Integration of Electromagnetics in Potash Mining Geohazard Analysis

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Summary

Potash mining in Saskatchewan has made extensive use of geophysics for a variety of engineering and environmental purposes since the first mines were built. One of the applications for geophysics in potash mining is the location and quantification of near mine geohazards associated with possible inflow sources. The source of these water inflows are anomalously porous sedimentary formations located either above the potash evaporate layer or within the salt itself (Gendzwill and Stead, 1992). The use of surface 3D seismic has proven to be a highly effective tool in identifying many geohazards; however, to better quantify these features other geophysical tools have been brought into use. These tools have ranged from DC resistivity (Eso, 2006) to frequency- and time-domain electromagnetics (Duckworth, 1992). This project focuses on the application of multiple types of transient (TEM) and frequency-domain (FDEM) electromagnetics systems over several different mine locations to delineate areas with suspicious geophysical signatures; this effort will be pursued through both analysis of survey data and computer modelling. Different locations for these targeted surveys will include both north and south Saskatchewan mines. Each of these large areas have distinctly different near-mine geological features. These surveys have been sponsored by Nutrien Ltd. through a Ph.D. Mitacs Accelerate project with the author. They will consist largely of in-mine surveys. These types of electromagnetic surveys suffer from certain restrictions related to low magnetic moment and high infrastructure noise, though through a combination of joint geophysical investigation and computer modeling such limitations are greatly alleviated. Surface surveys will also be considered, though the large depth to potash mines (around 1000 m) combined with the small scale of the geohazard features make these types of surveys typically impractical. Some in-mine TEM and FDEM survey data has already been collected in areas of concern. For details of this work, see Funk, Isbister, LeBlanc, and Brehm (2019), and LeBlanc (2020). Computer modelling for this project require a full-space environment to account for the diffusion of current in both directions above and below the transmitter. Forward modelling for this project has been performed in COMSOL Multiphysics and seeks to quantify the relationship between the change in the environment and the expected response from the TEM signal.

Theory / Method / Workflow

Several geohazards related to inflows have been identified. They are collapse structures, thin-backs, and cognate brine (figure 1). Of the three, the primary geohazard of concern for this project is thin-backs. Thin-back geohazards occur where water enters the Dawson Bay formation above the Prairie Evaporite. In general, significant portions of the Dawson Bay carbonates are tight and non-porous, serving as a strong seal against other aquifer layers above. However, this member has been known to become porous itself under specific geological conditions (figure 2). The Dawson Bay formation lies just above the Prairie Evaporite formation which contains the potash ore zones. The target carbonates vary in thickness depending on the mine site but are about 30 to 40 metres thick and reside around 25 to 40 metres above the potash seams.

Another feature of interest is thinning of the salt between the ore bed (usually cut on specific clay seam indicators) to the overlying shale bed thins – thereby rendering the “roof” of the mine less pronounced. These thin back features, as well as anomalously porous Dawson Bay, are often associated with other larger more distant geological features. These secondary phenomena include mounds in the Winnipegosis below the Prairie Evaporite and thinning or absent salt layers in the younger Souris River formation above. These secondary features are easily detected by 3D surface seismic. Determining the electromagnetic signature of these phenomena is also of interest to this project.

Transient electromagnetics was selected for this project for its superior depth sounding capabilities when compared with other similar techniques. Frequency-domain electromagnetics and smaller more portable TEM systems may also be used for their fast and efficient deployment. Injection of current into the highly resistive salt and lack of effective coverage in the mine panels make 2D/3D DC resistivity surveys difficult to deploy successfully. The breadth of tools that will be deployed for this project will vary with availability as well as with the type of suspected geohazard. Of specific interest will be the trade-off between early and late time EM signatures. Larger, less portable systems, with wide Tx-Rx spacing) have proven to be effective in detecting anomalous conductivity in the Dawson Bay (see results). However, more portable systems with smaller magnetic moments and spacing between the transmitter and receiver might be required for geohazards that are particularly close to the mine panels – such as the case of cognate brine or measuring the thickness of the salt in the roof of the mine.

Computer modelling of in-mine electromagnetics required the implementation of a full-space modelling environment with variation in the electromagnetic diffusion occurring both above and below the transmitting layer. Forward TEM modelling has been performed in COMSOL Multiphysics using the AC-DC magnetic fields module and 2D-axisymmetric geometry. Rudimentary inverse modelling has been performed in Matlab using the in-built simplex minimization algorithm and tied to COMSOL Multiphysics via LiveLink for Matlab.

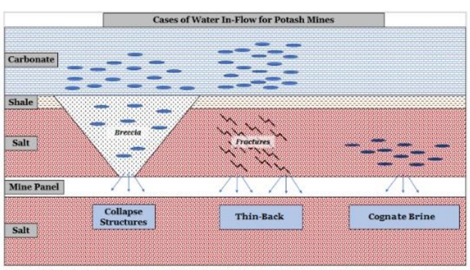

Fig. 1: Known types of potash mining geohazards. Our focus is on the second one. Thin-back geohazards.

Fig. 2: Examples of tight, non-porous carbonate core from the Dawson Bay formation on the left, and porous, likely brine-filled Dawson Bay carbonate core on the right. Figure courtesy of Funk, Isbister, LeBlanc, and Brehm (2019).

Results

An out-of-loop TEM system with a magnetic moment of around $2600\ \mathrm{A\ m^2}$ and transmitter-receiver separation of between $60\ \mathrm{m}$ was found to be ideal in detecting a Dawson Bay geohazard in one of the south Saskatchewan mines. Figure 3 shows the decay view results from one of the surveyed profile lines. Station 01-01 represents the westernmost station on this profile line and resided in a geologically normal area of the mine. Station 01-11 represents the easternmost station on the profile line and resided in an area with abnormal geological signatures. The decay response showed a large and repeatable conductive response beginning around 0.1 ms for both the in-line horizontal (radial) and the vertical fields toward the eastern end of the profile line. This conductive response coincided with the expected extent of the anomaly. A set of inverse models were constructed on this dataset to constrain the depth of this conductive anomaly (figure 4). The results of this survey suggest that the resistivity contrast in the anomalous area of this study predominantly reside in the Dawson Bay formation. More broadly, the project shows that TEM can be used effectively in conjunction with other geophysical tools to assist with the detection and quantification of anomalous geohazards near potash mines.

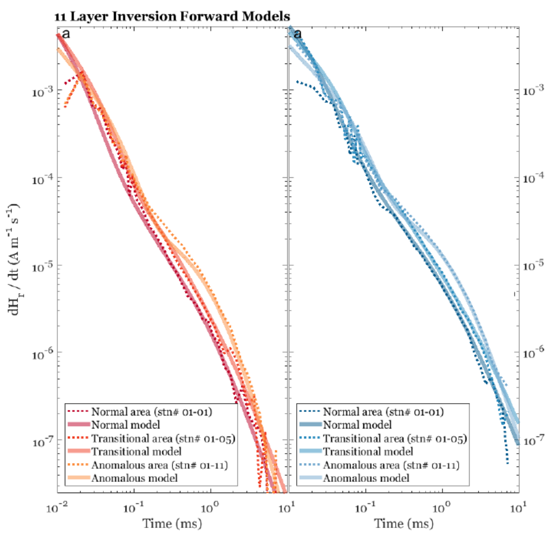

Fig. 3: Comparing the forward models using the inversion derived parameters for data-sets in the normal, transitional, and anomalous areas.

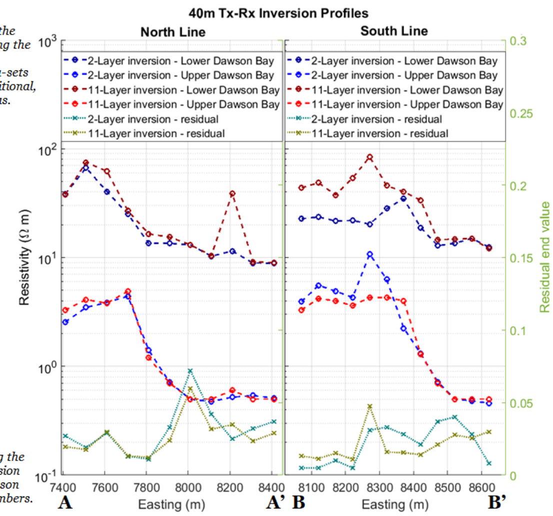

Fig. 4: Contrasting the two different inversion results for the Dawson Bay carbonate members.

Acknowledgements

Nutrien Ldt. for their funding, support, and expertise on this topic, especially the GeoServices & Land division. Additional thanks to Mitacs and NSERC for funding.

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