and 4 MCFGPD. When this well stabilizes, a tracer survey will be run to determine the origination of the water, and a stimulation will be attempted.

The Brock #13 had been producing from the Lower Grayburg and San Andres and was pumping 32 BO, 15 BW, and 4 MCFGPD. The Upper Grayburg (A, B, C, D) was completed and, at the end of the quarter, was pumping 61 BO, 254 BW, and 6 MCFGPD. The Lower Grayburg and San Andres will be added back when the well stabilizes.

The simulation indicated that the Lower Grayburg study wide was not being adequately produced. The southern part of the Foster Pegues Lease was still essentially "virgin" reservoir and an excellent candidate for a new drill. There was, however, a major problem with surface obstruction - Interstate 20, Highway 80 (Business 20), and the railroad tracks all cross the Foster Pegues Lease. The best location was chosen to combine surface and legal (field rules) location for a vertical well within the best area in the simulation. The available seismic was also evaluated to see if the chosen location had porous Upper Grayburg (for later use in the waterflood).

During the second quarter 1996, the Foster-Pegues #11 was drilled as a Lower Grayburg producer. The well was TD'd near the top of the San Andres, as the San Andres at the location is believed to be below the oil/water contact and completed in the Lower Grayburg from the "C" to "H" zone. The well initially flowed at rates as high as 400 BOPD and IP'd flowing for 106 BO, 39 MCF, and 34 BWPD. The fact that the well flowed, with a high oil/water ratio, and a GOR of 368 (close to the Original Field GOR), indicates that it was not influenced by the waterflood and has not been drained by surrounding wells. This validates the simulation results. The Upper Grayburg was not included in the completion as it is believed to be influenced by the waterflood.
Each of these wells was a success. The Foster #3 had been TA'd with no reentry plans. The Brock #12 was thought to be behind the flood front and might soon have been abandoned. The Brock #13 Upper Grayburg production replaced the production from the

Brock #2 (which was an Upper Grayburg only well making 3 BO, and 35 BW, 210 ft. to the west).

Production Rates

Obtaining production data for this project area was complicated by the fact that sixteen different companies had operated in the project area over sixty years. Production in many wells was commingled Grayburg and San Andres.

A program was initiated in December, 1995, and continues, to obtain accurate measurements of oil, gas and water production rates on all wells in the project area. A Portacheck was used where a test separator was not available.

The current production measurements plus the completed net thickness from logs were used to allocate the entire production history back to the zones where it originated.

Pressure Data

A program was initiated to conduct pressure buildups and falloffs on every well in the project area. The objectives of this program were:

1. Pressures for history matching,
2. Skin damage to identify stimulation candidates,
3. Permeability for simulation, and
4. Identification of flow barriers in the reservoir.

Flow barriers were seen in two injectors. The injectors have reservoir pressures in the range of 1,500-2,200 PSI. The producers have some damage with reservoir pressures in the range of 200-500 PSI. The conclusion is that the injectors and producers are poorly connected. Many of the wells have very low pressure and reservoir damage and tests ranges from days to weeks in length. Table 1 summarizes the tests for which analysis has been completed.

The three plots from the Brock 7 (Figs. 8A, B, & C) provide an example of a pressure buildup analysis in a producer while the three plots from the Foster WIW 5 (Figs. 9A, B, & C) provide an example of a pressure falloff in an injector. The analysis results are shown in boxes on the Figures.

Waterflood Evaluation

The existing waterflood facilities were visited and evaluated for projected use. Injection water quality was also evaluated as there had been a variety of issues (Sulfate Reducing Bacteria, high Total Solids, Scale, Corrosion, and Oil Carryover) and it was determined that these problems are all present, to varying degrees, in the present day injection system. Before recommending any mechanical or chemical changes, a water quality study needed to be conducted. The historic water analyses are useful in evaluating the flood water.

System Cleaning: It was noted periodically that black "Slugs" of water were seen in the injection system. These slugs have been analyzed and are a mixture of iron sulfate, fine grained silt, and organic material. It was determined that the four lease heater treaters were the source of this sludge. Each heater treater was manually cleaned, followed by chemical cleaning and flushing of the flow lines and the water supply tank at the main battery. Two of the four heater treaters contained significant deposits of the "Sludge". If this material was to continue to enter the injection system, the well bore interface in injectors would "sludge over" soon after any workover, as it is believed that the average particle size of the sludge was larger than the average pore throat (see millipore filter tests below).

A gun barrel will be set in the system for added system stabilization and retention time. This will also provide blending outside the existing suction tank, additional settling capacity, and oil skim capability to help alleviate the oil carryover problem.

Total Solids: Although the overall composition of the sludge is known (iron sulfate, fine grained silt, and organic material), it is first necessary to determine the particle size and composition of the solids in the system. To accomplish this, millipore filters of 75, 50, 25, 10, and 5 microns will be placed in series at the water injection pump outlet. Time/pressure relationships for each filter will also be determined.

Sulfate Reducing Bacteria (SRB): The SRB's have been a problem for some time. They attack iron and have caused numerous pitted rods, rod parts, tubing leaks, and pump failures. Present treatment for SRB's is bacteriacide (quarternized amine as biostate, surfactant, water-soluble corrosion inhibitor). Additionally, a very potent biocide is utilized at a rate of 1 gallon per well every three months. This treatment has significantly reduced corrosion over the past three years. However, a stringent maintenance program is required to keep the SRB problem in check. The source of the SRB's is suspected to be a result of the mixed source for injection water. It has been proposed that the San Andres may be a major source of the SRB's as the San Andres water is sulfate rich, and many of the wells with major corrosion problems are both Grayburg and San Andres producers. The Witcher #2 is being completed as a San Andres only producer and it will be watched carefully for SRB associated problems.

A new 750 barrel gun barrel tank is being installed at the main battery to help increase settling time and provide a larger storage capacity for the water system.

Conclusions

A number of different problems need to be addressed in order to successfully enhance production in this field. In addition to the integrated study of the reservoir, review of water quality, waterflood history, well bore availability, and present day status of the reservoir is necessary. Each workover and new drill completion requires an iterative review to determine if it "fits the model" or change it. This process is ongoing and will not end at the conclusion of Phase II of the DOE project.

Understanding that the "reservoir" is actually three separate reservoirs; the Upper Grayburg mature waterflood in need of realignment, the virgin Lower Grayburg with few producing points, and the San Andres with excellent primary but little secondary potential, is critical to a successful recovery program. The continued review and justification of each step are necessary if the project is to be ultimately successful.

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Table 1

	PRODUCTION TEST DATA				PRESSURE TEST DATA				
WELL	DATE	DAYS ON TEST	OIL RATE B/D	WATER RATE	PRESS. AVE.	PERM	FRAC 1/2 LNG	SKIN DMG	RADIUS OF INV
BR-2	12/12/95	3	3.39	25.30	539.60	0.3996	5.20	0.42	286
BR-5	12/25/95	3	11.24	10.39	380.30	0.4802	40.30	0.31	150
BR-6	1/3/96	3	6.00	6.00	420.80	0.275	50.00	1.08	116
BR-7	12/11/95	5	9.64	4.80	546.70	1.163	4.10	0.18	273
BR-8	1/4/96	3	4.10	10.20	340.20	0.1857	103.50	0.73	126
BR-9	1/8/96	6		-207.00	2178.80	64.18	4.70	3.03	2763
BR-10	1/2/96	4	3.00	56.00	535.00	0.1411	3.50	0.80	259
BR-13	12/18/95	3	32.00	15.00	567.80	2.477	4.10	0.80	300
FP-3X	1/18/96			-150.00	2255.40	7	1.00	0.07	1391
FS-1	1/3/96	4		-231.00	2212.50	16.53	95.70	1.72	1401
FS-2	1/9/96	6	5.30	16.80	1477.01	0.816	4.50	1.86	288
FS-5	1/10/96	4		-107.00	-	3.096	16.50	2.56	-
FS-6	1/3/96	4		-230.00	2009.20	8.06	479.90	0.51	971
FS-7	1/10/96	3	1.40	3.00	187.60	0.1357	1.90	7.05	141
FS-8	1/15/96	3	5.00	40.00	3132.80	0.01648	49.00	0.00	61
JN-6	1/15/55	4			769.50	28.03	1.00	10.60	969

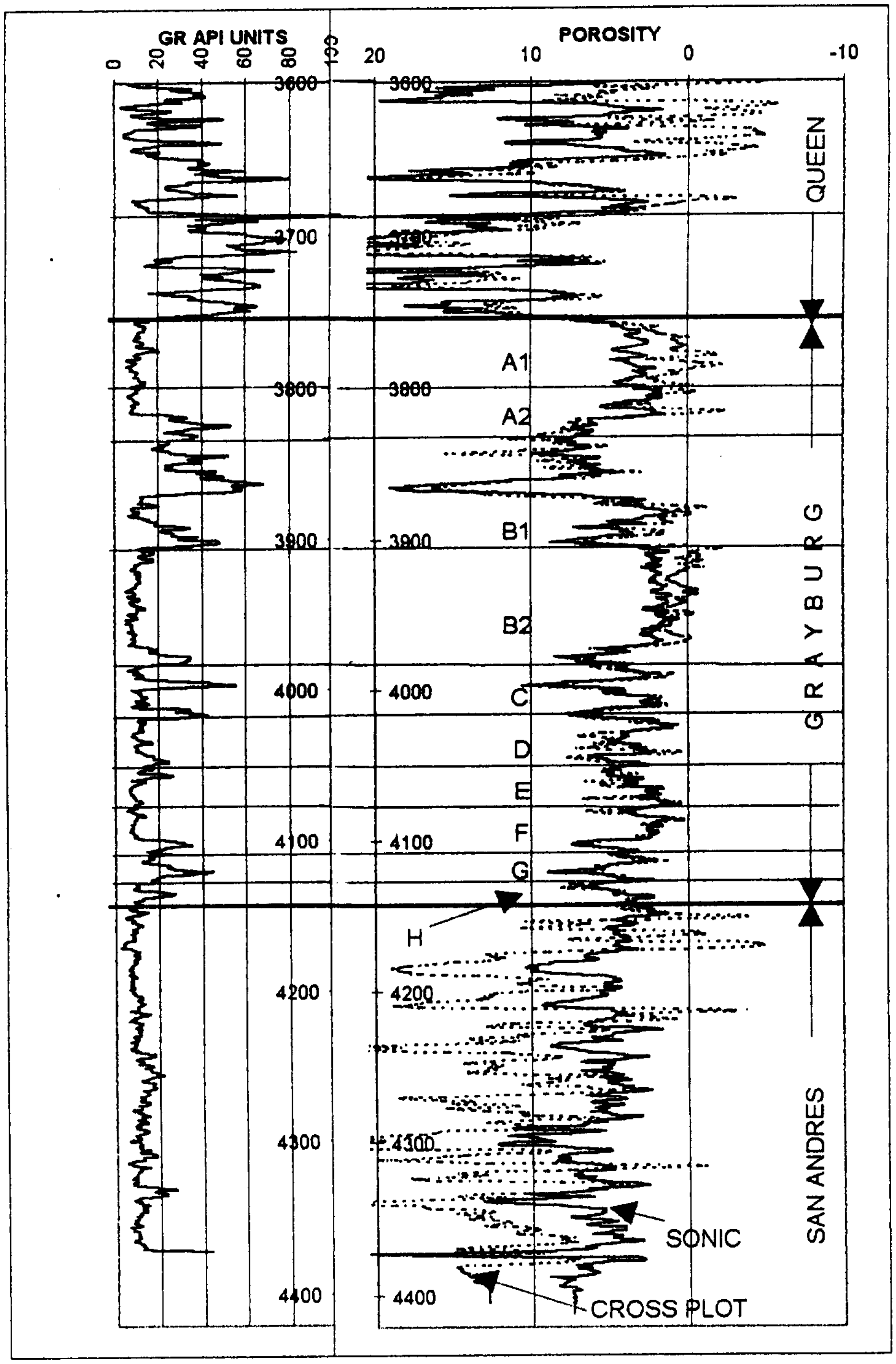


Figure 1 - Type Log for Study Area (Foster # 11)
Porosity Logs are Sonic and Neutron-Density Cross Plot.

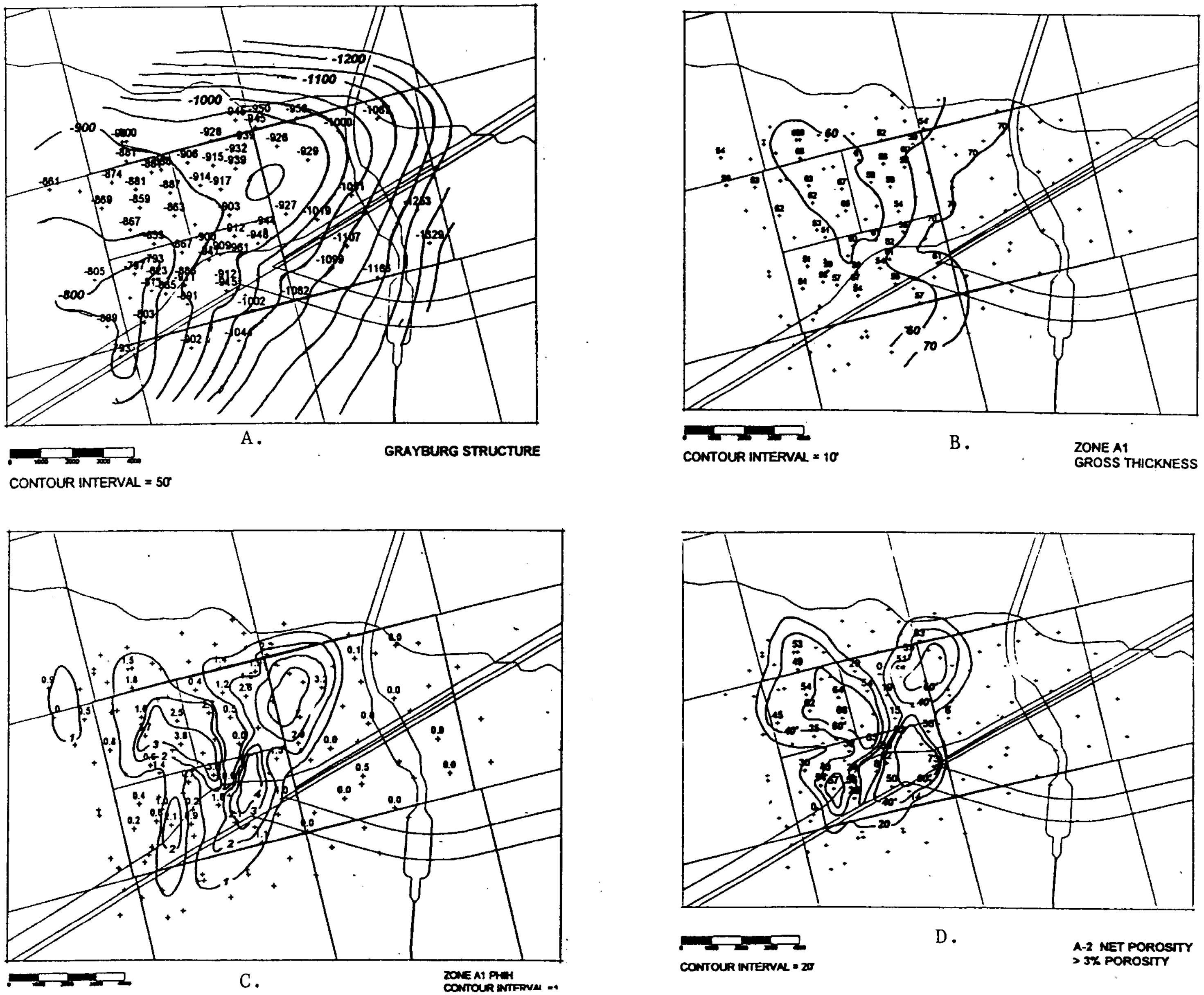


Figure 2 - Property Maps used in Simulation
A) Grayburg Structure, B) Gross Thickness of Zone A1, C) PHIH of Zone A1, D) Net Thickness of Zone A2

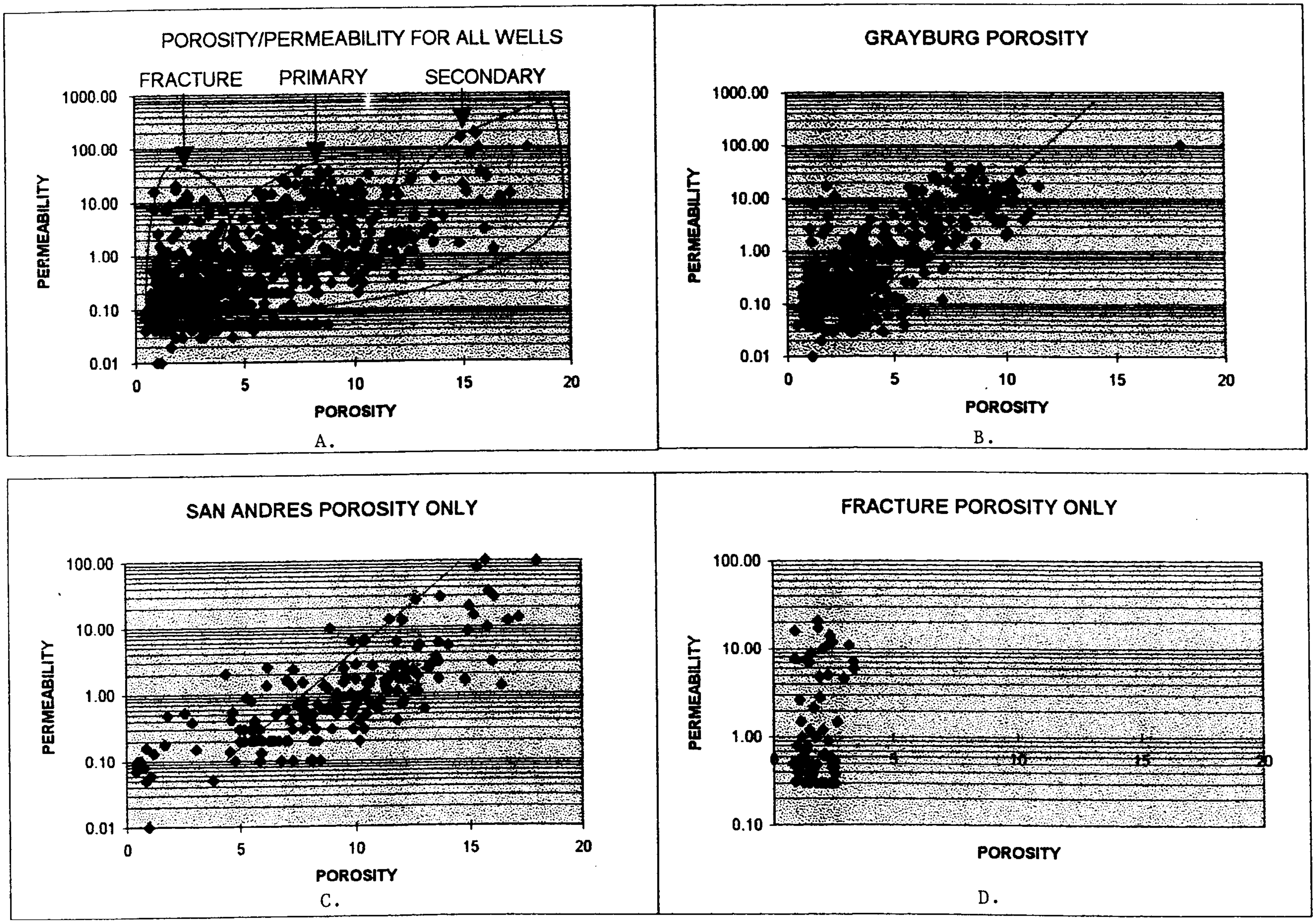


Figure 3 - Cross Plots of Zone Porosity Vs. Permeability
A) All Values Showing Fields of Primary, Secondary and Fracture Porosity, B) Values for Grayburg (Primary and Fracture)
C) Values for San Andres, D) Values Identified as Fracture Related

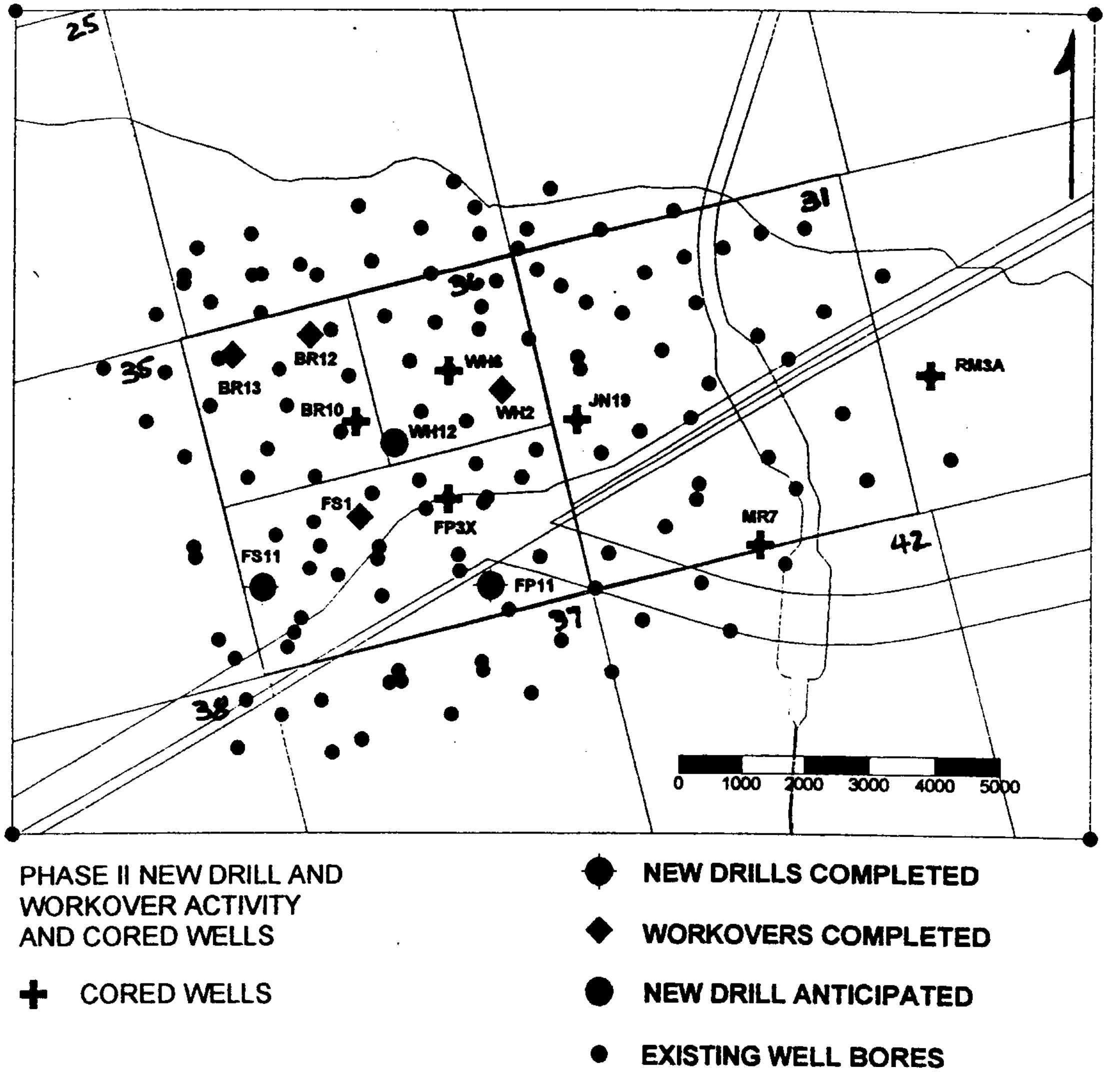


Figure 4 - Locations of Wells in Study Area

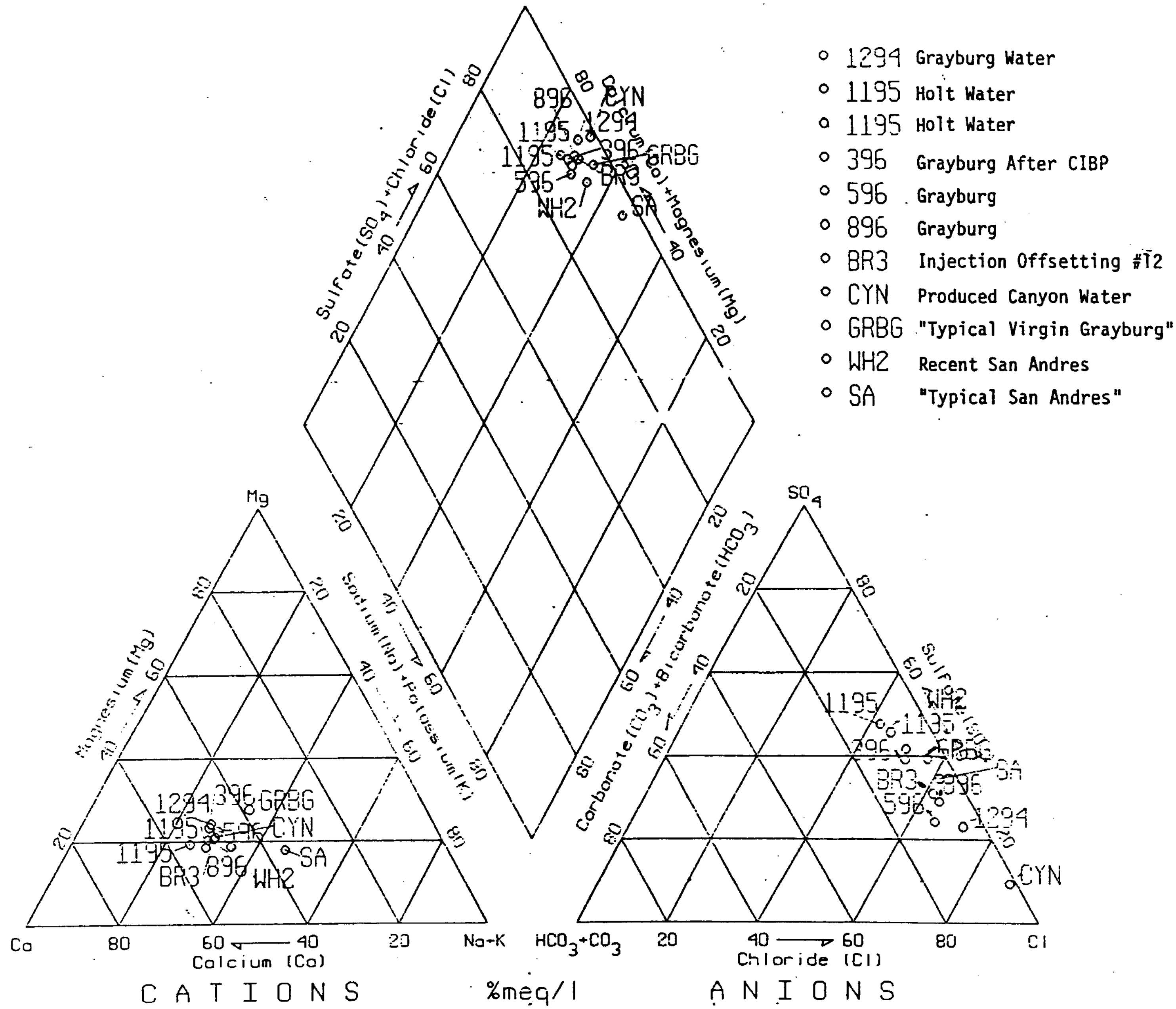


Figure 5 - Piper Plots for Brock 12 Water Samples

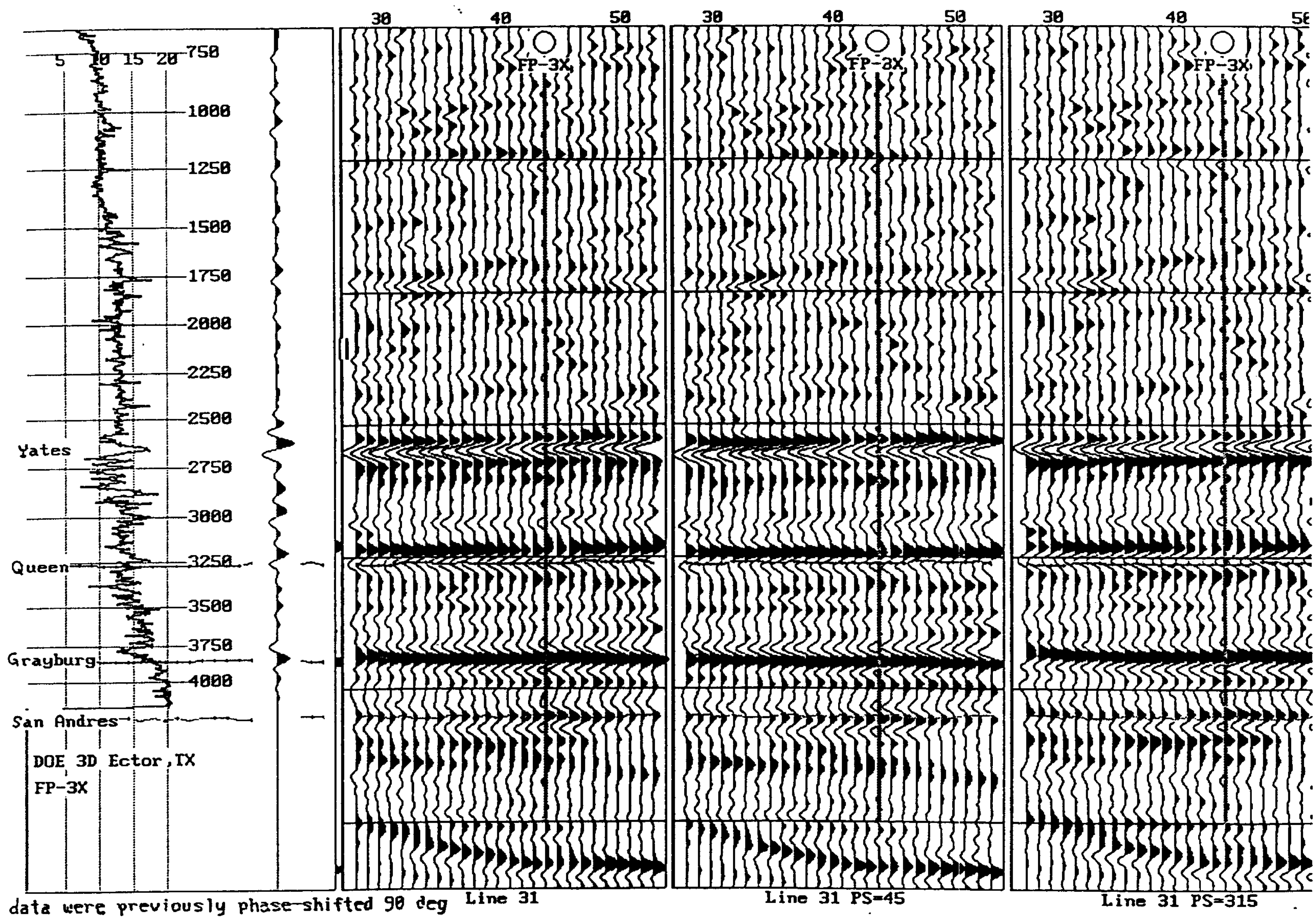


Figure 6 - Data as processed were phase shifted 90° to tie zero phase synthetic seismograms. Sensitivity of visual relationships is shown in the 45° examples.

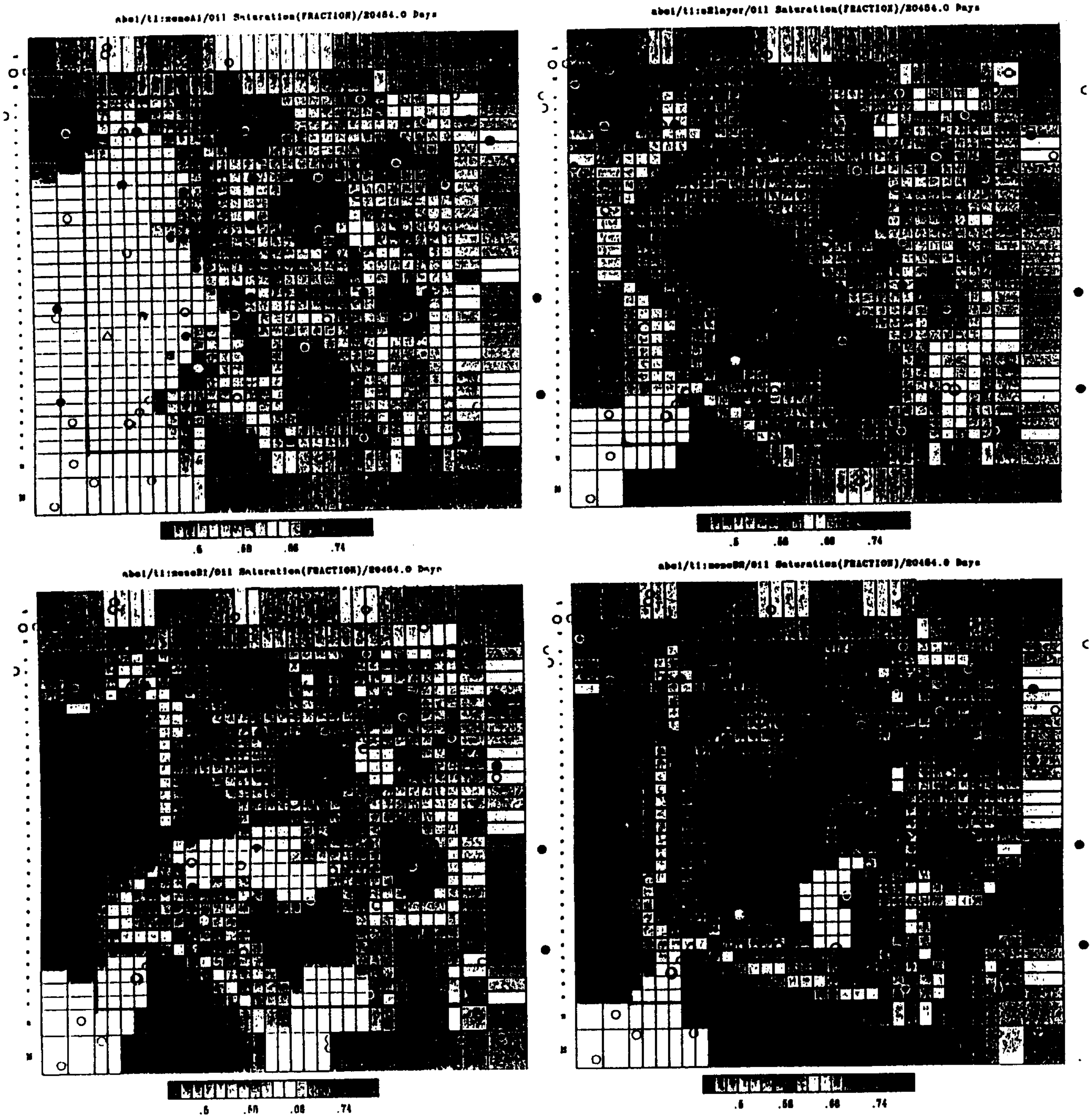


Figure 7 - Simulation oil saturations for layer A1, A2, B1, and B2 white areas are 0 (zero) porosity. Dark outline is section 36.

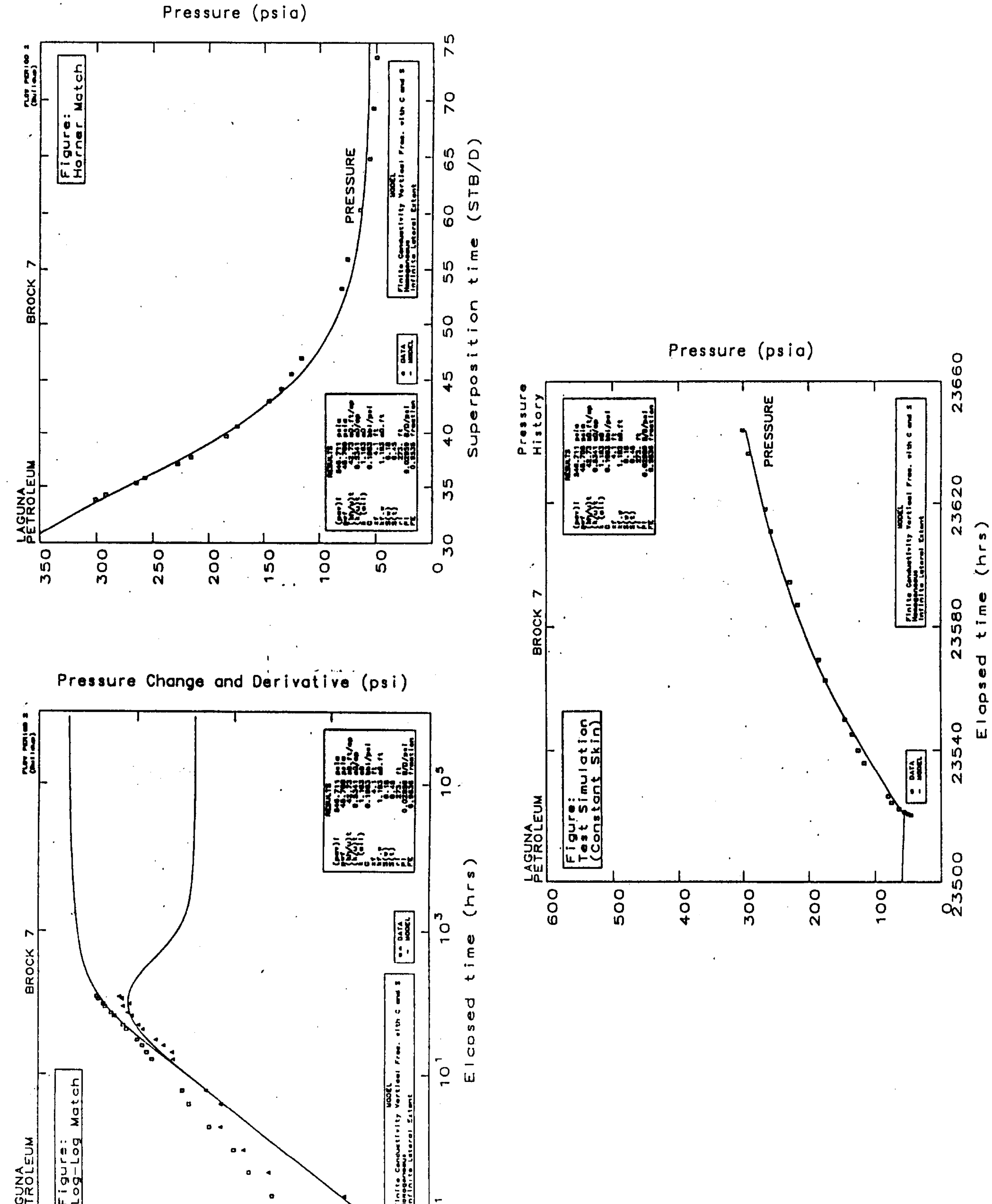
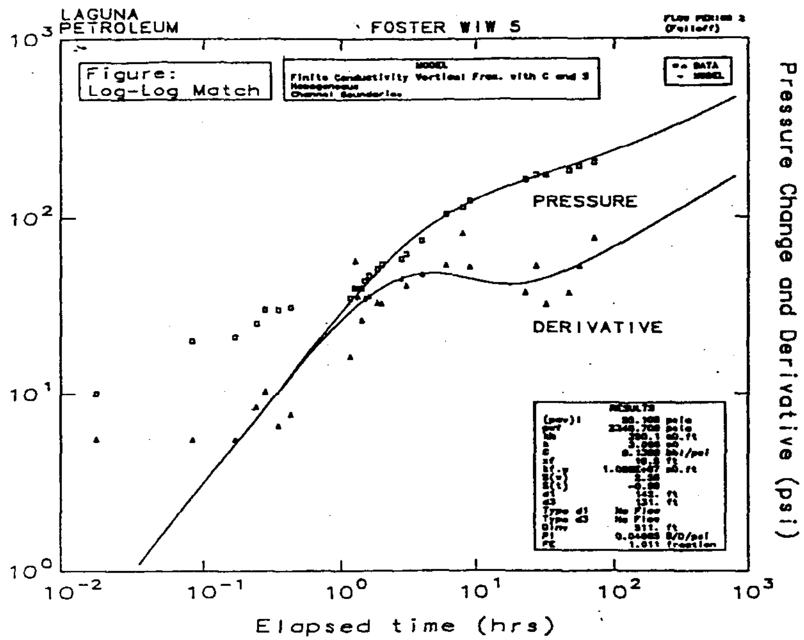
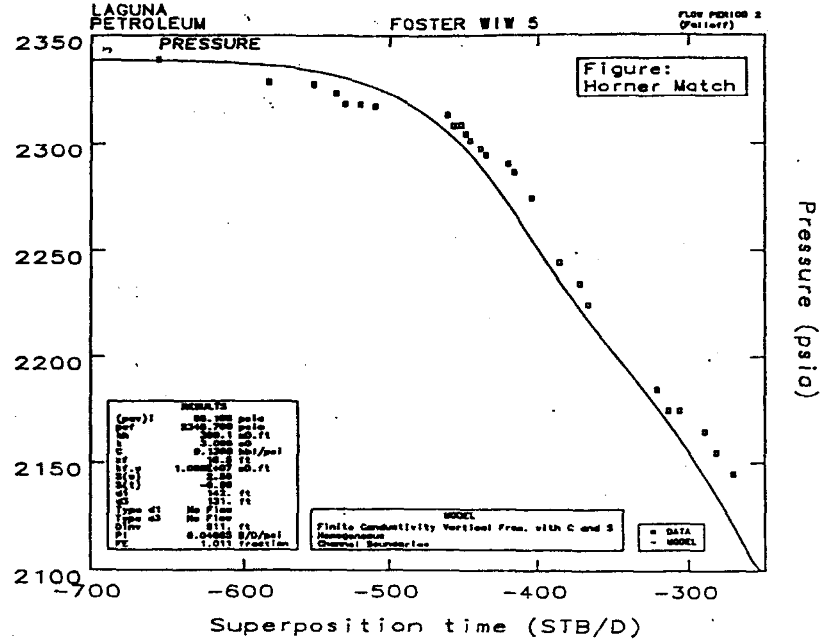


Figure 8 - Results of Pressure Buildup in Brock #7
A) Pressure Change Vs. Time, B) Horner Match, And C) Test Simulation





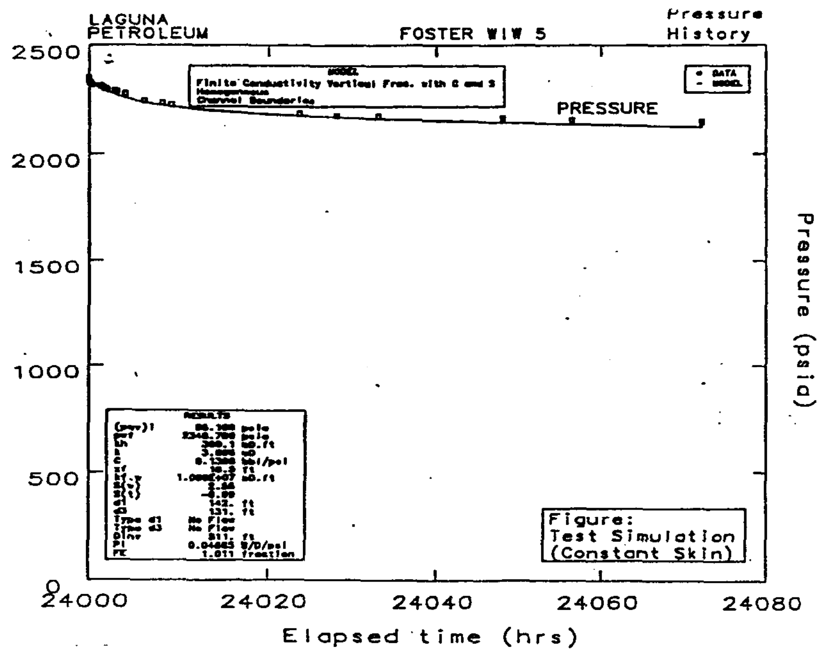


Figure 9 - Results of Pressure Falloff Test in Foster #5
A) Log-Log Match, B) Horner Match, C) Test Simulation