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Geological Significance of a New High Resolution Gravity Gradiometric and Magnetic Survey Over the Blatchford Lake Complex, Northwest Territories

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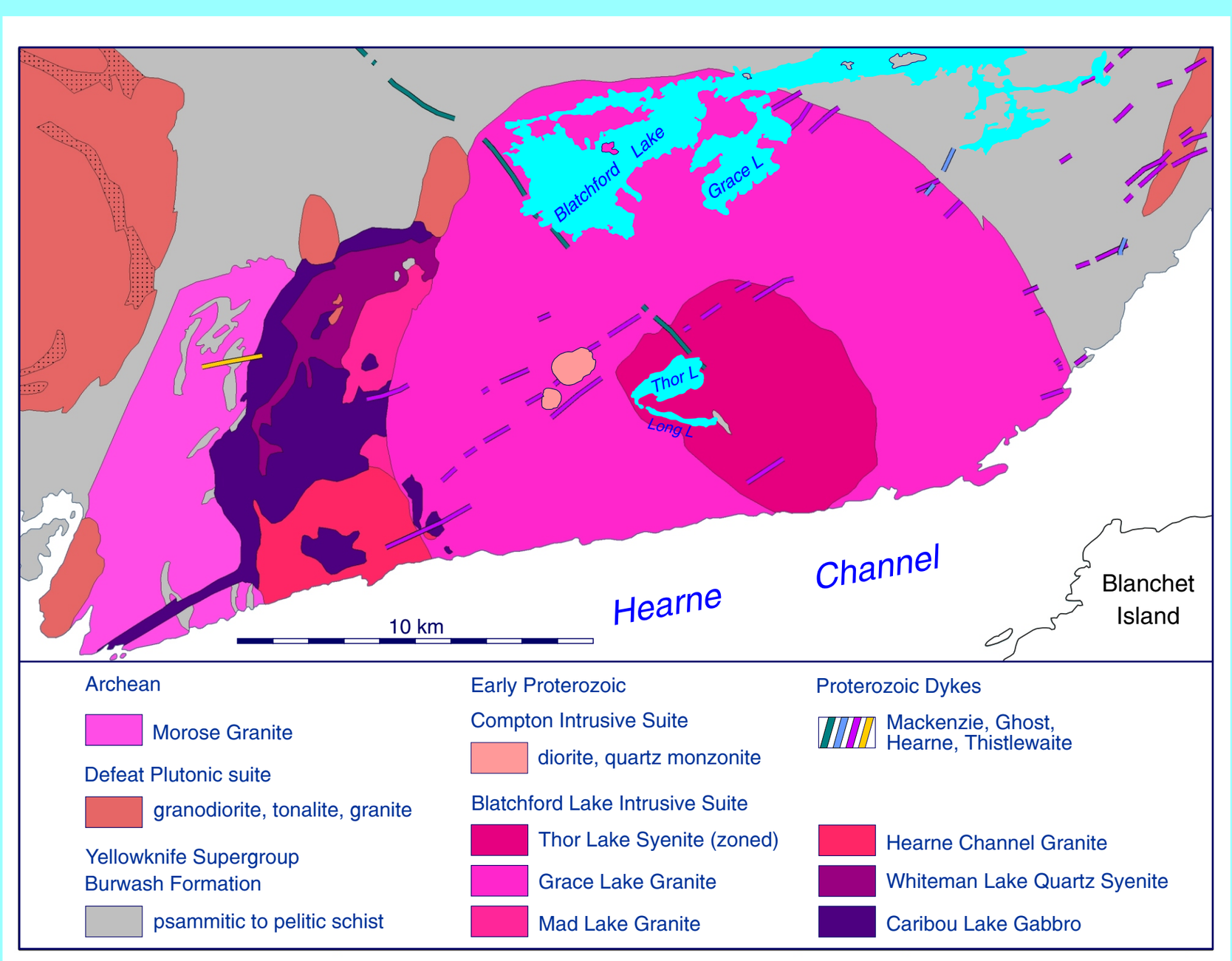
Geology of the Blatchford Lake Alkaline Complex



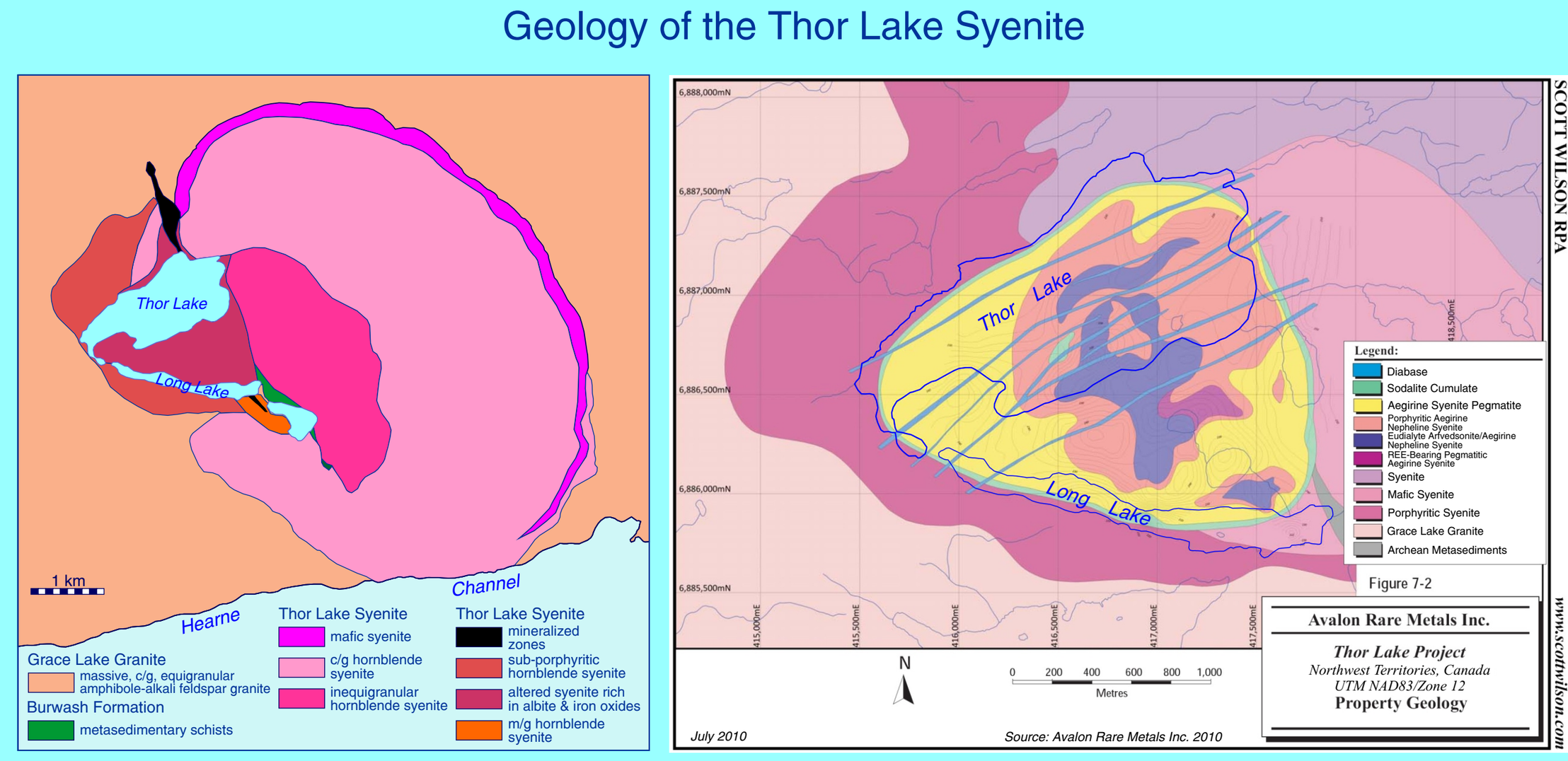
Introduction

A combined airborne gravity gradiometric and magnetic survey flown at 100 m mean terrain clearance and 250 m line-spacing has been completed over the Blatchford Lake alkaline igneous complex as part of Phase 4 of Natural Resources Canada's Targeted Geoscience Initiative. The new data provide significantly enhanced resolution of the gravity and magnetic fields compared to resolution offered by archived ground gravity measurements and aeromagnetic data. The Early Proterozoic complex is a target of active mineral exploration for rare metals, and the survey was flown with the objective of acquiring a 3D perspective on the geology of the complex to support exploration.

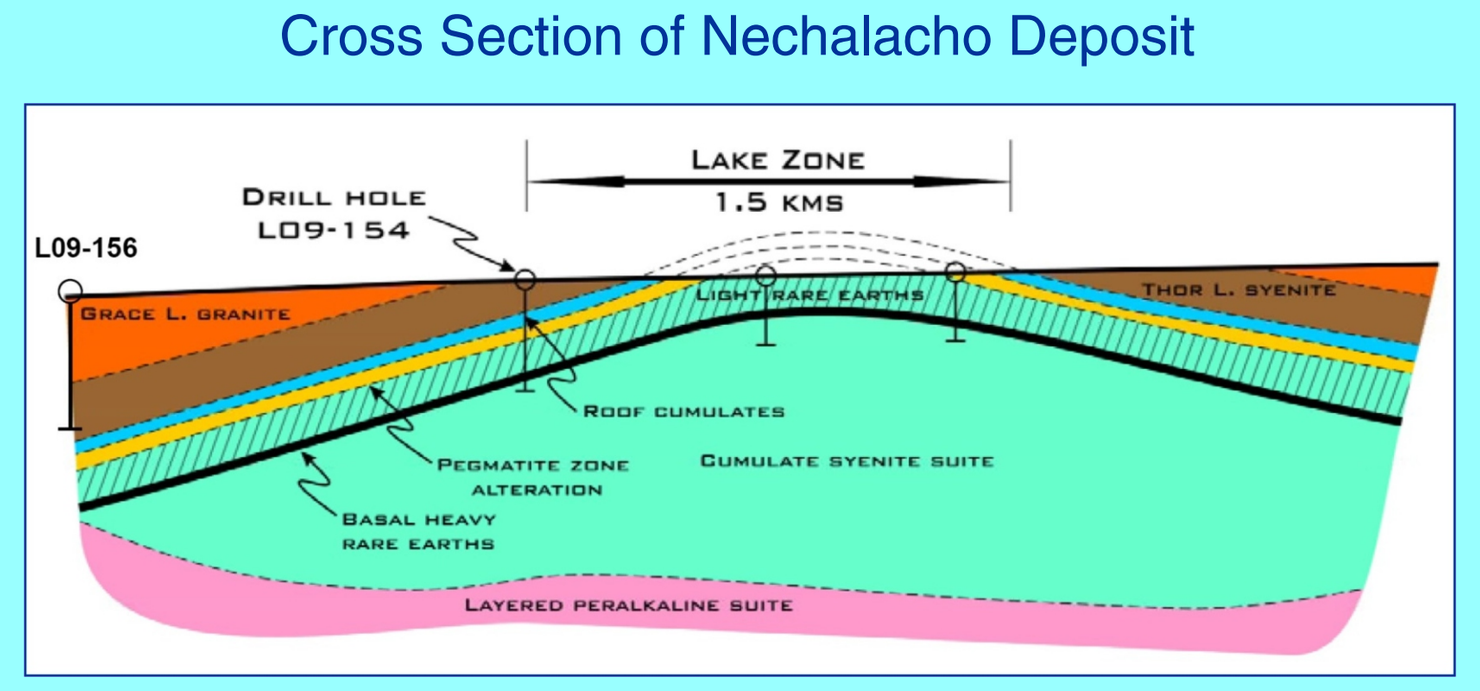
A gravity model based primarily on a relatively detailed ground gravity traverse, 1- 2 km station spacing, augmented by relatively sparse regional data spaced ~10 km apart predicted that much of the eastern lobe of the complex, comprising the Grace Lake granite and Thor Lake syenite, was underlain by a sill-like branch of the Caribou Lake gabbro, a component of the western lobe (Birkett et al., 1994). Recent measurements of rock density, and documented measurements, reveal that values are higher within the Thor Lake syenite, some of the largest being recorded for mineralized syenite within the Lake Zone, now referred to as the Nechalacho deposit, between Thor and Long lakes. This area, the northern part of the Thor Lake syenite and adjacent portions of Grace Lake granite to the west coincide with a weak culmination on the broad regional gravity high covering much of the Blatchford Lake complex pointing to a possible alternative explanation to the proposed gabbroic sill.

Exploration indicates that a nepheline syenite hosting the rare earth mineralization, observed in a window within the Thor Lake syenite, extends beneath the Thor Lake syenite in all directions. It is speculated that the weak culmination in the gravity field gravity high reflects the presence of mineralized syenite. An earlier exploration gravity survey delineated a 1.4 mGal amplitude gravity high partially coincident with the Nechalacho deposit that was modelled as a 240 m thick basin-shaped body.

Geology of the Thor Lake Syenite



Cross Section of Nechalacho Deposit



Geology

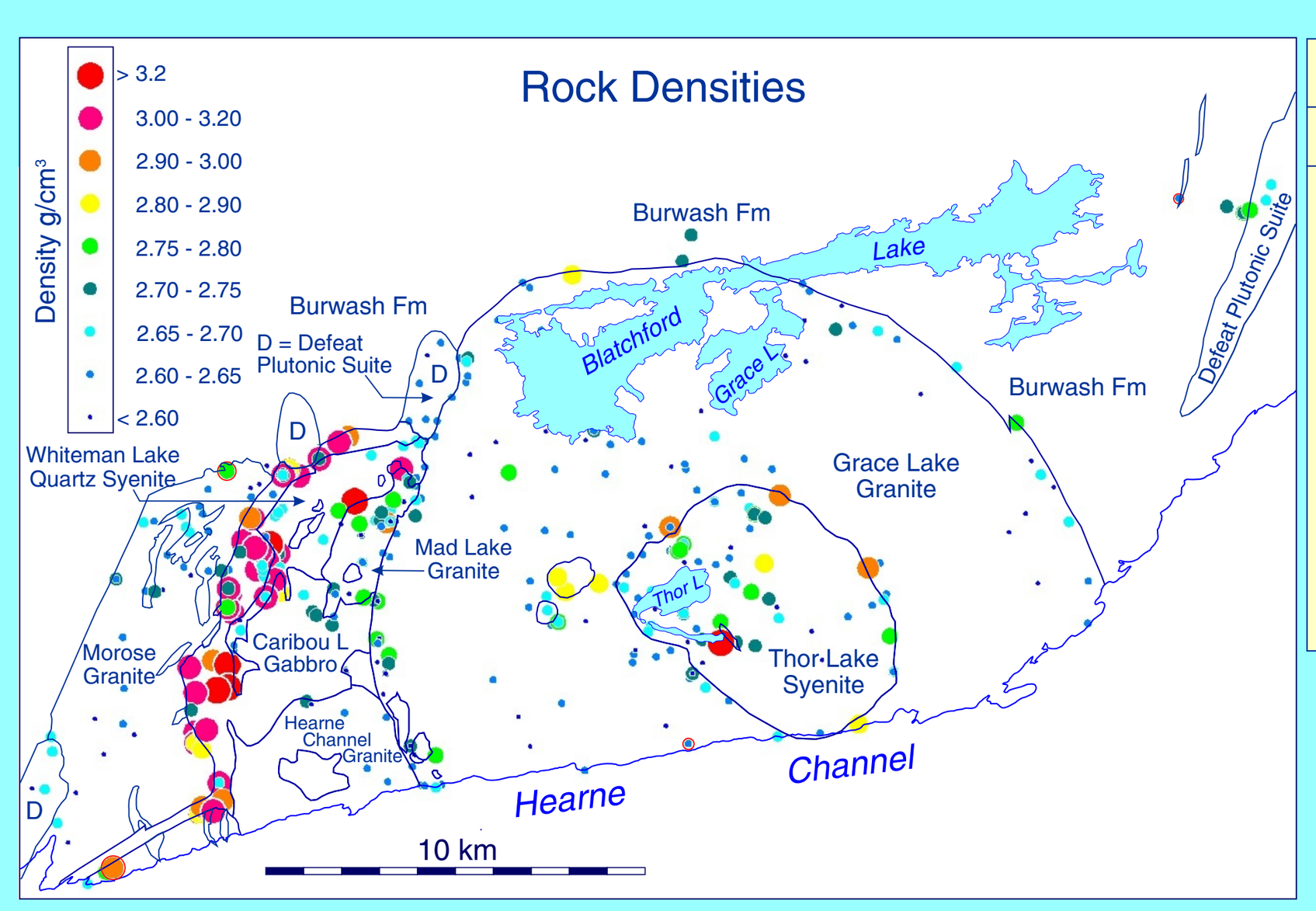
A map of the Early Proterozoic Blatchford Lake alkaline igneous complex based on maps by Davidson (1978) and Henderson (1985) is shown above to the left. The complex includes a circular eastern lobe (Grace Lake granite cored by the Thor Lake syenite) and a flanking, arcuate western lobe (Caribou Lake gabbro, Whiteman Lake syenite, Mad Lake and Hearne Channel granites). Davidson (1978) identified several lithological varieties within the Thor Lake syenite shown in the map to the immediate left. Several mineralized zones (rare earth elements) are also present including the R, S, T and F zones. The unit characterized by albite and iron oxides was interpreted by Davidson (1978) as a zone in which pre-existing syenites have been intensely altered and extensively veined by albite-rich rocks. This altered unit corresponds essentially to the Lake deposit described by Trueman et al. (1988), who proposed that the core zone of the deposit was formed by repeated and chemically progressive metasomatism leading to replacement of a syenitic protolith. The core zone was recognized as the principal host to rare earth metals that incuded aeschynite (trace), allanite, bastnasite, columbite, columbite-tantalite and lanthanite. Avalon Rare Metals Inc. renamed the Lake deposit as the Nechalacho rare earth element deposit.

The relatively high densities of the Nechalacho deposit and the association of a gravity high (~1 mGal amplitude) were recognized by Trueman et al. (1988) who modelled a roughly trough-shaped body having a maximum thickness of about 240 m and a lateral extent near surface of about 2800 m. Extensive exploration by Avalon Rare Metals Inc., supported by drilling, has provided a much more detailed picture of the deposit, both in plan view and at depth. The complexity of the surface geology is outlined in the geology of the deposit shown to the left (after Cox et al., 2010).

Conceptually, the Thor Lake syenite is now viewed as layered in its roof region (beneath the Grace Lake granite), a depiction of which is shown in the geological section to the left (Fulp, 2009 derived from the Avalon Rare Metals Inc. website). The lateral extension of relatively heavy mineralized rocks of the Nechalacho deposit beneath the Grace Lake granite must be considered in analysis of the gravity field.

Physical Rock Properties

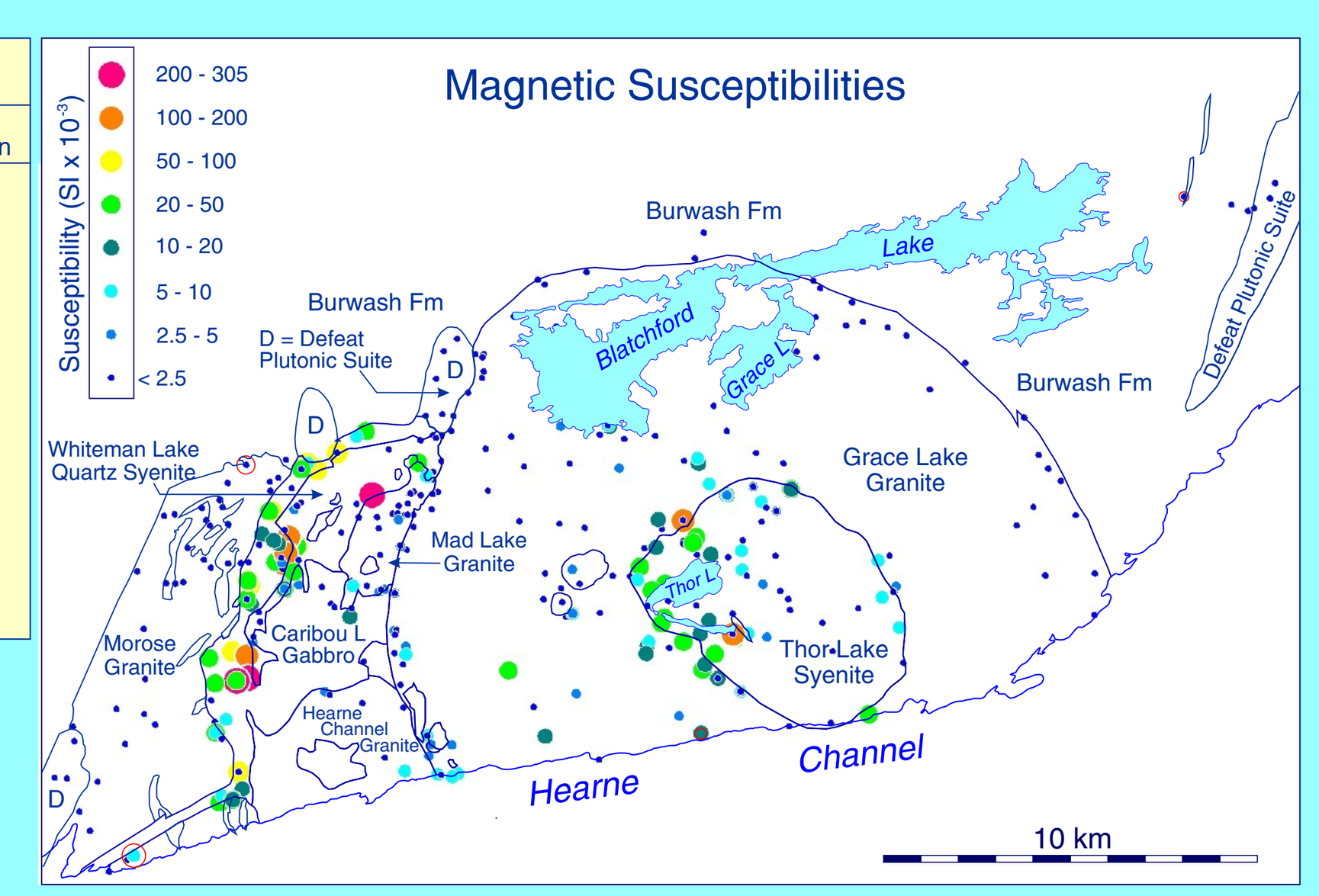
Rock Densities



Rock Unit	No. of Samples	Density & Standard Deviation
Compton Intrusion (north)	3	2.84 +/- 0.01
Compton Intrusion (south)	5	2.69 +/- 0.05
Grace Lake Granite	113	2.63 +/- 0.06
Thor Lake Syenite	56	2.66 +/- 0.08
Thor Lake Syenite Mineralized F and T Zones	18	2.87 +/- 0.22
Mad Lake Granite	20	2.66 +/- 0.08
Hearne Channel Granite	11	2.62 +/- 0.03
Whiteman Lake Quartz Syenite	42	2.66 +/- 0.05
Caribou Lake Gabbro	78	2.97 +/- 0.23
Morose Granite	44	2.63 +/- 0.06
Defeat Plutonic Suite	26	2.64 +/- 0.03
Burwash Formation Metasedimentary Rocks	30	2.72 +/- 0.04

Densities of Rock Units Within and Around the Blatchford Lake Alkaline Complex

Magnetic Susceptibilities

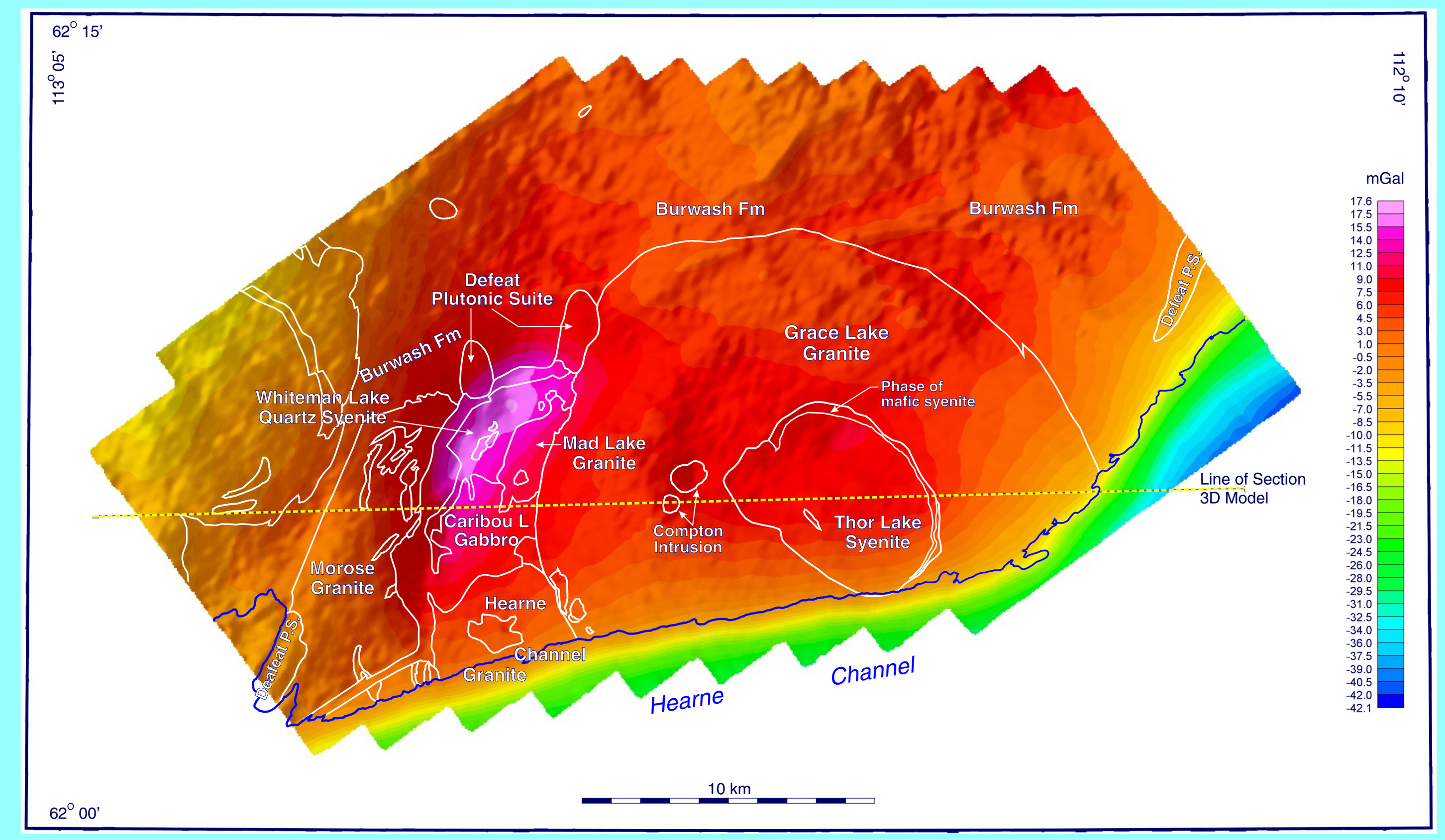


Physical Rock Properties

Physical rock properties such as density and magnetic susceptibility are critical constraints for the interpretation and modelling of gravity and magnetic fields, respectively. The availability of archived rock samples from 1970s field mapping by Tony Davidson for the Geological Survey of Canada provided an opportunity to measure these parameters for rock samples distributed throughout the Blatchford Lake alkaline complex and within neighbouring rock units. The results are portrayed in the two figures above where the particular parameter is shown as a coloured dot having a diameter proportional to its size. A table of mean values of density for rock units is also shown above. Noticeable in the table is the slight yet distinct difference (0.03 g/cm^3) between the lighter Grace Lake granite and heavier Thor Lake syenite; a similar difference was recorded by Birkett et al. (1994). This difference is clearly expressed in the density map above. Mineralized rocks of the Thor Lake syenite have a high density of 2.87 g/cm^3 exactly the same as a value for 1673 samples measured by Avalon Rare Metals Inc. (Cox et al., 2010).

Magnetic susceptibility values mimic those of density values for the Grace Lake granite and Thor Lake syenite with values for the former generally being < 2.5 SI x 10^{-3}, and many values for the latter in the region of Thor Lake being > 5 with some in the range 20 - 50 SI x 10^{-3}. These values are compatible with the observed strong magnetic field present over the northwestern half of the Thor Lake syenite. A few strong susceptibility values along the eastern margin of the syenite undoubtedly reflect the presence of the narrow marginal mafic fayalite-pyroxenite syenite body mapped by Davidson (1978). All other "granitoid" units in the area are characterized by low magnetic susceptibilities that are invariably < 2.5 SI x 10^{-3}. The Caribou Lake gabbro yields the highest magnetic susceptibilities in the area with several values in the range 20 - 50 SI x 10^{-3}, and a few attaining > 200 SI x 10^{-3}. The strong magnetic expression along the length of the Caribou Lake gabbro is reconciled with the consistently high magnetic susceptibilities of the component rock types.

Airborne Gravity Anomaly

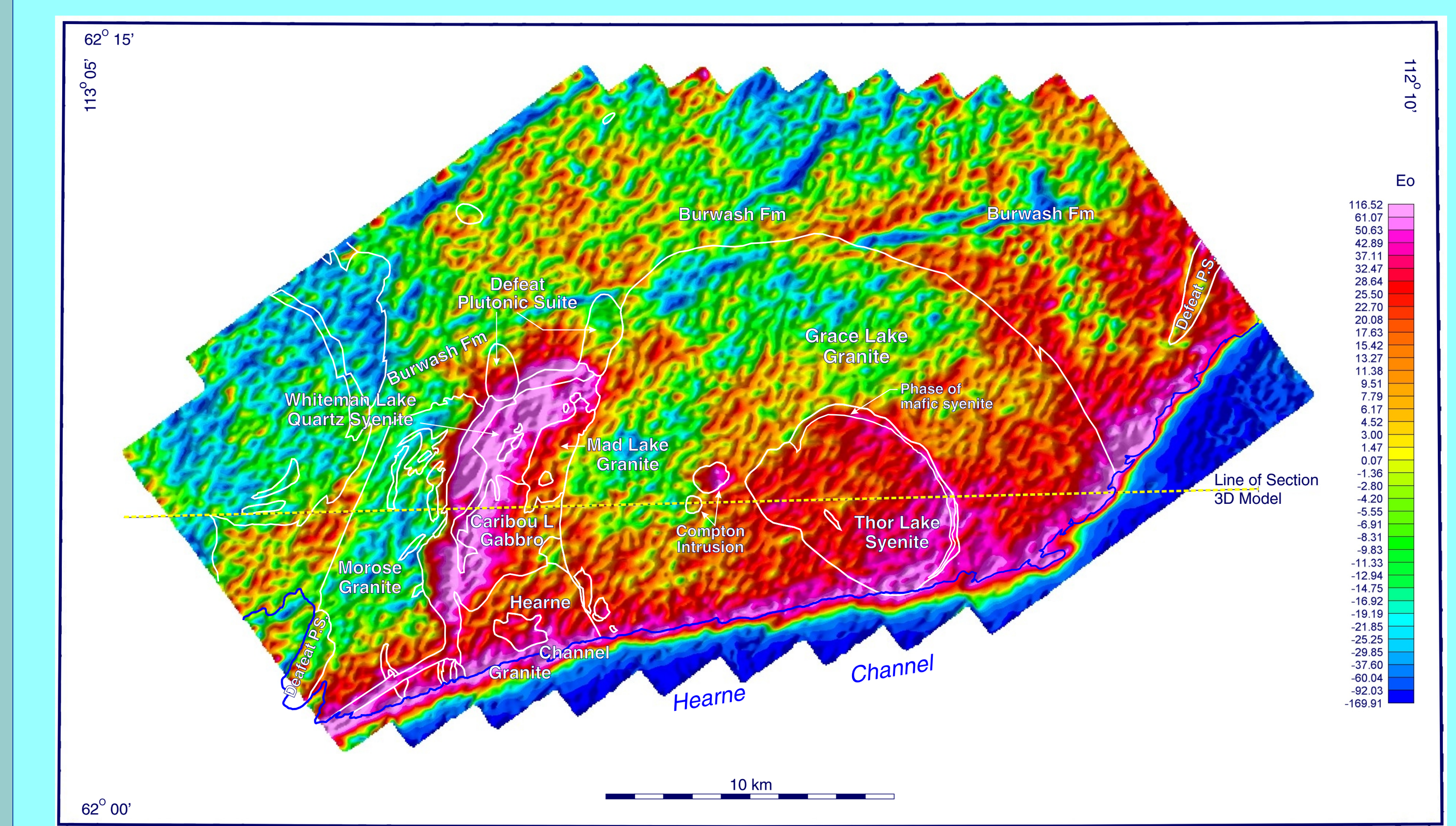


Gravity Field

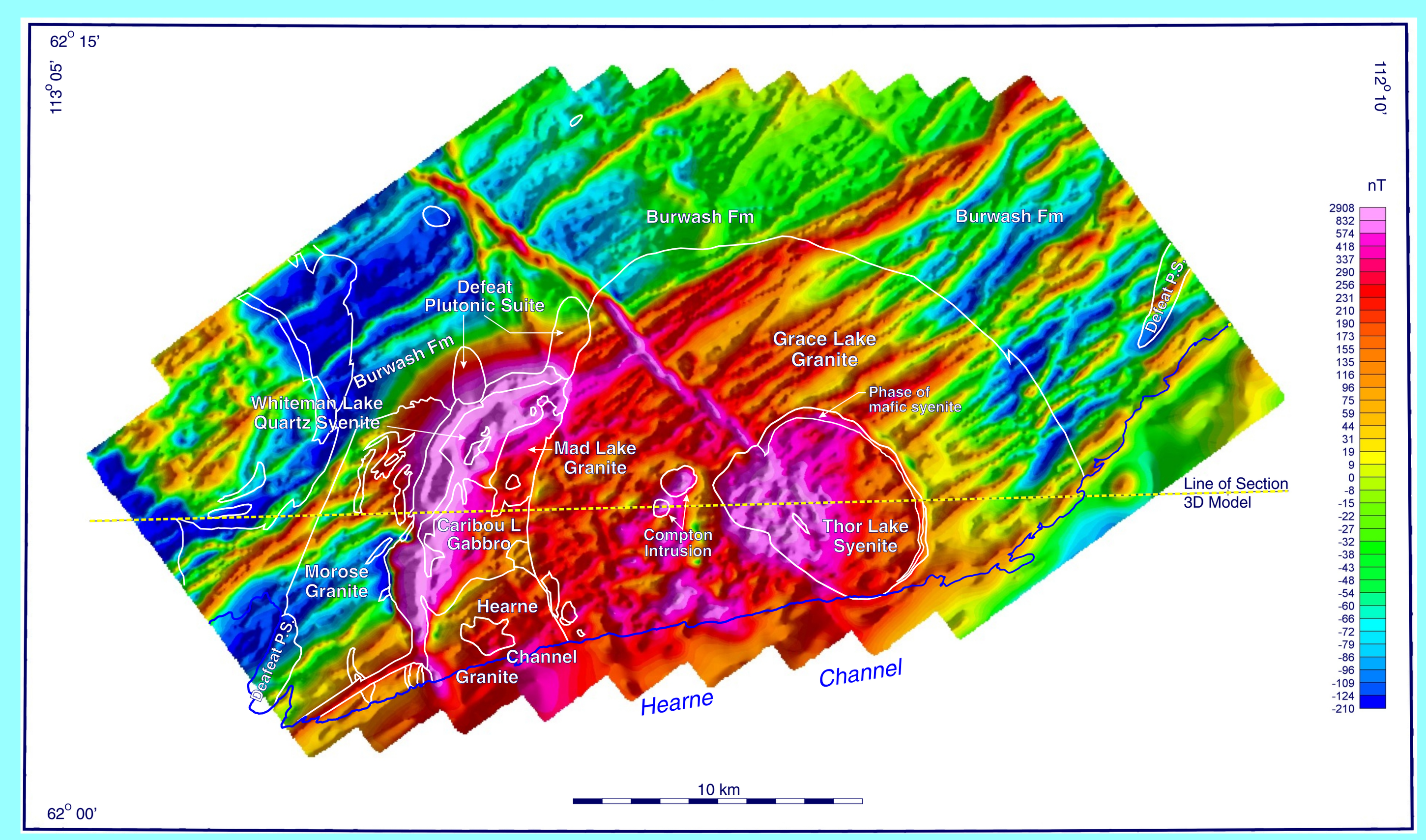
The gravity field is dominated by a broad gravity high that occurs over and extends beyond the Blatchford Lake Intrusive Complex. The anomalies are greatest over the Caribou Lake gabbro and northern portion of the Thor Lake syenite, presumably reflecting the relatively higher densities of the gabbro and northern portion of the syenite compared to densities of adjacent rocks. The high over the syenite is relatively subtle compared to the strong expression linked to the Caribou Lake gabbro reflecting the significantly smaller density contrast. These variations are superimposed on a large amplitude regional north-south gradient. More detail is apparent in the vertical gravity gradient image. Gradient highs are coincident with magnetic highs over the periphery of the Caribou Lake gabbro and extend southward into the Whiteman Lake quartz syenite. A small gradient high occurs over the northern Compton intrusion but not the southern one. The peripheral mafic unit on the eastern edge of the Thor Lake syenite shows a gravity gradient high coincident with increased magnetic anomaly values. East of the eastern edge of the Grace Lake granite a 1-2 km wide gradient high suggests reduced Grace Lake granite densities with respect to the surrounding Burwash Formation.

It is noted that several gravity and gravity gradient lows are associated with lakes. This is a consequence of the lack of bathymetric information for the computation of corrections to the observed gravity data. This effect is particularly severe at the northern shore of the Hearne Channel where a large gravity gradient is apparent.

Airborne Vertical Gravity Gradient



Total Magnetic Field



Magnetic Field

The most intense magnetic anomalies are associated with the Caribou Lake gabbro; peak values are generally > 1000 nT and attain > 2900 nT. Not all of the mapped extent of the gabbro is highly magnetized, only the western peripheral zone. The area just north of the Hearne Channel granite is much less magnetic comparable to regional values.

The Whiteman Lake quartz syenite includes several highly magnetic zones. The association of one of them with an included NNE-trending unit of Caribou Lake gabbro suggests that the latter is also present at shallow depth beneath other zones.

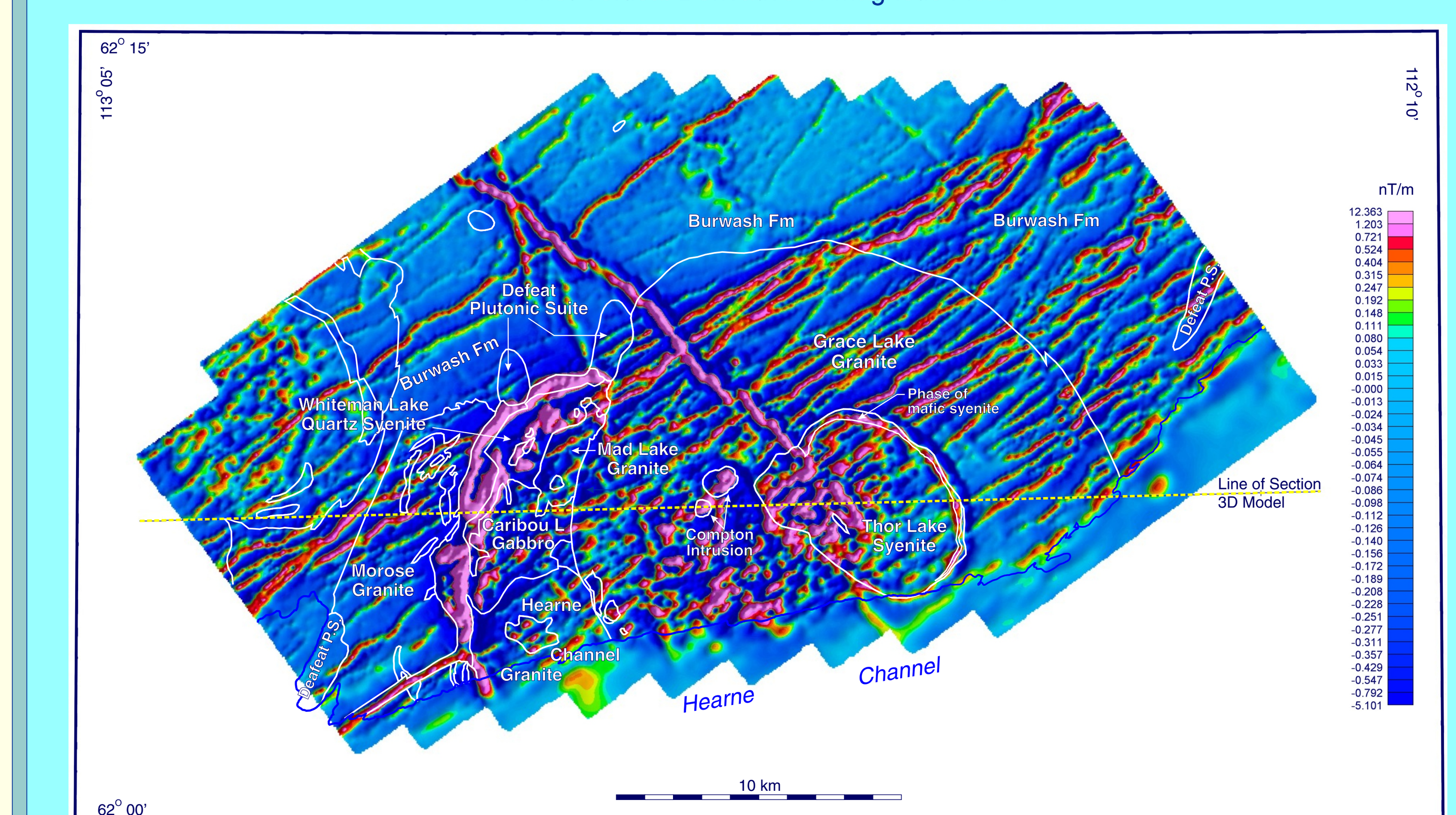
The western portion of the Thor Lake syenite is associated with a prominent positive magnetic signature within which numerous peaks attain >500 nT. The eastern peripheral mafic syenite produces a distinct positive anomaly with peaks attaining 100 nT.

The Defeat Plutonic Suite and the Mad Lake and Morose granites apparently lack a noteworthy magnetic signature, their magnetic fields being dominated by linear magnetic highs trending roughly ENE, the characteristic trend of the Hearne dykes to which they are probably mainly related.

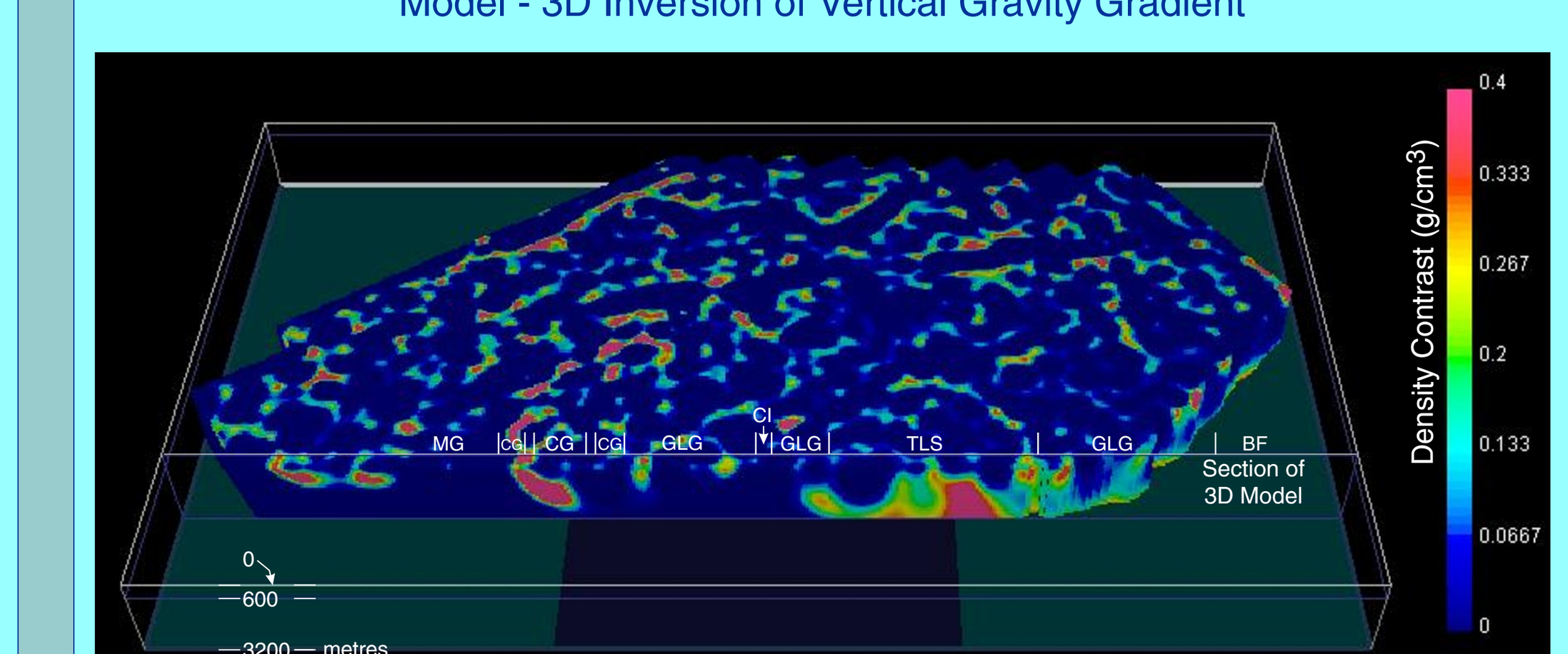
The Grace Lake granite is generally associated with a magnetic expression that is relatively positive compared to that over surrounding metasedimentary rocks of the Burwash Formation, but not as intense as that over the western part of the Thor Lake syenite. Ignoring dyke-related anomalies respective ranges of the fields over the granite and metasedimentary rocks are roughly + 50 to +150 nT and -125 to -25 nT.

Several magnetic highs south of the strongly magnetic Compton Intrusive Suite indicate either internal compositional/structural variations within the Grace Lake granite or the presence of buried Compton Intrusion units.

First Vertical Derivative of Magnetic Field

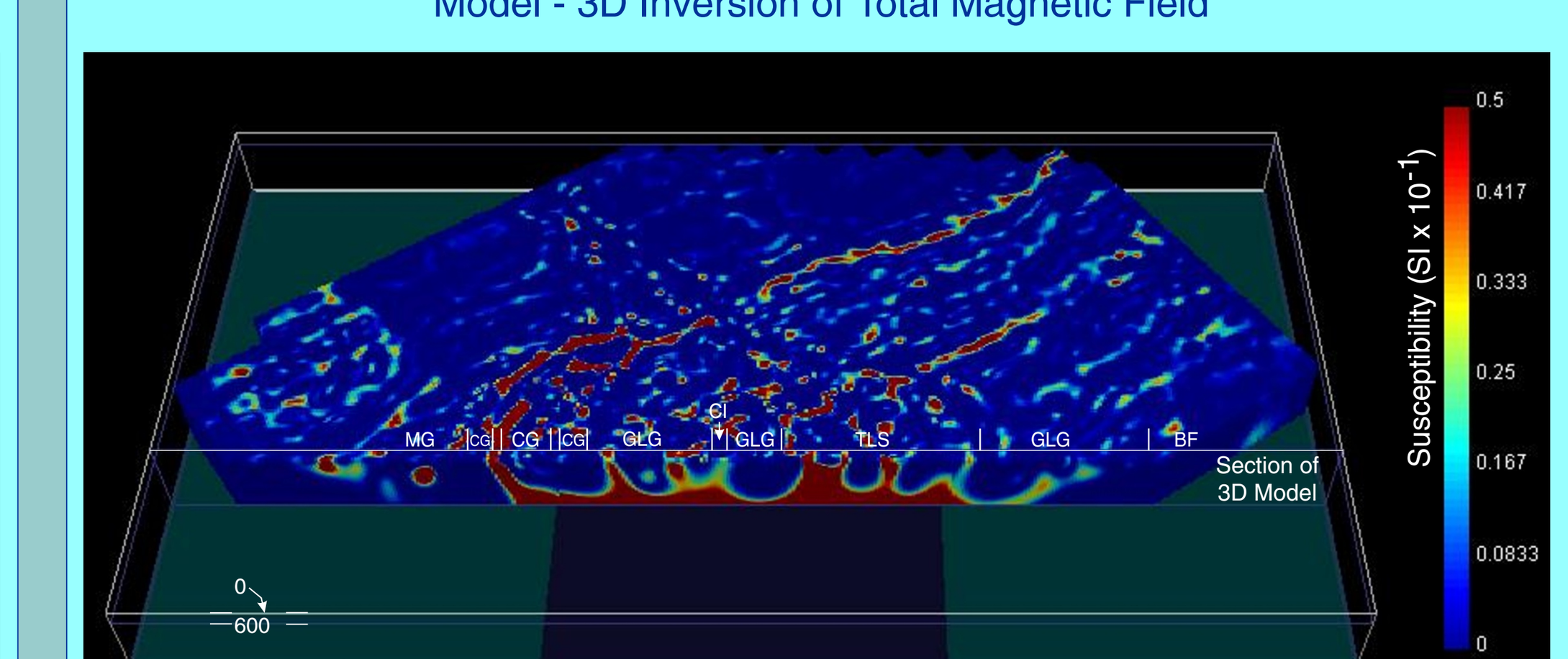


Model - 3D Inversion of Vertical Gravity Gradient



BF, Burwash Fm; CG, Caribou L gabbro; CI, Compton Intrusion; GLG, Grace L granite; MG, Morose granite; TLS, Thor L syenite

Model - 3D Inversion of Total Magnetic Field



BF, Burwash Fm; CG, Caribou L gabbro; CI, Compton Intrusion; GLG, Grace L granite; MG, Morose granite; TLS, Thor L syenite

Preliminary 3D Inversion Models of Gravity and Magnetic Data

3D inversion models of the gravity (vertical gradient) and total magnetic field above are portrayed as a perspective horizontal slice and vertical section. The line of the section (shown on the geophysical maps above) crosses the Blatchford Lake alkaline complex from west to east passing through the central part of the Thor Lake syenite. These unconstrained inversions were carried out on a 100 m grid and the modelled domain extends from ground surface at 0 m down to 3200 m. In the case of the gravity inversion, to avoid edge effects caused by the large gradiometer gradient along the northern shore of Hearne Channel, a portion of the southern edge of the grid was removed. The horizontal depth slice is at a depth of 600 m below the surface. The gravity model predicts mass excesses in the regions of the Caribou Lake gabbro and Thor Lake syenite below the 600 m depth of the horizontal plane, a result compatible with density data for surface samples and shallow drill holes. However, this 3D inversion does not delineate a distinct near-surface higher density body in the region of the Nechalacho deposit, where it might be expected, this not to rule out the presence of high density bodies at depth. These inversions represent a starting point in the modelling process and in subsequent phases models will be constrained by incorporating appropriate densities and susceptibilities within specific areas where it is deemed reasonable. The magnetic inversion also outlines relatively highly magnetic material below the Caribou Lake gabbro and Thor Lake syenite, consistent with higher magnetic susceptibilities measured on surface samples from these two geological units. The merging of several near-vertical highly magnetic segments of the crust into a near-horizontal layer at the bottom of the section may be an artifact of the inversion. This phenomenon will be monitored as constrained inversion models are developed.

Conclusions

The new airborne geophysical survey over the Blatchford Lake aklaline complex provides a greatly improved picture of the gravity field. Archived ground gravity measurements were generally widely spaced (~10 km) except along a single traverse (~1 km) and distribution was not uniform. The airborne survey provided uniform coverage and enhanced resolution. On a broad scale the gravity field is dominated by two gravity highs: a strong high associated with the Caribou Lake gabbro and a more subtle weaker high over the northern part of the Thor Lake syenite, adjacent marginal areas of the Grace Lake granite and the small intrusions of the Compton Intrusive Suite.

The new aeromagnetic data offer improved resolution over those acquired in a survey in 1988 (Charbonneau et al., 1994). Even though the line spacing of the surveys is the same (250 m) the new survey flight elevation was 100 m above ground level compared to the 120 m of the 1988 survey.

Physical rock property measurements have been made to help constrain modelling of the data. Results of the preliminary unconstrained 3D models presented here highlight the need to incorporate any available constraints.

Acknowledgements

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Geophysical Data

Gravity and magnetic data portrayed on this poster may be downloaded at no charge from Natural Resources Canada's Geoscience Data Repository website at http://gdr.nrcan.gc.ca

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