High-productivity, high-resolution 3D seismic surveys for open-cut coal operations

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SUMMARY

3D seismic is routinely used for structural characterisation for underground coal operations, however the implementation of this technology for shallow, open-cut resources has been limited. The perceived high cost of shallow 3D seismic has been one of the main factors holding it back. This paper will demonstrate that by adopting and adapting best practice technologies from the petroleum industry, 3D seismic is not only cost effective but also delivers higher confidence resource knowledge compared to traditional pattern grid structural and coal surface drilling. With higher resolution understanding of structure affecting the coal resource, the business can better predict and mitigate risks such as Geotechnical events, and minimise impacts to production with an improved mine plan.

A series of trial surveys were acquired over a range of geological settings, including variable thickness Tertiary basalt cover, multiple seams and very shallow target seams. Success of the 3D seismic technique in all of these trials validated the larger scale implementation at other open-cut mines. Next, through a process of iterative improvement of parameters and survey design, improvements in productivity and data resolution of these surveys were made to maximise value of information. The third step was to embed the subsurface knowledge obtained from seismic data into mine planning workflows and decisions. This work has already resulted in reductions in drilling and adjustments to geotechnical models.

Current work is focussing on further optimisation of the data acquisition, processing and interpretation workflows to ensure fit-for-purpose, long-lived information is delivered to the business. This includes revisiting and reprocessing legacy 3D datasets to harness advances in processing algorithms.

Key words: coal, 3D seismic, open-cut mining, structure.

INTRODUCTION

3D reflection seismic is a proven method for resolving coal geology, producing a more continuous image of the coal seams than can be achieved using drilling (Peters, 2005; Peters et al., 2005), yet to date it is rarely used for shallow, open-cut coal operations due mainly to the perception that collecting and processing the data is too costly to replace drilling. Improving productivity, reducing cost and maximising value of information of seismic surveys are therefore important for the coal industry to leverage the potential of seismic.

In Australia, commercial land seismic surveys typically use Vibroseis sources, which are usually more operationally versatile and economical than dynamite sources. Flip-flop acquisition using multiple Vibroseis sources has been used for a number of years, achieving typical production in the range of 100-200 VPs/hour. In recent years, for certain petroleum applications, several higher production Vibroseis techniques have been used, increasing Vibroseis production by orders of magnitude (Mougenot et al., 2012). Adapting these techniques for shallow coal seismic surveys has been a key enabler for the commercial acquisition of large-scale 3D seismic data across active coal operations.

The high source productivity has been possible because of a shift from cabled receiver systems to lightweight nodal systems. The use of lightweight nodes has enabled significantly higher receiver productivity by the relatively small Australian seismic crews (moving up to 600 nodes per person per day). Nodes have also enabled the freedom to explore more flexible survey designs (e.g. variable line spacing).

What follows is a description of the high-productivity, high data resolution techniques that are being employed for shallow coal 3D seismic, with examples of the impact the seismic data is having on active mining operations.

Figure 1. Representation of the flip-flop method (a) and (b) with the slip-sweep method (c) and (d) in time and frequency domains (Dean, 2016). Green represents the sweep while blue represents the listening time.
METHOD AND RESULTS

High-productivity Acquisition Techniques

The slip-sweep method was originally proposed by Roosmond (1996) and can be described simply as one sweep starting without waiting for the other sweep and listen time to be completed, which is diagrammatically represented in Figure 1.

When trialled by BHP in early 2018 on a series of 2D lines, slip-sweep acquisition resulted in a vibrator productivity increase of 35% (Figure 2).

While this represents a significant productivity increase, further productivity improvements were needed before 3D seismic could viably be embedded as a tool to characterise shallow resources. Again, the template for this was provided by the Petroleum industry, and soon after the 2D trial, the learnings were applied to a high-productivity 3D survey acquiring Distance Separated Simultaneous Slip-Sweep (DS4) data. This mode allows for sources beyond a certain separation to sweep simultaneously, with the distance set so that there is no overlap of reflected signal within the region of interest (Figure 3). The two fleets 1 (green) and 2 (blue) sweep simultaneously, producing reflections of from the horizon of interest (solid lines) that intersect with the other’s noise (dashed lines) only at times and offsets greater than Tm and Om respectively.

The high-resolution 3D, DS4 survey used 26,000 nodes on a 24 m x 4 m orthogonal design with 1:1 source:receiver ratio and a 50 line x 324 channel live patch (16,200 nominal).

Variable Design and Symmetric Sampling

The shallow nature of open-cut coal targets presents a unique opportunity to optimise survey geometry because of the large that provided an equivalent 1.2 times signal-to-noise improvement.
range of relative target depths. This allows us to consider variable source and receiver intensity, tailored to sampling requirements at each depth.

While variable line spacing designs had been used in the past on BHP projects, earlier design philosophy focused on structural outcomes and fold was the primary design metric. The proposed design methodology has shifted focus to adequate sampling of the assumed wave field (facilitating QI and inversion) and the requirements of modern processing algorithms (e.g. cross-spread domain processing). An example variable survey design is shown in Figure 5. This has been achieved by implementing symmetric sampling compliant principles, described for example in Vermeer (2012), the benefits of which include full isotropic sampling of the wave field, full range of azimuth and offsets and better sampling of sources.

Case Studies

Firstly, an example from a high-resolution 3D survey acquired over very shallow target coal seam horizons, at 30-40 m depth. This survey successfully imaged small structures with <1 m throw, and with ±7 m lateral accuracy. Features of this scale have previously had a very low detectability rate from untargeted (pattern grid) drilling (Figure 6). In fact, a number of previously unknown faults with potentially significant impacts to the mine plan were identified.

Encountering steepening coal beds (like those as shown in Figure 6) late can cause significant production delays as mining methods have to be adapted to deal with the changing seam geometry. Seismic data delivers Mine Planning departments with confidence that such features can be predicted, and necessary mitigating strategies are planned effectively and in a timely manner, minimising disruptions to production and better mitigating geotechnical risks that in the past, were attributed to poor geological knowledge. Importantly, this information is able to be gained with a fraction of the drilling used historically to identify and characterise such structure (Figure 7).

The second dataset further demonstrates the impact of seismic to significantly improve fault and coal seam resolution, in this instance merging and reprocessing 3D datasets using modern processing algorithms. This generated a uniform 3D volume of the coal resource, and as with the first example it was possible to resolve faults to a high degree of confidence with throws <2m and with higher confidence on fault locations (Figure 8).

The reprocessed dataset has also enabled the use of more advanced interpretation (e.g. attribute analysis) to relate seismic properties to rock mass properties (Pavlova, 2019).

CONCLUSIONS

A number of recent technical and operational developments mean that the acquisition of high resolution, large scale 3D seismic surveys is now a commercially viable option for the open-cut coal mining sector. These include lightweight nodes, high production Vibroses, depth-variable survey designs, crew...
productivity optimisation techniques and modern data processing algorithms.

Examples have been used to illustrate that, relative to traditional grid-drilling, 3D seismic data can provide significant improvements to the understanding of shallow coal geology and geotechnical risks.

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Figure 8. Top image showing ant-tracked coal horizon from seismic overlaid with faults identified from drilling in orange. Section border colour matches section line on plan, showing surface modelled from drilling data in maroon and seismic in blue.