ASEG-PESA-AIG 2016
25TH GEOPHYSICAL
CONFERENCE & EXHIBITION
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Toward 3D structural constraints from magnetic models: an example from the Montresor belt, Nunavut, Canada

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SUMMARY

New geophysical and geological results shed light on the tectonic history of the Montresor belt, located on the Rae craton of northern Canada – an Archean terrane that has been reworked by four Proterozoic orogenies. In this contribution we use forward modelling of high-resolution aeromagnetic data to explore the 3D geometry and structural history of the Montresor belt, part of the Rae cover sequence. Previously thought to be a simple syncline, our re-analysis of the aeromagnetic data has outlined a set of earlier structures that provide new insight on the deformation history of the belt. Five cross-sections model discrete magnetic-lithologic units truncated by a series of low-angle faults. Reconstruction of the magnetic map features and forward models reveals a pre-fold geometry analogous to foreland fold and thrust belts, produced by D1 deformation during the Trans-Hudson orogeny, bracketed by available geochronology between 1.94 and 1.864 Ga. The Montresor belt rocks have potential for a variety of mineral deposit types, including precious metals in hydrothermal settings, and are under study as part of the Geo-mapping for Energy and Minerals program in Canada.

Key words: magnetics, modelling, Montresor belt, Canada

INTRODUCTION

Located on the Rae craton of the Western Churchill province of Canada, the Montresor belt comprises Paleoproterozoic strata underlain by Archean basement that was reworked by Proterozoic orogenies at ca. 2.35, 2.0, 1.9 and 1.85 Ga (Figure 1). Initially considered to be a simple syncline (Frisch, 2000), the Montresor belt consists of a footwall complex made up of structurally interleaved (D1) Archean gneiss and quartzite-carbonate units of the lower Montresor group (<2190 Ma), and above a D2 décollement, low-grade sandstone and siltstone of the upper Montresor group (<1940 Ma; Percival et al., 2015), the focus of this study. Heavy-mineral beds in the upper Montresor give rise to magnetic marker units (Tschirhart et al., 2015) defining two doubly-plunging synclines (D3-D4 interference patterns) resembling elliptical bulls-eyes on aeromagnetic maps (Figure 2). The regional tectonothermal event at ca. 1.85 Ga is responsible for metamorphism, subsequent D2 extensional detachment, and D3-D4 folds producing the map patterns. Based on existing information it is unclear whether the lower and upper parts of the Montresor group underwent a common D1 event (e.g. ca. 1.9 Ga), or if the lower Montresor group was deformed in a pre-1.94 Ga event prior to deposition of the upper Montresor group, which experienced only D2-D4. Evidence for early structures in the upper Montresor has not been documented owing to the thick-bedded nature of units and lack of exposure resulting from widespread glacial overburden. However, in conjunction with outcrop dip observations, the prominent magnetic markers provide an untapped source of information, perhaps capable of resolving the question of whether the sedimentary strata were deformed prior to D3-D4 folding.

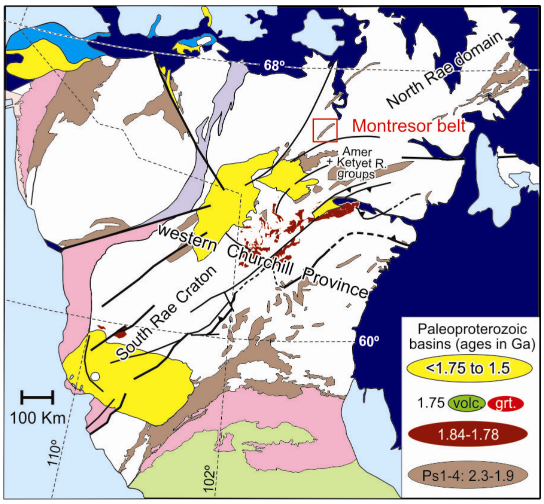

Figure 1: Geological context of the Montresor belt in Canada after Tschirhart et al. (2015).

This study defines the 3D structure of the north-eastern Montresor belt using geologically-constrained forward magnetic models to elucidate the geometry of key magnetic marker units at depth and provide new information on the deformation history of the belt.

METHOD AND RESULTS

The aeromagnetic dataset used in this study were acquired by the Geological Survey of Canada (GSC) at a 400 m line spacing oriented 315°, perpendicular to the geological strike of the region, and flown 150 m above the topographic surface (Miles and Oneschuk, 2013). The data were gridded to 100 m using minimum curvature, reduced to the pole (Figure 2), and the first vertical derivative grid was calculated. Four individual profiles (L01-L04) were extracted from the survey database and a longitudinal intersecting profile (T01) was extracted from the aeromagnetic grid (Figure 2). The regional component of the magnetic signal was removed from the profiles using a non-linear filter (Keating and Pinet, 2011). Subsequent interpretation and 2D forward modelling were conducted using the GM-SYS software package.

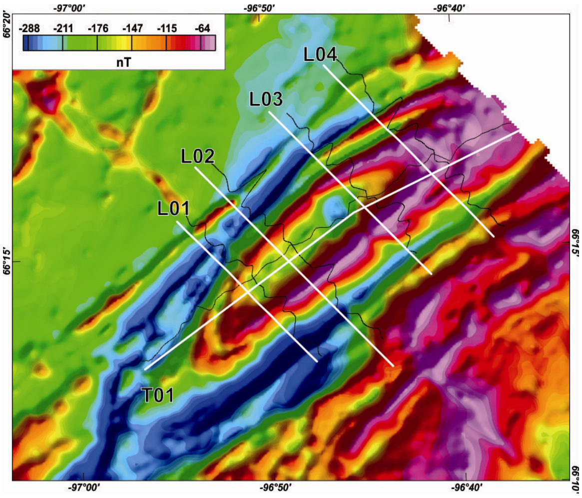

Figure 2: Reduced-to-pole aeromagnetic map showing the location of forward models plotted as white lines (L01-L04, T01) and first vertical derivative plotted as black lines.

Magnetic susceptibility constraints imposed on the models were derived from samples collected by GSC personnel during the 1982 and 2014 field seasons (Tschirhart et al., 2015) and measured using a Terraplus KT-10 magnetic susceptibility meter. Where available, strike and dip information from Frisch (2000) and Percival et al. (2015) was incorporated into the models.

Forward Models

Four cross sections and one longitudinal section modelling the sandstone and siltstone units of the upper Montresor belt were constructed by forward modelling the aeromagnetic data. The first vertical derivative grid distinguishes discrete magnetic units from the magnetic profile, resolving individual bodies from broad anomalies caused by the interference of adjacent anomalies (Figure 2 – first vertical derivative profiles). To ensure consistency, magnetic susceptibility values were held within ±0.002 SI for along-strike units and the intersecting longitudinal profile (T01).

Along the south-eastern flank of the syncline, three distinct anomalies on the first vertical derivative profiles are present in each of the four southeast trending cross-sections and were assigned susceptibility values of 0.013 SI (orange), 0.018 SI (red) and 0.022-0.023 SI (pink). A moderately susceptible unit (0.11 SI; yellow) corresponds to an anomaly along the northern limb of the syncline and tapers at depth where it intersects with the highest susceptibility (pink) unit. The contact could be stratigraphic or structural in origin. Toward the north-eastern and south-western ends of the syncline the magnetic strata are increasingly discontinuous and truncated at low angles by other units, as illustrated on T01.

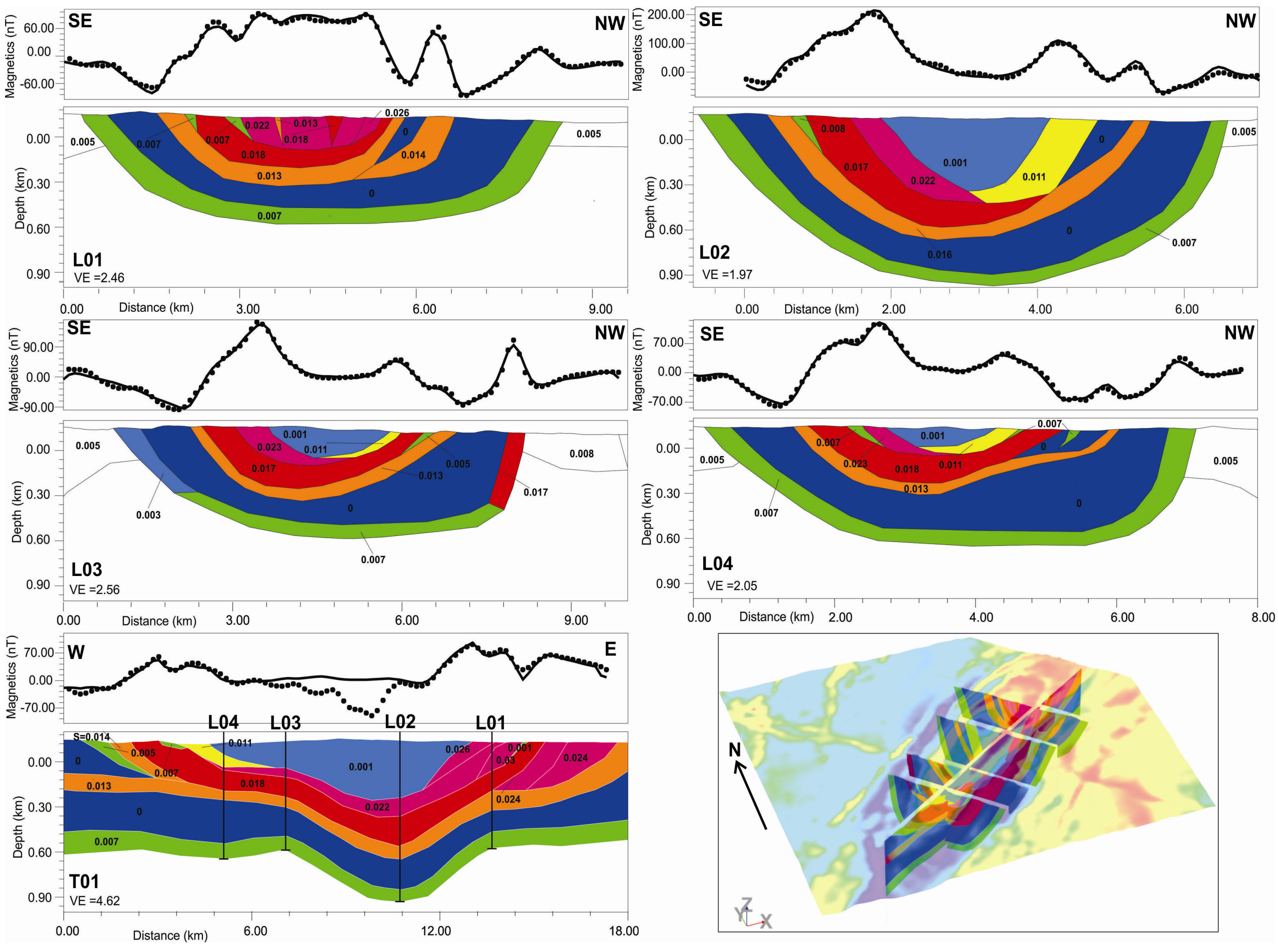

Figure 3: Magnetic forward models of the upper units of the Montresor belt. Top panel: black dots represent observed magnetic field, black solid line calculated magnetic field. The four northwest-southeast trending cross-sections achieve an RMS error of 15 nT (5%) and the longitudinal cross-section has an RMS error of 25 nT. Bottom panel: geological cross section, magnetic susceptibilities in SI as labelled. Lower right figure displays cross-sections in 3D draped under the reduced-to-pole aeromagnetic map.

At ~10 km on the longitudinal cross-section (Figure 3 – T01) a -100 nT magnetic low cannot be explained by the modelling results without the introduction of a negatively magnetized body (not shown), resulting in a poor match between the observed and computed magnetic field between L02 and L03. A similar non-magnetic lineament located in the southwestern Montresor has been correlated to a demagnetized zone of hydrothermal alteration (Tschirhart et al., 2015). Given that exposure is poor and the interior of the study area has not been mapped, it is possible that similar demagnetized zones may be present in the study area.

Geological Interpretation

The magnetically-defined units have only subtle geological differences. Rock units are thin-to thick-bedded, and cross-bedded sandstones and siltstones with inconspicuous heavy mineral concentrations. For example, one of the more susceptible sandstones (0.041 SI), containing <2 % modal magnetite in thin beds associated with detrital tourmaline and zircon, is visually indistinguishable from adjacent background units. Based on their consistent magnetic characteristics over strike lengths of at least 10 km, we infer that the magnetic units are stratigraphic in origin and laterally continuous, reflecting subtle variation in detrital magnetite content. Therefore, deviations from a concentric pattern around the syncline are interpreted as structural complexities present prior to folding.

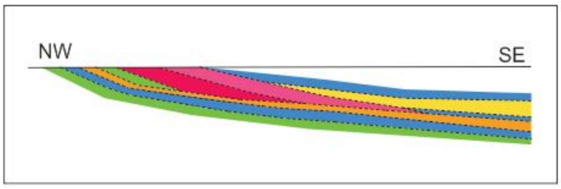

Figure 4: Schematic northwest-southeast cross section showing geometry of magnetic units prior to folding.

On both the map and section views, the main structural feature is low-angle truncations of magnetic units (Figures 2, 3). Upon restoration to pre-fold geometry (Figure 4), the schematic cross-section resembles the pattern of foreland fold and thrust belts, although without a defined stratigraphic sequence, low-angle extensional faults cannot be ruled out. However, additional observations favour the thrust-belt interpretation: 1) dips are irregular, but generally steeper on the northern limb of the syncline, suggesting northwest-verging ramps; and 2) D1 structural imbrication of lower Montresor units and Archean basement gneiss are interpreted as northwest-vergent thrusts (Percival et al., 2015), consistent with regional relationships (e.g., Pehrsson et al., 2013).

CONCLUSIONS

Forward modelling of magnetic data provides structural constraints on the geometry of the Montresor belt revealing a more complex geological history than previously recognized. Discrete magnetic units are interpreted as sedimentary strata with variable detrital magnetite content. Truncations of the magnetic units in both map view and forward modelled sections indicate significant structural modification prior to folding. The reconstructed geometry resembles that of foreland fold and thrust belts, suggesting that the upper Montresor strata underwent thin-skinned D1 deformation as the lower Montresor units were imbricated with basement at a deeper structural level. As the upper Montresor units are <1.94 Ga, this study therefore increases precision on the age of Trans-Hudson orogenic thickening in the region, between 1.94 Ga, the maximum age of Montresor deposition, and 1.864 Ga, the oldest recorded age for metamorphism in the belt. This contribution highlights the utility of potential field datasets for reconstructing structures in areas of poor exposure with limited ground control.

ACKNOWLEDGMENTS

This contribution was funded as part of the Geo-mapping for Energy and Minerals – 2: Geology and Mineral Potential of the Chantrey-Thelon Area, Montresor Project.

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