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Velocity Is Key Element For 3-D Earth Model

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HOUSTON–Today's quest for an earth model that can accurately predict depth has prompted intense scrutiny. Every element of this three-dimensional geophysical and geological representation of the earth's subsurface–from the collection and utilization of raw data through the optimal integration and interpretation of each individual science–is constrained by all of the information that today's new technologies can generate.

The utilization and ultimate accuracy of earth modeling designed to approximate the earth's lithology is influenced by a number of complex and interrelated elements. Each element plays a distinct and unique role in the optimum utilization of the earth model's problem-solving applications. One key element that can significantly impact depth prediction lies in the judicious collection, integration and interpretation of the velocity data used to develop the earth model. Velocity warrants particular scrutiny by the explorationist, and the appropriate application of velocity can maximize the effectiveness of an earth model.

Until recently, velocity was perhaps the most misunderstood and maligned geophysical parameter in interpretation. However, the advent of new and abundant 3-D seismic data, fueled by a decrease in risk tolerance and an increase in cost containment, has resulted in velocities being appropriately scrutinized and appreciated.

Today, velocity is recognized for what it is: a key parameter that is capable of significant impact, yet complex and difficult. As so aptly put by Anstey ". . . but velocity, alas, is a pain." That is true, yet it has the potential to influence every aspect of a geophysical interpretation–time-to-depth conversion, density model building, pre- or poststack depth migration, reprocessing, remigration, ray path modeling, impedance, and AVO work.

Seismic Velocity Data Base

The integration of seismic velocities to complement available, but usually limited well control data has become common place. However, in a world where depth predictions with 20-foot accuracies have become established benchmarks, significant local velocity gradients can wreak havoc, causing time-to-depth conversions to be in error by hundreds of feet. This magnitude of error can virtually be eliminated–or at minimum, drastically reduced–by rigorous integrating checkshot and seismic velocity data with geologic markers.

This approach to velocity analysis follows a specific criterion designed to produce a meticulous and consistent process of interpretation. The process begins with a uniform grid of the best available seismic data. The first criterion requires "picks" from the velocity analysis panels. This terminology describes the interpreted velocity value for a given x-y location, correlated to semblance clouds with high amplitudes, which are in correspondence with coherent reflections on the seismic section.

Next, the interval velocity computed from the interpreted velocities cannot exceed the reasonable range of sedimentary velocities, nor can they oscillate wildly between adjacent reflections on the seismic section or between adjacent velocity panels. The interpreted velocity value observed is defined as Vrms (dip corrected Vrmo or stacking velocity). Finally, these values are preserved in a data base with spatial sampling defined by the original seismic location and time sampling data dependent.

In order to develop a calibrated 3-D velocity volume, which captures the three-dimensional velocity gradients, it is essential to properly integrate the seismic velocity data base with well survey velocities (checkshot) and any other well data. Velocity measurements made from 3-D seismic reflection data are normally faster than measurements made in two-dimensional wells.

This effect can be primarily attributed

TABLE 1

Comparisons of Time/Depth Relationship of Well No. 0 with 3-D Seismic (Using Nearest Checkshots and Well-Calibrated Seismic Velocity Data Base)

Well Number, Data Source Type	Time > Depth (Checkshots)	Depth > Time (Velocity Data Base)
"Bright Spot," Seismic Time Section	2.775	
Well No. 0, Electric Log		10,175 ft.
Well No. 1, Checkshot	2.775 > 10,119 ft.	10,175 ft. > 2.789
Well No. 2, Checkshot	2.775 > 10,235 ft.	10,175 ft. > 2.758
"Bright Spot," Calibrated Seismic Velocity Data Base: (Interpolated)	2.775 > 10,170 ft.	
Well No. 0, Calibrated Seismic Velocity Data Base: (Interpolated)		10,175 ft. > 2.776

to sediment anisotropy, or using simplified methodologies for estimating velocity from seismic data (simplified seismic velocity processing), or various geometry (ray path) considerations. Adjustments or bias corrections are made to the seismic velocities in order to tie to the well velocities. Quality control of the input data is paramount. Therefore, it is essential to reject any data that is questionable because of its complex geology and/or problematic geometry. The result of this process is the recommended well-calibrated velocity volume that is input into the earth model.

The objective of the interpreter at this point is to identify and define subtleties in the velocity data itself, and in the interplay of all available data. The objective of the data processor is to stack the data cleanly and efficiently. The geology of the area and the objective of the earth model, and the detection and interpretation of any velocity gradients, can significantly impact the accuracy of the final interpretation. It is at this juncture that the interpreter's insight is most critical.

Velocity Gradients

Significant horizontal velocity gradients over short distances in simple clastic sediment environments can cause time-to-depth conversions to be in error by as much as 330 feet within a distance of less than two miles. The following example from the offshore Gulf of Mexico demonstrates a number of important findings, including:

- Checkshot velocity data may not be applicable away from the sampled location;
- Velocity fields, even in a simple geologic setting, can be complex;
- It is possible to make velocity interpretation from seismic data; and
- Proper velocity control can reduce drilling risk for targets that are sensitive to errors in time-to-depth conversion.

In an attempt to extend the life of a field and ensure depletion of all productive zones, a 3-D seismic survey was acquired over a 100 square-mile area in order to delineate and accurately locate any additional gas targets, and minimize the potential of missing those targets by ensuring correct well trajectories during additional drilling. It was determined that if a target was missed, sidetracking or redrilling would be more costly than the benefit of the additional gas production.

Comparisons of the time-to-depth conversions were based on known well penetrations and bright events from the 3-D seismic time interpretation and interpolating the existing checkshot data. This analysis indicated that the horizontal positioning of the events was good, but that the depths were much less accurate.

At first glance, the checkshots in the vertical portions of all the wells appeared to be in fair agreement with the seismic. However, discrepancies became increasingly significant as the distance between the well bores and the platform was increased.

In this example area, checkshots were acquired in each block's first well, but not in any of the subsequently drilled wells (with the exception of one that was acquired in a deviated hole). The checkshots in well Nos. 1, 2 and 4 (Figure 1) were acquired, either totally or partially, in anomalous low-velocity sediments. The positioning of the checkshot in well No. 2 clearly prohibited its use in any time-to-depth conversion or bias calculation.

Possible causes of the low velocities around the production platforms can be attributed to gas-saturated sediments, numerous gas accumulations, faulting, micro-fracturing and minor overpressure. Table 1 lists the variations in time-to-depth conversion for common times and common depths, interpolated from the checkshot wells. Well No. 0 was drilled into a seismic "bright spot."

Well-Calibrated Velocities

Accurate velocity control away from checkshot control can be achieved using high-quality seismic velocity interpretation, which builds local velocity gradients from the high-sample density seismic. Once the seismic velocity field is interpreted, the bias between the seismic velocities and the more randomly located well velocities are calculated at the well locations. The contoured biases are used to calculate the well-calibrated velocities. This is based on the assumption that the well-to-seismic velocity bias has geologic significance and is similar in mag-

FIGURE 1

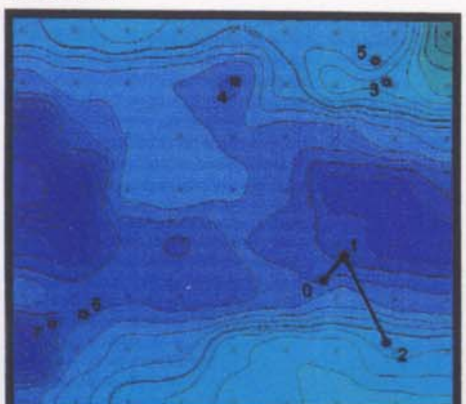


FIGURE 2

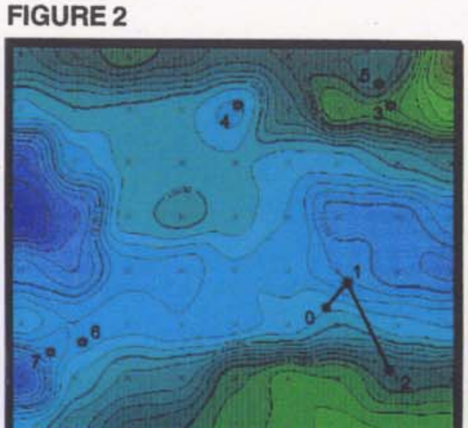
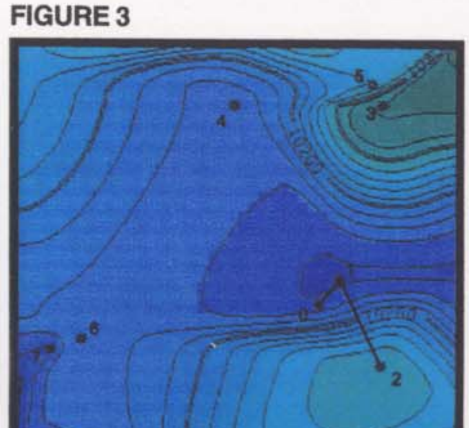


FIGURE 3



nitude over extended areas, or at least varies systematically within a local area.

A map of the well-calibrated average velocity at a constant time of 2.775 seconds as shown in Figure 1 demonstrates the magnitude of local velocity gradients, as well as the variability of velocity data over a relatively small area. Figure 2 is a map of the well-calibrated seismic depth, at the corresponding time slice, across the 3-D seismic survey.

A map of the well depths at 2.775 seconds derived from utilizing only the checkshot velocities is shown as Figure 3. A comparison of Figures 2 and 3 demonstrates the possible error in time-to-depth conversion when using only a single checkshot, or doing linear interpolations between a few checkshots. In an area of layered elastic deposition, even quality checkshot data may not be applicable for time-to-depth conversion when distanced away from the points of measurement, making reliance on checkshot extrapolation or interpolation for depth conversion a risky proposition at best.

This example demonstrates a common exploration problem, and the need for rigorous treatment of valid velocity data and for interpreters to remain vigilant to the simple truths that velocity fields–even in simple geologic settings can be complex, checkshot data is not always applicable, proper velocity control can reduce drilling risk for targets that are sensitive to time-to-depth conversion errors, and a well-calibrated velocity volume retains regional and local anomalies.

Because of the complexity of exploration problems that earth models are required to solve, it must be constrained by the integration of multiple sciences: seismic, gravity and magnetics. Each element plays a distinct and vital role in maximizing the earth model's problem-solving capabilities. Although velocity is only one parameter, it is a key element that has the potential to significantly improve depth prediction through the judicious collection, integration and interpretation of data by the skilled interpreter. ❐

Editor's Note: The preceding article is presented, in part, as a follow-up to "Earth Models Enhance Interpretations," which appeared in the February 1998 issue of *The American Oil & Gas Reporter.* The author refers readers to that article for a broader discussion of all the elements contained in a 3-D earth model, and how they can be incorporated to build a better model.