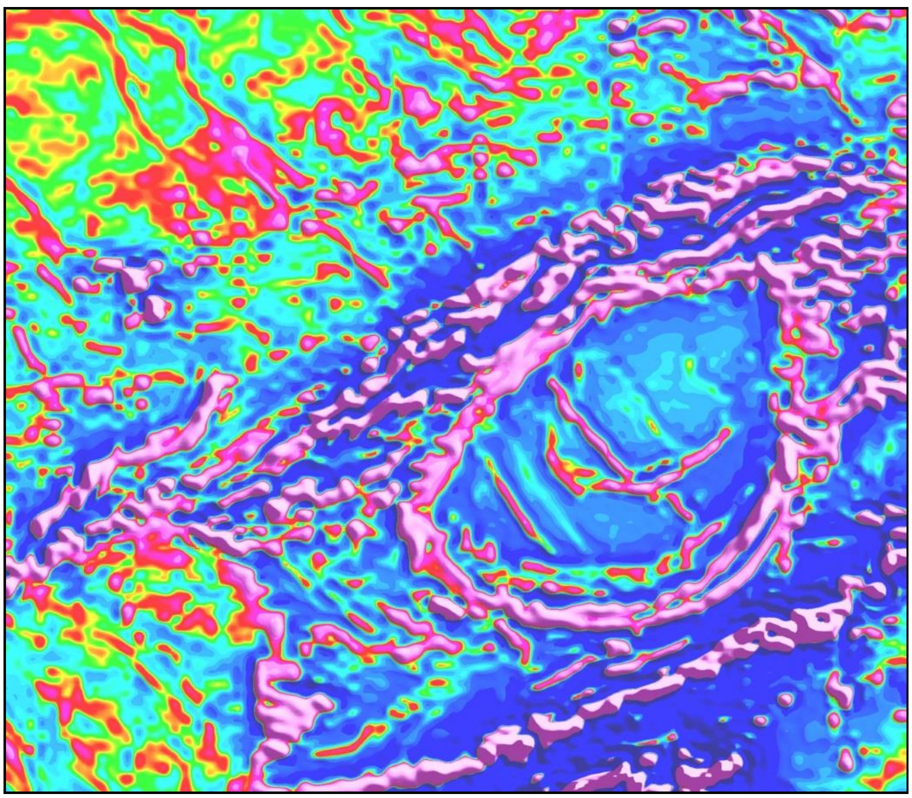
State of Minnesota

Aeromagnetic Data Processing

Pilot Project



By

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1. Introduction

The Minnesota Department of Natural Resources (the department) possesses a state-wide aeromagnetic dataset, which it makes freely available to the public to promote mineral exploration in the State. The data was acquired by the Minnesota Geological Survey over the period 1979 to 1991 in several contiguous survey blocks. The data has been subsequently broken into twenty-three databases, comprising a total of 588,566 line kilometers of profile data. A large part of the data was collected at a nominal flying height of 150 metres, with a general line spacing of 400m (with noted exceptions). Table 1 below summarizes some details of the survey blocks.

Database Name	Traverse (km)	Tie line (km)	Total (km)	Spacing (m)
bagley	25,020	2,749	27,769	400
brimson	14,168	5,512	19,680	400
buyck	6,371	1,296	7,667	400
cus_east	40,677	-	40,677	380
cus_west	25,404	-	25,404	400
forest_center	8,113	4,867	12,980	400
grand_marais	10,751	2,470	13,221	400
grand_rapids	18,045	2,8	20,123	400
hibbing	25,650	2,916	28,566	400
lake_superior	5,708	-	5,708	1900
lake_woods	3,043	183	3,226	926
little_falls	21,413	2,331	23,744	400
moose_lake	21,150	1,882	23,032	400
mora	14,884	1,531	16,415	400
northwest	43,133	4,651	47,784	400
southeast	51,880	5,535	57,415	500 / 1000
squaw_lake	19,015	1,971	20,986	400
swas	20,720	1,143	21,863	536
swmgs	37,147	3,290	40,437	500
twin_cities	5,933	-	5,933	1600
wadena	22,250	2,321	24,571	400
west_cent	78,248	7,474	85,722	400
whyte	9,928	5,715	15,643	400
Totals	**528,651**	**59,915**	**588,566**	

Table 1 – Airborne Survey Summary

Flightpath recovery was accomplished using photographic detail recorded at specific magnetic profile fiducials. The picked fiducials were transferred to air photo mosaics and then likely plotted on topographic maps. The profile data was linearly interpolated between the plotted fiducials.

During the period 2005 to 2007, the Minnesota Geological Survey (MGS) conducted a program to re-process the profile data, utilizing computer software that was not available during the original survey campaigns. Gross coordinate errors were corrected and selected traverse lines were re-levelled. A microlevel correction was applied to all the data.

Although the quality of the data was improved, deficiencies still remain. In April 2016, Scott Hogg & Associates Ltd. (SHA) submitted a proposal to the department that illustrated some of the deficiencies noted and made recommendations for further processing (in particular, the recommendation to re-grid the profile data using SHA's proprietary gridding process; SI-Grid).

A pilot project was proposed to test the potential benefits of re-processing. An area of interest was selected by the department that included subsets of three databases; Mora (7997 km), Grand Rapids (8449 km) and Cus East (8090 km). The following report summarizes the processing steps performed on the data.

2. Profile Data Processing

The following processing steps were performed on each of the three subset databases. Note that examples in this section have been taken from the Squaw Lake database, which was not a part of the pilot project, but was processed for the original proposal.

2.1. Mag Spikes

Throughout the datasets spikes were noted in the magnetic profile channel, which produced artifacts in the final grid. The spikes appeared to be single-record events and were not particularly common. Figure 1 below shows such a spike (point A). The magnetic profile is shown on the left (with 25 nT grid lines) and the total magnetic field grid on the right.

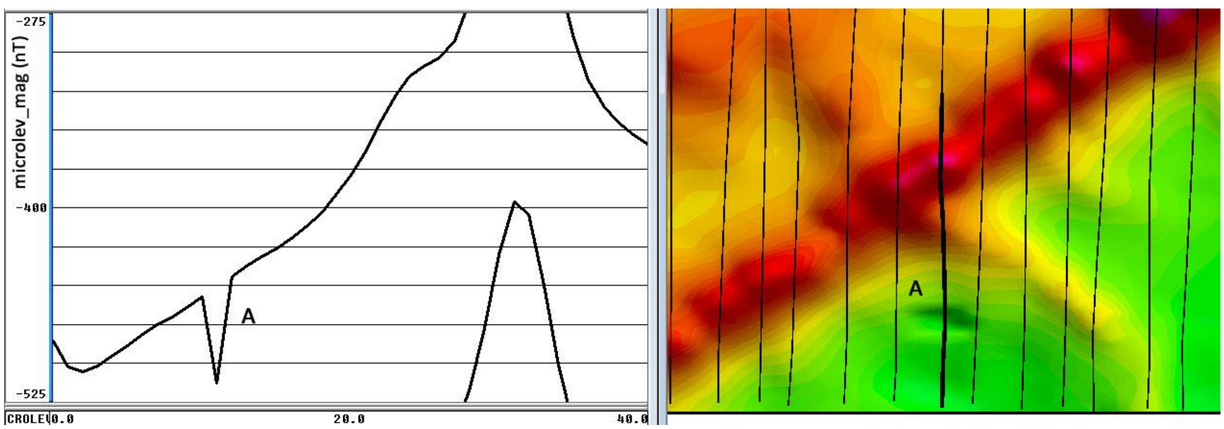


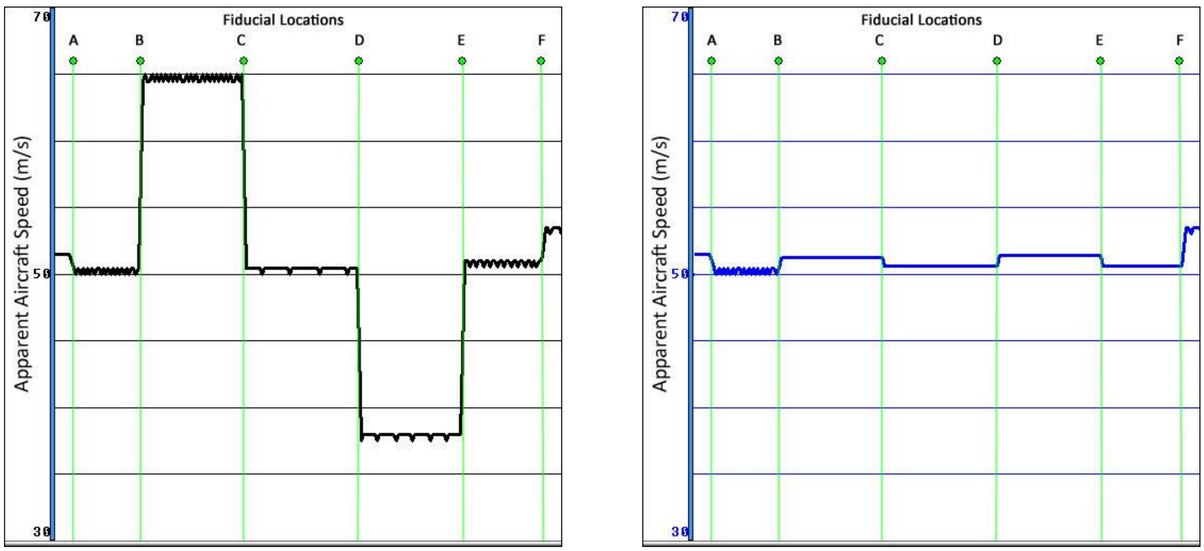
Figure 1 – Magnetic Data Spike

The solution was straight forward. The erroneous value in the database was deleted and the gap was filled by an Akima interpolation of the profile data. The input magnetic profile channel to the editing process was *RELEV_MAG* and the corrected magnetic profile was stored in the databases as *SHA_ed_mag*.

2.2. Positional Errors

The flightpath recovery method of plotting fiducials (fids) on a photo mosaic has many inherent sources of inaccuracy and error. A simple method to judge the suitability of the plotted fids is to calculate the apparent speed of the aircraft, using the coordinate channels. If the fids were positioned perfectly, the apparent aircraft speed would be relatively constant down each line. In practice, however, this is usually not the case. A misplaced fid will often create a segment in the speed channel of increased speed, followed by a compensating segment of apparent decreased speed (or the other way around).

Figure 2 below shows an example of two misplaced fids. The left image shows the apparent speed profile in black, with reference gridlines spaced at 5 m/s. The fiducial positions are easy to spot as steps in the speed profile and are indicated by green lines. The apparent speed between fids C and D matches the nominal 50m/s speed of the aircraft, indicating C and D are spaced the correct distance apart. The increased speed between B and C, followed by the decreased speed between D and E, however, indicate that the C-D pair is out of position. They were plotted too far away from B, and too close to E.



Apparent aircraft speed with original fids

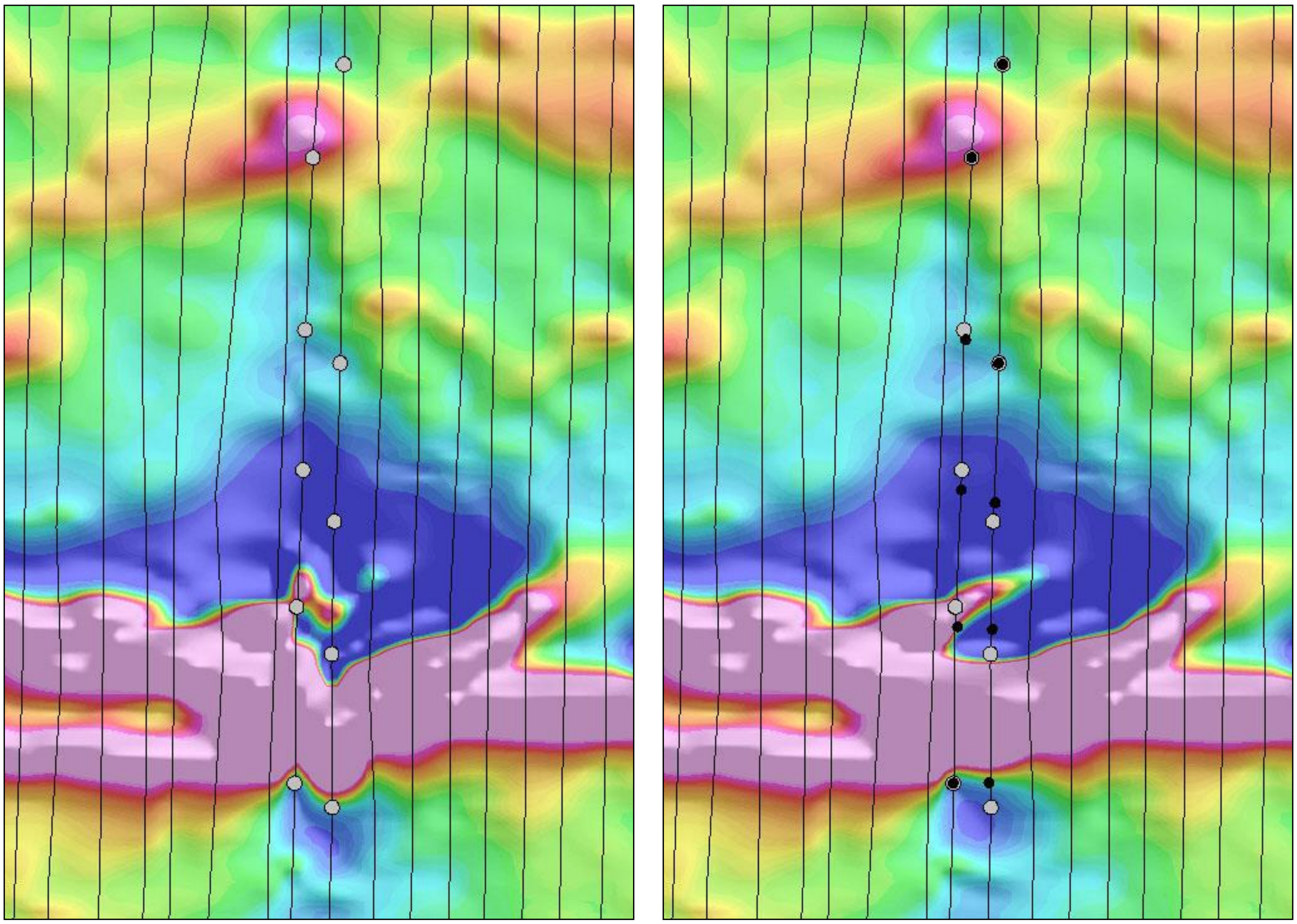
Apparent aircraft speed with re-positioned fids

Figure 2 – Apparent Aircraft Speed Check

In the figure on the right, the northing coordinates of C and D have been shifted 600m away from B and the speed recalculated (shown as a blue profile).

In relatively quiet areas in the magnetic map, a misplaced fid would produce a slightly visible artefact that may have been corrected by micro levelling. If there is a coordinate error associated with a high-amplitude magnetic feature, however, the result in the magnetic map can be significant. A useful tool in locating positional errors is the one-dimensional vertical derivative operator, applied to the profile data. The 1VD filter will attenuate long-wavelength features and accentuate the peaks of discrete features. When the 1VD profile is gridded, features may be examined from line to line and any positional errors will be readily apparent and quantifiable.

Figure 3 on the following page shows the gridded vertical derivative data surrounding a high-amplitude, linear feature. The plotted fids for two lines are shown on the left image, in their original position, as grey dots. In the right hand image, the fids have been moved and the coordinate channels were reinterpolated and the 1VD data was re-gridded. The original fids are still shown as grey dots, and the newly positioned fids as black dots.



1VD grid with original fid positions (grey) Corrected 1VD grid with new fid positions (black)

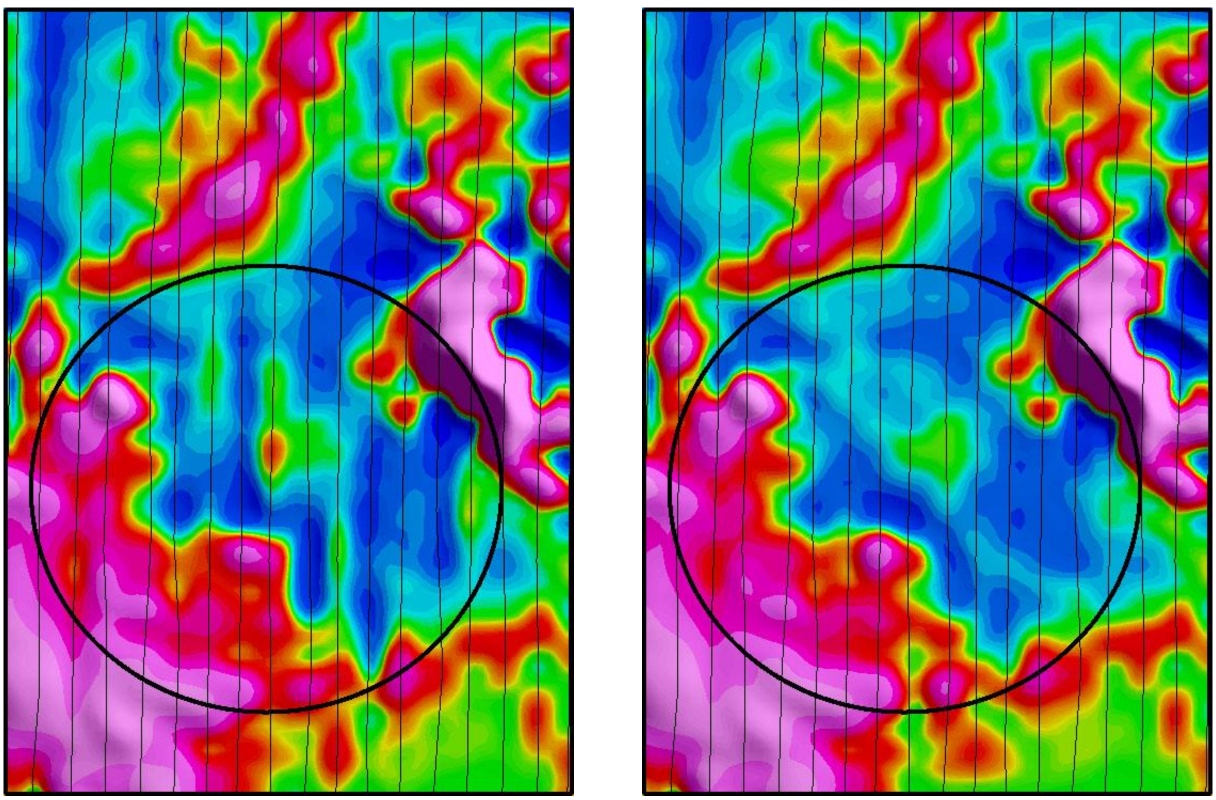
Figure 3 – Coordinate Correction

One can see that the adjustments made to the fiducial locations have had a positive effect on the mapping of the feature. For the pilot project two and half days were spent manually correcting the flight path. The modified coordinate channels were stored as *SHA_X* and *SHA_Y*.

Positional errors are ubiquitous throughout all of the datasets. The process of manually repositioning fids and re-interpolating the coordinates is an open-ended proposition, with diminishing returns. The time allotted for the pilot project was adequate to identify and correct a first-order level of errors that produced quite glaring artifacts in the map. The time spent works out to be one day for every 10,000 kilometers of profile data. It is recommended that this approach be considered for the rest of the state dataset. The positioning will never be perfect, but this “first-order” approach has made a significant improvement to the map.

2.3.Microlevelling

Although a final microlevel correction was applied to the data in the 2005-2007 re-processing, residual levelling artefacts were still noted. A microlevel correction was applied to *SHA_ed_mag* (which was derived from the (un-microlevelled channel *relev_mag*). The microlevel correction was limited to amplitudes less than 10nT and wavelengths longer than 2km. Figure 4 below shows a calculated vertical derivative grid of original microleveled (2007) data on the left, with an area of residual levelling errors circled. In the right hand image, the microlevelling was redone and the data was regridded. The microlevelled data was stored as *SHA_mag_lev*.



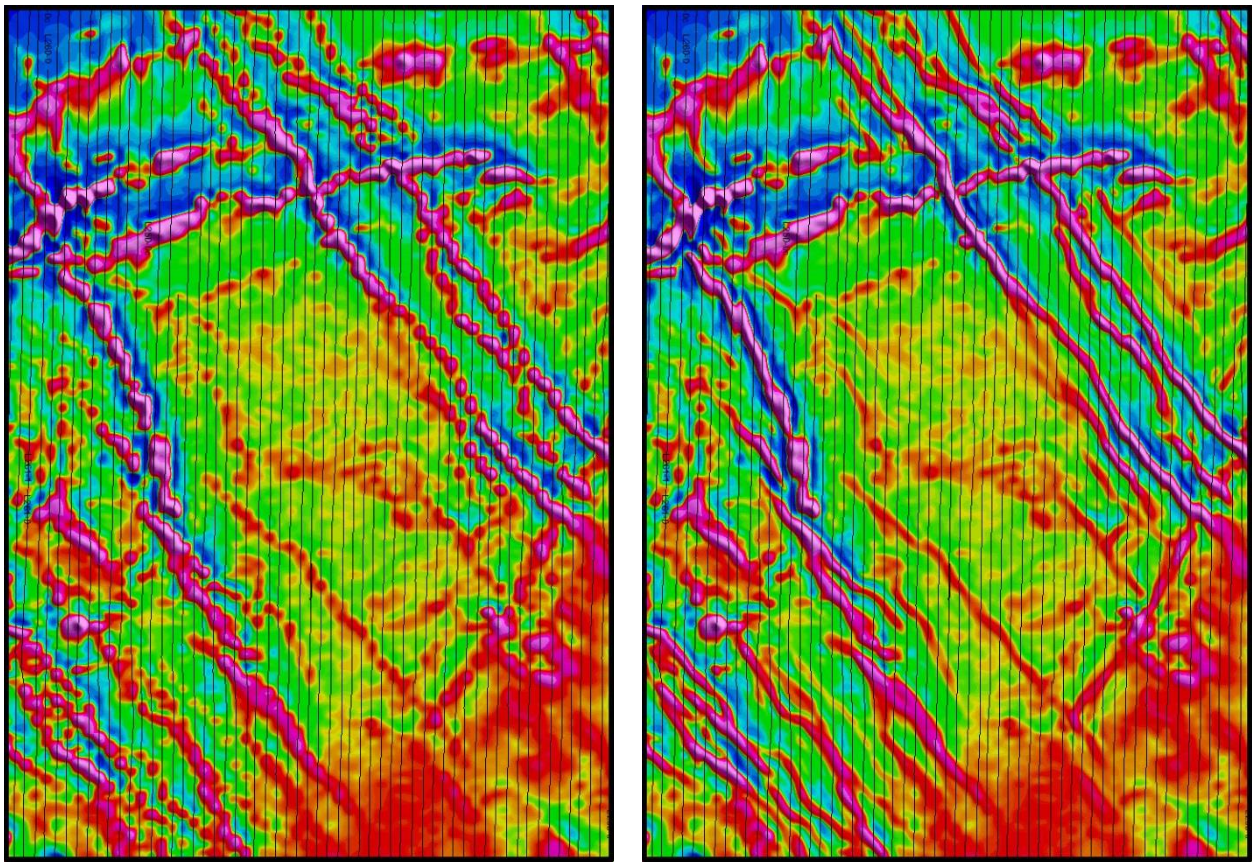
Original microlevelling | Microlevelling redone by SHA

Figure 4 – Vertical Derivative Grids before and after re-microlevelling

3. Strike Interpretive Gridding – SI-Grid

SI-Grid is a gridding program that is proprietary to SHA. The process is user-driven and the data interpolation direction may be varied throughout the map. Linear trends can be properly rendered, regardless of strike orientation. The process uses the magnetic profile data to create the final total field grid. No smoothing or filtering is used.

Figure 5 below shows an example of SI-Grid, taken from the Squaw Lake database. Each image is of a calculated vertical grid. On left is a grid produced by an Akima bi-directional spline. On the right is SI-Grid. The improved line-to-line coherence is immediately apparent.



Conventional Grid SI-Grid

Figure 5 – Vertical Derivative Grids before and after SI-Grid

The process is particularly effective when survey line spacing becomes significantly wider than the flying height. The airborne geophysical industry generally recommends that the line spacing for an aeromagnetic survey should not significantly exceed twice the height above magnetic surface without a notable degradation in map quality. In the Minnesota datasets, the nominal flying height was 150m. The survey blocks used in the pilot project were flown at 400m line spacing. Thus, the ratio of line spacing to flying height exceeds three to one. In some blocks, the ratio exceeds four to one, and even eight to one in some cases. The wide line spacing leads to incoherent mapping when using conventional gridding routines. Subsequent filtering, such as a vertical derivative, will only exacerbate the incoherence.

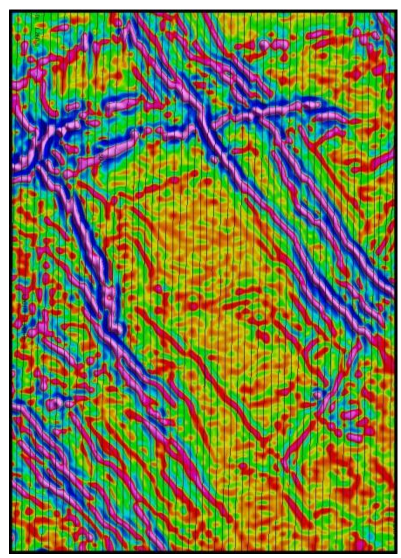
The final, microlevelled magnetic profile data from each of the three subset databases used for the pilot project were gridded individually, and subsequently merged together.

4. Supplemental Gridded and Vector Products

The following additional products were derived from the total magnetic field SI-Grids. For each of the products summarized below, a grid was calculated for each of the three survey databases, as well as a merged grid for the entire pilot project.

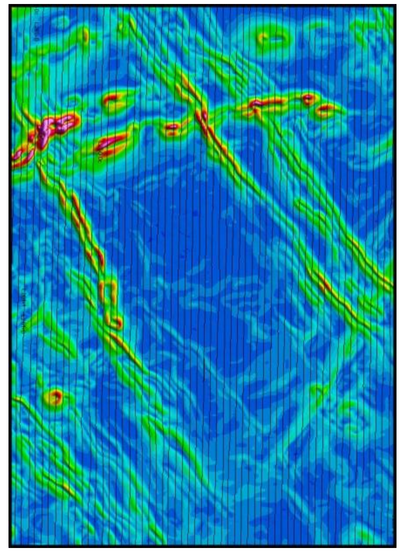
4.1. First and Second Vertical Derivative Grids

The first and second vertical derivative grids enhance small and weak near-surface anomalies. Derivative grids were calculated from the residual magnetic field SI-Grids in the Fourier domain.



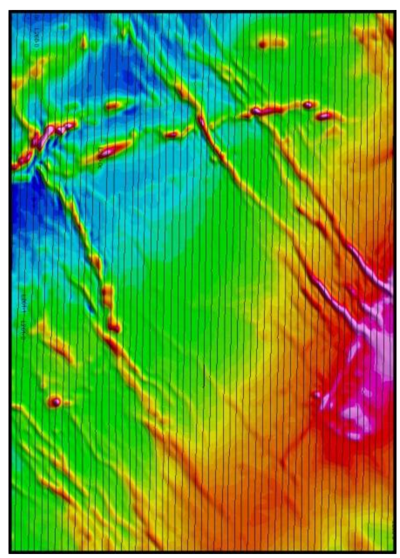
4.2. Total Horizontal Gradient Grid

The image to the right shows a grid of the scalar magnitude of the horizontal gradient vector. Grids of the horizontal gradient vector are useful at highlighting geological contacts.



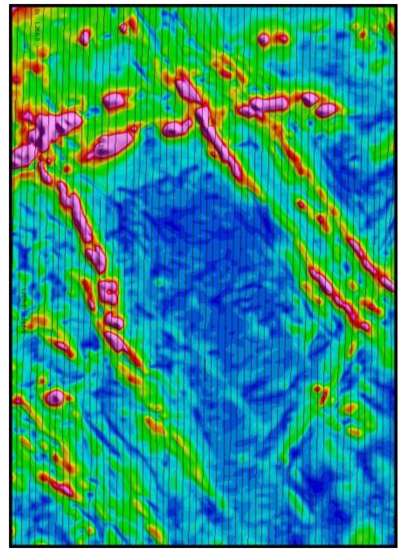
4.3. Apparent Magnetic Susceptibility Grid

This grid has the same cell size and dimensions as the input total magnetic field grid. Each grid cell is assigned a magnetic susceptibility value, such that when all cells are combined, the distribution will produce the input magnetic field grid.



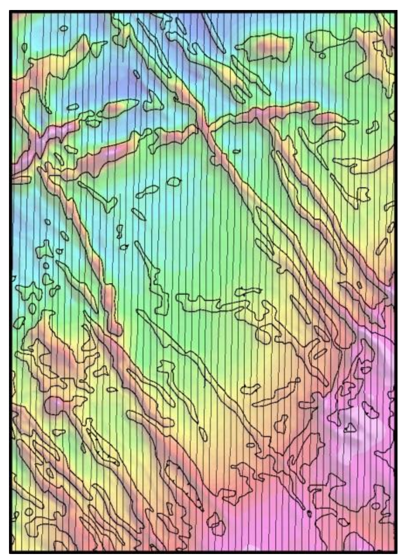
4.4.Analytic Signal Grid

The analytic signal grid presents the scalar magnitude of the full magnetic gradient vector.



4.5.Geological Contact Vector (DXF) File

When a magnetic anomaly is large, with respect to the survey specifications, a calculated vertical derivative of the magnetic field will cross over from positive to negative at or near the geological contact of the body. Simply put, the zero-value contour of the calculated vertical derivative can provide a trace along the geological contacts in the map. A vector file was generated from each of the SI-Grid magnetic field grids.



5. Summary of Products

Profile databases

The following subset databases have been included in Geosoft format:

- Mora_SHA.GDB
- Grand_Rapids_SHA.GDB
- Cus_East_SHA.GDB

Grids

The following grids have been provided in Geosoft format. For each grid type, three individual grids are provided for each of the subset survey blocks noted above, as well as a merged single grid for the entire pilot project area.

- Pilot_SI_TMI.GRD – Total magnetic field SI-Grid (nT)
- Pilot_SI_CVG.GRD—First vertical derivative SI-Grid (nT/m)
- Pilot_ SI_2VG.GRD—Second vertical derivative SI-Grid (nT/m^2)
- Pilot_ SI_ANS.GRD—Analytic signal SI-Grid (nT/m)
- Pilot_SI_Hor_Grad.GRD—Horizontal magnetic gradient SI-Grid (nT/m)
- Pilot_ SI_Susc.GRD—Magnetic Susceptibility SI-Grid (SI units of emu)

Vector Files (DXF)

Contact vector files have been provided in DXF format.

- Pilot_Contact.DXF

6. Discussion

The state-wide aeromagnetic dataset was acquired over a long period of time and portions of it are several decades old. The sample interval of the magnetometers varied from 20 to 50 metres down the line, which may seem large when compared to modern systems that sample at 10Hz or higher (resulting in a down line sample interval less than 10m). Considering the nominal flying height of at least 150 metres, however, the sample rate is sufficient. Generally speaking, an airborne magnetic survey is not able to resolve a magnetic anomaly with a wavelength shorter than the survey altitude.

The nominal line spacing of 400m is a little over two and a half times the flying height. The airborne survey industry recommends that the spacing to height ratio does not greatly exceed two to one. As the spacing increases, the line to line correlation of features becomes less and less coherent. At 400m, the spacing is past the upper end of this limit and linear features that aren't perpendicular to the flight path are not well mapped by conventional gridding methods.

The method of recovering flight path using plotted fiducials on photo mosaics was the standard at the time but it can be inaccurate, especially when compared to modern GPS methods. Positional errors in the dataset would be greatly emphasized if infill flying was attempted. It is the author's opinion that any attempts to infill the data with new flying would be ill fated and the cost of replacing the dataset with a modern survey would prohibitive.

The database should remain a stand-alone resource that is still very valuable as a tool to help guide exploration and to identify areas suitable for more detailed surveying. The spirit behind the re-processing recommended by SHA (and the subject of this pilot project) is to help achieve the maximum potential of the data, at a relatively minor cost.

In the test databases, the corrections made to the positional data have had a very positive affect on the magnetic map. SI-Gridding has greatly improved the line-to-line coherence of linear features and has sharpened up geological contacts. The improvements achieved in this pilot project are significant and if applied to the entire state database, would add great value to the resource.

Respectfully Submitted,

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Monday, May 15, 2017