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Geophysical evidence of upper-crustal Archean basement folding and/or faulting below the East Range of the Sudbury impact crater

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Summary

Recent geological and paleo-magnetic studies from the surface geology suggest a folding of upper crustal Archean basement rocks in the East Range of Sudbury impact crater, but no geophysical evidence from the subsurface has been provided. In the current study, the 3-D geometry of upper-crustal Archean basement rocks below the East Range of the Sudbury impact structure was predicted by 3-D potential field inversions performed using the VPmg algorithm combined with Mira-Geoscience GOCAD mining suite. We provide qualitative subsurface geophysical evidence of upper-crustal Archean basement folding and/or faulting that might have deformed and altered the basement rocks below the East Range of the Sudbury impact crater. We suggest that the above structures might have resulted in reductions of the gravity and magnetic field intensities observed on potential-field maps of the area.

Introduction

The current study is undertaken as part of an ongoing Metal Earth NSERC-CRD project in collaboration with the companies Vale and Glencore. During the summers of 2017 and 2018, geophysical data (seismic, magnetotelluric, gravity) were collected in the East Range of the Sudbury impact crater (Fig.1) to study the shallow to deep crustal-scale controls on metal endowment. The preliminary results from 3-D potential-field smooth-model inversions are presented here.

Geological settings of study area

The Sudbury impact structure lies near the juncture of the Superior, Grenville and Southern Provinces of the Canadian shield (Fig.1). The origin of this structure has been attributed to a large comet impact that occurred at around ~1.85 Ga (Krogh et al., 1984; Petrus et al., 2015). The Sudbury structure comprises the 58 by 28 km elliptical SIC (Sudbury Igneous Complex) which consists of a lower magmatic breccia unit, called the sub-layer, overlain by norite, quartz gabbro, and granophyre (Pye et al., 1984). For the purpose of geological discussions in the area, the common practice is that the SIC and immediate adjacent basement rocks are spatially subdivided into North, South and East ranges. The current elliptical shape of the Sudbury structure is a resultant of multi-phase deformation during NW-SE crustal shortening of an original circular shaped structure (Lightfoot, 2016). The SRSZ (South Range Shear Zone) is the most prominent structure in the Sudbury area, that is likely associated with Penokean deformation (Shanks and Schwerdtner, 1991). This zone is a south-dipping ductile thrust that displaced the South Range and the underlying Huronian rocks in the NW direction. The SRSZ transects the Sudbury structure (Cowan et al., 1999) and curves from the dominant NE direction to a more easterly direction at the southwestern terminus, where strain is concentrated at the interface between Archean basement and Huronian cover rocks. The North and East ranges of the SIC unconformably overlies Archean age granitic, gneissic, and granulitic basement rocks (Krogh et al., 1984), whereas the South Range overlies metasedimentary and metavolcanic rocks of the Paleo-Proterozoic age Huronian Supergroup. The East Range have undergone significant post-impact deformation which include the ca. 37 Ma Wanapitei impact structure (Dence and Popelar, 1972) (Fig.1). Using paleomagnetic data and spatial analysis of mafic dykes, Clark et al. (2012) proposed folding of the upper-crustal basement in the East Range of the Sudbury basin. Most recently, Clark and Riller (2018) explored the kinematics of folding and faulting in the East Range of the SIC using 3-D kinematic restoration methods.

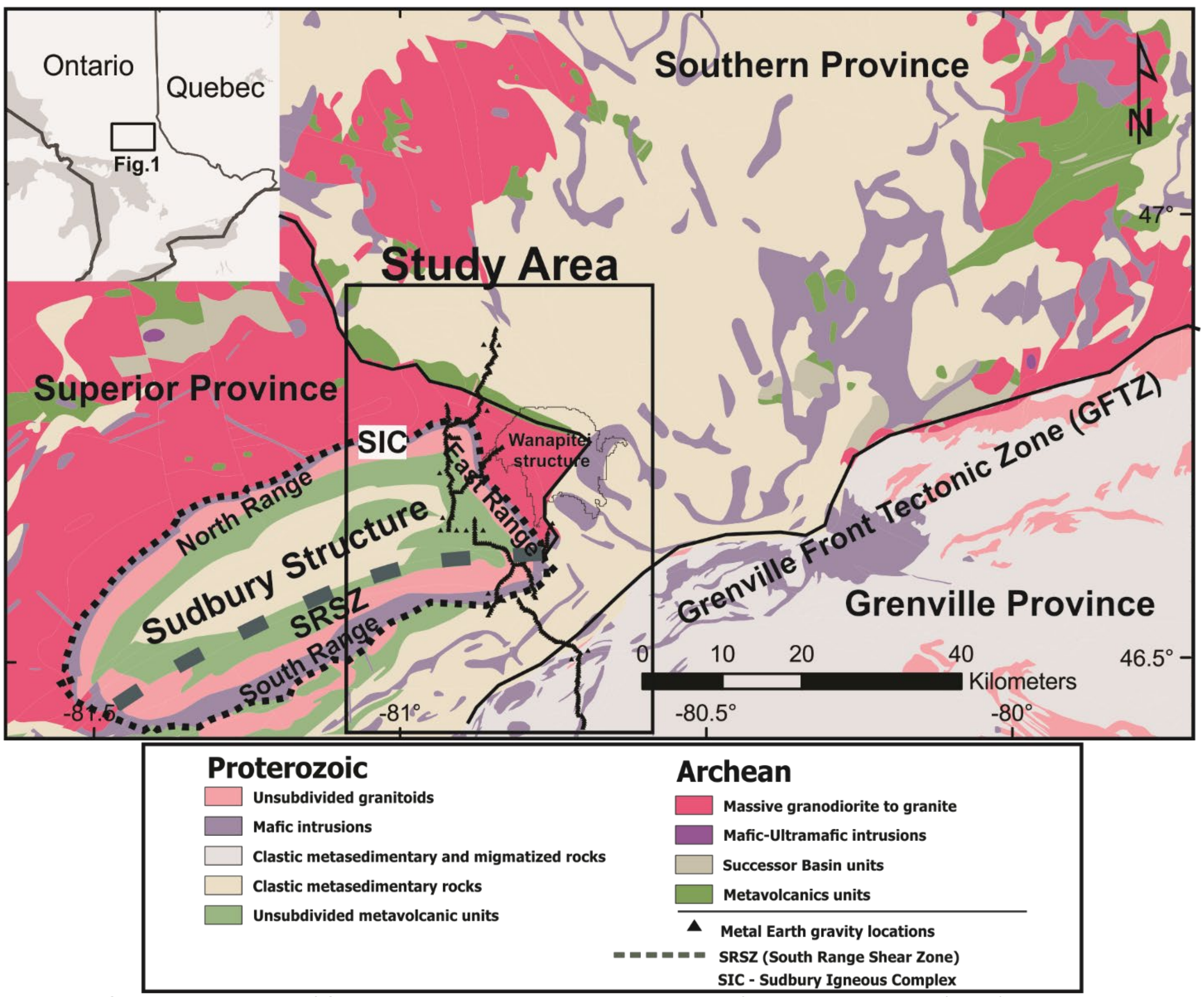

Figure.1. Geological settings of Sudbury basin. Map produced using data from Montsion et al. (2018).

3-D Potential-field modelling and inversion

The Mira Geoscience GOCAD mining suite combined with VPmg software (Fullagar et al., 2008) were used to perform smooth unconstrained density and susceptibility inversions. VPmg allows the user to have significant control on the inversion process such as using an accurate topographic representation during inversion (Fullagar, 2013).

Potential Field Data:

Ground gravity data were collected along the Metal Earth Sudbury transect with an average spacing of 300 m (Maleki et al., 2019). The data were combined with publicly available Geological Survey of Canada data downloaded using the Geosoft public DAP server (http://dap.geosoft.com). The combined data were subjected to standard gravity processing steps (latitude and elevation corrections). A Bouguer anomaly was calculated assuming background density of 2.67 g/cm^3. Terrain corrections were then applied to account for any effects of topography and a complete Bouguer anomaly grid (Fig. 2a) was created to be used for inversion. The measurement error in the gravity data are about 1 mgal.

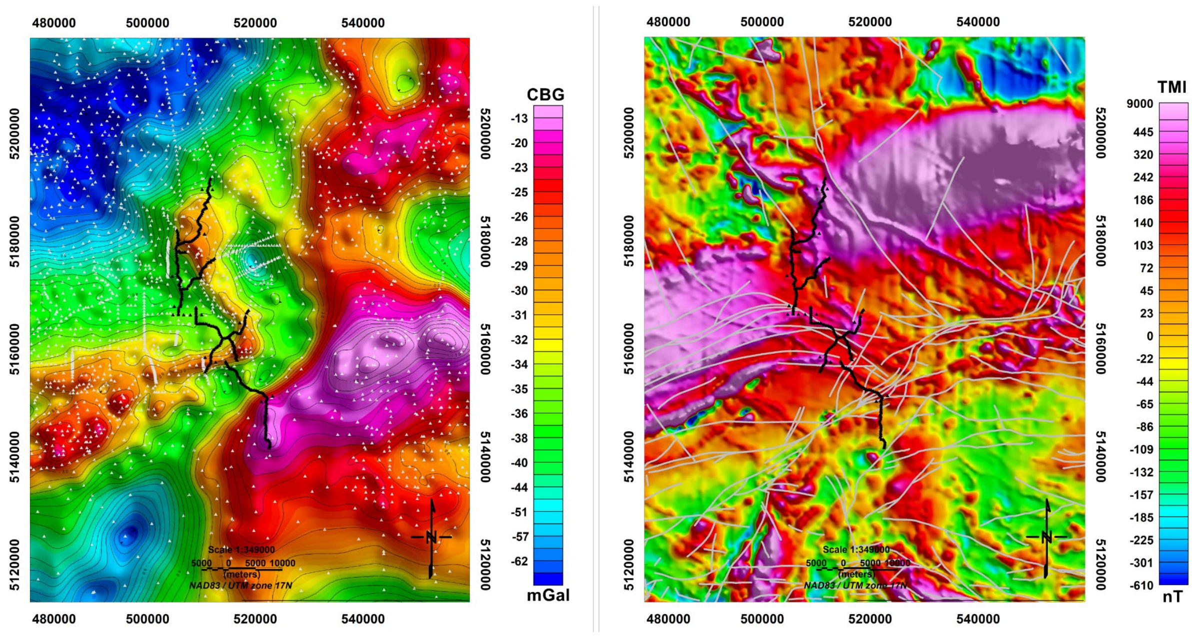

Figure.2. a) Gravity grid with Metal Earth (Black triangles) and GSC (Grey triangles) data locations overlaid and b) Aeromagnetic grid with Metal Earth transect (Black triangles) and regional faults (Grey lines) overlaid.

Aeromagnetic data used in this study were obtained from the Geological Survey of Canada (GSC) regional compilations that were downloaded using the same DAP server. The GSC grid has a 200 m cell size (Fig. 2b) and is a compilation of many surveys acquired since 1947 that have been levelled to a common datum (Miles, 2016). The aeromagnetic and gravity grids are sub-sampled to 450m grid cell size to reduce the computation time during inversion. This is justified as our focus in this study is the deeper structures.

Inversion:

The starting density and susceptbility models were constructed within a volume with dimensions 81x100x15 km covering the study area. The model was discretized into cells with cell size

450x450x100 m and its thickness increases by a factor of 1.2 for each deeper layer. The inversion modelling started with assigning an initial magnetic susceptibility value of 0 SI and a residual density value of 0 g/cm^3 for all the cells in the subsurface model and allowed VPmg to numerically change the property of each cell to fit the observed data, while at the same time ensuring smooth changes in the values. The lower and upper property bounds are fixed between values 0 and 0.5 g/cm^3 for gravity inversion and between 0 and 1 SI for magnetic inversion. The final unconstrained susceptibility inversion of magnetic data, after 50 iterations, returned an RMS misfit of 7 nT from an initial RMS misfit of 433 nT. The density inversion after 10 iterations, returned an RMS misfit of 1 mGal from an initial RMS misfit of 12 mGal. The final density and susceptibility models obtained after inversion was shown in Fig.3.

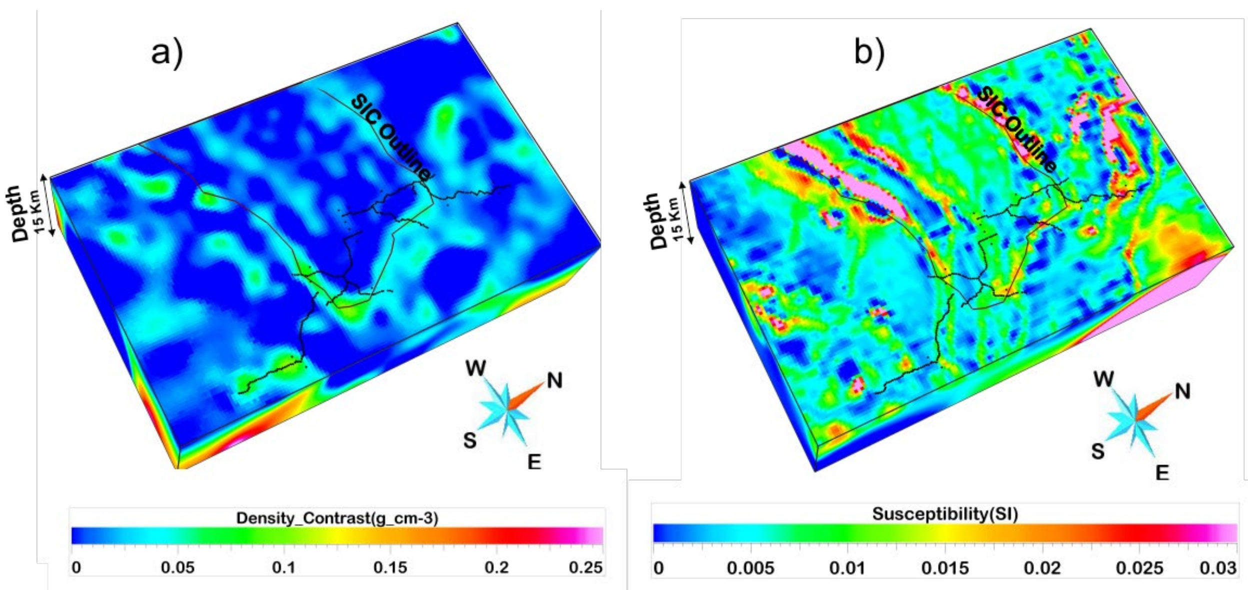

Figure.3. 3D perspective view of a) final density and b) susceptibility models derived from smooth gravity and magnetic inversions. Values on the top, south and western edges of the volume are shown in this presentation. SIC represents Sudbury Igneous Complex.

Results

Isosurfaces enclosing higher values were extracted from the final inverted density and susceptibility models using cut-off values of >0.15 g/cm^3 and >0.035 SI as shown in Fig. 4. Faults F1, F2 and F3 are interpreted to be deep-seated basement shear faults. Faults F2 and F3 might be associated with the South Range Shear Zone (SRSZ). D1 and D2 are high density bodies that lie exactly below the transect and might correspond to Archean basement mafic/ultramafic rocks. These anomalies appear to be folded along a trend starting in the NE, shifting to NS and are separated by fault F2 (Fig. 4). The D1 high density anomaly appears to be an anticline feature, having a peak that occurs at a depth of ~3 km and plunges to the NE and reaches to depths greater than 10 km. The D2 anomaly is shallowest at a depth of ~8 km and bounded by faults F2 and F3 to the north and south, respectively. The D3 high density anomaly to the SE might correspond to mafic rocks or ultramafic rocks of the Grenville Front Tectonic Zone (GFTZ). The

D4 anomaly has a limb that trends from the center of the volume towards the SW and continuous below Paleo-Proterozoic Huronian sediments. There is a second limb that trends from the SW corner towards the north below the central Sudbury impact crater. This D4 anomaly might correspond to mafic/ultramafic rocks of Archean age. The blue features, S1 and S2, represent high susceptibility anomalies potentially from deeper magnetic sources that are separated by the NS trending fault F1 (Fig. 4). The S1 anomaly peak occurs at shallower depths, i.e. ~1 km near the NE corner of the model and dips gradually downward to the west where it abruptly ends at F1. The S2 anomaly peak occurs at ~4 km depth at the west end of the model and then gradually dips to the center of the model where it ends. The D2 body could once have joined D1 and D4, but may have later been displaced east by F2 and F3, perhaps associated with the SRSZ.

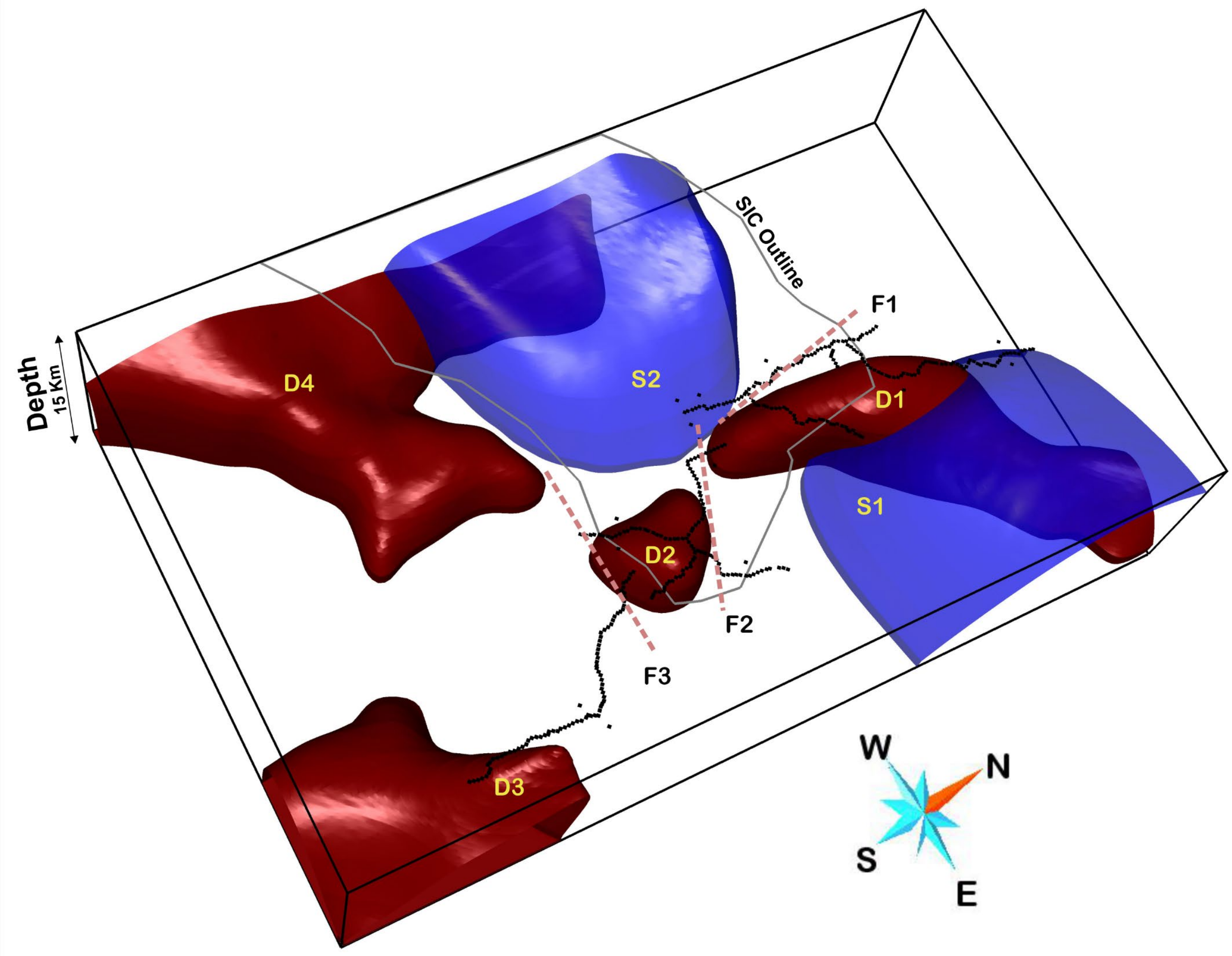

Figure.4. 3D perspective view of isosurfaces extracted from final density and susceptibility models. D1, D2, D3, D4 are high density anomalies and S1, S2 are high susceptibility anomalies. The S1 and S2 anomalies have been made partially transparent to view underlying higher density anomalies D1 and D4. Dashed lines are interpreted faults. Black dots represent Metal Earth gravity transect locations.

Conclusions

We provide qualitative subsurface geophysical evidence of folding and/or faulting of upper-crustal Archean basement rocks and suggest that the associated deformation might have altered the rocks resulting in reductions of the magnetic and gravity fields observed on potential-field maps in the East Range of the Sudbury impact crater. As 3D unconstrained potential-field inversions suffers the problem of non-uniqueness, the above results should be corroborated with other geophysical constraints such as data from the seismic method.

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