Capacitive-coupled resistivity survey of ice-bearing sediments, Mackenzie Delta, Canada

H. Thomas Calvert, Geological Survey of Canada, Ottawa, Ontario, Canada

Summary

Capacitive-coupled resistivity surveys have been carried out across permafrost terrain in the Mackenzie Delta, Northwest Territories, Canada. The first survey (Timofeev et al., 1994) was conducted in 1992 using a 10 m dipole-dipole array and a dipole-dipole spacing of 40 m. A new survey was conducted during March 2002 with a recently developed capacitive-coupled resistivity system using dipole-dipole spacings of 10 to 100 m in order to obtain a two-dimensional resistivity image of subsurface. There is good correlation between the two surveys. Inversion of the resistivity image has been useful in developing a geological model from which permafrost conditions can then be interpreted.

Introduction

Since the early 1970s the Geological Survey of Canada has been investigating the use of geophysical techniques to map ice-bearing sediments in the Mackenzie Delta of the Northwest Territories. The techniques used have included gravity, seismic refraction, electromagnetic terrain conductivity, ground penetrating radar (GPR), resistivity and down-hole geophysical logging.

A map showing the location of the Mackenzie Delta is shown in Figure 1. Lousy Point is located on the east side of Richards Island. A 7.4 km long transect across undulating permafrost terrain has been established at this site. A summary of the previous geophysical surveys has been presented by Calvert et al. (2001).

Method

The theory governing the capacitive-coupled resistivity method has been discussed by Timofeev et al. (1994). The method operates at frequencies in the range of 8 to 32 kHz using dipole transmitter and receiver antennae. Current is applied to the ground via capacitive-coupling and the resulting potential is measured at the receiver dipole. The method has an advantage in areas where surface resistivity is extremely high and galvanic resistivity surveys encounter current injection problems. In areas of permafrost, surface resistivities exceeding 10,000 ohm-metres are often encountered. Since direct contact with the ground is not required, the array can be towed along the surface while collecting data, resulting in high acquisition rates. In areas of high electrical conductivity the depth of investigation is limited due to the attenuation of the signal at high frequency (skin depth).

The most effective antenna array for the capacitive-coupled resistivity method is the dipole-dipole array since the distance between the dipoles (n-spacing) can be easily varied to change the depth of investigation. The geometry is identical to that of dipole-dipole galvanic resistivity surveys.

A capacitive-coupled resistivity survey was conducted previously along the Lousy Point Transect in March 1992 using the VCHEP system (Timofeev et al., 1994). A dipole length of 10 m and a dipole-dipole spacing of 40 m (n = 4) was used. The system was towed behind a snowmobile and measurements were taken at 100 m intervals.

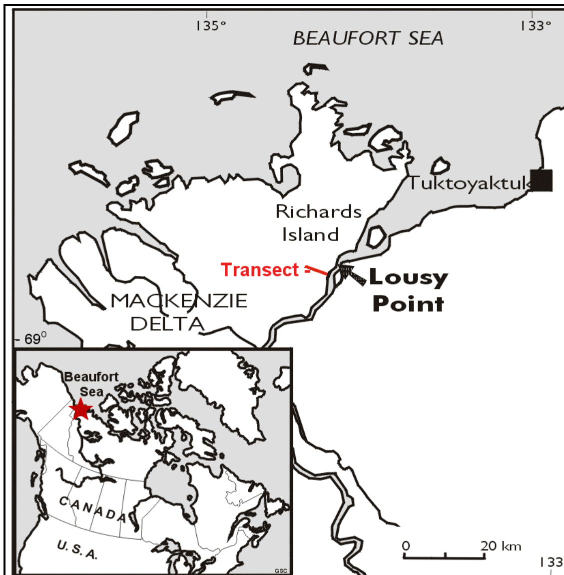

Figure 1: Location of Lousy Point Transect.

The Lousy Point Transect was revisited in March 2002 to evaluate the use of the Geometrics OhmMapper TR1 capacitive-coupled resistivity system, the basic design of which is similar to the VCHEP system. The system operates in a continuous mode, allowing high-resolution surveys to be acquired very quickly. For the Lousy Point Transect, a dipole length of 10 m and dipole-dipole spacings of 10 to 100 m (n = 1 to 10) were used. At dipole-dipole spacings of more than 100 m, it was found that the signal became too weak to measure in zones of lower resistivity. The system was towed behind a snowmobile at a speed of approximately 7 km/hr. By using continuous mode, a measurement interval of approximately 1 m was obtained.

Capacitive-coupled resistivity survey

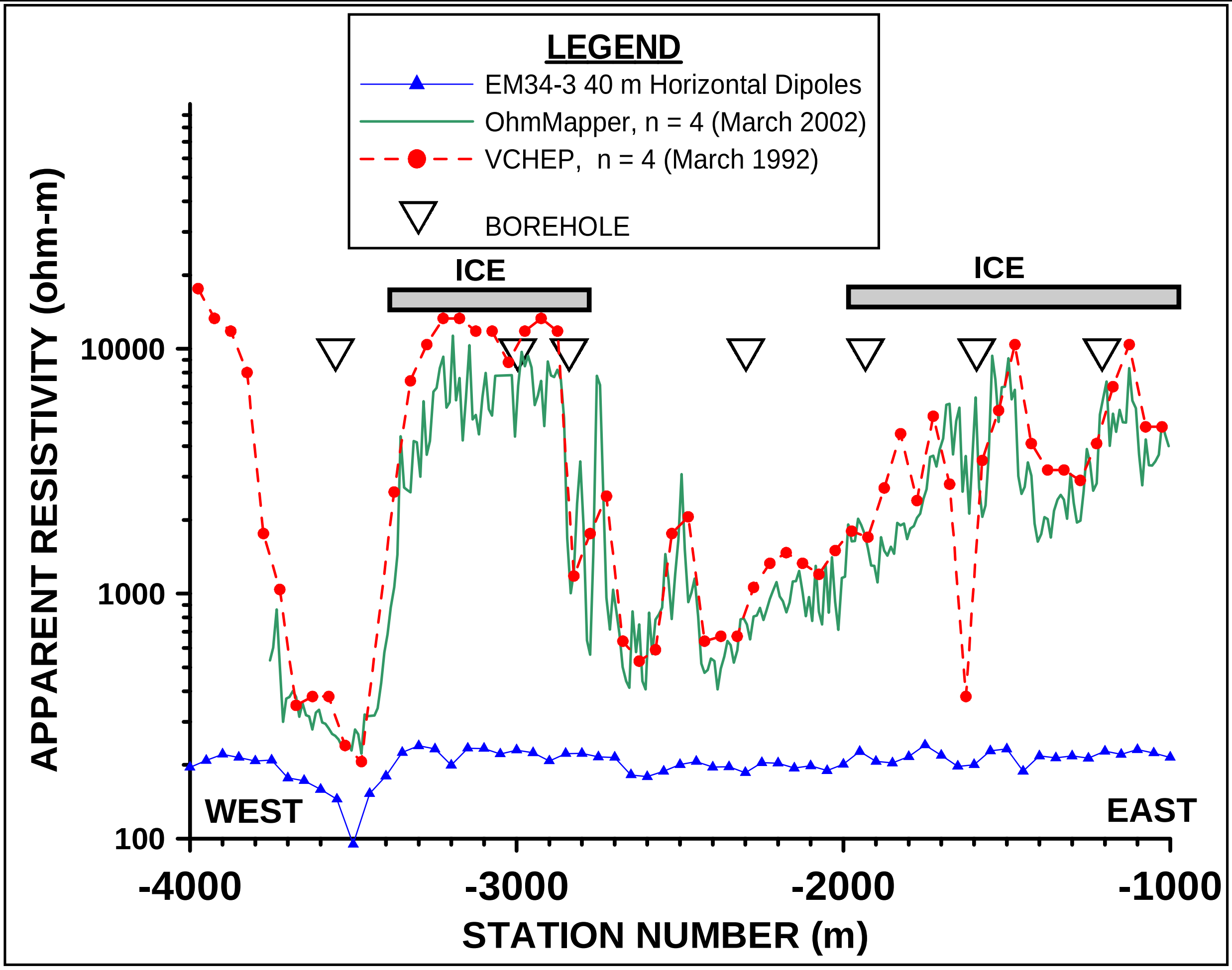

Figure 2: Lousy Point Transect resistivity profiles for Geonics EM34-3 (40 m horizontal dipoles), OhmMapper (10 m dipoles, n = 4) and VCHEP (10 m dipoles, n = 4).

Results

A comparison of the apparent resistivity profiles at a dipole-dipole spacing of 40 m for the VCHEP and OhmMapper systems is shown in Figure 2. There is good correlation between the profiles. High resistivity zones correspond to ground with massive ice or high ice content. The smaller sample interval in the 2002 survey indicates that there is significant lateral variation along the profile. The profile for the EM34-4 40 m horizontal dipole survey, which was also conducted in 1992, does not appear to be able to resolve the extremely high resistivities encountered.

The capacitive-coupled resistivity data set collected during the March 2002 survey was processed with the two-dimensional resistivity inversion software RES2DINV that uses the method described by Loke and Barker (1996). The measurements were re-sampled to provide a data set with a 10 m station interval before processing. The resulting measured apparent resistivity pseudosection, calculated apparent resistivity pseudosection and model resistivity with topography are shown in Figure 3. The vertical exaggeration for the topography section is 10 times. The east end of the section is on the bank of the Mackenzie River where saline sediments have been encountered. The good correlation between the measured and calculated apparent resistivity pseudosections indicates a reasonably fitting model. The high resistivity zones occur in areas with massive ground ice or greater than 30 percent ice content. The low resistivity zones correspond to areas where permafrost has thawed. Measurements with dipole-dipole spacings of greater than 60 m were not acquired in the zone from –3800 to –3200 due to high signal attenuation in the area of lower resistivity.

Capacitive-coupled resistivity survey

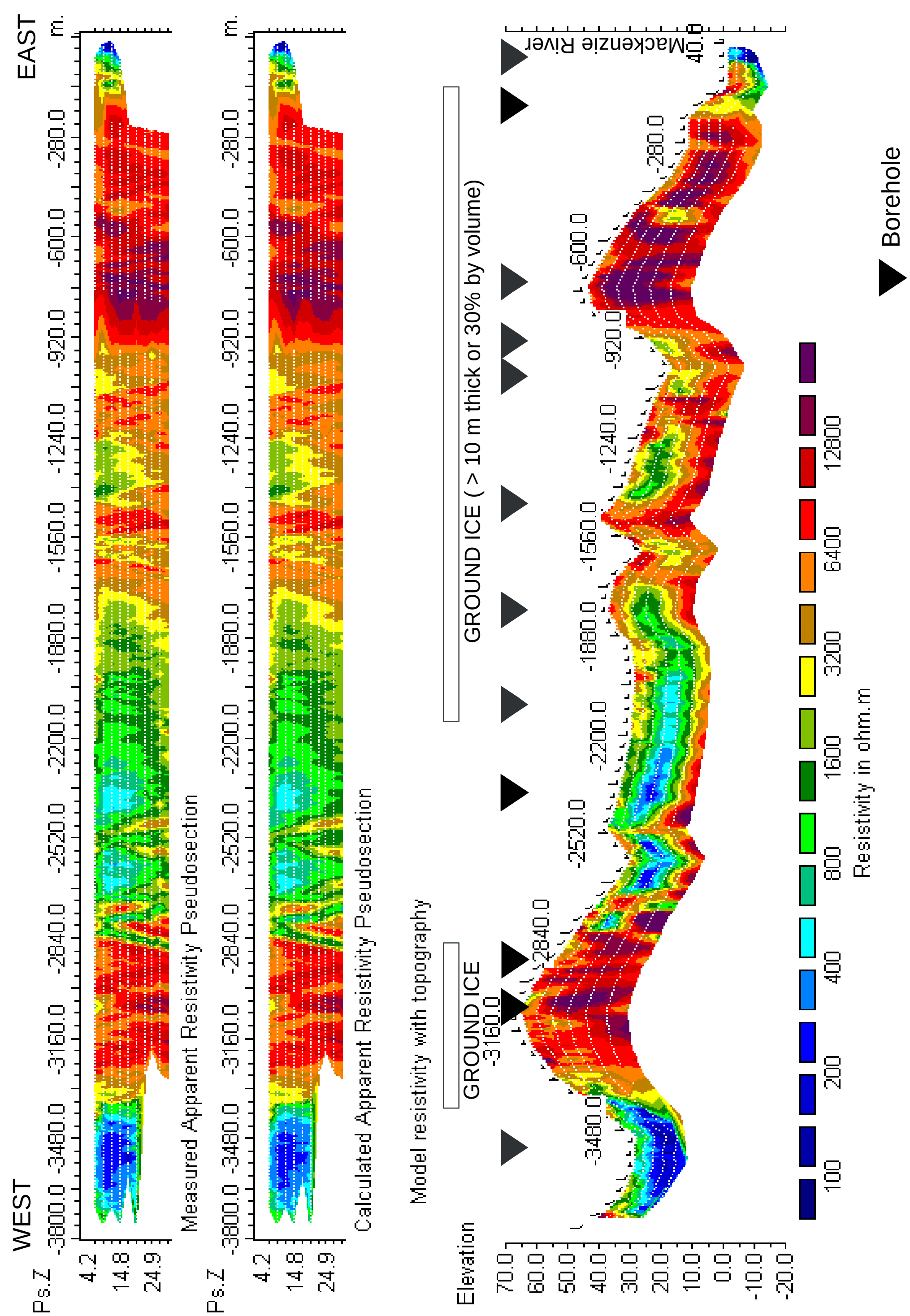

Figure 3: Dipole-dipole measured apparent resistivity pseudosection, calculated apparent resistivity pseudosection and model resistivity with topography for Lousy Point Transect.

Conclusions

Capacitive-coupled resistivity surveys have been shown to be effective in mapping ice-bearing sediments in the Mackenzie Delta where surface resistivity can be extremely high. Dipole-dipole spacings of up to 100 m can be used over most areas. In zones of lower resistivity, the depth of investigation is reduced. Excellent correlation was shown between the apparent resistivity profiles obtained from the surveys conducted in 1992 and 2002. Two-dimensional resistivity images can be acquired relatively quickly using capacitive-coupled systems and processed to obtain a geo-electric section that can aid in geological interpretation.

Acknowledgements

The fieldwork conducted at Lousy Point during March 2002 was carried out with the assistance of Ron Good and Chanelle Lépine of the Geological Survey of Canada. Marten Douma of the Geological Survey of Canada provided the data obtained during the 1992 survey. Thanks also to Dr. Jim Hunter of the Geological Survey of Canada for reviewing this manuscript.

References

Calvert, H.T., Dallimore, S.R., and Hunter, J.A., 2001, Application of geophysical techniques for mapping ice-bearing sediments, Mackenzie Delta, Western Arctic, Canada. Conference on the Geophysical Detection of Subsurface Water on Mars, Lunar and Planetary Institute, August 6-10, Houston TX, 14-15.

Loke, M.H. and Barker, R.D., 1996, Rapid least-squares inversion of apparent resistivity pseudosections by a quasi-Newton method. Geophysical Prospecting, 44, 131-152.

Timofeev V.M., Rogozinski, A.W., Hunter, J.A. and Douma, M., 1994, A new ground resistivity method for engineering and environmental geophysics. Proceedings of the Symposium on the Application of Geophysics to Engineering and Environmental Problems, EEGS, 701-715.