WS5-P14

The Application of Borehole Hydrophone Arrays in Hardrock Environments

A.J. Greenwood* (Curtin University), M. Urosevic (Curtin University), J.C. Dupuis (Universite Laval) & A. Kepic (Curtin University)

SUMMARY

The geometry of a VSP survey allows us to understand the characteristics of both the transmitted and reflected wavefields. As such, VSP is an “in-field seismic laboratory”, necessary for understanding the origin of seismic events. VSP enables calibration of surface reflection images and the survey can be designed to produce an image around the borehole at a much higher resolution than the surface reflection method. The main drawback of the method with respect to the mining community is the high logistic cost. Hence the main objective of the research presented here is to look into alternative ways of implementing VSP surveys that are cost effective, readily implementable in slim holes and pose lower risk to equipment in unstable uncased mineral exploration boreholes. As shown in this work, these objectives have been met using a borehole hydrophone array. Presented are two field trials in the Agnew-Wiluna and Kambalda regions of Western Australia. The results of these field experiments demonstrate that a borehole hydrophone array is capable of imaging structure in a complex geologic environment. These results, however, are not easily achieved because of the high sensitivity of hydrophones to acoustic modes in the borehole and the passive coupling to the formation.

Introduction

The geometry of a VSP survey allows us to understand the characteristics of both the transmitted and reflected wavefields. As such, VSP is an “in-field seismic laboratory”, necessary for understanding the origin of seismic events. VSP enables calibration of surface reflection images and the survey can be designed to produce an image around the borehole at a much higher resolution than the surface reflection method. The main drawback of the method with respect to the mining community is the high logistic cost. Hence the main objective of the research presented here is to look into alternative ways of implementing VSP surveys that are cost effective, readily implementable in slim holes and pose lower risk to equipment in unstable uncased mineral exploration boreholes. As shown in this work, these objectives have been met using a borehole hydrophone array. Presented are two field trials in the Agnew-Wiluna and Kambalda regions of Western Australia. The results of these field experiments demonstrate that a borehole hydrophone array is capable of imaging structure in a complex geologic environment. These results, however, are not easily achieved because of the high sensitivity of hydrophones to acoustic modes in the borehole and the passive coupling to the formation.

Field trials

Field experiments utilised a 24 channel hydrophone array and an 800 kg weight drop as the seismic source. Unfortunately hydrophone sensors are prone to contamination from strong coherent noise in the form of tube-waves and other self-coupled modes of vibration. Quality of the field records can be increased drastically via acoustic isolation mitigation strategies and the use of high-viscosity drilling fluids. Increased SNR through the use of borehole fluid viscosifiers, acoustic isolation and construction of densely populated (e.g. 2m) hydrophone strings provide the best conditions to make high quality VSP measurements. Such that are comparable in quality to the traditional offering but at a significantly lower cost.

The Agnew-Wiluna survey demonstrates the imaging potential of walk-away VSP with 24 channels in the borehole spanning 230 m and surface shots ± 500 m from the borehole collar. Data collection was conducted over a period of one day. The up-dip and down-dip shots were carefully examined at each stage of the processing flow, to determine the limits beyond which the reflection energy is no longer being added to the stack. In the up-dip direction this condition is rapidly reached, once the offsets are greater than the lateral extent of the receivers. In the down-dip direction large offsets are required. From a logistical approach, this requirement can be hard to accommodate in practice for very steeply dipping structures and limited source strengths. We recommend a careful study of the modelled response for the specific geologic settings prior to acquisition. To this end, one should pay particular attention to the polarity of direct wavefields and refracted arrivals in order to develop robust processing strategies and interpretation of the resulting images. The Agnew-Wiluna depth migrated image used all the down-dip and only 200 m of the up-dip shot gathers. This image is in strong agreement with the structural model of the area and is shown in Figure 1A. This experiment also highlights the difficulty in obtaining an accurate image. Despite VSP giving a true velocity profile, extrapolating this to 2 or 3 dimensions involves priori structural knowledge and leads to the classic seismic conundrum that; if an accurate velocity model is known, then you already know the structure that you are trying to image.

The second hydrophone experiment was conducted in Kambalda within a 27 km² 3D seismic survey. Here we show that a narrow aperture migrated image can be attained from a zero-offset VSP. Mineral exploration boreholes are typically drilled at acute angles to the surface to orthogonally intersect dipping geological horizons. The borehole deviation results in lateral aperture between the surface source and borehole receivers. In Kambalda this was approximately 160 m over the 610 m survey interval of the borehole. After wavefield separation, the up-going wavefields were depth migrated. The resulting zero-offset depth migrated image has an excellent correlation with the 3D cube and is shown in Figure 1B. The depth migration is restricted to imaging only shallow dipping events below

the borehole due to the short offset. However, this example clearly demonstrates the usefulness of VSP migration in deviated holes for “borehole ties”.

Figure 1 A) Walk-away hydrophone VSP image (top) and schematic earth model (bottom) at Agnew-Wiluna, Western Australia (modified from Greenwood, 2010). B) Zero-offset hydrophone VSP inserted into 3D cube at Marthas Vineyard, Western Australia (modified from Greenwood, 2012).

Conclusions

Borehole hydrophone acquisition has been shown to be a cost effective and efficient strategy to acquire high quality VSP measurements in hard-rock environments. Images obtained from field experiments show there is high potential for hydrophone VSP imaging (walkaway and 3D) in hardrock environments. Mitigation of high amplitude borehole modes, acoustic isolation and proper design of the acquisition parameters are key for the success of a hydrophone VSP survey.

Acknowledgments

The work has been supported by the Deep Exploration Technologies Cooperative Research Centre whose activities are funded by the Australian Government's Cooperative Research Centre Programme.

References

- Greenwood, A., Dupuis, C., Hashemi, A. and Urosevic, M. [2010] Hydrophone VSP Imaging in the Agnew - Wiluna Belt, Western Australia: *ASEG Extended Abstracts*, 1-4.
- Greenwood, A., Dupuis, C.J., Urosevic, M. and Kepic, A. [2012] *Hydrophone VSP surveys in hardrock Geophysics*, **77**, WC223-WC234.