The influence of coal-mine geology on seismic data quality in the Bowen Basin

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SUMMARY

Over the past two decades numerous seismic surveys have been undertaken to assist with exploration over Australian coal mines. More recently this has been extended to assist with mine design and coal extraction. This latter application is placing increasing demands on the quality and resolution achievable with the seismic method.

We present a number of examples of seismic surveys conducted in the Central and Northern Bowen Basin which illustrate that seismic data quality is strongly influenced by localised mine geology. Unfavourable near-surface conditions including variable weathering and the presence of basalt or other high-velocity layers can drastically impact on image quality. The stratigraphy of the target coal seams also affects the definition of the target seam.

We comment on various ways of reducing the adverse effects of unfavourable mine geology. By incorporating knowledge of mine geology in the acquisition design and by utilising appropriate processing solutions, it is possible to obtain high quality seismic imagery.

Key words: Seismic, Tertiary, basalt, mine, longwall

INTRODUCTION

Numerous seismic surveys have been conducted over Australian coal mines in the last twenty years. Whilst the majority have been successful in meeting objectives, some results, particularly in the earlier years, were less convincing. In retrospect, it appears that such failures were sometimes associated with incomplete understanding of regional and local geological variations, and of how these factors impact data quality. An improved understanding of these issues over the past decade has enabled the seismic method to move from the exploration arena to become the primary geophysical tool for mine design and coal extraction.

In this paper we present typical examples of situations where seismic data quality is influenced by variations in the localised mine geology. Perhaps the most striking geological influence relates to the near surface, where drastic degradation in the seismic image can result from lateral variations in topography and weathering, or from the presence of basalt or other high velocity layering. In addition the interpretability of the coal structures depends on the depth, and stratigraphic nature, of the coal itself.

The examples presented here are from the Bowen Basin, the major coal producing basin in Australia. However, the broad conclusions have also been observed in surveys from other Australian coal regions. Figure 1 identifies the geographical location of the Bowen Basin within central Queensland, and shows the approximate locations of the examples considered here.

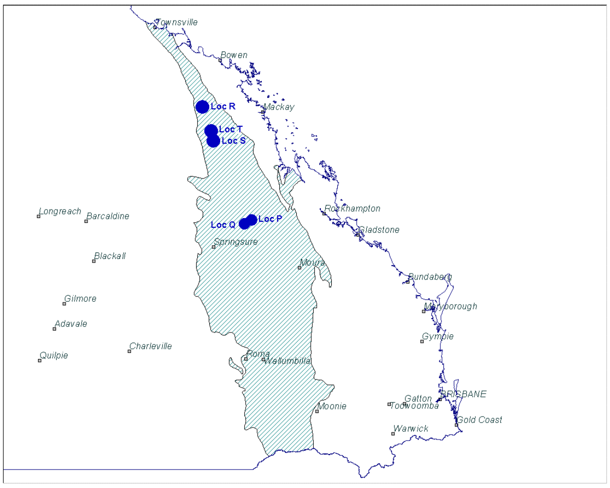


Figure 1. Geographical location of the Bowen Basin and the five example locations considered.

Locations P (Cook Colliery) and Q (South Blackwater Mine) are in the southern central basin. Location R (Newlands Mine) is in the northern basin. Locations S and T are in the northern central Basin. These different sites provide a range of near-surface conditions, as well as different coal depths and stratigraphies.

NEAR-SURFACE GEOLOGY

Locations P and Q are separated by less than 20Km. The coal seam geology is virtually identical, namely a dual seam with the mining horizon uppermost in the sequence stratigraphy. However, these locations exhibit quite different near surface geologies. Location P has a simple geology of shallow uniform weathering on top of fresh Permian sediments. On the other hand, Location Q has deep variable tertiary cover with topographical highs containing sub-surface hard bands (high velocity layers).

The impact of the different surficial geologies on seismic quality is illustrated in Figure 2. The raw record from Location P (Figure 2(a)) exhibits simple refractor behaviour, and strong, well defined reflectors. This 'classic' form is typical of areas of simple near surface geology. On the other hand, the raw record from Location Q (Figure 2(b)) indicates the thickness of the tertiary layer through the lower velocity refracted energy. The ‘leg jump’ feature seen on the first arrivals is the typical manifestation of the velocity inversion associated with the hard band overlying unconsolidated tertiary. The reflection energy is much less obvious on the field record from Location Q, compared to that from P.

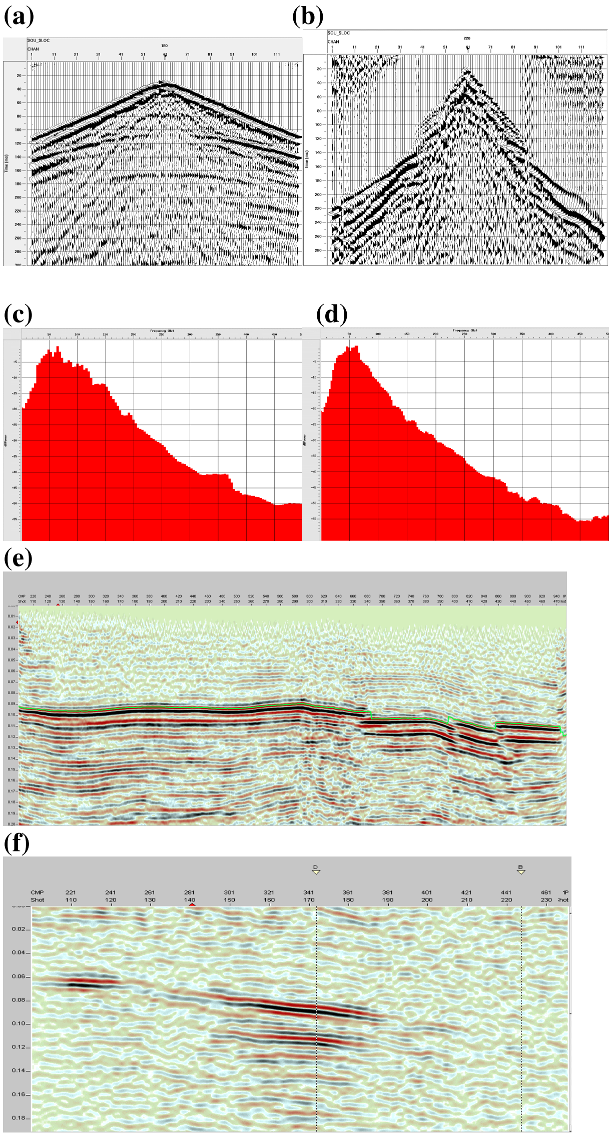


Figure 2 (a) Field record Location P, (b) field record Location Q (c) target-reflector spectral analysis Location P (horizontal axis 50Hz increments, vertical axis –5Db increments), (d) spectral analysis Location Q, (e) stacked section Location P, (f) stacked section Location Q.

Figures 2(c) and 2(d) show frequency spectra averaged over the traces in the field records from Figures 2(a) and (b) respectively. In these and subsequent spectral plots the non-reflection events have been muted, and the analysis window has been chosen to emphasise target reflectors. Figure 2(a) illustrates the excellent frequency bandwidth available in the Location P data. The complex near surface at Location Q is manifested by a significant reduction in reflection signal bandwidth. Figures 2 (e) & (f) are the resulting stacked sections from the two locations. Location P exhibits superior data quality with excellent fault definition. (The data from this region is consistently among the highest quality throughout the Bowen Basin.) The stack response over Location Q is of poorer quality, with the likelihood of accurate fault identification reduced.

This problem of obtaining good penetration beneath high-velocity, or multi-layered, surface situations is widely observed (e.g. Papworth, 1985; Roth et al, 1998; Evans and Ursovic, 1995; Battig, 2000). Recent modelling work on the Denison Trough (Battig and Hearn, 2001) supports the view that in such situations much of the shot energy is trapped as reverberatory noise in the near surface layers.

COAL SEAM GEOLOGY

We now give examples of how the seismic image is influenced by the stratigraphy of the coal itself. Firstly, we comment briefly on the effect of seam depth.

Location R, from the northern basin, provides a situation similar in most respects to that seen at Location P. For practical purposes, this is a single seam stratigraphy, since the mining horizon is the uppermost, and dominant, seam. As with Location P, this site is characterised by simple surficial geology. No thick weathering layer, or interbedded basalts, are present. The target seam at Location R is of comparable thickness to that at Location P. However the seam at Location R is at considerably greater depth (300 m) than at Location P (100m).

Figure 3 (a) illustrates that the quality of shot records at Location R is excellent, comparable to that seen at Location P. The reflection spectral bandwidth is only slightly reduced (Figure 3(b)) compared to that seen at Location P. Presumably there is a slight increase in scattering due to longer path lengths. Figure 3(c) shows that the stack quality is very good. In summary, provided surface conditions are favourable, image quality for simple seam situations should decrease only marginally with increasing seam depth.

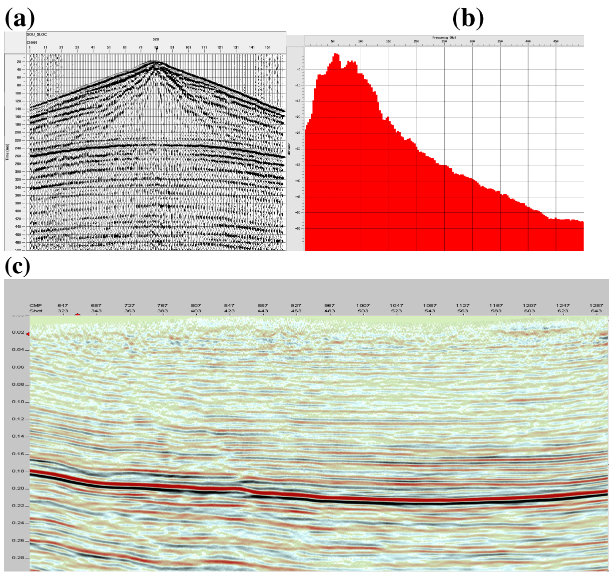


Figure 3 (a) Location R: Field record, (b) target-reflector spectral plot, (c) stacked section.

We now consider the situation where the target seam lies within a more complex coal stratigraphy. Locations S and T, situated in the northern central Bowen Basin, exhibit a multi-seam stratigraphy. Figure 4 shows a synthetic seismogram analysis for the area, and includes sonic, density and reflectivity curves. The mining horizon in this instance, is identified by the orange line in Figure 4. Note that a number of well defined seams overly the target. These shallower seams exhibit strong reflectivity at their upper and lower boundaries.

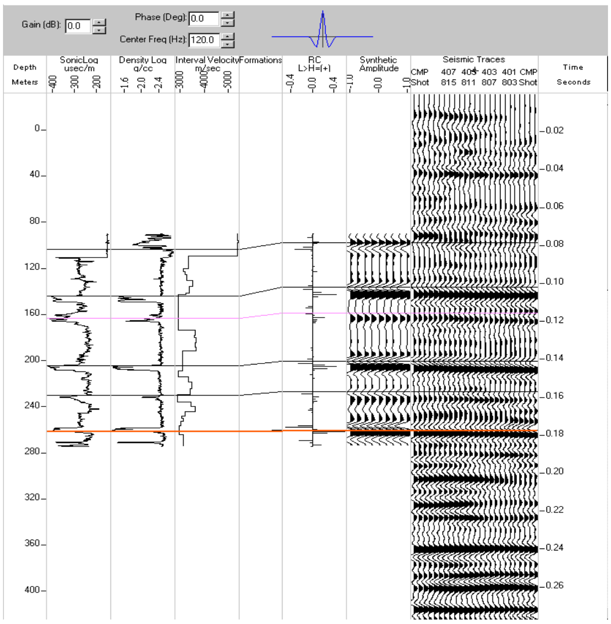


Figure 4. Synthetic Seismogram analysis from northern central Bowen Basin (Locations S, T). The quantities plotted are, from left to right: sonic, density, smoothed interval velocity, reflectivity, synthetic seismogram, real seismic section. (The real seismic section has been selected from a zone where all seams are well imaged, for purposes of tying to the synthetic. The image quality on lower seams is atypical.)

Figures 5 (a), (b) and (c), show a typical field record, spectral analysis (focussing on the target reflector), and stacked section, from Location S. At this site the near surface conditions are conducive to the seismic technique, i.e. shallow uniform weathering on fresh Permian sediments. The field record is characteristically simple in form, due to this favourable near-surface geology. Note however that the target reflector in this case is less clearly imaged, and has a reduced spectral bandwidth, compared with Locations P and R. This can be explained by transmission loss of the seismic wave as it penetrates the high-reflectivity seams shallower in the sequence.

CUMULATIVE EFFECTS

As our final example, Location T illustrates the combined influence of unfavourable surface conditions and a multi-seam stratigraphy. Location T has a similar coal stratigraphy and depth to that seen at Location S. However, now the surface comprises a severely variable Tertiary layer often in excess of 80m thick. In addition, this site has inter- bedded basalt stringers, typically following ancient river channels and underlain by unconsolidated river sands. Such adverse surface conditions are manifested in the raw records of Figure 6(a). As seen at location Q, the thick Tertiary layer is evident in the low-velocity refractor. A velocity inversion is again apparent on the refracted arrivals as a leg jump. The target spectral content (Figure 6(b) has been reduced due to the combined effects of an unfavourable surface and transmission loss through multiple coal seams

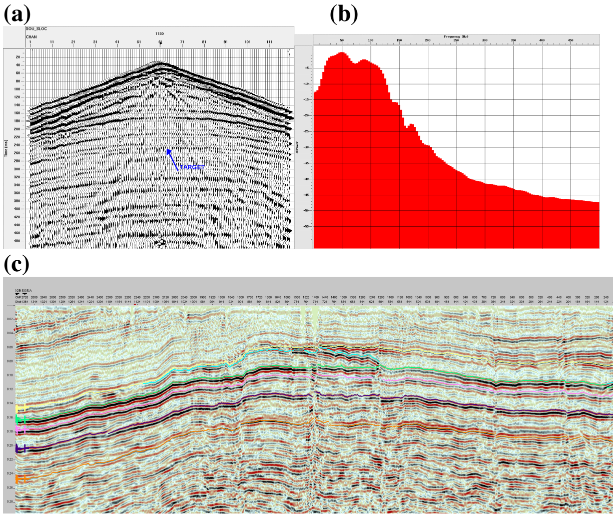


Figure 5. Location S: (a) field record (b) target-reflector spectral analysis (c) stacked section.

The left hand portion of the stacked section of Figure 6(c) exhibits the loss of quality caused by the combined effects of unfavourable surface conditions and multiple seams above the target. On the right hand portion of the section the surface geology is more favourable, although the target image quality is still adversely affected by transmission loss through the overlying seams.

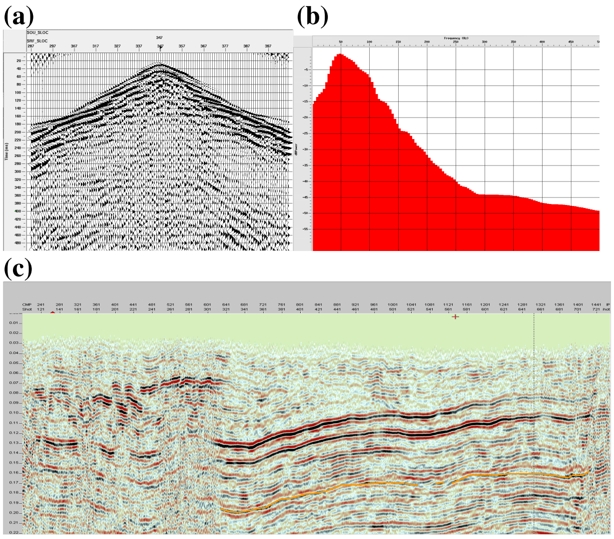


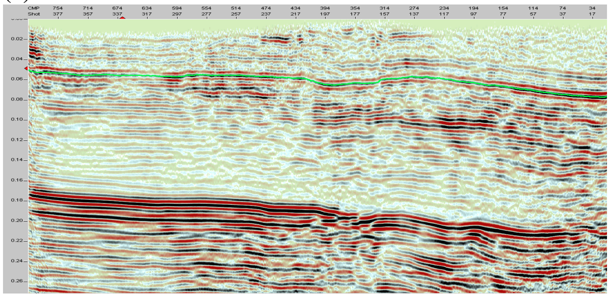
Figure 6. Location T: (a) field record (b) target-reflector spectral analysis (c) stacked section

SOLUTIONS

In the preceding sections we have given examples of how coal seismic quality is influenced by both near-surface geology, and the depth and stratigraphy of the coal seams themselves. We now comment briefly on potential means of reducing the adverse effects of certain mine geologies.

In the case where thick variable Tertiary or interbedded basalt is encountered one option is to make an effort to position the source below these anomalies. This would ensure maximum energy is directed down to the coal seams under investigation. An example of this is shown in Figure 7 below.

(a)



(b)

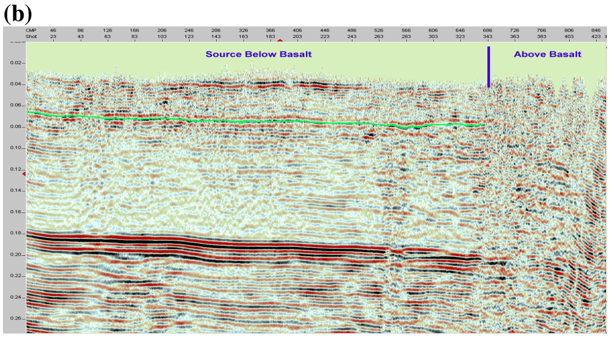


Figure 7 (a) Stacked data, no surface basalt, (b) Stacked data, surface basalt.

Figure 7(a) shows reflection quality obtained at BHP's Crinum Mine over terrain with favourable surface conditions. Figure 7(b) shows a section from an adjacent area at the same mine, where interbedded basalts occur near the surface. Mine staff were aware of the negative impact basalt would have on survey objectives, so an effort was made to position the source sub-basalt. As Figure 7(b) shows, this was successful for most of the line with good data quality through the entire sequence. Unfortunately it was not possible to always position shots below the thick basalt layer. The rightmost third of this line shows how data quality deteriorated when the shot was detonated in the basalt sequence.

In some circumstances, 3D recording provides improved scope for imaging below surface anomalies. This may be the case, for example, where the surface anomalies are restricted in lateral position, so that some ray paths in each bin provide useful reflection energy. This azimuthal variation in ray paths may also yield an improved refraction statics solution.

As an example, recall Figure 2(f) from Location Q (South Blackwater Mine). As previously discussed the data quality has been compromised

by thick Tertiary and interbedded hard bands. Figure 8 is a section extracted from a 3D volume, and identical in location to the 2D line. Neglecting the effects of reduced CMP fold towards the extremities, the 3D line exhibits superior Signal-to-Noise and continuity.

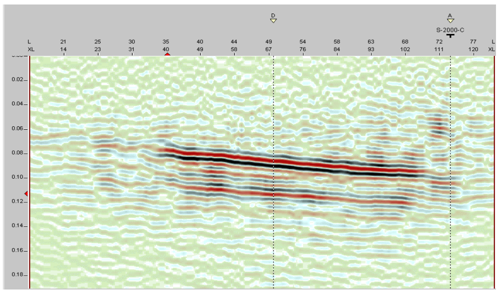


Figure 8. Location Q: Section extracted from 3D volume at the same location as the 2D line from Figure 2(f).

CONCLUSION

We have shown several examples which illustrate how localised mine geology can have a significant influence on reflection quality, and hence on the outcome of coal-mine seismic programs. The near-surface geology is often the most important factor, although the depth and configuration of the coal seams will also affect image quality. Mine planning staff often have a wealth of information on Tertiary/weathering thickness, and the presence or absence of basalt, and this should be fully exploited in the acquisition and processing design. With this approach it is possible to obtain viable imagery in situations previously considered unsuitable for seismic exploration. There is future potential for addressing the problems illustrated here with newer technologies, originating from the petroleum sector. These include wave equation datuming, pre-stack migration, and mode-converted reflection.

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