Shallow crustal structure of the Tehery Lake–Wager Bay area, western Hudson Bay, Nunavut, from potential-field datasets

V.L. Tschirhart¹, N. Wodicka² and H.M. Steenkamp³

¹Natural Resources Canada, Geological Survey of Canada, Ottawa, Ontario, victoria.tschirhart@canada.ca
²Natural Resources Canada, Geological Survey of Canada, Ottawa, Ontario
³Canada-Nunavut Geoscience Office, Iqaluit, Nunavut

This work is part of the Tehery-Wager geoscience mapping activity of Natural Resources Canada’s (NRCan) Geo-mapping for Energy and Minerals (GEM) program Rae activity, a multidisciplinary and collaborative effort being led by the Geological Survey of Canada and the Canada-Nunavut Geoscience Office (CNGO), with participants from Canadian universities (Dalhousie University, Université du Québec à Montréal, Université Laval and University of New Brunswick). The focus is on targeted bedrock and surficial geology mapping, streamwater and stream-sediment sampling, and other thematic studies, which collectively will increase the level of geological knowledge in this frontier area and allow evaluation of the potential for a variety of commodities, including diamonds and other gemstones, base and precious metals, industrial minerals, carving stone and aggregates. This activity also aims to assist northerners by providing geoscience training to college students, and by ensuring that the new geoscience information is accessible for making land-use decisions in the future.


Abstract

The Tehery-Wager geoscience mapping activity is a multiyear initiative conducted by the Geological Survey of Canada (GSC) and Canada-Nunavut Geoscience Office (CNGO) under the second phase of the Geo-Mapping for Energy and Minerals (GEM-2) program. The second of two field seasons included two ground gravity transects that complement the existing aeromagnetic coverage by providing information on the subsurface geology, and highlight the structure and geometry of the Wager shear zone (WSZ) and Chesterfield fault zone (CFZ). Preliminary processing of gravity data reveals discontinuities in the observed gravity field correlative with these major structures and mapped lithological units. On both gravity transects, the CFZ corresponds to a prominent gravity low and magnetic textural discontinuities. Contrasting potential-field signatures associated with two distinct supracrustal assemblages offer additional insight for remote discrimination. Associations between gravity and magnetic anomalies, physical rock properties and mineral occurrences have the potential to constrain the regional distribution of economically significant horizons.

Résumé

Les travaux de cartographie géoscientifique Tehery–Wager sont une initiative pluriannuelle menée conjointement par la Commission géologique du Canada et le Bureau géoscientifique Canada-Nunavut dans le cadre du second volet du programme de géocartographie de l’énergie et des minéraux. Au cours de la deuxième des deux campagnes de terrain prévues, deux transects de levé gravimétrique au sol ont été réalisés; ils viennent s’ajouter à la couverture aéromagnétique déjà disponible et fournissent des renseignements au sujet de la géologie de subsurface, tout en mettant en évidence la structure et les relations géométriques de la zone de cisaillement de Wager et la zone de faille de Chesterfield. Le traitement préliminaire des données du champ gravimétrique observé révèle la présence de discontinuités qui correspondent à ces structures importantes et aux unités lithologiques cartographiées. L’examen des deux transects gravimétriques a permis d’établir que la zone de cisaillement correspond à un creux gravimétrique visible ainsi qu’à des discontinuités texturales liées à des anomalies magnétiques. L’identification de signatures du champ potentiel contrastantes liées à deux assemblages supracrustaux différents fournit d’autres indications venant en aide à la discrimination des structures à distance. L’établissement de liens entre la pesanteur et les anomalies magnétiques, les propriétés physiques des roches et les venues minérales peuvent aider à circonscrire à l’échelle régionale la répartition des horizons d’importance économique.

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Introduction

Following reconnaissance work in 2012 to evaluate the potential for future mapping campaigns, the Tehery Lake–Wager Bay area was chosen for investigation during the second phase of the Geo-Mapping for Energy and Minerals (GEM-2 Rae project). The current mapping activity is part of a multiyear initiative involving the Geological Survey of Canada (GSC) and the Canada-Nunavut Geoscience Office (CNGO) to increase the level of geoscience knowledge in the area (e.g., McMartin et al., 2015, 2016; Steenkamp et al., 2015, 2016; Wodicka et al., 2015, 2016). To support the bedrock mapping and compilation efforts, two high-resolution ground gravity transects were conducted within the study area in conjunction with geological mapping and rock sampling. Gravity is easily measured in the field and can be used as a proxy to identify density contrasts in the underlying rocks, whereby an increase in the density of the underlying rock results in an increase in the observed gravity. In this manner, these data provide a noninvasive means of investigating the subsurface distribution of rock packages and allow the interpreter to define shallow crustal structures by modelling gravity signatures.

The purpose of this paper is to describe the acquisition, processing, analysis and preliminary interpretations of gravity data newly collected across two profiles transecting major crustal structures in the Tehery Lake–Wager Bay area. The study area is located in the Kivaliq Region of Nunavut, covering all or parts of eight National Topographic System (NTS) 1:250 000 scale map areas (46D, E, 56A, B, C, D, F, G, H; Figure 1). Helicopter-supported gravity transects were acquired in July 2016 out of the FPB camp. Each day, 8–11 km long segments of the two gravity transects were flown, along which geological observations and samples for rock-property measurements were collected. Future analysis to characterize the density of selected lithological units is planned and will constrain the forward geophysical modelling in conjunction with magnetic-susceptibility datasets.

Regional background

The Tehery Lake–Wager Bay study area (Figure 1) is located in the south-central Rae craton and is underlain predominantly by Archean tonalite to granodiorite orthogneiss (Steenkamp et al., 2015, 2016; Wodicka et al., 2015, 2016). Panels of folded Archean and/or Paleoproterozoic supracrustal rocks overlie the Archean gneissic basement. At least two main packages of supracrustal rocks are recognized in the study area (Figure 1): Paliak-like rocks and Ketyet River–like rocks. Supracrustal panels containing variable proportions of quartzite, psammite, semipelitic to pelitic gneiss, garnetite, iron formation, amphibolite, mafic gneiss, calcisilicate, rare marble and ultramafic bodies may correlate with the Paliak belt, exposed along the western shore of Wager Bay (Jefferson et al., 1991). Supracrustal panels characterized by thick quartzite units interlayered with psammite, semipelite, pelite and amphibolite share many similarities with the Paleoproterozoic Ketyet River group (Rainbird et al., 2010; Steenkamp et al., 2016; Wodicka et al., 2016). Together these rocks were reworked during the Trans-Hudson orogeny (ca. 1.86 Ga; van Breemen et al., 2007) and intruded by 1.83 Ga Hudson suite monzogranite plutons and contemporaneous ultrapotassic intrusions of the Martell syenite.

The northern part of the study area includes the Wager shear zone (WSZ), a 2–5 km wide dextral mylonite zone that parallels the southern shore of Wager Bay (Figure 1; Henderson and Broome, 1990; Panagapko et al., 2003; Steenkamp et al., 2016; Wodicka et al., 2016). The WSZ is associated with linear 200–800 nT magnetic anomalies (Figure 2A) and a colocated regional gravity lineament (Figure 2B), both of which extend more than 100 km to the west toward the Amer mylonite zone (AMZ; Broome, 1990). Broome (1990) attributed the positive magnetic anomaly of the WSZ to abundant magnetite concentrations, possibly formed during granulite-grade metamorphism, with superimposed local variations in magnetite concentrations. The linear gravity anomaly may be due to dense granulite-facies rocks at depth (Broome, 1990). The 1–3 km wide Chesterfield fault zone (CFZ), also located in the northern part of the study area, is interpreted by Panagapko et al. (2003) as the northeastern extension of a major shear zone that separates the Ketyet River group from higher grade gneiss to the south. Subtle magnetic textural contrasts are associated with the CFZ (Figure 2A); however, the regional gravity resolution (Figure 2B) does not permit discrimination of the fault zone.

Geophysical-data collection

During the 2016 field season, ground gravity measurements were taken at 235 stations along two transects in the Tehery Lake–Wager Bay map area (Figures 2A, B). Profile 1 is approximately 62 km long, oriented north-northwest–south-southeast, and profile 2 is 16 km long, oriented north–south. Profile 1 transects the WSZ and CFZ, whereas profile 2 transects only the CFZ.

Gravity at each station was measured with a Scintrex CG-5 AutoGrav™ meter and stations were spaced 300–400 m apart. A local base at FPB camp was tied to base station 93212011 in Baker Lake, Nunavut, and the FPB base was used for daily loop closure. The vertical and horizontal locations of each station were calculated by differential GPS using a Hemisphere S320™ GPS. The GPS data were postprocessed using the Canadian Spatial Reference System Precise Point Positioning (CSRS-PPP) online application. For the most part, preliminary processing results have an elevation accuracy of better than 15 cm. Several errone-
Figure 1: Simplified geology of the Tehery Lake–Wager Bay area, Nunavut (from Wodicka et al., 2016).
Figure 2: Regional potential-field data for the Tehery Lake–Wager Bay map area: A) merged residual total magnetic field; B) Bouguer gravity; black dots mark regional gravity stations. Thick white lines denote 2016 gravity transects, green line outlines the study area and dashed white lines denote fault zones.
ous elevation estimates (0.20–0.40 m) impact profile 2; however, they are expected to be resolved through differential postprocessing required for advanced forward modeling. The absolute ground gravity data were further corrected for latitude, instrument drift and Earth’s tides, and Free Air and Bouguer corrections were applied (Figure 3). The data were reduced to sea level using a Bouguer slab density of 2.67 g/cm³. No terrain corrections were made, as the topography of the area is fairly flat.

A regional gravity database for the study area, comprising ground gravity measurements spaced 12–15 km apart, was gridded to 3 km using minimum curvature (Figure 2B). The large station spacing of the regional grid only permits resolution of features greater than 25 km, limiting its resolving power for shallow crustal features. To investigate such structures, values interpolated from the regional gravity grid were subtracted from the detailed profiles to calculate the residual signal. The residual Bouguer data were used in subsequent modeling and interpretation using GeoSoft® GM-SYS gravity and magnetic modelling software.

**Magnetic data**

The Tehery Lake modern aeromagnetic survey (Coyle and Kiss, 2012) was acquired along east-west flight lines spaced 400 m apart and flown along a smooth draped surface at a height of 150 m. The Tehery Lake survey was merged with regional aeromagnetic data (805 m spacing) available through the Canadian Geoscience Data Repository (http://gdr.agg.nrcan.gc.ca/), to create a comprehensive aeromagnetic map of the study area (Figure 2A). The compilation grid was reduced to pole, and derivative products, including the first vertical derivative, tilt and horizontal gradient, were calculated. Derivative products help to delineate magnetic-lithological units by identifying magnetization contrasts, (i.e., ‘source edges’) and provide supplementary information for differentiating lithological units during forward modeling. Reduced-to-pole magnetic profiles were extracted along profiles 1 and 2 (Figures 4, 5).

**Preliminary interpretation and discussion**

**Profile 1**

Previous interpretations of the crustal structure underlying the study area are restricted to regional magnetotelluric (MT) studies by Spratt et al. (2014). They delineated the CFZ as shallow dipping to the south with a faint crustal MT response over their northwest–southeast transect (Spratt et al., 2014, profile 1), no MT response on their north–south transect (Spratt et al., 2014, profile 2), and no response crossing the WSZ on either transect. Profile 1 from the present study (Figure 4) displays the residual Bouguer gravity (bottom panel) and magnetic (middle panel) anomalies against geology (top panel). Coincident positive gravity and magnetic anomalies (Figure 4, anomaly H1) support the interpretation by Broome (1990), who suggested a dense, magnetic granulite body located beneath the surface north of the WSZ. At surface, the anomalies broadly correspond to extensive magnetite-bearing monzogranite with tonalitic and metasedimentary inclusions, all believed to have been subjected to granulite-facies conditions (Figure 1; Patterson and LeCheminant, 1985; Steenkamp et al., 2016; Wodicka et al., 2016). The CFZ corresponds to the most notable gravity low (L1) on the profile and is located on the northern flanks of coincident gravity (H2) and magnetic (H2) highs. It displays a shallower gradient to the south, suggesting a southward-dipping structure, in agreement with the interpretation of Spratt et al. (2014). However, this contrasts with the variable dips measured along the CFZ at surface (Wodicka et al., 2016). A mapped panel of undifferentiated Paliak-like supracrustal rocks north of the CFZ is associated with subtle magnetic highs (H3, H4) and corresponds to a broad (~7 km) gravity high (H3). These gravity and magnetic signatures suggest that this supracrustal panel is slightly wider than currently mapped (Figure 4, dashed lines). Two panels of Paliak-like supracrustal rocks, >1 km wide, correspond to two-station coincident gravity and magnetic highs (H5, H6). Although their gravity and magnetic responses on the profiles are not as anomalous, the Ketyet River–like supracrustal rocks correspond to a slight magnetic low (L2) and a moderate gravity high (M1) with a northward downslope.

**Profile 2**

Transecting the CFZ, profile 2 (Figure 5) is oriented over undifferentiated Archean tonalite to granodiorite orthogneiss (Figure 1). The range of gravity anomalies for profile 2 is not very large (~1.5 mGal), indicating that the orthogneiss has a significant degree of homogeneity. The
relatively subtle changes likely relate to compositional variations in the Archean basement. Previous regional geological maps for the Tehery Lake–Wager Bay area (e.g., Panagapko et al., 2003) positioned the CFZ farther north (Figure 5, CFZ-03), where it is situated on a gravity high. Mapping conducted during the 2016 field season led to a reassessment of the location of the CFZ (Figure 5, CFZ-16), based on the distribution of highly strained rocks. The new position adjacent to gravity anomaly L3 suggests a change in density across some kind of geological contact or structure, in this case the CFZ. It is also consistent with the position of the CFZ in the gravity signature in profile 1 (Figure 4, L1), where the fault zone is located at a gravity low with an amplitude of ~1.5 mGal. South of CFZ-16, the gravity anomalies are gently sloping to the south.

**Discussion**

On both profiles, the CFZ is on (Figure 4, L1) or adjacent to (Figure 5, L3) a gravity low. Wodicka et al. (2016) noted that the CFZ comprises strongly deformed rocks that have subsequently been cut by undeformed coarse-grained monzogranite. Undeformed monzogranite is less dense.
than foliated and deformed Archean gneissic rocks and Paleoproterozoic supracrustal rocks; however, these bodies are small at surface and may not be sufficient in volume to produce such gravity lows. The source of the CFZ gravity anomaly is expected to be resolved by rock-property measurements (provided there are sufficient representative samples) that could identify what lithological unit (if present) could generate such an anomaly, or determine if the gravity low cannot be correlated to anything at surface.

North of the WSZ (Figure 4), the (H1) magnetic and gravity anomalies are interpreted to represent granulite-facies rocks (e.g., Broome, 1990; Steenkamp et al., 2016; Wodicka et al., 2016). Potential field anomalies of similar amplitude and wavelength have been modelled by Tschirhart et al. (2016) along the AMZ ~1.5 km below the surface and continuing on beneath the Thelon Basin sedimentary cover. Similar magnetic highs are present over the length of the AMZ and WSZ, suggesting that analogous dense bodies are located at depth. The nature of the dense magnetic bodies along the AMZ is so far unknown.

Profile 1 highlights the different geophysical responses of the Ketyet River–like versus Paliak-like supracrustal belts. The Paliak-like panels have distinct positive gravity and magnetic anomalies associated with them, whereas the Ketyet River–like panel is a magnetic low and moderate gravity high (Figure 4). The Paliak-like panels host more diverse and dense rock types (e.g., iron formation, garnetite), perhaps contributing to their more pronounced geophysical response. Density and magnetic-susceptibility measurements of representative samples aim to further constrain the characteristics of each belt to enable easier interpretation of their presence in the airborne-survey data.

Future studies and economic considerations

In the absence of constraints, geophysical signatures are non-unique, and an infinite number of geological solutions can replicate the observed geophysical response. Detailed forward modelling of gravity and magnetic data will include physical rock-property values (e.g., density and magnetic susceptibility), along with potential remanently magnetized rock units and structural measurements to constrain the geological modelling solution. Remanence may be present where the measured dip of rock bodies can be replicated by the gravity data but not the magnetic data, which introduces additional complications to the modelling process. Furthermore, a wide distribution of rock-property values will help to geophysically characterize selected rock units for a comprehensive understanding of the contribution of individual geological units to the observed gravity and magnetic response, and will assist in regional-mapping efforts.

Within the study area, large-scale structures are prospective for a range of economic mineral deposits. As an example, a Paliak-like supracrustal panel in the immediate hanging-wall of the CFZ is adjacent to anomalous concentrations of Ag, Cu, Bi and Au in surface till (circled black cross in Figure 4; McMartin et al., 2013). A better understanding of the nature and geometry of the CFZ will allow discrimination of its potential to focus base- and/or precious-metal mineralization. North of the western segment of the CFZ (Figure 1), a large synformal structure hosting Ketyet River–like rocks contains several gossanous horizons near folded basement-cover contacts; these horizons are currently being investigated for their economic prospectivity (McMartin et al., 2016; Steenkamp et al., 2016; Wodicka et al., 2016).

Conclusions

The second field season of the Tehery-Wager mapping activity included the acquisition of ground-gravity data to map variations in the density of the underlying rock units. Based on the preliminary analysis of the gravity observations and aeromagnetic data, information related to the geometry of shallow crustal structures is apparent in the geophysical signatures (Figures 4, 5). However, in the absence of physical rock-property constraints, the preliminary interpretations are quite restricted. The WSZ and CFZ flank gravity highs accompanied by coincident magnetic anomalies. The CFZ is accompanied by a gravity low on both profiles. Subtle magnetic and gravity anomalies correspond to mapped panels of supracrustal rocks and highlight distinct differences in the geophysical characteristics of the Ketyet River–like versus Paliak-like supracrustal rocks; the latter apparently have higher magnetization and density, as indicated in the potential-field profiles. It is expected that the geometry of the structures and rock units at depth along these various profiles can be defined in future iterations of this work, following the inclusion of rock-property information as an important constraint.

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