Mapping Complex Geology with GPR in a Canadian Potash Mine

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***Abstract*—The application of GPR in a Canadian salt and potash mine in New Brunswick, within a structurally complex geological setting, is discussed. When the mine was started in 2014, occurrences of anhydrite were unexpectedly encountered in mining development rooms. Furthermore, occasional undulations and folding in the potash ore seam complicated production mining because the potash ore would get diluted with salt. To better understand the geology, abundant geological data was gathered from both in-mine drilling and geological observations. These data provided an excellent foundation for a comprehensive GPR investigation of the geology in this mine. It is shown that GPR is a valuable tool for such mines, with potential to reduce delays in development and production caused by challenging geology**

***Keywords*— potash, salt, mining, geology**

I. Introduction

The application of GPR in both salt and potash mines has enjoyed considerable success for many decades. Dry salt has a low dielectric permittivity, making GPR an ideal imaging technology for these environments. The Province of Saskatchewan in Canada has the largest potash deposits in the world, and GPR has been used in these mines for 40 years ([1], [2], [3], and [4]). Likewise, in Germany, where both salt and potash are mined, GPR has been a valuable tool and has been demonstrated to improve both operational efficiency and safety ([5], [6], and [7]). Potash and salt has also been mined in the Canadian Province of New Brunswick (on the coast of the Atlantic Ocean) since the 1980's, but the use of GPR in these mines has been sporadic. In the recently commissioned Picadilly potash mine in New Brunswick, two operational challenges were encountered: 1) occasionally the ore seam had more variability than expected and thus following the seam while mining was challenging; and 2) development and salt mining in the geomechanically competent salt (below ore level) occasionally encountered large seemingly isolated "blocks" of anhydrite which impacted development schedules. As development of the mine progressed, comprehensive in-mine horizontal drilling and auger drilling was used to better understand the geology. The abundance of geological information provides valuable ground-truthing data for testing the efficacy of GPR in the Picadilly mine. What follows is a description of the GPR investigations at this mine.

II. Background

A. Location and Geology

The Picadilly potash mine is located near the town of Sussex (New Brunswick, Canada), about 35 km from the Bay of Fundy on the Atlantic Ocean. Mining of potash and salt in New Brunswick has been taking place since 1982; the Picadilly mine was recently completed and went into operation in 2014. Depth of mining ranges from 700 m to 850 m and the potash is hosted in the Windsor salts (part of the Windsor Group) of Mississippian age (Fig. 1). The Windsor Group consist mainly of evaporites (including limestone, gypsum, and salts) and is sandwiched between a thick deposit of water-bearing siltstone above (the Mabou Group), and siltstone below (the Hillsborough Formation). At the top of the the Windsor Group (above the salt) is a thin and relatively uniform anhydrite layer known as the Upper Anhydrite, and at the base of the Windsor Group (below the salt) is a thicker and considerably more complex anhydrite layer known as the Basal Anhydrite. The potash is found in two relatively horizontal, gently undulating seams which were fold limbs deformed through halokinesis to be roughly parallel to one

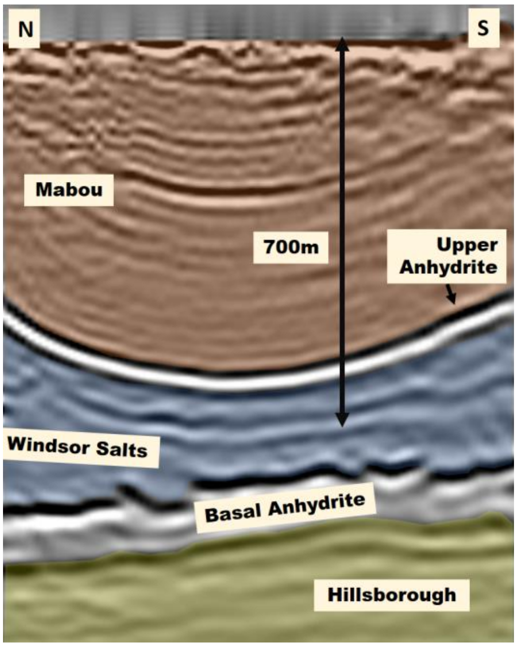

Fig. 1. A typical seismic cross-section through the Picadilly mine with major geological formations labeled.

another. The salts in which the potash is found, are not pure, while the salts below the potash (Basal Halite) are very clean. The Upper Anhydrite is typically 50 m above the potash, and the Basal Anhydrite ranges from 2 m to 180 m below. The long-term mining rooms, which are to remain in service for the life of the mine, are in the Basal Halite below the potash. These halites are strong, having geomechanical properties which make them advantageous for long-term entries.

B. In-mine Geological and Geophysical Investigations

To better understand both the extent of ore seam undulations and occurrence and nature of the anhydrite within the Basal Halite, both in-mine exploratory drilling and GPR were used to gain a better understanding of the structure and stratigraphy. Extensive horizontal drilling campaigns provided valuable geological data for modelling the Upper and Lower Anhydrites and the salts and potash. It was recognized that GPR would be a valuable imaging tool in this mine due to the relatively clean salts. Some early work with GPR in a New Brunswick potash mine in the 1980's and 1990's was successful, but no publications were made. Initial trials at the Picadilly mine with 250 MHz GPR showed promise: coherent and believable events were imaged at over 20 m depth. These results were the justification needed to carry some comprehensive GPR data collection campaigns

III. GPR DATA COLLECTION CAMPAIGNS

In total, three campaigns were carried out between 2015 and 2016 to test whether GPR could be useful for operations planning and risk reduction.

A. Spring 2015 GPR Campaign

The purpose of this campaign was mainly to test viability of both upward- and downward-looking GPR at the mine and to also determine appropriate parameters. The 250 MHz, 500 MHz, and 1000 MHz Sensors & Software Noggin systems were used for downward-looking (floor) surveys. While 250 MHz and 500 MHz frequencies were tested for upward-looking profiles into the roof. Room height at the Picadilly mine is nominally 3.66 m, exceeding 4 m occasionally. Collecting upward-looking profiles is challenging without mechanical assistance. For this campaign, a personnel lift was used and short profiles were captured by the geophysicist while elevated in the lift. The downward-looking GPR was not successful possibly due to the floor conditions (high moisture content introduced from mining operations). The upward-looking profiles depth of penetration was 5 m to 6 m, which was encouraging. A constant value of 6.25 was assumed for the dielectric constant of salt to convert the radargrams to depth. This value was not confirmed with wide-angle surveys, but is a well-known value for salt and is use in the Saskatchewan mines ([3]).

B. Fall 2015 GPR Campaign

The purpose of this campaign was to use both 250 MHz and 500 MHz GPR equipment to image into the roof and floor in several development mining entries, to test viability of GPR for routine application in the mine. The main application for these frequencies and survey configurations is to image the stratigraphy within the vicinity of the mining rooms to better understand the structural undulations and whether the changes are concomitant with ore zone variations. A GPR-RTV was brought into the mine to be used for collecting upward-looking GPR. These vehicles are routinely used in Saskatchewan potash mines ([3]). The GPR-RTV was designed for 1000 MHz antennas, but lower frequencies with deeper penetration were determined to be beneficial for Picadilly. Furthermore, the rooms are taller than rooms in Saskatchewan mines. To address this difference, the GPR-RTV mechanical lift was modified to be operational up to 5 m and to house 250 MHz, 500 MHz and 1000 MHz antennas (Fig. 2). In total, 980 m of downward-looking 250 MHz GPR profiles were collected and 550 m of 500 MHz upward-looking profiles. Data quality was exceptional having both high quality and excellent correlation with known depths, as determined by in-mine and surface drilling (Fig. 3). Both salt and potash have similar dielectric constants, so the potash seams cannot be differentiated from the salt by direct imaging. However, within the Windsor Salt stratigraphy, known "markers" imaged by GPR can be used to infer the overlying potash seams. These markers are simply sharp contacts between various evaporitic sequences in the Windsor Salt having different amounts of impurities. Some of these markers are imaged in the GPR sections, thus proving that GPR is a useful and economic tool for rapid determination of orientation and proximity of overlying geological sequences.

Fig. 2. The GPR-RTV used in the Picadilly mine. A 500 MHz antenna is mounted on the lift.

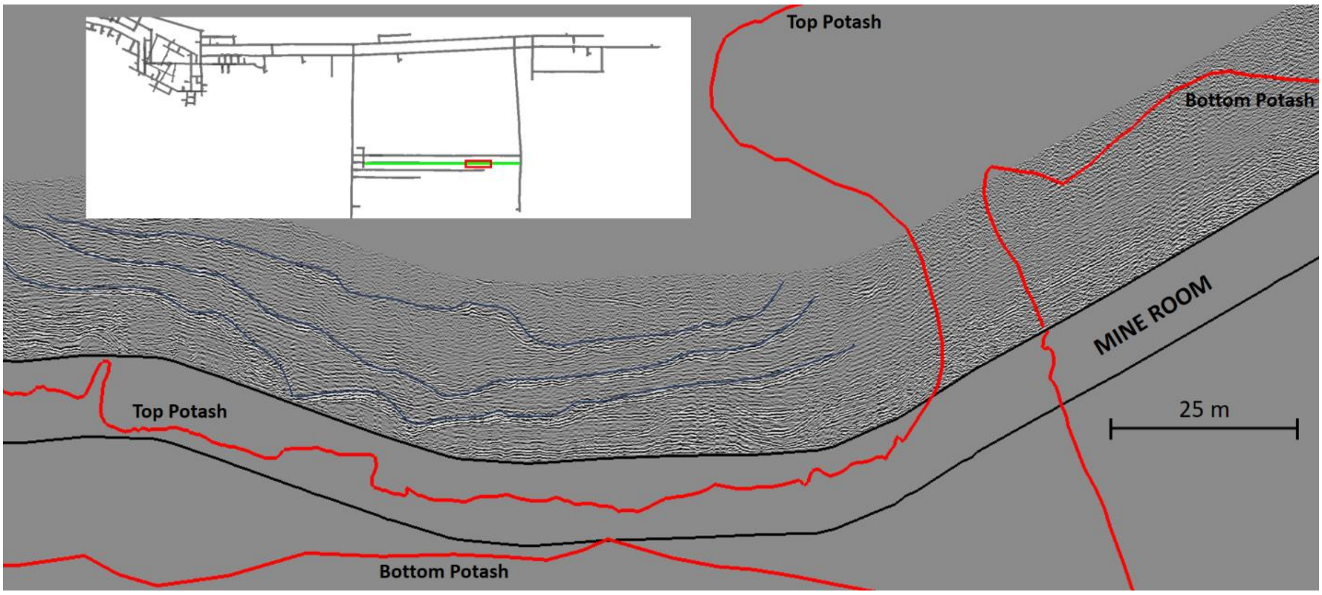

Fig. 3. Vertical section of 500 MHz GPR (upward-looking) data displayed in true depth on a earth model. The mine room position was determined from surveying. The top and bottom of ore was mapped from outcrops (in room) and drilling intersections. In general, the trend of the stratigraphic markers imaged above roof (marked on the section) follow the trend of the ore.

C. March 2016 GPR Campaign

To better understand the anhydrite below the mining, it was decided to collect 50 MHz GPR throughout most of the mining development entries (15 km in total). Collecting these data manually with push carts was not practical, so a crude sled was fabricated which could be dragged behind a vehicle (Fig. 4). The campaign took 5 days to complete and in general, data quality was excellent. Typical processing flow consisted of horizontal coordinate assignment, Dewow, background removal, migration, gain correction, and finally vertical coordinate assignment. The GPR sections were then converted to true depth and loaded into a comprehensive 3D earth model (Paradigm's Gocad software) for interpretation. Included in the earth model were drill hole trajectories and depth to geological sequences identified in the holes. In general, agreement between the drilling and GPR is very good.

Areas of divergence occur where there was standing water on the floor, or when there was significant mining equipment or infrastructure within proximity of the survey profile, causing degradation of the GPR. Given the complex structure of the Basal Anhydrite, some of the reflections could not be explained with available geological data so it is presumed that these events may be side-swipes from off-line structures. Fig. 5 shows agreement between the GPR image of an anhydrite feature which outcropped in the mining room floor. Fig. 6 shows another protruding anhydrite feature imaged by both 50 MHz and 250 MHz GPR. Remarkably, an in-mine drill hole (75.4 mm diameter) is also clearly imaged with both frequencies; the known trajectory having excellent agreement with GPR image. This is one of the better examples of several drill holes that were imaged.


Fig. 4. The "sled" used to collection 50 MHz GPR.

IV. CONCLUSION

Initial development and production planning at Picadilly was guided by geological information gathered from surface and in-mine drilling. Drilling is expensive so GPR was viewed as both cost-effective and a quick alternative if it could be proven to work in the mine. The GPR campaigns showed that the higher frequencies (250 MHz and 500 MHz) could be useful for assisting operations to stay on-grade (follow the ore seam) when undulations were encountered. The 50 MHz GPR was also successful, and would be useful for identifying anhydrite in the floor up to 30 m depth.

This is important for both development mining in the strong and competent Basal Halites and for salt mining. Unfortunately, due to unfavorable market trends, it was decided to stop development and production at Picadilly and place it in "care and maintenance" mode, in January of 2016. Further drilling and GPR collection at the mine was halted.

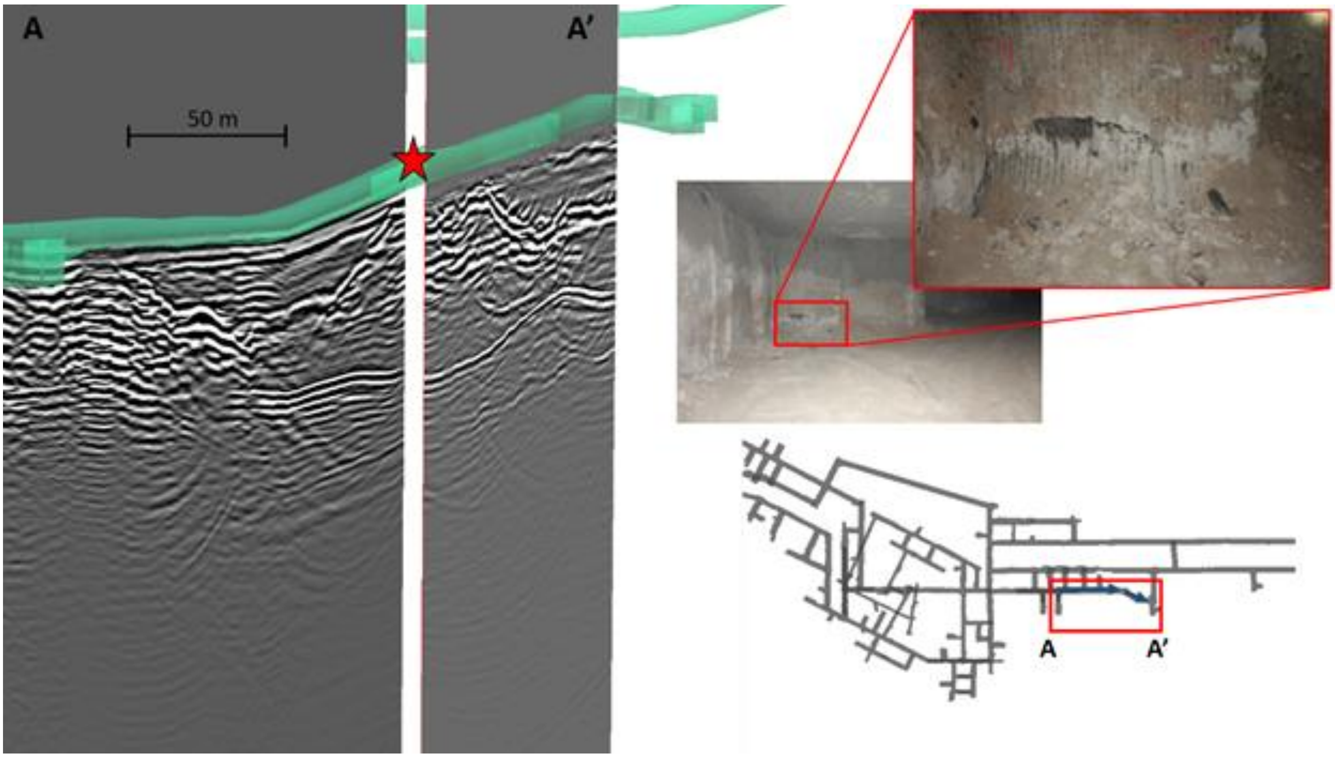

Fig. 5. Several 50 MHz GPR profiles properly referenced in the earth model. The star shows the location of the anhydrite outcrop in the floor. The trend of the anhydrite feature into the floor is evident on the GPR. The picture is taken at the location of the outcrop.

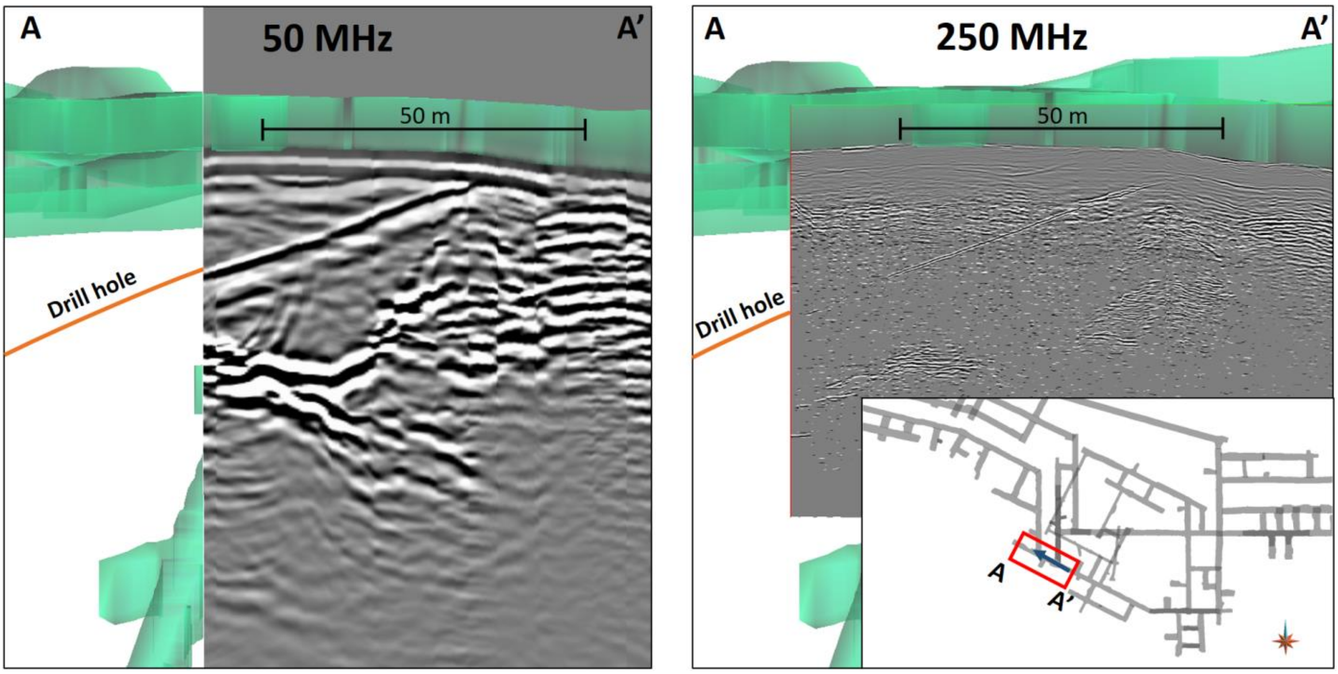

Fig. 6. Downward-looking 50 MHz and 250 MHz GPR profiles collected in a mining room over an abandoned drill hole, which is clearly imaged on both GPR profiles.

However, given the success of GPR, if Picadilly resumes operation GPR will be used routinely to gain geological images for guiding both production and development.

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