BOREHOLE-RADAR REFLECTION IMAGING AT THE MCCONNELL NICKEL DEPOSIT, SUDBURY

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ABSTRACT

Borehole radar surveys were acquired in two configurations at the McConnell nickel deposit near Sudbury: single-hole, with source and receiver antennae offset by 4.7 m in the same borehole, and crosshole, with source and receiver, located above the deposit in different boreholes and separated by up to 60 m. A strong reflection from the sulphide zone was detected in one of the two single-hole surveys; other coherent arrivals are present in both data sets, but cannot be precisely located due to the lack of tool directivity. In contrast, the crosshole survey images two south-dipping reflectors, which overlie the sulphide zone and extend between the boreholes; these conductivity boundaries can also be identified in borehole resistivity logs and a velocity tomogram derived from first arrival travel times. The sulphide deposit itself is not well imaged due to the attenuation of the signals from shots fired in the overlying conductive zones, and to the truncation of the recording time in a survey designed for first arrival analysis. With longer record lengths and greater spatial coverage to avoid localised attenuation anomalies, future crosshole surveys should be able to map the geometry and changing nature of the surface of the nickel deposit.

INTRODUCTION

The McConnell nickel deposit near Sudbury has for a several years been used as a test site for various geophysical survey techniques. The ore deposit is a sheet-like structure, which dips steeply to the south, subparallel to the stratigraphy. A number of deviated, north-dipping boreholes, in which geophysical logs have been recorded by the Geological Survey of Canada (GSC), intersect the sulphide mineralisation. A borehole radar imaging survey was carried out using a 60 MHz Ramac LI tool deployed in two of these holes, 78929 and 78930, with the objective of evaluating the response of the nickel deposit to radar illumination. The radar survey comprised two elements: first, single-hole imaging in both boreholes with source and receiver in the same hole; second, crosshole imaging, in which the source was positioned in the upper hole, and the receiver in the lower (Figure 1).

SINGLE-HOLE REFLECTION IMAGING

The probe configuration was identical in each of the two single-hole radar surveys, with source and receiver separated by 4.7 m. The depth measured along the borehole is referenced to the midpoint between the centre of the source and receiver antennae. Radar signals were recorded every 0.25 m from 75 m to 130 m and 170 m measured depth (MD) in holes 78929 and 78930 respectively. Thus both single-hole radar surveys recorded signals above, within and below the zone of massive sulphide mineralisation.

The recorded radar data display a great degree of variation in amplitude along the boreholes (Figure 2); in some areas, signal can be recovered by application of a time-varying gain function, but in others, for example the zone of massive sulphide mineralisation, the high attenuation prevents the recording of any useful signal. Propagation velocities estimated from the direct arrival are in the range 60–75 m/microS, and suggest that the host rock, which usually has a radar velocity in the range 100–140 m/ns, has been altered by fracturing in the vicinity of the borehole. Few secondary arrivals possess amplitudes similar to the first arrival, and so are not easily identified in the ungained data. However, after application of a gain function, a clear radar reflection from the top of the zone of massive sulpide mineralisation can be identified in hole 78929; the reflection projects back to the depth of the top of the mineralised zone. This interpretation has been verified by forward modelling. In contrast, there is no clear reflection from the top of the sulphide zone in hole 78930, although some other weak reflected arrivals can be tentatively identified.

In "Proceedings of Exploration 97: Fourth Decennial International Conference on Mineral Exploration" *edited by* A.G. Gubins, 1997, p. 701–704

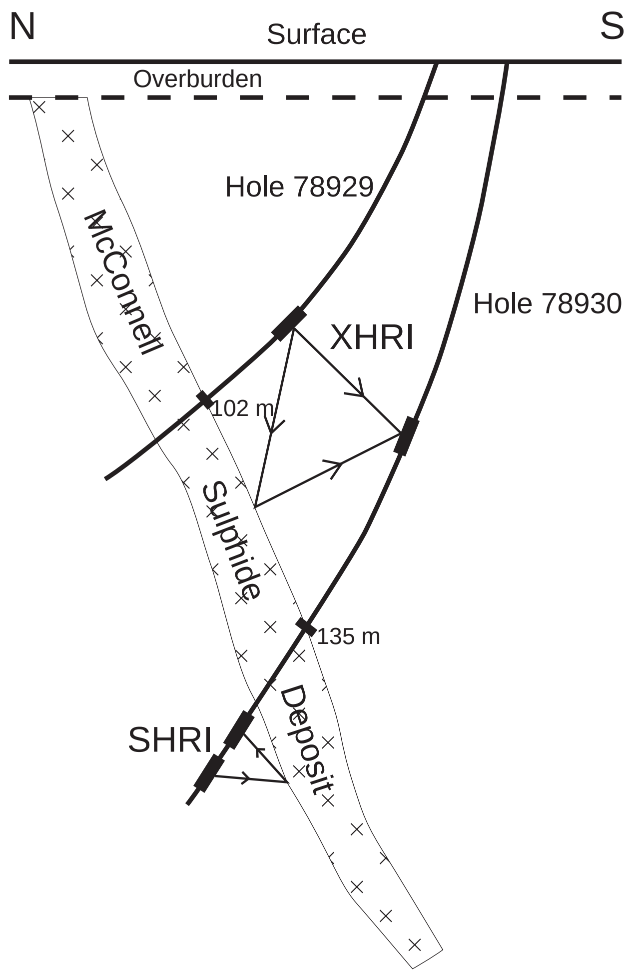

Figure 1: *Geometry of radar surveys at the McConnell nickel deposit, Sudbury.*

Both radar profiles are correlated in Figure 2 with resistivity logs recorded in the same boreholes. The resistivity logs, which are clipped at around 30 000 Kohm-m due to the difficulty in measuring small currents in such resistive rocks, are coded by the lithologies intersected along the boreholes. The depths, at which the radar signal is attenuated by the massive sulphide, correspond well to the regions of low resistivity identified in the borehole logs, the 2–3 m offsets likely associated with the non-zero offset of the source and receiver in the borehole radar probe. However, the regions of less severe signal attenuation at shallower depths, for example 85–92 m in hole 78929 and 108–115 m in hole 78930, are offset by around 6 m from resistivity lows in the logs. The resistivity logs also suggest that these latter zones of low resistivity are not correlated with lithology, perhaps representing fluid-filled fracture systems. Of relevance to the later interpretation is the observation that above the ore zone, there exists a 10 m-thick low resistivity region in hole 789929, but that in hole 78930 two 4 m- and 8 m-thick resistivity lows are identified.

CROSSHOLE IMAGING

The crosshole survey was originally designed to image the region above the ore deposit by tomographic inversion of the first break arrival times. As a result, the survey comprised 18 shot points in the upper borehole, 78929, each of which was recorded at 25 receiver depths in the lower borehole, 78930; both shot and receiver spacings were 3 m. This gave good ray coverage for the tomographic inversion using the Migratom software package (Figure 3). The tomogram indicates that lower velocities are concentrated largely around the bottom half of the upper borehole with a lobe of lower velocity rock extending down and toward hole 78930.

The tomographic survey was designed to image the rock mass above the sulphide ore, because the signal recorded from shot points in, or behind, the ore zone would be severely attenuated in the mineralised zone, and be of no use. Thus the information on the deposit geometry that this type of survey can provide is limited, the deposit being deeper than the imaged rock mass. One solution to this difficulty is to utilise the later arrivals, which have been reflected and scattered from the ore body and can be focussed into a high resolution image by migration. The strong, direct arrival must be suppressed, and an amplitude correction for geometric spreading applied. The multiple shots can then be migrated, assuming a constant velocity of 100 m/ns in this case, using a Kirchhoff-style algorithm (Figure 4). The crosshole reflection image indicates that a thick reflective zone intersects the upper borehole at a true vertical depth (TVD) of 63 m, corresponding to the wide zone of low resistivity identified in hole 78929 at 93 m MD. The reflective zone in the crosshole reflection image can be traced towards the lower borehole, and correlates with the low velocity region identified in the velocity tomogram. However, where the low velocity region appears to terminate between the boreholes, the broad reflective zone divides into two thinner splays, which continue to hole 78930 and correlate with the two thinner low resistivity zones seen in the log. Modelling of reflections from the ore deposit indicates that they mostly arrive at transit times greater than the last recording time except for the deepest shot points, which are mainly located within the deep conductive, i.e. attenuative, zone just above the sulphide mineralisation in hole 78929. As a result, the upper surface of the ore body is not well resolved, although the reflection at around 90 m TVD near hole 78930 may be associated with this boundary.

CONCLUSIONS

The single-hole reflection surveys show that the McConnell nickel deposit can reflect radar signals quite strongly. However, the reflection response is much weaker in the deeper borehole, suggesting that the change in reflection amplitude may be linked to a variation in character, perhaps the concentration of conductive minerals, of the deposit. The crosshole reflection survey geometry permits conductive zones to be mapped between boreholes, but delineation of the ore deposit was limited by truncation of recording times in a survey designed primarily for direct arrival tomography. Future surveys with finer spatial sampling and longer recording times should be able to resolve the limits of the mineralised zone, although highly attenuative regions near the deposit could limit the quality of the final image.

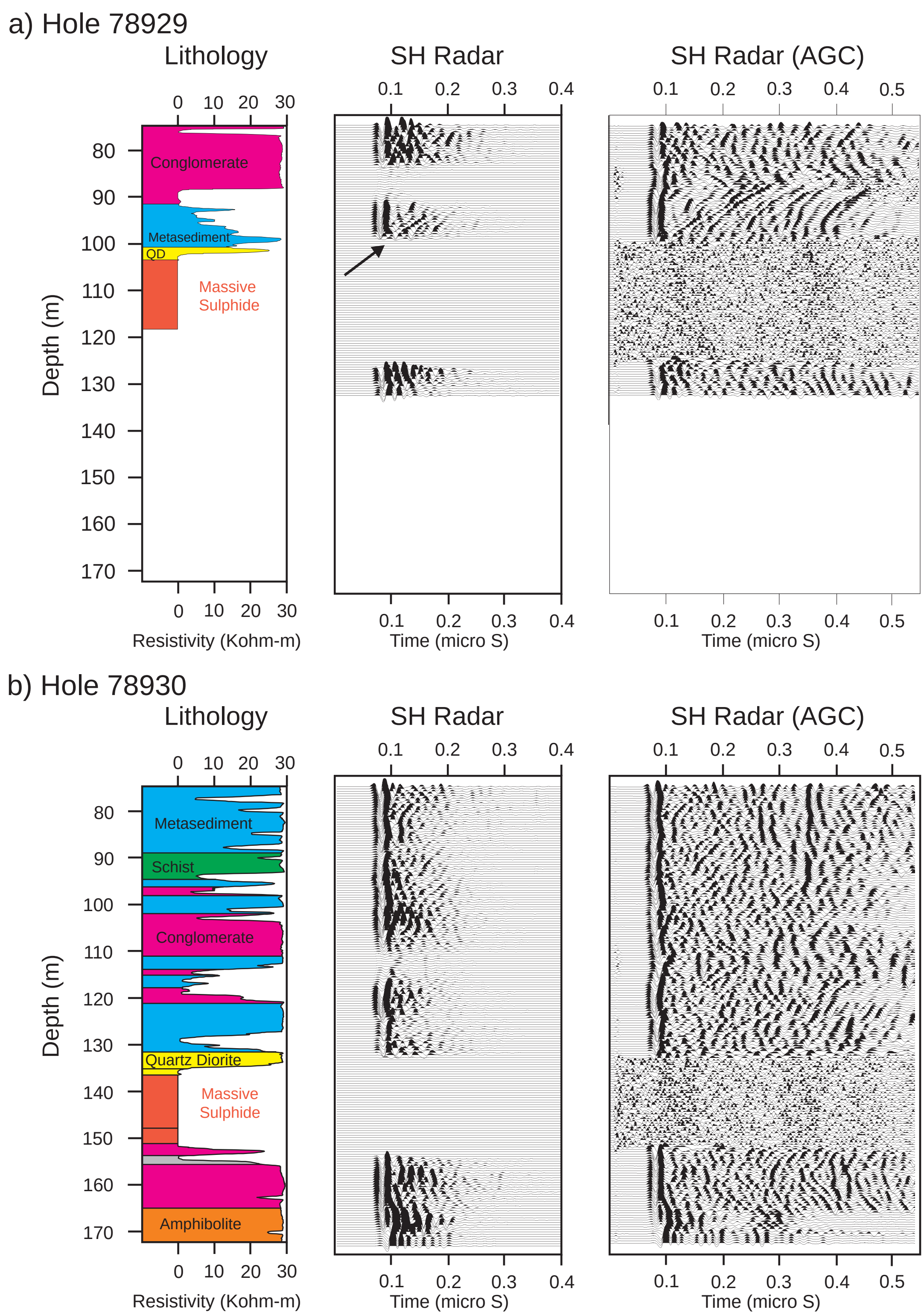

Figure 2: *Single-hole radar imaging profiles recorded along: (**a**) hole 78929 and (**b**) hole 78930. The radar data are displayed both with no amplitude scaling and with a time-varying gain (AGC) applied. Also shown are resistivity logs coded as a function of lithology in the boreholes.*

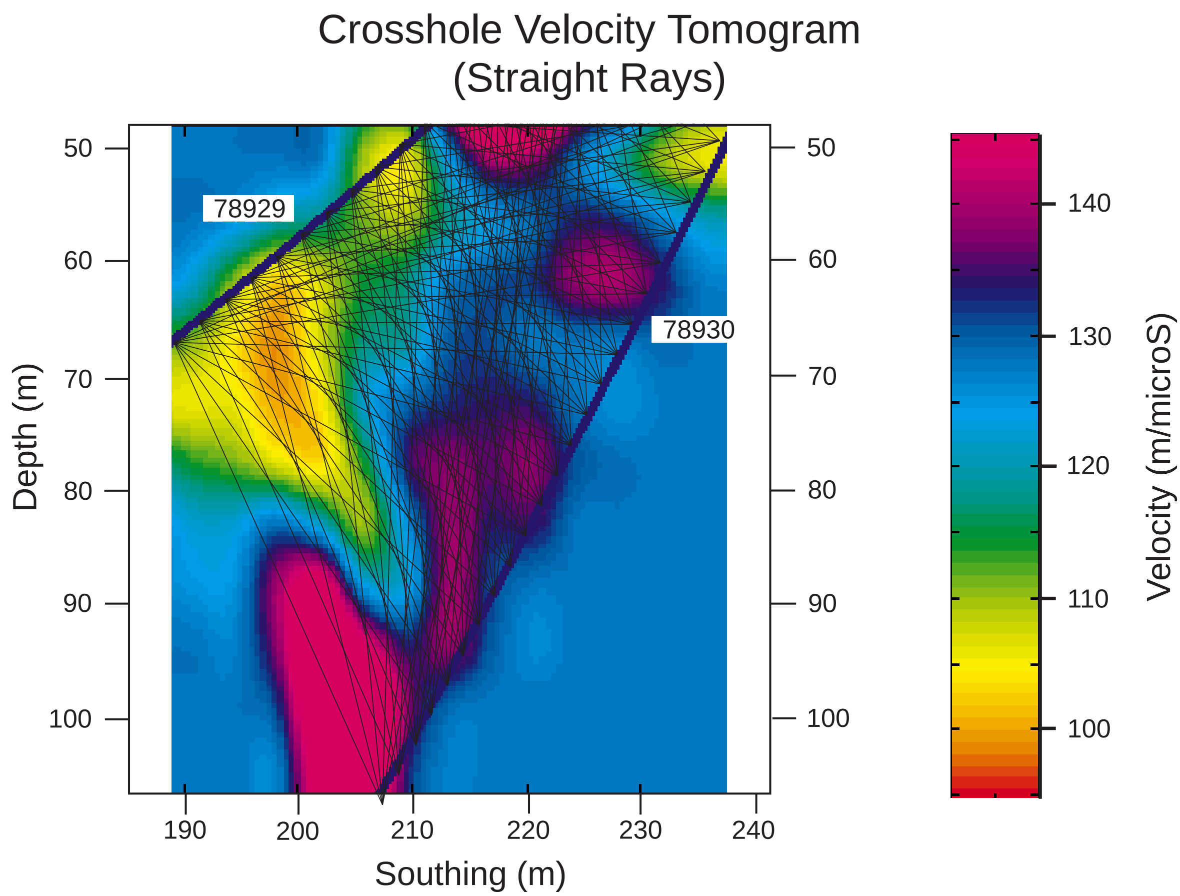

Figure 3: *Velocity tomogram derived from the crosshole radar survey using the straight ray paths shown.*

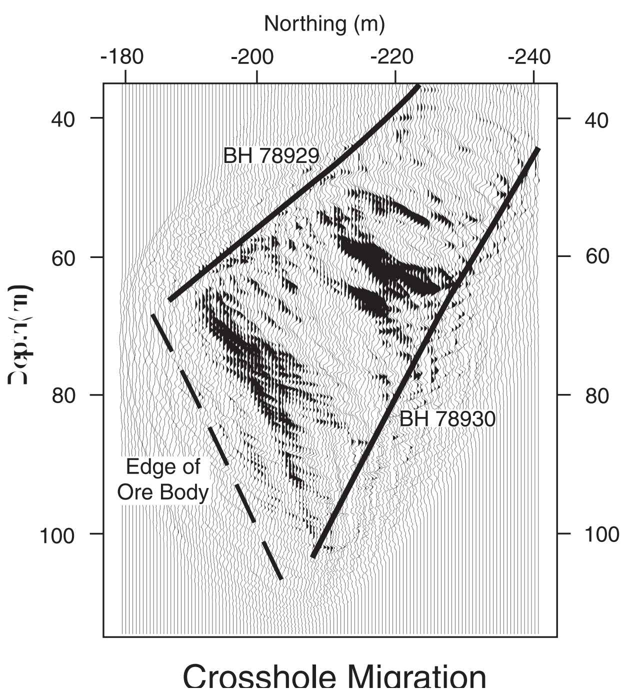

Figure 4: *Migration of the crosshole radar reflection data.*