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Foreword/Context

The Geo-mapping for Energy and Minerals (GEM) program is laying the foundation for sustainable economic development in the North. The Program provides modern public geoscience that will set the stage for long-term decision making related to responsible land-use and resource development. Geoscience knowledge produced by GEM supports evidence-based exploration for new energy and mineral resources and enables northern communities to make informed decisions about their land, economy and society. Building upon the success of its first five-years, GEM has been renewed until 2020 to continue producing new, publically available, regional-scale geoscience knowledge in Canada's North.

During the 2018 field season, research scientists from the GEM program successfully carried out 18 research activities, 16 of which will produce an activity report and 14 of which included fieldwork. Activities applied a variety of geological, geochemical, and geophysical methods. These activities have been undertaken in collaboration with provincial and territorial governments, Northerners and their institutions, academia and the private sector. GEM will continue to work with these key partners as the program advances.

Project Summary

This open file reports on a ground geophysical survey conducted on Southampton Island in the summer of 2018. The potential of ground geophysics to map the presence of porous intervals in the shallow sub-surface has been previously demonstrated in the Churchill area during GEM-1. This new survey will help with the spatial characterization of these rock layers, which are potential hydrocarbon reservoirs on Southampton Island. The area of interest is an approximately 100 km^2 region near Cape Donovan, roughly 75 km north of Coral Harbour.

Introduction

Fault-controlled hydrothermal dolomites (HTDs) are important intracratonic hydrocarbon reservoirs (Lavoie et al., 2013) and an occurrence of hydrothermal dolomites is known to be present at Cape Donovan, Southampton Island in Nunavut, Canada (Figures 1 and 2). A magnetotelluric (MT) survey was completed in July of 2018 resulted in 26 MT stations to map the subsurface extent of the HTDs.

The MT technique is an electromagnetic geophysical technique that provides imaging capabilities to mantle depths at relatively low cost in comparison to other techniques such as seismic reflection. The technique is entirely passive as it utilizes fluctuations in the Earth's natural magnetic field as a virtual transmitter. MT receivers and sensors are portable and low power, and can be deployed in remote locales with a small crew of two or three persons from a helicopter. Electromagnetic investigations, such as are involved in MT soundings, of sedimentary basins are primarily sensitive to the electrical resistivity of fluids in pores in addition to the connectivity of the pore spaces. Secondarily, EM techniques are sensitive to the host matrix of the rock and in sedimentary basins particularly, to the clay content of shale units. As such, MT techniques offer a viable manner to explore for both contrasts in lithology due to layering or faulting, and provide insights into fluid compositions within the pore matrices. For further information about MT soundings the reader is referred to Chave and Jones (2012).

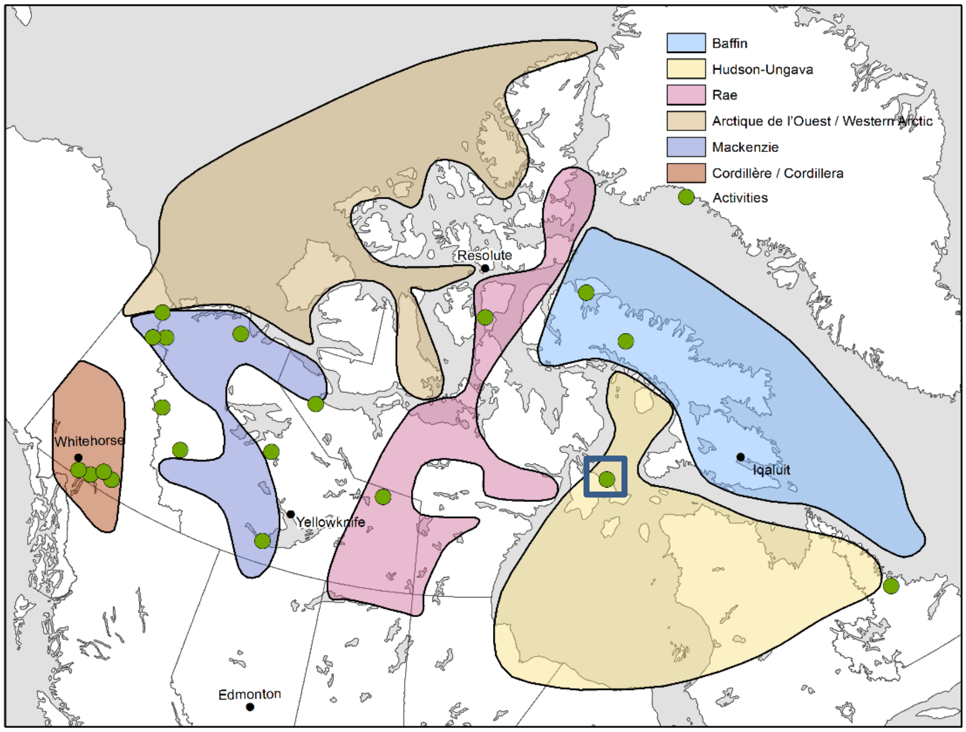

Figure 1 2018 GEM Activity Locations. Blue box highlights the study area for this report.

MT is often used for deep crustal studies however this method has proven successful during GEM-1 in generating information pertinent to the prospectivity of hydrocarbon systems by mapping and discriminating porous versus tight shallow carbonate units near Churchill, Manitoba (Bancroft et al., 2014; Roberts and Craven, 2012). This report describes a ground magnetotelluric survey that was carried out on Southampton Island in the summer of 2018 to help with the spatial characterization of potential hydrothermal dolostone hydrocarbon reservoirs (size and extent).

A previous MT survey was carried out on Southampton Island (Spratt et al., 2012) as an initiative between the Canada-Nunavut Geoscience Office and the Geological Survey of Canada to update geoscience knowledge and allow the island’s mineral and energy resource potential. The survey focussed on better understanding of outcropping and subcropping (beneath Paleozoic cover) basement geology.

Goal(s) & objective(s)

Recent GEM-funded geological mapping has indicated hydrothermal dolomite reservoirs exist within the basal sequences of the exposed Paleozoic succession on Southampton Island. The outcrop exposure, however, is insufficient to determine if the observed HTDs are regional in scope and if they, or the same host rocks beneath the Hudson Bay itself, can be inferred to possess a significant oil and gas reservoir potential. Previous ground geophysical work (magnetotelluric profiling) in the Hudson Bay lowlands has imaged unexposed HTDs where they are known to exist from stratigraphic log data and analysis of magnetotelluric data also shows that MT corroborates nearby stratigraphic logs indicating the absence of HTDs. Ground MT surveys are therefore a low-cost proven method to investigate the spatial extent of HTDs on Southampton Island. The data for 3D extension of porous zones will be used as a proxy for evaluation of size of potential hydrothermal dolomite hydrocarbon reservoirs for any specific (future) quantitative resource evaluation of the Hudson Bay and Strait basins.

Scientific question(s) addressed

The overarching question the new survey will help address is: how have tectonic factors such as faulting, burial and exhumation influenced the architecture and geological evolution in relation to petroleum prospectivity of the Hudson Bay basin? In particular, MT surveys will help determine if HTDs are a significant mechanism involved in the formation, evolution and hydrocarbon potential of Hudson Strait and Foxe Basin and would ascertain if key faults related to the HTDs are an important factor contributing to the petroleum prospectivity of the Hudson Bay basin.

Methodology

The MT method is an electromagnetic technique measuring the Earth's natural magnetic and electrical field at various ground locations. At each location shown in Figure 1 four electrodes and three magnetic coils are buried in shallow holes and recordings of the variations in the electric and magnetic fields are recorded overnight. There were four or five such locations deployed each night and the survey lasted for roughly two weeks. Processing of the data collected is occurring now to reveal images of sub-surface layers, but preliminary plots and maps can be made just from the data itself. The time series of electric and magnetic field variations collected at each site were transformed into apparent resistivity and phase curves in a manner similar to that described in Roberts and Craven (2012). An example of the transformed data from site 12 is shown in Figure 3. The data were transformed using an Electric -field remote referencing system (Chave and Jones, 2012) to compensate for the low ambient signal amplitudes of the natural magnetic field and relatively high noise levels of the sensors utilized (MTC-80H). These sensors were utilized primarily because of their low weight and small size that facilitated remote acquisition and helicopter access. Their low power draw meant lighter batteries (35 Ah) could be used to power the recordings.

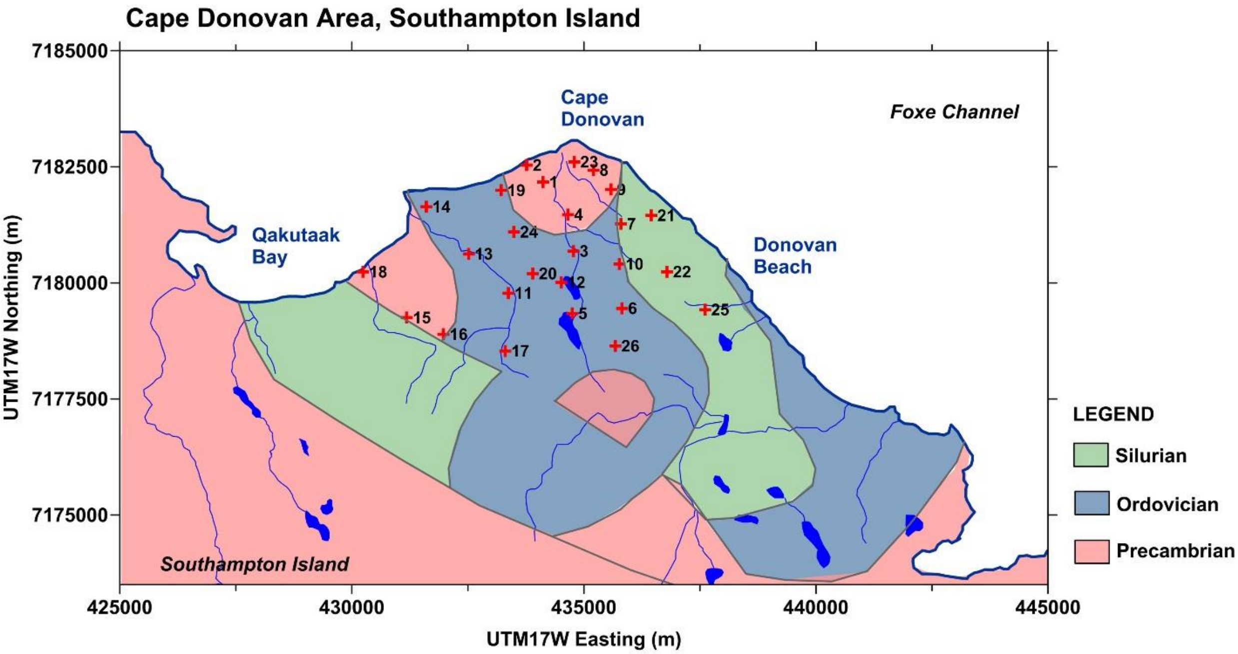

Figure 2. Geology from Zhang (2010) and locations of the 26 MT sites

The curves presented in Figure 3 are commonly called responses and have been plotted using a coordinate system where responses are computed at 0 degrees rotation from magnetic north. In this coordinate system, XY responses are computed from an electric field at 0 degrees from magnetic north and a magnetic field at 90 degrees. Similarly, the YX responses are computed from an electric field at 90 degrees and a magnetic field at 0 degrees from magnetic north. The responses are commonly shown as apparent resistivities and phases as they tend to be useful for qualitative analysis such as described in the next section. In general, where respective XY and YX curves within a frequency or period band differ from each other, it is an indication the subsurface is departing from simple layered geometries to more complex geological situations related to faulting, folding ore fluid infiltration. Data in the split period band are in fact dependent on the azimuth selected. We can see such a band at periods longer than approximately 100 Hz (10^{-2} s) in Figure 3. Care must be taken to choose the correct azimuth of the coordinate system used for further data analysis in this band. Further information about the dimensionality of data (1-D, 2-D or 3-D) can be found in Chave and Jones (2012).

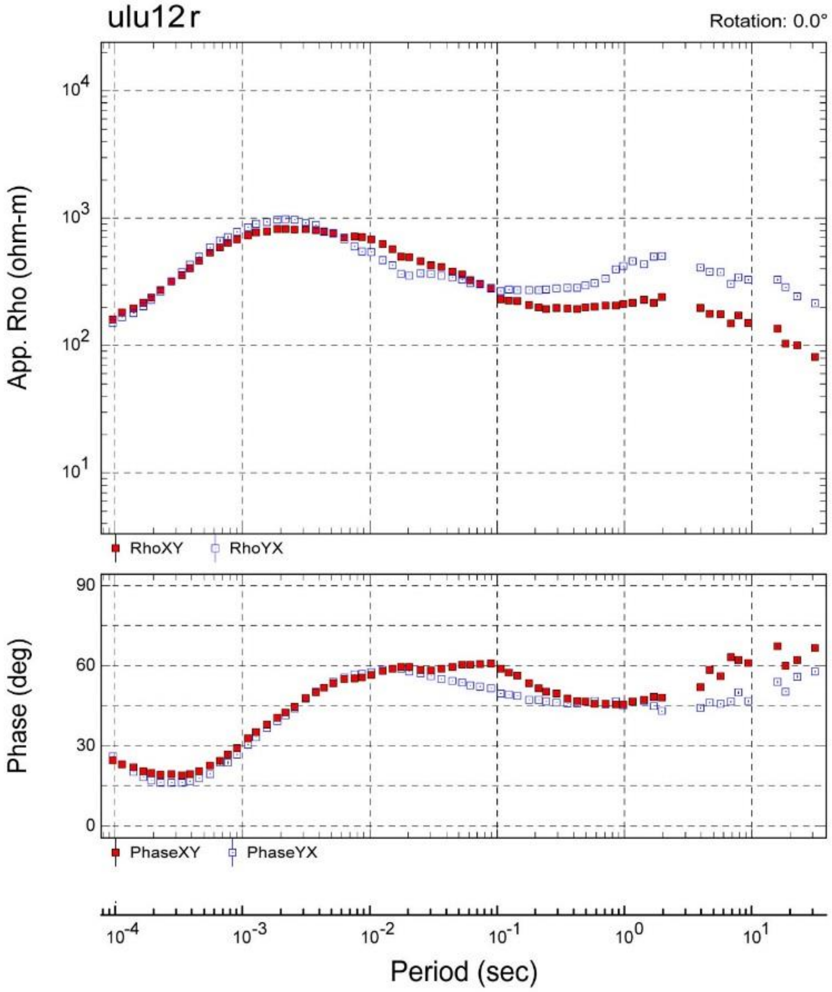

Figure 3 Apparent resistivity and phases for site 12.

Results

Quantitative analysis of the data involves modelling the data to derive spatial variation in electrical resistivity and porosity. Such an analysis will arise in future reports and papers; however, qualitative analysis of the data can be done by simply contouring the data to form maps or profiles. We present here two maps of based on invariant properties of the data collected, meaning the quantities presented do not depend on the azimuth selected. The invariant is calculated by taking an average of the two responses. The map shown in Figure 4 represents contours of the invariant apparent resistivity at each site at 100 Hz. The apparent resistivity is a volumetric average of the true electrical resistivity near each site and so provides a qualitative guide to the subsurface structure. The higher apparent resistivity values are plotted in green and blue and represent more resistive material such as limestone or Precambrian basement. Basement shown in Figure 2 near site 14 is apparent in Figure 4 but elsewhere the relationship is complicated suggesting the geological maps may need updating based on our data. The warmer colours in Figure 4 may be more related to shales or porous material such as HTDs. The HTDs occur in outcrop near site 23.

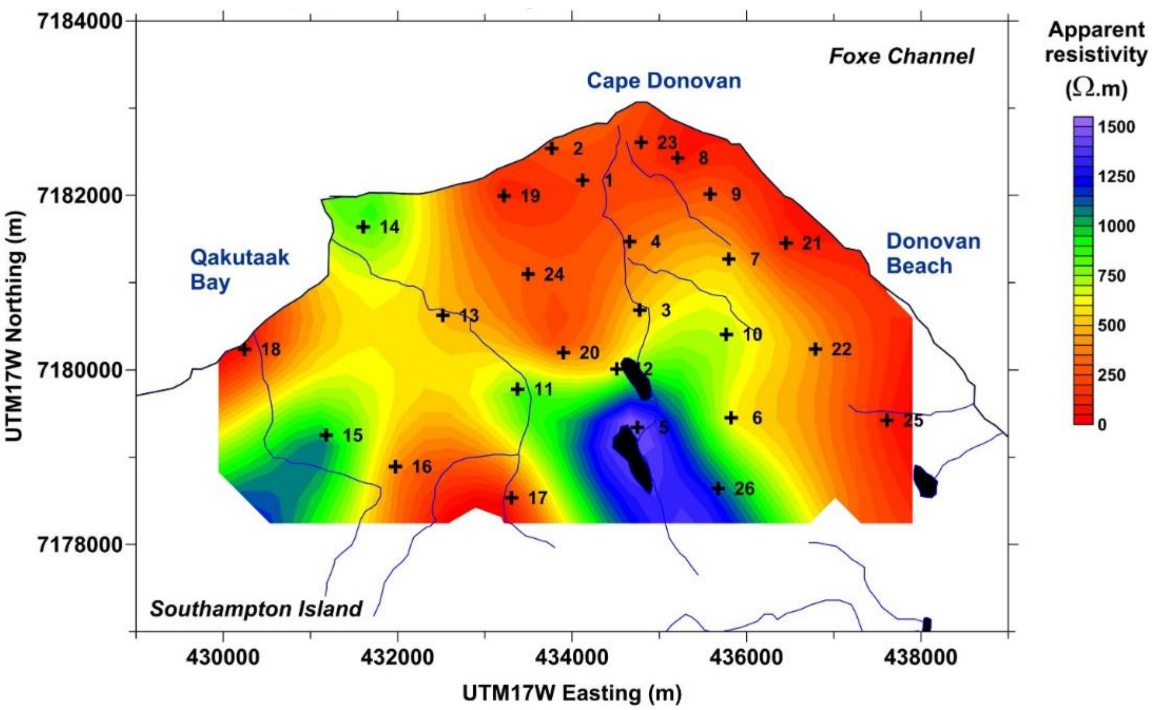

Figure 4 Map of invariant apparent resistivity at 100 Hz (10^{-2} s).

The invarant phase shown in Figure 5 is a little more complicated as it respresents an average change in the resitvitity with depth near each site and in general shows that the region of low apparent resitivity visble near site 23 transitions inland as it deepens and appears to form a broad corrridor towards the southeast (towards site 26).

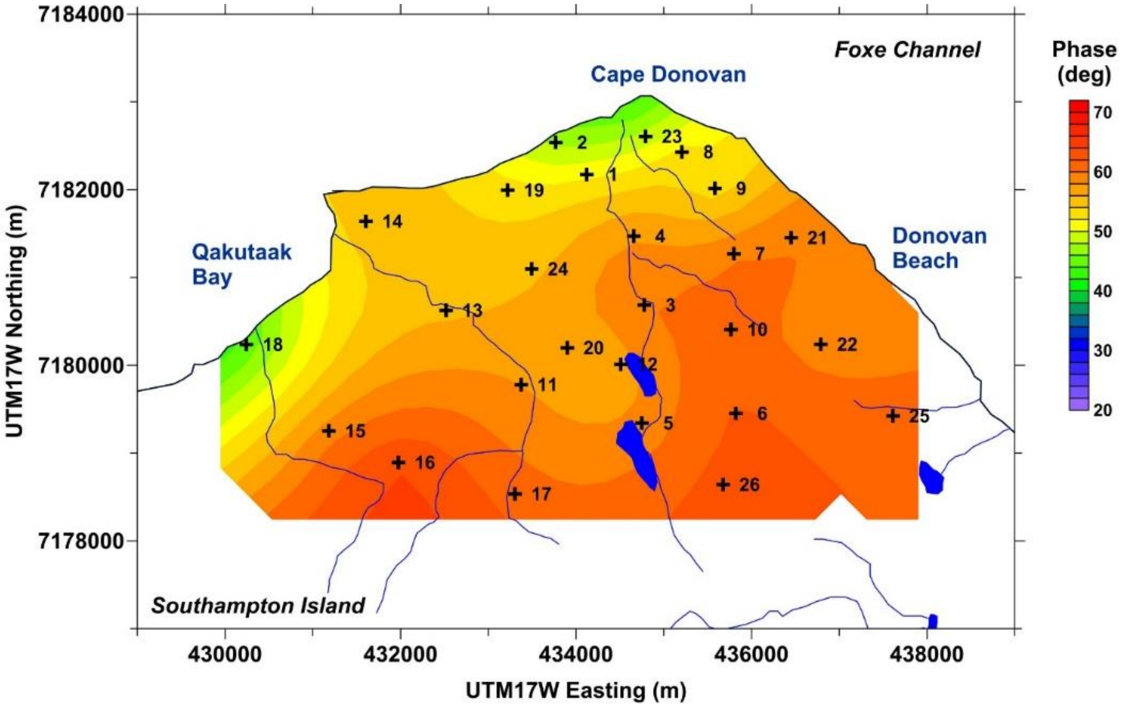

Figure 5 Map of invariant phase at 100 Hz (10-2 s).

Future work/next steps

The next step is to move towards quantitative understanding of the spatial and depth variation of low resistivity zones likely associated with porous HTDs. Such a quantitative step can only be done using model studies to map features of interest. Rock property petrophysical studies are vital to identify the resistivity signatures of HTDs and host geological units (similar to that performed in Bancroft et al 2014). The model studies need to be preceded by studies of the data using methods described in Chave and Jones to derive the dimensionality of the data and determine an appropriate modelling methodology, be it 1-D, 2-D or 3-D.

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