The Look Ahead VSP Survey: Its Utility and Future*

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General Statement

Vertical seismic profiling (VSP) technology although not new, is still viewed by some as something of a novelty. Our industry has been using it somewhat reluctantly since the early 1970's--reluctantly, perhaps because there may be a tendency to view surface seismic data as a sort of panacea and ultimate resource to get subsurface information between wells. General industry knowledge of surface seismic techniques are widely known; not so with VSP technology. Fortunately, more and more VSP surveys are being run today because advantages of producing high-resolution seismic images to help tie the well bore to surface seismic data to lower overall drilling risk are starting to be more appreciated and documented. Of course, other types of subsurface data are used. Included are the obvious well-log curves and the occasional use of gravity and magnetic coverage to augment deficiencies and gaps which may be encountered in surface seismic data sets--especially where regional and frontier work is involved. We are always asking structural and stratigraphic questions about the subsurface and wanting to know what lies ahead of the drill. The writer re-visits "Look Ahead" VSP or PAB ("Prediction Ahead of Bit") VSP (whichever acronyms are preferable) technology and presents this type of VSP survey as an accurate and versatile seismic method available for imaging an appreciable distance around and ahead of the drill bit.

The Zero Offset VSP Survey as a Start

The look ahead VSP survey is not much more than special data processing treatment of the standard zero offset VSP survey. The zero or near offset VSP survey (these terms tend to be distance from wellhead related and generally used interchangeably), is defined as a VSP survey where the energy source whether a vibroseis truck, airgun array, dynamite shothole, etc., is positioned as close as logistically possible to the wellhead in an effort to focus downgoing energy in and around the bore hole from near-surface to T.D and beyond. This geometry favors the recording of reflected arrivals to the downhole geophone tool for about an approximate 100 ft. radius (depending on dip), around the well bore as well as reflected arrivals several thousands of feet below the T.D. of the well. Typical objectives of this type of survey are (1) to obtain velocity control to allow surface-seismic-time to depth conversion and (2) to produce a processed seismic image known as a corridor stack of the area around and including the well bore. Zero offset surveys are either run alone or in conjunction with some type of offset vertical seismic profiling (Figure 1). Included may be an offset VSP, static or walk-away or a salt-proximity, survey. Offsets are designed to image some distance laterally away from the well bore in the direction of the energy source, image a salt dome flank or perhaps a granite intrusive interface. Zero offset is the most common type of VSP survey. The surveys are usually recommended by geophysicists seeking accurate on-depth seismic correlation to tie a well to a 2D and/or 3D surface seismic survey. Those who run VSP's routinely have appreciation from past experience of the limitations and pitfalls involving surface-seismic-time to depth conversion and seismic-reflection-character-tie challenges. They understand the problems that may result from trying to get too much information from just a checkshot velocity survey alone and/or a simple and limited synthetic seismogram made from a sonic log. The checkshot velocity survey is basically a seismic travel time study that measures almost exclusively the downgoing energy traveling from a surface energy source to a downhole geophone tool. The checkshot survey is valuable for velocity control, however, it contains virtually no reflected arrivals and cannot be used to produce an optical reflection seismic image of the subsurface unless it is used to calibrate a sonic log that has been transformed into a hybrid known as a synthetic seismogram. Synthetic seismograms are popular because they are inexpensive, easy to produce and use from available

sonic log data, and they may give satisfactory results in cases where rock velocities are already well known and more predictable. Difficulties may arise in softer rock regimes, such as the U.S. Gulf Coast and areas of more complex structure and stratigraphy.

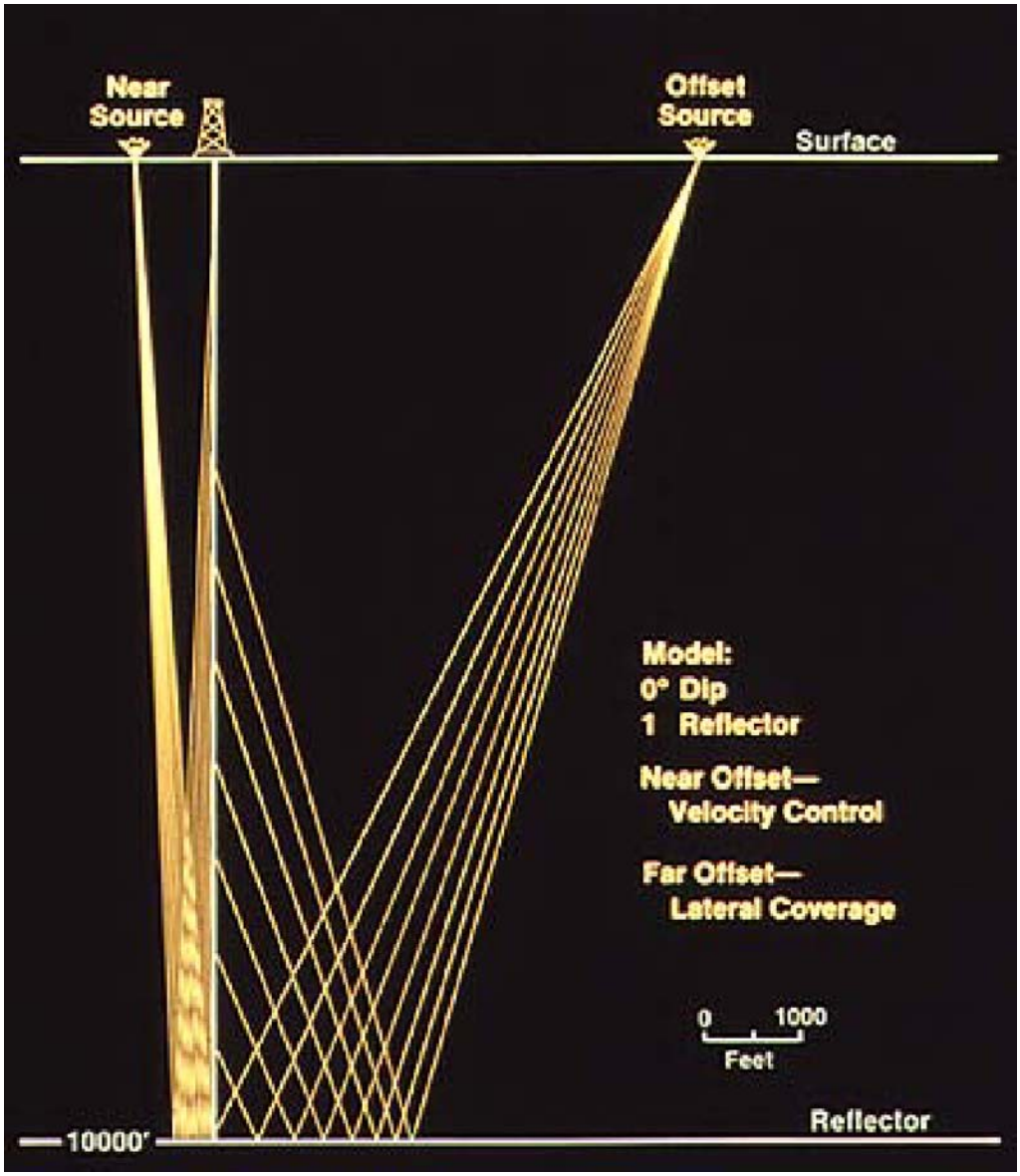

Figure 1. Near or zero offset source surface position with offset position for comparison. An offset VSP survey design should always include a zero offset source location to calibrate the offset to the well bore and to provide velocity control.

Look Ahead VSP Survey Utility

Because genuine reflected arrivals from strata a significant distance below the T.D. of a well are recorded by the downhole geophone tool in a VSP survey, there usually is always an opportunity to handle this information selectively during the data processing phase of the project. More information about the subsurface is available from a VSP if one is willing to make a small investment of time and money to produce an additional computed product, such as an impedance profile log. The log is an inversion technique that takes the recorded VSP data and inverts the process that generated the reflection response to derive the original reflection sequence that allows the look ahead aspect inherent in virtually every VSP

survey to be utilized. The look ahead VSP survey is an option any time one wants seismic information ahead of the T.D. of a well to help locate a suspected overpressured zone, fault, amplitude anomaly, or any other structural or stratigraphic feature that may be imageable by seismic data. The prospect of getting useful information ahead of the drill bit and then being able to use it to save time and money is an exciting possibility, and this proven application of VSP technology helped propel it to fame in the early 1970's, when VSP surveys started to be conducted in earnest in the U.S. An application of the computed products of the look ahead VSP survey, among them the upgoing wavefield display and how it may be used to "predict" or indicate at what depth a target formation and its corresponding seismic reflector via visual correlation will be encountered in the subsurface by the drillbit, is illustrated in Figure 2. A check of the method's accuracy may be done if and when the well is deepened and additional VSP data levels are recorded, compared to the actual strata encountered in the well bore, and then compared back to values anticipated earlier before drilling continued. A sonic log will be very helpful with the process.

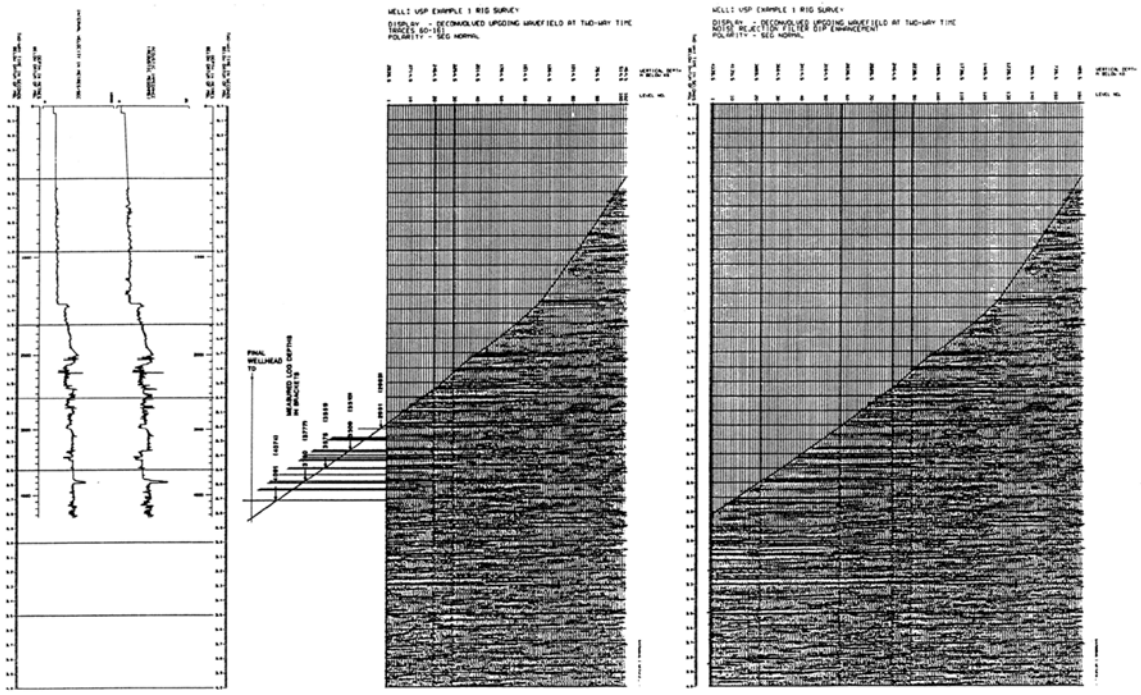

Figure 2. Comparison of predicted data (center panel) with well results - log data (left panel) and additional VSP data recorded after well was deepened (right panel).

VSP Data Inversion Produces Acoustic Impedance Log Below T.D. of Well

Inversion is a process that is closely related to look ahead or prediction ahead of the bit and entails one of the most useful tools for this application. The process that generated the reflection response of the recorded VSP data is inverted to derive the original reflection sequence. Corridor stacking of a zero or near offset VSP survey can be used to generate an acoustic impedance log (sometimes known as a pseudo sonic log), below the total depth of a well. Acoustic impedance variations indicative of changes in rock properties can be identified. The information is useful in identifying a particular target below the well, such as a salt layer, overpressured zone, or a sequence of sands in an otherwise homogeneous shale section. Specific details of the inversion process are beyond the intended scope of this article; however, they basically involve describing the acoustic profile associated with a reflectivity sequence of discrete reflection coefficients. Additional applications of inversion include modeling to fill gaps in logs, lateral impedance prediction in a deviated well, aiding surface seismic inversion after wavelet correction, and porosity studies. There are four generally considered data-processing options regarding how the velocity profile may be extended beneath the TD of a well (1) letting the estimated impedance wander, (2) forcing all trends out of the inversion to remove low frequencies, (3) forcing a trend that mimics the general increase in velocity with depth, and (4) modifying the profile below TD to include prior knowledge

(essentially "training" the profile) of acoustic data from nearby wells (Figure 3). When acoustic data from nearby wells is unavailable, experienced practitioners have had limited success carefully integrating lithologic information interpreted from gravity and magnetic profiles. Letting the estimated impedance wander and forcing out all trends are not recommended. Forcing a trend that mimics the general velocity increase with depth and modifying the profile with known information from nearby wells are the recommended options. The modification, or "training," of the velocity profile below TD option is the most intriguing to the writer as it theoretically should have applications to the neural network forward modeling studies that have been done with well logs.

The Future

VSP surveys will be performed more often as our industry strives to get the most useful and cost-effective seismic data available in a prospect area to help make critical drilling decisions. The shortcomings of surface seismic profiling relating to recorded frequency bandwidth limitations, shadow zones in areas of complex subsurface structure, higher cost and significantly slower data-processing turnaround than the VSP will continue to encourage explorationists to consider borehole seismic surveys. The look ahead capability of the zero or near offset VSP is currently an under-utilized option in our industry. Its usage will undoubtedly increase with time because it is easy to include in a well's logging program and is probably the most cost-effective and accurate way to obtain information about the nature of the rocks ahead of the drill.

Recommended References

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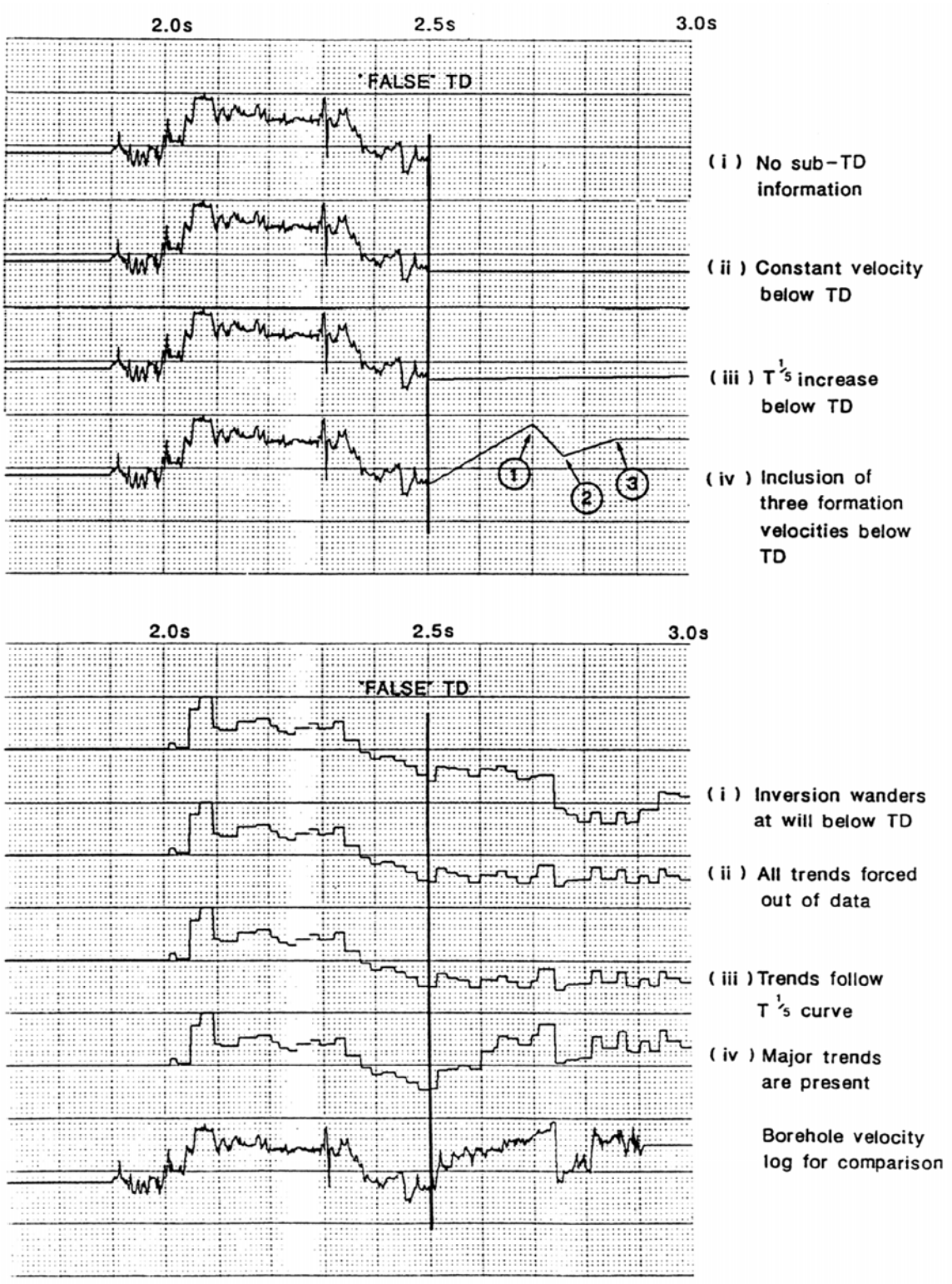

Figure 3. Effects of different velocity trends applied below TD of a well. Top panel represents available choices for handling velocity below TD. Bottom panel shows resultant impedance log below TD with actual sonic log for comparison.