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Abstract: At extreme latitudes the magnetotelluric method is not generally utilized. This is due primarily to difficulties in making electrical contact with the ground sufficiently well to measure the electric field. Because of this, the magnetotelluric technique has not been previously investigated to direct detect gas hydrate in on-shore permafrost environments. The authors present the results of recent field tests at the Mallik gas hydrate production research well site, Northwest Territories that demonstrate good quality magnetotelluric data can be obtained in this environment using specialized electrodes and buffer amplifiers similar to those utilized previously by other workers. This result suggests that subsurface images from larger magnetotelluric surveys will be useful to complement other techniques to detect, quantify, and characterize gas hydrate.

Résumé : En général, la méthode magnétotellurique n'est pas utilisée à des latitudes extrêmes. Cela s'explique principalement par la difficulté à établir avec le sol un contact électrique suffisant pour mesurer le champ électrique. Pour cette raison, la méthode magnétotellurique n'avait pas été retenue antérieurement pour la détection directe d'hydrates de gaz dans des milieux côtiers à pergélisol. Nous présentons les résultats de récents essais y sur le terrain au site des puits de recherche sur la production d'hydrates de gaz Mallik, dans les Territoires du Nord-Ouest, qui démontrent qu'il est possible d'obtenir, dans cet environnement, des données magnétotelluriques de bonne qualité au moyen d'électrodes spécialisées et d'amplificateurs intermédiaires similaires à ceux utilisés par d'autres chercheurs. Ces résultats indiquent que les images du sous-sol, obtenues lors de levés magnétotelluriques plus étendus, seront utiles pour compléter d'autres techniques servant à mesurer, quantifier et caractériser les hydrates de gaz.

INTRODUCTION

The Earth Science Sector is responsible for providing realistic estimates of the quantities of gas hydrate deposits across Canada (*see* for example Osadetz et al. (2005)). Such estimates are hampered by the rather harsh environments in which gas hydrate deposits are found and the sparse well-log intersections. Estimates of permafrost gas-hydrate quantities and properties are no exception. Because gas hydrate in the Arctic is difficult to detect from the surface, different geophysical techniques need to be investigated for their reliability and efficacy to assess gas hydrate concentrations. Contours in Figure 1 are the depth to the base of this layer inferred by Majorowicz and Smith (1999) at Mallik. Only a few geophysical techniques have the ability see this deep. One method which may be of use and should be tested is the magnetotelluric (MT) technique. As discussed in more detail in Craven (2007), the magnetotelluric technique is a low-cost, portable, environmentally benign geophysical technique to probe the subsurface resistivity structure. Craven (2007) showed that as the concentration and resistivity of the gas-hydrate layer increases then one can see certain changes in the MT response curves, most noticeably the phase. This effect becomes less pronounced as the resistivity of the layer becomes sufficiently high due to the fact that, as with all inductive electromagnetic techniques, while excellent at finding conductive units, MT response is generally not as sensitive to resistive targets such as ice. The goal of the authors is to find a signature in the data, perhaps due to the dramatic decrease in resistivity at the base of the gas hydrate layer that will permit it to be mapped over large areas.

The presence of winter roads and exploration camps in areas of permafrost gas hydrate suggests winter deployments may be simpler logistically. In addition, the presence of the snow and ice upon the surface minimizes any environmental damage that can be done in this sensitive area. For these reasons it may be advantageous to make recordings in the

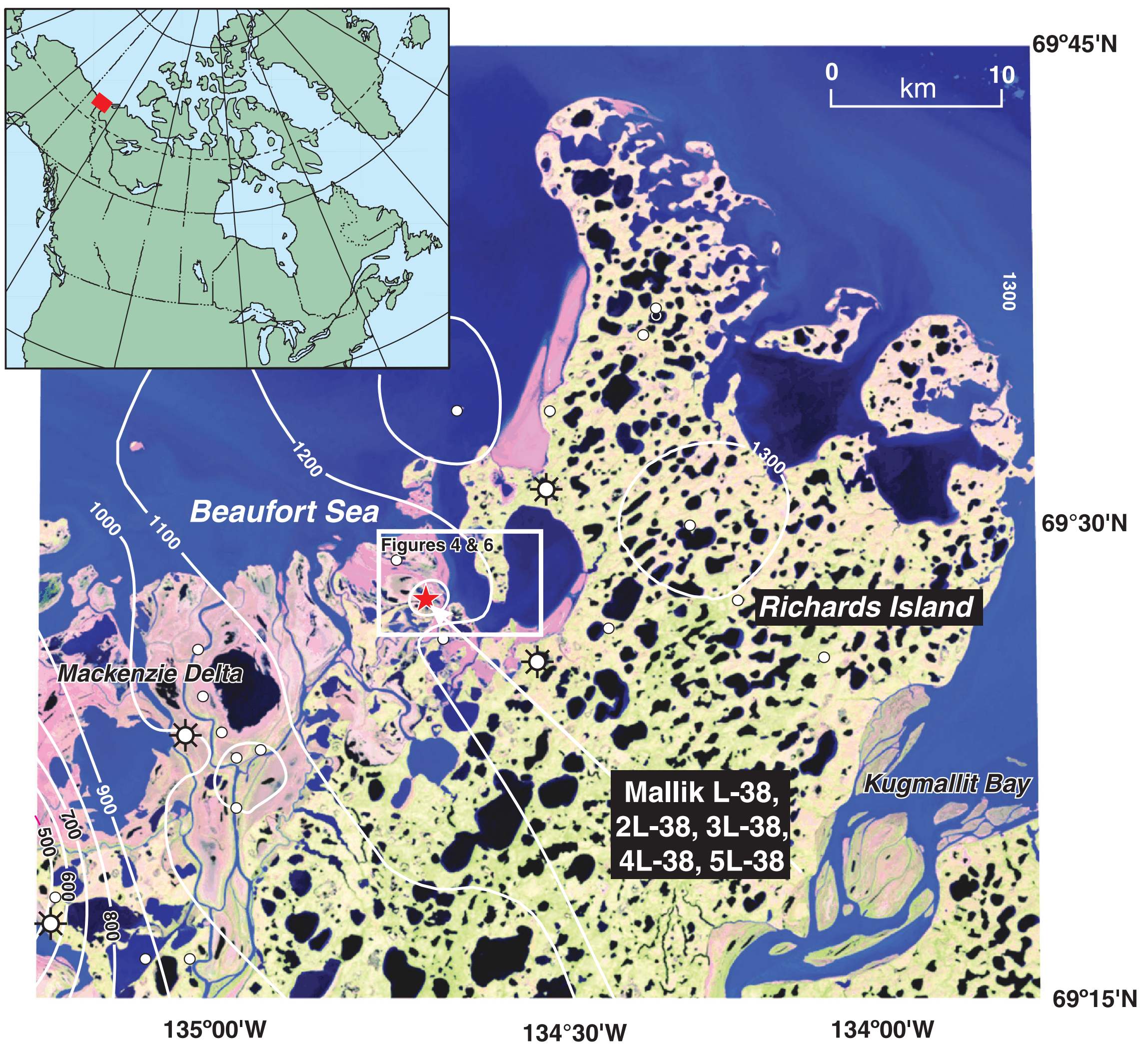

Figure 1. Mallik well site location (*modified from* Dallimore and Collett, 2005) showing location of Figures 4 and 6.

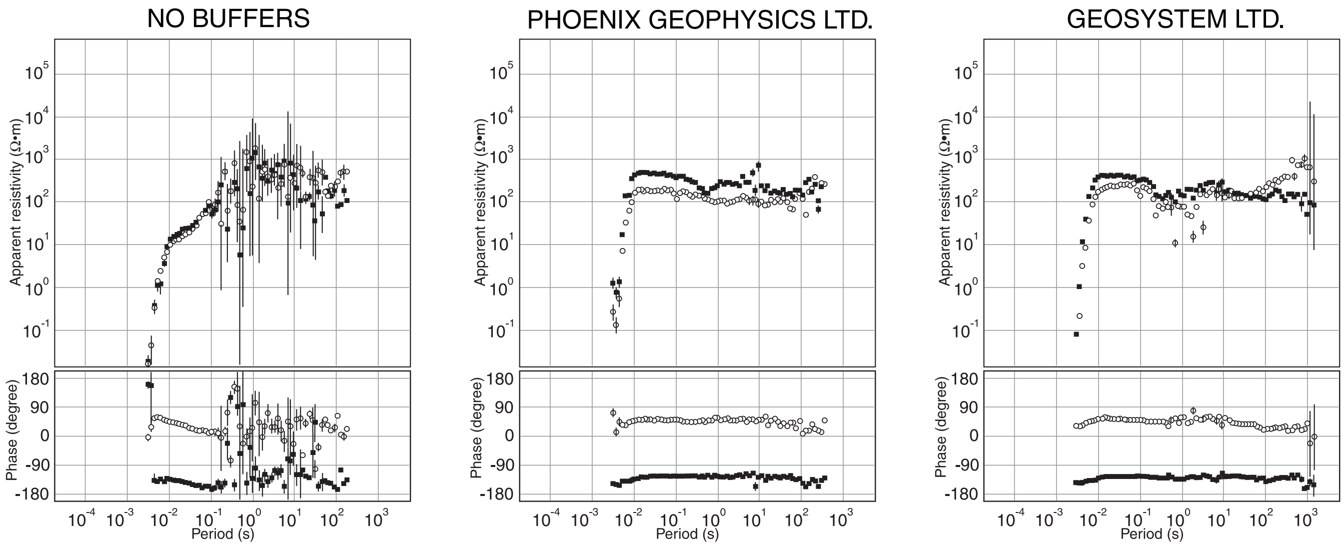

Figure 2. Magnetotelluric response curves calculated with a common set of magnetometers and electrodes with no buffer amplifiers, with buffer amplifiers supplied by Phoenix Geophysics Ltd., and with those borrowed from Geosystem Ltd.

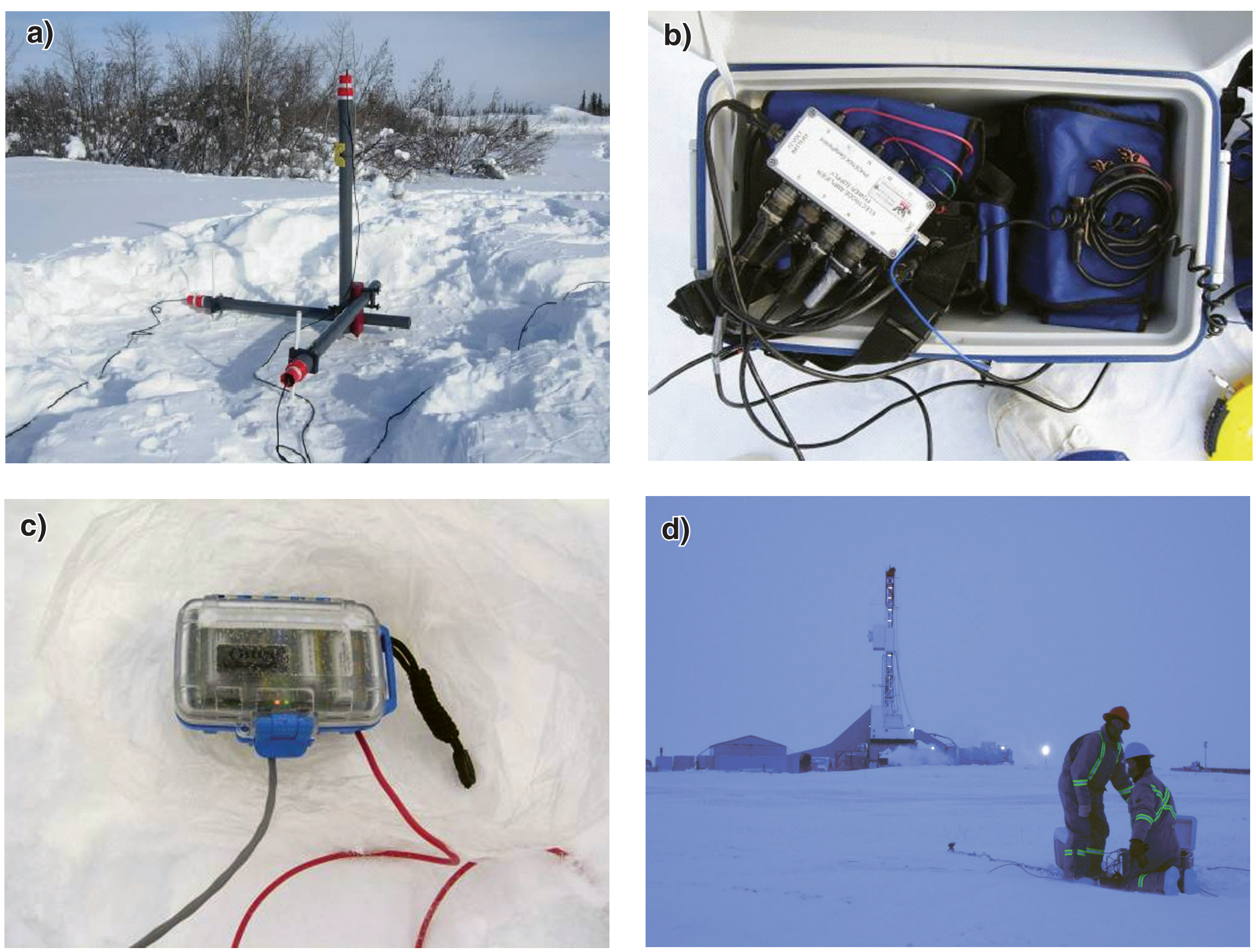

Figure 3. Photographs of the magnetometers in **a)** a tripod; equipment is 2 m high; **b)** Phoenix Geophysics Ltd. buffer amplifier power controller; Coleman® cooler is about 50 cm across; **c)** Geosystem Ltd. buffer amplifier; box is 8 cm wide; and **d)** 'malsewage' (Fig. 4) site location; people are approximately 2 m tall.

winter. The drawbacks, of course, are the prevailing weather conditions and the ability, or lack thereof, of making the galvanic contact necessary for electric field measurements due to the high electrical resistivity of the snow and ice at the surface. This paper explores the electrical properties of the gas hydrate deposits, the potential of MT techniques to detect them, and finally shows preliminary data collected to test the ability to record electric field and earth responses in this harsh environment.

BUFFER AMPLIFIER TESTS

Figure 2 illustrates the results of three simultaneous measurements of the MT response just outside Inuvik, Northwest Territories. The recordings in each case were 6 h long. The magnetic fields common to each response estimate were collected using a special tripod for winter work (Fig. 3a). The electric fields were collected using the titanium sheet electrodes borrowed from P. Wannamaker at the University of Utah. The generally high contact impedance of frozen earth and snow relative to the input impedance of the electronics make amplification and subsequent recording of the electric fields difficult. Buffer amplifiers make this situation tractable by amplification of a signal with a low-input impedance amplifier that preserves signal amplitude and phase.

Three cases are shown in Figure 2, the first without any buffered amplifier. The last two with buffer amplifiers purchased from Phoenix Geophysics Ltd. and manufactured by Numeric Resources Ltd. and borrowed from Geosystem Ltd. The Phoenix Geophysics Ltd. buffer amplifiers require external 12 V battery power, shown housed in the central recording cooler (Fig. 3b), in contrast to the Geosystem Ltd. buffer amplifiers (Fig. 3c), which operated using AA batteries. In both cases special wiring and grounding is required to complete the connection. The authors concluded from an examination of these plots that the buffer amplifiers are necessary, provide reasonable estimates of ground resistivity, and for this test case the Phoenix Geophysics Ltd. data are slightly better in quality. On the whole, the authors found the Phoenix Geophysics Ltd. buffer amplifiers easier to use, but this may be due more to unfamiliarity of the authors with the equipment.

TEST DATA

In March of 2007 data were collected at three locations near the Mallik drill-test site (red dot in Fig. 4) during drilling operations (Dallimore et al., 1999; Dallimore and Collett, 2005). The first site, 'malsewage' (informal site name used for convenience) (Fig. 5a), was clearly affected by the noise related to the various power sources (Fig. 3d). The remaining two sites, about 500 m and 1000 m down the winter road to the Mallik site, were of better quality. One site, 500 mark (Fig. 4, 5b) was unfortunately affected by data loss due to a short at the connection of the Geosystem Ltd. buffer amplifiers to ground. The third site, 1000 mark (Fig. 4, 5c), furthest from the noise sources and collected using Phoenix Geophysics Ltd. buffer amplifiers, was of fair to good quality.

In late March of 2008 a number of sites were occupied along a line near the Mallik research well drill site. The profile of sites is shown in Figure 6. The 2007 sites are shown in yellow and the 2008 sites are shown in green. Note the bulk of the sites extend across a frozen inlet. The red dot is the location of the drill rig. Again, the area was quite noisy electrically during recording. The background contours of seismic velocities were estimated from tomographic analysis of an industry 3-D seismic-reflection data set. The depth slice is at 100 m through a 3-D P-wave velocity model obtained from direct-arrival traveltime tomography. Low P-wave velocity (blue) areas are found beneath large lakes and deepwater channels and related to partly thawed permafrost.

The 2008 data are of highly variable quality; however, one site (location identified by arrow on Fig. 6) produced exceptionally good data (Fig. 7). The data collected at this site were daytime only and therefore there are holes in the

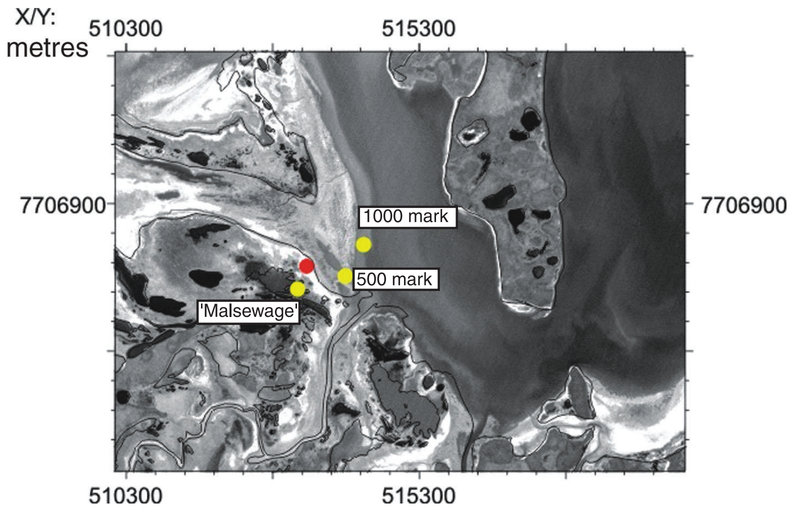

Figure 4. Zoomed in area shown in Figure 1 with location of the Mallik well site, 'malsewage', 500 mark, and 100 mark site locations shown.

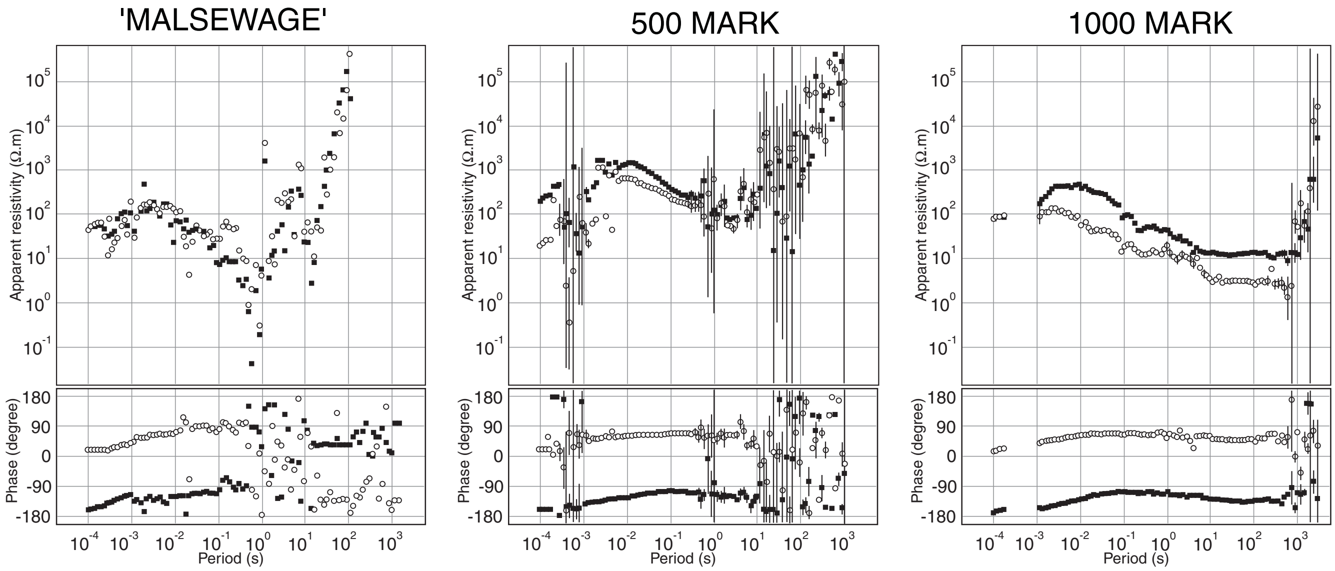

Figure 5. Plots of data collected in 2007 at the three test sites: 'malsewage', 500 mark, and 1000 mark. Some large error bars have been omitted for clarity.

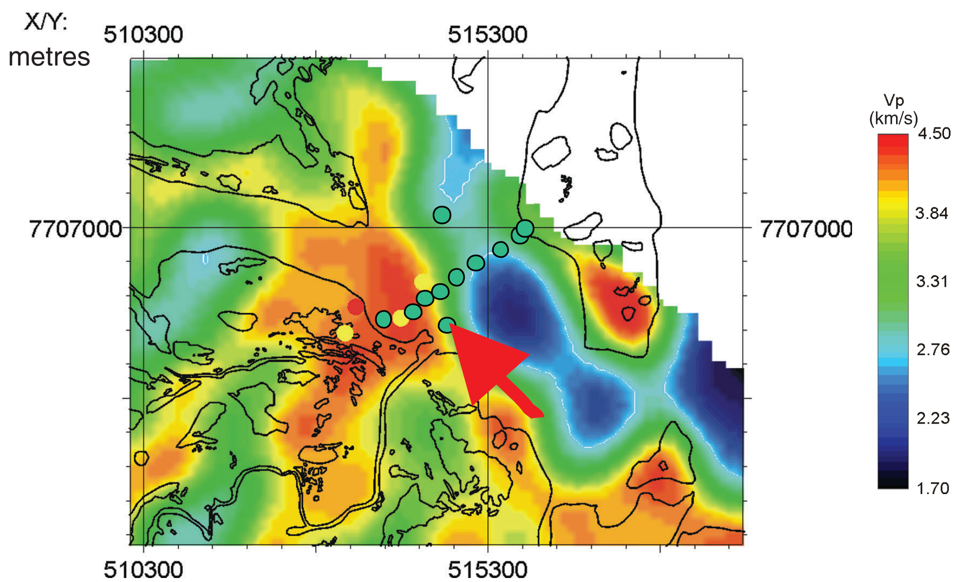

Figure 6. Map of shallow seismic velocity (Bellefleur et al., 2008). Colours in the blue range are indicative of melt zones in the permafrost. Site locations for 2008 work are shown. The site location of data shown in Figure 7 is highlighted with red arrow.

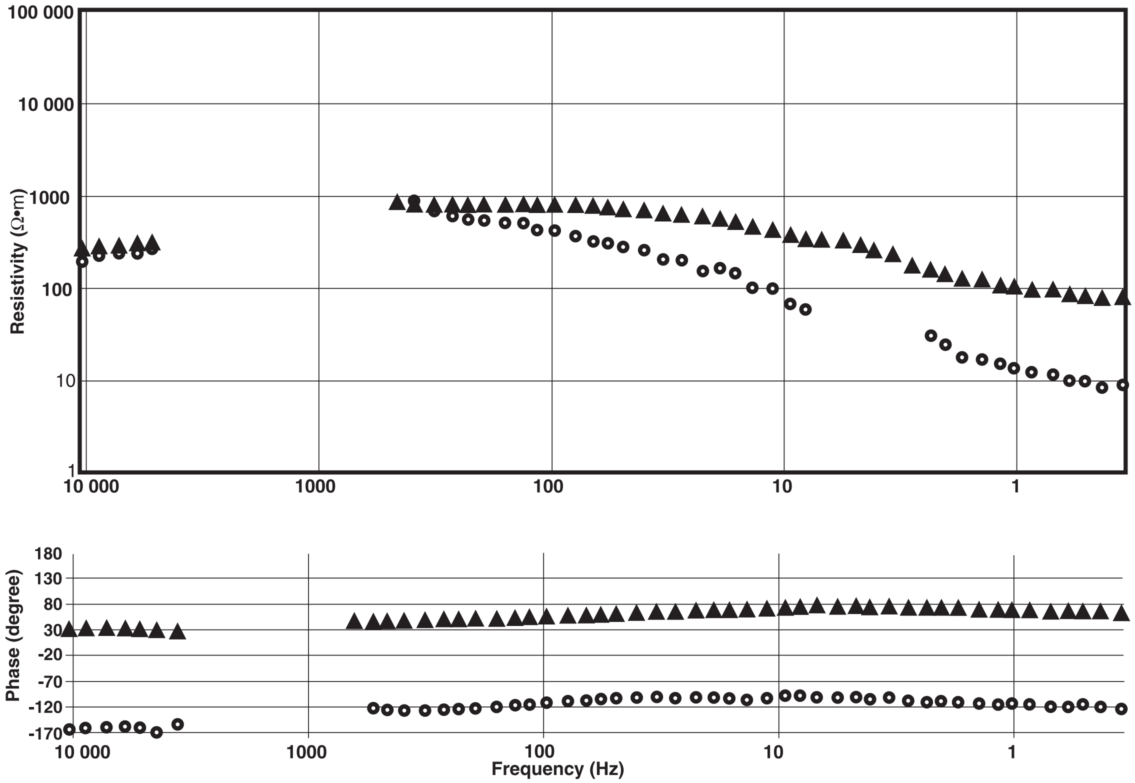

Figure 7. Plot of data collected in 2008 at the site shown in Figure 6.

spectral estimates due to weak signal. This site was located on the mainland and the tripod was not used. The authors therefore suspect tidal ice movement and wind are significant sources of noise.

CONCLUSIONS

The authors have shown that high quality MT recordings can be made in this harsh environment. This result is one step in the process of investigating MT techniques as an inexpensive, environmentally friendly geophysical tool to map or detect gas hydrate deposits regionally. The overarching goal for ESS is to be able to provide more reliable estimates of the volume or quantity of methane as resource in the permafrost environment. From knowledge gained over the last two field excursions the authors seek to reinvestigate the area winter 2009 when there is little or no electrical noise in the region and to generate sufficient data to render a subsurface profile.

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