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The Value of VSPs

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Summary

A Vertical Seismic Profile (VSP) directly connects borehole measurements to surface seismic measurements via time-to-depth calibration and as a result, VSP's are the perfect bridge between the geological and petrophysical analysis performed as a part of any work done to understand the subsurface. This presentation will review the basics of VSP design, acquisition, and processing as well as show how VSP data can be used to help in all phases of exploration and development. Case studies will be utilized to showcase how proper VSP acquisition planning and processing can enable geoscientists to get the most value out of their data. Some key factors that will be discussed are direct seismic ties in sparse data areas and complex imaging for structural and stratigraphic plays. VSPs connect borehole measurements to surface seismic measurements forming a perfect bridge between the geological and petrophysical analysis performed as a part of any work done to understand the subsurface.

Theory

A Vertical Seismic Profile, or VSP is the process of recording seismic data in a wellbore environment rather than along the surface. The difference between surface and borehole data acquisition is the geophones are deployed within the borehole versus horizontally across the surface as in surface seismic, this may seem like a small difference but the fact the data is recorded in this manner allows for direct correlation between the data collected from a wireline survey and the surface seismic response thus making the VSP the perfect bridge between the wellbore and the surface seismic data. The drive to use VSP's has always been its direct tie to the borehole in its deployment and its ability to have some form of risk control either during the drilling phase or as a field development tool.

As the VSP capabilities have grown over the years so has the potential for applications. Opportunities to use VSP data are not just limited to velocity/time depth ties, or corridor stack ties anymore they extend to proactive applications for improving the understanding of your reservoir and the surrounding geology. The diverse types of wavefields generated while acquiring a VSP survey can be used to determine the: reservoir depth with a much greater accuracy, refine the volume, determine heterogeneity, look at the content, and analysis the formation rock mechanics/elastic properties. A lot of these advantages when acquiring VSP's can be done prior to drilling, during drilling, or after you have reached TD. VSP's do not just looking at the near-field formation, but also the far-field allowing for a much broader look at data around you well. The VSP data can be used for detailed exploration and production analysis in both complex geology and high-resolution stratigraphic areas.

Most exploration/development programs include a component of surface seismic to help guide the drill bit to the target or optimize locations for wells. The seismic data is often interpreted based on geologic models, horizon continuity, and any nearby wellbore data that is available for velocity and density calibration (synthetic) as well as time-to-depth calibration, without some direct calibration to substantive data from the area the surface seismic is assumed to be a good representation of the subsurface geologic reflections with little distortions. In most areas around the world there are a lot of supportive data to assist in the interpretation of the surface seismic data, but in the case of the Canadian Rockies and the South American Andes this is often not the case. The lack of a tie-in capability and inherent imaging issues due to complex geomechanical conditions often seen in these areas can result in errors when mapping the seismic horizons. As a result of these mapping errors misplacement of wellbores either by offset or depth, errors in delineation of the reservoir, and structural dip evaluation of the target zone.

Some key factors that will be discussed are direct seismic ties in sparse data areas and complex imaging for structural and stratigraphic plays. VSP's are a direct seismic recording, they use the same source and receiver recording so the data you get is as mentioned the best bridge between what you are seeing in your borehole measurements and what you have on your surface measurements. The difference between the two is normally related to assumptions used for surface data imaging, and or limited data bandwidth and quality. By having the receivers down the wellbore, close to the formation(s) of interest the data quality is often much better, and the direct velocity information obtained by having the receivers downhole allows for improved data imaging away from the well (Whitmore and Lines, 1986).

Common applications when analyzing a VSP data set, using the data to determine the validity of your surface data are:

- Time-Depth determination
- Geologic velocity ties
- Energy dispersion (Q)
- Phase
- Wellbore guidance's during drill (look ahead)
- AVO/AVA
- Shear wave imaging (P, PSv, S)
- Anisotropy

One more complex application of VSPs is anisotropic velocity corrections for complex structural imaging. The geometry of VSP acquisition allows for in-situ measurements of angular velocities that can then be used to improve the imaging of the surface seismic that is affected by anisotropy.

Anisotropy is defined as the variation of a physical property depending on the direction in which it is measured. In the case of seismic exploration, the physical property is "velocity", and the direction is the path of the seismic waveform as it travels through the earth. The most common application used for surface data is what is referred to as "Weak Elastic Model". Thomsen

(Geophysics Vol. 51, 1986) describe the model where the velocity should be faster in the horizontal direction that in the vertical direction. Measuring this change in velocity has been problematic. Core samples can be used, as well as full waveform sonic data. The problem with these approaches is that in order to get very accurate measurements multiple wells need to be drilled at various angles of penetration to simulate the change in direction. In the VSP case by having a receiver string down hole and source positions walking away from the zero degree (vertical to the well) you can directly measure velocities based on direct arrival times for multiple angles of the energy path, all in one well. Not understanding and properly dealing with anisotropy will potentially give you errors in imaging as well as any elastic property interpretation.

Results

This presentation will show how VSP data can be used to help in all phases of a drilling program, from exploration through various phases of development. Case studies illustrating modeling and processing results will be shown.

Further information to be added based on processing results.

Acknowledgements

TBD

References

N. D. Whitmore and Larry R. Lines, 1986, Vertical seismic profiling depth migration of a salt dome flank, GEOPHYSICS 51:5, 1087-1109

Leon Thomsen, 1986, "Weak elastic anisotropy," GEOPHYSICS 51: 1954-1966.