SEISMIC AND MAGNETIC SURVEY OF THE CHARITY SHOAL SUSPECTED IMPACT STRUCTURE, EASTERN LAKE ONTARIO, CANADA

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The Charity Shoal structure (CSS) is a 1.2 km diameter, bedrock-rimmed circular depression in the lakebed of northeastern Lake Ontario (Fig. 1). The CSS has been interpreted as a possible Ordovician-age simple impact crater based on multi-beam imaging of the lakebed (Holcombe et al. 2013) but the subsurface structure was not resolved. Other possible origins include a karst sinkhole, glacially erosion (e.g. kettle hole), basement structural depression or Jurassic volcanic intrusive (Suttak, 2013). Detailed magnetic and high-resolution chirp and 1.5 kHz boomer seismic (>400-line km) surveys were conducted across a 9-km^2 area to investigate the subsurface structure.

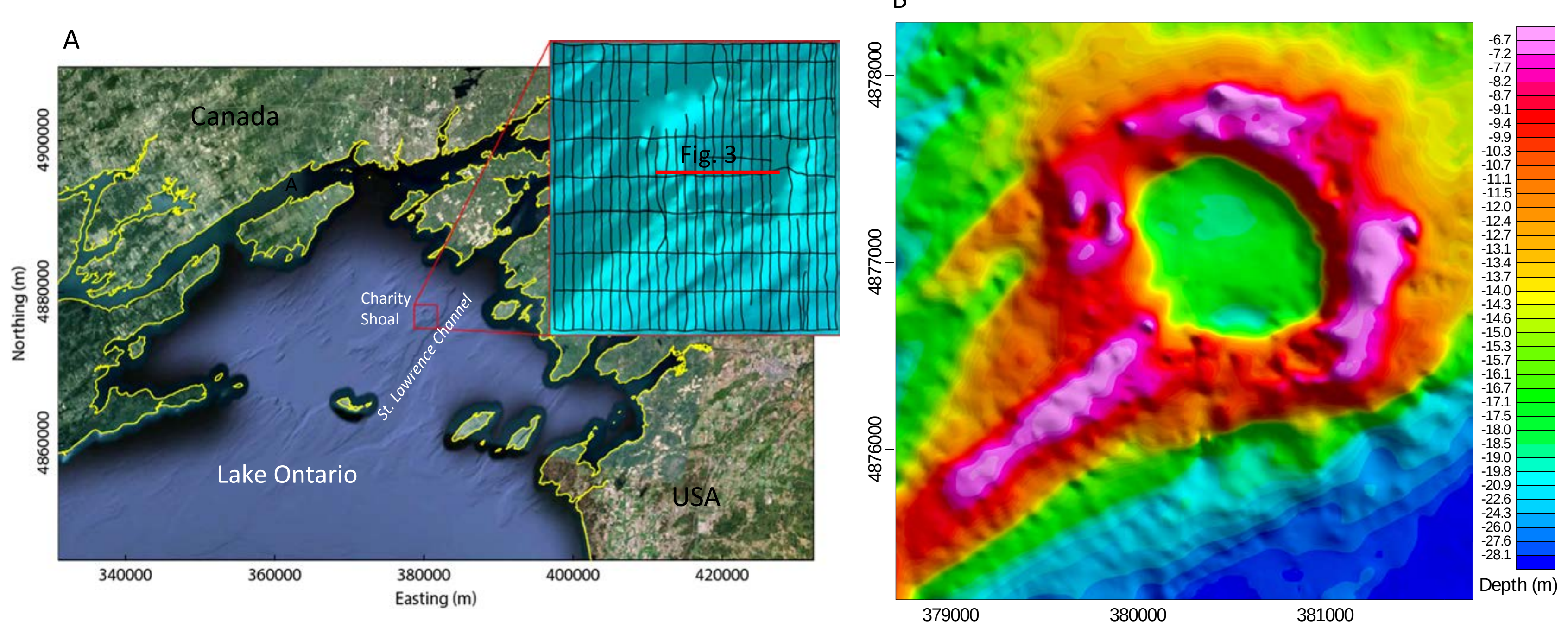

Figure 1 – A. Location of study area and survey lines. Magnetic and seismic data acquired over a 9-km^2 area at 200 m line spacing. Location of boomer seismic line (Fig. 3) shown in red. B. Bathymetry map showing raised bedrock rim and 20 m deep central crater-like basin.

Total magnetic intensity (TMI) data (Fig. 2) reveal a large (>1400 nT) magnetic anomaly centered over the crater basin and a ring-like magnetic high (40-50 nT) corresponding with the raised bedrock rim (Fig. 3). Depth to basement below the structure was estimated at ~600 m using extended Euler deconvolution (Fig. 3F).

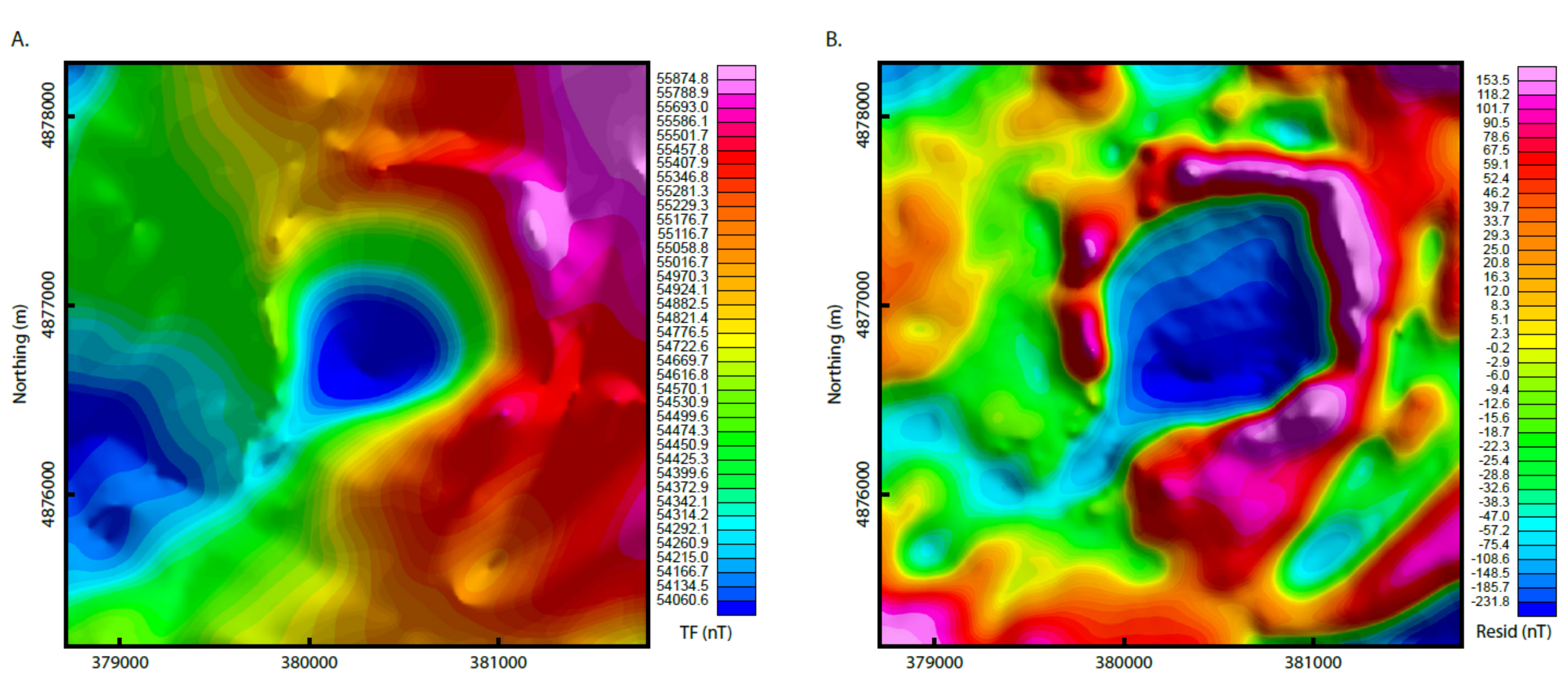

Figure 2 - A. Total magnetic intensity (TMI) B. Residual magnetic field map produced by subtraction of 200 m upward continued grid.

Boomer seismic profiles revealed >30 m of stratified glacial/post-glacial sediments overlying Middle Ordovician (Verulam Fm.) limestone bedrock. Three seismostratigraphic units (Fig. 3) were identified in the Quaternary infill sediments and the Paleozoic bedrock surface mapped in seismic data. Apparent offsets in the bedrock reflector indicate the presence of high-angle faulting of the structure rim (Figs. 3, 4).

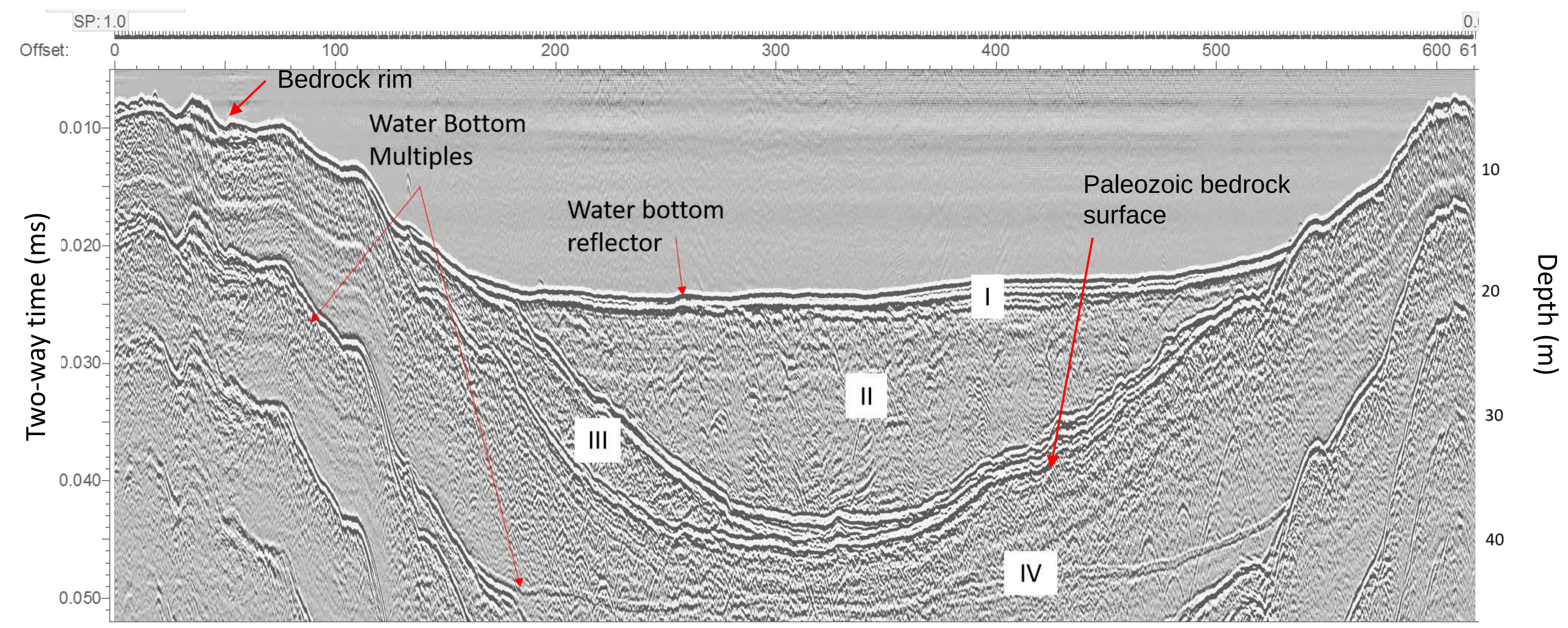

Figure 3 – W-E 1.5 kHz boomer seismic profile across central basin. **SU I** – Holocene laminated mud/silt: parallel seismofacies (1-4 m thick), **SU II** – Quaternary basin fill sediments: chaotic reflections, abundant diffractions indicating bouldery sand/gravel (10-15 m), **SU III** – subglacial till?: lensate unit with discontinuous reflectors, scattered diffractions (0-10 m), **SU IV** – Paleozoic bedrock: undulating, high-amplitude reflector, internal reflectors conform with top of bedrock surface.

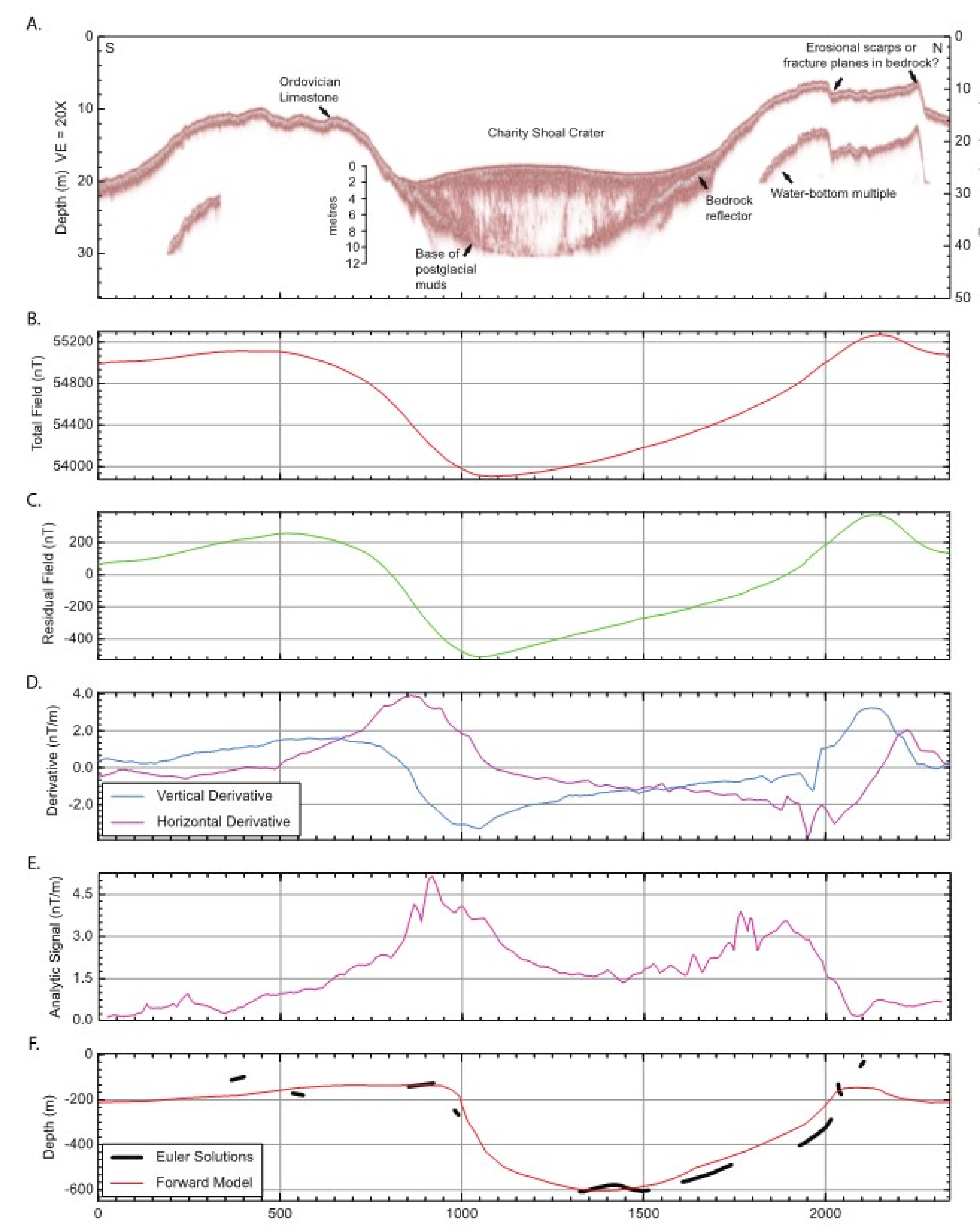

Figure 4 –A. S-N 12-24 kHz chirp seismic profile. Note apparent fault offset on north rim. B. Total magnetic intensity profile. C. Residual magnetic field. D. Vertical and horizontal derivatives. E. Analytic signal. F. 2-D Euler depth-to-basement solutions compared with modelled top of basement from 2-D forward model (Suttak, 2013).

2-D forward magnetic modelling considered a number of possible structures, (Fig. 5). These include: kettle/sink hole in Paleozoic bedrock, basement structural depression, Jurassic intrusive (diatreme) or impact crater. Models verify that the observed TMI anomaly requires a deep (>450 m) depression in Precambrian basement or a source body (i.e. diatreme) with a remanent magnetization opposing the main field (Fig. 5). Although a deep structural depression in the basement can be fitted to the data, it requires a higher susceptibility than the mean Precambrian basement rocks in the region. Jurassic age kimberlite dykes are known in the region (Barnet et al. 1984) but are generally less than a meter in width.

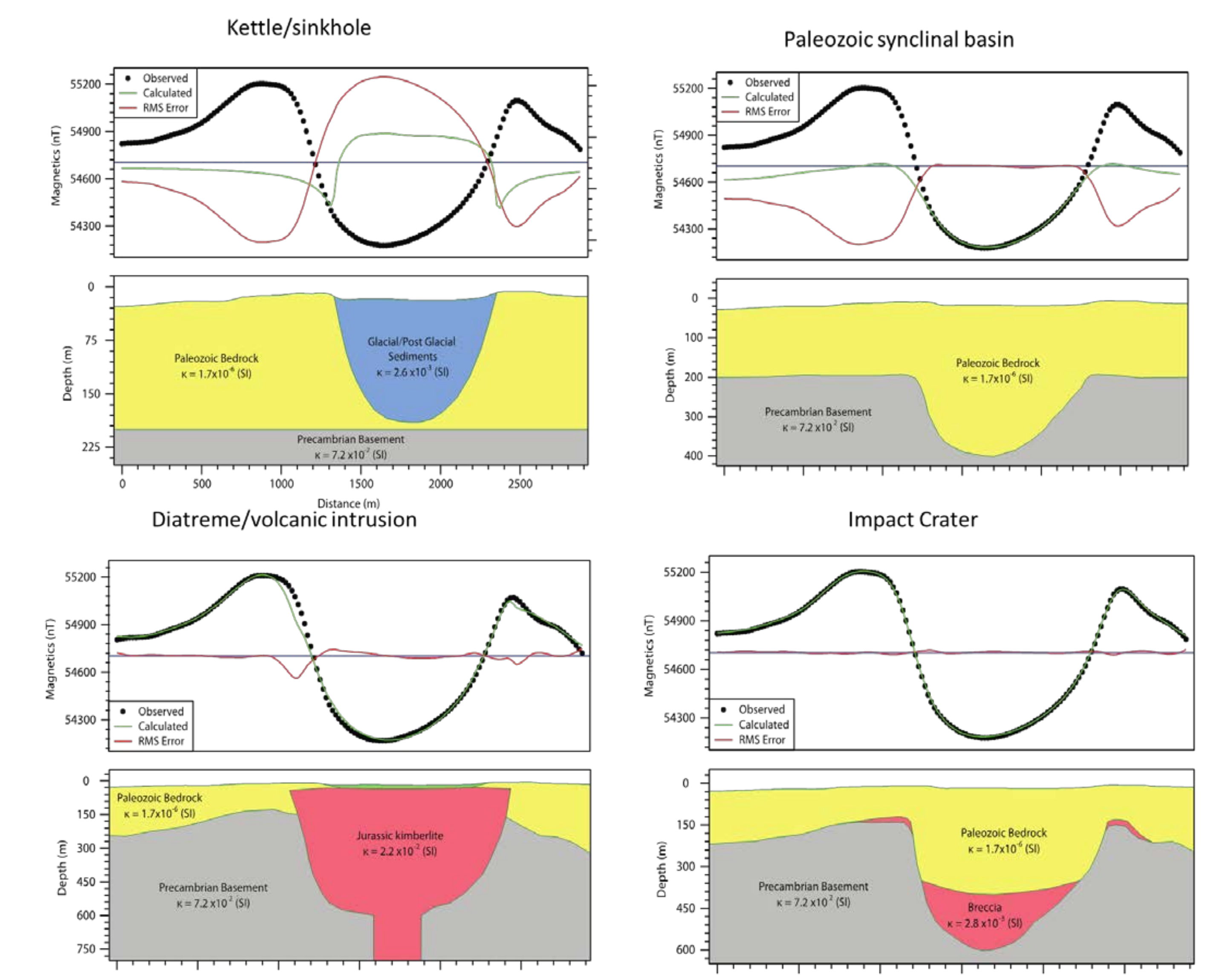

Figure 5 – 2-D forward magnetic models generated in GM-SYS.

Geophysical results are not consistent with a shallow glacial erosional or karst feature. Modeling and geophysical results indicate a deeply-seated structure in Precambrian basement and are most consistent with an origin as a volcanic intrusive body or a deeply buried (Late Proterozoic-Ordovician?) simple impact crater (Fig. 5) as proposed by Holcombe et al. (2013). Future work will include coring and sampling of crater sediments and bedrock for evidence of meteoritic material and shock metamorphic effects, and analysis of vector magnetic data collected over the crater.

The Holleford impact crater (approximately 40 km north of CSS) is estimated to be of Late Proterozoic or early Ordovician age which raises the possibility of a double impact (Ormö et al. 2014). If Charity is a simple impact crater of Ordovician age, it may provide further evidence for break up of a parent chrondite body ~470 Ma ago as proposed by Alwmark et al. (2015)

References

Alwmark, C., Ferrière, L., Holm-Alwmark, S., Ormö, J., Leroux, H., & Sturkell, E. (2015). Impact origin for the Hummeln structure (Sweden) and its link to the Ordovician disruption of the L chondrite parent body. Geology, 43(4): 279-282.

Barnet R. L., Arima M., Blackwell J.D., Winder C.G., Palmer H.C. and Hayatsu A. (1984). The Picton and Varty Lake ultramafic dikes: Jurassic magmatism in the St. Lawrence Platform near Belleville, Ontario. Canadian Journal of Earth Sciences 21(12): 1460-1472.

Holcombe T.L., Youngblut S., Slowey N., 2013. Geological structure of Charity Shoal crater, Lake Ontario, revealed by multibeam bathymetry. Geo-Marine Letters 33: 245-52.

Ormö, J., Sturkell, E., Nõlvak, J., Melero-Asensio, I., Frisk, Å. and Wikström, T. (2014), The geology of the Målingen structure: A probable doublet to the Lockne marine-target impact crater, central Sweden. Meteoritics and Planetary Science, 49: 313–327.

Pilkington, M. and R. A. F. Grieve (1992). The geophysical signature of terrestrial impact craters. Reviews of Geophysics 30(2): 161-181.

Suttak P. A. (2013). High Resolution Lake based magnetic mapping and modelling of basement structures, with example from Lake Küçükçekmece Turkey and Charity Shoal, Lake Ontario. School of Geography and Earth Science. Open Access Dissertation and Theses, McMaster. MSc.

Acknowledgements

Research supported by a Natural Sciences and Engineering Research Council of Canada (NSERC) Discovery Grant to Boyce. We thank Marine Magnetics corporation for access to field instrumentation and Geosoft Ltd. for academic software grants.