Clay Layer Separation Detection in Potash Mines using Stepped Frequency Radar Technology

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Abstract

MIRARCO, a mining industry research organization based at Laurentian University, in collaboration with RST GmbH, a German radar company, have investigated the application of space-born radar technology for use in mine environments. Through funding provided by the European Space Agency (ESA) and the Canadian Mining Industry Research Organization (CAMIRO), MIRARCO and RST developed the Crack Identification System (CRIS). CRIS is a stepped frequency radar, operating in the 2-6 GHz bandwidth, specifically designed to detect cracks within the first 1-2 metres around an underground opening in the hardrock mine environment.

Field trials were undertaken at potash mines in the Saskatoon, Saskatchewan area belonging to the Potash Corporation of Saskatchewan Inc, to demonstrate the functionality of CRIS in a softrock environment. This paper highlights some of the results of those field trials. The CRIS GPR was able to identify separations in the mine-room roof to a depth of approximately 1.5 metres. CRIS was also able to see past the first separation and identify separations higher in the roof. However, CRIS was unable to identify clay layers present in the roof above the mining horizon.

For the field trials, RST also brought along their "radar laboratory" called SUSI (Stepped frequency Ultra wideband Synthetic aperture radar Instrument). The SUSI radar can operate over a number of frequency bandwidths. This instrument also served as the development platform for CRIS. A section of drift was profiled using SUSI operating in the frequency band 200 MHz to 1000 MHz. At these lower frequencies the roof-clay stratigraphy could be readily identified and mapped. These field trials indicated that stepped frequency radar technology could be "tuned" to identify both separations and clay stratigraphy in the softrock, potash mine environment.

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Introduction

Falls of ground in a mine are a serious concern for the safety of both personnel and equipment. The detection of locations of potential instability prior to the occurrence of a fall of ground event will lead to improved safety conditions, i.e. the miners/shifters will know exactly which areas need to be bolted. MIRARCO, a mining industry research organization based at Laurentian University, in collaboration with RST GmbH, a German radar company, have researched the applicability of space-born radar technology for use in such environments. Through funding provided by the European Space Agency (ESA) and the Canadian Mining Industry Research Organization (CAMIRO), MIRARCO and RST developed the Crack Identification System (CRIS). CRIS is a stepped frequency radar specifically designed for the detection of near surface fractures in the hardrock mine environment. Operating in the 2-6 GHz bandwidth, CRIS is able to detect near surface parallel cracks within the first 1-2 metres around an underground excavation or opening (Cotesta et al., 2001).

The ability of CRIS to detect cracks in the hardrock environment intrigued the softrock (potash) mining community. Potash mines experience similar instabilities in that separations form along clay layers above the mining horizon and constitute a potential genesis for instability. A series of field trials was thus undertaken at the Allan and Lanigan Divisions of the Potash Corporation of Saskatchewan to assess the applicability of this technology.

The potash mining industry also expressed the desire to be able to track the stratigraphy in the mine roof. To demonstrate the ability of the radar technology to do this, RST also brought along their “radar laboratory” denoted SUSI (Stepped frequency Ultra wideband Synthetic aperture radar Instrument). A section of drift was profiled using the SUSI radar adjusted to operate in the frequency band 200 MHz to 1000 MHz. At these lower frequencies the roof-clay stratigraphy could be identified and mapped.

Radar Background

In contrast to classical pulse radar systems, stepped frequency radar systems such as CRIS operate with amplitude-continuous radar signals. The signal bandwidth required for the desired radar resolution is generated sequentially in discrete steps through the desired frequency range. In the receiver section, both phase and amplitude measurements of the return signals are performed. The resulting data is then IFFT (Inverse Fast Fourier Transform) processed to generate a synthesized pulse (Figure 1; Valle et al., 2000).

The advantages to this modulation technique can briefly be summarized as follows: low instantaneous bandwidth, high sensitivity, high penetration depth, low sensitivity to RF interferences, low power consumption, high resolution with respect to measurement frequency, low output data rate and reduced wide-band antenna problems. An additional benefit is the unique ability for instrument calibration in the frequency as well as in the time domain that can yield enhanced radar range resolution performance. CRIS also incorporates innovative software features including a graphical user interface that automates certain processing steps and adds interactive 3D display functionality. Algorithms specifically tailored to fracture detection were specified, developed and implemented.

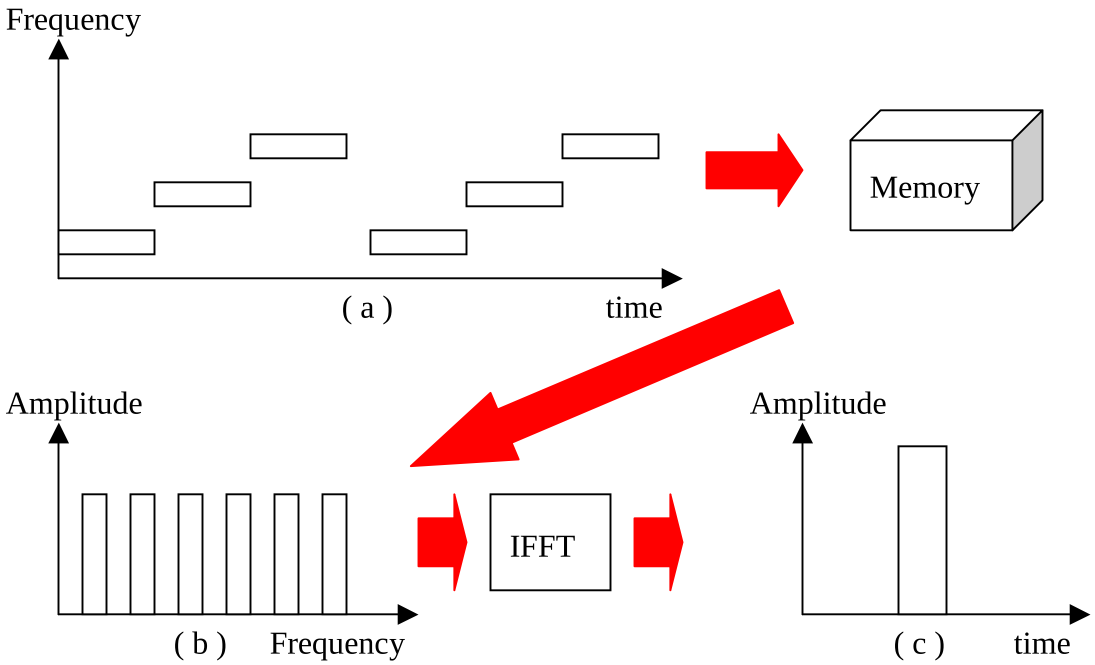


Figure 1: Stepped frequency radar operation. (a) Measurement of echoes at single frequency lines, (b) compiled receive spectrum and (c) synthesised pulse. (after Valle et al., 2000)

Wilchek (2000) evaluated the fracture detection capabilities of conventional pulse radar systems in hardrock environments around Sudbury. These same sites were used to evaluate the performance of CRIS. At one site (Hwy. 17 Bypass) the rock structure was clearly defined (Figure 2). Two fractures were visible behind the face of the rock cut, one at a depth of 20 cm and the other at a depth of 50 cm. Figure 3 presents the radar data obtained by Wilchek (2000) using the 1000 MHz pulse system. The fracture locations, indicated by the solid lines, are not immediately apparent, particularly to the untrained eye, because of multiple reflections and noise. A scan of a portion of the same rock cut using the CRIS radar is presented in Figure 4. The two fractures are easily identified in the image (Note: the weaker reflection at 35 cm is clearly an artefact as the reflected energy is lower than that from the deeper feature). The detection capability and the ease of interpretation offered by CRIS were the key factors in enticing the potash industry to pursue the technology further.

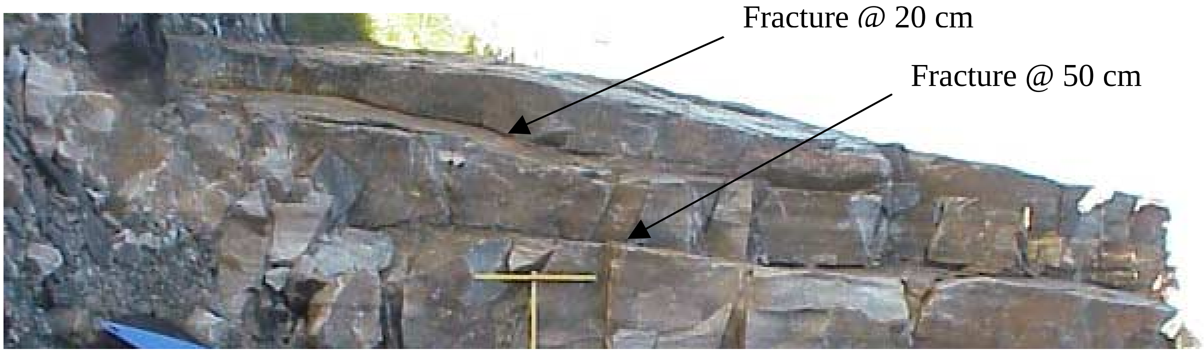
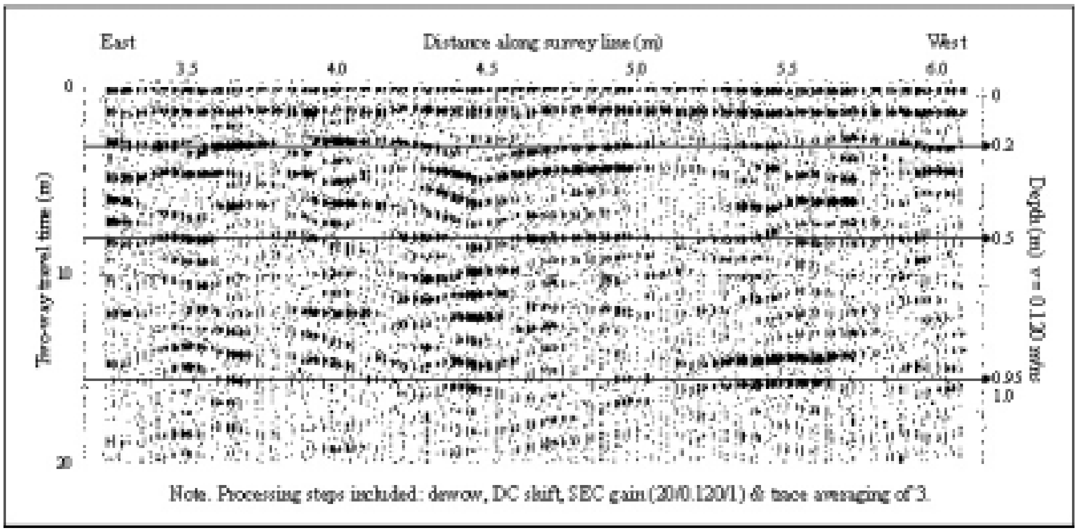


Figure 2: Photo of granitic rock cut near Sudbury used for radar trials. Photo is rotated to match with radargrams (Wilchek, 2000).



Note. Processing steps included: dewow, DC shift, SEC gain (20/0.120/1) & trace averaging of 3.

Figure 3: Radargram of rock cut obtained using 1000 MHz pulse radar system (Wilchek, 2000).

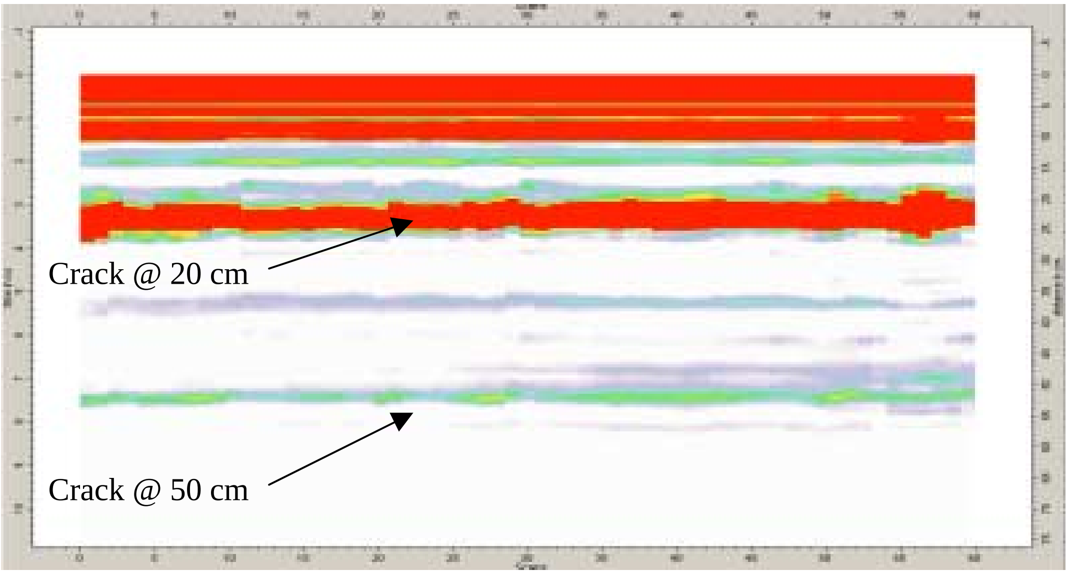


Figure 4: Radargram of portion of same rock cut obtained using CRIS GPR. The first two fractures are clearly identifiable.

Field Trials in Potash

A series of trials were undertaken at various underground operations of the Potash Corporation of Saskatchewan. Two stepped frequency radar systems were employed, CRIS and SUSI. The operating specifications for these two are presented in Table 1.

Table 1: Radar operating specifications.

	CRIS	SUSI
Frequency range	2 GHz – 6 GHz	5 MHz – 8 GHz
Number of frequency lines (steps)	512	Up to 2048
Output power		5 mW
Quantisation	16 Bit	16 Bit
Number of antenna transmit/receive	1 / 4	1 / 1
Antenna type used	Vivaldi	dipole

In the radargrams accompanying the text, the left ordinate axis represents the two-way travel time of the radar wave. The right ordinate axis denotes the depth to the feature which is calculated using the two way travel time and an assumed velocity for the wave through the salt (0.12 m/ns). The radargram is inverted; i.e.- the back of the drift is at the top of the plot and penetration into the back is shown below.

Trials with CRIS

The following select examples demonstrate the ability of CRIS to detect bed separation features in the back of drifts mechanically excavated in potash. Photos showing the typical field operation of the CRIS unit are shown in Figure 5.

Figure 5: Hand scanning of brow along 13 Conveyor Drift at Lanigan Mine.

Test Site 1 - Brow Along Main 5 at Lanigan Division

A brow along the Main 5 access drift with a visible fracture was selected as an ideal test location. The scan proceeded along the axis of the drift from 1 m in front of the brow to 6 m past it (Figure 6). Figure 7 is a photo of the observed fracture.

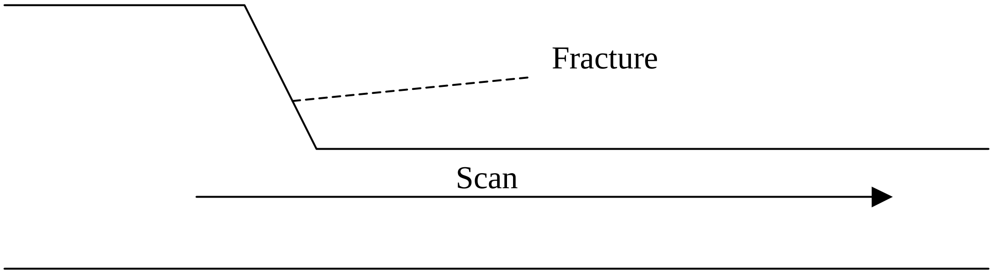


Figure 6: Longitudinal section of Main 5 access drift showing radar scan and fracture orientation.

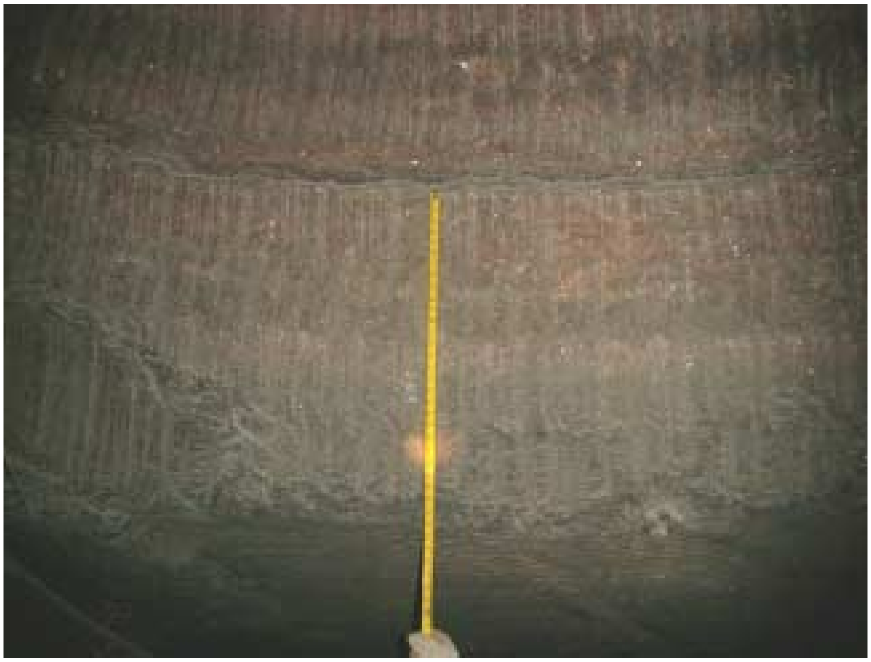


Figure 7: Photo of observed fracture in brow along Main 5 access drift.

Figure 8 shows the results of the radar scan. A hyperbola indicating the vertical face of the brow is visible, as is the fracture at a distance of approximately 80 cm above the back at the brow face. The radar indicates that the fracture is inclined relative to the back. However, this could not be verified, as no test hole was available at this location.

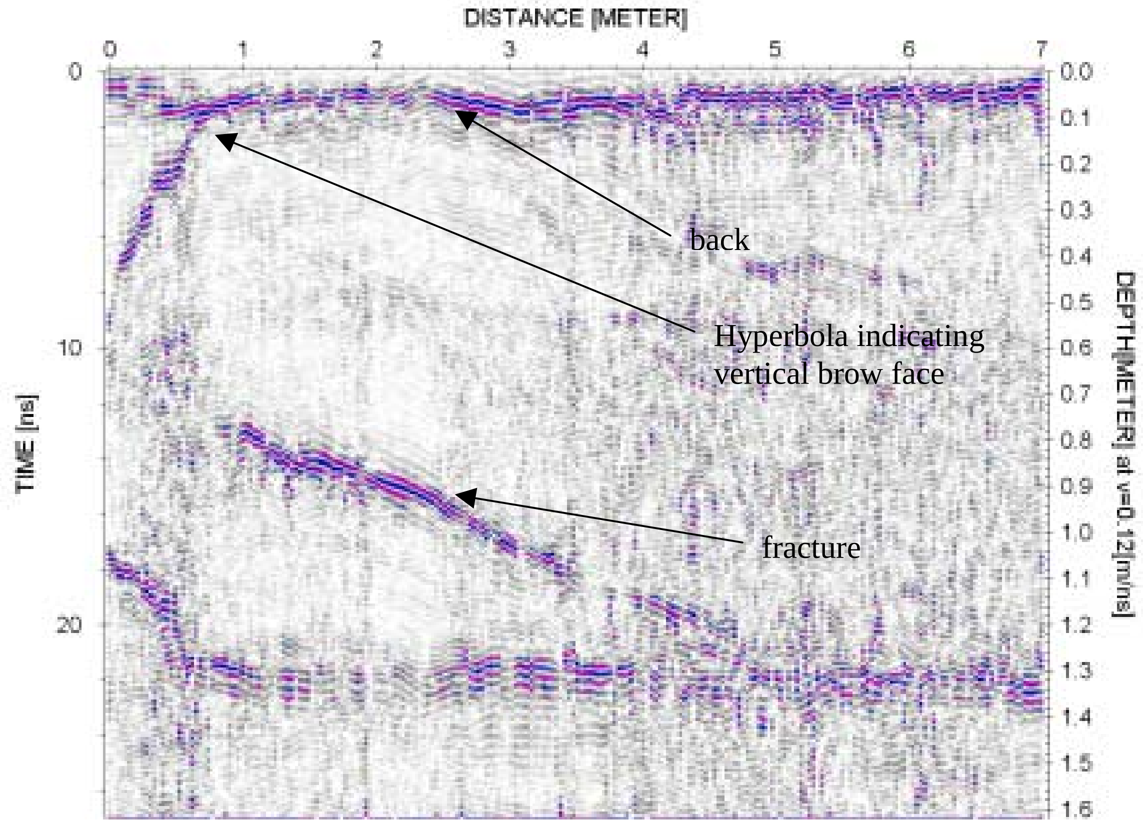


Figure 8: Longitudinal profile of brow in Main 5 access drift showing fracture in brow.

Test Site 2 - Brow Along 13 Conveyor Drift at Lanigan Division

A second test site, along the 13 Conveyor Drift, was selected to demonstrate the ability of CRIS to identify multiple fractures. This time the scan was performed across the width of the drift as illustrated in Figure 9. Visual inspection of the brow indicated three fractures at heights of 30 cm, 83 cm and 130 cm (Figure 10 and Figure 5). The first two were not continuous across the width of the scan area.

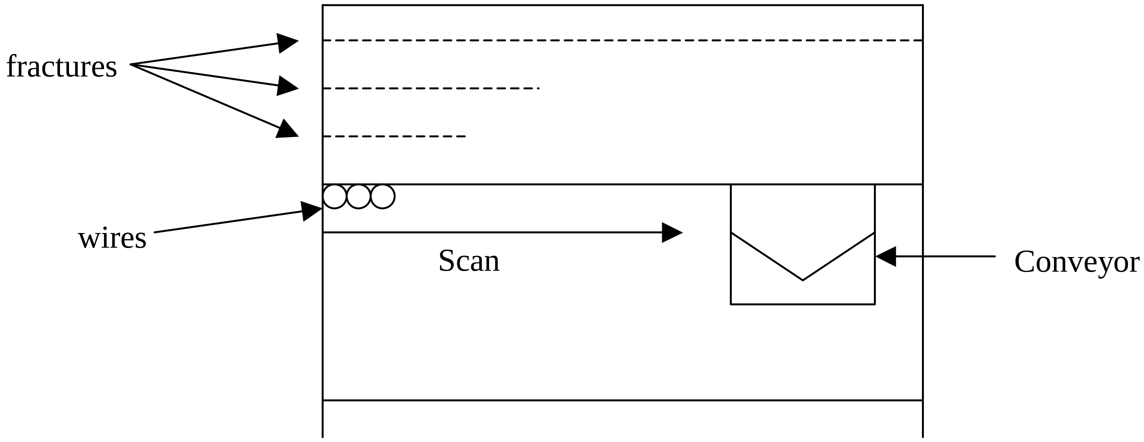


Figure 9: Cross-section of 13 conveyor drift showing approximate locations of fractures.

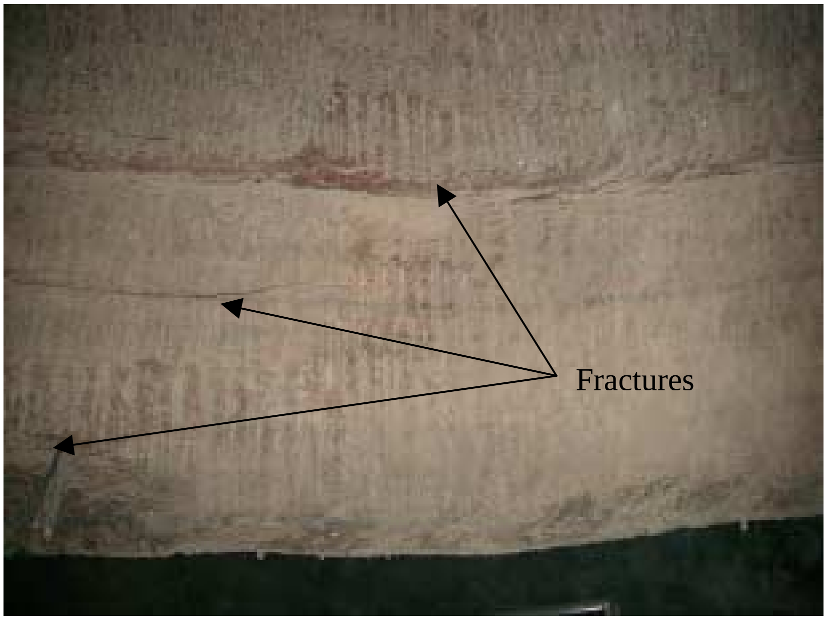


Figure 10: Photo of fractures observed in brow along 13 Conveyor Drift.

Figure 11 is the radargram obtained from the survey. Notice that the two uppermost fractures do not span the entire width of the scan (visually confirmed). A multiple in the radargram occurs just below the lowermost fracture. This feature was inherent to the CRIS GPR as configured. New potash specific versions of the GPR hardware have eliminated this artefact.

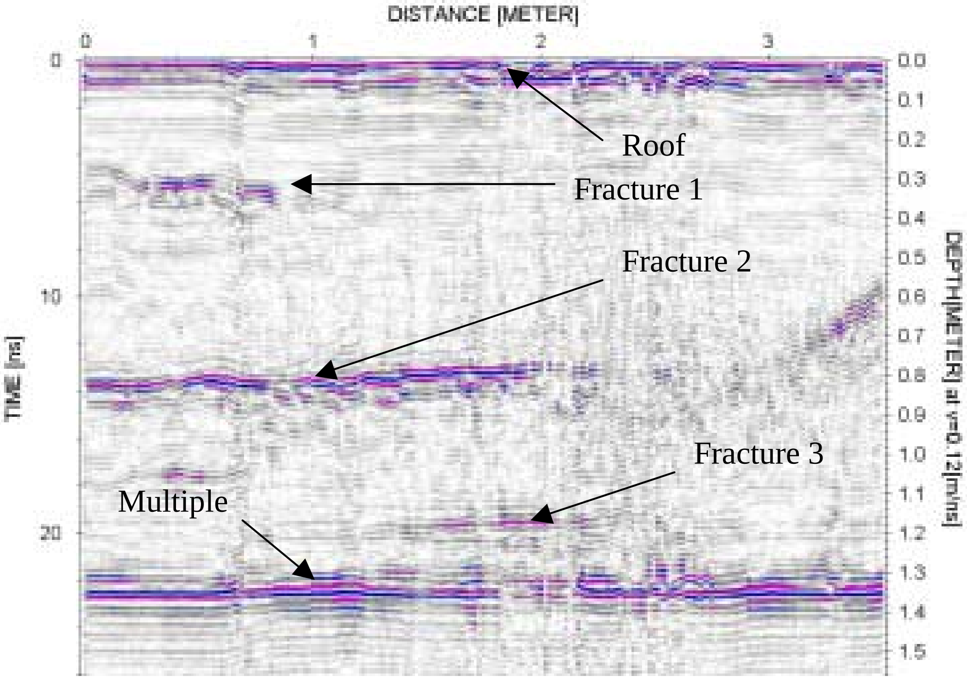


Figure 11: Cross-sectional profile of brow in 13 Conveyor Drift showing location of fractures.

Test Site 3 - N33W (West fresh air vent) at Allan Division

This test site was in close proximity to the active mining face (Figure 12). The crew had just finished bolting this location because they had determined it to be unstable through sounding with a scaling bar. A test hole (th2) was drilled to verify the location of a fracture above the roof (at approximately 47.5 cm above the back, with an aperture of approximately 2.5 cm). This presented an ideal situation in which to use CRIS to detect this fracture. A scan was performed along the diagonal line shown, from the back of a moving jeep. The resulting radar profile is presented in Figure 13. A further two test hole locations (th1 and th3) were proposed to verify the location of the inclined fracture observed using the CRIS radar (i.e. the fracture was predicted to be at a depth of 2 ft (0.61 m) at th1 and just under 1 ft (0.25 m) at th3). Before confirmation could be made, a portion of the back came down at this location. Darrel Wagner, Allan ground control engineer, described the piece that dropped as being wedge shaped (with a shape very similar to what had been predicted using CRIS data). Subsequent drilling at th1 located the fracture at 0.66 m (2 ft 2 inches). The roof failed in this area before th3 could be drilled. The observed shape and location of the fracture surface were in very good agreement with the measurements made using the CRIS radar.

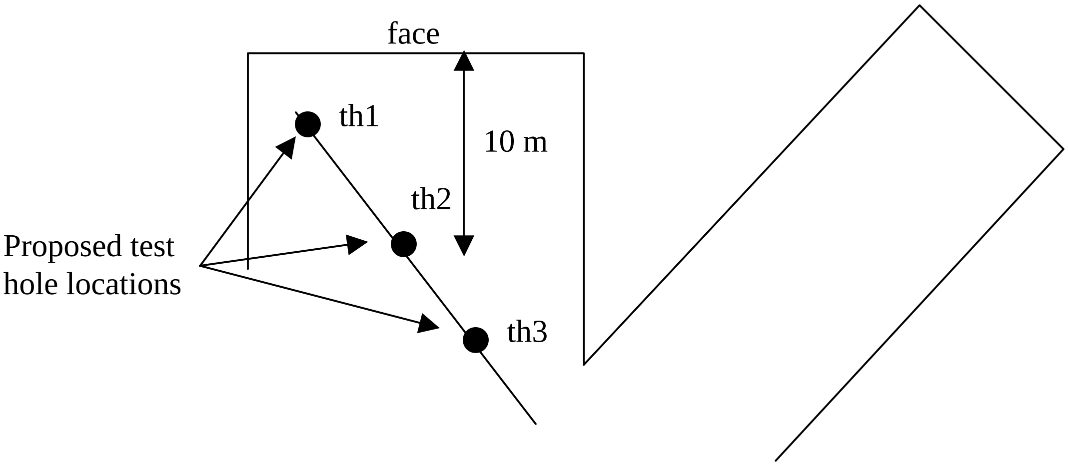


Figure 12: Sketch of Test Site 4 at Allan Mine (N33W fresh air drift).

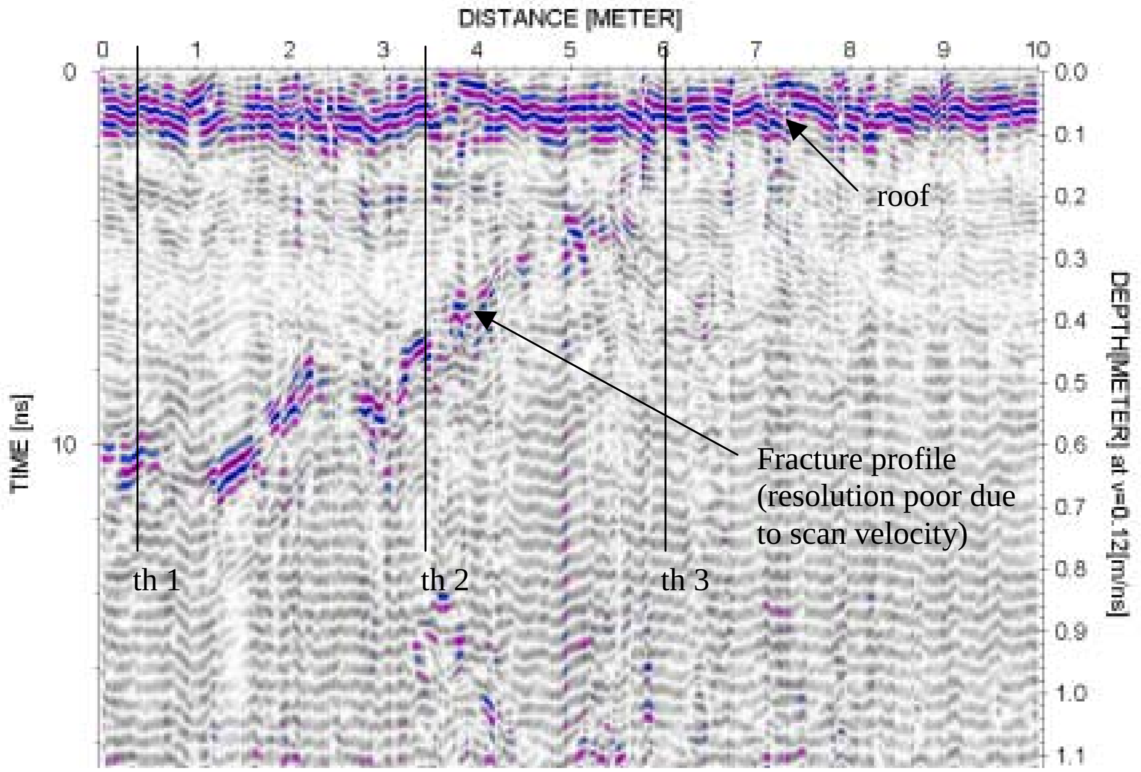


Figure 13: Radar profile along line in the N33W fresh air drift at Allan Mine.

Field Test Results – SUSI

Field tests with SUSI, operating in the frequency range of 200 to 1000 MHz, were performed at the Lanigan Mine to assess the capability of this radar technology in delineating lithology.

Test Site 4 - Room C-0253 at Lanigan Division

At the time of the test, Room C-0253 was actively being mined in the third pass. Figure 14 is a photo showing the geometry of the room at the test location. Scans were performed from the 1700 foot marker to the 1600 foot marker along the upper bench of the room. This location was selected because at the 1670 foot mark (approximately), the shadow band clay seam dipped down and daylighted in the room (Figure 15). The mining crew had previously bolted this area, recognizing the potential for instability.

Figure 14: Photo showing geometry of Room C-0253 at the time of the test using the SUSI radar.

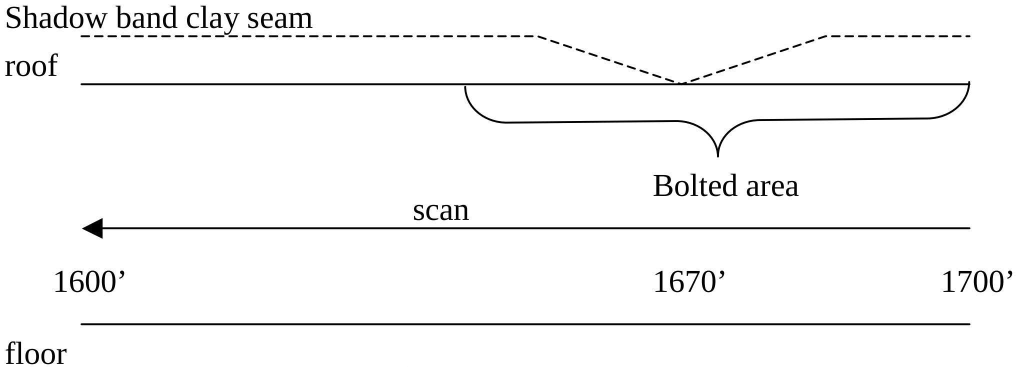


Figure 15: Sketch of test site in Room C-0253 at Lanigan Mine.

The SUSI radar picked up a strong reflection above the roof (Figure 16). The location of this reflection is higher than the expected location of the shadow band. However, the shape of the feature does correspond to the expected shape of the shadow band in this area. There are some other, less intense, shallow reflections but they are difficult to separate from the "ringing" in the radargram. Non-directional dipole antennas were used in this test, thus reflections were picked up from all directions. Subsequent work using ridged horn antennas (not reported herein) has greatly improved the resolution for clay layer mapping.

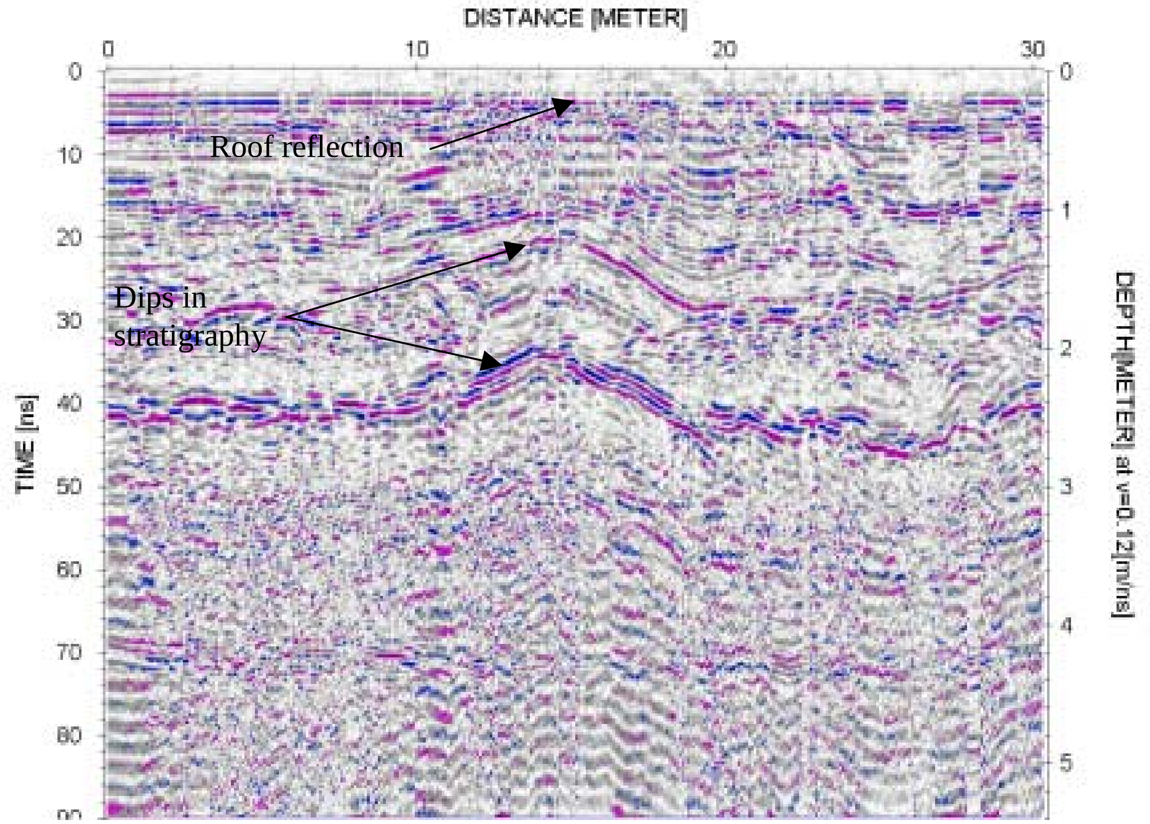


Figure 16: SUSI radargram from Room C-0253 at Lanigan Mine.

Conclusions

The CRIS radar was able to identify the location of fractures in the backs of drifts at both of the test mines; however, it was unable to identify the locations of the clay seams. The SUSI radar, operating over the lower frequency range of 200 MHz to 1000 MHZ, was better able to identify the stratigraphy but not the thin, open fractures. The transition from salt to clay is relatively gradual when compared to the resolution of the high frequency CRIS system; hence, it is not readily apparent in the radargrams. However, the transition from salt to an open fracture is very abrupt and easily identified. Conversely, for the lower frequency SUSI system, the more gradual transition from salt to clay is closer to its resolution than the abrupt transition from salt to an open crack, and hence more readily visible.

The wedge-shaped failure of the roof in drift N33W at Allan Mine is an excellent example of the potential benefits of a radar crack detection system. Through sounding, the miners were able to identify a potentially hazardous area, but they were unable to quantitatively measure the detailed shape of the failure surface. A radar system, which could be used to scan a grid of the entire heading, would better delineate the problem zone. Such a tool would add valuable information to those deciding what should be done about that zone (eg.- abandon, bolt, support, cut down, …).

While CRIS was successful in detecting and mapping fractures within 1.5 m above the roof in potash, the packaging of the instrument was not ideal for this environment. A re-engineered radar, customized for the potash industry, is currently under construction.

Acknowledgements

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