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Seismic Vital in Coal-Mining

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The need for geophysics in the coal industry is mostly quite different from its need in the oil industry. Geophysics is used in the oil industry to help find the oil reserves. Seismic reflection surveys in particular are used as a cheap way to comb large areas of land and sea to locate promising places where oil and gas reserves may exist. As a corollary, of course, many large areas are *excluded* from further consideration because they hold no promise of either oil or gas.

Coal in Britain is not difficult to find. The problem is to mine it cheaply. A major factor affecting the costs of extraction is geological structure. If the seismic system has sufficient resolution to pick up the structure, it is obvious, to anyone with a nodding acquaintance with geophysics, that seismic reflection should be applied to determine the structure. And since every inch of the survey is likely to be over an area of potentially extractable coal, the information it reveals is likely to be extremely important.

This should be contrasted with most oil surveys, in which much of the area is likely to be of no special interest, and therefore of no importance. The costs which can be tolerated for coal seismic surveys are therefore much higher than for oil.

The first place where seismic exploration was really needed in this country was Selby. This was recognised immediately by Mr. A.M. Clarke, deputy chief geologist at the time (subsequently chief geologist and now geoscience advisor to the National Coal Board). There was a major problem in deciding on the mine layout because, first, there was no firm information on structural trends in the area of the Selby coalfield, and, secondly, only one seam was to be mined.

The lack of information on structural trends meant that any layout which gave a good fit to the boundaries of the take would be as good as any other, all other things being equal. However, because mining was to be confined to only one seam — a restriction imposed by subsidence considerations in this low-lying area — it was exceptionally important to get the layout right.

In the normal situation, where more than one seam can be worked, it is possible to prove the structure in the first seam and reap the benefit in the subsequent seams. This option was not open at Selby and it was obvious after the experience at Bevercotes*, that the main structural trends *had* to be determined before any financial commitment to a particular layout was made. The initial losses which could be incurred by trying to mine on such a scale (Selby will be the biggest deep mine in Europe and, possibly, the world), with the wrong layout were potentially disastrous for the industry — especially as Selby was to be followed by a succession of new mine prospects. It was not a risk worth taking.

The first Selby seismic survey took place between October 1973 and May 1974. By July 1974 the results had revealed the broad structure of northeast/southwest trending normal faulting with approximately three faults per square kilometre. It was then possible for the National Coal Board to commit itself to the 440 million pounds (at 1976 prices) capital investment on the new mine complex without an unacceptable level of risk. The cost of the combination of boreholes and seismic survey which permitted this decision to be taken was less than 1 million pounds.

The mine layout which had been proposed before the survey was undertaken was based on some rather indirect gravity evidence that the structure was east-west. The original mine layout was therefore planned to be on east-west, north-south lines. The new layout, designed to minimize costs and to maximize the percentage extraction of coal, is based on the northeast/southwest structure. The original layout would have been a very expensive mistake. The investment in the survey has more than paid for itself.

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This initial survey was a very broad-brush affair, the seismic lines being spaced about 2 km apart in a rectangular grid. It was capable of detecting only the largest, longest faults. Some of the gaps have now been filled in as detailed investment decisions on the siting of shafts, underground roadways, conveyor systems etc. have had to be made. The broad structure found in 1973-74 is still correct, but more minor faults have now been found, a few of which trend at right angles to the main trend.

The philosophy of the exploration at Selby is that of the Coal Board's whole National Exploration Program. The program is designed to allow the better prospects,

such as Selby and Northeast Leicestershire Prospect, to be explored early, and enable the limited exploration resources to identify the best places first. After a few initial boreholes, Selby was identified as an obvious place where there were sufficient coal reserves for a substantial mining complex. The question that the first seismic survey answered was: is the coalfield sufficiently undisturbed by geological structure to enable modern mechanical longwall mining methods to extract the coal efficiently?

As each significant new coalfield has been discovered, often with a combination of boreholes and seismic lines, its evaluation enables it to be put in a hierarchy of attractiveness against other coalfields. This hierarchy determines the priority for the disposal of scarce exploration resources. A number of very large new coal fields have now been discovered, including South Warwickshire, East Staffordshire, East Yorkshire, Yorkshire Block 5, etc. Each one of these has reserves rivalling oilfields such as Forties in the North Sea.

Each new mine prospect that gets upgraded to the point where a decision is made to go ahead and develop a new mine begins to take on a life of its own. Detailed exploration has to be done to enable the more detailed investment decision to be made about the *exact* location of access to the coal.

Eventually, of course, it is detailed face layouts that have to be planned. Since it is faults with throws of the order of seam thickness or more, say two meters, which can stop a working face and cause interruptions to the continuity of production, it is all the faults above this size that need to be found. At the moment, this is beyond the resolution of present seismic reflection surveys in most British coalfields.

The smallest fault which can be detected by a seismic line at coal seam horizons is normally about 10 meters in most British coalfields. Occasionally, in good data areas the resolution is better than this. But although there is a limit to the resolution that can be obtained, because of the costs which can be incurred when unexpected geological structure interrupts mining, it pays to try to obtain the highest possible resolution. There are plenty of problems for geophysicists to investigate here, most of which arise from the difference of scale between surveying for oil and surveying for coal.

Given that the seismic reflection survey cannot resolve everything of importance, and given that faults have strike lengths of finite length, there is an optimum grid of seismic lines in a given geological environment which will resolve most of the structure that can be resolved for this minimum cost. Beyond this point, additional seismic lines will not add significant information unless the resolution improves.

The size of this grid will vary with the geology, but it could be as little as 100 meters between seismic lines. Of course, there will still be face-stopping geological structure which will remain undetected because it is below the resolution of the surveys. The risk of encountering unexpected structure will have been reduced — because all the large structures will be anticipated — but it will not have been eliminated entirely. Spare face capacity will still be required, but at a lower level, and therefore at lower cost. This exploration will thus permit coal to be extracted in places which were previously uneconomic.

It is now possible to use seismic methods *underground* to assess the risk of faces being stopped by unexpected geological structure too small to be resolved from the surface. The underground in-seam seismic surveys are basically complementary to the surface seismic surveys. The shots and geophones are placed in the coal seam underground — perhaps along a roadway, or along a face-line, or even both. If the seam is faulted then there will be a discontinuity at the fault between coal on one side and rock on the other. Seismic waves travelling in the seam will be reflected off the fault according to the laws of reflection. If the geometry of the fault strike with respect to the disposition of shots and geophones underground is favorable, it is possible to detect the fault.

At the moment it seems possible, from the results of the work of Dr. Buchanan's group at the NCB's Mining Research and Development Establishment, and from parallel work in Germany, to detect faults at a range of 200-300 meters and with throws of about seam thickness or even less. It is very promising. However, there are several constraints which make it essentially complementary to the conventional surface techniques. Although it can detect small faults, it is not yet possible to estimate the throw of the fault from the data. So far, it is only possible to estimate the *location* of the fault — provided the geophones can be placed in the proper locations to receive reflections off the fault plane. If there is a succession of faults, one behind the other, it seems very likely at the moment that only the first, or maybe the first two, will be reflected.

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The in-seam tool is very specific, but with enormous potential for saving costs. In an area where the overall layout is constrained by the major structural features — determined by drilling, underground workings and surface seismics — there may be some freedom to choose the layout of individual faces and also some doubt as to which of several planned faces had the least risk of reaching its planned life. *That* is the situation where an in-seam seismic survey would pay off, by locating any hitherto-unknown structure.

However, there are also non-specific constraints on coal-mining geophysics. At each level of investment decision in a mine there is a need to know something about

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the geological structure of the coal reserves. The detail required varies with the level of decision. Seismic reflection surveys can provide this information at very low cost, to minimize the investment risk. At the level of detailed face layouts, when an underground structure already exists, surface reflection techniques lack the resolution to guarantee that the ground ahead of an advancing face is free of face-stopping disturbances. This guarantee may soon be provided by in-seam seismic surveys. If all the required surveys are carried out, the savings to the country will be enormous. This is a matter of national importance. It is therefore worthwhile considering whether the effort being applied to this task is adequate.

The effort required comes down to money and people. Adequate finance is required to pay for the exploration and an adequate staff must exist to administer the exploration (which is normally contracted out) and to turn the results into meaningful information to the mining engineers. However, the mining engineers in the Coal Board have often had a rough deal from geophysicists, who have come along, claiming to solve all their problems and have then failed to deliver.

Sometimes this has been because it has been difficult to get good results and thus convert them into useful structural maps. Often it has been because the rate at which the data have been processed or interpreted is too slow. Thus, even when the money is available to fund the program, the results have not been forthcoming. There is therefore something of a credibility gap to be bridged before the money, which is controlled by mining engineers, is assured.

At the bottom of the geophysicists' failure to deliver everything on time is insufficient staff. There are too few geophysicists to cope with a seismic exploration program of about 5 million pounds per year. The number of geophysicists which have been responsible for the contracting and supervision of the acquisition, processing and interpretation of this program has never been greater than five.

This is wildly inadequate. Clearly, provision for far more geophysical staff must be made if this problem is to be tackled in time. But that in itself will not guarantee that more staff will be hired. The demand for geophysicists, especially those with any experience in interpretation of seismic data,far exceeds the supply. Competition between oil companies for these experienced geophysicists is very stiff, and the salaries offered are now very high. The National Coal Board can only compete in this market by offering a level of responsibility not normally available at such salaries. This is sufficient attraction for geophysicists who wish to make things happen.

But what about the supply of geophysicists trained in seismic exploration? New graduates, and new graduates with MS degrees in geophysics, are often taught very little about seismic reflection. The teaching of geophysics in British universities is hardly tailored to the needs of the exploration industry. In this respect geophysics is perhaps typical of many subjects taught at universities, so we should not be surprised. On the other hand, we might be justified in feeling that our university geophysics departments could have contributed a little bit more. The North Sea has been intensively explored since 1965. The technology of geophysical exploration has developed very rapidly in that time, and the contribution of British geophysics departments to the technology has been absolutely negligible.

Of the capital that is spent on geophysical exploration by industry, more than 90% is devoted to seismic reflection, because this is the technique that gives more of the answers. Of the teaching and research and development done by British geophysics departments, probably less than 20% is on seismic reflection.

Obviously there does not have to be a 1:1 correspondence between money spent in industry, and effort made by universities. But there should be *some* relationship between them — especially since the geophysicists are going to find jobs in industry. If universities are at present having a hard time getting research funds, while industry is fighting for good geophysicists, it is time some self-examination by university geophysics departments took place.

The reduction of mining costs is a big act to get in on, and it can obviously be achieved with sufficient geophysical support. It is time that support was provided.

**Bevercotes was a mine sunk in the 1960s in unproved ground. Its output was to be 1 million tons per year. For seven years it was beset by geological problems (all unexpected) which reduced its output to a trickle. This was followed by three years of extensive roadway driveage and investigations, after which serious production began. The cost of the lost production can only be imagined. Bevercotes is now a very successful mine.*

REFLECTIONS

By Robert D. Hoeft

A large fish leaping in the calm lake
left huge circles that with a touch
of imagination became a phonograph record.

All I would need would be a needle
large enough to fit those gigantic grooves,
a pointed stick or the tip of my oar.

I settled for a nail found in my mind
and placed it in the outermost groove.
Waves of vibration tingled up my arm

to shoulder, to traffic-jaded ears.
I heard the syncopated click of fresh-water
clams playing underwater castanets.

I heard muted glissandoes of weeds
rubbing on the sounding board of submerged rock
and the rhythm-keeping snap of crawfish claws.

Somewhere in the silty depths of sound
I heard the lilting solo of a lunker
Singing his scorn of the lure.