BC/14982-10
40/96

TITLE: AN INTEGRATED STUDY OF THE GRAYBURG/SAN ANDRES RESERVOIR, FOSTER AND SOUTH COWDEN FIELDS, ECTOR COUNTY, TEXAS

DOE/BC/14982--10

Cooperative Agreement No.: DE-FC22-93BC14982

Contractor Name and Address: Laguna Petroleum Corporation, 1003 N. Big Spring, PO Box 2758, Midland, Texas, 79702

Date of Report: March 17, 1997

Award Date: August 2, 1994

Anticipated Completion Date: February 2, 1998

Government Award for Current Fiscal Year: $649,100

Prinicipal Investigators: Robert C. Trentham, DGS
Richard Weinbrandt, Ph.D. P.E.
William Robertson, M.S.

Project Manager: Chandra M. Nautiyal, Bartlesville Project Office

Reporting Period: Fourth Quarter 1996, October-December, 1996

DISCLAIMER

OBJECTIVES

Seismic objectives addressed during the fourth quarter concerned seismic recognition of Grayburg carbonate porosity and development of maps of the distribution of seismic properties which can be related to reservoir porosity. Synthetic seismograms representing various porosity combinations for the Grayburg A sequence were interpolated in forward models to demonstrate waveform character, and a seismic inversion model was used as the basis for work with seismic-guided attribute maps which have been instrumental in defining porosity within the upper Grayburg.

Synthetic models of variations of porosity in the Grayburg A1 and A2 zones show that porosity may be expected to cause reflection changes prominent enough to be noticed. Recognizing porosity in actual seismic data would be very subjective because of weak criteria, and mapping suspected changes would be inaccurate. The complication of interpretation is caused by the presence of the seismic wavelet, which has inherent problems of distortion due to compound reflection interference related to bandwidth limitation (resolution). The seismic trace does not adequately resemble a well log for the purpose of displaying fine rock qualities, nor does it have the ability to accurately resolve important lithologic boundaries. Analyses of specific zones of rock sequence are inherently wrong where the zone boundaries are picked from these compound reflections, as demonstrated with previously made forward synthetic models.

Removing the wavelet from the stratigraphic analysis in this project is of primary interest, and it has been accomplished by calculating a constrained inversion model of the 3D seismic data volume. Horizons tracked from amplitude trace data were revised using the inversion model boundaries in order to accurately isolate zones for analysis.

The geologic objectives addressed during the quarter were the integration of the geologic model into the 3D to accurately portray the lithologic markers, the coring and logging of the Witcher #12, and working toward the development of a successful completion technique for the lower Grayburg and San Andres. Considerable effort went into developing a usable seismic velocity/log porosity transform.

There were a number of engineering objectives this quarter. The development of a successful completion technique for the lower Grayburg and San Andres which would contact the maximum volume of reservoir, minimize potential water production, and be cost effective was a high priority. The Witcher #12 was drilled, and Foster-Pegues #4 re-entered and converted to injection this Quarter. The first steps in the quantitative

integration of seismic data into the reservoir simulation were taken this quarter. Work on water quality, buildup and fall off tests and the update of production and injection data in the model was ongoing.

A paper was presented on the use of core in an integrated project and a paper on the progress of the project prepared for presentation in the spring.

Summary of Technical Progress
Geologic Integration with Geophysical Data

Large scale cross sections L-L' & M-M' were completed. These large wall displays consist of a line of profile connecting wells with sonic logs, accompanied by enlarged (log scale, 1"=40') synthetic seismograms with the purpose of demonstrating seismic waveform compared to the vertical size of the zones being studied. The seismic amplitude profile along the cross section track demonstrates the general structural relationships of the project and hints at the stratigraphic changes present.

Synthetic models were created (Fig. 1a,b,c) to demonstrate the complexity of mapping porosity for the A1 and A2 zones within the top 120 ft of the Grayburg formation. Except for basal quartz sand deposits less than 10 ft thick at major inter-formation boundaries, the Grayburg lithology is carbonate and anhydrite. Reflections within the Grayburg most likely emanate from porosity differences. This model demonstrates seismic response to some possible combinations of porosity. Model limits range from no porosity to extreme porosity. The responses likely to be observed in project data are from 0% to 18%.

Seismic Inversion Modeling

Seismic inversion modeling is a method of converting processed seismic amplitude trace data (wiggle traces) into traces which resemble sonic log curves. The advantages of analyzing seismic data in this format are many, including using a calibrated, lithologically meaningful view of the subsurface with an accurate depiction of bed boundary positions. The ambiguities of the seismic wavelet (resolution and interference) are removed from observations. The inverted traces are still represented in time, not depth. Density is not considered in the inversion process. The inversion process is done using PC-based software within the *Vest 3DSEIS* system. By comparison, forward synthetic modeling attempts to predict seismic effect from a defined geology, where inversion modeling attempts to calculate lithology from seismic data.

Constrained inversion modeling input parameters consider: (1) tracked reflection horizons, (2) sonic log-derived velocity values, and (3) the interpreters experience with the project geology to extend log-defined velocity limits. A range of velocity values is defined for each tracked reflection (an approximate lithology boundary) and for the total interval between tracked reflections. Provisions are made for other geological situations which may also occur. Amplitude data to be modeled must be zero phase in order to provide geologically correct results. The inversion model result is very sensitive to data phase and can also be used effectively as a tool to refine phase correction. Model testing is an essential precursor to model building. Testing constraint parameters, amplitude factors, and comparing test models to well logs requires (well-spent) time.

A preliminary model was calculated for this project to specifically analyze the Grayburg and San Andres sequences. The model input parameters will be refined and expanded in the future, but the results of the preliminary model are remarkable in the presentation of velocity-related characteristics of the seismic data. The inversion model is effective for the shelf area of section 36 of the seismic project, but the outer shelf geology in the eastern part of the survey was not included in the following analyses because of inadequate constraint control in the preliminary model.

Inversion Model Analysis

The primary geologic objective is to map the distribution of rock properties, tied at each well bore, which can be used to describe past fluid movement between wells during the long production history of the oil field and predict future behavior and be directly inserted into engineering models for fluid flow simulation.

The objectives of the analysis are to find relationships of seismic data characteristics with rock properties, and to map the distribution of those properties for the studied geologic sequences. In order for these relationships to be meaningful, several factors must be resolved: (1) seismic characteristics of velocity must be accurately portrayed, (2) compared intervals must be accurately defined, and (3) geologic properties under consideration must be represented in the seismic data. Seismic waveform attributes which are commonly discussed in the literature and are easy to produce were examined initially, but it has been concluded that their use does not meet the above criteria and provides only vague, empirical observations at best. At worst the observations cannot be precisely tied to a geologic interval.

Geologic properties represented in seismic data include thickness, lithology, and average porosity, displayed on inversion model profiles as changes in time thickness and interval velocity. In this project, because the rocks in question are carbonates, pore fluid and permeability effects are probably not visible. Structural characteristics such as faults and fractures may be visible and their distribution may be important.

Horizons tracked using reflections were overlaid onto the inversion model profiles and were seen to agree with lithology breaks in some areas and to disagree in other areas, as demonstrated by the forward synthetic models. In order to use the horizons as boundaries for interval analysis, the discrepancies were repicked using the inversion traces to define the boundary positions. Horizons repicked were the lower Queen sand, the top of Grayburg, and zone A1 top. The lower boundary of the A zone was created by adding 10 milliseconds to the revised A1 pick.

Initially the Grayburg interval was split into the A1 and A2 zones for independent analysis, but test comparisons were inconclusive and the A zone (110-130 ft thick) was considered as a unit thereafter. Splitting zones to less than 100 ft is desirable, but significant differences in lithology must be present in order to track the boundaries. The Grayburg B zone is composed of an upper part of dominantly porous carbonate and a lower part of dominantly anhydrite, so splitting the B zone is a near-term objective.

Results

The interval of the Grayburg A from the inversion model (Fig.2) was measured for average interval velocity using the interval averaging technique which considers all samples (spaced 1 ms apart) within the 10 ms window used. The interval average follows the time structure of the tracked horizon and is not a time slice. The distribution of higher and lower velocities is hoped to relate to observed rock porosity.

Data for all wells with porosity logs (40 of 64) were compiled for values of porosity in some form. Porosity times height, net porosity thickness, and gross average porosity were considered initially. It was decided that seismic data are most likely to respond to velocity changes quantified as gross average porosity, which is defined as porosity times gross thickness on a foot by foot basis, divided by the zones gross thicknesss.
The interval velocity distribution (Fig. 3) was compared to the gross average porosity values at included well points using the seismic-guided log analysis software in the *Vest* interpretation system. The comparison for all wells

available with some sort of porosity estimate has a random appearance (Fig. 4). It was recognized that the neutron-type logs, ranging in age from the 1950's to 1970's, lack the calibration consistency needed to, in turn, calibrate seismic data to porosity data. Sonic logs record only primary porosity and would therefore under-report the total porosity. Values of gross average porosity range from less than 4% to 10% and variations of only a few percent create unacceptable scatter. When only wells with recent, calibrated neutron density logs were considered, the correlation of inversion-derived average interval velocity with gross average porosity was very high (Fig. 5). Several wells do not fall on the curve; these wells have very low values of porosity. Inspection of the well locations within the survey shows that each well is adjacent to a seismic bin with a high velocity value that would move its graph point much closer to the correlation line.

The final step in mapping is to convert the inversion velocity map to porosity units using the graph line relationship. The conversion is handled automatically by the *Vest 3DSEIS* program, which uses a linear recursion method to determine the fit of the line. In order to improve the line fit to the large majority of points, the off-curve wells were not used to set the final conversion curve (Fig. 6), but are corrected with a difference map. The distribution of gross average porosity (Fig. 7) was used in a fluid flow simulation.

A preliminary look has been given to the Grayburg B and C zones. The comparison of sonic log curves with the inversion model is visually good, but preliminary interval average maps show questionable correlation. If the use of seismic data to define porosity is to be effective, the high correlation must be observed for other zones. Improved results are expected after a careful retracking of bed boundaries is made and the preliminary model is refined.

Other Observations

Inversion model profiles show dips and truncations within and below the San Andres formation that are virtually unnoticed on the seismic amplitude (wiggle trace) displays. These dips are related to tectonic events contemporaneous with deposition and may hold the keys to understanding truncated San Andres facies tracts.

GEOLOGY

Witcher #12 Core

The Witcher #12 (Fig.8) was cored in the lower Grayburg from 4190 to 4225 feet and the San Andres cored from 4226 to 4369 feet, with full recovery. The core analyses had begun at the end of this quarter.

A review of the unslabbed core indicates the San Andres interval has excellent oil shows and fluorescence. There are three main intervals with porosity and shows. The deepest zone (4341- 4355 feet) is an interval of leached fusulinacean wackestone with bleeding oil. This zone appears to have excellent porosity (12% to 16% on the neutron/density cross-plot). The next zone (4316-4332 feet) is a fine grained skeletal packstone to grainstone with excellent oil stain. The upper porous zone in the San Andres (4268-4302 feet) is a mottled packstone with fractures bleeding oil. These zones are being evaluated and will be tested during the first quarter 1997.

Geological/Geophysical Integration

A considerable amount of time this quarter has been spent working closely with Bill Robinson, Project Geophysicist, in an effort to combine the geologic model with the seismic interpretation. The geologic model consists of a high energy packstone/grainstone dominated San Andres with a exposed, eroded and karsted top, a tidal flat dominated lower Grayburg with multiple small exposure surfaces, and a high stand dominated upper Grayburg with laterally extensive grainstone/packstone shoals. This triad also reflects the variable production history with the upper Grayburg being a mature field with a poorly designed waterflood, an essentially undeveloped lower Grayburg with essentially virgin pressures, and a San Andres with a varied production history and multiple oil/water relationships.

For the seismic inversion to be successful, it is essential that the zones, identified geologically, be properly identified in the seismic. The first "problem" was identifying the A1 Zone top, as well as the Grayburg top, and delineate the "Lowstand Wedge" of sediments which is present between the Grayburg and A1 in the east part of the survey. If the wedge zone, which is predominantly low velocity, is included in the A1 zone, the inversion would be incorrectly interpreted. This error would then have been carried down through the section. This "wedge zone", which appears to thicken to the east and south, may equate to part of the Grayburg 4 sequence identified in the South Cowden Field Study (Ruppel and Lucia, 1996).

A second problem is the scatter plot of the "total gross porosity" from logs and the seismic velocity. It was noted that the smallest error bars were associated with the most modern logs. Those wells where both neutron and density are the best fit to the velocity in the A1 and A2 zones. Although there is less secondary porosity in the Grayburg than in the San Andres, where the cross plot neutron/density porosity is typically twice the sonic porosity, sonic or density logs alone under-report the gross interval porosity.

ENGINEERING

Witcher #12

During the fourth quarter 1996, the Witcher #12 was drilled to test the simulation and contact additional reserves in the San Andres and the lower Grayburg. The well was located in the southwest corner of the northeast quarter of section 36 to take advantage of the lack of producing wells in the SW/4 of the NE/4 of the section (Fig.8). The well is 330' southwest of the #4WIW Witcher, a 40 acre well drilled in 1941, converted to injection in 1961, and plugged in 1991, and 690' north of the #8 Foster-Pegues.

The well TD'd at 4435 feet in the San Andres. A full suite of logs: Compensated Neutron, Three Detector Density, Long Spacing Sonic, Dual Lateralog, Micro-CFL, Spectral Gamma Log and Mud Log were run. Additionally, a Repeat Formation Tester was employed in an effort to obtain reservoir pressure data. Twelve unsuccessful tests were attempted, with two different pad configurations before the effort was abandoned. Core was cut in the lower Grayburg and San Andres to provide rock property information for these two intervals. Production casing was set and, at the end of the quarter, the well logs were being evaluated and the core analyzed.

Foster-Pegues #4

During this quarter the #4 Foster-Pegues (Fig.8) was reentered and converted to injection. This well, originally directionally drilled under the interstate, had been shut in for lack of production. The simulation indicated this location would provide lower Grayburg pressure support for the recently completed #11 Foster-Pegues and the #10 Foster-Pegues, a Grayburg plug back completed in November 1995. Injection is scheduled to begin early next quarter. Produced water analyses will be completed for the Foster-Pegues #10 and #11, and for the injection water from Foster-Pegues #4, to create a base line for floodwaters in this area. In addition, fluid levels and production

tests in the producing wells, and injection pressures and injection rates will be monitored in the injection well.

Well Testing

Well testing continues, reinforcing the preliminary conclusion that the water flood, as designed and implemented, is ineffective.

Simulation

The first steps in the quantitative integration of seismic data into the reservoir simulation were taken this quarter. The A1 and A2 zone porosity maps were generated in the *Vest* seismic software package and imported as an array of X, Y, Z points into the SSI WorkBench simulator. The process is to work from top down, validating the seismic porosity maps with the history match process. The A zones took 71% of the cumulative injection so when it is correct most of the waterflood history match will be done. The objective of the waterflood history match is to optimize the sweep of the old flood 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. The match of the waterflood history is the point.

Production data for the model was updated through November using a spreadsheet system. The 1996 well work has affected sweep and this knowledge will be used to plan future well locations, injector conversions, and recompletions.

Analysis of buildup and falloff tests continued on a routine basis. The results of these tests have been incorporated into the design of the fracture treatments. The main problem has been how to fracture the low permeability oil zones without communicating with the high permeability and high pressure water zones.

Completions

At the end of the quarter, work was being planned on the Foster #11 to attempt to improve production. A pressure build up test of the well indicates the fracture wing length is less than 30'. This is unacceptable, as the well is uneconomic at present rates (3BO, 15BW,2MCF) after being on production for less than 3 months. It is believed that the frac was too small to be have been successful. A larger frac is planned.

The ongoing "mini-boom", the result of higher crude prices, has delayed even simple well work. Drilling rigs, fracture trucks, down hole tools, surface equipment and workover rigs are all more expensive, in short supply and or must be scheduled up to six weeks in advance. This has resulted in unavoidable delays in implementing many of the recommendations.

Water Quality

Continued work on the quality of the injection water has resulted in dramatic improvements in water quality. The size of solids in the injection system water has been reduced from over 100 microns to less than 5 microns. This will enable the waterflood realignment to proceed, as it was thought to be counterproductive to clean out injection wells before to water quality was improved.

Tech Transfer

Project personnel presented a paper titled "The Use of Core and Core Analysis in an Integrated Study of the Grayburg/San Andres Reservoir, Foster Field, Ector County, Texas at the West Texas Geological Society 1996 Fall Symposium Permian Basin Oil and Gas Fields: Keys to Success That Unlock Future Reserves, on October 31 & Nov 1. The abstract appears on p.39.
A paper titled "An Integrated Study of the Foster (Grayburg/San Andres) Field, Ector County, Texas" was submitted for the Southwestern Petroleum Short Course, Lubbock, Texas. To be held April, 2-3,1997.

Acknowledgements

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.

Fig 1a.

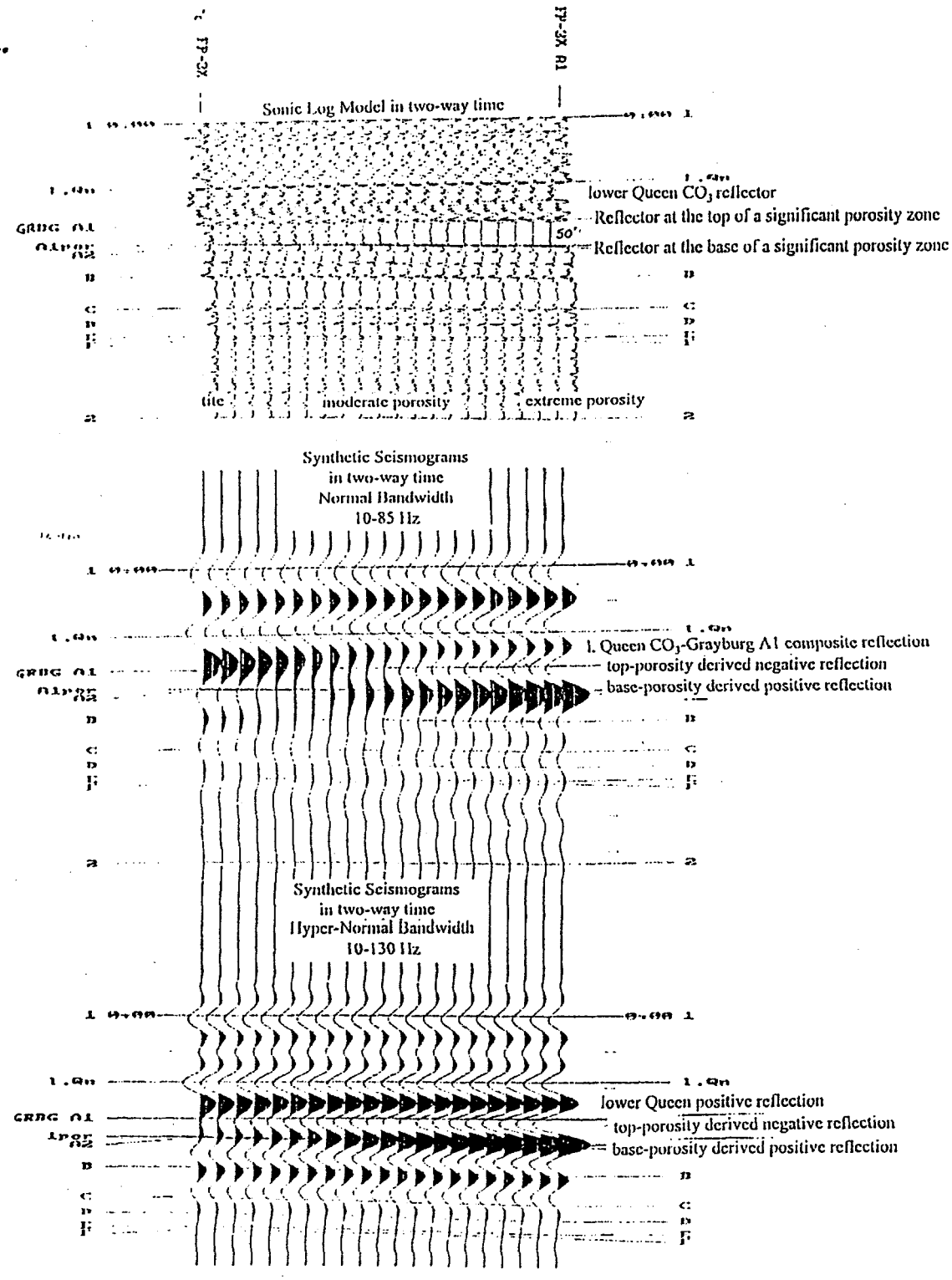
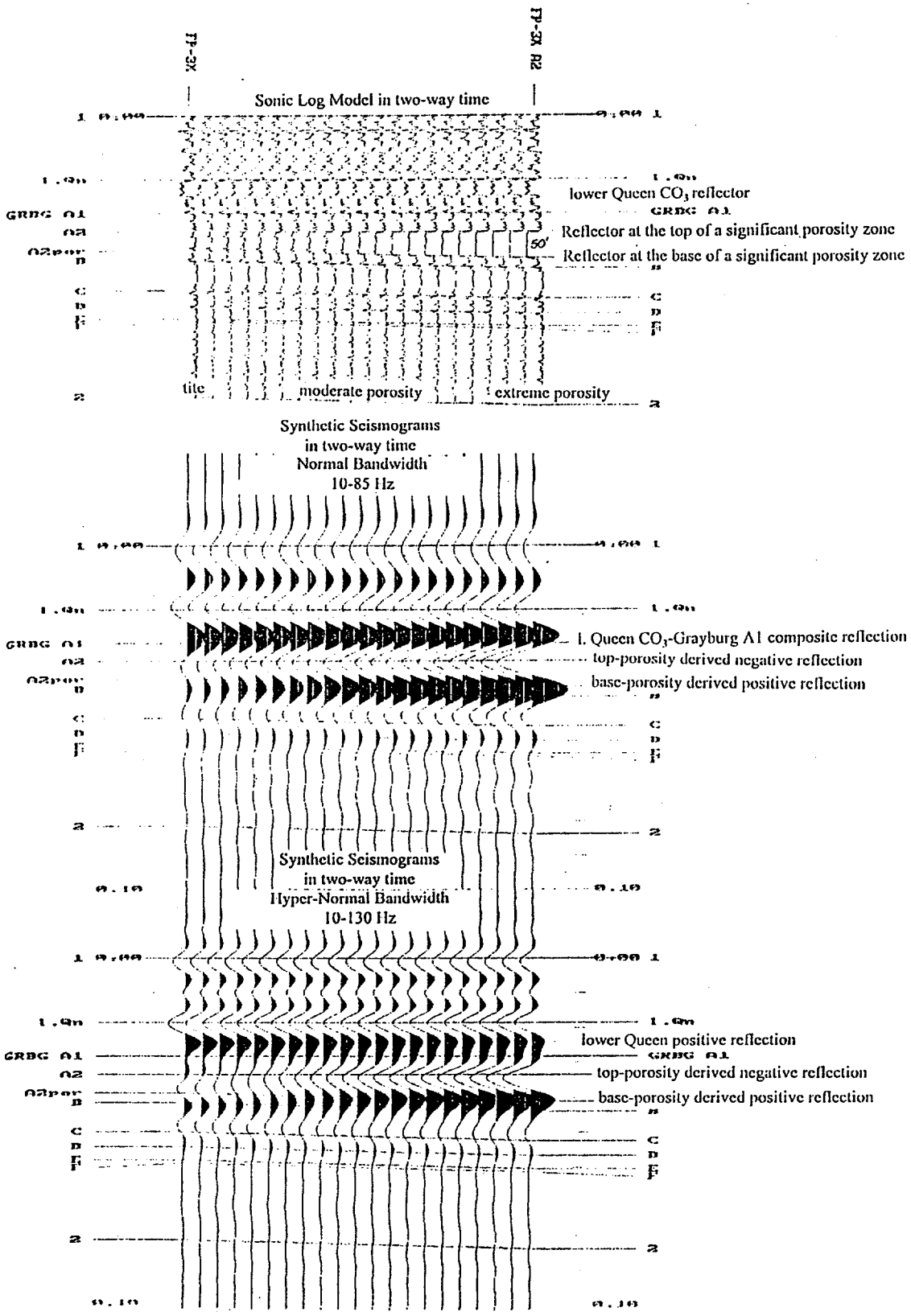
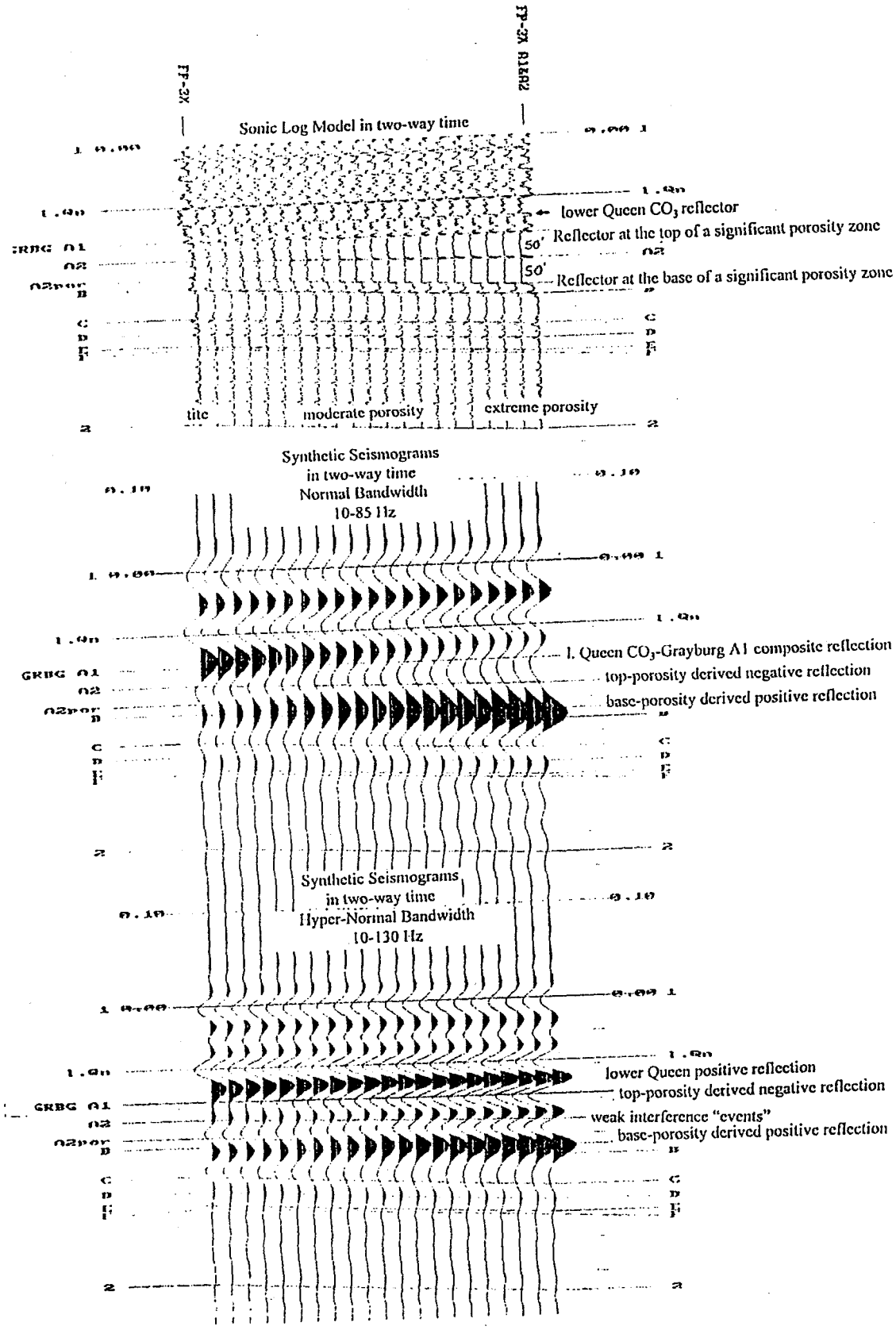


Fig. 1 a,b,c. Syntetic models for porosity changed in A1 and A2 zones. (a.) Zero to 50' of 12% porosity in zone A1, zero porosity in zone A2. (b.) Zero porosity in zone A1, zero to 50' of 12% porosity in zone A2. (c.) Zero to 50' of 12% porosity in zone A1 and zero to 50' of 12% porosity in zone A2.

1b.


FF-3X
FF-3X #2
Sonic Log Model in two-way time
lower Queen CO_3 reflector
Reflector at the top of a significant porosity zone
Reflector at the base of a significant porosity zone
50'
tite
moderate porosity
extreme porosity
Synthetic Seismograms
in two-way time
Normal Bandwidth
10-85 Hz
I. Queen CO_3-Grayburg A1 composite reflection
top-porosity derived negative reflection
base-porosity derived positive reflection
Synthetic Seismograms
in two-way time
Hyper-Normal Bandwidth
10-130 Hz
lower Queen positive reflection
top-porosity derived negative reflection
base-porosity derived positive reflection

1c


FP-3X
FP-3X A1&A2
Sonic Log Model in two-way time
lower Queen CO_3 reflector
Reflector at the top of a significant porosity zone
50'
50'
Reflector at the base of a significant porosity zone
tite
moderate porosity
extreme porosity
Synthetic Seismograms
in two-way time
Normal Bandwidth
10-85 Hz
I. Queen CO_3-Grayburg A1 composite reflection
top-porosity derived negative reflection
base-porosity derived positive reflection
Synthetic Seismograms
in two-way time
Hyper-Normal Bandwidth
10-130 Hz
lower Queen positive reflection
top-porosity derived negative reflection
weak interference "events"
base-porosity derived positive reflection

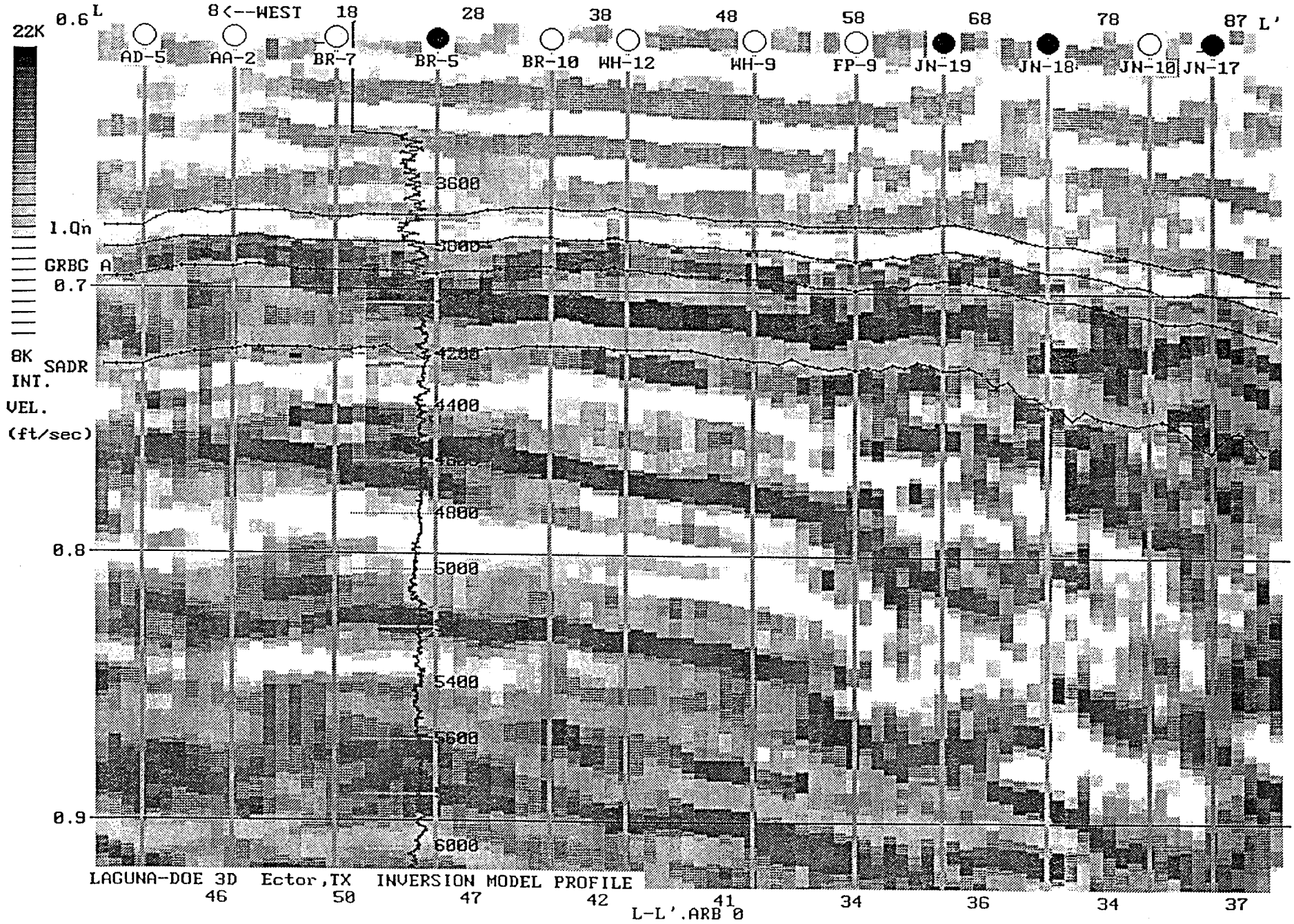


Fig. 2. Inversion model profile line L-L' (East to West).

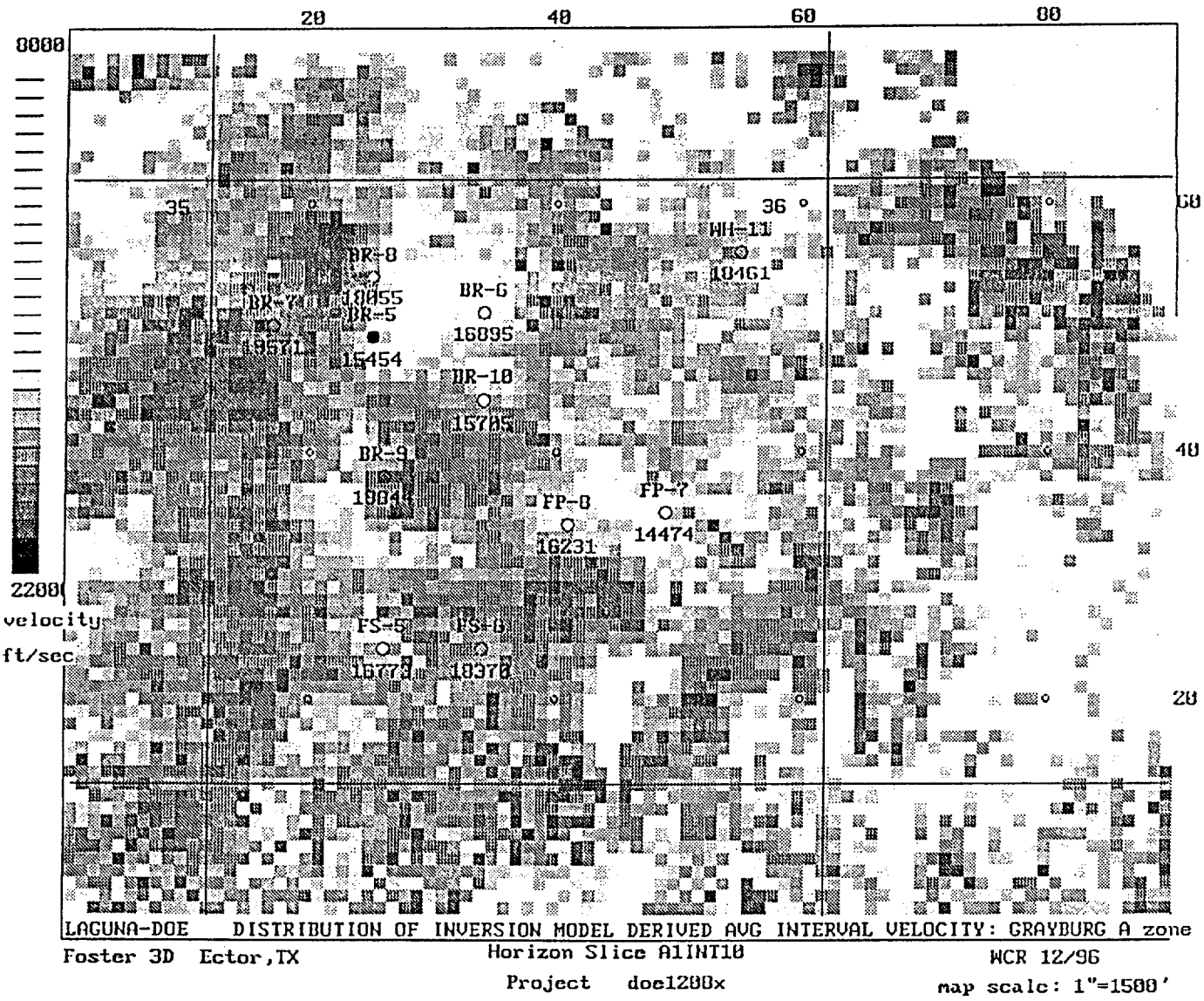


Fig. 3. Distribution of inversion model derived average internal velocity for the A zone (A1 & A2).

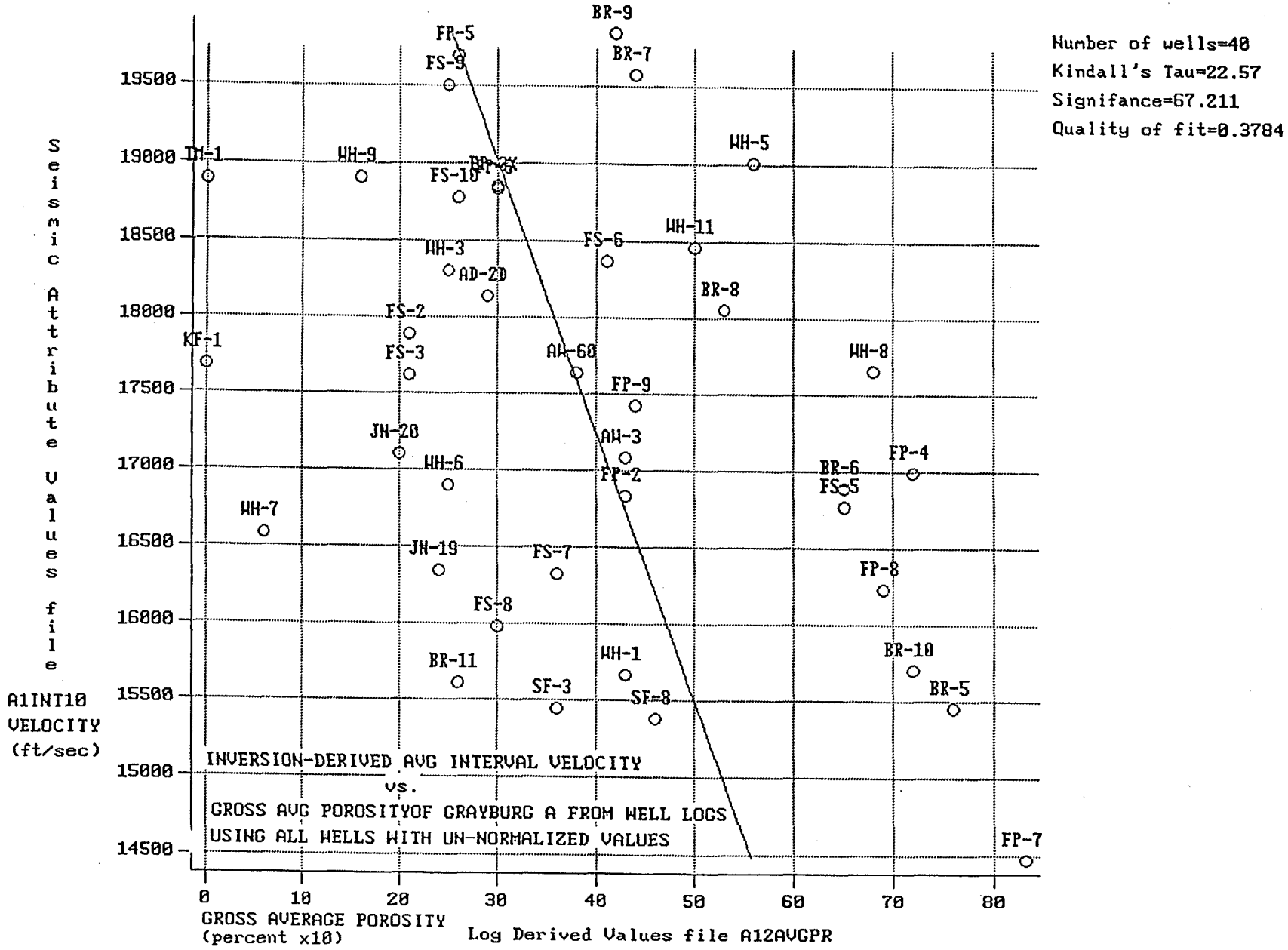


Fig. 4. Comparison of average interval velocity from inversion model vs. gross average porosity from ALL available porosity logs.

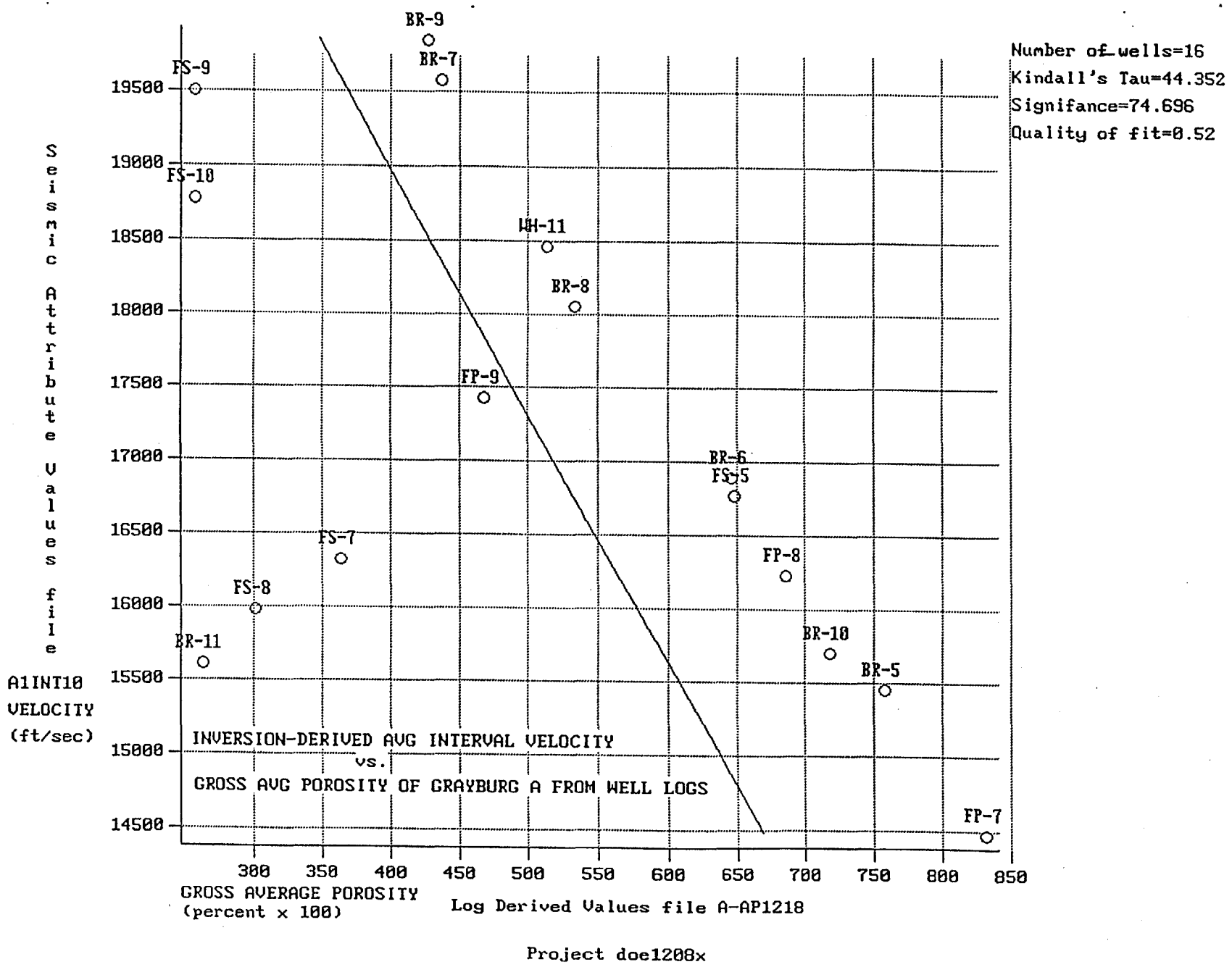


Fig. 5. Comparison of average interval velocity from inversion model vs. gross average porosity from ONLY modern neutron-density crossplot logs.

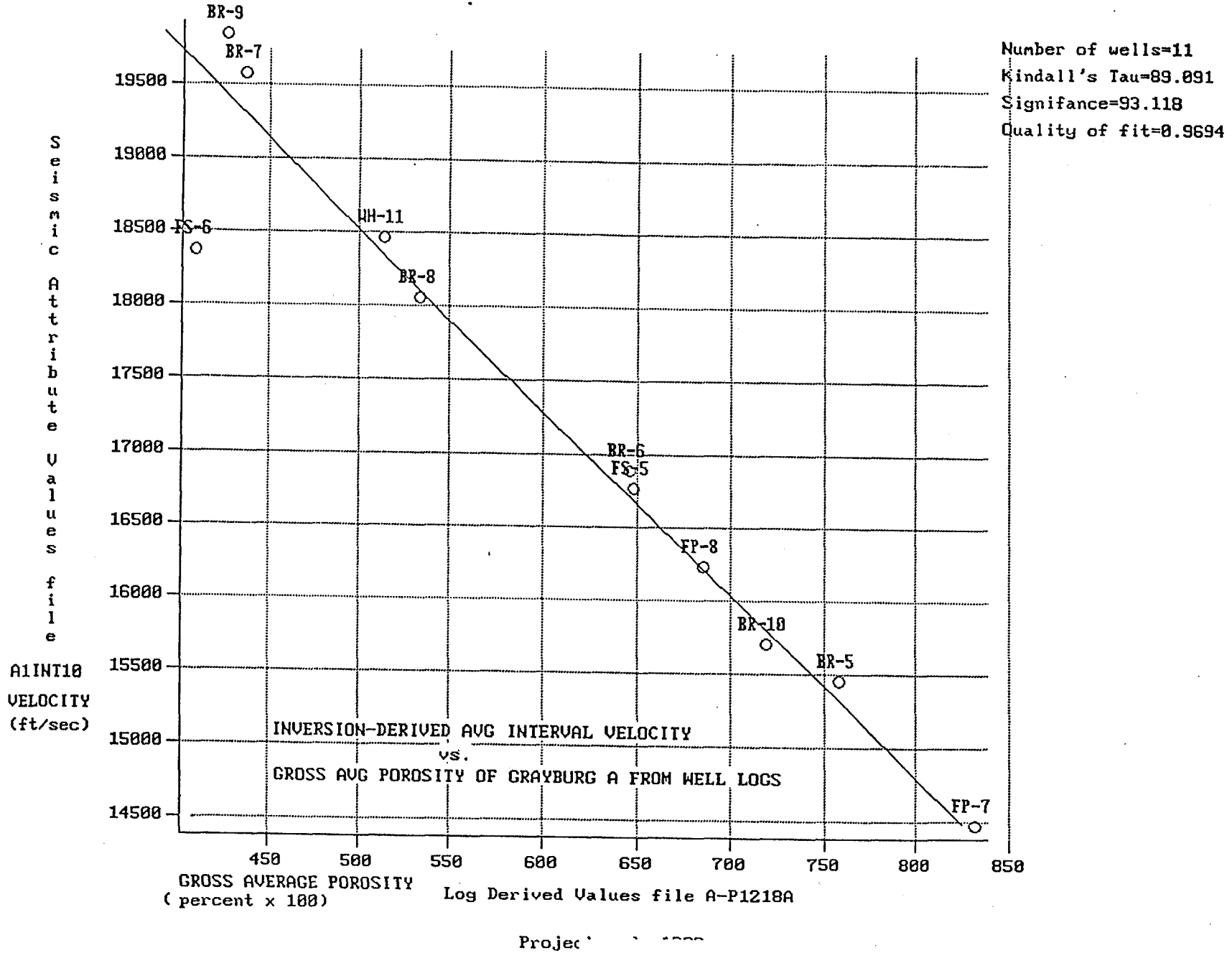


Fig. 6. Same as fig. 5. with off curve, low porosity wells not utilized to set the final conversion curve.

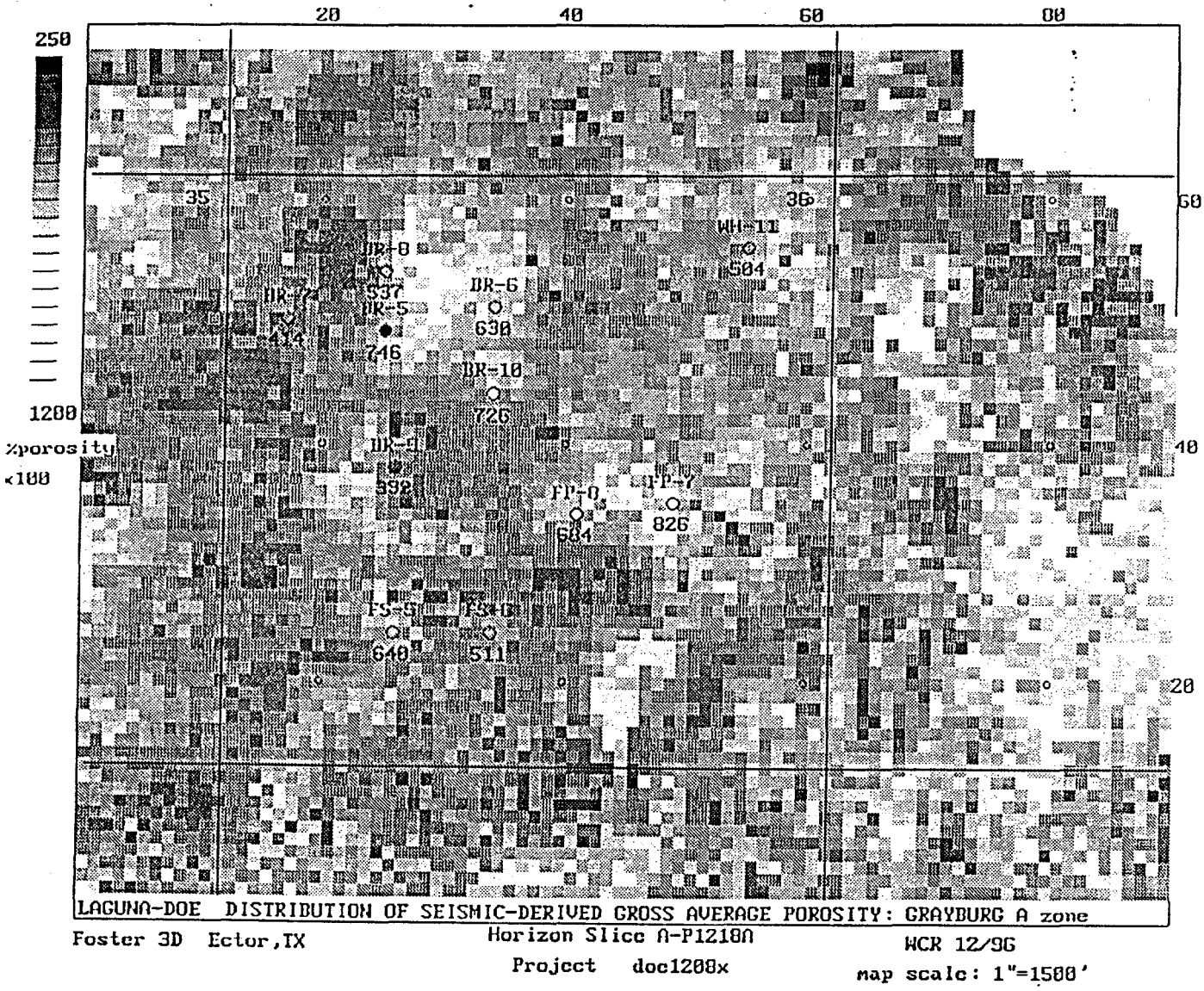


Fig. 7. Distribution of seismic derived gross average porosity for zone A.

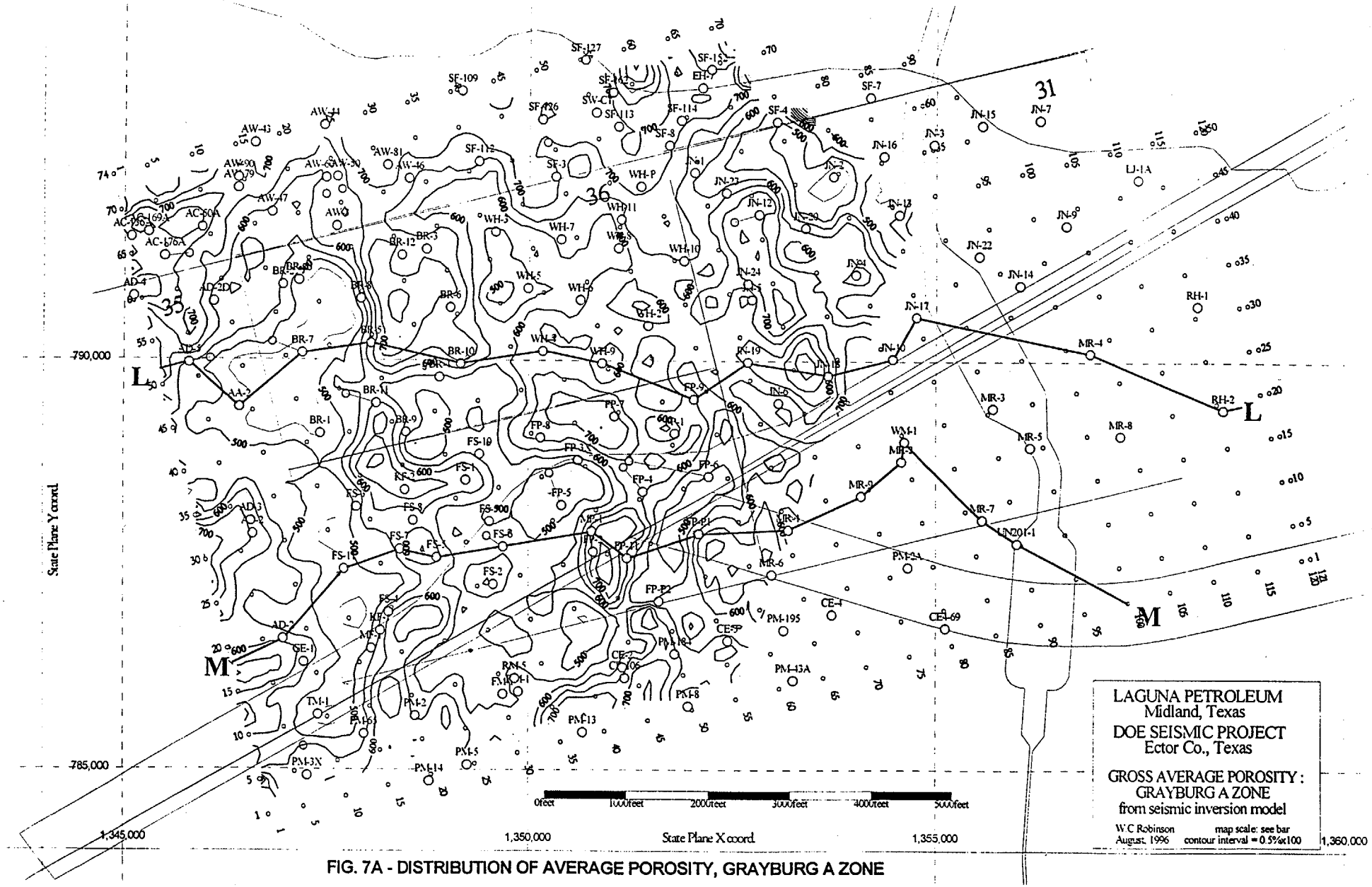


FIG. 7A - DISTRIBUTION OF AVERAGE POROSITY, GRAYBURG A ZONE

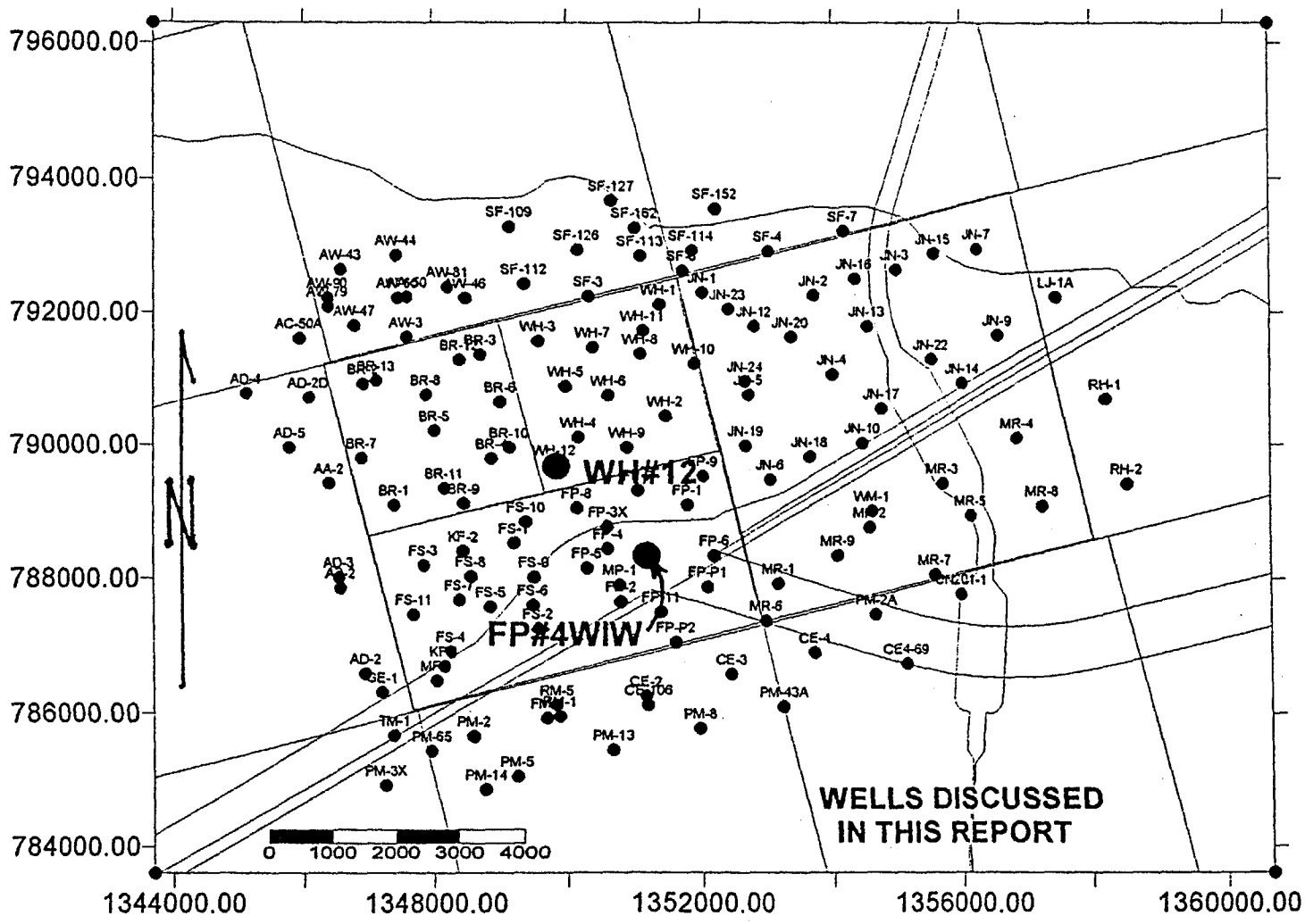


Fig. 8. Location of wells discussed in this report.