[GC]VSP Image Adjustment to Stratigraphy and 3-D Seismic*

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General Statement

Vertical seismic profiling (VSP) is a measurement procedure in which a seismic sensor is lowered to a sequence of selected depths in a well by wireline, and at each of the downhole receiver stations that sensor then records the downgoing and upgoing seismic wavefields produced by a surface-positioned source (Figure 1). An important concept to understand regarding VSP imaging is that VSP recording geometry causes the stratigraphy at a VSP well – where sequence boundaries are known as a function of depth from well logs and sample/core control – to be welded to the VSP image, which is known as a function of VSP reflection time.

This welded relationship between stratigraphy and a VSP image results because VSP receivers are distributed vertically through geologic image space, allowing both stratigraphic depth and seismic travel time to be known at each downhole receiver station. This dual-coordinate domain (depth and time) involved in a VSP measurement means that any geologic property known as a function of depth at a VSP well can be accurately positioned on, and rigidly welded to, the time coordinate of the VSP image (Figure 1).

The reverse situation also is true: The VSP image can be accurately positioned on, and welded to, the depth coordinate of the stratigraphic column at a VSP well. This latter option of transforming a VSP image to the stratigraphic depth domain is not done as often, because the usual objective of prospect interpretation is to insert stratigraphy into 3-D seismic data volumes that are defined as functions of seismic image time, not as functions of stratigraphic depth.

Concept

A VSP image and a 3-D seismic image often have different time datums, because the images were made by different contractors who used different depth datums for the time origin, different replacement velocities to move source stations to this depth datum, and different illuminating wavelets. As a result, an interpreter often has to shift a VSP image up or down relative to a 3-D seismic image to determine an optimal match between the two images.

The concept of a welded bond between a VSP image and the stratigraphy at a VSP well means that whenever an interpreter moves a VSP image up, say by 20 ms, to better correlate with a 3-D seismic image, the stratigraphy moves up by the same amount (20 ms) in 3-D seismic image space. Likewise, if the VSP image has to be moved down to create an optimal waveform character match with the 3-D data, then the straigraphy shifts down by the same amount in the 3-D seismic volume.

The fact that VSP data provide an independent image that can be moved up and down to find an optimal match between VSP and 3-D seismic reflection character is the fundamental property of the VSP-to-seismic calibration technique that establishes the correct time shift between 3-D seismic image time and VSP image time. When the time shift between the 3-D seismic and VSP images is determined, then the correct time shift between the 3-D seismic image and the stratigraphy at the VSP calibration well is also defined, because that stratigraphy is welded to the VSP image and moves up and down in concert with the VSP image-time axis.

Example

An example of a VSP-based stratigraphic calibration of a 3-D data volume is shown as Figure 2. This VSP image is the same one displayed in Figure 1 and was produced from a large-offset VSP survey where the source was positioned 600 meters (2,000 feet) from the receiver well. The fact that stratigraphy is welded to the VSP image, causing stratigraphic interfaces to move up and down in concert with the VSP image during the VSP-to-seismic image calibration process, is what ensures that targeted thin-bed units are positioned in the correct time windows in the 3-D seismic volume when an optimal alignment is established between the VSP and 3-D images.

In Figure 2, this VSP-based interpretation procedure leads to the conclusion that although the tops of thin-bed units 19C and 15 are positioned at VSP image times of 1.432 s and 1.333 s, respectively, they have to be inserted into the 3-D data volume 18 ms earlier in image time at 3-D image times of 1.414 s and 1.315, respectively.

Conclusion

Note that this interpretation procedure leads to the conclusion that some thin-bed units correlate with peaks in the 3-D volume. Some thin-beds are associated with troughs. Some thin-beds are positioned on zero-crossings of the 3-D wiggle-trace data. However, for each thin-bed unit we can be sure that we have defined the proper 3-D seismic data window at the VSP calibration well, where seismic attributes can be calculated to study the distribution of each thin-bed reservoir throughout 3-D image space.

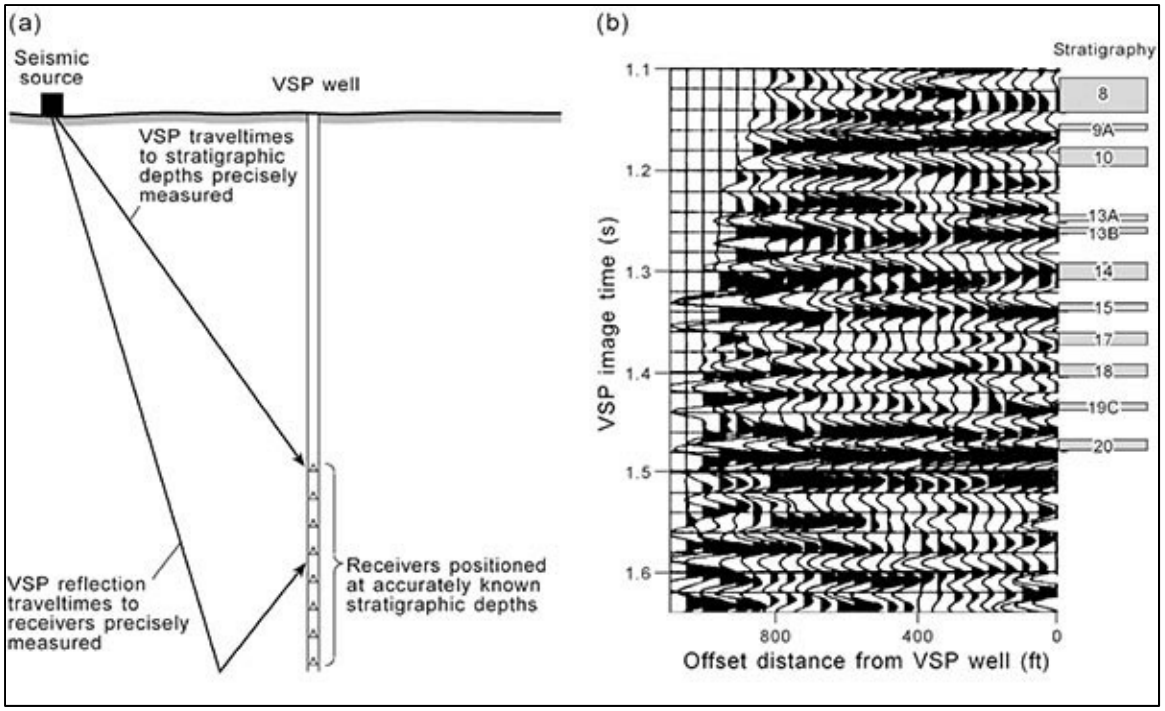

Figure 1. Concept of VSP depth-to-time calibration. VSP data are unique in that they are the only seismic data that are recorded simultaneously in the two domains that are critical to geologic interpretation: straigraphic depth and seismic reflection time (a). As a result, specific stratigraphic units – known as a function of depth from well log data – can be precisely positioned in their correct VSP image-time windows (b). With the exception of unit 8, each reservoir labeled here is a thin-bed penetrated by the VSP well. When the VSP image is shifted up or down to better correlate with a surface-recorded seismic image, the VSP-defined time window that spans each thin-bed unit should be considered as being welded to the VSP image, causing the stratigraphy to move up and down in concert with the VSP image as an optimal match is established between the VSP and seismic images.

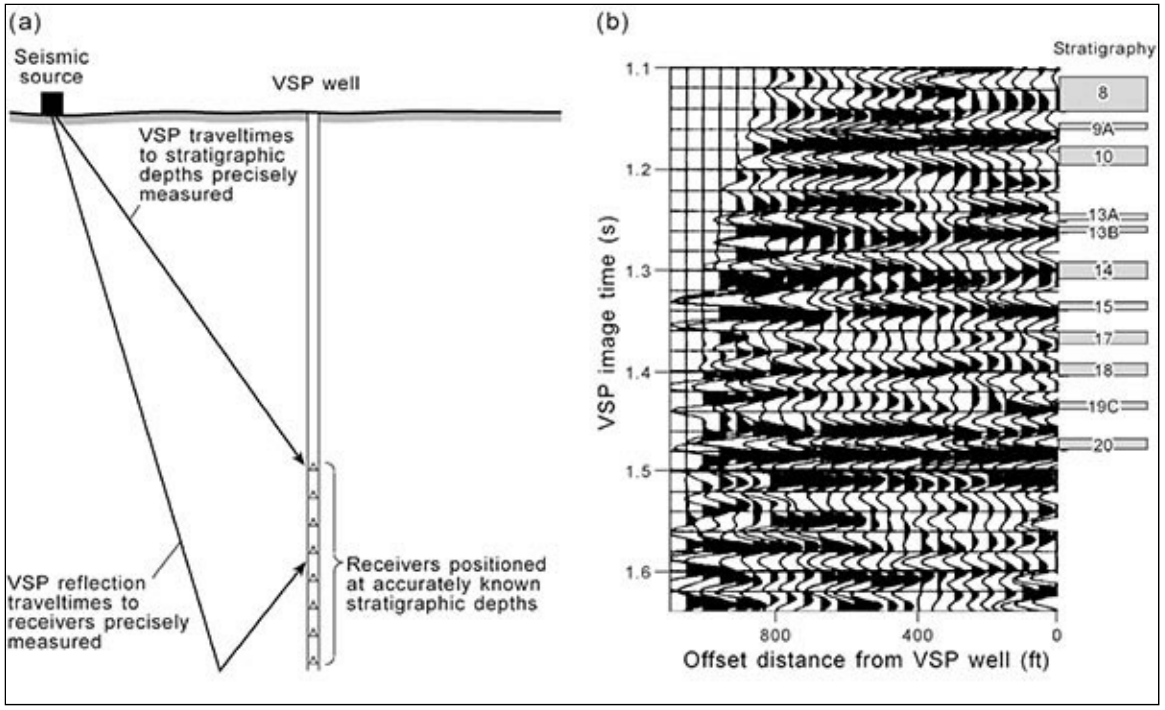

Figure 2. VSP-based calibration of thin-bed stratigraphy in 3-D seismic image space. The rigid welding of stratigraphic depth to VSP image time described on Figure 1 is used here to interpret a 3-D data volume. In this example, the VSP image from Figure 1b must be advanced (moved up) by 18 ms to optimally align with the 3-D seismic image. Because the stratigraphy penetrated by the VSP well is welded to the VSP image, the positions of the stratigraphic time windows in the 3-D image must also move up by 18 ms. The fact that VSP technology provides not just a time-versus-depth calibration function but also an independent image that can be time shifted to correlate with a surface-recorded image is the unique feature that makes VSP calibration of stratigraphy to 3-D seismic image time more reliable than check-shot-based stratigraphic calibration.