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Central Baffin Electromagnetic Experiment (CBEX), Phase 2

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Abstract: As a part of the Central Baffin Multidisciplinary Project (a collaborative effort of the Geological Survey of Canada, The Canada-Nunuvut Geoscience Centre, and the Polar Continental Shelf Project), a 45 station, 500 km long regional-scale magnetotelluric profile was acquired. The profile crosses the northern margin of the Trans-Hudson Orogen and extends northward into the Archean Rae Craton. To the south, the profile crosses the Paleoproterozoic Piling Group. The primary goal of the experiment was to determine major geological boundaries by delineating regional electrical structures. Preliminary analysis shows that the conductive Astarte River Formation can be mapped and used as a proxy for the base of the Piling Group. Analysis has also revealed a high conductivity contrast between the Piling Group metasedimentary rocks and the northern Archean granite and gneissic complexes. Laboratory results indicate that the conductivity in the Astarte River Formation is due to the high content of interconnected graphite.

Résumé : Un profil magnétotellurique d'étendue régionale, composé de 45 stations et s'étirant sur une longueur de 500 km, a été réalisé au cours des deux derniers étés dans le cadre du Projet scientifique multidisciplinaire de l'île de Baffin centrale (une initiative menée en collaboration par la Commission géologique du Canada, le Bureau géoscientifique Canada-Nunavut et l'Étude du plateau continental polaire). Ce profil recoupe la marge septentrionale de l'orogène trans-hudsonien et se prolonge vers le nord dans le craton de Rae de l'Archéen. Au sud, le profil recoupe le Groupe de Piling du Paléoprotérozoïque. Le but principal de l'expérience consistait à définir les principales limites géologiques en délimitant les structures électriques d'étendue régionale. L'analyse provisoire des données démontre que la Formation d'Astarte River, à comportement conducteur, peut être cartographiée et servir d'indicateur indirect de la base du Groupe de Piling. Un autre résultat de l'analyse tient à l'identification d'un contraste marqué de conductivité entre les roches métasédimentaires du Groupe de Piling et les complexes de granite et de gneiss de l'Archéen au nord. Les résultats obtenus en laboratoire indiquent que la conductivité de la Formation d'Astarte River est attribuable à sa teneur élevée en graphite à cristaux jointifs.

OVERVIEW

During July and August of 2001 and 2002, magnetotelluric (MT) measurements were made on Baffin Island, Nunavut, Canada (Jones et al., 2002b). The magnetotelluric surveys were undertaken as part of the Geological Survey of Canada's multidisciplinary Central Baffin project to study the northern margin of the Paleoproterozoic Trans-Hudson Orogen (Corrigan et al., 2001; Scott et al., 2002, 2003). In 2001, broadband (1000–0.001Hz) and long-period (20–10 000 s) data were recorded at 15 locations approximately equispaced along the 300 km long northwest-southeast profile (Fig. 1). In 2002, 30 broadband measurements were made at stations located between the 2001 stations and beyond, thus extending the profile 200 km northward onto the Archean Rae Craton and outside the project area (Fig. 1). The survey line thus comprises 15 long-period stations and 45 broadband stations with a total profile length of approximately 500 km.

The Central Baffin project area (Fig. 1) straddles the northern margin of the eastern segment of the ca. 1.8 Ga Trans-Hudson Orogen (Hoffman, 1988; Lewry and Collerson, 1990), a Himalayan-scale collisional mountain belt that is exposed from Greenland in the east, across Baffin Island and beneath Hudson Bay, to Manitoba and Saskatchewan in the west. The northern part of the project area is underlain by various orthogneiss, metamorphosed sedimentary and volcanic rocks of the Mary River Group, and younger felsic plutonic rocks, all of Archean age and ascribed to the Rae Craton (Jackson, 1969; Bethune and Scammell, 1997; Corrigan et al., 2001; Scott et al., 2002, 2003). The central part of the area is underlain by siliciclastic, carbonaceous, and mafic volcanic rocks of the Paleoproterozoic Piling Group (Morgan et al., 1975, 1976; Morgan, 1983; Henderson et al., 1988, 1989; Henderson and Henderson, 1994; St-Onge et al., 2001, 2002).

The primary goal of the magnetotelluric experiments was to determine the subsurface geometry of major geological boundaries, particularly between Archean rocks to the north and Paleoproterozoic continental-margin units to the south. Within the Piling Group lies a black shale and sulphide-facies iron-formation unit, the Astarte River Formation. Given its enhanced electrical conductivity, this formation is a particular horizon for electromagnetic imaging of crustal-scale structural geometry.

MAGNETOTELLURIC DATA ACQUISITION AND QUALITY

Two different acquisition systems were used during the two summers of fieldwork. In 2001, both long-period (LiMS) and broadband (V5-2000) magnetotelluric measurements were taken at 15 sites (Jones et al., 2002b). The GSC-designed LiMS system acquires long-period magnetotelluric data at periods of 20 to 10 000 s, probing the middle crust to upper mantle, by recording five components of the time-varying electromagnetic field, i.e. the two horizontal components of the electric field (Ex, Ey) and all three components of the magnetic field (Hx, Hy, Hz). The systems remained at each site for 4 to 5 weeks from July to mid-August. The sites were visited whenever helicopters were available in order to minimize data loss due to local wildlife. Data loss was a major issue at sites baf003 and baf013, where wolves chewed up electrode lines.

Broadband measurements, in the band of 0.001 to 1000 s, were made using two Phoenix MTU V5-2000 systems. With these systems, the depth of investigation is typically from a few kilometres down to the lower crust. The shallow occurrence of permafrost prevented the installation of the vertical magnetic field sensor, and thus only four components of the electromagnetic field were measured (Ex, Ey, Hx, and Hy). The MTU systems recorded for a period of two days at each site. Broadband measurements were taken at a total of 45 stations, i.e. at 15 sites during the summer of 2001 and at 30 sites during the 2002 field season (including the 10-site extension to the northwest).

One of the problems encountered in these two surveys was very high contact resistances between electrodes, especially at sites with little surficial cover due the recent retreat of the Barnes Ice Cap. In magnetotellurics, we strive to have resistance between the electrodes below 10 kΩ to ensure good ground contact. At the worst site (001), situated in a boulder field, resistances were measured at greater than 2 MΩ. Such high contact resistances result in capacitive coupling with the ground becoming important and with the consequence that the ground acts as a low-pass filter to the electric signal. This can be seen in the data from sites baf001 and baf201 where a significant decrease occurs in the apparent resistivity and phase at a period less than 0.1 s (Fig. 2).

Electric-field distortions due to local heterogeneities were strong at some sites and can be attributed to current channelling. The most severe distortions are seen at the sites located in river valleys (sites baf003 and baf205) and result in phases shifting into the wrong quadrant for two-dimensional modelling. In severe cases of distortion, it may only be possible to extract information about one of the two modes.

PROCESSING AND ANALYSIS

Magnetotelluric data consist of a number of time series that reflect temporal changes in the Earth's magnetic and electric fields. The spectral ratio between the electric field and the perpendicular magnetic field provides information about the electrical properties of the subsurface. High-frequency signals contain information about shallow structure and low-frequency signals are sensitive to deep structure.

The first step in processing raw magnetotelluric data involves the spectral analysis of the time-series data using robust processing codes. Both the long-period magnetotelluric and the broadband data were processed using the Jones-Jödicke code (Jones and Jödicke, 1984; method 6 in Jones et al., 1989). In the cases where two or more sites are

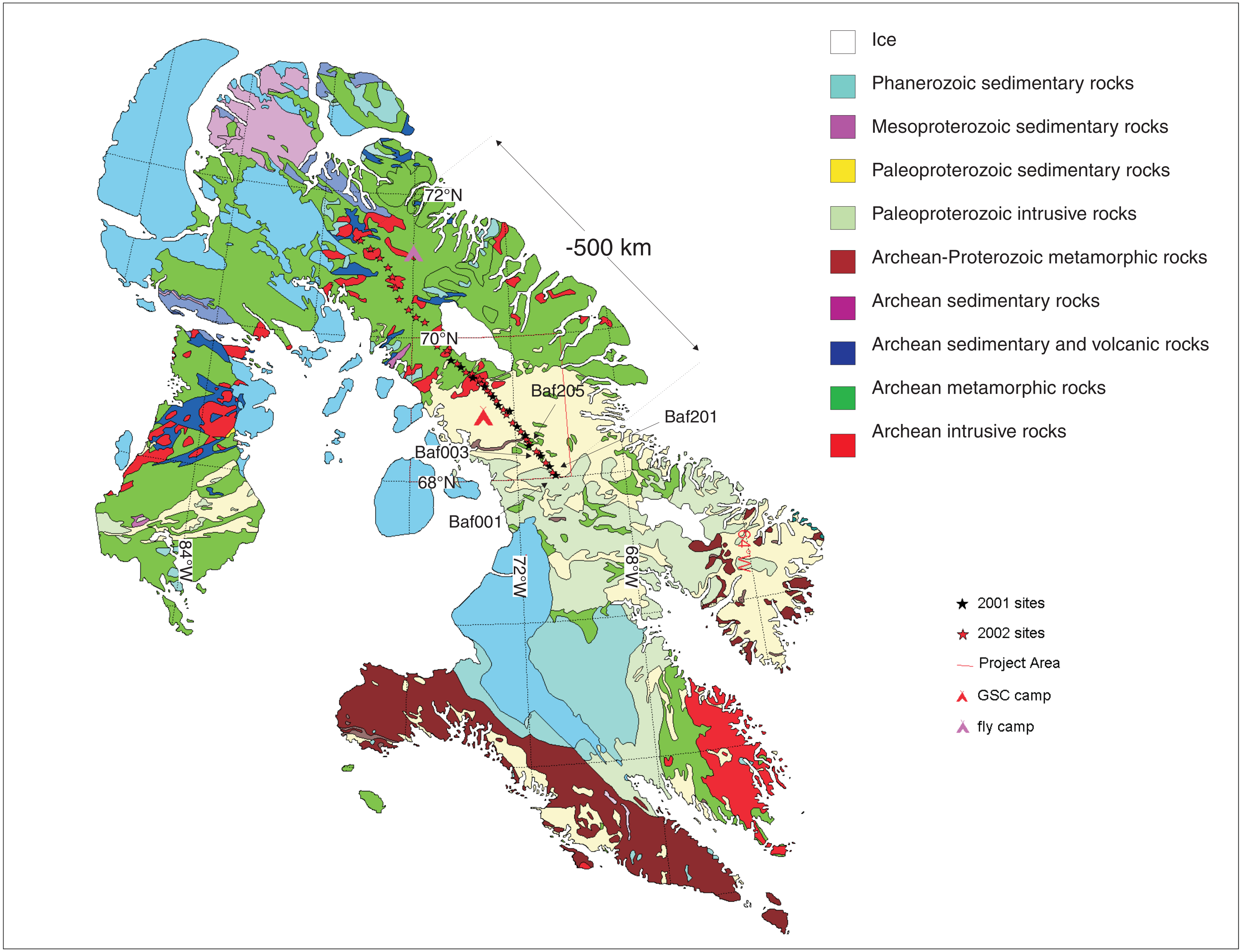

Figure 1. Magnetotelluric site locations superimposed on Baffin Island regional geology.

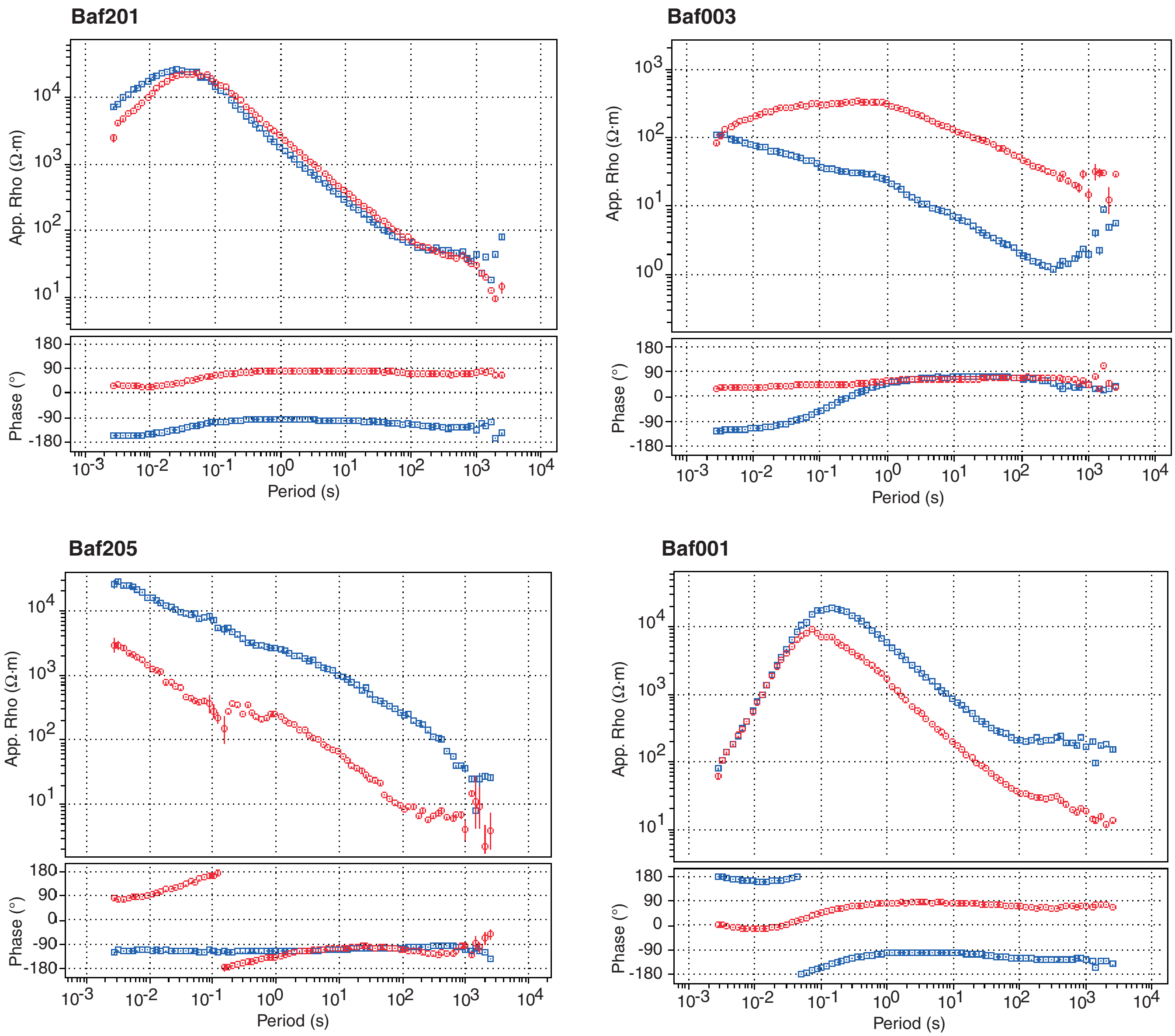

Figure 2. *Magnetotelluric response curves derived from data acquired at sites baf003, baf003, baf201, and baf205* (see *Fig. 1). Red curves are the responses for currents flowing perpendicular to the profile, and blue profiles are the responses for current flowing along the profile.*

recording concurrently, the remote reference technique (Gamble et al., 1979) is used to reduce the biasing effects of noise in the data. In the case of the long-period magnetotelluric data, given that all 15 sites recorded simultaneously, multiremote processing was possible.

The magnetotelluric data were analyzed for galvanic distortions caused by small, near-surface inhomogeneities using the McNeice and Jones (2001) multisite, multifrequency distortion decomposition code, and to determine appropriate strike direction. Distortions due to coastal effects have not yet been investigated. However, the presence of conductive seawater within 70 km of the profile may affect the data at longer periods. Strike angles and phase differences in decade-wide bands for single-site analysis are shown in Figure 3 for four bands of data. A great variation of strike angles can be observed along the profile, and regions with consistent strike angles can be distinguished throughout. The electrical strike direction correlates well with the surface observation of geological strike. A strike angle of 33° was determined to be most appropriate for the decomposition when all sites at all periods are being analyzed. The decomposition analysis has revealed

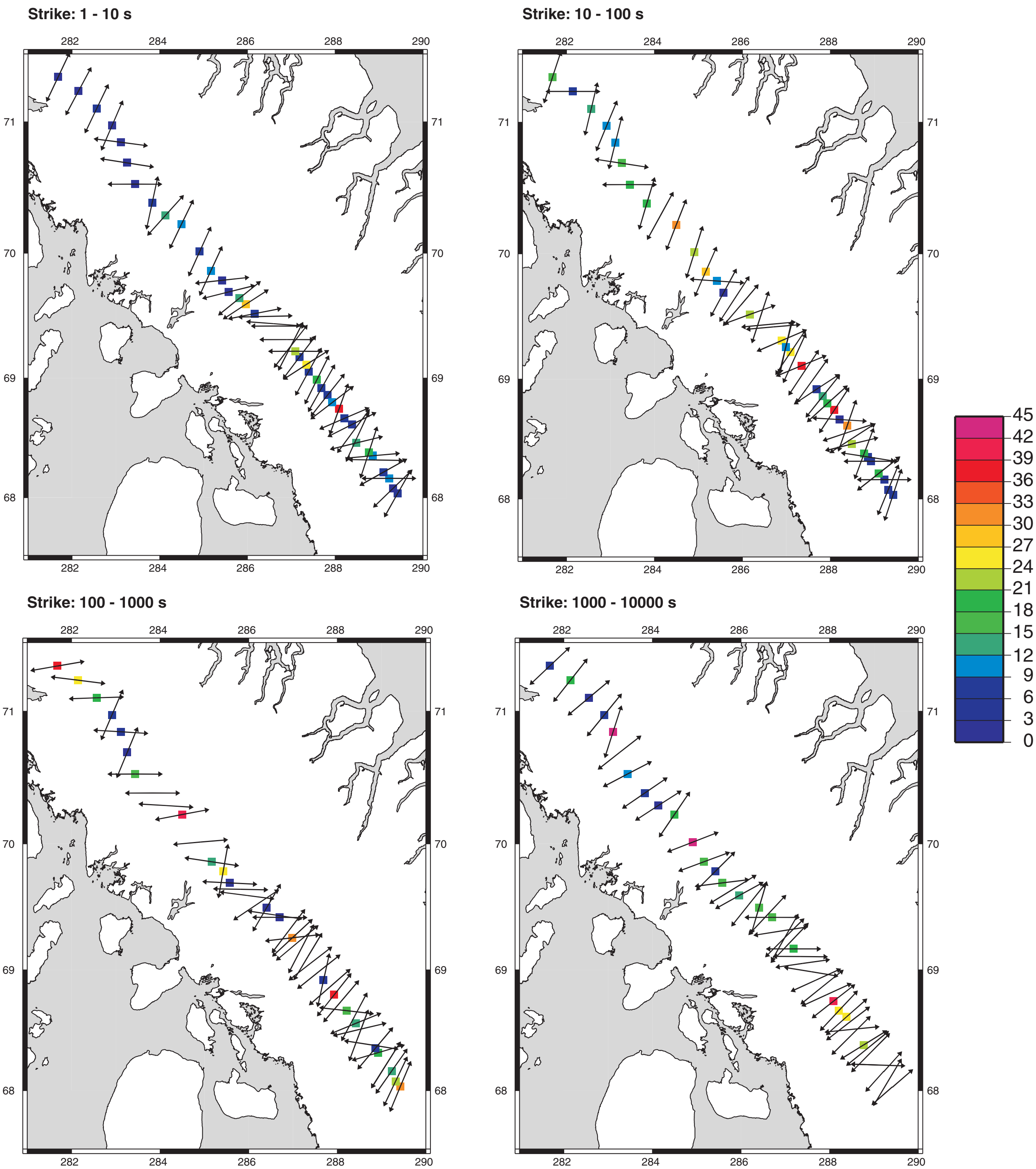

Figure 3. *Single-site strike angles calculated at decade-wide bands between 1 and 10 000 s.*

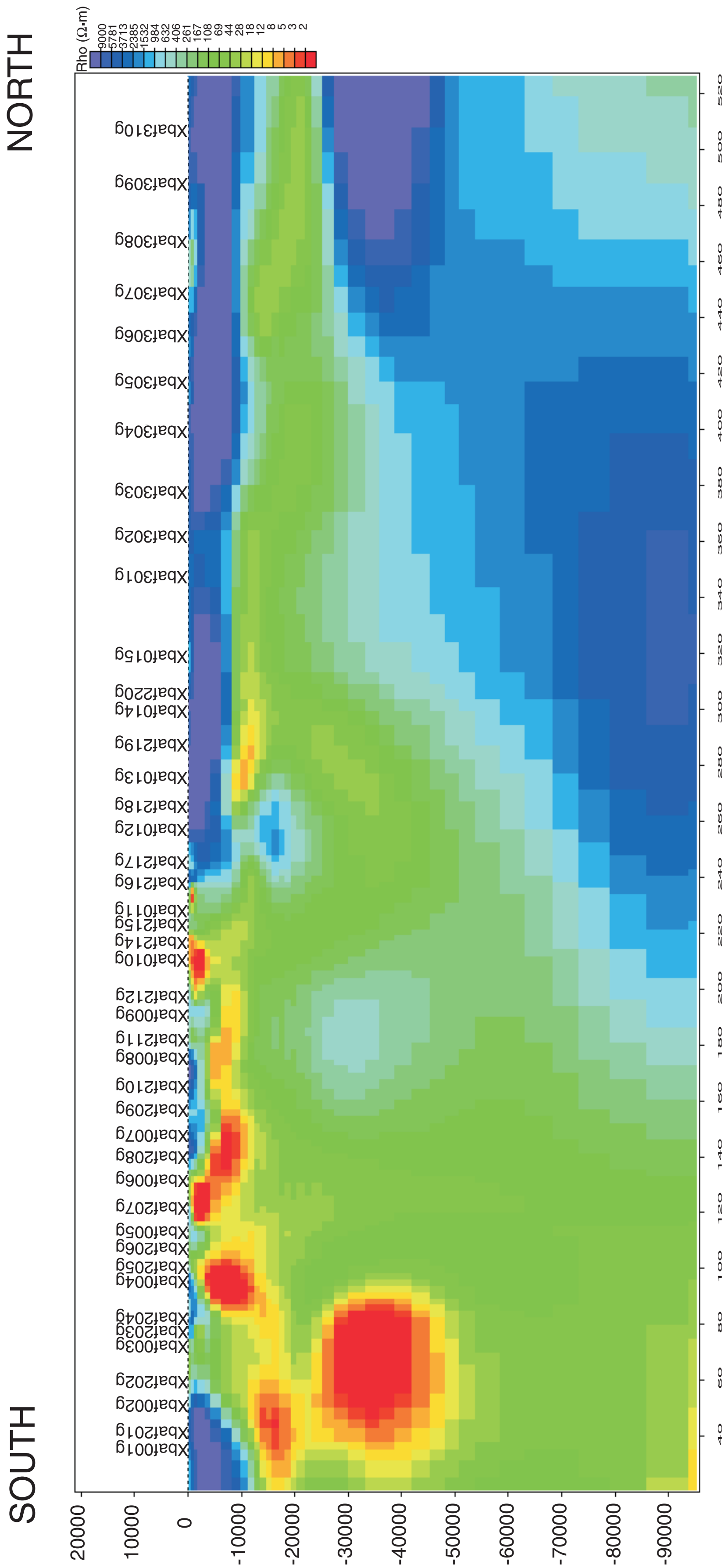

Figure 4. Magnetotelluric resistivity model.

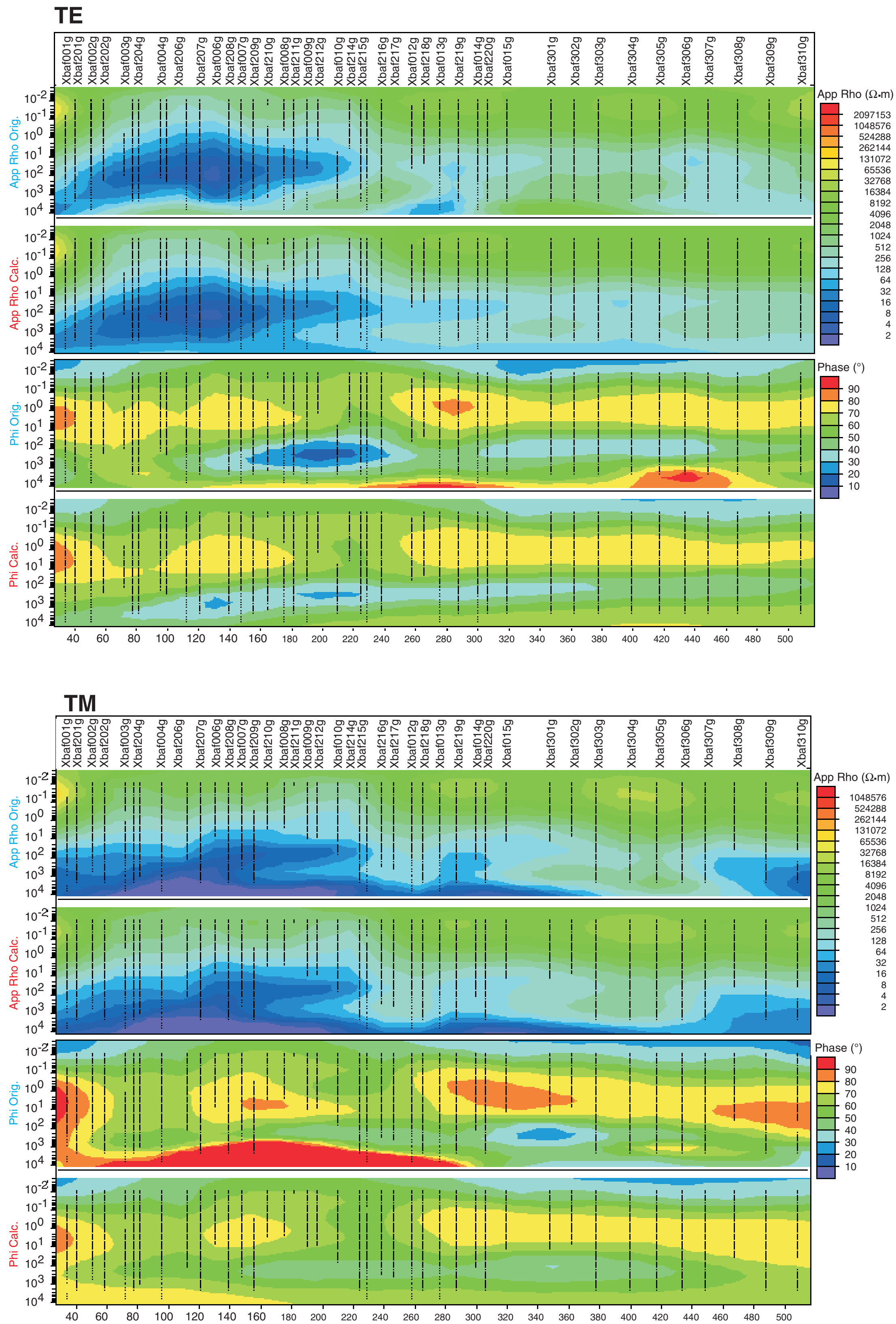

Figure 5. *Pseudo-sections showing apparent resistivity and phase from the raw data and calculated from the model for TM and TE modes.*

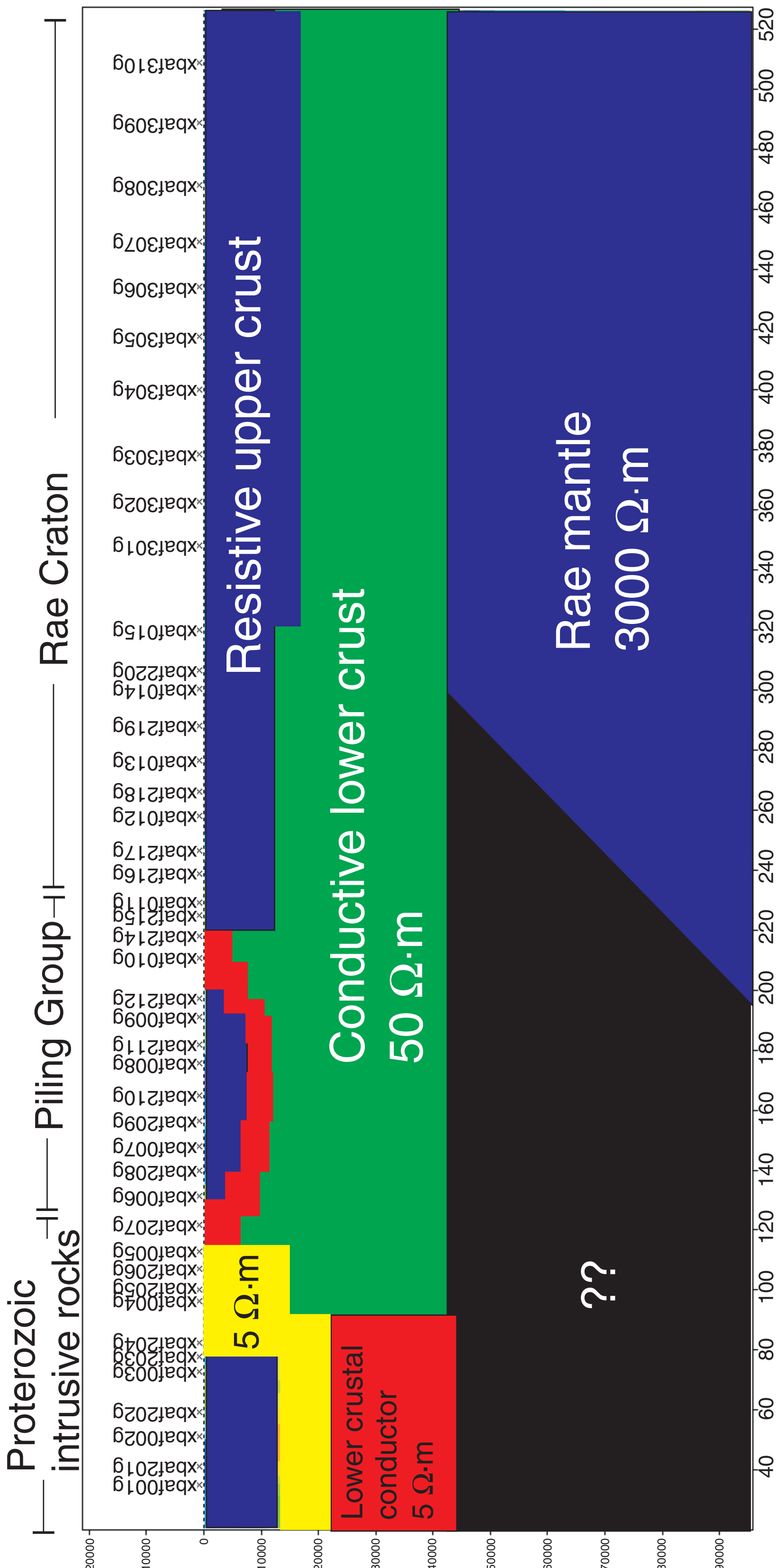

***Figure 6.** Cartoon interpretation of preliminary magnetotelluric data.*

that at some sites, processing artefacts have been introduced to the data in an effort to reduce the RMS misfit. This may be due to the variation in dimensionality along the profile. In most cases, the artefacts occur at high frequencies; as a consequence, the interpretation of shallow features must be investigated further to ensure their robustness. As part of this distortion analysis, estimates are derived of the frequency-dependent magnetotelluric impedance tensor apparent resistivity and phase due to regional structures. The apparent resistivity and phase information can then be imported into analysis and modelling software packages (e.g. WinGLink, Geotools) in order to derive a two-dimensional model from which geological interpretations are made.

PRELIMINARY MODEL

A preliminary two-dimensional resistivity-depth model is shown in Figure 4. It was obtained using the RLM2DI code of Rodi and Mackie (2001), using data from both the MT mode for current flowing parallel to strike (TE mode) and the MT mode for current flowing perpendicular to strike (TM mode). The theoretical response of the model fits observations very well in some parts of the profile and not no well in other parts (Fig. 5). The main misfit occurs at the longer period in the phase (100–1000 s). This is not an uncommon occurrence when trying to model a profile with a large number of stations. The modelling procedure nonetheless ensures low structural complexity, and subsequent modelling to improve the fit will likely still have the following large-scale electrical structures:

1. A conductive layer forms a basinal feature with a maximum depth of approximately 15 km between sites baf207 and baf010. This structure can be associated with the graphite-rich Astarte River Formation.
2. A distinct contrast, to a depth of approximately 20 km, can be seen as we go northward from sites baf214 to baf216. This contrast is indicative of the contact between the southern Paleoproterozoic metasedimentary rocks and the northern reworked Archean Rae Craton. The resistive Rae Craton can be mapped to the northern end of the profile.

3. Beneath the Rae Craton is a lower crustal conductor whose northern extent appears similar to that of the overlying craton and that also extends beneath the Piling Group. Such lower crustal conductors have been observed pervasively around the world (Jones, 1992), although electrical properties of the lower crust of the Rae Craton are markedly different here from those in the western Churchill Province (Jones et al., 2000, 2002a). Although the cause of the enhanced conductivity of the lower continental crust is still contentious, it is clear that different formation and deformation processes must have occurred here compared to the western Churchill Province.
4. Closely associated resistive and conductive bodies south of site baf205 are possibly related to the Cumberland batholith and mafic–ultramafic intrusions

INTERPRETATIONS

These preliminary observations give good insight into the geometry of the regional structures along the profile. The Astarte River Formation is of particular interest as it is exposed over a large area and laboratory analyses show that the conducting phase is interconnected graphite. The Astarte River Formation is mapped between sites baf207 and baf010 and can be used as a proxy for the base of the Piling Group as Piling Group rocks beneath the Astarte River Formation are at most 2 km thick (Scott et al. 2002, 2003). To the north, a high conductivity contrast between the Piling Group metasedimentary rocks and the northern Archean Rae Craton places the contact between the two at approximately site baf011.

A resistive body beneath sites baf001 to baf203 is spatially associated with the Cumberland batholith. Beneath and north of this resistive body is an upper crustal conductor. Sulphides associated with the Bravo Lake Formation (Stacey and Pattison, 2003) may be the source of the conducting phase within this body.

The lower crustal conductor seen in the northern half of the profile may be attributed to the Mary River Group. The imbrication of Archean basement or the emplacement of younger granitic bodies may explain why this feature is seen at such depths. Further localized analysis of this area may reveal the southern extent of this body and shed light onto questions about the basement beneath the Piling Group (Fig. 6).

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