Engineering Seismic Refraction Surveys over Elura

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Introduction

In the early days, the Elura orebody was considered as a potential open pit mine. In order to evaluate the cost of overburden stripping, it was necessary to estimate the depth to which excavation could be carried out by ripping and scraping instead of the more expensive drill-blast-shovel and truck procedure that is used in a rock mass that is too strong to rip. The depth of economic rippability depends on: the size of the bulldozer and arrangement of the rippers being used; the rock substance strength; the orientation of major fractures such as shears and faults; the orientation, spacing, continuity and degree of interlock of the joints. It is common engineering practice to estimate rippability in terms of the capability of a Caterpillar D9 Bulldozer with single tyne hydraulic ripper. This is largely because of the pioneering work of the Caterpillar Company in the development of methods of estimation of rippability, particularly those involving seismic refraction as outlined in their handbooks. Other bulldozer and ripper systems are then evaluated by comparison with their performance relative to the D9.

The seismic velocity as measured in seismic refraction surveys provides an index which is closely related to the rock substance strength and the presence of major fractures but is only related to a limited degree to the characteristics of the jointing. For this latter reason, reliance on seismic velocity alone has often lead to errors in interpretation of rippability. As extreme examples: some weak, porous limestones and sandstones with few joints have proved to be costly to rip despite very low seismic velocities which would normally indicate easy rippability; some strong, dense but favourably jointed basalts and granites have proved to be easy to rip despite high seismic velocities which would normally indicate that the mass was not rippable.

In a gradationally weathered sequence such as that present at Elura, there is no well defined boundary to rippability; the economic cut-off is gradually reached as the speed of ripping decreases and the cost of wear and tear on the equipment increases. At Elura, the rippability of the overburden was evaluated by means of seismic refraction traverses in conjunction with rock mechanics studies of the available diamond drill cores.

This paper describes the seismic refraction surveys carried out and presents the results obtained in terms of the estimated ripping characteristics of the overburden materials. Although the seismic traverses were designed primarily to investigate the characteristics of the overburden, they were also reviewed to see if they showed any evidence of the presence of the orebody that could be used as an exploration tool.

Seismic Procedure

A total of eight seismic traverses involving 51 blasts were carried out using a Geospace GT2B 12-channel seismograph reading to one millisecond. The blasts involved between one and ten sticks of Plastergel and were detonated instantaneously using ICI Geophysical Detonators.

The locations of the traverses are shown in Figure 1. Of these traverses 1 and 2 were short traverses without overlap which were done for preliminary evaluation of the ground conditions. The remaining traverses 3 to 8 were carried out with up to 7 shotpoints and provided more detailed information.

The data was interpreted by the Reciprocal method (Hawkins, 1961) with results of the type shown in Figure 2. Results are summarised in the form of contour plans in

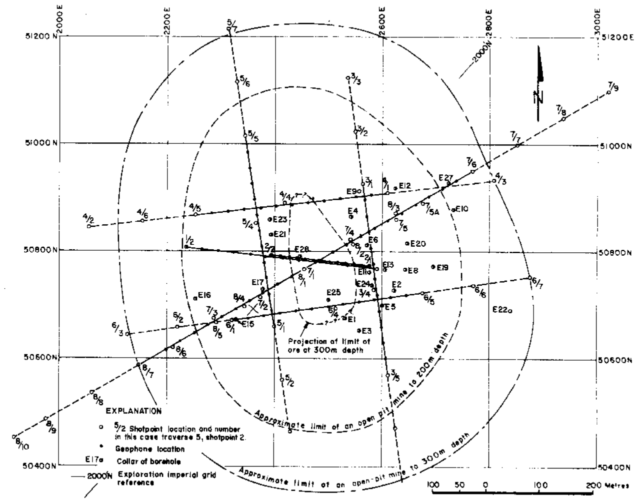

FIGURE 1
Locations of Seismic Refraction Traverses

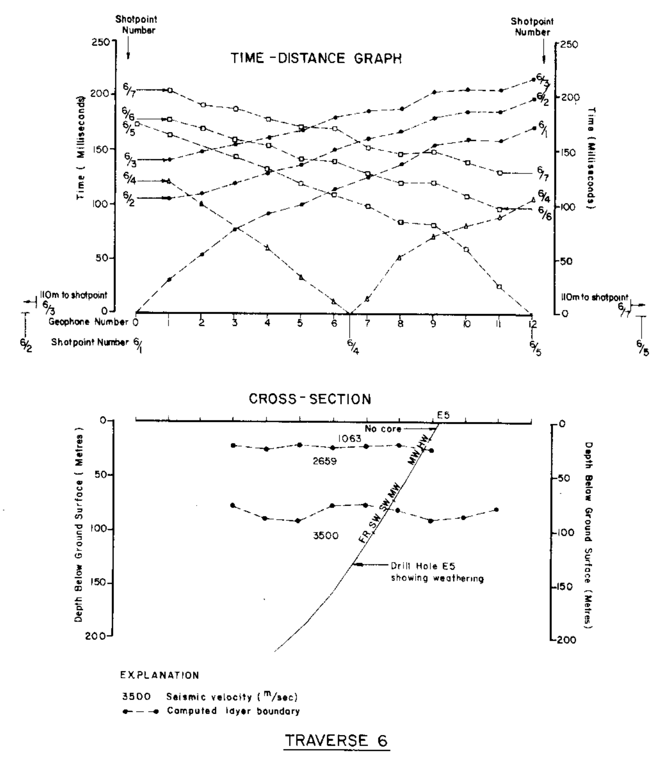

FIGURE 2
Example of Seismic Refraction Results

Figures 3 and 4. Depths of rippability and likely production rates for a Caterpillar D9G bulldozer with a single tyne hydraulic ripper have been estimated from these results interpreted in conjunction with borehole observations, laboratory strength tests and information obtained from the rock fracture survey carried out on oriented borehole cores.

Results of Seismic Traverses

The seismic traverses showed that the rocks at Elura can be classified into three layers with respect to seismic velocity:

1. An upper layer with mean seismic velocity of 1140 m/sec (standard deviation 150 m/sec)
2. An intermediate layer with mean seismic velocity of 2500 m/sec (standard deviation 230 m/sec)
3. A deep layer with mean seismic velocity of 3570 m/sec (standard deviation 155 m/sec)

Computed depths below ground surface to the layer boundaries as shown in Figures 3 and 4.

The results indicate that the layer boundaries are fairly irregular. The depth to the base of the upper layer varies from 17 to 43 m across the site and is deepest in the north west corner and shallowest above the orebody (Figure 3). The depth to the base of the intermediate layer varies from 44 m to 130 m across the site and is deepest in the western side and shallowest above the orebody and on the eastern side as shown in Figure 4.

The generalised contours on the layer boundaries shown in both Figures 3 and 4 show a pronounced trend in the direction N 40°E. Mr B.L. Schmidt, then Resident Geologist for EZ at Cobar, advised us that this was also the trend of the local drainage pattern and also the trend of a pronounced air photo lineament passing through the site.

Correlation of Seismic Results with Borehole Information

The seismic traverses were correlated with boreholes drilled close to the traverse lines as shown for example in Figure 2. From these correlations the following composite description of layers in the country rock surrounding the orebody has emerged.

The *upper layer* (mean velocity 1140 m/sec) consists mostly of highly weathered siltstone shale and minor sandstone with minor moderately and extremely weathered zones. Core recovery mostly varied from 40 to 70% and RQD (Rock Quality Designation) varied from 15 to 70%. Joints and other fractures are mostly spaced 0.2 to 1.0 m. The rock is non-abrasive and easily scratched with a pen-knife. The rock is weak to very weak with point load tensile strengths less than 0.7 MPa.

The *intermediate layer* (mean velocity 2500 m/sec) consists of mostly moderately weathered siltstone shale and minor sandstone with some highly weathered and slightly weathered zones. Core recovery varied mostly from 50 to 98% and RQD varied from 35 to 90%. Joints and other fractures are mostly spaced 0.3 to 2.0 m. The rock is non-abrasive and earily scratched with a pen-knife. The rock substance is medium strong to strong with point load tensile strengths mostly between 1 and 3 MPa.

The *deep layer* (mean velocity 3570 m/sec) is slightly weathered siltstone shale and minor sandstone with minor moderately weathered zones. Core recovery was mostly greater than 80% and RQD varied from 40 to 90%. Joints and other fractures are spaced mostly 0.4 to 3.0 m. The rock is non-abrasive and easily scratched with a pen-knife. The rock substance is strong with point load tensile strengths mostly between 3 and 8 MPa.

Even deeper layers probably with higher velocities are indicated in the boreholes but the seismic traverses did not penetrate below the deep layer described above. Allowing for the effects of projection there is very good agreement between the seismic traverses and the drill hole data for the country rock. There is also a good degree of internal consistency in the seismic velocities and depths between adjacent traverses. The correlation between the seismic traverses and the borehole information above the orebody however is not clear. The only boreholes intersecting the layers above the orebody are drill holes E1 and E25. Both boreholes intersected soft clay and weathered shale to vertical depths below the surface of 77 and 72 m respectively and below this intersected hard strong gossan overlying the orebody. Seismic traverse 6 indicated that the top of the hard layers (velocity 3500 m/sec) is around 77 m in the area of drill

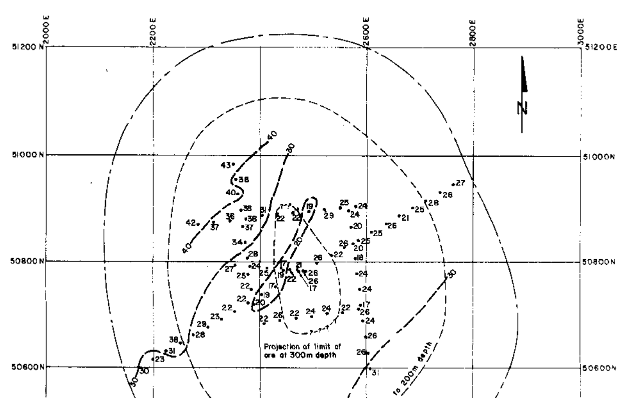

FIGURE 3

Contours on the base of the surface layer

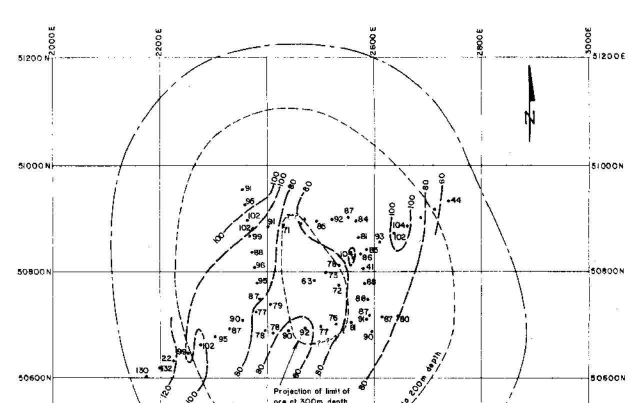

FIGURE 4

Contours on the top of the freshrock

holes E1 and E25 which is in good agreement. However, the velocity of 2659 m/sec for the overlying material (Figure 2) is far higher than one would expect from the borehole information. In fact, a velocity of about 1000 m/sec would be more consistent.

No objective criteria by which the presence of the orebody could be inferred were observed.

Evaluation of Rippability

It can be concluded quite confidently that: the deep layer (mean velocity 3570 m/sec) cannot be economically ripped but the upper surface layer (mean velocity 1140 m/sec) can be readily ripped by a Caterpillar D9G bulldozer with a 9D single shank hydraulic ripper, or equivalent machine. A production rate of 1000 to 1200 bank cubic metres per hour can be expected. Maintenance costs would probably be of the order of 20 to 30% greater than earth moving costs. A pass spacing of 1 to 1.5 m should be adequate.

Estimation of the rippability of the intermediate layer requires considerable judgement and the following points are pertinent: the mean velocity (2500 m/sec) indicates that the rock is close to the limit of rippability by a single dozer although it could probably be handled by dozers acting in tandem. The time-distance graphs and the borehole cores indicate that the boundaries between the layers are gradational. Therefore, the upper third of the layer can probably be more easily ripped than the lower third. The rock is non-abrasive which is a factor in favour of ripping. The rock does not break along bedding laminations and would probably break out in slabs 1 to 2 m wide and up to 0.5 m thick. These would be relatively difficult to load by scraper. The seismic data and drill hole information indicate that there are hard bars of very-difficult-to-rip material within this zone. A rough estimate is that the hard bars might comprise 10% of the material in the upper third of the layer and 40% in the lower third.

Our best estimate therefore was that the rock can be easily ripped to the base of the surface layer as shown in Figure 4 by a Caterpillar D9 or equivalent with a production rate in excess of 1000 bank cubic metres per hour. Below this the rate or production will gradually drop off rapidly over the next 10 to 20 metres to a rate of around 200 bank cubic metres per hour for a single machine or 500 bank cubic metres per hour for tandem machines. Maintenance costs would also gradually increase to about 50% greater than earth moving costs. The product size will also gradually increase and become more difficult to load by scraper. At this point further ripping is unlikely to be competitive with open pit drilling, blasting, shovel excavation and truck haulage.

The possible exception is in the area above the orebody. Judging by the borehole information above this area may be economically rippable to about 70 m below the surface. However, this is not supported by the seismic data.

Conclusions

The material within the limits of the proposed open pit mine at Elura can be ripped to the base of the surface layer as shown in Figure 3 with a production rate probably in excess of 1000 bank cubic metres per hour. Below this ripping becomes gradually more difficult and probably becomes uneconomic by comparison with drill, blast and shovel excavation within 10 to 20 metres below the base of the surface layer. It is therefore concluded that the average depth of easily ripped material at Elura is about 30 m but ripping may probably be extended to 40 or 50 m with increasing difficulty. The depth of rippable material is about 10 m deeper on the west side of the mine than on the east side. It is also possible that economic ripping could be carried out as deep as 70 metres directly above the orebody but the seismic and borehole data in this case are contradictory.

As the survey was primarily for evaluation of the rippability it was restricted to a depth penetration of the order of 100 m from the surface. Within this depth no objective indication of the presence of the orebody was observed.

Reference

HAWKINS, L. V., 1961. The Reciprocal Method of routine shallow seismic refraction investigations. *Geophysics*, v. 26, pp 806-819.