Explor97 Master Page ◀ GOTO ▶ Author Index
Explor97 Contents ◀ ▶ Section Contents
Previous Paper ◀ ▶ Next Paper

A Crosshole Seismic Survey at the McConnell Ore Body

Wong, J.[1]

ABSTRACT

Crosshole seismic instrumentation based on a piezoelectric source and hydrophone detectors were used to gather seismograms between boreholes at the McConnell ore body near Sudbury, Ontario. High-frequency seismograms were recorded across rock sections 50 to 100 metres wide containing a continuous zone of sulphide ore. First arrival travel times obtained from a highly detailed scan were used to create a P-wave velocity tomogram which clearly delineates the ore zone. The survey demonstrates that it is possible to do cost effective, high-resolution crosshole seismic surveys for delineating ore bodies on a scale useful for planning mining operations.

INTRODUCTION

There is growing interest in using geophysics to assist in the planning of mining operations. In particular, crosshole methods are being recognized as having exceptional potential for this purpose. By using crosshole geophysics to provide greater geometrical detail than is available from traditional delineation via pattern drilling, mining of an economic deposit can be designed or modified in order to minimize costs (Williams, 1996). This paper discusses a test survey in which high-resolution crosshole seismology is demonstrated to be effective for ore body delineation.

The McConnell Deposit owned by INCO Limited is located near Sudbury, Ontario, Canada. It has been used for testing various downhole and crosshole geophysical techniques. Meng and McGaughey (1996) have reported on using crosshole seismic reflection to image the deposit. They used blasting caps as downhole seismic sources and recorded seismic frequencies in the 1 to 5 kilohertz range. Livelybrooks *et al.* (1996) and Fullagar *et al.* (1996) have described crosshole electromagnetic surveying to map the ore body. The technique, called radio-frequency imaging (RIM), employs electric dipoles operating at frequencies of 500 kilohertz and 5 megahertz.

The target at the McConnell Site is a near-surface, steeply plunging massive sulphide ore body residing in a host rock consisting chiefly of amphibolite and metasediments. A number of BQ-sized (60 mm ID) boreholes have been drilled through the ore zone (Figure 1). Borehole velocity logging has indicated that the P-wave velocities of the host rock range from 5.8 to 6.3 km/sec. By contrast, the velocity within the massive sulphide zone are at least 20 per cent lower, in the range 4.2 to 4.6 km/sec. The situation is almost ideal for evaluating crosshole seismic methods for possible use to support planning of mining activities.

INSTRUMENTATION

The CORRSEIS borehole seismic system used for field data acquisition includes a controlled piezoelectric vibrator as the source and multiple high-sensitivity hydrophones as detectors. Similar equipment has been described previously by Wong *et al.* (1983, 1987) and Harris *et al.* (1995). In the present case, the source was about 53 mm in diameters and 75 cm in length. Each hydrophone was about 50 mm in diameter and 10 cm in length. Because both the source and the detectors are coupled to the rock by water in the boreholes, the recorded seismic energy is primarily P waves. The dominant seismic frequencies generated by the source are about 3.3 kilohertz, resulting in wavelengths of about 2.0 m in the host rock, and about 1.4 m in the ore body. These wavelengths give an indication of the resolution that can be expected from the crosshole seismic survey.

There are several practical advantages in using a controllable piezoelectric vibrator as the source for crosshole seismic scanning. Once deployed with electrical power in a borehole, the vibrator can be operated for long periods of time without needing to be returned to the surface and is more repeatable and safer than microexplosives or blasting caps. The vibrator is driven by a pseudo-random binary sequence (PRBS) in continuous cycles, and impulsive seismograms are obtained from the detected vibrations by cross-correlation with the PRBS pilot signal. Cross correlation in conjunction with waveform stacking results in very large gains in signal-to-noise ratios. In many cases, this feature makes it possible to record good-quality seismograms even in the presence of drilling noise. If sixteen or more hydrophones are used in the detector array and the equipment is configured with automatic winches, acquisition rates greater than 2500 crosshole seismograms per hour are possible in low-loss rock.

---

1. JODEX Applied Geoscience Limited, Calgary, Alberta, Canada

In “Proceedings of Exploration 97: Fourth Decennial International Conference on Mineral Exploration” *edited by* A.G. Gubins, 1997, p. 697–700

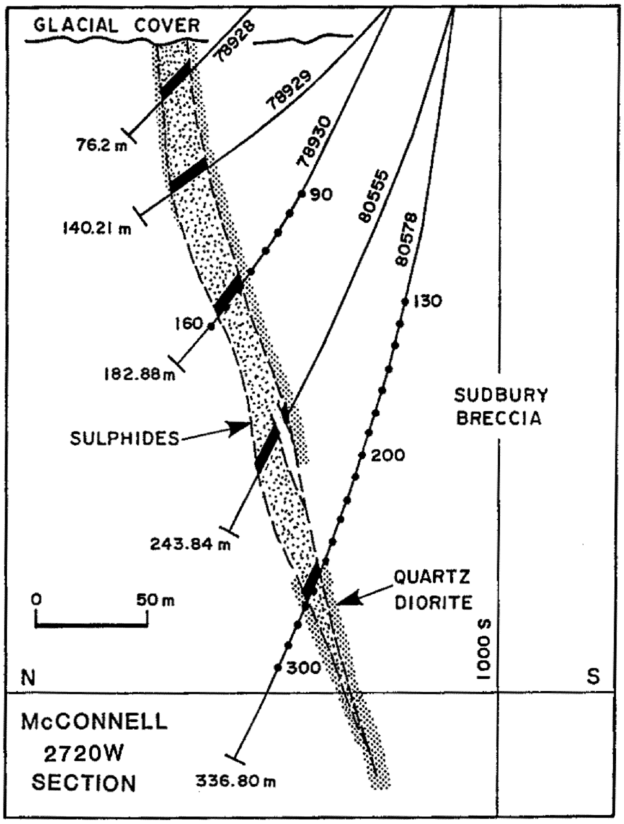

Figure 1: *Cross-section of the McConnell ore body with exploratory boreholes.*

FIELD RESULTS

Seismograms were recorded with detectors in Borehole 78929 and the source in Boreholes 78930 and 80555. The hole-to-hole separations between BH-78929 and BH-78930 at depth are 20–60 m. The hole-to-hole separations between BH-78929 and BH-80555 at depth are 50–130 m. Each recorded seismogram consists of 512 or 1024 16-bit samples with a sampling interval of 50 microseconds. Sample seismograms for each hole pair are shown in Figures 2a and 2b as common detector gathers. The columns of numbers to the right of the figures under the headings TX and RX are the source and detectors depths in metres. The signal-to-noise ratios of the traces in both cases are very good, and the dominant frequencies are in the 3 to 4 kilohertz range. These data indicate that piezoceramic-based equipment is capable of producing excellent crosshole seismograms for source-detector distances of over 100 m in the rocks at the McConnell Site.

For tomographic imaging, a complete seismic scan of the rock panel between BH-78929 and BH-78930 was done. The detectors were located in BH-78929 at depths from 30–140 m on 2-m intervals. The source was located in BH-78930 at depths from 30–170 m on .62-m intervals. The scanning pattern is depicted schematically on Figure 3, where seismic raypaths joining source and detector positions are represented by straight lines (the true raypaths would be curved or bent according to Snell's Law). The entire scan consisted of over 4200 raypaths, but only every fifth raypath has been drawn on Figure 3.

DATA ANALYSIS

First arrival times for the scan of Figure 3 were picked using an automatic routine and checked and edited visually on a computer display. These first arrival times were used in a straight-ray back-projection algorithm (Peterson *et al.*, 1985) to produce a P-wave velocity tomogram. In essence, the algorithm assigns seismic velocity values to an array of rectangular pixels overlying the rock section between the source and detector boreholes. Seismic travel times for direct P-wave arrivals are calculated and compared with the observed times for all the raypaths in the scan. The velocity values are then automatically adjusted to reduce the differences or residuals between observed arrival times and calculated arrival times. This is done repeatedly until the residuals are

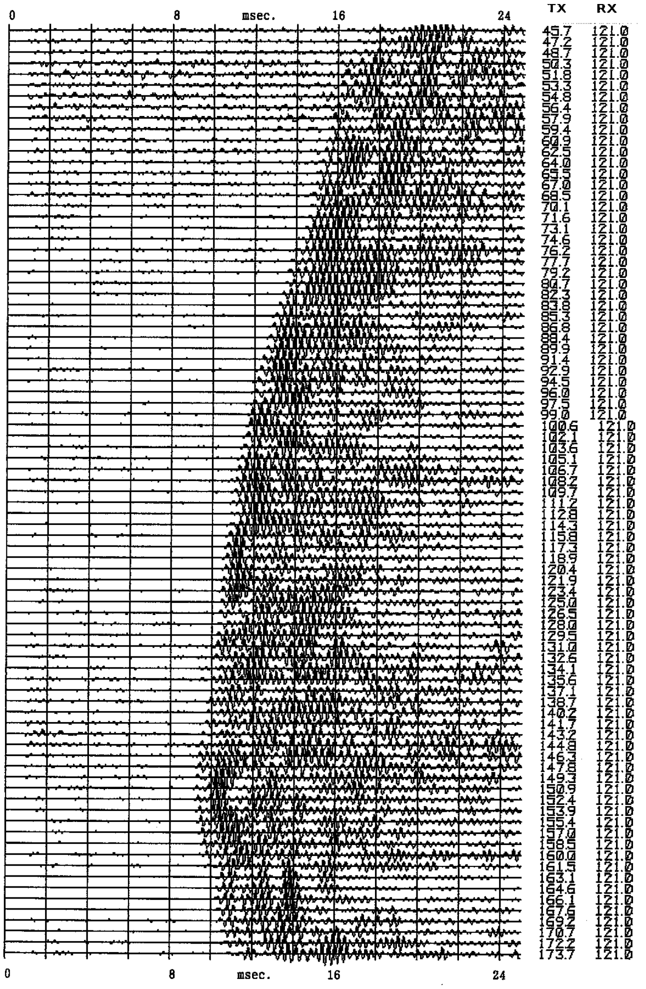

Figure 2a: *Crosshole seismograms between boreholes 78929 and 78930. First arrival times are between 3 and 11 milliseconds; source-detector separations are approximately 20 to 60 metres.*

reduced to an acceptable level, at which point it is assumed that the array of velocity values within the pixels is a good representation of the true velocity distribution in the scanned rock section between the boreholes.

For the panel between boreholes 78929 and 78930 at the McConnell Site, the RMS (root-mean-square) value of the 4202 observed arrival times was about 6.8 milliseconds. After six iterations of the imaging algorithm the RMS value of the residual arrival times was reduced to less than .3 milliseconds. The resulting velocity tomogram is shown in Figure 4. The ore zone is clearly outlined by the low-velocity (4.0–4.5 km/sec) zone residing in the higher-velocity (5.9–6.2 km/sec) host rock.

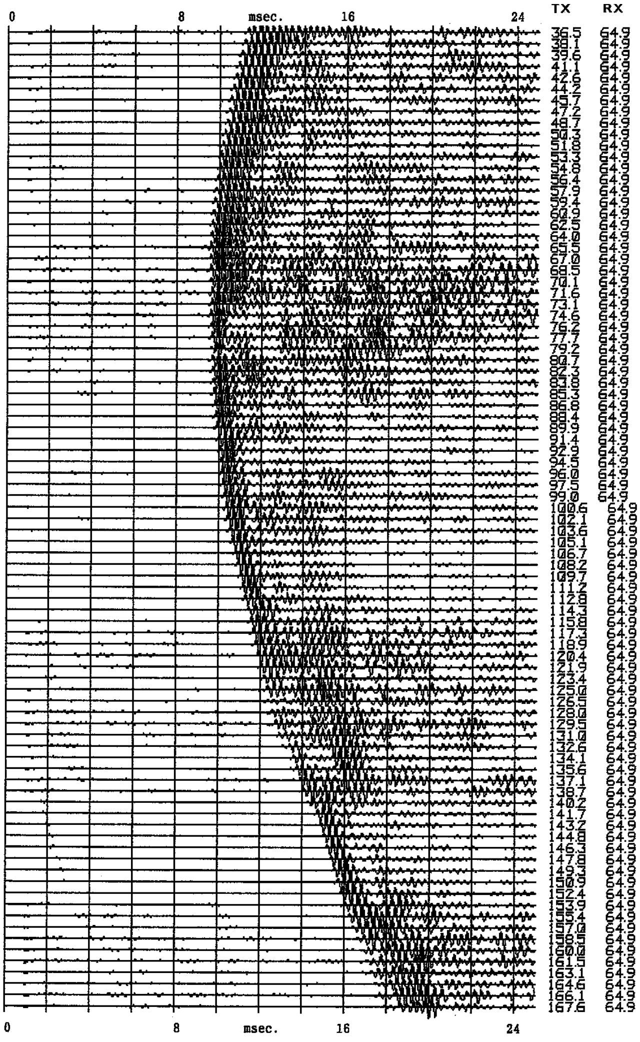

Figure 2b: *Crosshole seismograms between boreholes 78929 and 80555. First arrival times are between 10 and 16 milliseconds; source-detector separations are approximately 60 to 100 metres.*

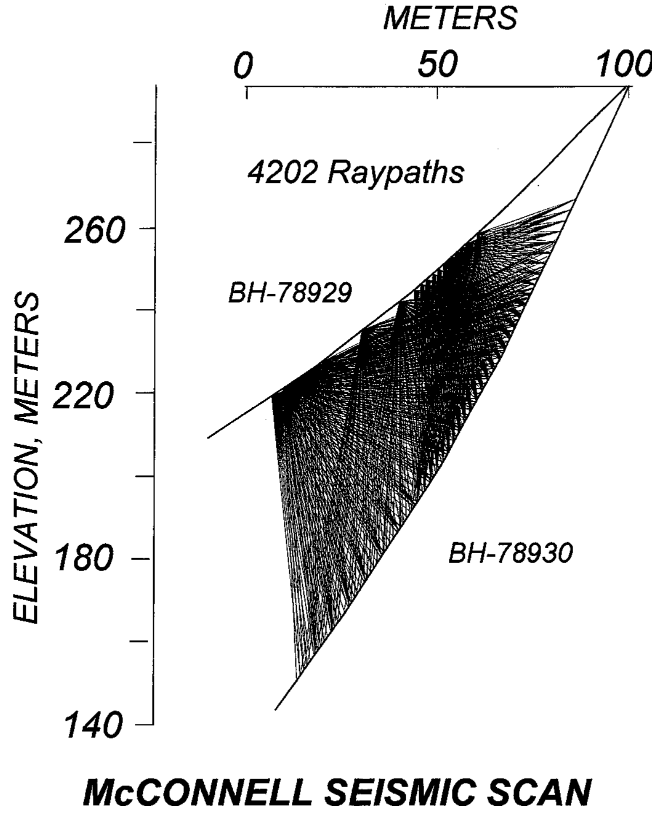

Figure 3: *Schematic diagram showing the raypaths of a detailed seismic scan between holes 78929 and 78930. In the complete scan, there are over 4200 raypaths; only every fifth ray is shown here.*

CONCLUSIONS

Crosshole imaging using high-resolution seismic data recorded with piezoceramic source and detector technology appears to be a practical method for delineation of ore bodies. This type of seismic imaging complements the information available from pattern drilling by providing more details about the geometric aspects of an economic deposit. The additional information gained by seismic imaging may assist in optimizing mining procedures in order to reduce costs. As the crosshole seismic technique evolves in its role for investigating ore bodies, it may be possible that seismic velocities can be used reliably to estimate ore grade.

The most critical factor in determining whether or not crosshole seismic imaging will become widely accepted by people responsible for planning mining operations is its cost effectiveness. In actual practice, and for routine application, field acquisition time is likely to be the largest cost component in the crosshole seismic method. It is thus important to have technology which allows for the rapid recording of high-quality crosshole seismograms. The experience at the McConnell Site supports the contention that piezoceramic-based equipment similar to that described in this paper should have the resolution, range, and operational efficiency to meet the practical requirements.

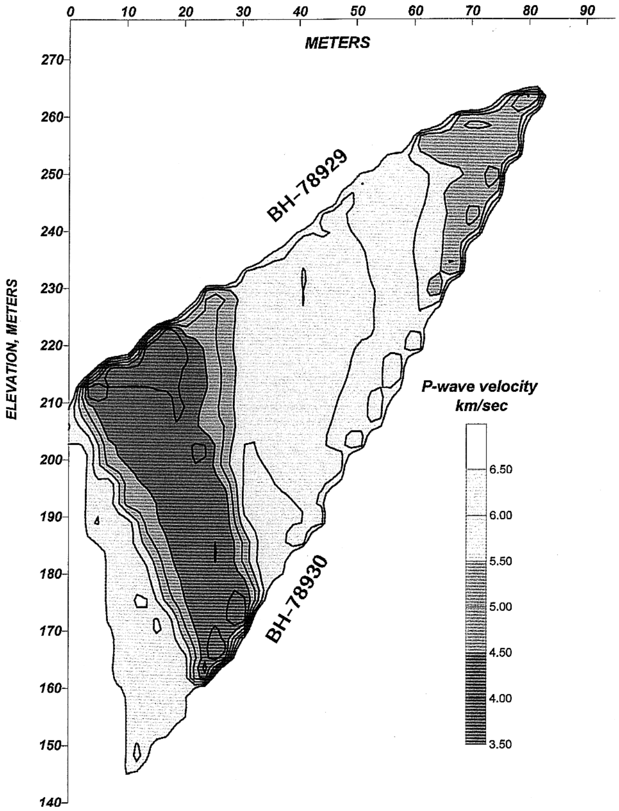

Figure 4: *Tomographic image of the P-wave velocity for the scan of Figure 3. The tomogram was produced from observed first arrival times using a straight-ray iterative back-projection algorithm.*

REFERENCES

Fullagar, P.K., Zhang, P., Yu, Y., and Bertrand, M.J., 1996,. Application of radio-frequency tomography to delineation of nickel sulphide deposits in the Sudbury Basin, in Expanded Abstracts, 66th Annual International Meeting, SEG, 2065-2068.

Harris, J.M., Hoeksma, R.C., Langan, R.T., Van Schaak, M., Lazaratos, S.K., and Rector, J.W., 1995, High-resolution crosswell imaging of a West Texas carbonate reservoir: Part I—project summary and interpretation, Geophysics, **60**, 667-681.

Livelybrooks, D., Chouteau, M., Zhang, P., Stevens, K., and Fullagar, P., 1996, Borehole radar and radio imaging to delineate the McConnell ore body near Sudbury, Ontario, in Expanded Abstracts, 66th Annual Int'l. Meeting, SEG, 2060-2063.

Meng, F. and McGaughey, J., 1996, Ore body hunting with crosswell imaging methods, in Expanded Abstracts, 66th Annual Int'l. Meeting, SEG, 626-629.

Peterson, J.E., Paulsson, B.N.P., and McEvilly, T.V., 1985, Application of algebraic reconstruction techniques to crosshole seismic data, Geophysics, **50**, 1566-1580.

Williams, P., 1966. Using geophysics in underground hard rock mining: a question of value and vision, *in* Expanded Abstracts, 66th Annual Int'l. Meeting, SEG, 2046-2047.

Wong, J., Hurley, P., and West, G.F., 1983, Crosshole seismology and seismic imaging in crystalline rocks, Geophysical Research Letters, **10**, 686-689.

Wong, J., Bregman, N., Hurley, P., and West, G.F., 1987, Crosshole seismic scanning and tomography, The Leading Edge of Geophysics, **6**, 36-41.