

University of Oklahoma
Center for Reservoir Characterization

**GYPSY FIELD PROJECT
IN RESERVOIR CHARACTERIZATION**

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GYPSY FIELD PROJECT IN RESERVOIR CHARACTERIZATION

Objectives

The overall objective of this project is to use the extensive Gypsy Field laboratory and data set as a focus for developing and testing reservoir characterization methods that are targeted at improved recovery of conventional oil.

The Gypsy Field laboratory, as described by Doyle, O'Meara, and Witterholt (1992), consists of coupled outcrop and subsurface sites which have been characterized to a degree of detail not possible in a production operation. Data from these sites entail geological descriptions, core measurements, well logs, vertical seismic surveys, a 3D seismic survey, crosswell seismic surveys, and pressure transient well tests.

The overall project consists of four interdisciplinary sub-projects which are closely interlinked:

1. Modeling depositional environments.
2. Sweep Efficiency.
3. Tracer testing.
4. Integrated 3D seismic interpretation.

The first of these aims at improving our ability to model complex depositional environments which trap movable oil. The second is a development geophysics project which proposes to improve the quality of reservoir geological models through better use of 3D seismic data. The third investigates the usefulness of a new numerical technique for identifying unswept oil through rapid calculation of sweep efficiency in large reservoir models. The fourth explores what can be learned from tracer tests in complex depositional environments, particularly those which are fluvial dominated.

Summary of Technical Progress

During this quarter, the main activities involved the "Integrated 3-D Seismic Interpretation project, for which the progress is reported below:

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ACCOMPLISHMENTS

- Identification and interpretation of velocity measurements at the Gypsy test site which seem to be contradictory,
- Computer program written to compute the effective media response (used in the interpretation described above),
- Presentation of a paper at the Society of Exploration Geophysics meeting in Los Angeles on these reconciled velocity measurements, and
- Presentation of a second paper at the Society of Exploration Geophysics meeting in Los Angeles on geologic modeling and scaling arguments. These topics relate to the problem of seismic mapping of reservoir parameters at the reservoir scale.

DISCUSSION

During the initial assessment of the data taken at the Gypsy site, several apparent discrepancies in the velocity measurements were observed. The discrepancies and their interpretation are described below.

Four Vertical Seismic Profiles (VSP) are available at three of the wells. The travel times determined from the VSP data to the top of the Gypsy interval in each of the wells were in disagreement by as much as 50 msec (Figure 1). After a review of the sonic logs (Figure 2) and the VSP data (which were in agreement below 122 meters that was the starting depth for the surveys), near-surface velocity variations were identified as the cause of the large differences. Unfortunately, not all of the wells were logged to the surface and the seismic data was muted so that only a hint of the feature suspected to be responsible for the velocity anomaly could be identified (Figure 3). A schematic illustration of the feature is shown in Figure 4.

In addition to the VSP velocity problems, the sonic logs indicated that the velocity of the Gypsy sandstone interval was faster than the surrounding strata whereas the crosswell seismic measurements indicated that the Gypsy sandstone was

much slower than the surrounding strata (Figure 5). The average velocities from the VSP measurements indicated still another picture of the velocities. The sonic, crosswell, and VSP differences have been explained in terms of frequency-scaling effects due to attenuation and elastic scattering in layered media. Figure 6 illustrates why thinly layered media are suspected as having caused the frequency dependence of the measured velocities in the strata surrounding the Gypsy sandstone interval. For example, the marine section above the Gypsy interval consists of layered shales and dolomites. At very high frequencies, e.g., the 10,000 Hz measurements of the sonic logs, the wavelengths are comparable or shorter than the thickness of the layers. At these frequencies we can approximately treat interval velocities determined by integrating the sonic travel times as a ray theoretical estimate of the velocity. For lower frequencies, such as the 1000 Hz used for the crosswell measurements, the waves will appear to travel at a slightly slower velocity than that described by ray theory. The reason for the apparent slowing is that scattered energy mixes with the leading waveform. The interference between the direct wave and the scattered signals causes most of the energy to arrive at a later time, resulting in a slower velocity. At the intermediate range of frequencies (1000 Hz for the marine section), i.e., when the wavelengths and bed thickness are comparable in size, measurements are frequency dependent. Finally, at very low frequencies (e.g., 30 Hz as assumed for the VSP), the wavelengths are much longer than the layer thicknesses. The velocity reaches its slowest value and becomes independent of frequency at this point. Backus (1962) developed a method of averaging elastic properties for layered media in order to predict the velocities of a layered media when the wavelengths are much longer than the thickness of the beds. Following Marion et al. (1994), this velocity will be referred to as the effective media velocity, VEMT, and the high frequency velocity measurements (sonic in this case) as the ray theoretical velocity, VRT.

The integrated sonics have been used to estimate the value of VRT for the upper marine interval. Estimates of the components of the layering in the upper marine section were also made from the sonic and other data so that an estimate of VEMT could be made with software written to use the Backus (1962) results. The high frequency VRT and low frequency VEMT velocity estimates were used to estimate the limits of the effects due to elastic scattering. The differences between the effects predicted from scattering and the actual measurements were attributed to attenuation and modeled using the same equations that were used by Gopa et al. (1994).

These ideas described above were used in an interpretation of the frequency-dependent velocity measurements which appeared to be contradictory. The interpretation in terms of elastic-scattering effects and attenuation is presented in Figures 7 (vertical propagation) and 8 (horizontal propagation). In order to complete the integration of the frequency-dependent velocity measurements into the surface-seismic interpretation, modeling software will have to be written. A change in the scope of the project is requested at the end of this section to develop a better understanding of the well control and its relation to the surface seismic measurements.

The reconciliation of the measurements at the Gypsy test site was presented at the 1994 Society of Exploration Geophysics (SEG) meeting in Los Angeles. A draft of a paper describing the work is nearly completed and will be included in the next quarterly report. The paper is being submitted to *Geophysics* (SEG) for publication.

Work related to geological modeling of fluvial systems was also accomplished and presented at the same SEG meeting with Ray Levey from the Texas Bureau of Economic Geology. Some of the modeling concepts presented at the SEG will be incorporated into the inversion algorithm to be developed as a part of the revised scope of work described below.

The tasks originally proposed for this two year project included the following:

First Year – Original Proposal

1. Construct 1-D synthetic seismograms at each well to tie well and seismic data.
2. Use 3-D Gypsy data, processed by Western Geophysical, to construct 3-D isopach maps and seismic attribute maps of the Gypsy interval. Contour maps and a variety of color displays of the seismic response will be constructed.
3. Invert seismic data to obtain 2-D estimates of the acoustic impedance along selected traverses.

Second Year - Original Proposal

(Contingent upon first year results)

4. Match the estimated 2-D acoustic impedance to the impedance of 2-D geological models.
5. Construct an initial 3-D reservoir model using interpolation between 2-D geological models.
6. Invert the 3-D seismic to obtain a full 3-D acoustic impedance estimate.
7. Match the estimated 3-D acoustic impedance to 3-D geological models.

The above first-year tasks (Tasks 1–3) for the integrated 3-D seismic interpretation portion of the contract need to be modified as a result of the initial assessment of the seismic data and the identification of the scaling effects upon the velocity differences. The first two tasks were a part of the initial assessment of the seismic data with the below-listed results.

Task 1 – Results

The 1-D synthetic seismograms constructed at each well did not give a satisfactory match to the surface seismic data. Since the algorithm used to generate the 1-D synthetics was limited by simple assumptions, the task of understanding the seismic response at the well control needs to be expanded in order to account for the full wave theoretical response at the well control. In this way the frequency-dependent effects and other wave phenomena, e.g., leaking seismic energy through thin high-velocity layers, can be taken into account.

Task 2 – Results

The 3-D isopach maps, seismic attribute maps, and color displays of the seismic response, as viewed on the 3-D seismic workstation during the initial assessment, did not have any clear relationship to the interpretation at the well control.

All three of the tasks originally proposed represent basic interpretation tools already in use by the industry. Continuing to perform the above three tasks would not represent a research contribution to the project. However, the tasks have served the purpose of allowing us to examine the data at the Gypsy test site so that the important problems associated with an integrated 3-D seismic interpretation can be identified. In the efforts to perform these basic tasks, the problem of using measurements made at different frequencies has been recognized in the data at the Gypsy test site. In essence, the seismic response at different frequencies is largely the result of the geologic heterogeneity and attenuation. Elastic-wave modeling software is needed in order to describe the seismic response at different frequencies. In particular, the integration of the sonic, crosswell-seismic, and surface-seismic measurements requires a more complete modeling software than is currently available. The 1-D synthetic modeling program used thus far is a ray-theoretical modeling package which ignores important wave phenomena that are thought to be important at the Gypsy test site. Thus, a first revised task for the remaining period of the first year is listed below.

Revised Task 1 – Develop or obtain from outside sources an elastic-wave-equation modeling program for modeling the complete seismic response of a layered elastic medium.

Once the revised Task 1 is accomplished, work will begin on the following two tasks:

Revised Task 2 – Use the full-wave modeling software from Revised Task 1 to integrate the seismic measurements associated with the well control at the Gypsy test site. The effective seismic response of the surface seismic data then can be tied to the seismic measurements made in the wells at other frequencies. An important part of this revised Task 1 is the quantification of geologic scale.

Thus, if time permits before the end of the year, some of the geological modeling ideas described at the 1994 SEG meeting in Los Angeles will be incorporated into a Revised Task 3 described below.

Revised Task 3 – An important part of the revised Task 2 is the quantification of geological scales which affect the seismic response at different frequencies. In other words, an accurate 3-D model of the seismic parameters within the environment being explored is required. The “reservoir” at the Gypsy test site is a fluvial environment. Since the scale of geologic heterogeneity affects the seismic response, it is important to be able to quantify this heterogeneity in terms of the variability of seismic parameters within the geological environment being explored. Thus, revised Task 3 is a refinement of revised Task 2 to evaluate variations within the reservoir that affect the seismic response at different frequencies while revised Task 2 is dedicated primarily to understanding the seismic background response at the same frequencies. The seismic-background response of the reservoir is basically the seismic response that would be received if the reservoir were homogeneous. Process-based geological modeling concepts, along with input from the other team members, will be used in this part of the project.

The revised scope of work for the first year presented above is the result of our interpretation of the frequency-scaling effects at the Gypsy test site. The revision of the project is necessary in order to point the project toward the problems identified that the industry needs solved rather than the simple interpretation of the data as defined in the original Tasks 1–3 of the original proposal.

The revised tasks as defined will address the fundamental problem of understanding the relationship between the seismic response and the ratio of the wavelength to the length scales of the geologic heterogeneity. Although a revised scope of work is presented, the revised tasks honor the original intention of the proposal to use seismic data to control the estimation of reservoir scale parameters. The original three tasks proposed for the first year have served their purpose by allowing us to recognize the timely problem of scaling measurements at different frequencies. The new scope of work should lead to research efforts that are more sympathetic to the needs of the industry.

The overall project direction is not changed by the revised tasks. The first year now includes:

- the revised Tasks 1 and 2 associated with frequency scaling and understanding the well control, and
- some initial work on the ideas of process-based geological scale modeling (revised Task 3).

The second year will now be modified to include the portion of the seismic-inversion work originally proposed for the first year. In addition, a portion of the geological modeling studies originally scheduled for the second year has now been shifted into the first year (revised Task 3) as a result of the scaling problems identified that are critically dependent upon the scales of geologic heterogeneity.

References

- Backus, G. E., 1962, Long-wave elastic anisotropy produced by horizontal layering, *Journal of Geophysical Research*, 67, 4427–4440.
- Burns, D. R., Reiter, E. C., Tang, X. M., and Foley, J. E., 1992, Elastic property scaling relationships and the seismic characterization of flow units, an unpublished abstract of a presentation to the Gas Research Institute by New England Research, Inc., Quincy, Massachusetts.
- Gopa, S. De, Winterstein, D. F., and Meadows, M. A., 1994, Comparison of P- and S-wave velocities and Q's from VSP and sonic log data, *Geophysics*, 59, 1512–1529.
- Marion, D., Mukerji, T. and Mavko, G., 1994, Scale effects on velocity dispersion: From ray to effective medium theories in stratified media, *Geophysics*, 59, 1613–1619.

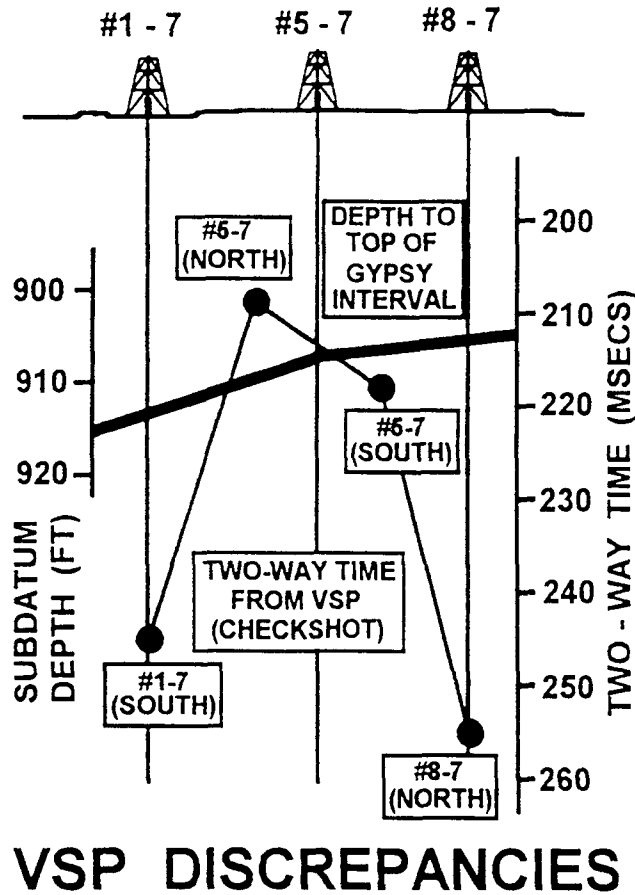


Figure 1. Schematic illustration of the 2-way times (dark circles) to the top of the Gypsy interval as determined from the four VSPs at the Gypsy test site. The depth to the top of the Gypsy interval is indicated with a solid line. The sources were approximately 60 meters from the surface positions of the wells in the directions indicated in the figure. Two surveys were shot in the 5-7 well. All of the surveys gave distinct results for the two-way travel time to the top of the Gypsy interval.

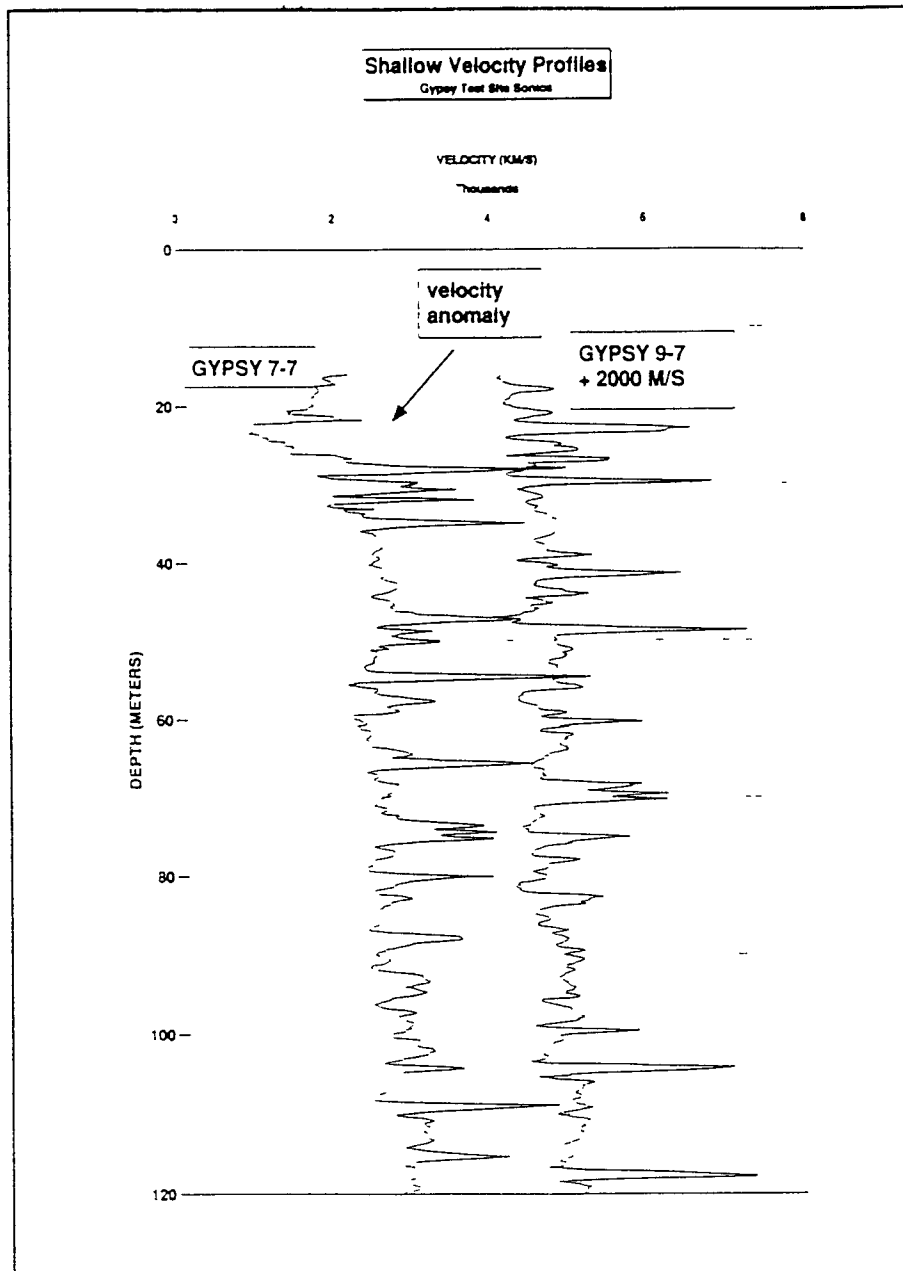


Figure 2. A comparison of two of the sonic logs at the Gypsy test site that are recorded almost to the surface indicates a potential near-surface velocity anomaly and some structural changes in the near surface that are probably related near-surface-velocity changes responsible for the large differences between the VSPs.

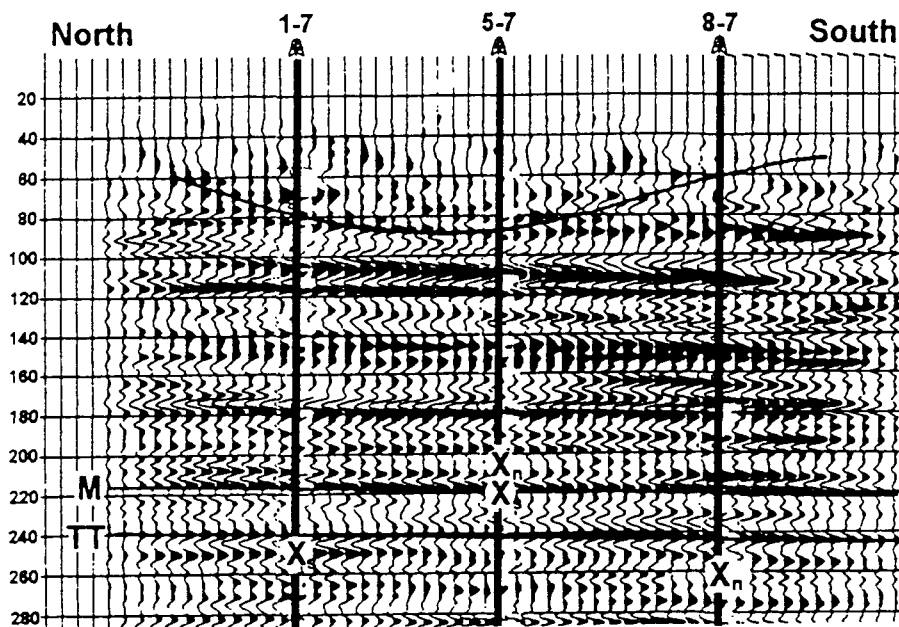


Figure 3. 3-D seismic traverse (modified from Seifert, 1994) through the three wells at the Gypsy test site in which VSPs were collected. The "X"s indicate the times to the top of the Gypsy interval for the each of the wells. The subscripts "n" and "s" indicate that the source position for the VSP was either north or south of the surface position for the well—a distance of approximately 60 meters. The "M" and "TT" represent reflections that approximately mark the top and bottom of the Gypsy sandstone interval. The line at the top indicates the position of a near-surface feature which appears to be related to the apparent disagreements between the VSPs.

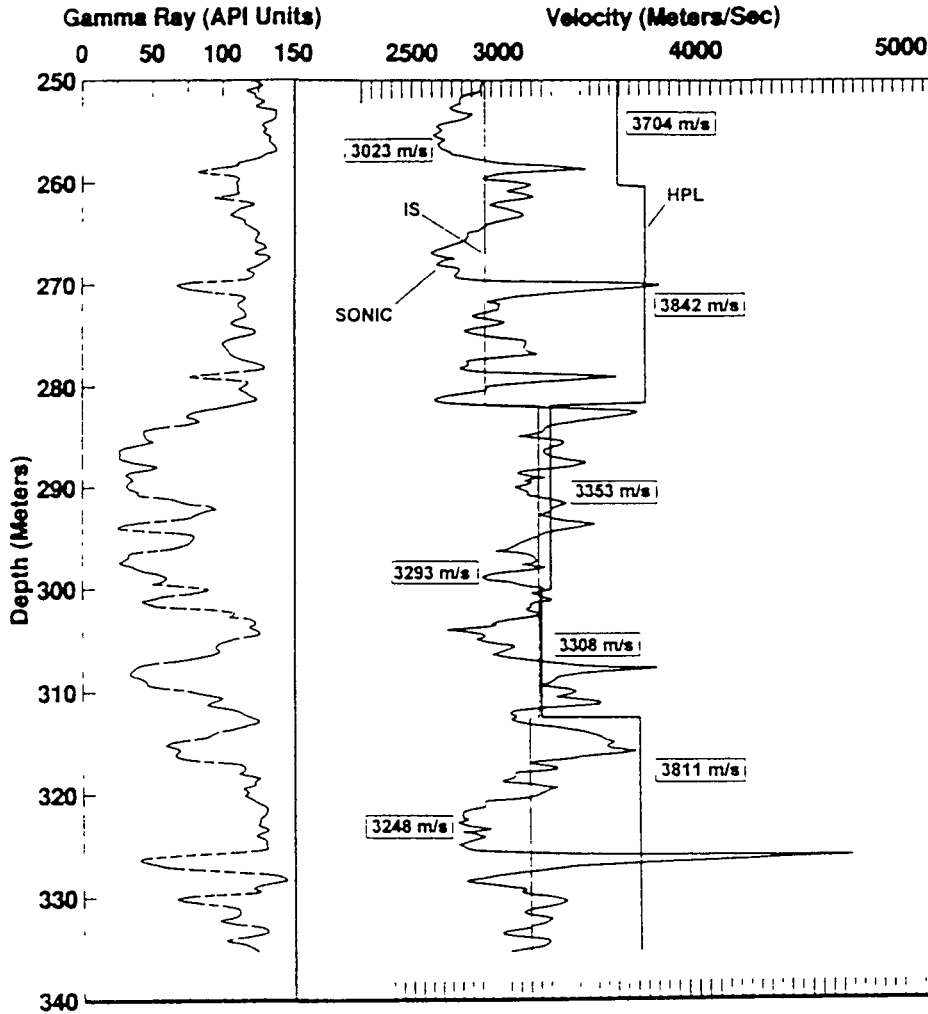


Figure 5. Gamma ray and velocities from the sonic in the 5-7 well as well as the HPL, a crosswell measurement between the 5-7 and 7-7 wells for the zone including the Gypsy sandstone interval. The velocity values determined from the HPL are plotted on the right side of the plot. The straight lines are used to represent the velocities determined by dividing the distance between wells by the first arrival times. In addition, the velocities obtained by integrating the sonic travel times through selected intervals are drawn through the sonic curves. At face value, the sonic and HPL velocities give contradictory indications of the velocity and the impedance profile through the Gypsy sandstone interval.

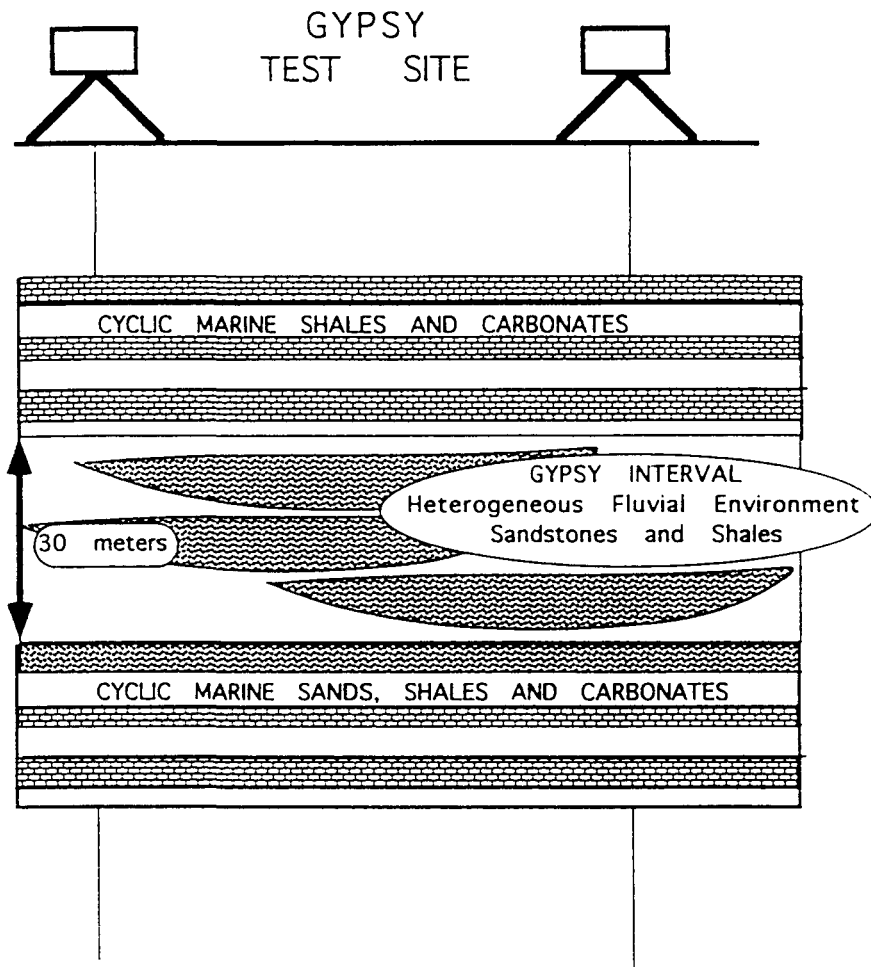


Figure 6. Schematic of the types of depositional environments including the Gypsy interval for the section of the 5-7 well shown in Figure 5. The strata above and below the Gypsy are cyclic marine sequences while the Gypsy interval is a heterogeneous fluvial environment. The upper marine sequence consists of shales and dolomitic streaks while the lower marine sequence contains sands, shales, and dolomitic streaks.

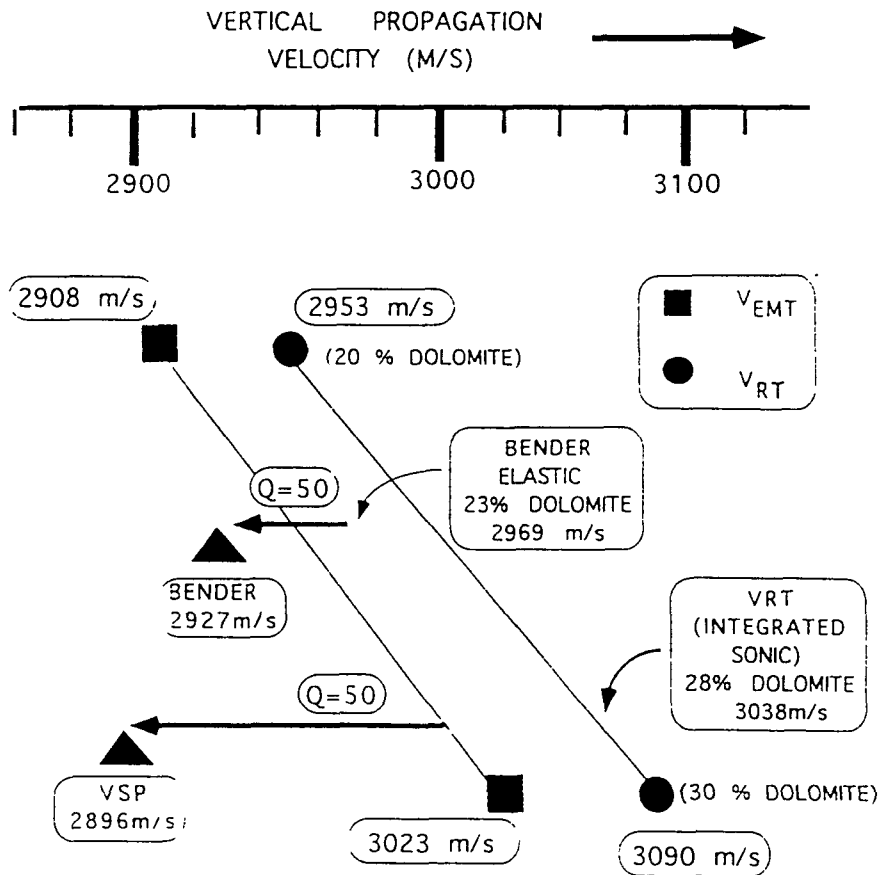


Figure 7. Illustration of interpretation used for vertical measurements in the upper marine section. The integrated sonic for the interval corresponds approximately to a model with 28% dolomite. The value of VRT of 3038 m/s for 28% dolomite is indicated. The VEMT corresponding to the elastic estimate of the VSP measurement is 3000 m/s. The attenuation represented by $Q = 50$ is represented by the arrow from 3000 m/s to the observed value for the VSP (2896 m/s). The VSP and Bender log measurements were made by Burns et al. (1993) in a smaller interval than used for this study. We interpret the VSP as averaging over a slightly larger volume because of the longer wavelengths. The effective percentage of dolomite for the Bender measurements is reduced because of averaging measurements over a restricted subinterval from 250-260 meters. The model value of the VRT that is equivalent to the interval velocities for this shale-prone interval (based upon integrating the sonic travel times) corresponds to 23% dolomite. The attenuation required ($Q = 50$) is the same used to explain the VSP measurements.

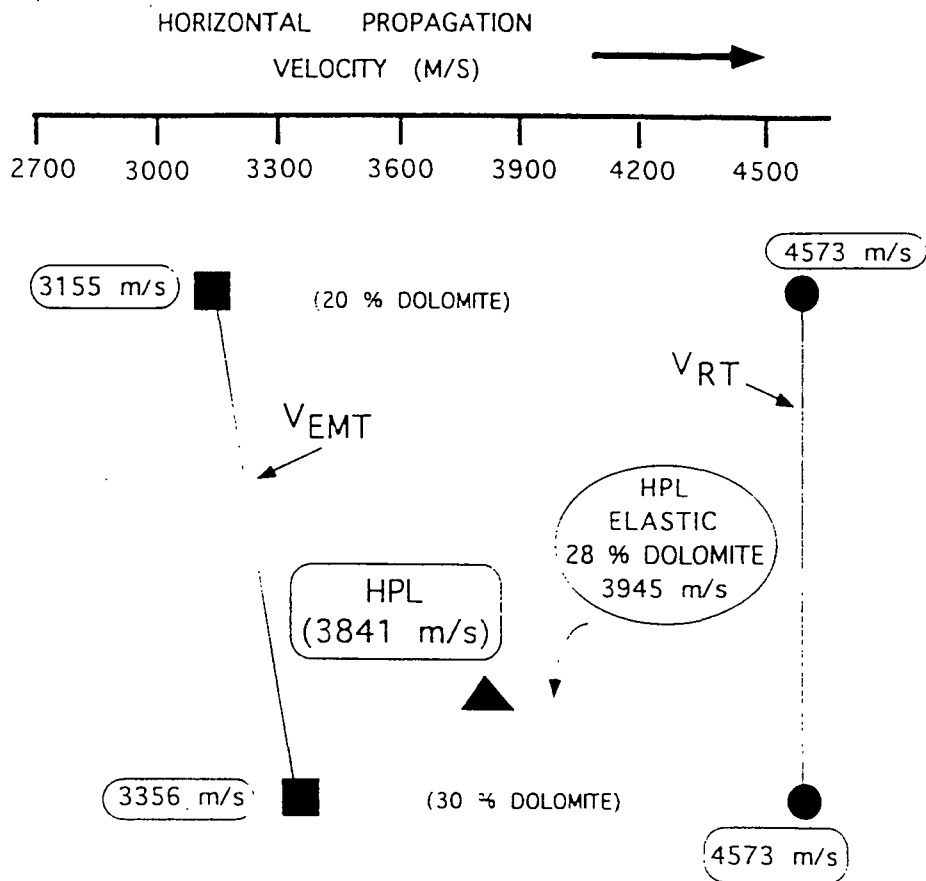


Figure 8. Interpretation of horizontal velocities in the marine section above the Gypsy sandstone interval. The VRT is the fastest velocity in the layered model corresponding to the dolomite streaks. The VEMT is the effective media results based upon the averaging scheme of Backus (1962). The HPL is a crosswell measurement whose velocity estimate is interpreted to best be approximated by wave theory. The value of wave theoretical velocity (VWT) is assumed, for the sake of discussion, to be scaled as indicated to the value indicated (3945 m/s). The actual crosswell velocity measured is 3841 m/s. More detailed wave theoretical modeling is necessary in order to understand the degree of anisotropy expected for the upper marine section.

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The overall objective of this project is to use the extensive Gypsy Field laboratory and data set as a focus for developing and testing reservoir characterization methods that are targeted at improved recovery of conventional oil. The Gypsy Field laboratory consists of coupled outcrop and subsurface sites which have been characterized to a degree of detail not possible in a production operation.