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Borehole Hydrophone Aquisition - Some pitfalls and solutions

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SUMMARY

Hydrophones are highly sensitive broadband pressure sensors. They are slim-line, lightweight, rapidly deployable and do not require clamping. Strings of 24 – 48 receivers can be manufactured for the same cost as a single slim-line 3C shuttle.

The passive hydraulic coupling and suspension within the water column employed by the hydrophones lead to specific acquisition issues due to noise sources related to cable and borehole seismic modes. With the use of a 24 channel hydrophone string, over several surveys in predominately mineral exploration boreholes, we have investigated suppression of these noise sources.

Improvement of hydrophone coupling to the formation is achieved through higher viscosity drilling fluids. It is also encouraging that very high quality converted shear waves can be recorded with hydrophones.

We show that due to easy deployment and rapid acquisition time it is possible to utilise very fine hydrophone increment of just 1m which enables a proper registration of tube waves and hence their effective removal.

Finally we test our hydrophone array in a complex hard rock environment. Using a known geological model, through extensive elastic modelling we prove the validity of an ultra-high resolution VSP image constructed from hydrophone data.

Introduction

Borehole seismology whether it is check-shot or reflection imaging typically uses 3-component (3C) receivers that clamp to the borehole wall. Good receiver coupling is essential for data quality and tools thus require considerable engineering to produce the required clamping forces reliably. VSP is considered a costly technique due to the long data acquisition times of relocating and clamping shuttles and the associated costs of drill rig standby (Chopra and Hardage). Acquisition efficiency of VSP surveys is constrained by the number of receivers deployed at one time within the drillhole. Development of receiver arrays of up to 1000 levels are expected within the next few years (Muller, et al.).

Mineral exploration, engineering investigations and environmental monitoring boreholes are usually small in diameter (<100mm) and relatively shallow (200m -100m) in comparison with petroleum exploration wells. The associated drilling costs of small diameter boreholes are in the order of 10’s to a few 100’s of thousands of dollars; a fraction of the cost of an oil well. Similarly the engineers and mineral explorers’ geophysics budget is only a fraction of its oil counterpart. There are few lightweight, multi-shuttle and slim-line VSP tools available. In addition, their cost are often comparable to the cost of the borehole itself and thus exploration managers are standoffish to trial VSP techniques which may double the cost of the hole should the tool be lost. As such VSP in small diameter holes is infrequent and remains expensive for the mineral industry.

Hydrophones are highly sensitive broadband pressure sensors. They are slim-line (<50mm), lightweight, rapidly deployable and do not require clamping. Strings of 24 – 48 receivers can be manufactured for the same cost as a single slim-line 3C shuttle. Thus hydrophones are an attractive borehole seismic alternative for mineral, environmental and engineering geophysicists.

The passive hydraulic coupling and suspension within the water column employed by the hydrophones lead to specific acquisition issues due to noise sources related to cable and borehole seismic modes. With the use of a 24 channel hydrophone string, over several surveys in predominately mineral exploration boreholes, we have investigated suppression of these noise sources. Trials included hydrophone baffling, isolation /suspension of the borehole string, effects of drilling fluid viscosity and variation of acquisition parameters.

Viscosity of drilling fluids

One example is shown in Figure1, where the improvement of hydrophone coupling to the formation is achieved through higher viscosity drilling fluids. It is also encouraging that very high quality converted shear waves can be recorded with hydrophones.

On the acquisition side we show that due to easy deployment and rapid acquisition time it is possible to utilise very fine hydrophone increment of just 1m which enables a proper registration of tube waves (un-aliased) and hence their effective removal.

Finally we test our hydrophone array in a complex hard rock environment. Using a known geological model, through extensive elastic modelling we prove the validity of an ultra-high resolution VSP image constructed from hydrophone data.

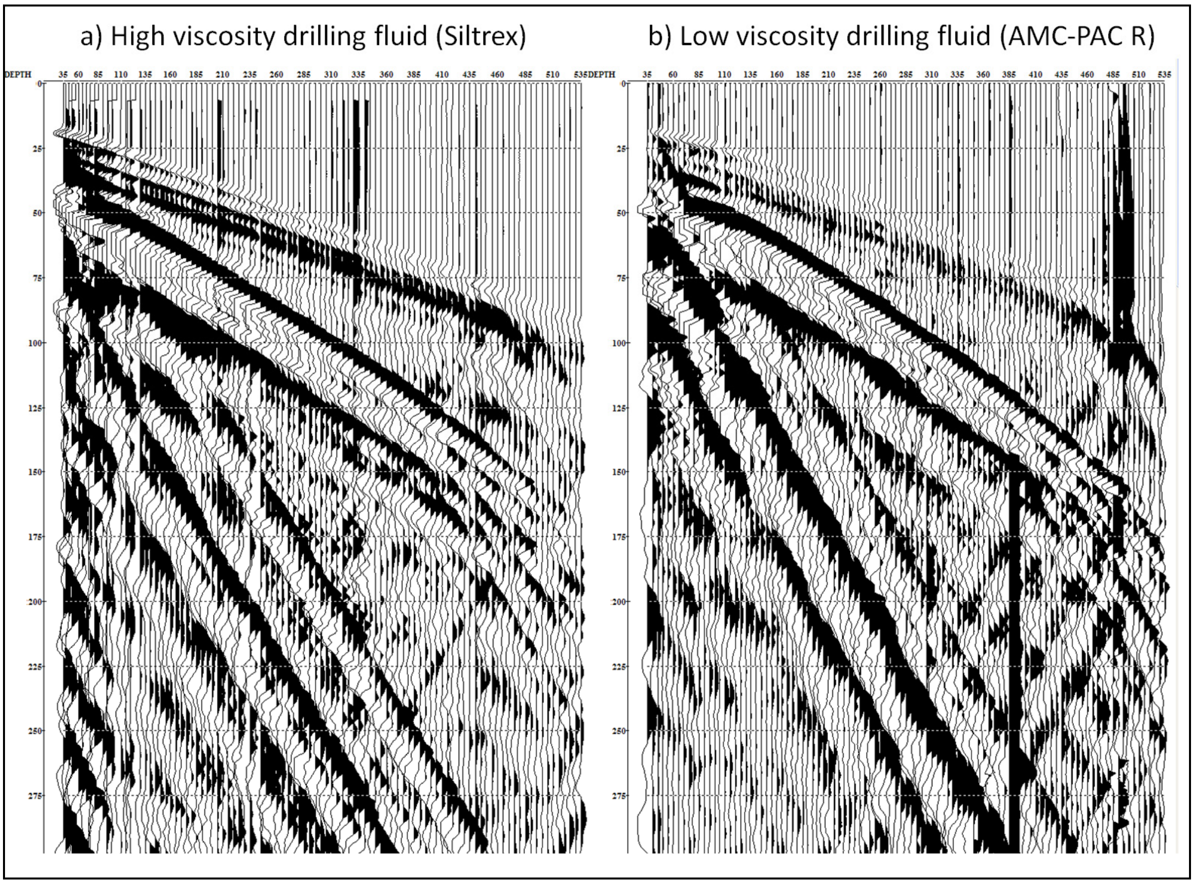

Figure 1 *Two shot gathers collected in the same portion of a borehole (35m-535m) before and after flushing the hole with different viscosity drilling fluids to clear a blockage at 550m . In the left hand image (a) a high viscosity drilling fluid was used to hold up the borehole. The right hand image (b) is after flushing the hole with a lower viscosity drilling fluid. Both images are presented with the same gain and display parameters. Data were collected with a 24 channel hydrophone string and 800kg weight drop hammer in a mineral exploration hole in the eastern goldfields of Western Australia. The string was isolated from the drill rig and suspended on a foam damper at the collar.*

Conclusions

Hydrophones offer an inexpensive opportunity to conduct borehole seismology surveys where borehole diameters are limited. We have produced high SNR records adequate for reflection imaging and acquisition efficiencies of up to 4 offset VSPs being collected during a single shift in a 1000 m borehole with 5 m spatial sampling.

As hydrophones are passively coupled to the formation through the borehole fluid the primary source of ambient noise is via the hydrophone cable. Isolating the hydrophone string from the sheave wheel and rig mast (or tripod) and suspending the cable from the collar with a damping device significantly improves SNR.

Higher viscosity fluids improve SNR reducing ambient noise and better coupling the hydrophone to formation. Also with appropriate use of drilling fluids and borehole preparation, induced tube waves from fracturing and washout zones can be partially negated. The full effects of different drilling fluids is not known and is worthy of further investigation.

Tube waves are the dominant source of coherent noise in the hard rock environment and propagate up and down the hole for many oscillations. It is not possible to suppress tube waves with baffling in hard rocks, however with correct spatial sampling and high SNR it is possible through deconvolution, 2D and velocity filters to remove tube wave noise.

Acknowledgments

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