3D Modelling & Synthesis of Geophysical Data in Nash Creek, New Brunswick, Canada.

Alexander Furlan
Brock University
1812 Sir Isaac Brock Way,
St. Catharines, ON
afurlan@brocku.ca

Hernan Ugalde
Dip Geosciences, Brock University
1812 Sir Isaac Brock Way,
St. Catharines, ON
hugalde@brocku.ca

Alzbeta Ondercova
University of Toronto
27 King's College Cir,
Toronto, ON

Bernd Milkereit
University of Toronto
27 King's College Cir,
Toronto, ON

SUMMARY

'Hotspot' geophysical exploration has passed its zenith. In areas like New Brunswick, where this exploration style has been successful, deposits with a more complex signature have been left behind. Using improved computational power and geophysical modelling, deposits like those found at Nash Creek can be reinvestigated. Nash Creek hosts a Zn-Pb-Ag deposit on the western limb of the Jacquet River Syncline and is truncated by the N-S trending Black Point Arleau Brook (BPAB) Fault. While regional mapping was the goal, the Archibald Settlement and Sunnyside formations which host the deposit were looked at more in depth as well. Previously collected geophysical surveys, surficial mapping efforts, borehole logs, petrophysics, and local perspective were all considered in the modelling process. Using this information, 2D cross sections were created of the survey area. These sections were employed to match geophysics first and elucidate what could be modellable. These sections were then used to derive a 3D geological model that was supported by geophysical data rather than derived from it. This model was inverted to investigate the optimized subsurface structure. The final model and inversion had mixed results. While a regional model could not be derived, BPAB fault and the Archibald Settlement formation were discerned to a reasonable degree. The Archibald Settlement formation had a distinct contrast with the surrounding units which was clear in the inverted data. BPAB fault was found to have a steep (70-80°) westward dip, unlike previous research which suggested a near vertical or eastward dip. It is recommended that a more extensive survey be conducted with the express purpose of constraining the fault. An E-W seismic survey would provide both overburden thickness and fault structure over Nash Creek.

Key words: geophysics, 3D-modelling, exploration, structural geology, base-metal

INTRODUCTION

Since the development of the Bathurst Mining Camp (BMC) in the 1950s, New Brunswick has been characterized by its extensive volcanogenic sulphide deposits. Early electromagnetic surveys had success detecting 'hotspot' anomalies that lead to the development of mines such as Brunswick No. 6. While there are 45 known deposits with the BMC, only 4 have been discovered since 1989. The decrease in exploration can be attributed to several factors: fewer easy-to-detect geophysical targets, changing prices of base metals, less economic incentive, and most importantly, lack of subsurface knowledge. As exploration efforts expand and geophysical methods improve, regions such as Nash Creek show potential to revitalize the mining industry of New Brunswick. Located within the Chaleur Bay Synclinorium, Nash Creek plays host to a hydrothermal Zn-Pb-Ag deposit (Figure 1). It is located along the western limb of the Jacquet River Syncline, east of Black Point Arleau Brook (BPAB) Fault (Dostal et al., 1989). This deposit is hosted in both the Archibald Settlement and Sunnyside formations, both of which crop out in the area and have been previously described (Greiner, 1967; 1970). Like Bathurst, a plethora of airborne and ground-based geophysical surveys have been conducted (Fugro, 2004; Geotech Ltd., 2006). While the deposit has been intersected, most of the logs record basalt and nothing discernible in modelling space. BPAB has only been intersected by a couple unoriented holes, so its subsurface structure is largely unknown. Some 3D modelling of the deposit has been completed (Ugalde et al., 2007) but lacks geologic control and was restricted to the deposit. A true synthesis of all available geophysical data has yet to be conducted. The purpose of this study is to fill that gap and construct a 3D geological model of the Nash Creek exploration area using a multidisciplinary approach. New software and more powerful computers make the construction of multiparameter 3D models highly accessible, however, adding proper geological constraints to mitigate non-uniqueness is a problem that cannot be solved by the many semi-automatic tools that have become popular over the past few years. 2D sections were modelled using ground gravity and drone magnetics with guidance from borehole logs and surficial geology. These sections were then used to build a regional 3D geology model supported by geophysical data. The fault and Archibald Settlement were adequately modelled but the complex structure at Nash Creek make modelling the entire package a futile task.

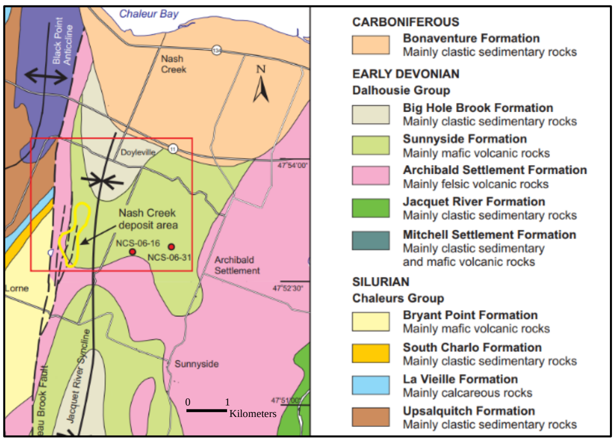

Figure 1. Modified from Walker (2009). Major rock units at Jacquet River Syncline. Red box indicates modelled region. Deposit footprint has since expanded.

METHODS

Data Processing

Creating a 'complete' picture of Nash Creek required multiple data sources. Regional gravity, magnetic, and radiometric data were acquired from Canada's Open Data repository. These data give context to magnetic and gravity surveys collected by Fugro (2004), Geotech Ltd. (2006), & past students (Ugalde et al., 2007; Bongajum et al., 2009; Veglio, 2017;) over the Nash Creek Deposit. Cunningham (2018) also completed a high-resolution UAV survey over the deposit which provided the lowest flying height. For quality control, the magnetic data were reprocessed and micro-levelled. The complete list of data is extensive, however for modelling purposes, only magnetic and gravity data were used (Figure 2). Geologic data were provided through mapping efforts by the Government of New Brunswick (Wilson, 2013) and borehole logs from Callinex drill program. The area selected for modelling was selected based off several key aspects; 1) Greatest coverage of geophysical surveys & borehole data, 2) It intersects BPAB fault, which has little structural information, and 3) The majority of the region contains the Archibald and Sunnyside formations which host the Zn-Pb-Ag deposit (Walker, 2009).

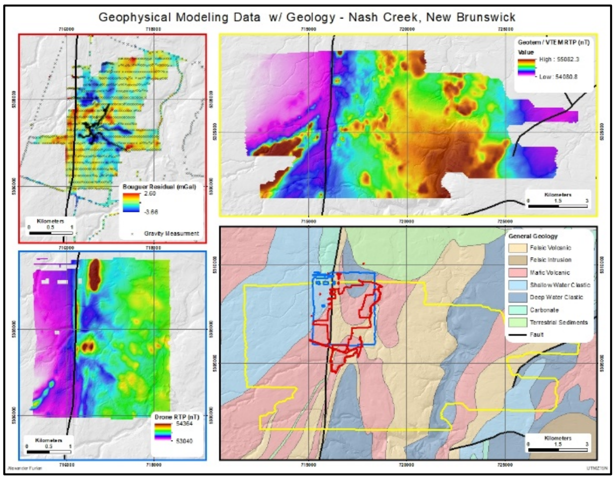

Figure 2. Geophysical survey coverage. Bottom right: Total coverage over Nash Creek with simplified geology. Archibald Settlement and Sunnyside are orange and red respectively. Bottom left: Drone RTP. Top right: Compilation of Geotem & VTEM RTP. Top left: Bouguer residual anomaly. Stations indicated with X.

2D Sections

2D modelling was a starting point that could later be extrapolated to three dimensions. The drone magnetic survey and ground gravity were sampled along six East-West trending model lines (Figure 3). Each model line or section were interpreted using available borehole logs and surficial maps. Many of the logs were sub 100m depth and intersect overburden and a basalt unit. Summaries of each formation are available and provided an estimated thickness range that could be used as a control variable. Certain units, such as Archibald Settlement Formation, have their thickness at the survey site recorded providing additional control (Walker, 2009). Units were assigned ranges of physical properties based on previous petrophysical work (Ugalde et al, 2006; Veglio, 2017) but substantial overlap between the properties of each unit prevented a complete and clear distinction. In response, indiscernible units were grouped together to simplify modelling. The 2D sections provided a good idea of structure and geometry at depth but were severely limited by the inherent limitations of 2D modelling and the aforementioned overlap of physical properties. In such structurally complex areas, having uniform body properties will greatly reduce the fit of a model. It is common for geological units to have a range of physical properties; a more complete model should reflect this.

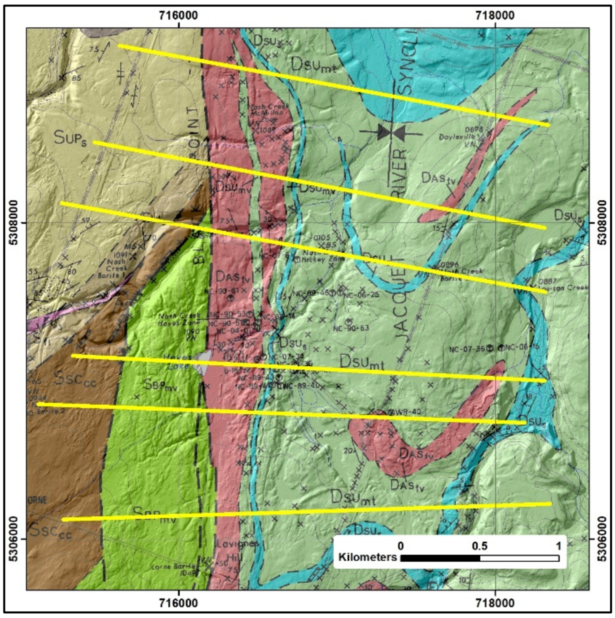

Figure 3. Zoom in of Figure 1. Yellow line represents cross sections that were modelled (1 at to, to 6 at bottom). Mode detailed geology is used (1:20,000 scale).

3D Modelling

Three-dimensional modelling was completed using GeoModeller and the 2D cross sections as a starting template. The geological map from Wilson and Walker (2012) was used to build a stratigraphic pile for the 3D model. This helps the model follow certain geological rules such as making sure stratigraphic succession is followed unless otherwise noted. Black Point Arleau Brook Fault was related to the stratigraphic pile, so the younger Devonian units moved correctly relative to the older, Early and Late Silurian Groups. Fault structure is largely unknown in the area and was thus interpreted from the 2D cross sections. Once the units from ModelVision were 'transferred' to Geomodeller, the geologic model could be constructed. Here, a range of physical properties can be assigned to each unit. While the issue of overlapping physical properties still exists, the change in variability is now reflected by statistical distributions in our model. A stochastic inversion was used after the structural and physical property distributions were applied. Our model was computed 100000 times with the properties fine-tuned to improve the data misfit. This is done with respect to geological rules (as mentioned above), so while optimizing, it will not do anything geologically 'impossible'. The output of this inversion was used to re-evaluate the initial model. The result is a 3D geological model constructed from geologic knowledge with the support of geophysical data.

RESULTS

2D Sections

The results varied depending on the model line (Figure 4). Using strict limits on our physical parameters produced a model that could match gravity unanimously but magnetics sparingly. Homogenous body properties limit the models' ability to accurately match the geophysical response and most likely hindered magnetic modelling. While we have a good picture for gravity, we are missing some component of the magnetic response in this region. The intercalated volcanic and sedimentary units of the Sunnyside Formation were largely indistinguishable as well. The units used for these sections were derived based on similarities in rock properties, not formations. Many small sedimentary lenses were lumped into the basalt portion of the Sunnyside Formation. The areas associated with the Archibald Settlement formation provided the greatest contrast and was thus the most ‘modellable’ unit. Multiple folds and changes in thickness seem apparent from the initial sections but the complexity puts everything into jeopardy. The BPAB fault was modelled using various densities and susceptibilities to constrain its dip. Through multiple iterations, an eastward dip of 70-80° would provide the most reasonable model. Unfortunately, the Jacquet River formation was incorrectly modelled as younger than Sunnyside. However, on the surface map, it is at the core of a doubly plunging syncline. While this is less of an issue for the southern cross-sections, the northern group are to be viewed with high levels of scrutiny.

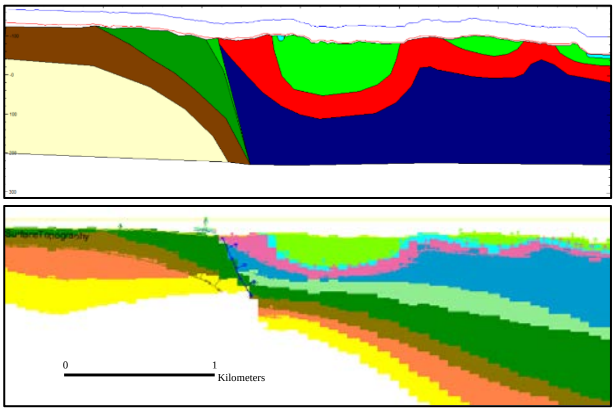

Figure 4. TOP: Line 5 cross section, oriented E-W. Archibald and Sunnyside are shown in red and lime green, respectively. Fault was steeply dipping to the east and consistently this orientation in all cross sections. BOTTOM: Resulting lithological model for line 5 from inversion.

3D Modelling & Inversions

Initial 3D modelling provided some elucidating details (Figure 4). Since GeoModeller follows geological rules, the oversight of the Jacquet River Formation was a substantial hinderance to the starting model. The algorithm could not accommodate the Jacquet River Formation since we gave it incorrect starting information. It also has an issue with the Mitchell and Archibald Settlement formations. As we move further south from the JR formation, the model improves. Thickening of the Archibald Formation toward the BPAB fault is apparent in these sections and is confirmed in borehole logs. The plan view of the block provides a crude picture of the surficial geology map. The issues with Jacquet River are evident but the Archibald Settlement felsic volcanic unit and the Sunnyside Sedimentary unit along the fault seem like a fine match. These units are of key importance to the deposit in the area so while not ideal, they are still useful. The new geophysics-supported 3D geological model (Figure 5) was inverted to improve the starting model using the improved parameter distribution ability of GeoModeller. The resulting stochastic inversion (Figure 6) was rough but still gave some structural insights. The fault and its interaction look plausible, with the density and susceptibility models highlighting the contrast between the Sunnyside mafics and the Archibald felsics. While units could have a distribution of susceptibility or density, the inversion parameters were set too stringent and resulted in minimal distribution. Resolving the Sunnyside sedimentary rocks proved most difficult but this it to be expected with its intercalated nature.

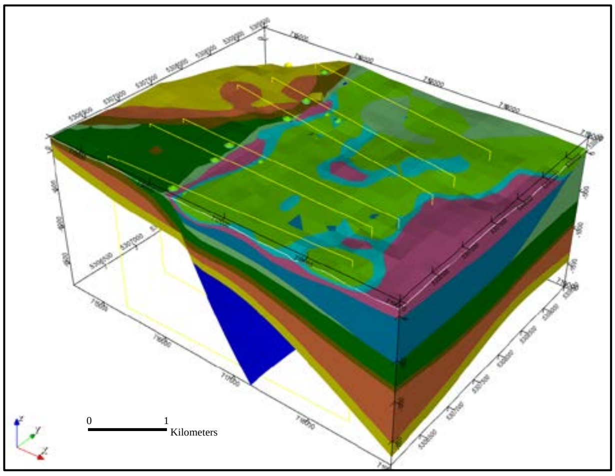

Figure 5. 3D view of geological model. Synclinal shape present, but issues with the Jacquet River & Archibald formation can be seen through the central area / eastern limb of the syncline.

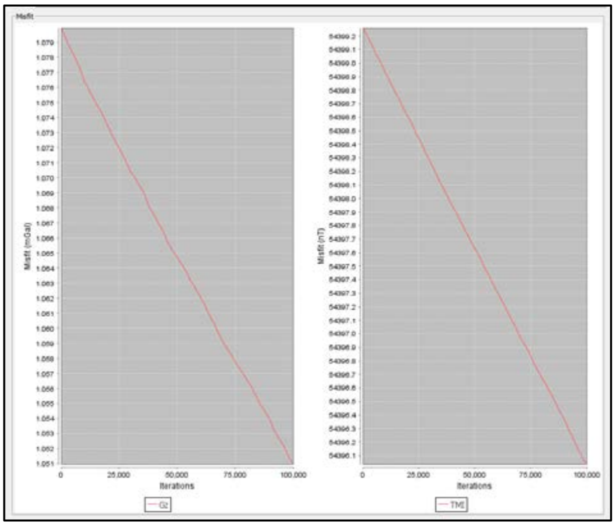

Figure 6 – Stochastic inversion process. Model computed 100,000 times while properties are adjusted to improve the misfit of the gravity (left) and magnetic (right) data. Geological rules are still respected.

A more structurally competent model was created using the information from the first iteration (Figure 7). The Jacquet River Formation on the east side of BPAB fault more resembles a doubly plunging syncline. Onlap stratigraphy was used when modelling and forces the units into stratigraphic order. As a result, the intercalated Sunnyside Formation was not modelled properly. The complex folding of the Archibald Settlement Formation was captured rather well, and as mentioned, was the most modellable unit. The Silurian units of the Black Point Anticline were modelled to the west of BPAB fault, but some issues are apparent. The eastern side of the model added an inlier of Silurian units that should not exist. On the contrary, an inlier of Early Devonian units should be seen on the west side of the fault, but this is south of the survey area. Improvements to this model are numerous but it has provided some insight into Archibald Settlement and the Black Point Arleau Brook fault.

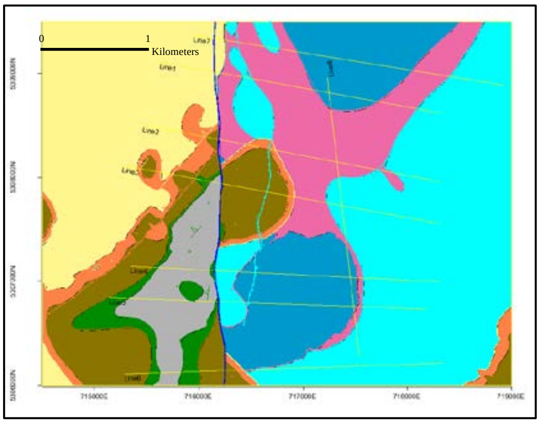

Figure 7. Plan view of updated model. Surface expression is lacking. In previous model, lime unit was Sunnyside mafic volcanic rocks, but here it is represented as Sunnyside sedimentary rocks in light blue.

CONCLUSIONS

The models presented for Nash Creek were supported by geophysical & geological data and provided some insight into the structure of the region. Archibald Settlement and Black Point Arleau Brook Fault were most successfully modelled at the Nash Creek deposit. Unlike the other formations, Archibald Settlement had a contrast with surrounding units and was distinct enough to be modelled reasonably well in both the magnetic susceptibility and density models. The formation crops out to the east (completing the 'synclinal' shape), but this subsurface geology is not reflected in the model. Based on real mapping efforts, Archibald Settlement should continue under the Sunnyside formation. The anticlinal shape west of BPAB was achieved but the eastern syncline proved too complex to model with current parameters. While this is a relatively easy fix, its location in respect to deposit and fault make it low priority. How the Archibald and Sunnyside units interact with the fault are plausible, but this plausibility decreases as we move eastward. Increased constraints (i.e., surface observations and borehole logs) closer to BPAB fault allowed for this greater plausibility. The normal fault was consistently modelled with an eastward dip of 70-80° (Figure 8). The strike was identified in the Lidar data but is further confirmed by our modelling. A survey focusing on constraining BPAB fault is the recommended next step for Nash Creek. With such thick overburden geophysical methods must be implored. A seismic survey is an ideal candidate to map both the fault and overburden thickness. Previous work suggests the fault as a potential method of transport for the disseminated sulphides (Veglio, 2017). Constraining Black Point Arleau Brook Fault is key to understand the Zn-Pb-Ag deposit and regional geology.

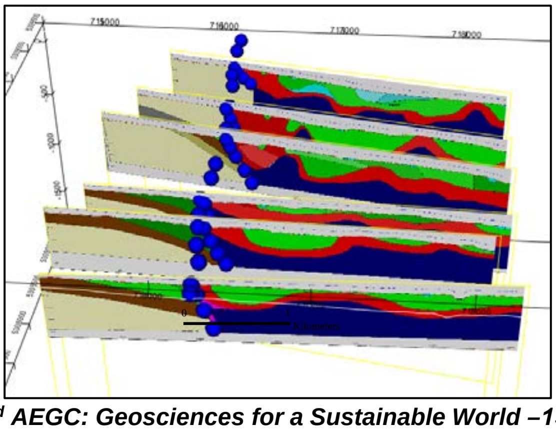

Figure 8. Trace of BPAB Fault through cross sections. Gravity & magnetic signatures constrain dip to 70-80°.

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