The use of seismic methods for the detection of dykes

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ABSTRACT

Seismic methods have become common for the detection of low-throw faults ahead of underground coal mining. Surface seismic methods cannot theoretically be used where dykes occur, because seismic waves transmit from the surface down to the seams, and reflect back to the surface. Consequently, where sub-vertical structure such as dykes occurs, the surface seismic method fails.

The ability of seismic methods to image dykes depends on the geometry used, the dyke thickness and the seismic wave propagation mode in relation to dyke composition and internal structure. Surface seismic methods find it difficult to distinguish between faults/fractures and very thin dykes (1-2m in thickness) when the dyke's thickness is less than the seismic wavelength. Consequently, borehole seismic methods have to be used to detect the presence of such thin dykes.

This paper presents the first results from an ACARP project, which in part is a breakthrough in seismic technology for the detection of dykes. It explains how surface seismic methods were used to detect a thick dyke and associated faulting. An alternative approach, that of going downhole with seismic sources and receivers (borehole seismic profiling), shows that dyke sides can be imaged at depth, and that in future, it should be possible to produce an image of both sides of a dyke, in its correct orientation, using existing boreholes.

INTRODUCTION

The conventional geophysical approach to the detection of dykes is by sensing their induced and/or remanent magnetism. If a dyke is magnetic, then it may be detected by ground or aeromagnetics and mapped. However, when dykes have no magnetic signature, their presence goes undetected and can thereafter cause extreme interruption to underground mining. This is often the case.

The surface seismic method has been developed since the early 1950s to image sedimentary layering. Seismic energy is exploded at the surface using a charge of explosive, and the seismic-wave travels downward, reflecting off seam tops to return back to the surface, where it causes ground vibrations. These vibrations are felt by geophones placed along a line at the surface, which act like microphones when connected to a recording instrument (Evans, 1996).

Seismic reflections occur best when the downgoing seismic wave is reflected from horizontal seams, and when there is a termination of a seam with a change in seam depth, then a fault is inferred (Fig 1).

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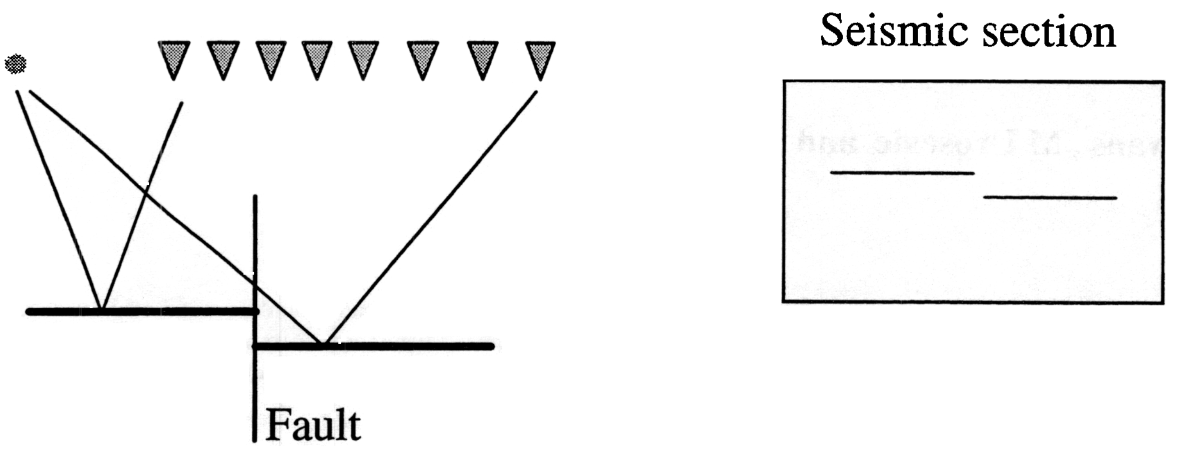

Fig. 1 - A fault is a termination in the seam image

If dykes or vertical structure have intruded through the seams, the dyke's thickness becomes important. If a dyke is relatively thick (greater than 20 m), it may be similar to the wavelength of the seismic wave passing through it and affect the seismic wave propagation by diffracting it. If it is shorter than the wavelength, the seismic wave may be unaffected by the dyke and pass through it without any interference. In this latter case, the dyke is undetected. In the wide-dyke case, an image of the dyke is produced where the lines of the seam reflections break (Fig 2). Unfortunately, such an image has been rare to find.

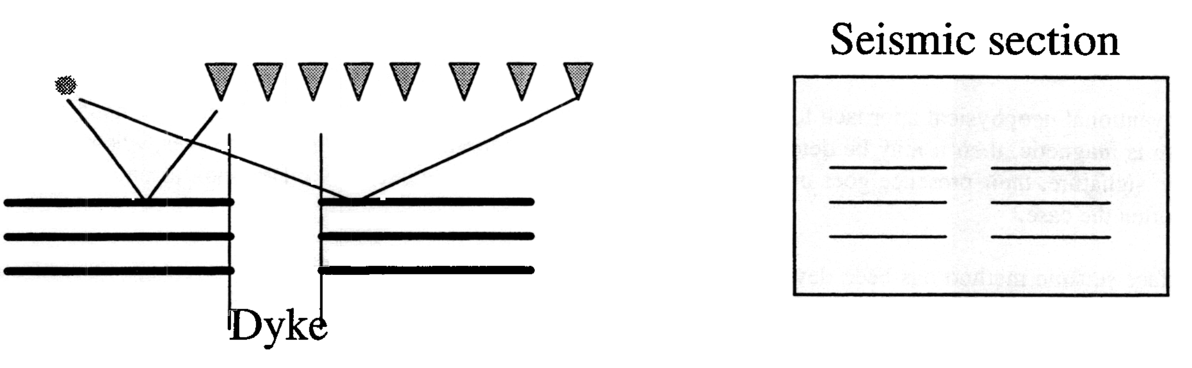

Fig. 2 - A dyke is a break in seam reflections

An alternative seismic solution may be to go down a borehole with a seismic source and receivers effectively tilting the earth on its side, so that reflections can be received from the sides of the dyke (Fig 3). This would provide an image of a dyke at depth, and potentially map the dyke's sides at depth.

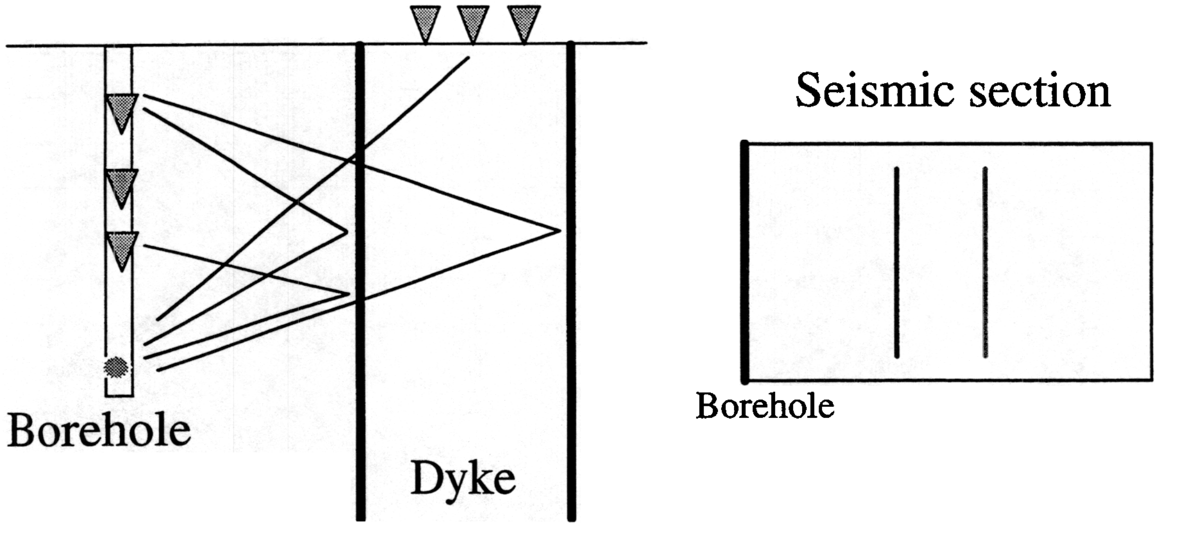

Fig. 3. - Waves can pass through a dyke or reflect from a dyke's sides

SURFACE SEISMIC METHODS

The surface seismic method applied in mining uses a shot fired at the surface and geophones also at the surface detecting the reflected energy. The geophones also respond to waves travelling in any other direction, so waves that travel near to the surface will pass horizontally through the top of a dyke.

Seismic reflections from coal seams depend on there being a velocity and/or density contrast between the top of the seam and the overburden. Where dykes exist at depth, any seismic waves which reflect from their hard-rock sides reflect downwards and away from the surface geophones. Otherwise, the seismic energy passes through them, being modified by the dyke in proportion to the thickness, velocity and quality of the dyke rock.

Compared with the hard-rock nature of dykes at depth (with a velocity around 5000 m/s), the weathered tops of dykes can often be very soft and similar to clay in texture. Such material often has a slower velocity (around 1800 m/s) than the adjacent sedimentary rock (around 2500 m/s), while the weathered dyke-top may act like a sponge to the seismic wave, attenuating the wave's amplitude and reducing its velocity as it passes through. Consequently, it is possible that dykes could be observable on field records as waves arriving late (slower velocity giving a 'statics' anomaly), and being weaker in the vicinity of the dyke (attenuation). This knowledge may be used as an alternative key to magnetics for the detection of dykes.

Figure 4 shows two conventional field records of seismic data. The records show 96 seismic 'wiggle' traces which are moving positive or negative over a period of time, dependent upon the amount of seismic (and therefore electrical response) energy they experience. The first arriving seismic wave is either a 'refracted' or 'direct' wave which travels from the shot location to each receiver. In Fig 4a), the refracted wave is the first wave to arrive along the receiver line. In this figure, the first arrival is weaker amongst a group of receiver stations. Figure 4b) shows a normal record, and how the first arrival would appear with no dyke present. In the case of Fig 4a), we know that the geophones were located precisely across the dyke, so this is the effect of a large dyke some 40 m wide.

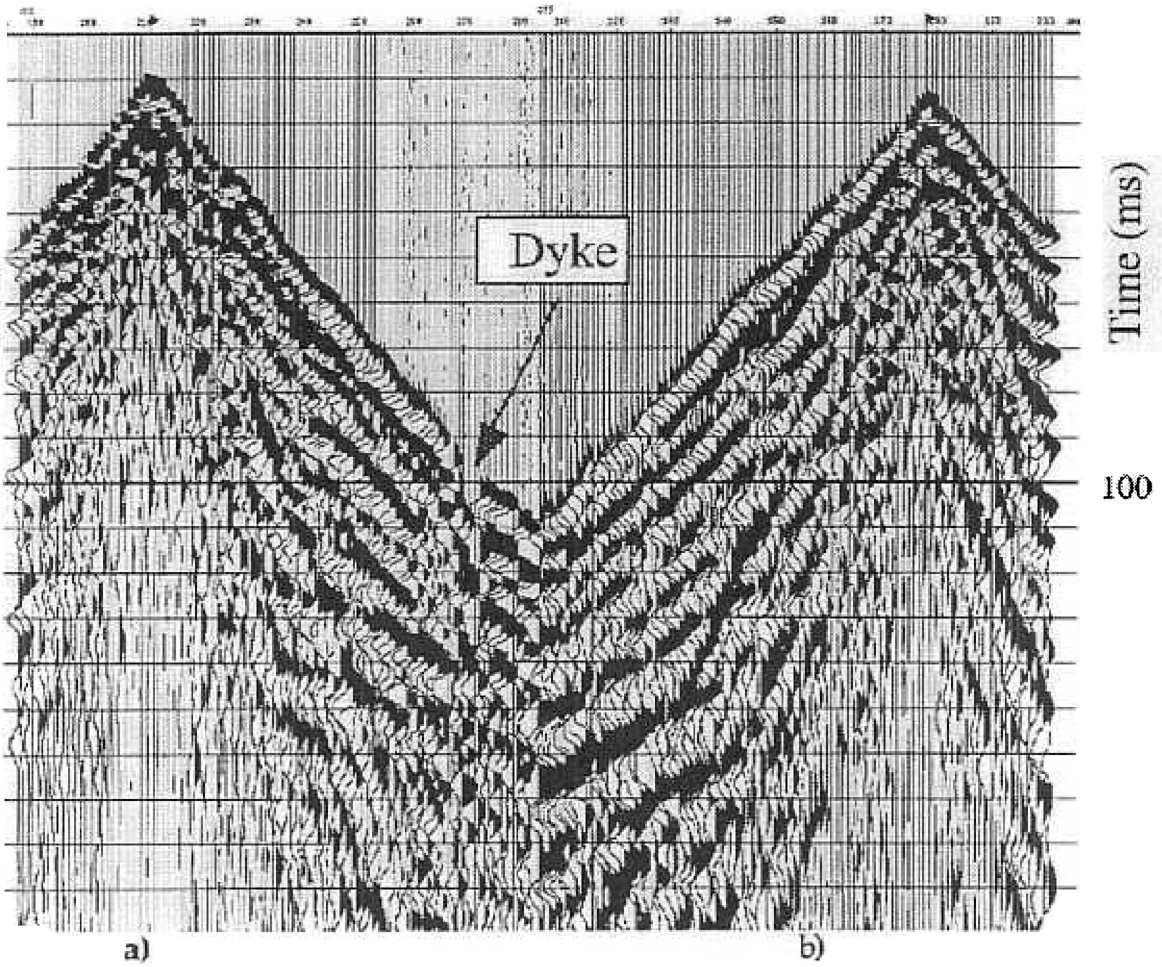

Fig. 4 - a) Field record showing effect of dyke, b) normal record (no dyke)

If a shot is fired in a deep borehole, say at 180 m depth some 155 m from this 40 m wide dyke, the direct waves coming from the explosive to the surface receivers will pass through the weathered dyke as shown in Fig 3 and again affect the wave's amplitude detected by the geophones. The result is shown in Fig 5, where clearly there is a 'notch' in the first arriving seismic wave as it passes across the geophone stations. Such responses are observed frequently both in the field and during seismic data processing, but ignored as readily as they are observed because their use is not understood.

A seismic line was recorded for Powercoal at their Morisset lease over a dyke, and the data carefully processed to retain all of the dyke's character. This produced a seismic section (Fig 6a) which contains all of the typical coal sedimentology hall-marks of faulting and seam rolls. Note the subtle variations in lithological response across the section which properly acquired and processed seismic data can produce. Faults are observed to be almost vertical, while short vertical faults are probably linked by seam floor or roof-stress transfer breaks.

However in this case for the first time, we have captured a profile of the dyke passing upwards through the coal section, probably intruding along a fault or plane of weakness.

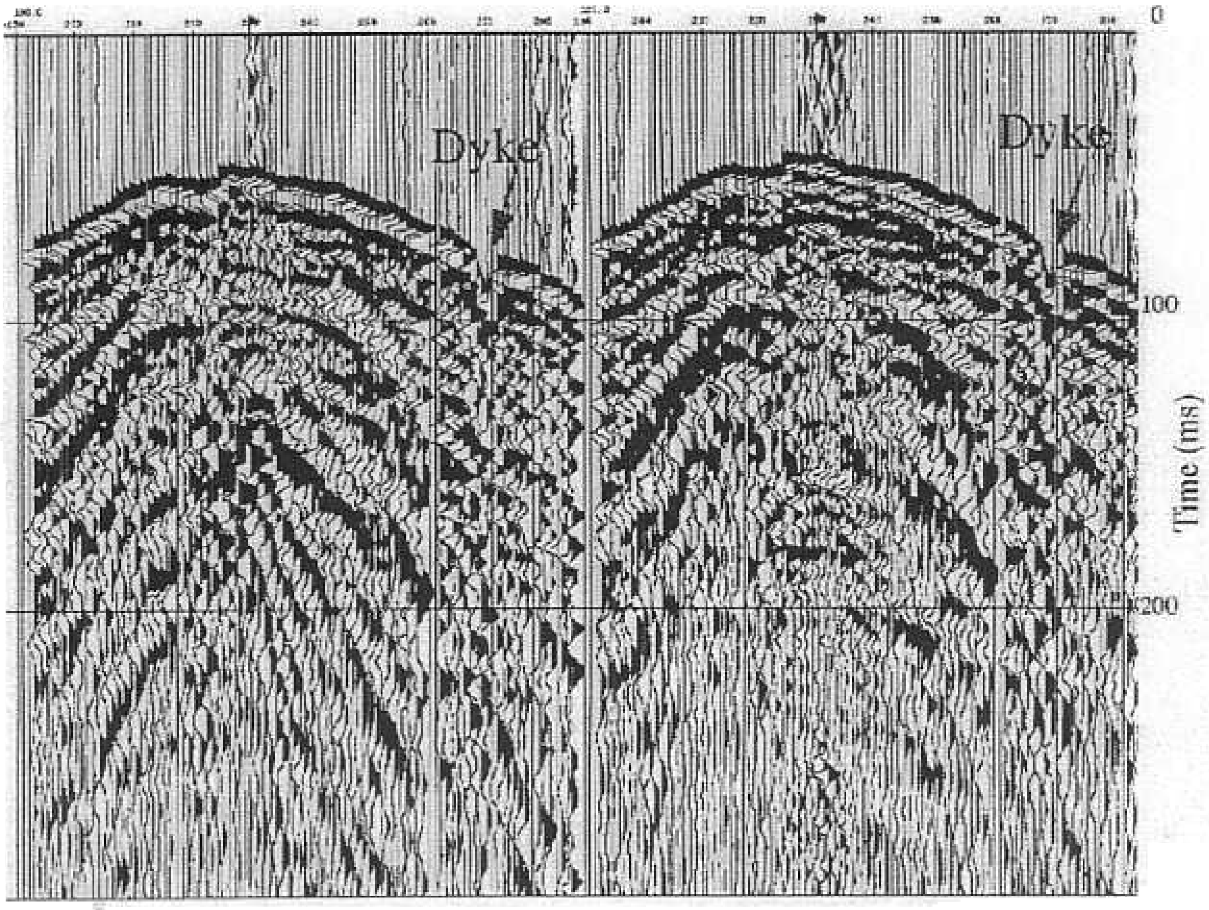

Fig. 5 - Shots at 190 m and 180 m depth, showing effect of a dyke

The interpreted section is shown in Fig 6b) where the dyke is observed to be as narrow as 30 m at 400 m depth, sinuous in shape, and broadening in champagne-glass form within the weathering. At depth, the dyke's intrusion has certainly caused a buckling of sediments at 700 m. The dyke passes up through the Fassifern seam at 200 m with a width of some 35 m, and forewarning of this dyke's presence is a clear requirement prior to mining the seam. In this case, a recommendation not to mine here would be expected.

Ground magnetics had put the dyke's width at 38 m. The seismic data indicates that the dyke is not straight sided, and varies in width between 30 and 45 m. Both data sets were within metres of each other at the surface and this is considered to be an excellent correlation between two different geophysical methods.

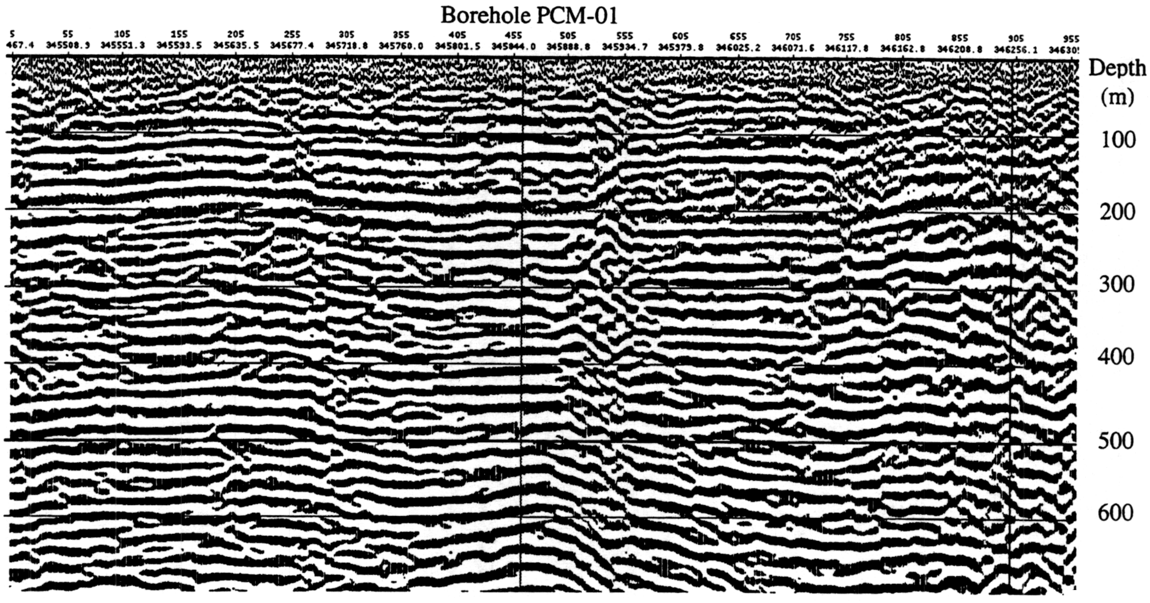

Fig. 6a) - Uninterpreted depth section

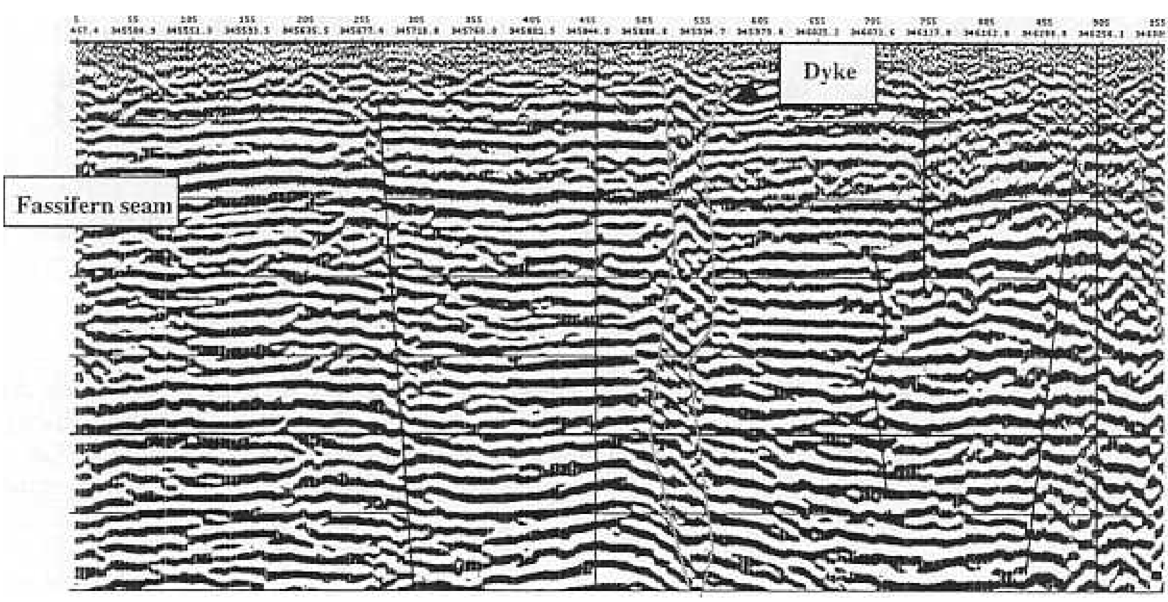

Fig. 6b) - Interpreted depth section.

BOREHOLE SEISMIC METHODS

An alternative to surface seismic methods is that of borehole seismic, in which both sources and receivers are positioned down a borehole, and the source is fired in similar manner to the method of surface seismic. This method has not been tested to our knowledge in mining previously, because it is considered that firing an explosive beneath a string of receivers is asking for trouble.

During a seismic test program at BHP Coal's Goonyella site, a 12 channel hydrophone cable was lowered down a borehole which was some 150 m from the centre of a suspected dyke (indicated from aeromagnetics). The Goonyella Middle seam was at a depth of 180 m in this case. Small explosive charges (25 g) were fired up the borehole coming no closer than

20m to the cable. The cable was raised step by step as a number of charges were fired, until 90 m when it was accepted that the hydrophones were losing their sensitivity. The arriving pressure wave after each shot was too strong to bear for the nearest hydrophone which finally lost all sensitivity and the test was abandoned.

The seismic data were then processed using conventional CMP stacking to produce the section of Fig 7a). Depth conversion was performed using velocities observed from other seismic data so that in this section, distances are shown down the side and across the top, with the borehole being located down the left-hand side. From this figure it can be seen that the section is an image of geology between 105 and 185 m vertically, and up to 300 m laterally away from the borehole.

Figure 7b) is the interpretation of the same data, in which the closest face of the dyke to the borehole would be the black-peak to the left of the interpreted line. The interpreted line in the white-trough could be the other side of the dyke, which would fit with drilling indications of dykes no more than 5 m wide in this area. A number of reflection surfaces are also clearly apparent, the nearest one at 135 m, a second about 160 m away from the borehole and another some 220 m away. If the reflection at 135 m is the nearest side of a dyke, the image details how a dyke's surface appears in greater detail than in the sedimentary section of Fig 6b), albeit only for a small distance in depth.

However, this is the first observed image of a dyke's form at depth, and with modifications to equipment, such an approach could be developed into a standard logging tool at some stage in the future.

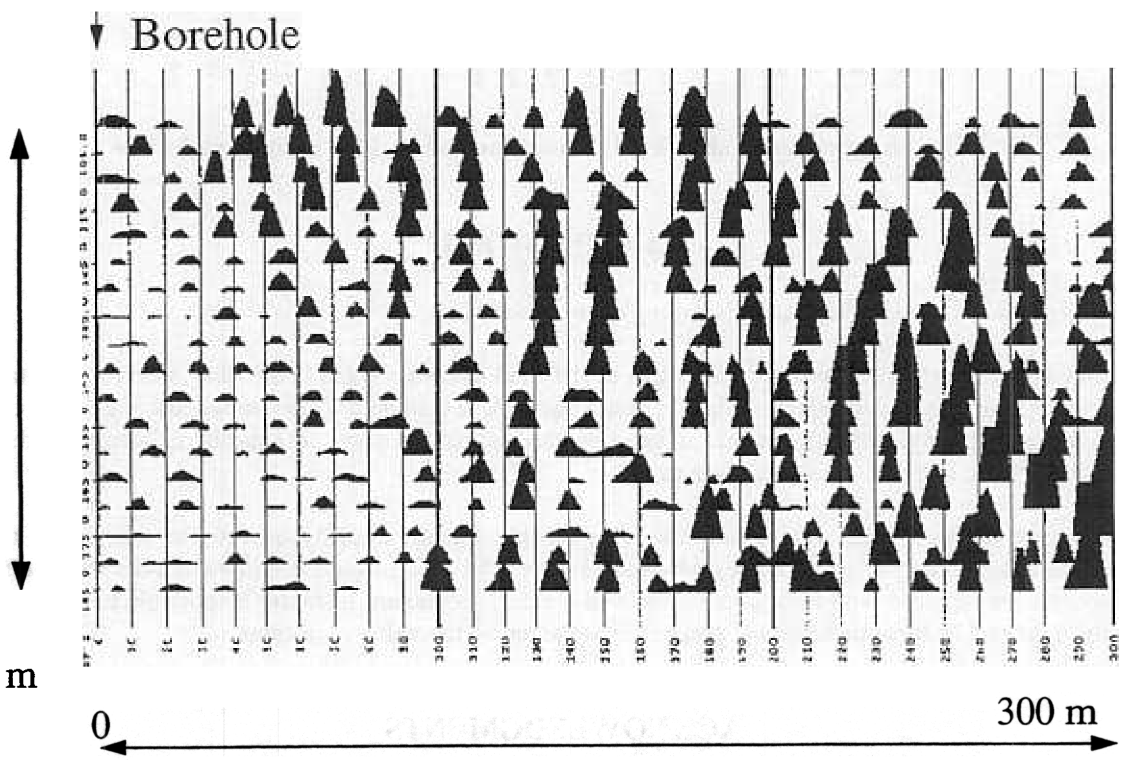

Fig. 7a) - Uninterpreted section away from the borehole

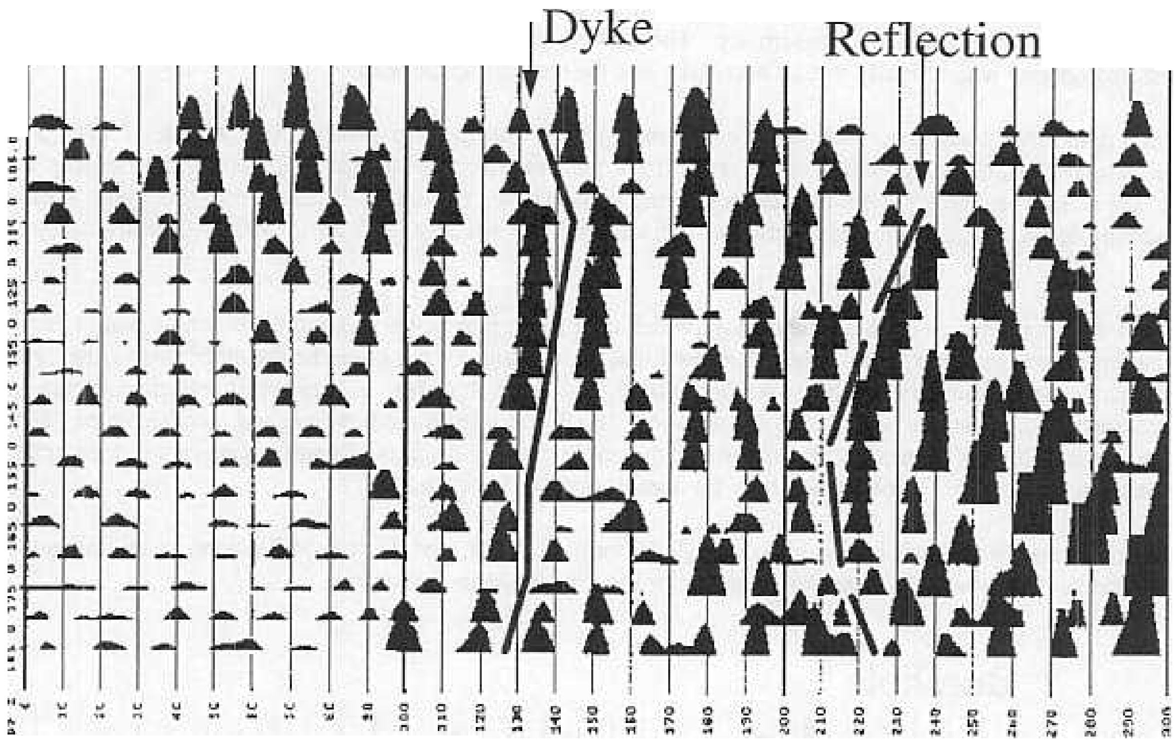

Fig. 7b) - Interpretation showing dyke location and position of other reflection

CONCLUSIONS

Two seismic methods have been presented for imaging dykes at depth.

The surface seismic method has shown that dykes can be detected in field records if the field operator or data processor has the experience to understand its affect on first arrivals. The surface method has also shown that if the data is processed with care, an image of the dyke can be obtained to great depths- in this case some 700 m- and its form provides a clue to its vertical movement up and through the coal seams.

The downhole seismic method has shown that reflections can be obtained from dykes away to one side of any chosen borehole. In this case, a string of home made hydrophones were used which would position the dyke in any direction. If the hydrophones were replaced with three component wall-locking geophones, it should be possible to obtain the precise location of the dyke and its three-dimensional shape in space as an aid to mining operations.

ACKNOWLEDGMENTS

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REFERENCE

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