IN THE SHADOW OF LARGE GRAVITY ANOMALIES – RECOVERING USEFUL GRAVITY DATA FOR GEOLOGIC EXPLORATION (SUPPLEMENT)

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1. MOTIVATION AND OBJECTIVES

1. To explore methods of levelling Global Geopotential Model (GGM) data to terrestrial gravity control stations.

2. To evaluate the effectiveness of using GGM data to remove the regional component from small-scale, high-resolution gravity data.

- GGM data can sit at a different level compared to ground readings. Since gravity surveys are usually tied to a terrestrial reference point, the regional field should be at this same level.
- GGM data can only directly map long wavelength features, and to a low (10's of km's) resolution. This means that the shape/curvature of even large anomalies could be distorted. Correcting to terrestrial readings could help alleviate this.
- Most measurements used to construct a GGM are taken from space, so there could be long wavelength errors as well. For example, a GGM may struggle to account for long wavelength variations in near-surface bedrock density.
- Terrestrial readings are incorporated into many GGMs; however, the final product may still sit at a different level than the ground control network. This study will explore steps that the end user can take to resolve this issue.

2. BACKGROUND – THE NASH CREEK AREA

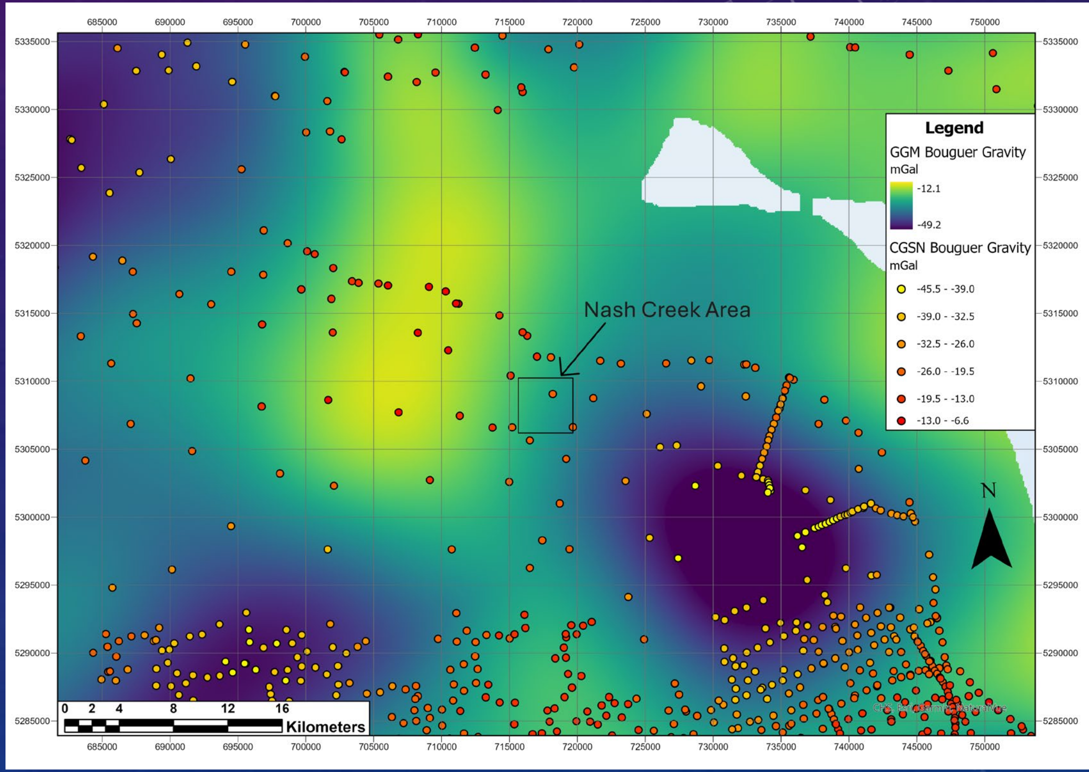
- The Nash Creek area in Northern New Brunswick is home to a blind Zinc-Lead-Silver sulphide deposit.
- Exploration has been ongoing since the 1960's to characterize the deposit, and a wealth of geological and geophysical data has been collected.
- In 2007, a high-resolution terrestrial gravity survey was conducted; however, it has not yet been meaningfully incorporated into the analysis. One of the issues plaguing the gravity data is the presence of a strong regional gradient.
- Unfortunately, the local geology is poorly understood due to the thick layer of overburden blanketing the region. Using geophysics to map the bedrock is one of the broader goals of this study. If gravity is to be used for this purpose, the subtle near surface anomalies need to be isolated.

Location of New Brunswick in Canada

(https://upload.wikimedia.org/wikipedia/commons/thumb/8/8a/New_Brunswick_in_Canada_2.svg/330px-New_Brunswick_in_Canada_2.svg.png)

3. THE REGIONAL PICTURE

- The GGM data comes from GGMPlus - a high resolution GGM that incorporates GOCE/GRACE measurements, EGM2008, and the modelled effects of topographic gravity/bathymetry. It is available at 7.2 arc-second resolution, or approximately 200m depending on latitude.
- The terrestrial data comes from the Canadian Gravitational Standardization Network, or CGSN.
- Based on both regional datasets, the Nash Creek area sits directly between a ~20 mGal positive anomaly and a similarly sized negative anomaly, relative to background.
- The strength of the gradient is approximately 1.6 mGal/km on average.
- CGSN station spacing is also very sparse in the area around Nash Creek, presenting another challenge.



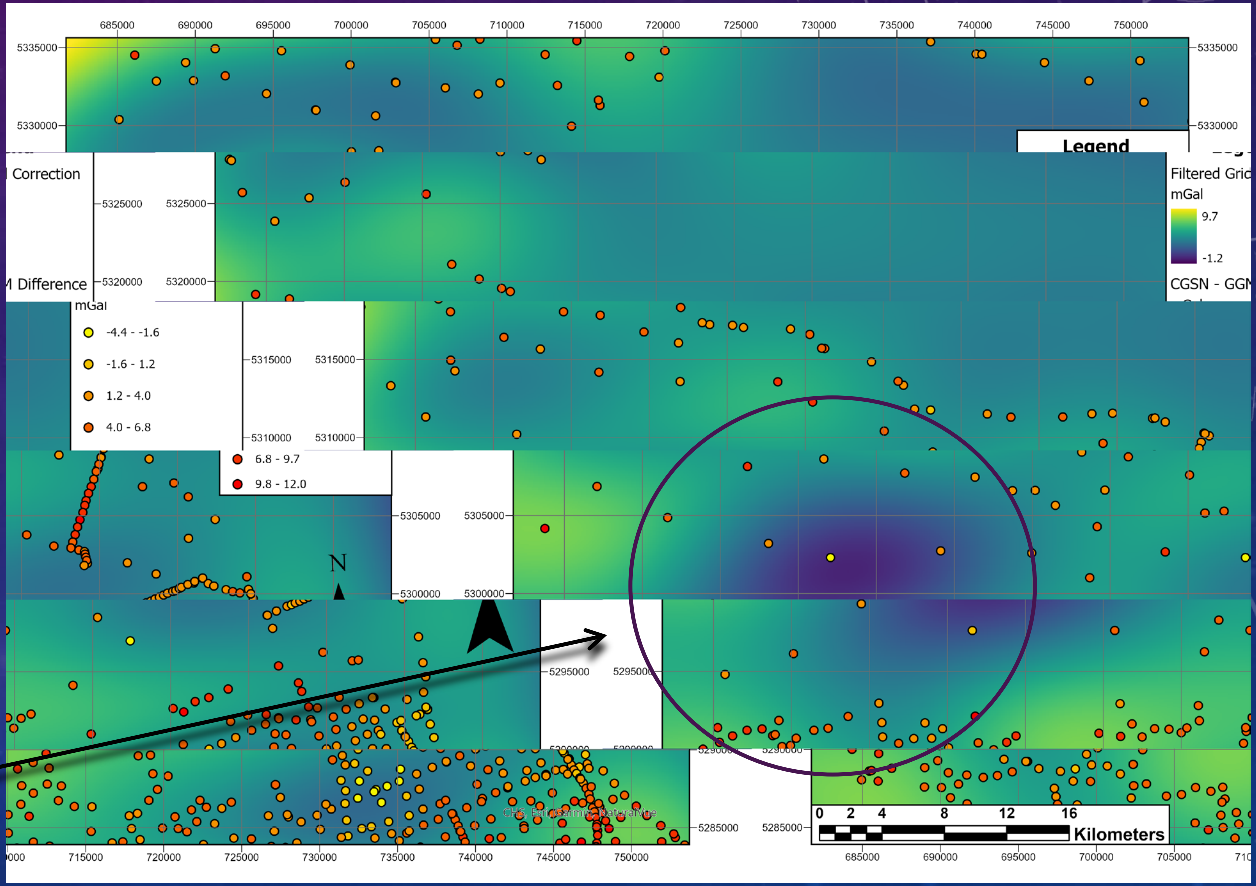
4. METHODS

After performing the standard suite of corrections on the various gravity datasets, the process is as follows:

1. Find the difference between the CGSN and GGM values at each station location to generate correction surfaces.
2. Generate correction surfaces using two methods:
   a) Grid the difference and apply a low pass filter;
   b) Use a higher order polynomial to fit the difference values.
3. Add these correction surfaces to the GGM data to create levelled grids.
4. Use these grids, along with the raw Bouguer corrected GGM data to remove the regional component of the Nash Creek data.
5. Compare to a traditional polynomial fit method for regional separation.

5.1.1 CORRECTING THE GGM: FILTERED GRID METHOD

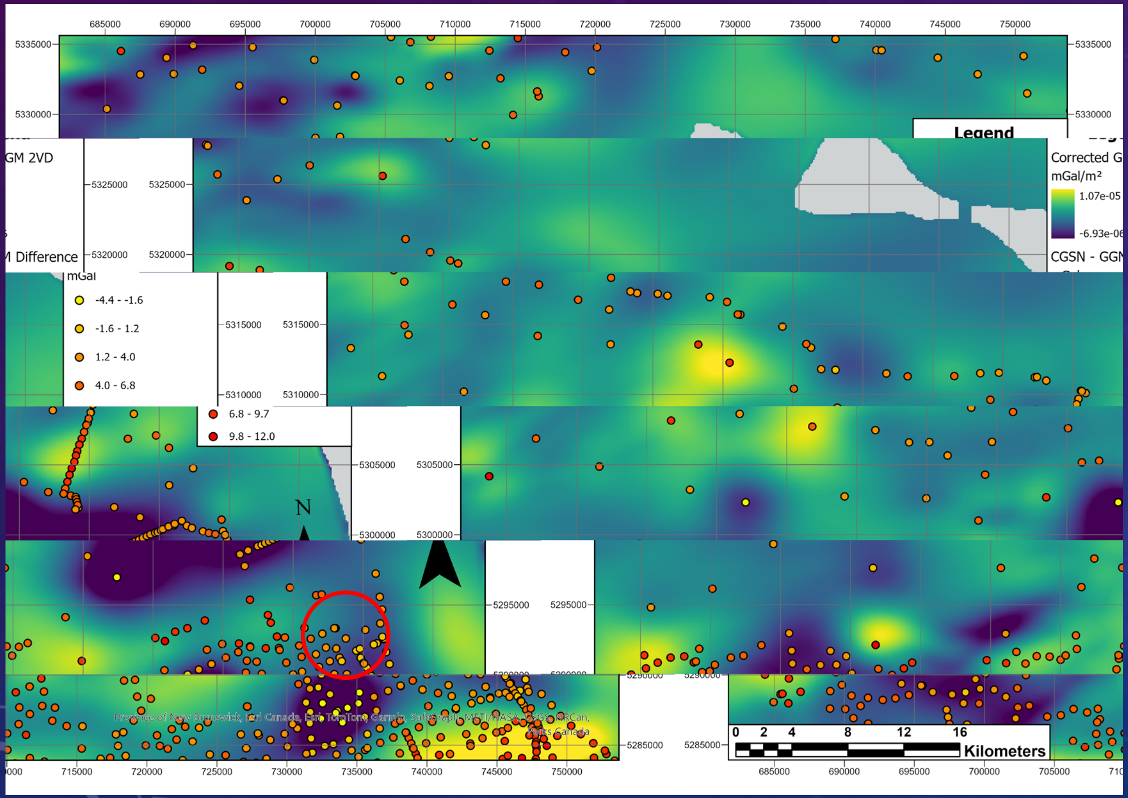
- The difference was initially gridded using a minimum curvature algorithm.
- Multiple cut-off wavelengths were tested, based on:
    - The Nyquist wavelength of the area immediately surrounding Nash Creek;
    - The Nyquist wavelength of the most sparsely sample region;
    - The maximum wavelength resolvable in my survey area.
- However, a 19.2 km cutoff wavelength was ultimately selected - double the Nyquist wavelength of the region with the highest station spacing. Lower wavelengths introduced strong aliasing effects.
- This method encapsulates certain features well. For example, the ring of elevated correction values around the Eastern gravity low indicates that the GGM distorts the true shape of this anomaly.



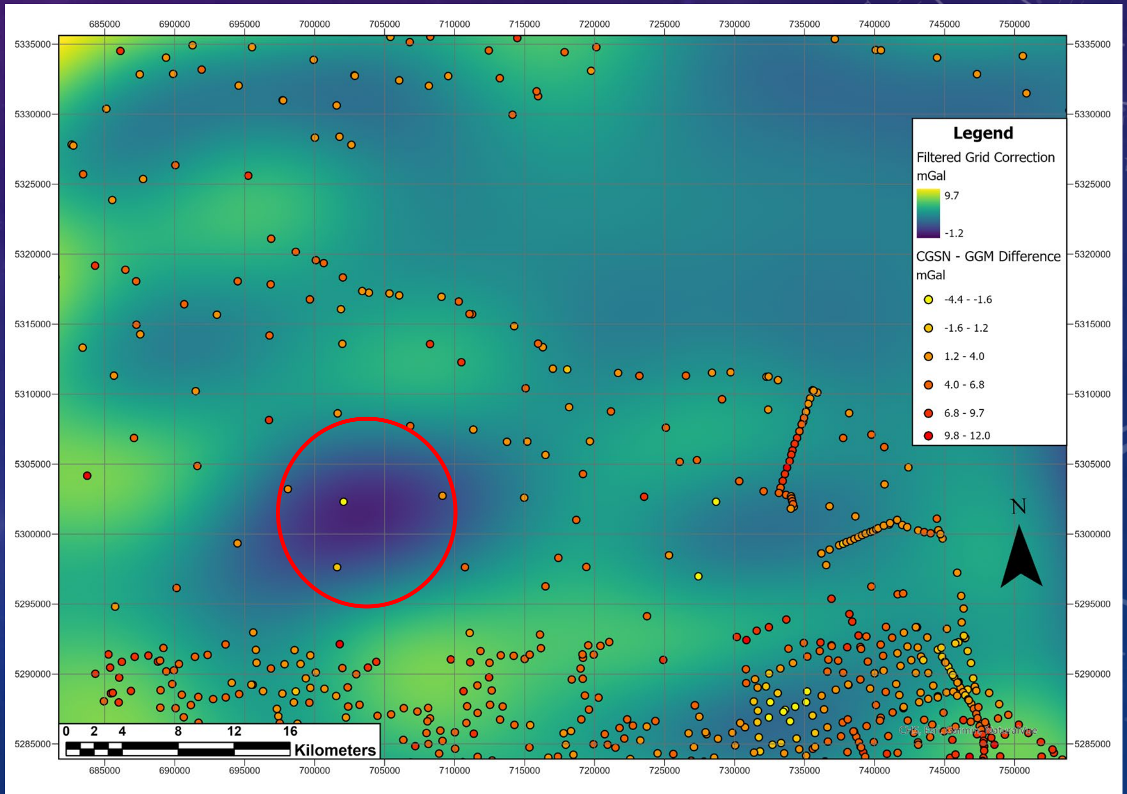
5.1.2 ALIASING IN THE FILTERED GRID METHOD

The second vertical derivative of the regional gravity was used to detect aliasing effects. A strong gradient surrounding a single CGSN point indicates aliasing. The figure below shows the 2nd vertical derivative of the 11 km wavelength correction surface. Aliasing is very clear

The 2nd vertical derivative of the 19.2 km correction surface revealed low gradients everywhere; however, the region circled below could still be distorted by aliasing. The strong negative correction value in the center appears to follow a general trend based on its neighbors, but this could be an illusion.



2nd vertical derivative of GGM corrected using grid filter method with an 11 km cutoff wavelength



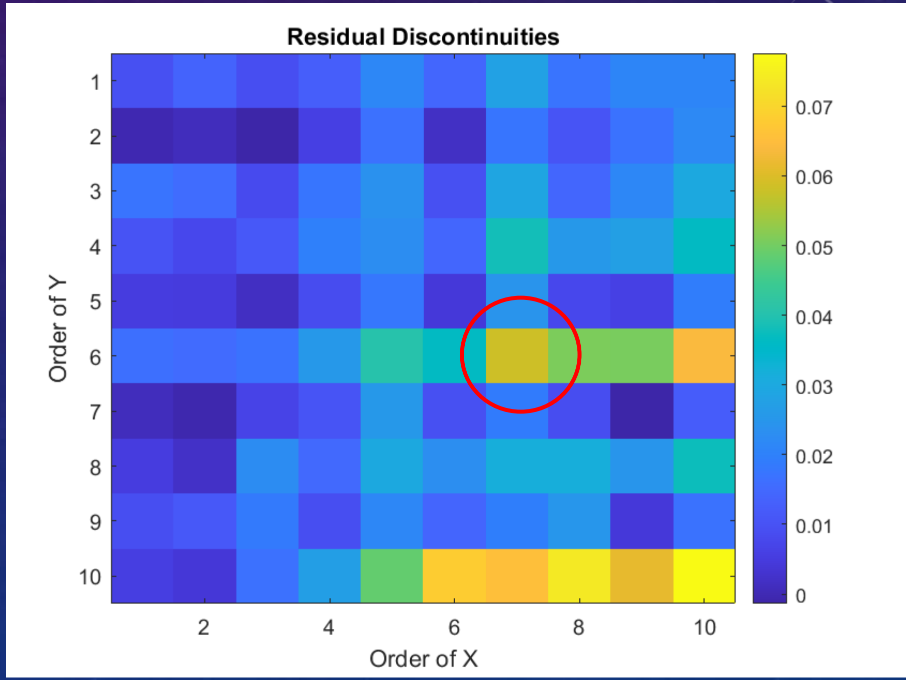
Grid filter correction surface for 19.2 km cutoff wavelength

5.2.1 CORRECTING THE GGM: POLYNOMIAL METHOD

- The polynomial surface was generated using a MATLAB routine called PolyfitN (D'Errico, 2025), which fits an N-dimensional polynomial surface to point data using a Marquardt inversion algorithm.
- Since Free Air/Bouguer corrections had been applied, the elevation was assumed to be zero everywhere, and a 2-dimensional polynomial was used.
- Locations that were 10 km or more from the nearest gravity station were fixed with the median difference value to control ringing.
- Uneven sampling density was also an issue. Densely sampled regions had a stronger influence on the final polynomial as the inversion algorithm tried to minimize residuals without accounting for the distribution of the points. To solve this, densely sampled regions were randomly subsampled before the algorithm was applied. After 100 iterations with different subsets, the results were averaged.
- Another issue was the selection of polynomial order.

5.2.2 SELECTING THE POLYNOMIAL ORDER

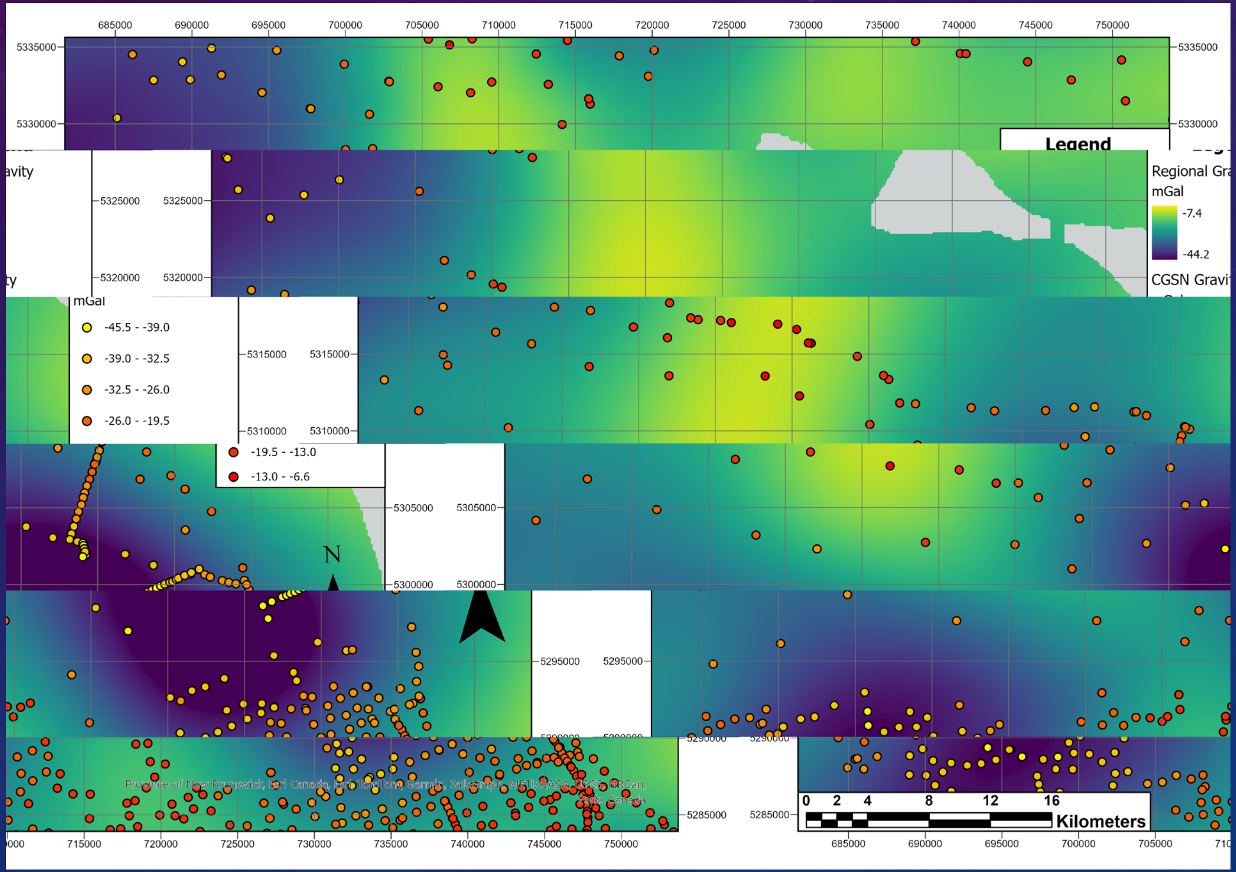
- Different combinations of x/y order were tested – up to order ten for each variable.
- Sudden drops in the residual were interpreted as sudden increases in the frequency content of the correction surface. The polynomial surface was just an approximation, so over-fitting needed to be avoided.
- Thus, orders immediately preceding sudden jumps (“discontinuities”) in the residual were favored.



- The order of x=7, y=6 was selected based on this criterion. It was observed that higher orders introduced ringing/distortion, particularly in sparsely sampled regions.

5.2.3 POLYNOMIAL CORRECTED GGM

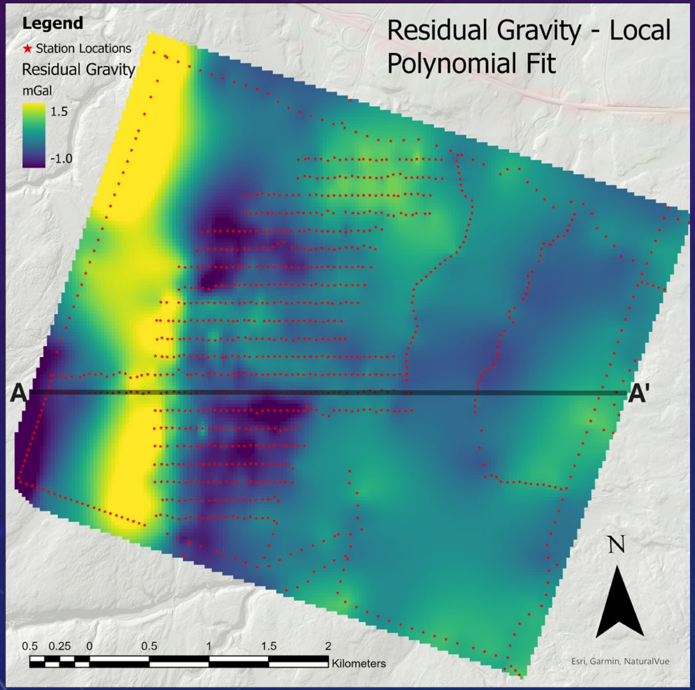
- The polynomial corrected GGM (PCGGM) was selected to represent the regional field. This is because it conservatively corrected for long wavelength errors in the GGM, particularly around the Nash Creek area.

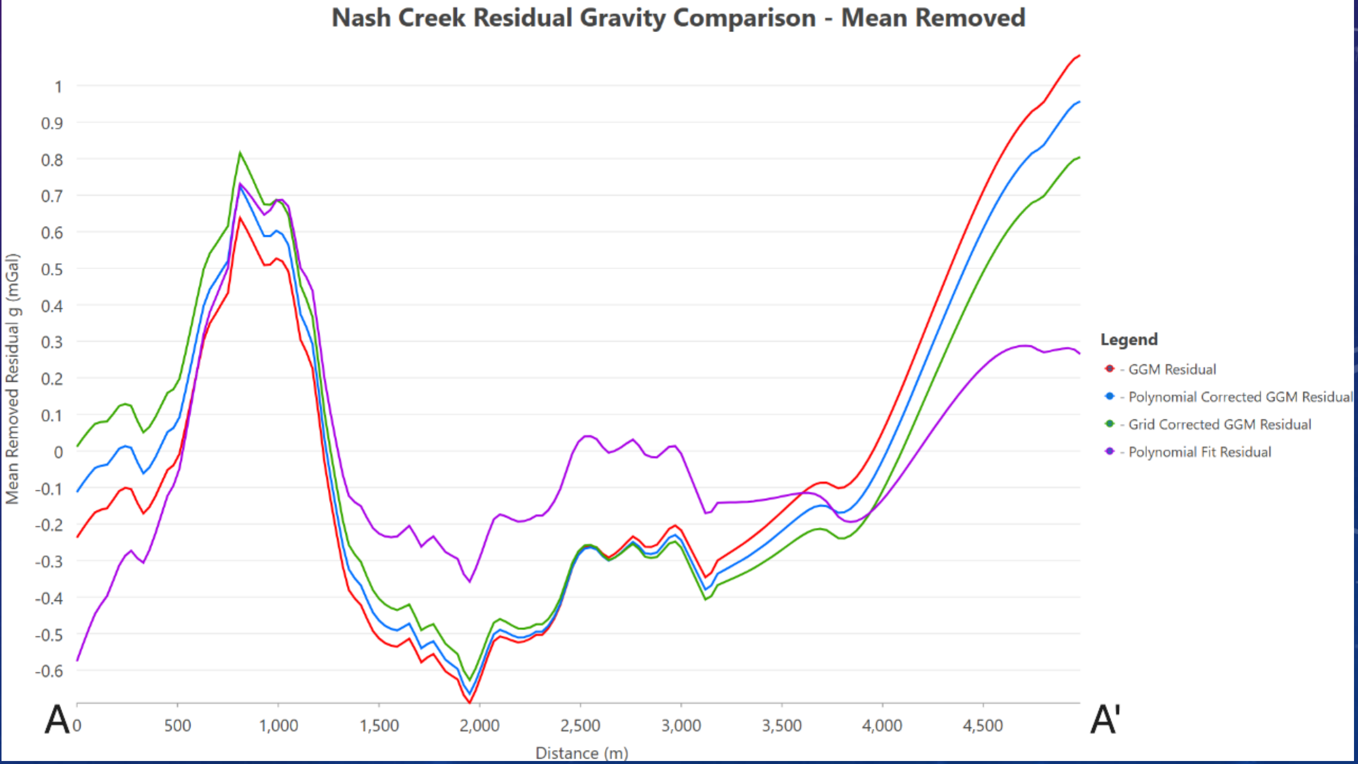


The PCGGM

6. REGIONAL – RESIDUAL SEPARATION

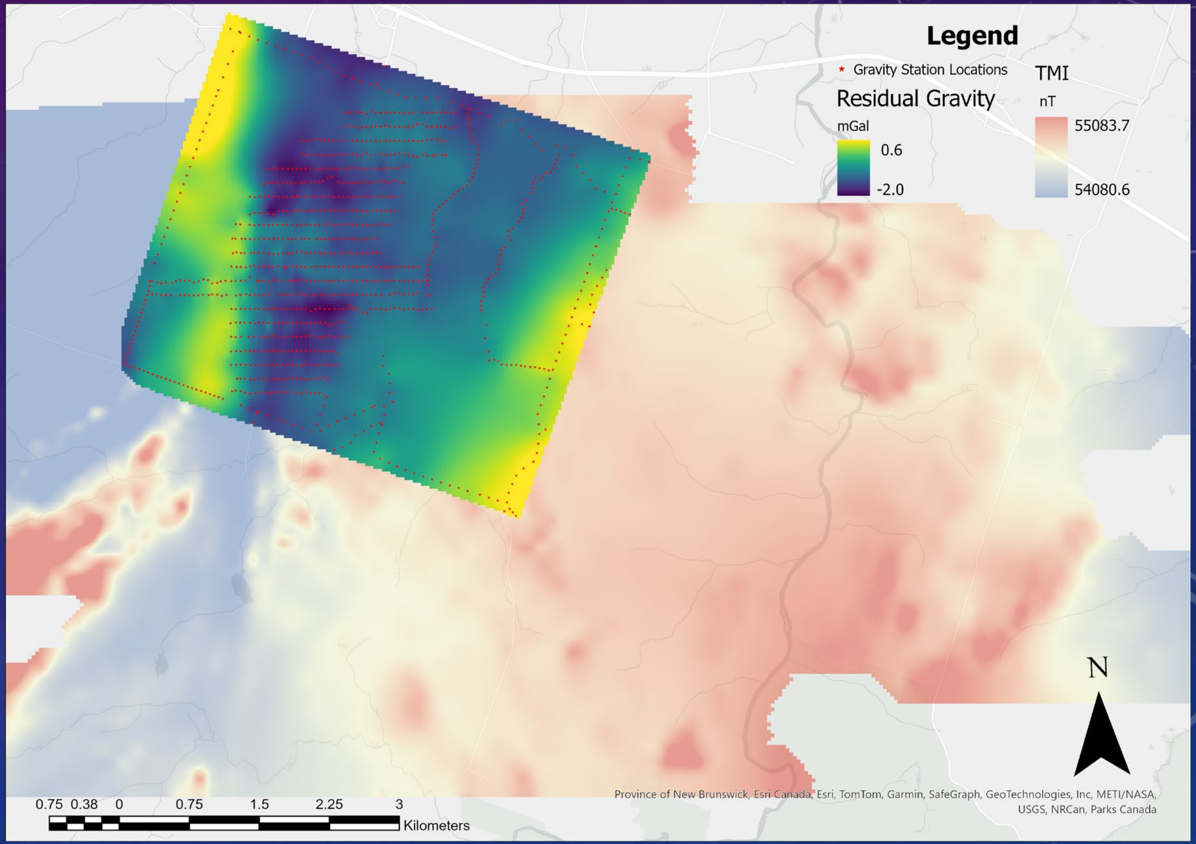
- The GGM based regionals were compared to a 2nd order local polynomial fit to isolate the residual component of the Nash Creek gravity data.
- The local polynomial fit better accentuated subtle, near surface features.
- At this scale, the GGM corrections merely seemed to introduce a slight linear tilt.





6. REGIONAL – RESIDUAL SEPARATION

- At first glance, the GGM based residuals did not account for the curvature of the local gravitational field.
- However, comparing the PCGGM residual map to aeromagnetic data, it was seen that the elevated gravity in the East coincided with a broad magnetic anomaly.
- In this region, elevated magnetic field strength is generally attributed to dense mafic units, indicating that this feature in the residual gravity is likely real and not just an artifact of regional-residual separation.



7.1 DISCUSSION – REPRESENTING THE REGIONAL FIELD

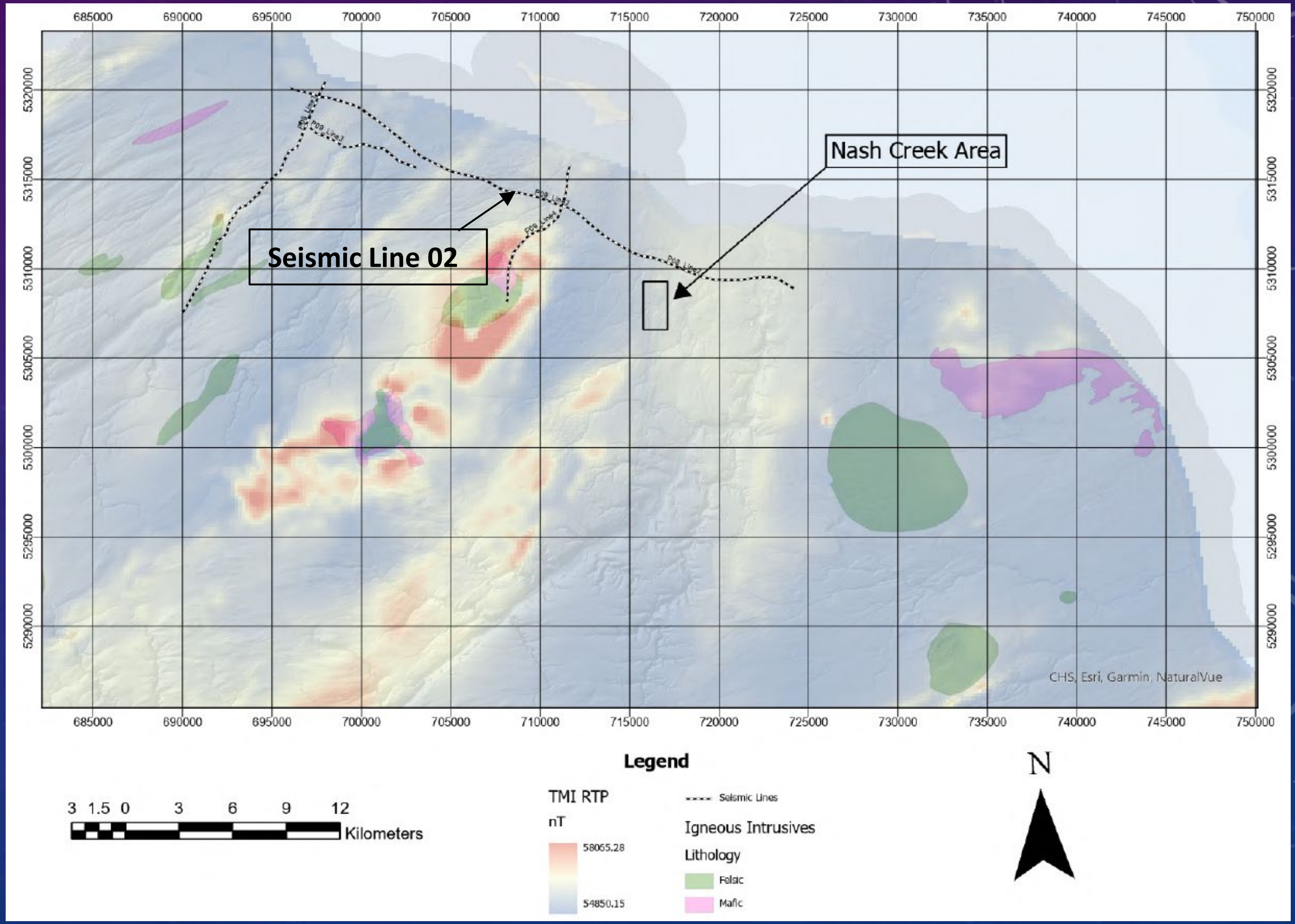
- The grid filter method is prone to aliasing, particularly at low wavelengths.
- Even at high wavelengths, large outliers can have an outsized impact on the correction surface.
- A potential improvement would be to either reject or interpolate outlier correction values - could implement a maximum correction gradient to determine these outliers.
- The polynomial method corrects for much longer wavelength errors in the GGM. Based on broader patterns in the data, it seems to have done a good job of this; however, it is prone to ringing around the edges and creates artifacts in areas with large data gaps, despite the addition of artificial fixed points. This is likely due to the sparsity of artificial points added (necessary to prevent these artificial points from influencing the optimization too much).
- The PCGGM was selected to represent the regional field. The flaw in this method is that the “true” correction surface is fundamentally not a polynomial, so there will be erroneous tilts/curves added to the data in certain areas. The grid filter method suffers from a similar issue though, as large difference values get smeared out. Due to the sparse station spacing, approximation is inevitable, and the polynomial surface qualitatively worked well while being conservative.

7.2 DISCUSSION – REGIONAL – RESIDUAL SEPARATION

- The maximum resolvable wavelength in a geophysical survey is constrained by the size of the survey.
- GGM data is inherently restricted to measuring long wavelength anomalies, generally on the order of 10s of kms. Thus, when using GGM data on a small-scale gravity survey, there will be a significant band of wavelengths that are too big to be seen in the local data, but too small to be seen in the GGM.
- These wavelengths will be treated as regional by the local polynomial fit, and residual by the GGM. This is especially useful for wavelengths that are just slightly out of the wavelength band of the local survey, like what we see in this case.
- The GGM based methods were especially useful in this case due to the strong background gradient. The elevated gravity to the East would have otherwise been visible prior to regional-residual separation.

8. CURRENT WORK - MODELLING

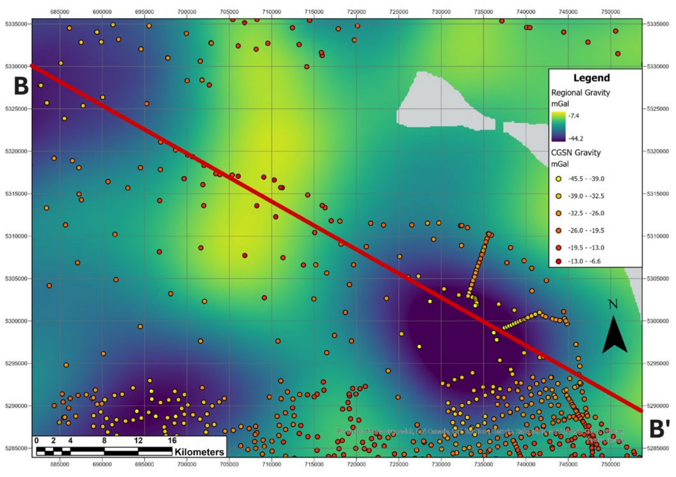
- The negative gravity anomaly to the East of Nash Creek is associated with a large granitic intrusion.
- The positive gravity anomaly to the West is associated with a bimodal intrusive complex.
- This intrusive complex shows strong near surface magnetization and is currently under investigation as an Iron-Oxide-Apatite type REE deposit.
- Initially, simple shapes with different density contrasts will be tested.
- Seismic Line 02 crosses over part of this intrusion and will be used to help constrain the model.

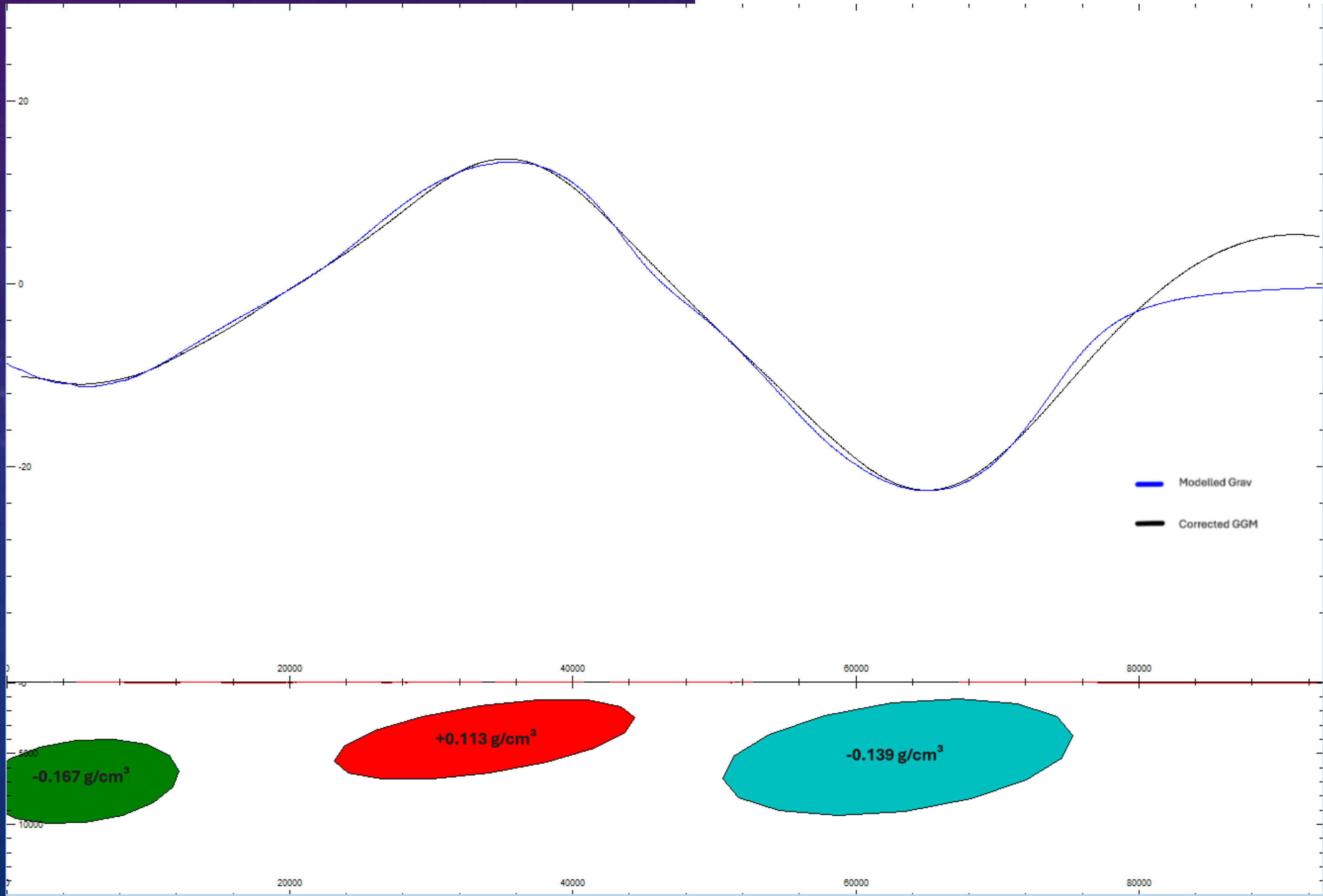


8. CURRENT WORK - MODELLING

- The focus of the modelling is on the bimodal intrusive complex – the positive density anomaly.

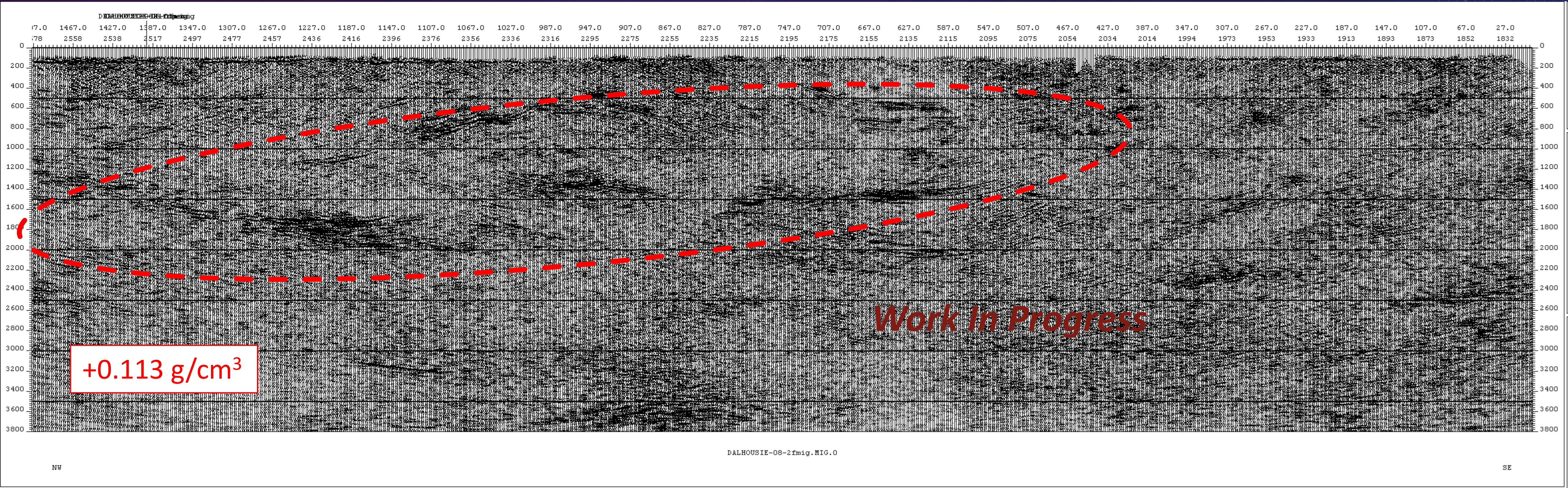
- The models for the negative anomalies did not incorporate any geologic information. They were introduced solely to place the positive anomaly in the proper geophysical context.





8. CURRENT WORK - MODELLING

- Compared to other simple shapes such as prisms and cylinders, the dipping ellipse had the best fit to the data while honoring the seismic section.
- Higher density contrasts (> +0.15 g/cm^3) required higher depths, contradicting the seismic section.
- Low densities required large widths and/or extreme depth extents.
- All models tested dipped to the Northwest.



FUTURE WORK

- Continue refining these GGM levelling methods.
- Conduct a high-resolution gravity profile over the bimodal intrusion.
- Collect density measurements on core samples extracted from this intrusion.
- Work on tying the Nash Creek gravity data in with the wealth of geologic and alternate geophysical data collected over the property.

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