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DOE/BC/14982--15

Third Quarter 1997 June to Sept

GEOPHYSICAL OBJECTIVES:

The goals of work done this quarter were to 1) refine the maps of seismic-derived porosity for the upper Grayburg for reapplication to the production model, 2) determine rock fabric and porosity patterns for the lower Grayburg and the upper San Andres, 3) relate any seismic-derived porosity characteristics, particularly seismic waveform attributes, to the historical production of oil allocated to lower Grayburg and San Andres zones, and 4) to test other geologic attributes for possible inter-relationships.

GEOLOGIC OBJECTIVES:

Continue the integrated geological/geophysical effort to develop a usable seismic velocity/log porosity transform for each Grayburg producing interval. The lower Grayburg and San Andres core were revisited to glean lithology and porosity information for the seismic inversion model. Update recent production and injection for each well in the study area. Add new production and injection wells to spreadsheet. Continue evaluation of effectiveness of recent completions, plug backs and injector conversions by monitoring oil production and produced water composition.

ENGINEERING OBJECTIVES:

To build the most accurate reservoir picture by continued integration of all data types available and utilize that model to optimize oil production. Monitoring and testing of new and worked-over wells continues to test the early production models. Methods to improve water quality are being evaluated using normal field management procedures.

GEOPHYSICS

Work during the quarter:

Upper Grayburg:

The initial porosity maps (June 02) calculated from seismic inversion velocity data for the Grayburg A, B, and C zones were used as reservoir parameters in a new flow simulation model. For section 36 the revised original oil in place (OOIP) value calculated for this model is on the order of 37 MMBO (Million Barrels of Oil), about 12 MMBO more than an earlier history match model based on contour maps using well data only. Since 25 MMBO is assumed correct, the seismic-derived distribution of porosity is optimistic. The current recovery of 6 MMBO from 25 MMBOOIP represents a factor of 24%, and the recovery of 6 MMBO from 37 MMBOOIP represents a factor of 16%.

Table 1 presents results of the initial production model simulation for section 36, by quarter section. Produced oil from the A, B, and C zones, allocated by log-derived porosity in each zone, is shown in columns 2-4. OOIP modeled using the new porosity distribution is in columns 5-7. The ratio of OOIP to produced oil is indicated in

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columns 8-10. Calculated oil recovery based on this preliminary model is shown in columns 11-13. The estimated remaining oil in place is not shown, but it is the difference between the modeled OOIP and the produced amount for each zone.

column 1	2	3	4	5	6	7	8	9	10	11	12	13
section36	Aalloc	Balloc	Calloc	AmodOOIP	BmodOOIP	CmodOOIP	Amod:Alloc	Bmod:Blloc	Cmod:Calloc	A-recovery	B-recovery	C-recovery
Brock	996	568	232	4611	2410	2020	4.63	4.24	8.71	21.59%	23.58%	11.48%
Foster	431	260	93	5540	2531	1666	12.85	9.73	17.91	7.82%	10.28%	5.60%
Witcher	1151	378	440	6222	1591	1208	5.41	4.21	2.75	18.48%	23.75%	36.36%
F-Pegues	778	406	249	4856	2286	2611	6.24	5.63	10.49	16.02%	17.76%	67.11%

Table 1. General results of production simulation using porosity distribution from the initial conversion of seismic velocity to porosity. Amounts are in Thousands of Barrels of Oil (MBO).

Although the porosity values derived from seismic data compare favorably with log measurements in most of section 36, in the northeast quarter, the Witcher lease, porosity values are higher than can be demonstrated in the few well logs available, contributing to the calculated excess oil (Figure 1). The Gross Average Porosity estimated from modern neutron-density-porosity logs does not exceed 10%, although the calculated seismic-derived values in the area reach 14%. Sidewall neutron-porosity and cased-hole neutron logs from several other wells in the Witcher lease indicate porosity under 10%, but cannot be calibrated for porosity, are not among the calibration log set, and do not appear on crossplots.

The ratios of estimated OOIP to produced oil for the Foster lease are very high, suggesting a low oil recovery. The total oil amount produced there is the lowest of the quarter sections; the highest potential error in the ratio may exist there because of the small volume considered. Revisions to the porosity map are discussed below, but a revised production model will not be available until the fourth quarter.

The porosity field for the A zone was recalculated using a revised, two-slope conversion function (Figure 2). The overall A zone porosity for section 36 was reduced by moving the measured velocities to lower porosity positions. The orientation of the conversion function is chosen by the interpreter, but is guided by the distribution of data on the crossplot. The slope for higher velocities (above 17,400 ft/sec) was decreased slightly and the conversion line was lowered, causing converted porosities (for values less than 6.5%) to be slightly lower than in the initial model (up to 14%). The slope for lower velocities (below 17,400 ft/sec) was increased and the line was lowered, causing converted porosities (for values between 6.5% -10%) to be significantly lower than in the initial model. Using this scheme, porosity values are truncated at 10% (the y-intercept for the lowest velocities measured in the data set). The new porosity map looks much like Figure 1, but the porosity quantities are lower.

Unacceptably high porosities were not a problem in the B and C zones, which are also used in the production model. Those maps were reviewed for potential improvement, but were left unchanged. The revised porosity maps for the three zones were sent as spreadsheets to the project engineer via e-mail.

Lower Grayburg and San Andres:
Lower Grayburg zones (totaling between 70-130 ft gross) are considered to be the E,F,G,H for the seismic analyses being made. The upper 100 feet of the San Andres is considered for the seismic analyses being made, since that zone has been the primary reservoir for oil. The two are being studied in combination because the seismic reflection possibilities associated with each zone are interrelated. Analyses of the lower Grayburg and the upper San Andres zones using the inversion model have not lead to porosity maps that can be qualified with good crossplot relationships with limited well data. For that reason inversion model data, successfully used to map porosity in the upper Grayburg, have not yet been used to evaluate the lower Grayburg and San Andres. Instead, reflection characteristics associated with those zones have been evaluated as *indicators* of porosity. The seismic attribute judged most promising for recognizing and mapping porosity is the Instantaneous Amplitude waveform attribute its interval average across specific geologic zones. However, a quantitative measurement of porosity is not yet possible.

Wells that penetrated the San Andres (and the lower Grayburg) are indicated in Figure 3. Logs and cores indicate dolomite lithology is predominant, with locally large amounts of anhydrite occurring within the San Andres. The current hypothesis is that seismic reflectivity in these zones is the result of rock property changes directly linked to rock porosity. The simplified geologic model (see GEOLOGY section) provides that the lower Grayburg in section 36 was deposited as a broad range of porous and non-porous carbonate facies. These deposits were altered to dolomite and were, in places, partly filled with small amounts of anhydrite, but were not eroded or greatly altered from their original depositional fabric. Only minor amounts of terrigenous mud particles are seen in cores, but that small presence may be significant to both fluid flow and seismic response. The lower Grayburg porous areas are expected to be moderately extensive. The seismic response for the lower Grayburg is expected to show areas of consistent reflections.

Grayburg deposition followed a period of low sea level stand, which allowed extensive vadose karst development of the upper 100 feet (and more) of the San Andres strata. Cores demonstrate that the San Andres deposits are of high energy origin, but have been greatly affected by the karst formation and filling of pores and caverns by anhydrite and non-carbonate mud. Thus, the San Andres porosity is expected to be cavernous, spotty, and perhaps not well connected, having a very heterogeneous fabric. The seismic response for the San Andres is expected to show discontinuous anomalous areas.

To identify the seismic expressions of these zones, a matrix of nine forward synthetic seismogram models was built. Combinations of rock porosity result in reflections at different levels within the sequence of study. Two examples of the models are shown and explained in Figure 4. A practical example of porosity-caused seismic reflectivity is seen in Figure 5, where a stronger (trough) amplitude is associated with the lower Grayburg production in the WH-2 well. The map of the Instantaneous Amplitude of the lower Grayburg GH zones is shown in Figure 6, where a strong trend of higher reflectivity occurs through the middle of section 36, including the WH-2 well location.

Reflectivity is the seismic response to be measured, and its position is critical to accurate mapping. The hypothesis is that Instantaneous Amplitude is a representation of reflectivity, independent of a particular zone reflection. The use of a simple reflection strength (a peak or trough) is impossible since no single reflection exists to define any geologic zone. Reflectivity is a measure of the combination of acoustic impedances within a zone, here dependent on rock porosity. Determination of the zone boundaries was thus: Grayburg GH (approx. 60' or less thick) surface was determined 6 ms above the San Andres surface; zones of the San Andres are the 1st 50 ft (0-5 ms) and 2nd 50 ft (6-10ms). The value of Instantaneous Amplitude at a horizon surface does not portray a full picture of the stratigraphic situation.

Relationships of porosity and thickness were tested (see Figures 7, 8,& 9) for the lower Grayburg and San Andres by crossplotting values. Useful relationships may be recognized in wells which can also be interpreted in seismic data. The clarity of relationships may be complicated by the existence of multiple lithologies: dolomite, anhydrite, and shale. Two examples of parameters that were compared for the lower Grayburg GH zones (the pay zone in the WH-2 well) are presented here.

Figure 7 shows that as net CO_3 thickness within the zone increases, the CO_3 percent of the gross interval also increases. One explanation of this relationship is that the non-carbonate component to the gross zone is fairly consistent, and is diluted as the zone is thickened. Higher effective porosity, capable of good oil production, is more likely with larger zone thickness. Also, higher quality reservoir rock is more likely to exist in zones with larger amounts of CO3 component. The gross thickness of the zone is not involved in this graph.

Figure 8 shows no real correlation of gross porosity value compared to zone thickness. Porosity development is not very dependent on the gross thickness of the zone, but does increase with a larger amount of carbonate rock, as in figure 7.

Figure 9 shows no obvious relationship between porosity from well logs and the Instantaneous Amplitude waveform attribute over the GH zone. This observation is unfortunate since model and drilling results suggest that there should be a useful connection. Continued investigation may explain the graphical results and validate the use of a measured seismic reflectivity to map porosity in these complicated zones.

Additional studies:

Additional graphical comparisons have been made attempting to relate the lower Grayburg EF and GH zones and the GH and San Andres zones. More comparisons will be made. Similar depositional environments in parts of the project area may have affected lower Grayburg reservoirs similarly, where other parts are not alike. For example, the range of GAP for the GH zone is 4-8%, and the range for the EF zone is 0-8%. San Andres GAP values range from 3-10%. Perhaps the GH zone was deposited in a stable environment in section 36, where the San Andres values show the effects of karst dissolution. San Andres rock fabrics have been quantified as net feet of high-energy carbonates, low-energy carbonates, and anhydrite. Further comparison of seismic data to maps of those distributions is necessary.

GEOLOGY

Upper Grayburg Porosity Maps

After deriving the porosity log/seismic velocity transform (see GEOPHYSICS), it was necessary to quality control the seismic porosity maps for each zone by reviewing IP's, production and injection history and total production of oil and water. This was an iterative process which involves estimating the production from a well based on the seismically derived porosity maps and comparing it with historical information. One example was the Foster - Pegues #P1. This well is located in the southeast corner of the study area (Fig. 3) and is separated from the main producing northeast to southwest trend by a break in slope between the inner shelf and outer shelf and an associated non-porous barrier. The well IP'd Flowing for 1461BOPD in 1940, completed open hole, with nitro, in the upper Grayburg only. No logs were run then or subsequently, so log porosity for this well location can only be approximated. The well produced flowing until Nov. 1946 when it was put on pump. In June 1955 the well was hydro-fraced and produced 285BO, 443MCF, and 0BWPD after workover. In 1985, the well tested at 1BO, 0MCF, and 20BWPD. The well was P&A'd in 1990.

In the seismic porosity map, the Foster - Pegues #P1 well falls in an area of high porosity in the A1-A2 interval, and suggests the presence of unswept reserves in undrilled offset locations. This would not have been predicted from the log derived porosity map, and could have been only guessed at from the production history.

The overall iterative geological/geophysical review of the data develops a high confidence level in the seismic derived porosity maps, which is necessary as use of the seismic porosity maps did not generate a perfect match to the geologically derived engineering history match. The tendency is to believe to "Hard Numbers" generated by the log calculations. In order for this integration to proceed, however, the seismically derived porosity maps must be accepted as accurate.

Lower Grayburg and San Andres Porosity Mapping

The lower Grayburg and San Andres core from the Foster - Pegues #11, Foster #11, and Witcher #12 was again reviewed for clues to the source of seismic character. Although there is some shale, there is no lithologic break (dolomite/sand or dolomite/shale) at the San Andres - lower Grayburg boundary that is capable of producing a strong trough reflection. Facies and porosity changes were evaluated therefore as the source of the reflection. The upper San Andres is composed of porous, high energy grainstones and packstones with interparticle porosity and low porosity, anhydrite-rich karstified mudstone to packstone intervals. The lower Grayburg is composed of thin bedded, shallow subtidal to intertidal mudstones, wackestones and packstones with fenestral, fracture, and interparticle porosity. These changes are difficult to quantify and therefore seismic modeling is essential.

Pipeline Fracturing

Work with the production team members continues to evaluate the performance of a fracture completion technique designed to significantly increase the fracture length in the lower Grayburg and San Andres.

The Witcher #2 (see First Quarter 1997 Report for details) was plugged back from the San Andres and recompleted in the lower Grayburg during the first quarter 1997. A different type of fracture treatment, a Pipeline Frac, was utilized in an attempt to stay "in zone" in the lower Grayburg and not fracture down into the San Andres. At the end of this quarter, the lower Grayburg in the Witcher #2 (WH#2) well had produced over 12,000BO and 2,350MCFG, and the well was pumping 45BO, 102BW, and 12MCFGPD. A produced water analyses taken in mid-August indicated that the Pipeline frac had indeed stayed in zone as the produced water from the WH#2 still contained 37,000PPM total dissolved solids(TDS), indicative of uncontaminated lower Grayburg water.

The historic "Production Deck", used in the history match and simulation was last updated at the end of 1996. In order to include the results of the three new drill and the workovers it was necessary to update the production deck. Oil, gas, and water production was determined for each well based on lease production totals and production tests. The net feet of pay (by zone), in the completed interval is calculated and the production allocated to each producing zone.

ENGINEERING

Simulation

Quantitative integration of the seismic data into the reservoir simulation continued this quarter. Initial runs with the A1 and A2 zone porosity maps were encouraging. Discussion of the seismic derived porosity maps, and the resulting production history matches continued.

The objective is to history match the old waterflood and use the validated model to optimize the current waterflood by recompleting existing wells and drilling new wells. This is an iterative process which integrates geophysics, log analysis and reservoir simulation and it is not expected that the current maps will be the final ones.

Reservoir Engineering

Monitoring of the recently drilled wells, and workovers continues. Of note is the results of the Witcher #2 deepening. The well has produced over 12,000 BO and 2650 MCFG since the "Pipeline Frac" completion at the beginning of the second quarter. In addition, analyses of the produced water continue to demonstrate that the well is producing from the lower Grayburg only.

Water Quality

Continued work on the quality of the injection water has resulted in dramatic improvements in water quality. Further injection well work will proceed with the objective of sweep improvement when the seismic derived simulations are complete.

Conclusions:

Dependable, accurate recognition of porous carbonate rocks in the lower Grayburg and San Andres remains to be validated; since both the geology and well data are more complex and uncertain than for the upper Grayburg case. Inversion model traces do not consistently match well log characteristics, so have not been used for mapping. Instantaneous Amplitude values may quantify reflectivity across zones to be mapped, and reflectivity may be proportional to changes in porosity. Complications from non-carbonate components, recognized from well data, preempt good reservoir response on seismic data and must be superimposed onto maps where they exist.

Well data alone demonstrate links and limitations of relationships of thickness and porosity. Graphical comparison of these data will guide further studies of seismic data in order to optimize results over time.

Acknowledgments

We would like to acknowledge James J. Reeves and Hoxie W. Smith for conceiving and managing the DOE study and for being responsible for the geophysical study. We would like to acknowledge that, since April, 1996, William C. Robinson has been responsible for the reprocessing and reinterpreting the seismic data and for the geophysical study. Also since that date, Robert C. Trentham has been responsible for project management.

Tech Transfer

The abstract of a paper titled "Incorporating Seismic Attribute Porosity Maps Into A Flow Model Of The Grayburg Reservoir In The Foster - South Cowden Field", was accepted for presentation at the Technical Session of the SPE Annual in Tulsa,Ok May,1998.

Project Personnel presented a project demonstration to the Petroleum Technology class from Midland College on Sept.29,1997. In attendance were students with a wide range of interests and expertise.

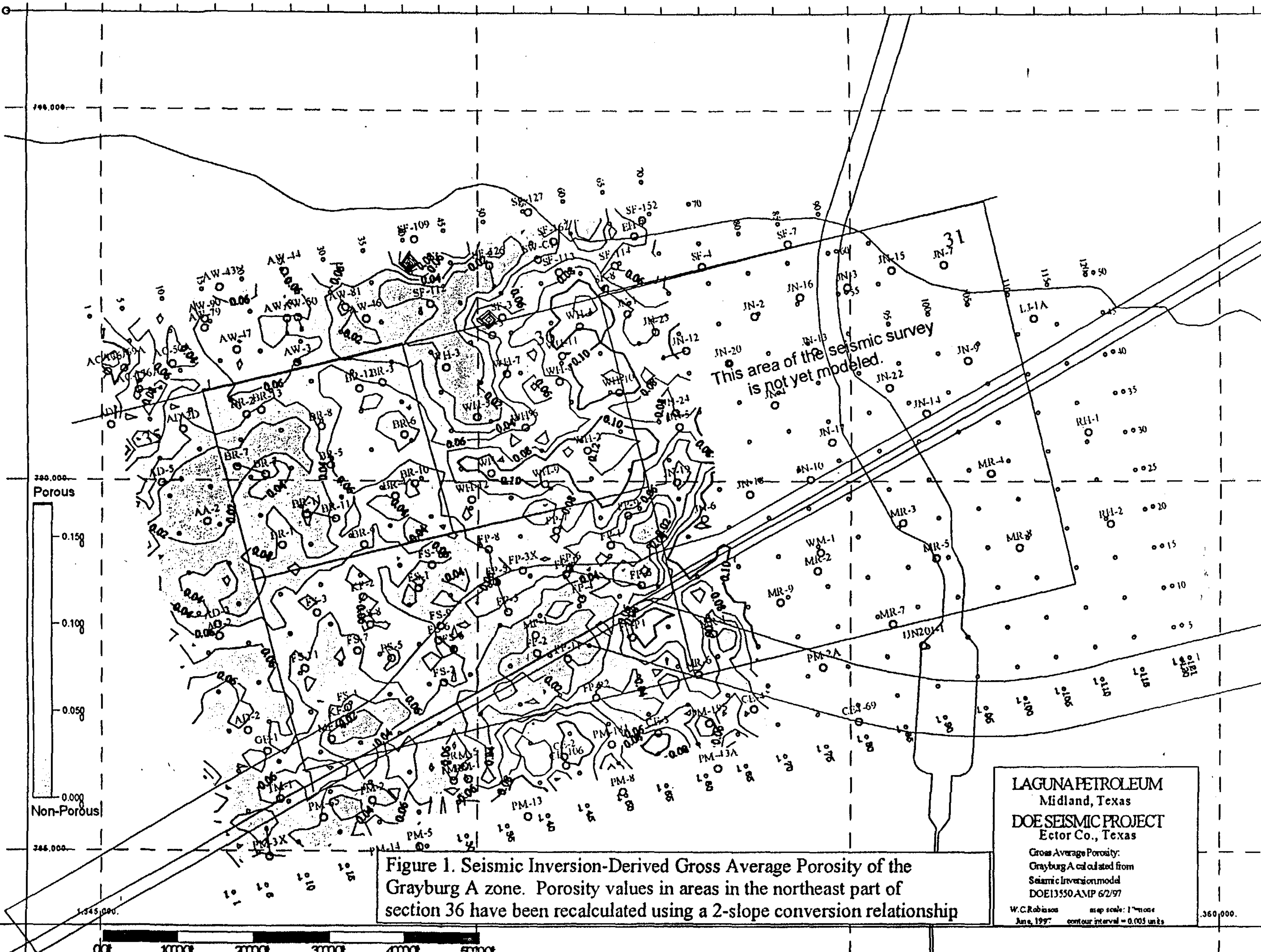
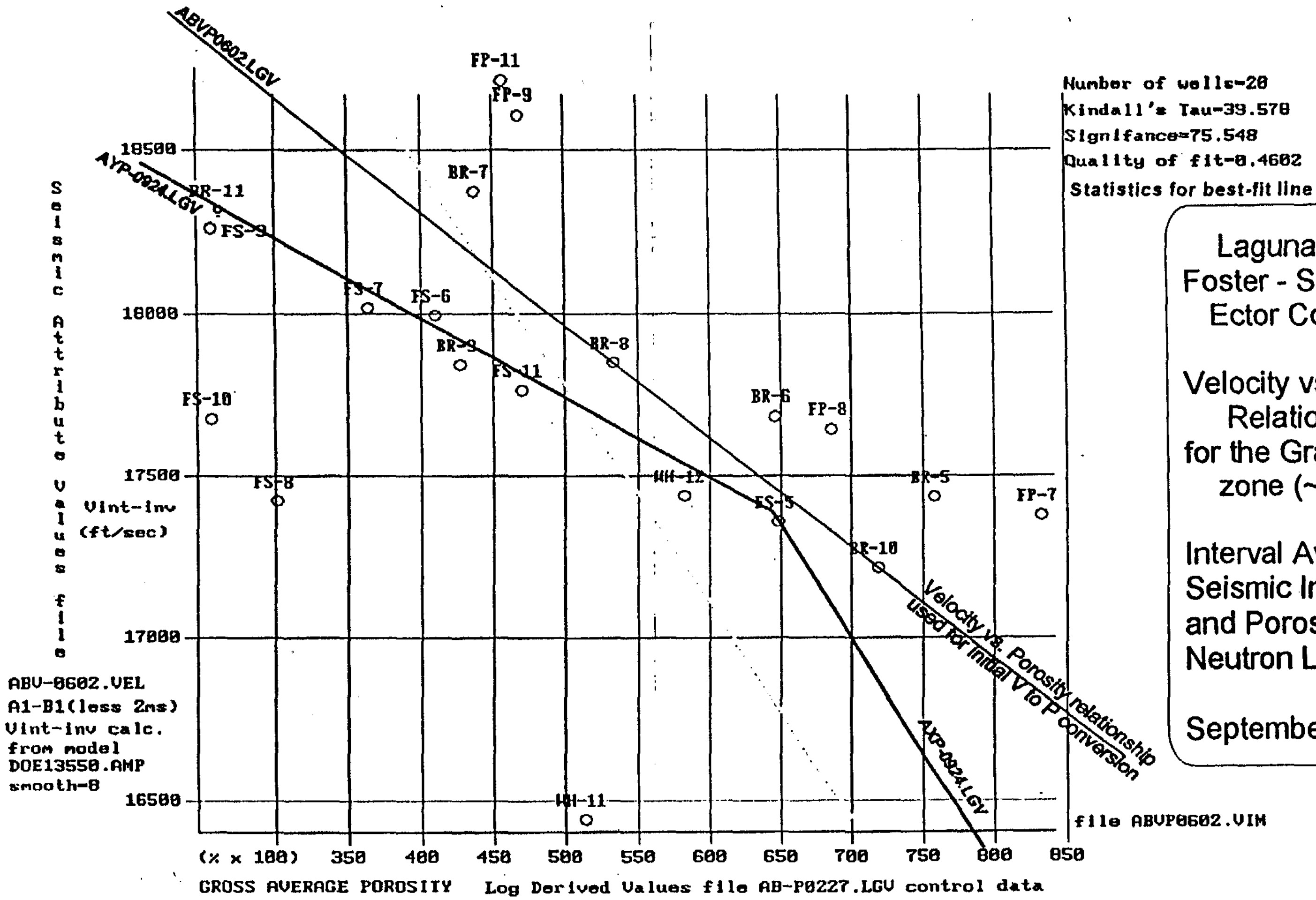


Figure 1. Seismic Inversion-Derived Gross Average Porosity of the Grayburg A zone. Porosity values in areas in the northeast part of section 36 have been recalculated using a 2-slope conversion relationship



Laguna - DOE 3D
Foster - So. Cowden Field
Ector County, Texas

Velocity vs. Porosity Relationship for the Grayburg A1-B1 zone (~120ft)

Interval Average Velocity from Seismic Inversion Model and Porosity determined from Neutron Logs from wells.

September, 1997

Figure 2. Crossplot showing the relationship used in the initial porosity conversion (2 June 97), and the two-slope curve used in the revised conversion (25 Sept 97). The curve has been "lowered" to produce lower porosity values overall, and a steeper slope has been drawn to reduce the highest porosities to a maximum of about 10% (measured velocities are lower than represented in this plot)

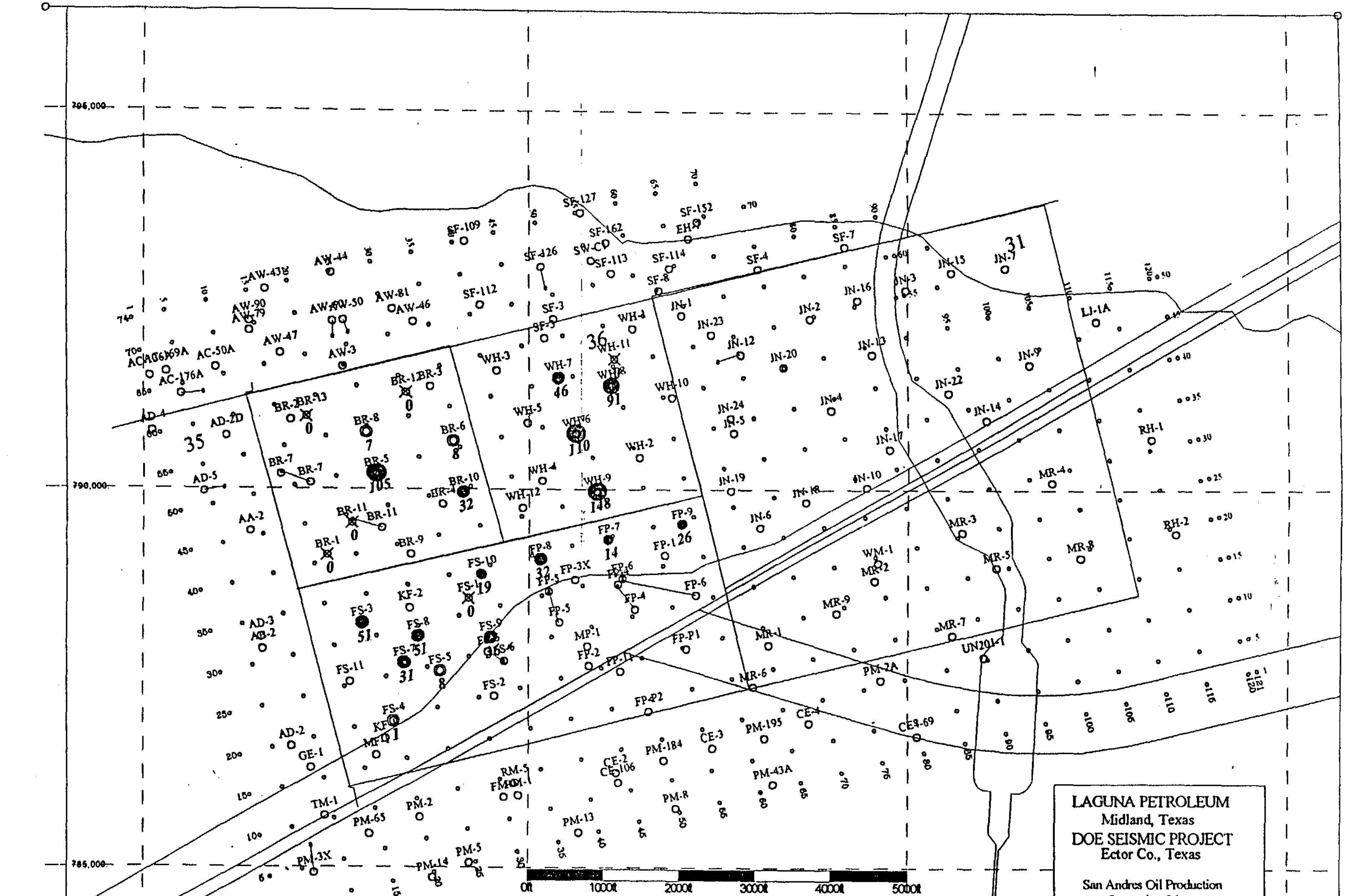


Figure 3. San Andres wells in section 36. Relative production is indicated by bubble size, and is indicated numerically in mbo. Non-producers are shown with an x

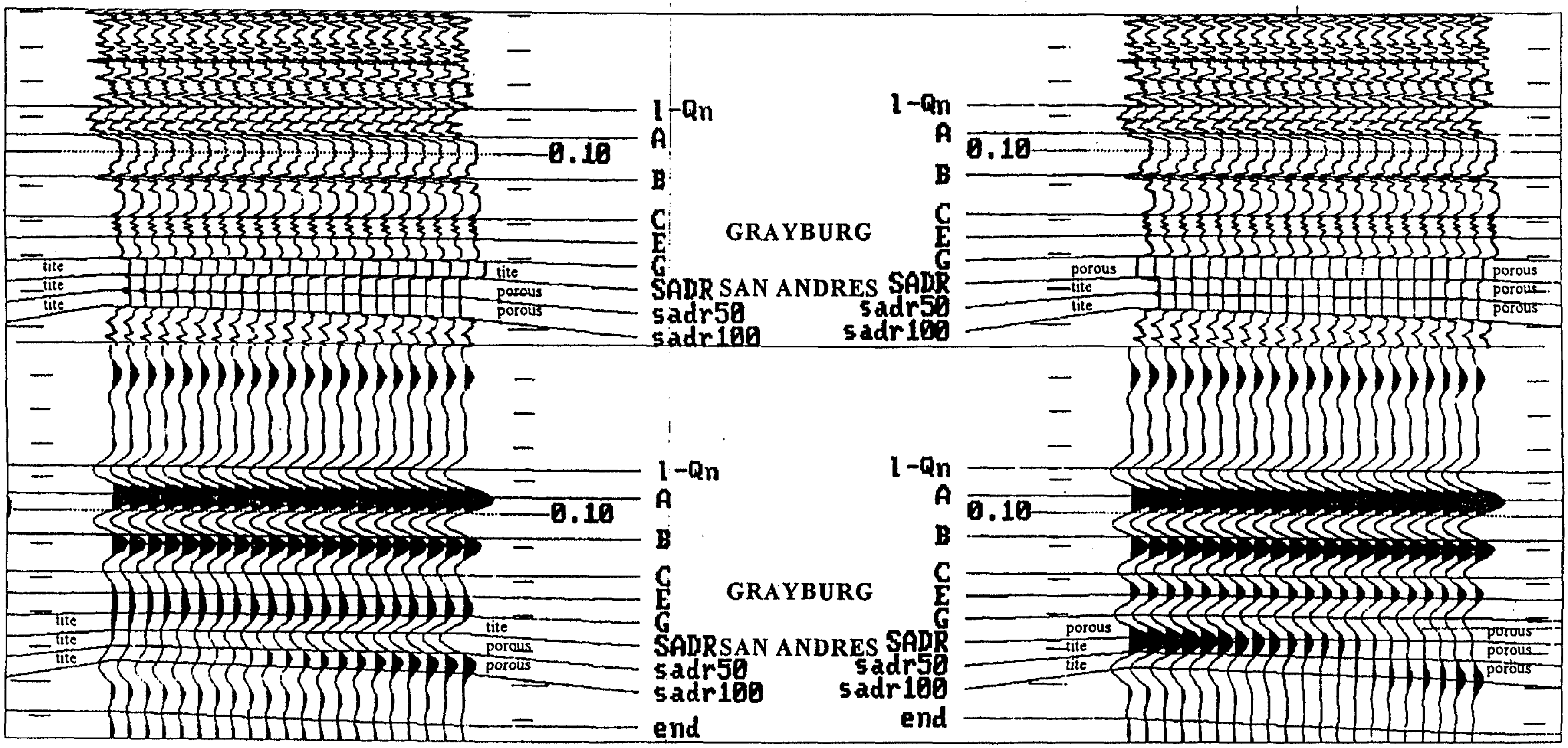


Figure 4. Examples of synthetic seismogram models made to test variations of porosity (lower velocity) within the lower Grayburg and San Andres. Log traces are shown above seismic traces in each display.

In the example on the left, the lower Grayburg is consistently non-porous while the San Andres upper 100' is non-porous on the left side of the model, becoming gradually more porous toward the right side. Reflectivity increases within the San Andres zone. Note there is very little reflectivity where both zones are tite.

In the example on the right, the lower Grayburg is consistently porous while the San Andres upper 100' is non-porous on the left side of the model, becoming gradually more porous toward the right side. Reflection amplitudes decrease as detuning occurs and the peak reflection position moves lower within the increasingly porous San Andres.

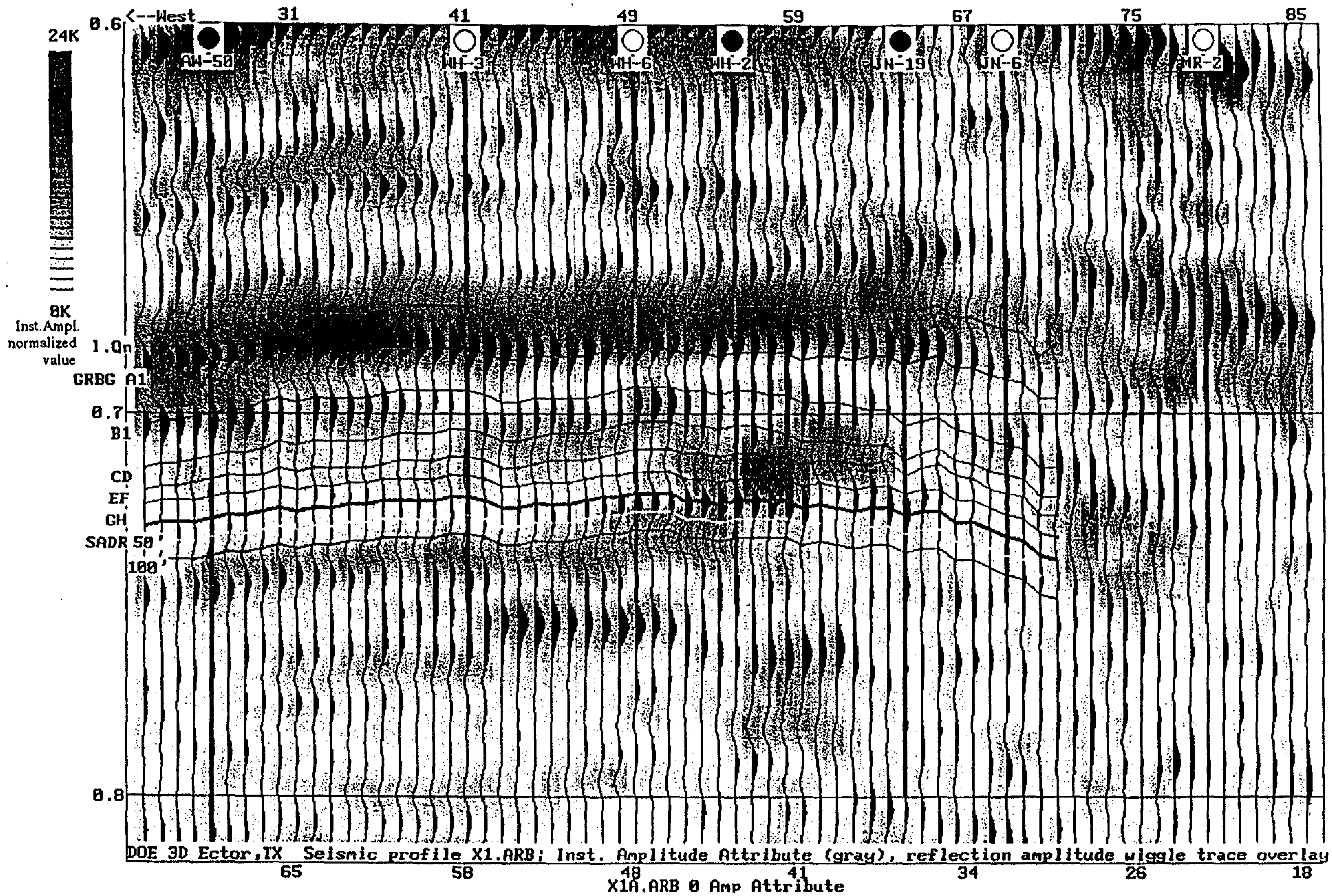
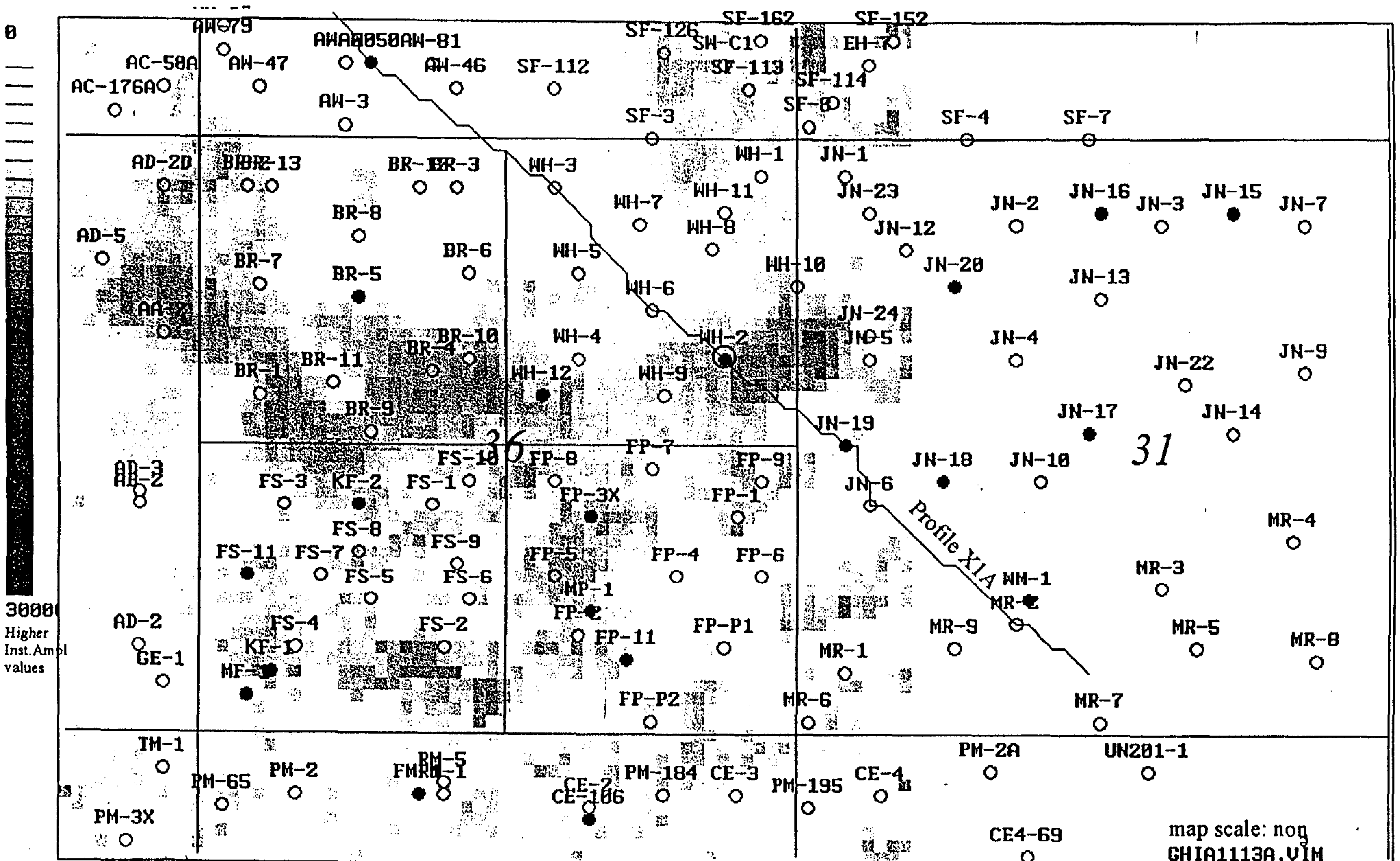


Figure 5. Seismic Profile showing stronger Instantaneous Amplitude value (darker gray) associated with the WH-2 well, which is productive from the lower Grayburg GH zone. Other Grayburg and San Andres zone boundaries are also shown. Conventional reledction amplitude traces are also shown.



DOE 3D Ector, TX Map showing stronger Instantaneous Amplitude Waveform Attribute across the Grayburg GH zone. The trace of seismic profile X1A.ARB is shown.

Figure 6. Map showing the distribution of stronger Instantaneous Amplitude Waveform Attribute (interval average) for the lower Grayburg GH zone. An anomalously strong response is associated with the WH-2 well, which produces oil from that zone.

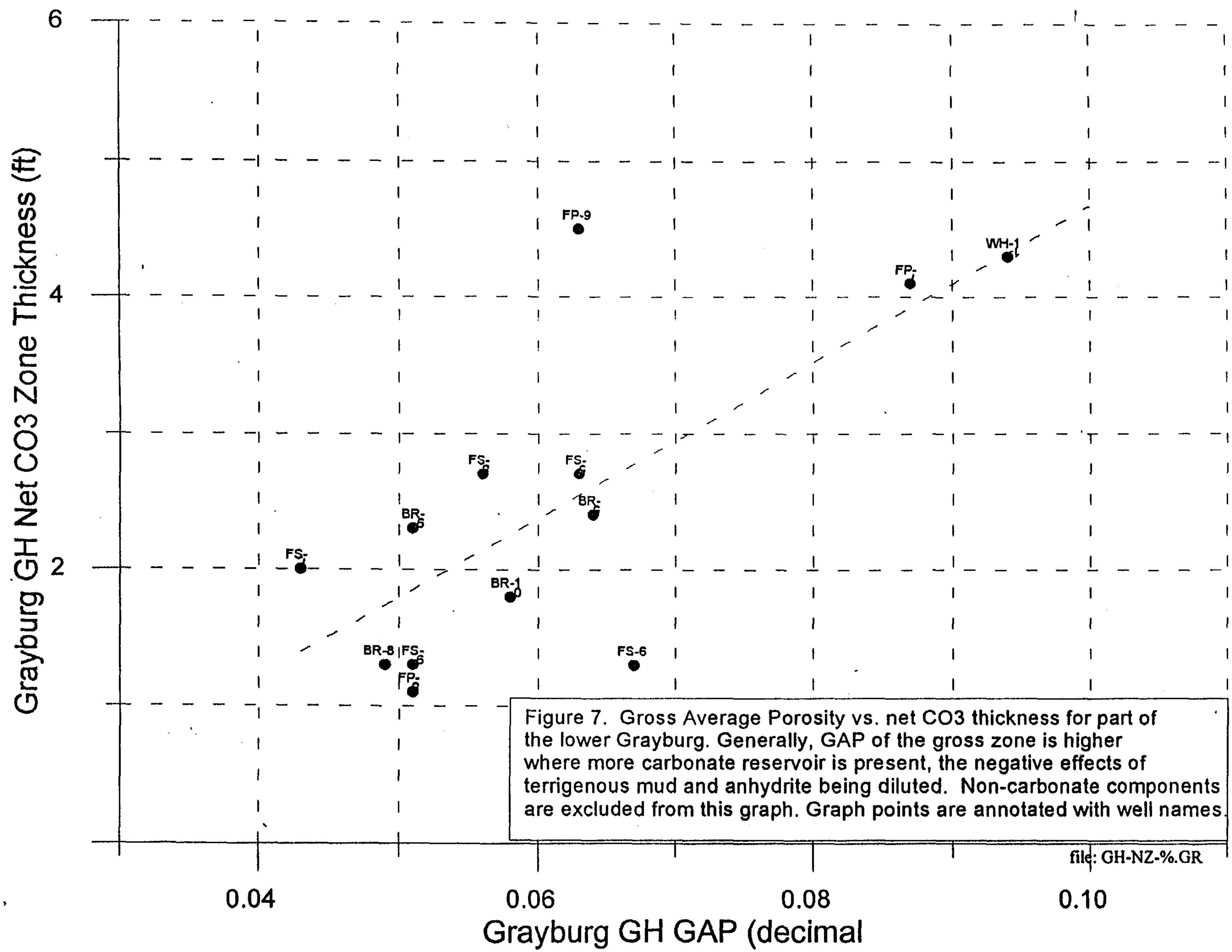


Figure 7. Gross Average Porosity vs. net CO3 thickness for part of the lower Grayburg. Generally, GAP of the gross zone is higher where more carbonate reservoir is present, the negative effects of terrigenous mud and anhydrite being diluted. Non-carbonate components are excluded from this graph. Graph points are annotated with well names.

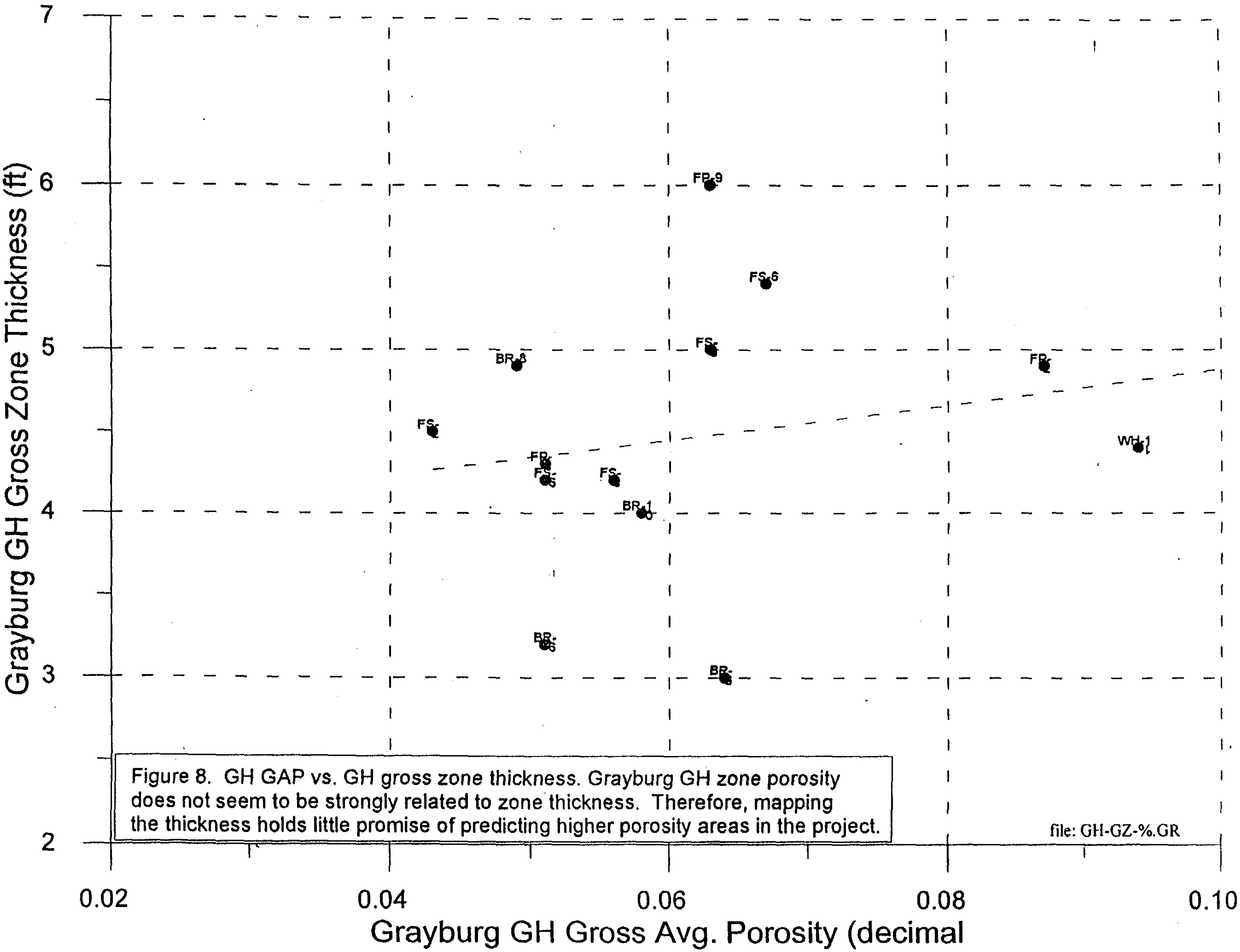


Figure 8. GH GAP vs. GH gross zone thickness. Grayburg GH zone porosity does not seem to be strongly related to zone thickness. Therefore, mapping the thickness holds little promise of predicting higher porosity areas in the project.

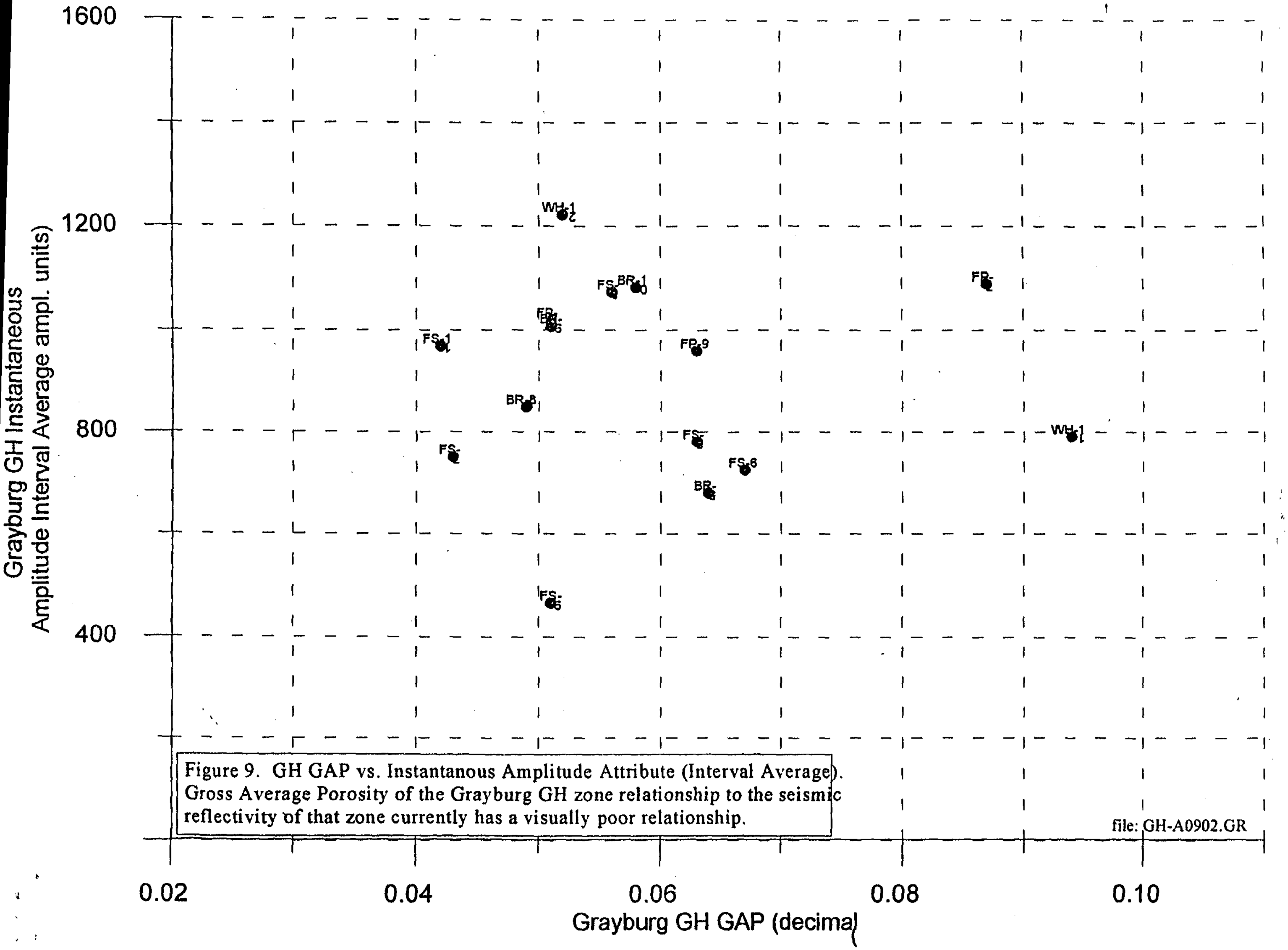


Figure 9. GH GAP vs. Instantanous Amplitude Attribute (Interval Average). Gross Average Porosity of the Grayburg GH zone relationship to the seismic reflectivity of that zone currently has a visually poor relationship.