the seismic velocities of the layers. Usually the source of these errors is in the surface layer where the seismic velocity is low and often varies laterally. Reconsideration of the time section so as to give a well behaved depth section will improve the refraction interpretation.

Conclusion

With digital seismic data, automatic processing using the generalised reciprocal method can be achieved. Arrival times may be accurately picked and the problems associated with handling large amounts of data are minimised. Not only can the required interpretation be quickly made after the completion of a field survey, it will also be improved through the accuracy and thoroughness of the processing methods.

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HIGH RESOLUTION SEISMIC REFLECTION EXPERIMENTS IN REGIONS OF PRECAMBRIAN SEDIMENTS

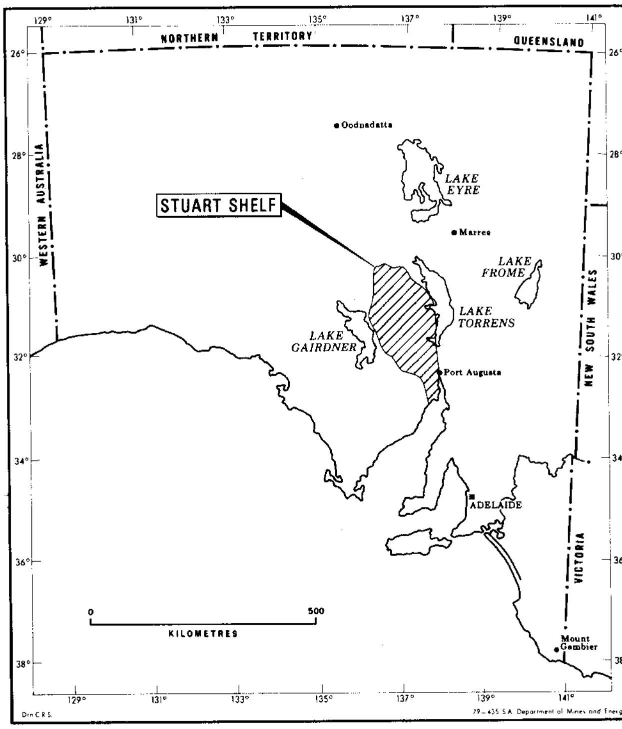
R.G. Nelson

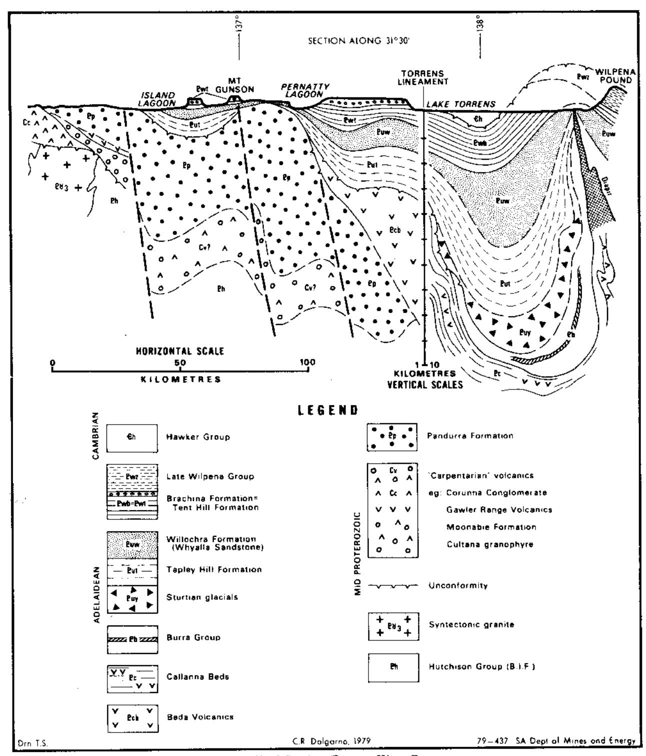
South Australian Geological Survey (08 – 272 5711)

The thick sedimentary sequence that forms the Adelaide Geosyncline in South Australia accumulated in a subsiding trough east of the Gawler Craton, which is part of the Australian Precambrian shield. Between the mobile Torrens Hinge Zone on the western edge of this trough and the crystalline basement of the Gawler Craton, a gently dipping shelf facies was deposited over an irregular and gently undulating basement surface. This stable shelf zone is known as the Stuart Stable Shelf (see Fig. 1) and it has become an area of intensive exploration for base metals since the discovery of the Cattle Grid orebody at Mount Gunson in 1972 and the Olympic Dam copper-uranium orebody in 1975.

The Upper Proterozoic sedimentary sequence constituting the Stuart Shelf contains a wide range of lithologies, including sandstones, dolomitic shales, siltstones and quartzites, with extensive and thick volcanic flows near the base (see Fig. 2). In contrast to the intensive folding noted in the Adelaide Geosyncline, sediments in the Shelf have responded to earth movements by epeirogenic block faulting and gentle warping.

The Olympic Dam deposit was discovered by reconnaissance drilling of coincident magnetic and gravity highs and it has followed that most other exploratory drilling has been sited on such anomalies. Drilling to depths of up to 999 m in these hard Precambrian rocks is costly and it has become apparent that more direct control is needed. This has given





Generalised Section, Torrens Hinge Zone

impetus to experiments aimed at obtaining seismic reflections from acoustic discontinuities within the Shelf sequence and from crystalline basement.

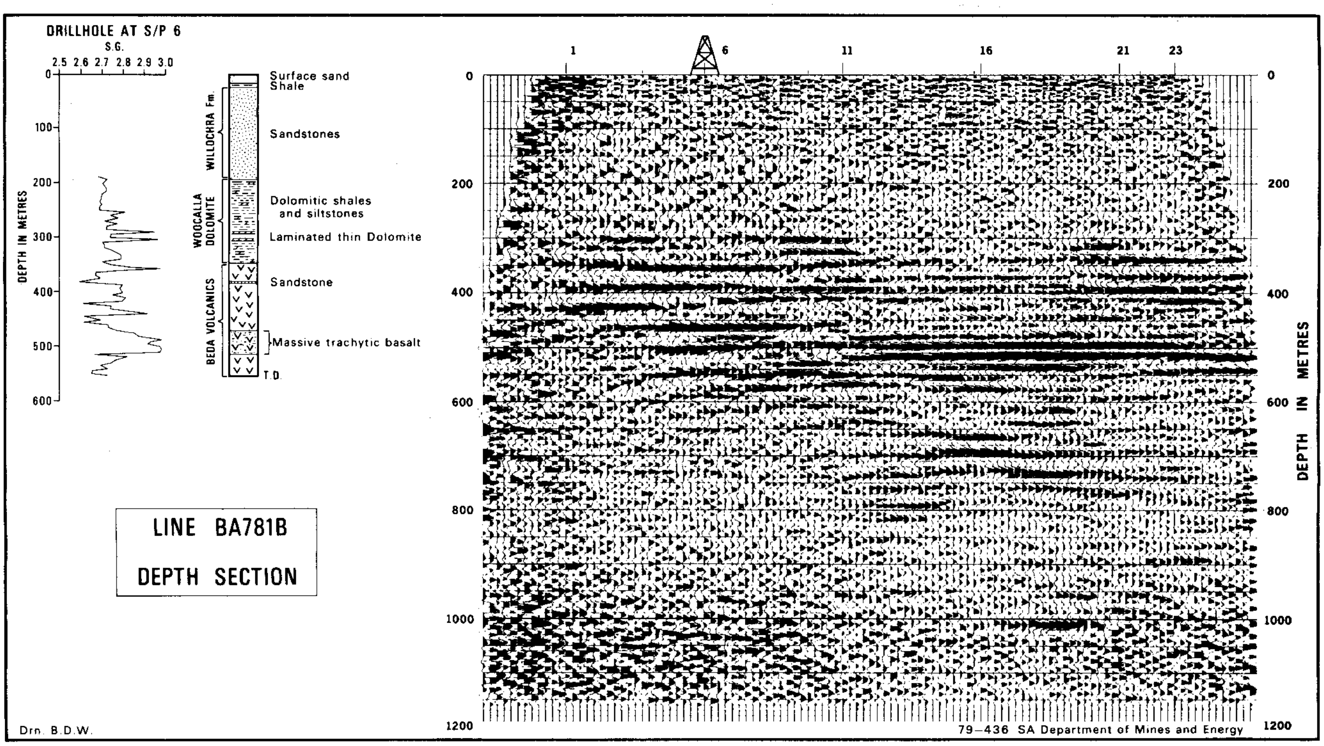
Mineralization reported at Olympic Dam lies between 300 and 800 m subsurface. Maximum depth to magnetic basement over the Shelf is about 1 500 m. Because of their age, formations are well indurated and of low porosity, so that seismic velocities are generally greater than 5 km/s and, in terms of two-way travel time, the seismic section is less than 0.75 second in length. Under such conditions, the main problem is to determine whether contrasts in acoustic impedance are sufficient to generate reflections observable at the ground surface in the presence of seismic noise.

Velocities of rocks within the Stuart Shelf sequence depend, by virtue of their low porosity, on the elastic properties and densities of the minerals making up the rock material itself. In fact, where porosities are low, it is reasonable to assume a close relationship between velocity and density. Grain densities of some common rock forming minerals can have a wide range, for example, from 2320 kg/m^3 for gypsum to 5270 for haematite (Clark, 1966). The same source records the close values of quartz grains (2650 kg/m^3) and common shale minerals (2600 – 2650) and the anomalous value of pure dolomite (2870).

In general, consideration of formation lithologies represented in the Shelf sequence would lead us to expect only very weak reflections from most formation boundaries as in, say, the transition from sandstone to dolomitic shale. However, it is lithological variations within formations, particularly monomineralic bands such as dolomite laminae within dolomitic shales, which offer the best possibilities for generating strong reflections. Veins and inclusions in ore bodies should also be observable because of their higher densities. Each of these cases illustrates the need for generating and recording high frequencies in order to achieve resolution of the reflectors, in the first case because such bands are likely to be thin with respect to seismic wavelengths such as those employed in normal petroleum exploration, and in the second because the lateral extent of inclusions needs to fall within the reflection zone corresponding to the first Fresnel zone.

An example of a seismic section obtained in part of the Stuart Shelf is shown in Fig. 3. Here, the low velocity overburden is 25 m thick and is underlain directly by high velocity (5 km/s) sandstone. The strong acoustic discontinuity created by this interface poses a special problem, common to most parts of the Shelf, because it causes much of the seismic energy to be channeled into the low velocity layer, creating a strong ground roll component, in addition to the strong attenuation of high frequencies in the low velocity layer itself. Here, it was overcome by firing small explosive charges at depth and by using low-cut recording filters which would, in most circumstances, be considered far too severe. A high redundancy of data was achieved by vertical as well as by CDP stacking.

Geological control for this line is provided by a well drilled to 553 m at shotpoint 6. Measurements of density have been made on core from this well at 1 m intervals and the results are shown with a generalized geological log. The correlation between density variations and seismic reflections is evident. The effect of thin dolomite laminae in dolomitic shales at about 300 m depth is shown by peaks in the density plot and as reflections in the seismic section at that depth. From 347 m to the bottom of the hole at 553 m a thick volcanic section exists. A zone in the upper 10 m of the volcanics is quite dense and forms a useful seismic marker horizon. Significant density variations in the underlying basalts and occasional sandstone lenses yield several good reflections, with a zone of massive trachytic basalt between 467 and



514 m being particularly prominent. No control is available below 553 m, although the character of the basalt reflections is maintained to 750 – 800 m. A quieter zone beneath this is followed by a weak reflector at about 1 000 m, which is in the vicinity of depth to magnetic basement.

Further experiments are being undertaken in this and other areas on the Stuart Shelf. As more core becomes available for measurements, and with the purchase of new equipment to allow vertical seismic profiling and attenuation measurements to be performed, it is hoped that a viable technique for exploration in such environments can be produced.

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SEISMIC REFLECTION TECHNIQUES IN COAL EXPLORATION

Hugh Rutter
Chief Geophysicist
The Broken Hill Pty. Co. Ltd.
(03) 60 0701

Phillip Harman
Geophysicist
The Broken Hill Pty. Co. Ltd.
(07) 31 1041

In recent years coal has regained its importance in the world as a major energy source. Much of Australia's coal lies at depths necessitating extraction by underground techniques which are extremely vulnerable to coal seam disruptions such as faults and washouts. In order to plan for the most economic and efficient mining of underground reserves, there is a need to know the exact location of these features long before they are encountered at the working face. Experience has shown that deep drilling is prohibitively expensive and lacks the ability to indicate even large structures between drill holes.

Geophysical methods are now being adapted to solve the "ahead of the face problem" and recently in Europe, seismic reflection methods have been successfully applied.

There is at least an order of magnitude difference in scale between the application of seismic for oil exploration and seismic for coal exploration. The oil geophysicist deals with structures tens of metres in size at depths of thousands of metres, whereas the coal geophysicist deals with structures often less than ten metres in size at depths less than 500m. Two factors have made the use of seismic methods possible in coal exploration; firstly, advanced data recording and processing; secondly, the increased value of coal.

The B.H.P. Co. Ltd. first used seismic reflection methods in coalfields during 1962 but the existing technology severely limited the usefulness of the data and the vertical resolution of structures was no better than 15 m. In 1978, the geological and structural complications encountered by the miners at two collieries in the Blackwater coalfield, Queensland, led B.H.P. to consider applying detailed seismic reflection surveys in the area.

The purpose of the survey was to locate small faults beyond the current zone of mining so that mine planning could be more effective. Experimental surveys were also carried out at Broke in N.S.W. where the coal seams are outcropping and dip at about 15^{o}; and also at Capella in Queensland where the coal seams are covered by Tertiary basalts and soft Tertiary sediments.

Strata Resolution

The main concern in coal seismic work is not to define the thickness of a coal seam but to identify accurately the structures which disrupt the seam. Consequently the surveys at Blackwater were not designed for deep penetration and total resolution of a coal seam sequence, but were designed to give the maximum information concerning the upper seam being mined, so that faulting could be confidently identified. The ultimate structural resolution is the minimum sized structure that can be positively identified. It depends on the quality of the seismic record and the ability of the seismic interpreter. The seismic section can be improved by advanced technology and field techniques, being limited only by the earth itself; but the ability of the interpreter depends on a basic confidence in the data quality and a clear understanding of the geological environment.

The Field Approach to Higher Resolution

To improve resolution, more data is required both vertically and horizontally, or, in another sense, there is a need to sample a high frequency wave form at close spaced geophone positions.

The field parameters were based on those developed in the U.K. by the National Coal Board. Two ounce charges were placed below the weathering zone and shot into 50 Hz geophones. The geophones in marsh cases were buried 20 cm at intervals of either 5 or 10m. The recording instruments used a fully floating point digital system, sampling the wave form at 1 millisecond intervals. Hi-cut alias filters of 375 Hz, 72 dB/octave, and lo-cut filters of 80 Hz, 12 dB/octave were used. Single geophones were used throughout, because of the filtering effect of even short geophone groups, an effect which is exaggerated by the dip moveout. Six-fold redundancy was obtained for better subsurface coverage.

Residual static corrections between adjacent geophones were as high as 10 milliseconds which also supported the use of single geophones. Any static difference of four milliseconds between two geophones in a group would be sufficient to place two incoming signals of 130 Hz, about 180^{o} out of phase.

A comparison of parameters used in the first seismic survey at Blackwater in 1967, and the 1978 survey are shown in Table 1.

Static Corrections

The static correction is a major problem with all seismic reflection surveys. The problem is increased in coalfields where, because of the shallow depth of investigation, a larger proportion of the wave travel-time is spent in the