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Magnetic Contribution to 3D Crustal Modelling in the Purcell Anticlinorium, Southeastern Cordillera

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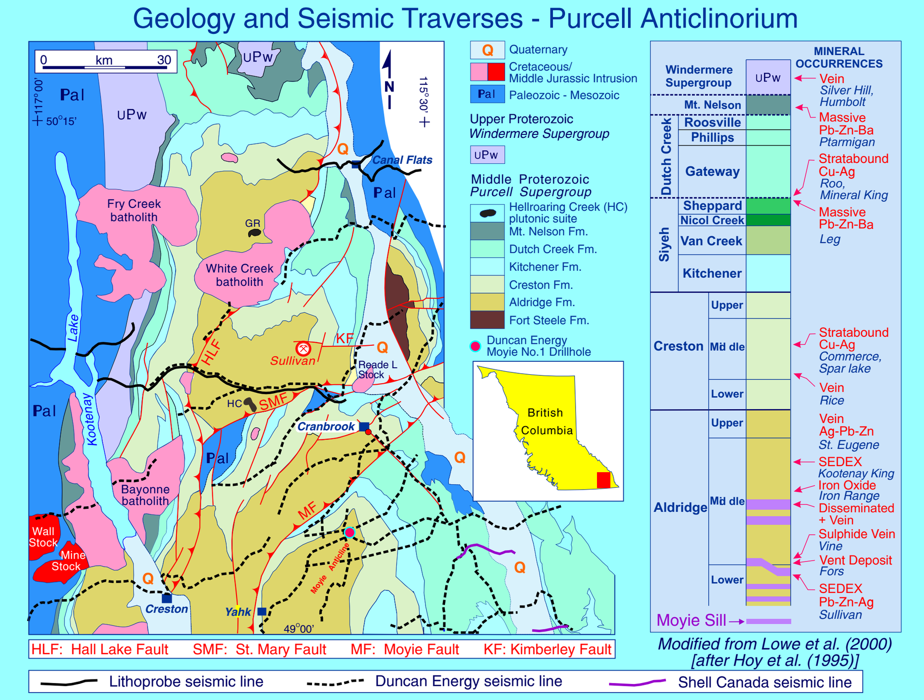
Geology and Seismic Traverses - Purcell Anticlinorium



Modified from Lowe et al. (2000) [after Hoy et al. (1995)]

Geological Setting and Reflection Seismic Traverses

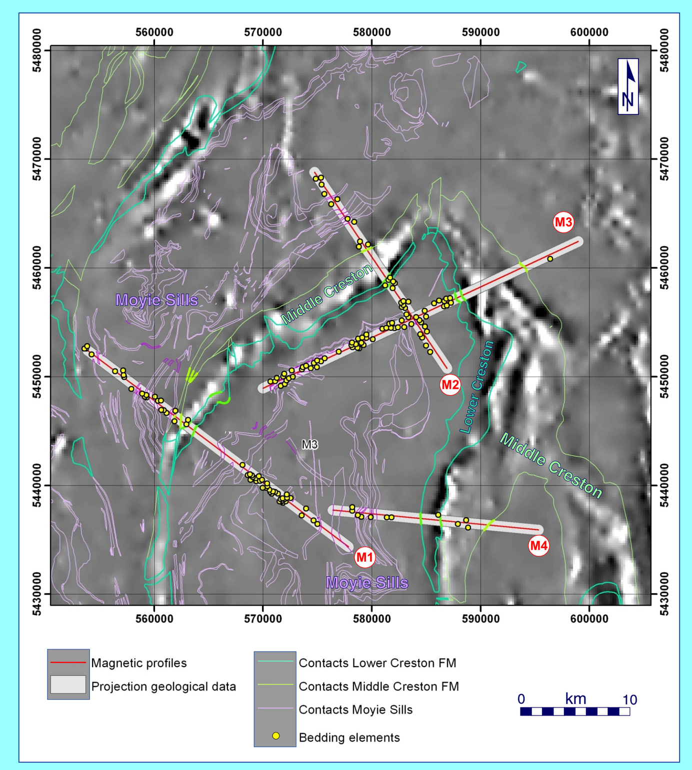
A simplified geological map of the Purcell Anticlinorium, above, displays a broad core comprising mainly sedimentary rocks of the Aldridge Formation and flanking Creston Formation, the latter itself flanked by several other mainly sedimentary Middle Proterozoic formations. The map shows the locations of a fairly large number of seismic reflection lines that are widely distributed throughout the anticlinorium. These provide unique and invaluable images of the structural framework of the underlying upper and lower crust, which are key elements in the development of a 3D crustal model. These seismic images are well described in papers by Cook and Van der Velden (1995) and Van der Velden and Cook (1996). The region also benefits from the release of 12 new 1:50 000 scale Geological Survey of Canada (GSC) geological maps in 2011.

Introduction

Creation of regional 3D crustal models is largely dependant on surface structural data and geology. Unlike 3D models of mine properties, where many drill holes are commonly present to help control interpolation and extrapolation of structural data, regional models generally rely on a sparse and irregular distribution of such holes. In the Purcell Anticlinorium the utility of surface structural data is enhanced to some extent by the rugged terrain with its large range in elevation, but this is a limited benefit. However, from a 3D perspective, the region of the anticlinorium is favoured by a reasonably widespread network of reflection seismic sections that provide a series of structural images across many critical structures. Such images are invaluable for 3D modelling, yet even these lack a reflective signature in certain areas, and frequently seismic responses are weak or absent in the uppermost few kilometres of the crust.

One means of addressing the generally thin and uneven distribution of surface structural data is by utilizing magnetic and gravity potential field data. Such data provide continuous coverage across the anticlinorium, though there is significant variation in their resolution. Gravity data are generally spaced 10 km apart and hence lack the resolution to image geological features less than about 10 km in width. Magnetic data within the anticlinorium have been collected with much higher resolution. Magnetic surveys have been flown at 805 m line-spacing (305 m mean terrain clearance (MTC)) across all of the Purcell Anticlinorium, and higher resolution surveys at 400 m line-spacing (60 m MTC) cover areas near St. Mary River, Yahk and Findlay Creek. The utility of magnetic data is further enhanced by generally greater differences in magnetic susceptibility relative to differences in density between rock units, variations in susceptibility being orders of magnitude higher than variations in density. Magnetic patterns permit creation of pseudo-structural images, and distinct magnetic anomalies can be modelled to help extrapolate surface structures and units to depth. Such modelling can fill in the near-surface blanks in the seismic sections, help link surface features with deeper seismic signatures and help integrate geological and other geophysical data. Here, we present preliminary models of some prominent anomalies in the region to demonstrate the utility of the magnetic method in 3D crustal modelling.

Capturing Structural Data within Magnetic Profile Corridor



Magnetic Modelling in the Moyie Anticline

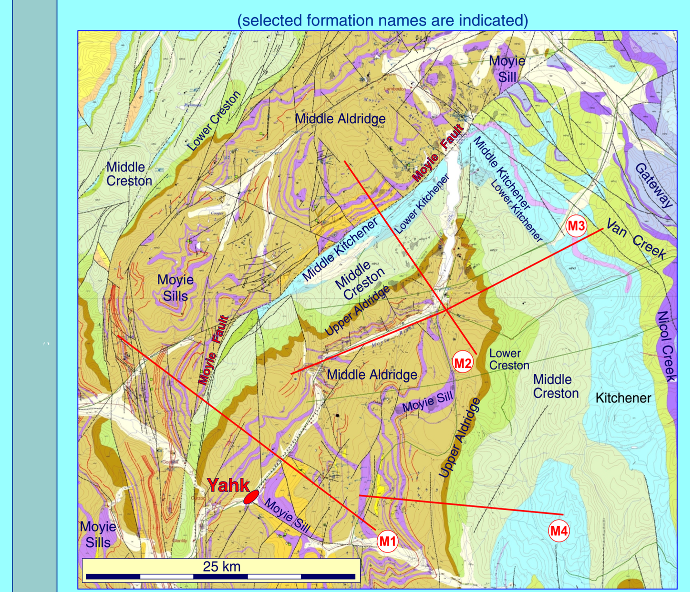
The flanks of the Moyie anticline are characterized by a very prominent and more or less continuous magnetic high. This generally correlates closely with the Middle Creston Formation consisting of quartz arenite and wacke, and lesser siltite and argillite, although west of Yahk the anomaly follows the Lower Creston Formation that comprises mainly argillite and siltite and lesser quartz wacke. The geology of the anticline is shown in the figure to the right and is based on an unpublished working compilation of Geological Survey of Canada 1:50 000 geological maps, courtesy of Roger MacLeod, Pacific Geoscience Centre, Sidney, B.C. Lowe et al. (2000) have noted that this conspicuous anomaly is probably linked to magnetite in Middle Creston Formation green quartz arenite and arenaceous siltstone at upper greenschist metamorphic facies. The arenite contains >2% porphyroblastic magnetite. In the Yahk area, the anomaly is attributed to disseminated and stringer magnetite in fine-grained argillite of the Lower Creston Formation.

The image to the left displays a grey-shaded image of the total magnetic field with locations of 4 magnetic profiles crossing flanks of the Moyie anticline. Superposed selected geological contacts provide a spatial reference. Software used in 3D modelling studies can contribute to related geophysical studies, such as the magnetic modelling studies discussed here, in various ways. One is the simple extraction and display of structural information, e.g. bedding plane dips and strikes, foliations and lineations, within a corridor of desired width centred on the line of the magnetic profile to be modelled. This provides a valuable constraint and helps guide the modelling process.

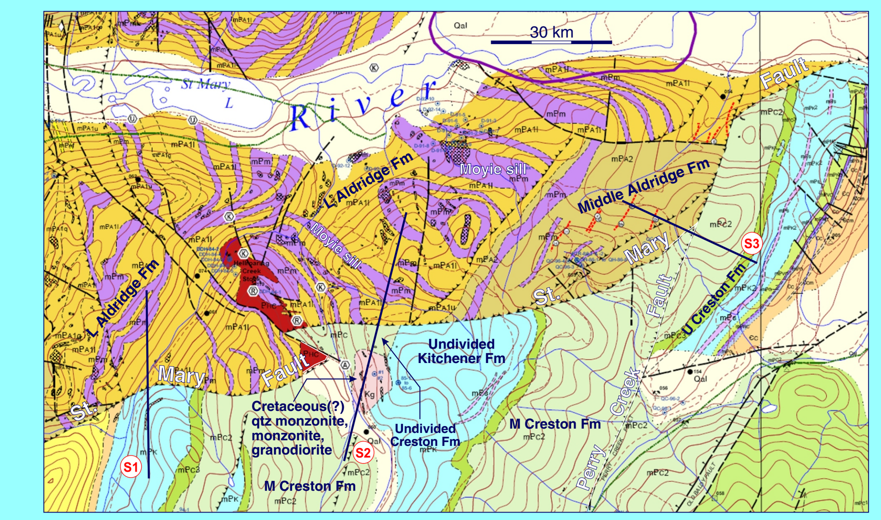
Another facet is the ability to view sub-surface data and features in a 3D perspective from a variety of angles. This helps the visualization process of searching for correlations between buried features from profile to profile, and for links between geological/structural features and magnetic anomalies. The 3D image below displays several reflection seismic sections viewed from the south. The distributions of the units of the Lower and Middle Creston formations are superposed at the surface. Magnetic profiles of interest (M1, M2, M3, M4) are shown along with bedding strike/dip information. Modelling was conducted assuming that the magnetization in bodies is entirely induced.

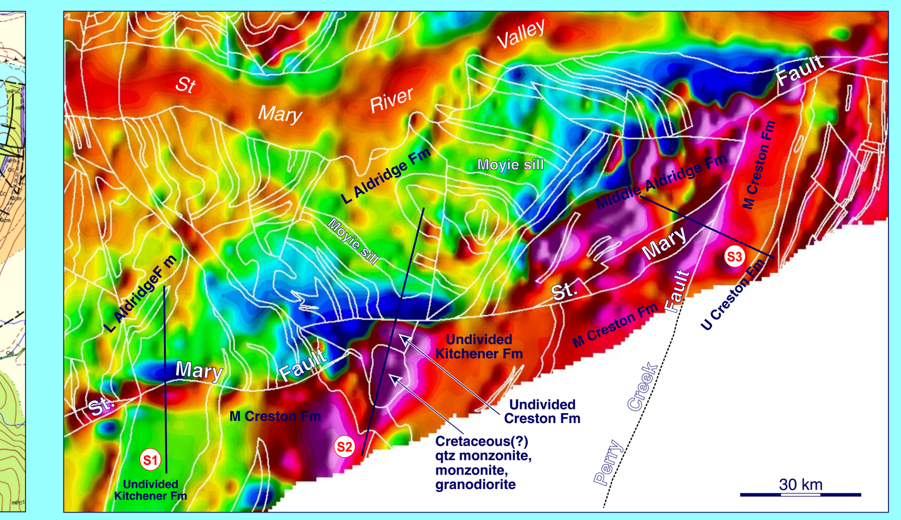
Geological Map of Region of Moyie Anticline

(selected formation names are indicated)



Geological and High Resolution Total Magnetic Field Maps of the Region of the St. Mary Fault





Magnetic Modelling along the St. Mary Fault

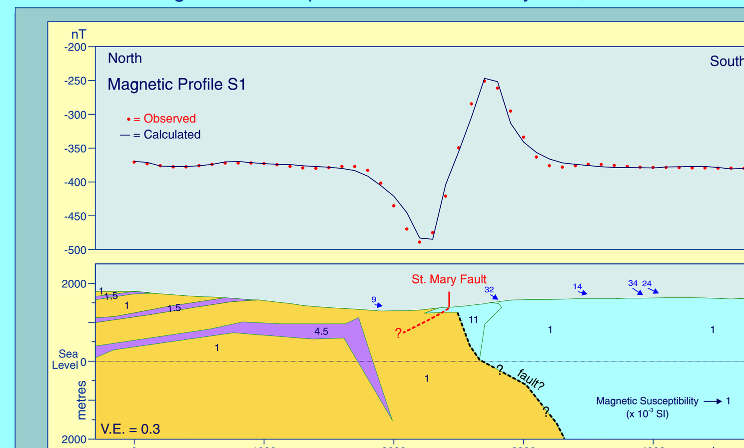
The St. Mary fault is one of a family of probably pre-mid Cretaceous imbricate thrust faults (Cook and Van der Velden, 1995). Geological maps present it as a thrust fault with its upthrust side to the north. An interpretation of a SW-NE reflection seismic line (Van der Velden and Cook, 1996) portrays it as a thrust fault dipping roughly 30° north along the line of section, though the uppermost 3 km or so of the seismic section is devoid of reflectors. The interpretation probably is based on linking a feature in the deeper part of the section to the surface position of the fault.

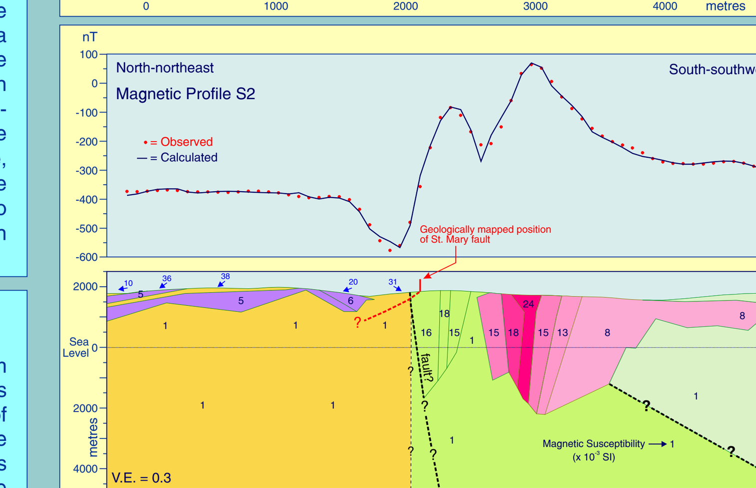
A high resolution magnetic map for the area of the fault displays a belt of prominent magnetic anomalies lying along the fault, mainly to the south, but also straddling it. There is no singular magnetic anomaly following the length of the fault, but certain anomalies have steep gradients that coincide with the fault. Three of these have been selected for modelling with a view to obtaining information on the dip of the fault in the uppermost few kilometres of crust. The profile lines crossing them (S1, S2, S3) are shown in the geological and magnetic maps above.

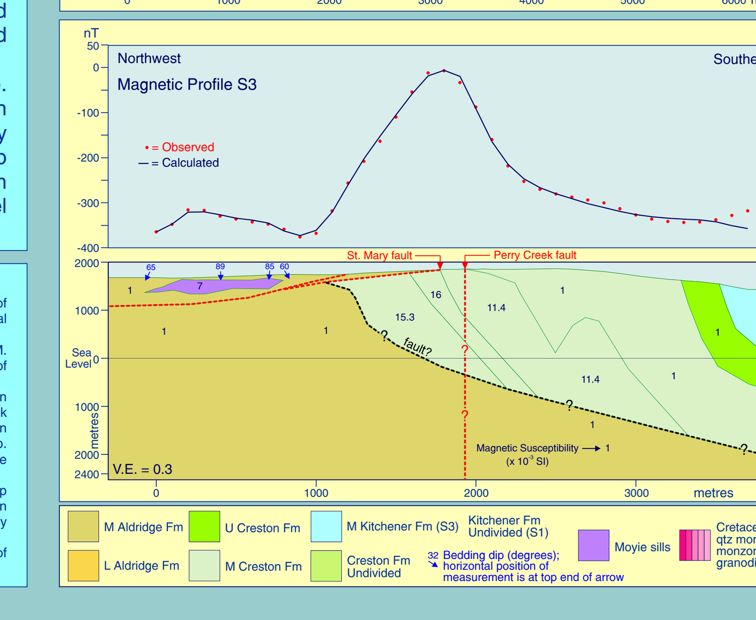
Magnetic Profile S1 crosses a short (~2 km long) linear magnetic high running subparallel to the St. Mary fault, which locally separates relatively non-magnetic sedimentary rocks of the Lower Aldridge and Kitchener formations. A distinct anomaly in this geological setting running transverse to the local geological strike is unexpected. The high is accompanied by a complementary intense low to the north, typical of dipolar magnetization within a single body. The high is modelled in terms of a single body having the shape of an inverted triangle and a moderate magnetization (susceptibility = 11 x 10^{-3} SI) lying within the Kitchener Formation. Its northern contact dips steeply southward below a depth of about 150 m, and if this represents the St. Mary fault, it conflicts with opinion that this fault dips northward. However, a thin horizontal wedge of magnetic material extending ~200 m north of the fault above 150 m depth and forming part of the magnetic triangular body is required to improve the match between observed and modelled north flanks of the magnetic high. Possibly, this wedge reflects the influence of a gently northward-dipping St. Mary fault? It is speculated that the steep northern contact of the triangular magnetic body is a fault, and this is tentatively projected steeply southward along the boundary between the Aldridge and Kitchener formations. This latter facet of the model is not based on magnetic modelling, because susceptibilities of both formations are identical below sea level.

Magnetic Profile S2 crosses a strong magnetic high comprising two peaks, one correlating with a Cretaceous (?) quartz monzonite-monzonite-granodiorite intrusion and the other with sedimentary rocks of undivided Creston Formation. Two moderately magnetic bodies (susceptibilities range from 8 to 24 x 10^{-3} SI) have been modelled within each of these two geological units. Susceptibility units within both are steeply dipping and descend to depths of about 4 km. Magnetic patterns on the map indicate that the northern peak could signify a shallowly buried Cretaceous (?) intrusion. The model sheds little light on the disposition of the St. Mary fault, which lies near the northern contact of the modelled body under the northern peak. This contact may be a fault contact.

Magnetic Profile S3 defines a strong magnetic high straddling the St. Mary fault very close to its intersection with the Perry Creek fault and coinciding with sedimentary rocks of the Middle Aldridge Formation to the northwest and Middle Creston Formation to the southeast. The most likely candidate for a magnetic source is a magnetite-rich horizon(s) in the latter formation, and modelling proceeded with this in mind. Presumed magnetite-rich rocks of the Middle Creston Formation are modelled to extend roughly 700 m northwest beneath a thin wedge (maximum thickness ~150 m) of Middle Aldridge Formation, the bottom of which is taken to be the St. Mary fault. By this interpretation the St. Mary fault dips ~20° northwest (measured at natural scale; vertical exaggeration (V.E.) in all St. Mary models is 0.3). The bottoms of steeply dipping magnetic horizons in the Middle Creston Formation are truncated by a southeast-dipping contact with underlying Middle Aldridge Formation, which at natural scale has an overall dip of about 55°. It may indicate a southeast-dipping fault. The steep dips modelled within the Middle Creston Formation (~75°) seem reasonable, given steep dips ranging from 89° to 60° in the Middle Aldridge Formation to the northwest, and from 64° to 75° approximately 2 km along strike from the profile in the Middle Creston Formation.





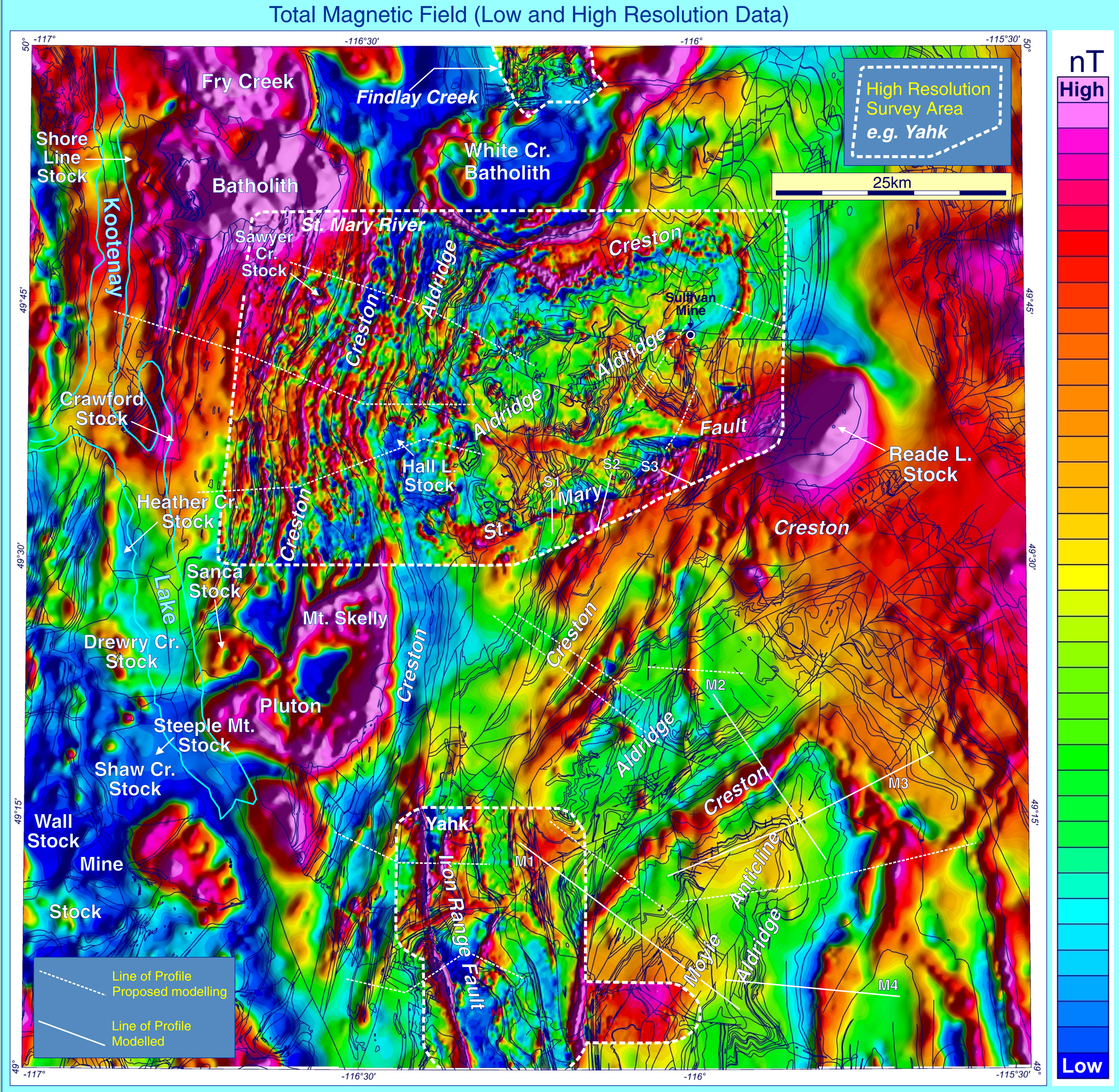


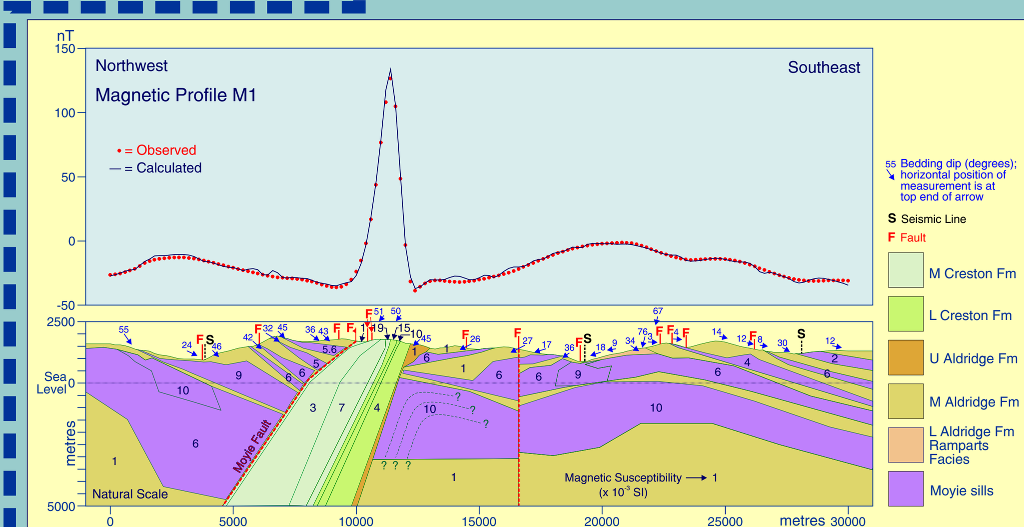
Total Magnetic Field Map and Magnetic Profiles of Interest

An image of the total magnetic field incorporating regional low resolution data and relatively higher resolution data from the Findlay Creek, St. Mary River and Yahk areas is shown below. The Aldridge Formation correlates with broad, smooth and generally subdued magnetic signatures. In contrast, the Creston Formation, particularly the middle part of its stratigraphy, is associated with a strong positive magnetic expression. Such strong anomalies afford a means to model near-surface crustal structure that may not be imaged in seismic sections, and to possibly establish links with deeper seismically-defined structure. Strong linear magnetic anomalies associated with the flanks of the Moyie anticline and distinctive anomalies along the St. Mary fault are targeted in this poster. Line geology (Joseph et al., 2011) compiled from the new release of GSC maps provides a reference framework.

Profiles investigated in this presentation are indicated on the magnetic map below as solid white lines, profiles scheduled for investigation, such as those across the Iron Range fault and the western flank of the Purcell Anticlinorium north of the Mount Skelly pluton, are indicated by dashed white lines.

Total Magnetic Field (Low and High Resolution Data)





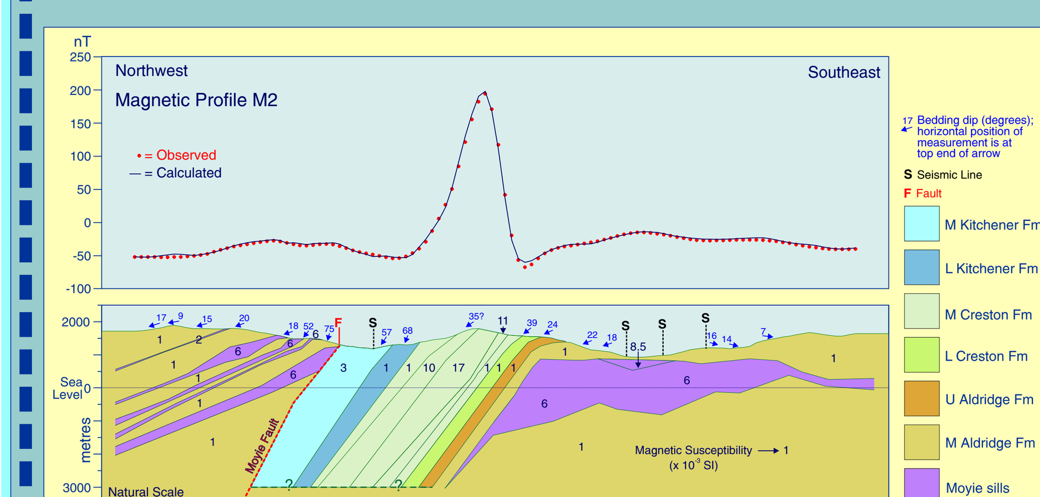
Magnetic Profile M1 Model

The relatively high amplitude (~170 nT) central magnetic high over the Creston Formation on the northwest flank of the Moyie anticline is flanked by broad low amplitude (30-40 nT) highs to either side, attributed to gently dipping Moyie sills. Reproduction of the central peak requires several contiguous, relatively high magnetic susceptibility (7-19 x 10^{-3} SI), steeply dipping layers within the Creston Formation. Steep dips of about 50° are observed at surface at the position of the high, but modelled dips are somewhat steeper at about 66°. Surface units of Moyie sills have been modelled constrained by surface dips recorded in their vicinity. In the southeast modelled sills present a broad anticlinal structure. At depth, below modelled sills with a link to the surface, a very thick unit of Moyie sill has been modelled. Although a quantitatively derived unit it is schematic in the sense that several thinner sills may be a more likely source. Modelling at these depths produces solutions that are more non-unique than solutions for units that have a surface expression.

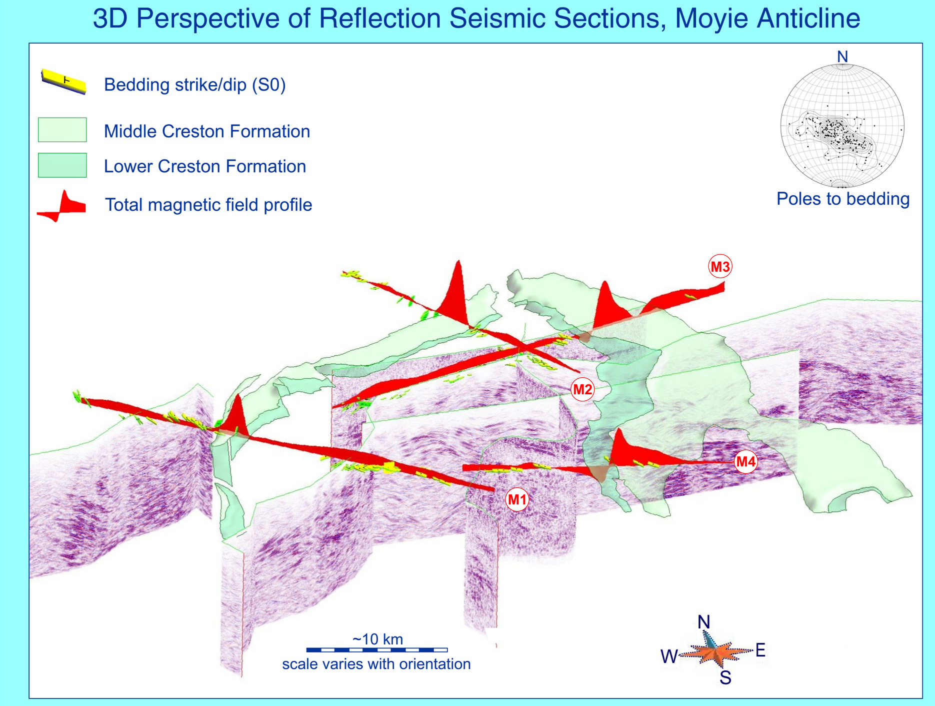
A modelled feature of concern is the abrupt, steep fault-like contact between the southeastern boundary of the thin upper Aldridge Formation and the deep modelled Moyie sill (see figure above). The geological map shows no fault in this position, but portrays a conformable northwestward-dipping sequence of geological units. Possibly, the Moyie sill is represented by a series of monoclinally folded thinner sills that steepen dramatically (shown schematically by dashed lines) towards the Lower Creston Formation, becoming more or less conformable with the formation. On the northwest side of the Middle Creston Formation modelling indicates that the Moyie fault dips overall about 50° northwest and truncates a series of southeast-dipping Moyie sills. Again, the deepest modelled, very thick sill could be represented by a series of thinner sills.

Magnetic Profile M2 Model

Characteristics of the magnetic signature are similar to those of Profile M1. The model is also similar with a sharp increase in steepness of dips northwest of the Middle-Upper Aldridge contact. Susceptibilities attain 10 and 17 x 10^{-3} SI within the Middle Creston Formation, where units dip about 52° northwestward. The Moyie fault is modelled to dip roughly 60° northwestward, truncating a modelled northwestward-dipping Moyie sill.



3D Perspective of Reflection Seismic Sections, Moyie Anticline



Magnetic Models

Magnetic models displayed here are preliminary and evaluation is still in progress. The magnetic field is dominated by the linear high following the Creston Formation. Less noticeable, but nevertheless distinct, broad smooth anomalies coincide with concentrations of Moyie sills mapped within the core area of the anticline and near the northwest end of profile M1. Both the Creston Formation high and Moyie anomalies are a focus of modelling. Available constraints for modelling are locations of geological contacts and faults, bedding dips and strikes, and measurements of magnetic susceptibility.

Lowe et al. (2000) presented susceptibility estimates for various geological units in the Purcell Anticlinorium. A mean value of 6.67 x 10^{-3} SI (range 0-160 x 10^{-3} SI) was provided for the Moyie sills, a mean value of 15.2 x 10^{-3} (0-125.7) for the Creston Formation, and mean values of 0.67 (0-5), 0.72 (0-40.2) and 0.42 (0-2.5) x 10^{-3} SI for the Lower, Middle and Upper Aldridge formations, respectively. Our own measurements of susceptibility on surface outcrops yield a mean value of just 0.64 x 10^{-3} SI (maximum = 1.9) for Moyie sills, a mean value of 0.75 x 10^{-3} SI (maximum = 19.7) for the Creston Formation, and a mean value of 0.29 x 10^{-3} SI (maximum = 2.0) for rocks of the Lower and Middle Aldridge formations. Our measurements indicate that the sedimentary Kitchener Formation is the least magnetic unit in the Moyie anticline with a mean susceptibility of 0.13 x 10^{-3} SI (maximum = 0.24). Differences in values obtained by Lowe et al. (2000) and ourselves may stem from regional differences. For example, Lowe et al. (2000) note that the magnetic response of Moyie sills is everywhere quite variable and often an anomaly is observed over only a portion of a sill outcrop. These measurements provide a guide for assigning reasonable values to modelled units.

The near-surface portions of the seismic sections generally lack distinctive features, and at this preliminary stage of investigation the seismic images have not played a significant role in constraining the magnetic models, which descend to depths varying between roughly 5 and 7 km below the surface. It is anticipated that seismic input will play a more important role in the next stage of modelling.

An important constraint in modelling the conspicuous, narrow magnetic high along the Creston Formation was utilization of the position of the zero value of the first vertical derivative of the magnetic field to indicate the boundary positions of the magnetic unit producing the high. At high magnetic latitudes, if magnetization boundaries are steep, the zero value is coincident or close to a boundary.

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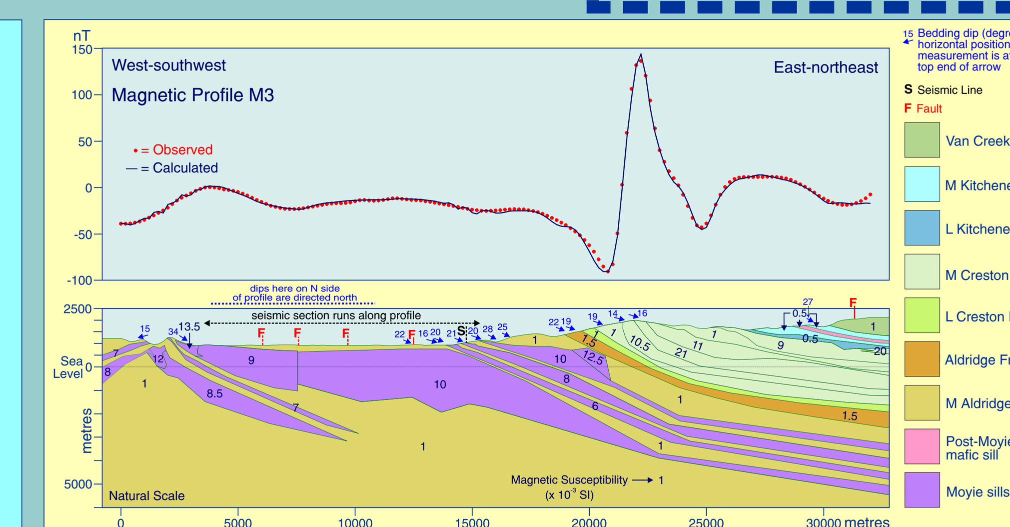
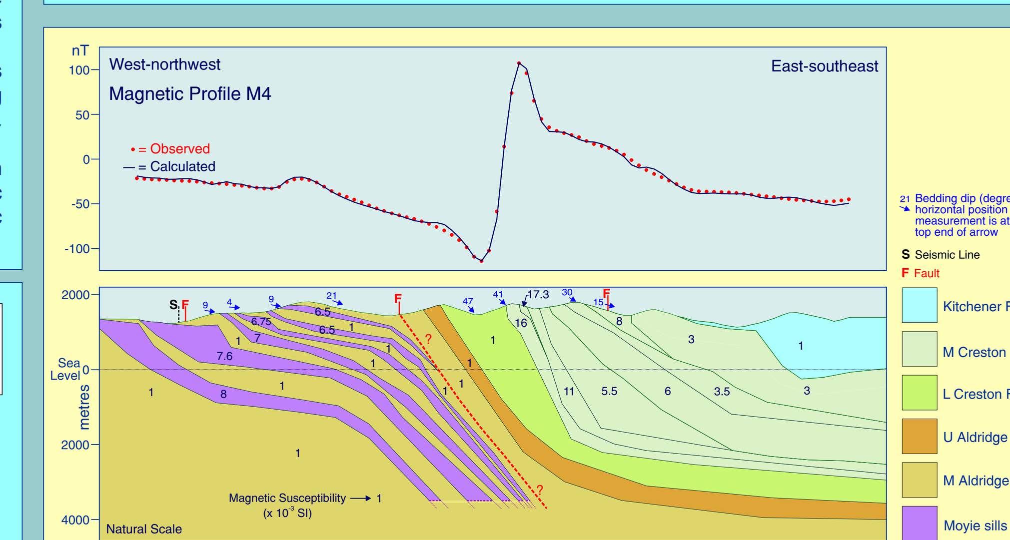


Magnetic Profile M3 Model

Profile M3 crosses the northeast flank of the Moyie anticline. A prominent (~200 nT amplitude) central magnetic high coinciding with the Middle Creston Formation is flanked to the east-northeast by a moderate amplitude (~70 nT) high over the Kitchener and Middle Creston formations. West-southwest of the central high a very broad, low amplitude (~40 nT) high falls mainly over the Middle Aldridge Formation. Matching the central magnetic high requires susceptibilities in the range 10.5 to 21 x 10^{-3} SI within the Middle Creston Formation. Most modelled layers conform in dip with shallow dips (14° to 28°) on the geological map, but local steepening is required to produce the steep flanks of the central high. Overall, modelled Moyie sills and layers of Upper Aldridge Formation through Van Creek Formation present a conformable east-northeast dipping package. A small antiform involving Moyie sills is modelled at the west-southwest end of the model. The uppermost 2 km of part of a seismic section along Profile M3 is basically transparent; signatures below need to be enhanced to provide reliable modelling constraints. The magnetic high east-northeast of the central high is attributed mainly to a magnetic (9 x 10^{-3} SI) horizon at the top of the Middle Creston Formation.

Magnetic Profile M4 Model

The central magnetic high (~200 nT amplitude) of Profile M4 crossing the eastern flank of the Moyie anticline coincides with Middle Creston Formation sedimentary rocks. It differs from central highs of other profiles by a broad shoulder on one side (eastern) indicating wider distribution of higher magnetic susceptibilities within this particular part of the formation. On the western side of the profile, over Middle Aldridge Formation intruded by east- dipping Moyie sills, no distinctive anomaly is present. The model displays an east-dipping series of sedimentary formations and sills having general conformity. Dips of Moyie sills increase eastward towards the central magnetic high, and dips as steep as 64° are modelled in the Middle Creston Formation. The steepest dips mapped in the formation are 30°, though dips as high as 47° are observed in the Lower Creston Formation. Higher susceptibilities within the Middle Creston Formation range from 8 to 17.3 x 10^{-3} SI.



Conclusions

Magnetic modelling in the Purcell Anticlinorium constrained by surface structural observations provides insight into the geometry and structure of geological units up to ~6 km depth. Limbs of the Moyie anticline are modelled from strong magnetic highs coinciding mainly with sedimentary rocks of the Middle Creston Formation. Less intense highs associated with Moyie sills yield a picture of their structure and distribution.

Modelling along the St. Mary fault was inconclusive. The fault may or may not be coplanar with certain steep contacts between magnetic units. If not, it may truncate crust characterized by earlier steep structures. Future analysis of magnetic anomalies in the anticlinorium will refine existing models, model other anomalies and integrate seismic data.

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