DISTRIBUTED ACOUSTIC SENSING FOR MINERAL EXPLORATIOIN: CASE STUDY

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SUMMARY

Vertical seismic profiling (VSP) is commonly used in the oil and gas industry for better subsurface imaging and characterisation, as well as for providing depth calibration for surface seismic. The use of VSP in mineral exploration and mine planning is not very common mostly due to the small diameter and stability of the boreholes, as well as the relatively high cost of such surveys. These issues can be mitigated by using cheap and potentially disposable borehole sensors, such as fibre-optic cables utilised in distributed acoustic sensing (DAS).

The questions we want to answer in this work are how the quality of DAS data compares to other types of borehole measurements and what are the operational benefits and constraints for the use of this technology in mineral exploration settings. To this end, we have tested performance of DAS measurements in one of the boreholes of the Mineral Systems Drilling Program in South Australia and compared them to hydrophone measurements. The DAS measurements provide data quality that is much better than a hydrophone string, in particular it has consistent amplitudes at different depths, shows less cable and tube waves, and the reflections are much clearer. The acquisition of DAS data is quicker than any other borehole measurements that require multiple pulls of the receivers. The reduction of the acquisition time increases with the depth of the borehole. This case study demonstrates that DAS measurements show big potential for mineral exploration and exploitation.

Key words: Distributed Acoustic Sensing; Vertical Seismic Profiling; Fibre-optics sensing, Mineral exploration.

INTRODUCTION

The use of distributed acoustic sensing (DAS) for vertical seismic profile (VSP) surveys is rapidly gaining in popularity due to its high efficiency when compared to conventional acquisition systems. This efficiency is a result of the systems use of a fibre optic cable as the sensor. An interrogation unit (IU) on the surface transmits pulses of light that travel down the fibre. Inhomogeneities in the cable cause some of the light to be scattered back up the cable where it is detected by the IU. If the cable is strained by the passage of seismic waves then the travel time of the backscattered light, and thus its phase, changes. By measuring the change in phase we can estimate the strain on the cable and detect the passage of the waves (Parker et al. 2014).

DAS can be potentially very well suited for mineral exploration and exploitation due to the negligible cost of the fibre, its ease of deployment in small diameter boreholes, and the speed of acquisition due to the sensitivity along the entire length of the cable. These characteristics are in contrast with the standard borehole seismic sensors that are expensive, difficult or impossible to deploy in small diameter boreholes, and need to be gradually pulled up the borehole as they measure only at a single location (or a small number of locations for a string of sensors). DAS has however some potential disadvantages. One of them is the limited sensitivity of the ground motion to only the direction along the fibre; geophones can be oriented along different directions and hydrophones sense changes in pressure. Another potential disadvantage is the lack of a mechanism to couple the fibre to the formation; geophones can have a mechanical arm and hydrophones are coupled through the borehole fluid.

To establish viability of field use of DAS for mineral exploration, we performed a field study of measuring VSP data with a DAS system and compared the results with hydrophone measurements. The field study was done at the Mineral Systems Drilling Program (Fabris et al. 2107) site with two closely spaced boreholes MSDP02 and coiled tubing (CT) drilled MSDP15. This site was chosen because we had acquired VSP data with a hydrophone in MSDP02 borehole in 2016, which could be used for comparison of data quality and field work complexity between the DAS and the hydrophone systems.

FIELD DATA ACQUISITION

To acquire data with a 24 channel hydrophone string with spacing of 2m between the receivers, one needs to deploy a generator powered winch that allows the string to be unspooled to the bottom of the borehole. The speed of unspooling of the hydrophone string is comparable to unspooling optical cable from a spool (Figure 1). Once the hydrophone string is deployed at the bottom of the borehole, the seismic source can generate the necessary energy that can be recorded by the system. This is the same for all the seismic borehole systems. The difference is that for a DAS system is that all the recording is done at this stage, whereas the traditional systems need to be winched up the borehole. In the case of the hydrophone string, it needs to be moved by 48m and the seismic source repeated. This needs to be done for the entire length of the borehole. If the borehole is ~500m deep, one needs to perform 10 pulls of the string and 10 repeats of the source effort. Since the unspooling and spooling of the systems takes approximately the same amount of time, the time difference between the systems is due to the necessary repeats of the source and the quality control of the acquired data. For the case of MSDP02, this time difference resulted in around five times shorter acquisition by the DAS system compared to the hydrophone string.

Figure 1 Left: DAS cable on its reel showing the ease of deployment – no need for special winches. Right: A DAS cable inserted in MSDP02 borehole. The rugs in the hole are to protect the hole from "air-blast" – a wave induced by air-wave produced by the source.

Another feature of DAS data acquisition is the sacrificial nature of the sensor. This is important as lowering sensors to open, and sometimes in cased, boreholes always carry the risk of losing the tool. This concern is irrelevant in the case of DAS, as the typical cost of the cable is a few dollars per meter. Thus, if the cable does get stuck in the borehole, one can just leave it there (Figure 1). The source used for this survey was a skid-steer mounted 720 kg weight drop. The offset of the source location from the boreholes head was ~20m. For the DAS acquisition we stacked 12 shot records, whereas for the hydrophones we used single shot.

DATA COMPARISON

Figure 2 shows the data acquired in the same borehole (MSDP02) using the hydrophone string and DAS. The borehole was PVC cased to 170m depth. There are some stark differences between these two datasets, in particular:

1. Hydrophones show different amplitudes and tube waves for each set of 24 traces; this corresponds to the different conditions for different pulls of the string, as the tube waves are not repeatable between different shots.
2. Contamination of the record with tube waves and cable waves in the hydrophone data is much greater than in the DAS data.
3. DAS data shows much more reflected body waves than the hydrophone data.

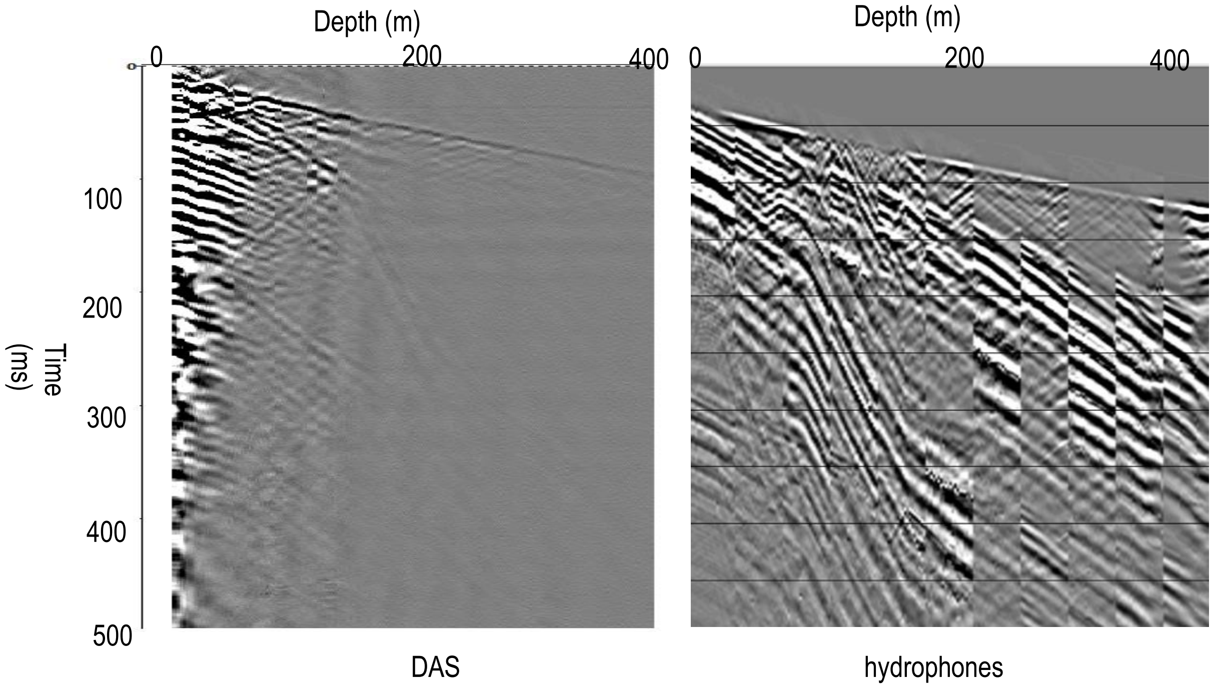

Figure 2 Comparison of DAS (left) and hydrophone (right) data from MSDP02 borehole. The strong change in the quality of the DAS data at 170m depth corresponds to the bottom of the PVC casing.

It is clear that DAS provides much better data quality compared to the hydrophone data. To see how well this data can be used for velocity estimation (necessary for good time to depth conversion for surface seismic and, also, for imaging and interpretation), we show the processed DAS data acquired in the CT drilled borehole, MSDP15. We chose this borehole because it is not cased and allows for better coupling between the sensor and the formation.

Figure 3 (left) shows the data before we filtered out the tube waves. The tube waves appear only in several locations; this can be explained by the generation mechanism of these waves. Tube waves can be generated by P-waves if these waves encounter fractures connected to the borehole fluid. The fluid from the fractures is pushed into the borehole and creates tube waves. We have indicated the fractured zones by the blue lines. The locations of these fractured zones were confirmed from the core data from the neighbouring MSDP02 borehole. Figure 3 (left) also shows the picked vertical velocity (red curve) that can be used for interpretation and for time to depth conversion of surface seismic data.

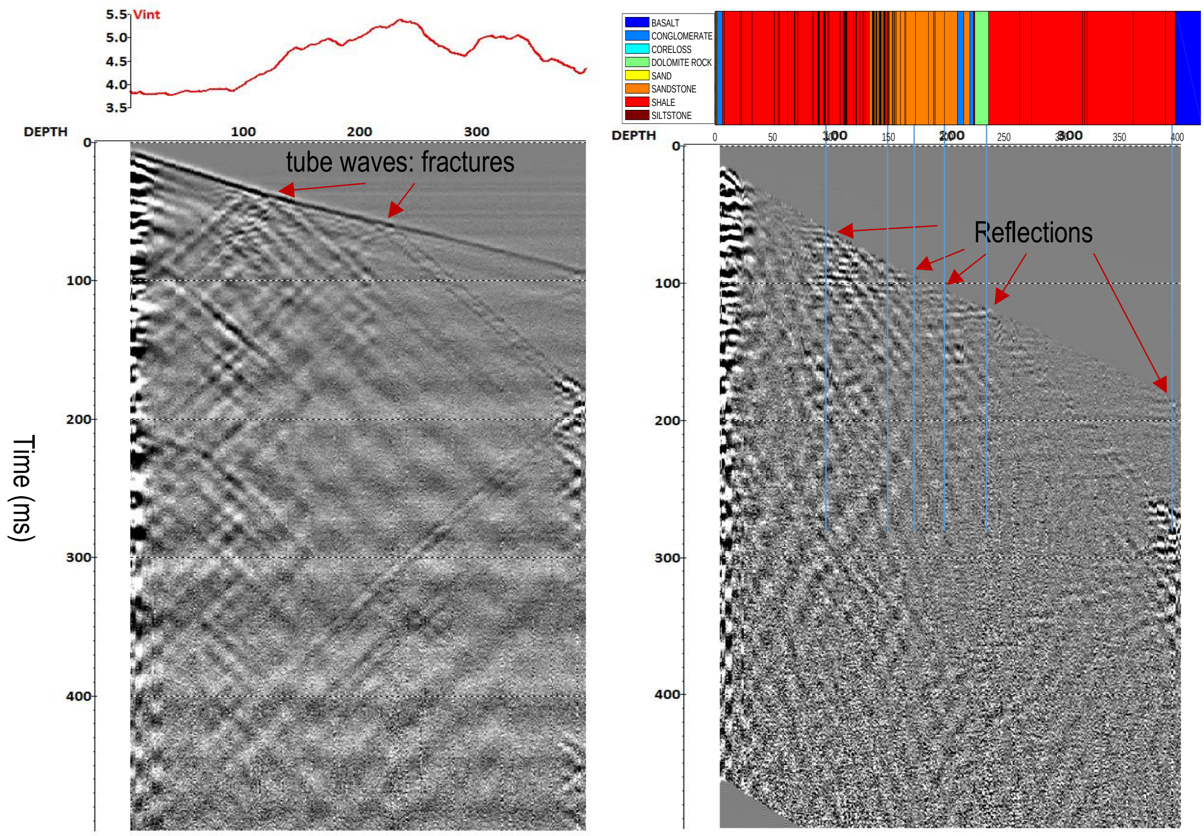

Figure 3. DAS data from MSDP15. Left: Unprocessed data clearly showing the direct and reflected P-waves. Red curve shows the derived interval P-wave velocity (in km/s). The arrows indicate depth intervals where tube waves are created – likely locations of fractured rock. Right: The data is shown in two-way travel time that flattens the reflected waves (indicated by the blue lines). The corresponding lithology derived from core is shown above the data.

To emphasise the reflected P-waves, we filtered out the down-going waves and flattened the reflected waves by transforming the dataset to two-way travel time. Figure 3 (right) shows this transformed dataset, and illustrates the agreement of the location of the reflections with the lithology log created from the core data. We have highlighted some of the stronger reflections by the blue lines.

CONCLUSIONS

Based on this study, DAS has the following clear advantages compared to hydrophones as the seismic sensors in mineral exploration boreholes:

- Consistent amplitudes
- Less tube and cable waves
- Clearer reflections
- Faster acquisition (in this example ~5x faster) = cheaper
- Sacrificial, low cost cable

DAS seems to exemplify a "seismic shift" in available technology that promises much broader uptake of VSP data acquisition for mineral exploration.

The quality of the DAS data can be impeded by the presence of non-grouted casing in the borehole. The sacrificial nature of the sensor allows for cost-effective acquisition in uncased holes, which produce better data.

ACKNOWLEDGMENTS

We acknowledge the support from Silixa and CSIRO. Special thanks to Light Touch Solutions for the cable preparation. 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.

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