Ground Ice Detection with Spectral Induced Polarization
A Case Study at Haines Junction

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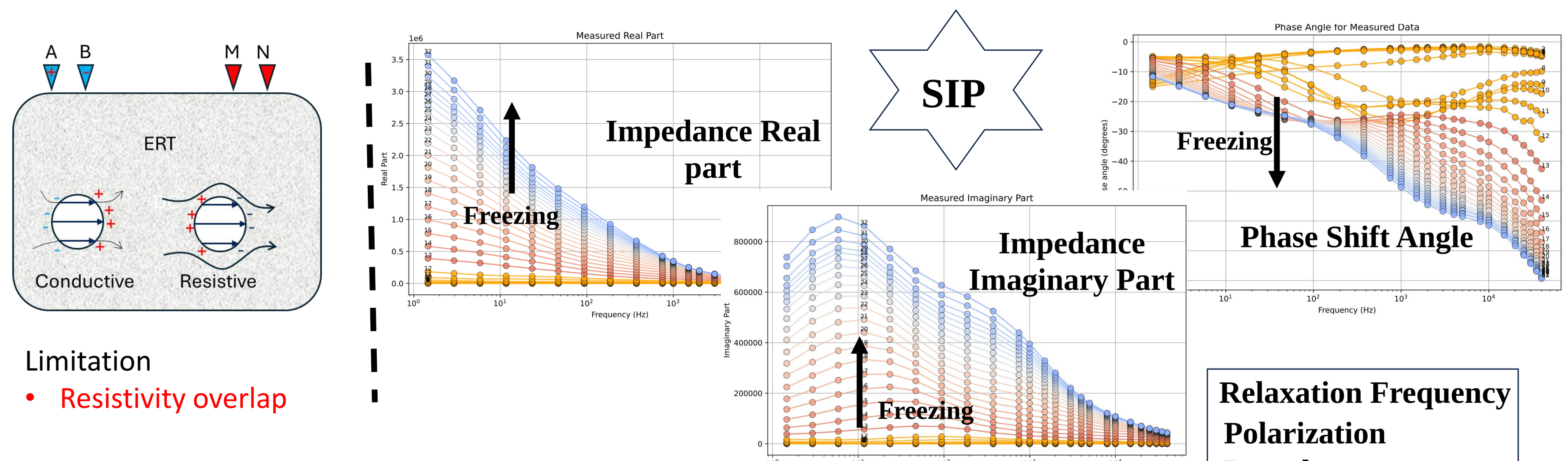
Introduction

Spectral Induced Polarization (SIP) measures material impedance at different frequencies.

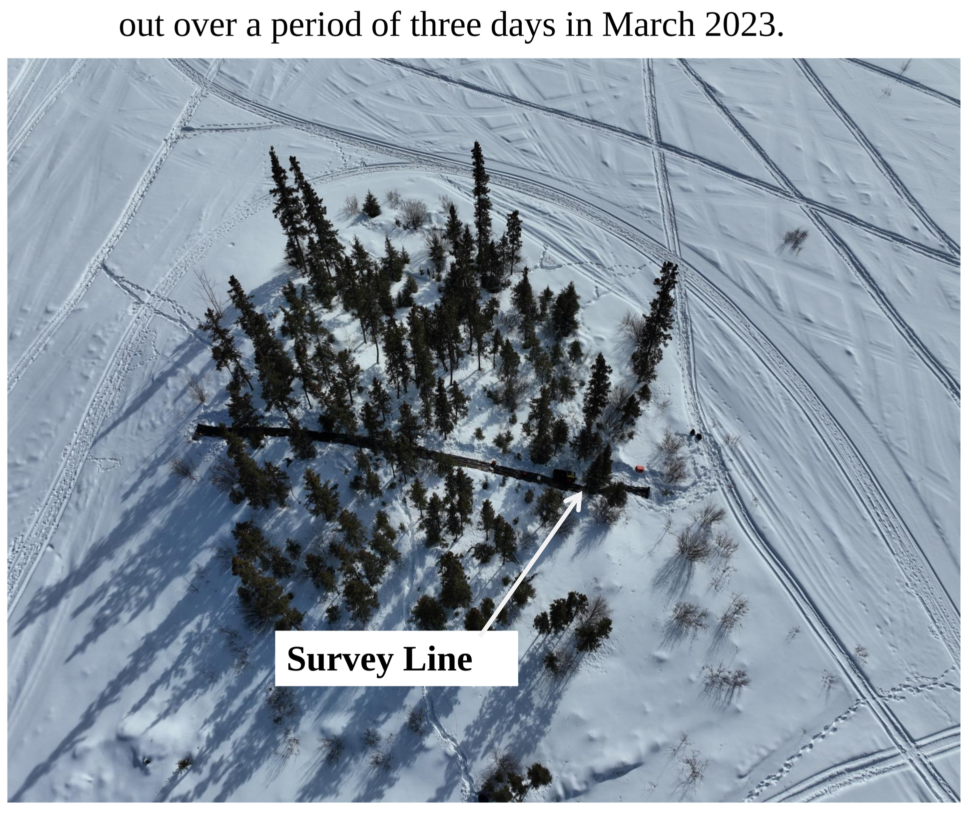
Electrical Resistivity Tomography (**ERT**) measures materials resistivity.



A, B = Current Electrodes   M, N= Potential Electrodes

Study Area, Measuring Instrument and Configuration

The research took place at a specific pingo site in Haines Junction, field measurements were carried out over a period of three days in March 2023.



The FUSCHS III+ device was used to collect data at the site along a 30-meter survey line, equipped with 30 electrodes spaced at varying intervals of 1-5 meters in a dipole-dipole arrangement.

Results – The Highest Frequency Inversion

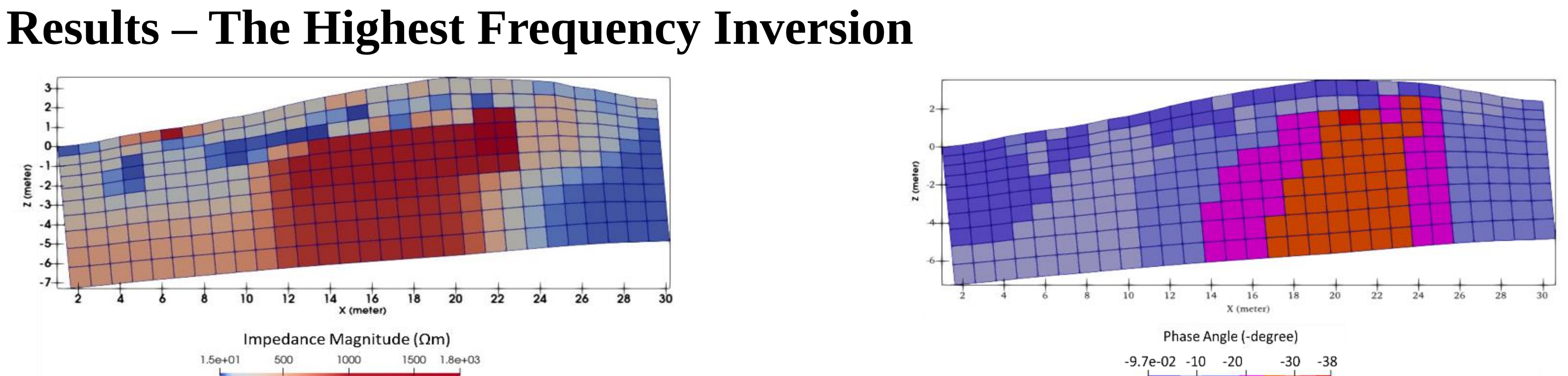


Figure 1. Impedance magnitude (Ωm) and phase angle (degree) at 40 kHz.

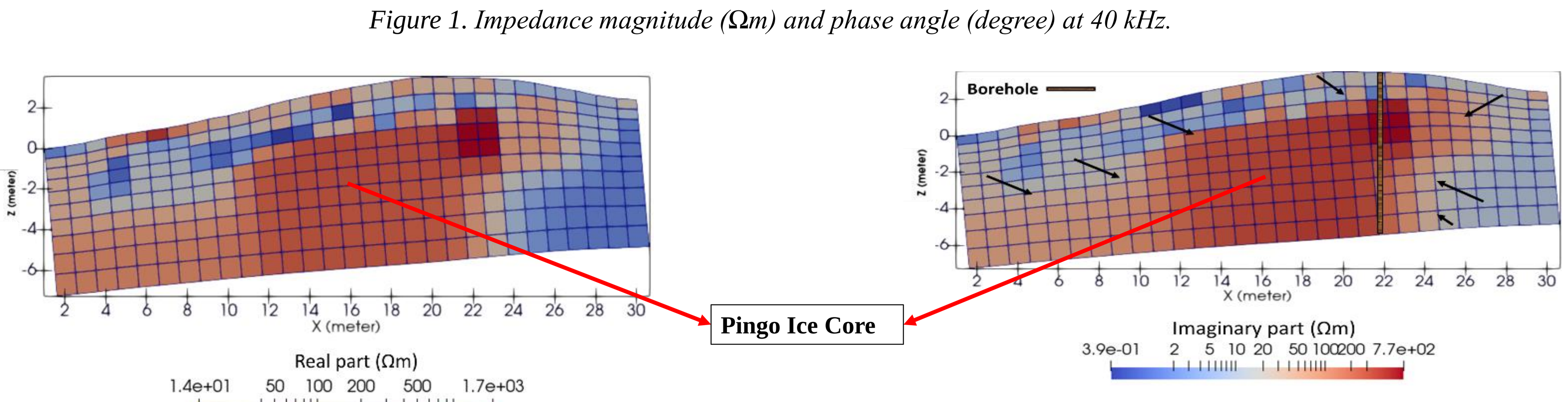


Figure 2. Real and Imaginary part (Capacitance Reactance) of impedance at 40 kHz.

Results – The RFE result

Figure 3 shows Resistivity Frequency Effect (RFE) image for the study area. The higher values correspond to a higher ice content. The red pixels in RFE plot shows higher ice content that almost compatible with the electrical impedance inversion results at 40 kHz (Figure 3), there are some unanticipated difference among them that can be explained by the presence of clay in the study area especially when the presence of clay affect the real part resistivity values in the highest and the lowest frequencies [RFE = ($\rho_{1.46Hz}$ - ρ_{40kHz}) / $\rho_{1.46Hz}$, Where ρ shows the apparent resistivity].

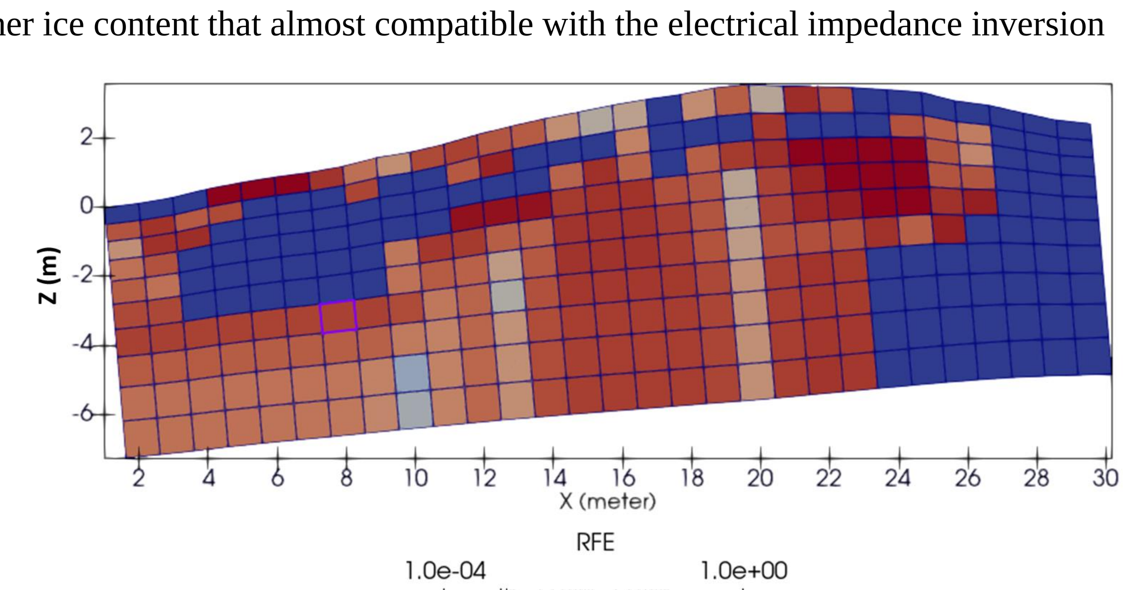


Figure 3. RFE result for the study area.

Drill Logs

The borehole log (Table 1) reveals fibric organics, including mosses and wood fragments near the surface (0–0.1 m) and subsequent layers (0.1–0.3 m) are composed of notably dry and dense silt. An air-filled void (0.3–0.6 m) is associated with cracking at the pingo's apex. Clayey silt (1.25–2.4 m) displays 5% visible ice volume and the silty clay below features increasingly prominent ice lenses. The most significant ice body (3.6–8.3 m) has a visible ice content of 98%. Notably, sporadic lenses of silty clay transition into diamict lenses as depth increases, with thicknesses ranging from 5 to 20 cm. Below 8.3 meters, there is a water-filled section.

Table 1: Log details

Depth (m)	Material	Frozen	Ice (%)	Ice
0–0.1	Fibric organics	Y	Nil	Nf
0.1–0.3	Silt	Y	Nil	Nf
0.3–0.6	Air		Nil	-
0.6–2.4	Clayey silt	Y	5	Vx
2.4–2.9	Silty clay	Y	20	Vr
2.9–3.6	Silty clay	Y	30	Vr
3.6–8.3	Ice	Y	98	ICE+clay +diamict
8.3–10.8	Gravel	N	0	-

Figure 4. Core recovered from 3 0 to 3.6 meters depth.

Comparison with Drill Logs

A) Phase Shift Change

Figure 5 illustrates phase shift angle variations at a borehole location. It shows a low phase shift of -2.83 degrees at 0-0.6 meters in the ice-free zone. With the presence of ice, it changes to -2.87 degrees at 0.6 meters, aligning with the clayey silt and air layer boundary. At 1.5 meters, a significant shift to -24.2 degrees likely due to ice polarization is observed. Another change occurs at 2.2 meters, marking the boundary between silty clay and clayey silt with more ice. From 3.6 to 8.3 meters, as ice volume increases, phase shift angles gradually become more negative, reaching -25.2 degrees at 8.3 meters. The last layer's initial phase shift change is at 4.7 meters one meter away from the boundary between the ice layer and silty clay, possibly due to lower resolution at greater depths.

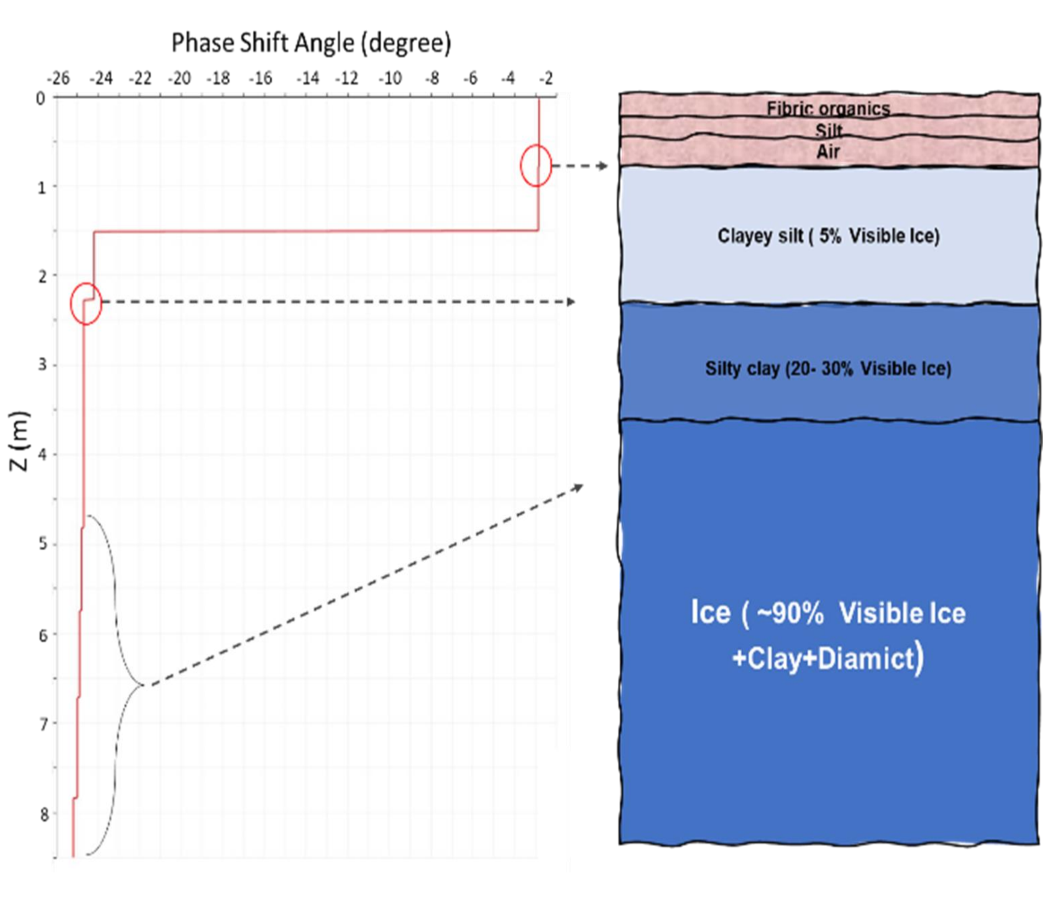


Figure 5. Phase Shift Angle at 40 kHz (extracted for the borehole Location).

B) Impedance Changes

Figure 6 illustrates changes in electrical impedance magnitude, real and imaginary part (on the left side), as well as the change of real and imaginary part relative to impedance magnitude at 40 kHz (on the right side). In the ice-poor layers, the imaginary part remains stable at around 1.6 Ωm. However, at a depth of 1.5 meters, these values significantly increase to 500 Ωm due to the presence of icy clayey silt layers. In the upper depth (ice-poor layer), the real part is nearly equal to the electrical impedance magnitude, with a ratio close to 1. Conversely, within the ice layer, the real part contributes less to the electrical impedance magnitude, while the imaginary part takes on a more significant role. Despite decreasing resistivity values at greater depths (due to clay present), the increasing ice content results in a higher contribution of imaginary part, as the contribution of the real part decreases.

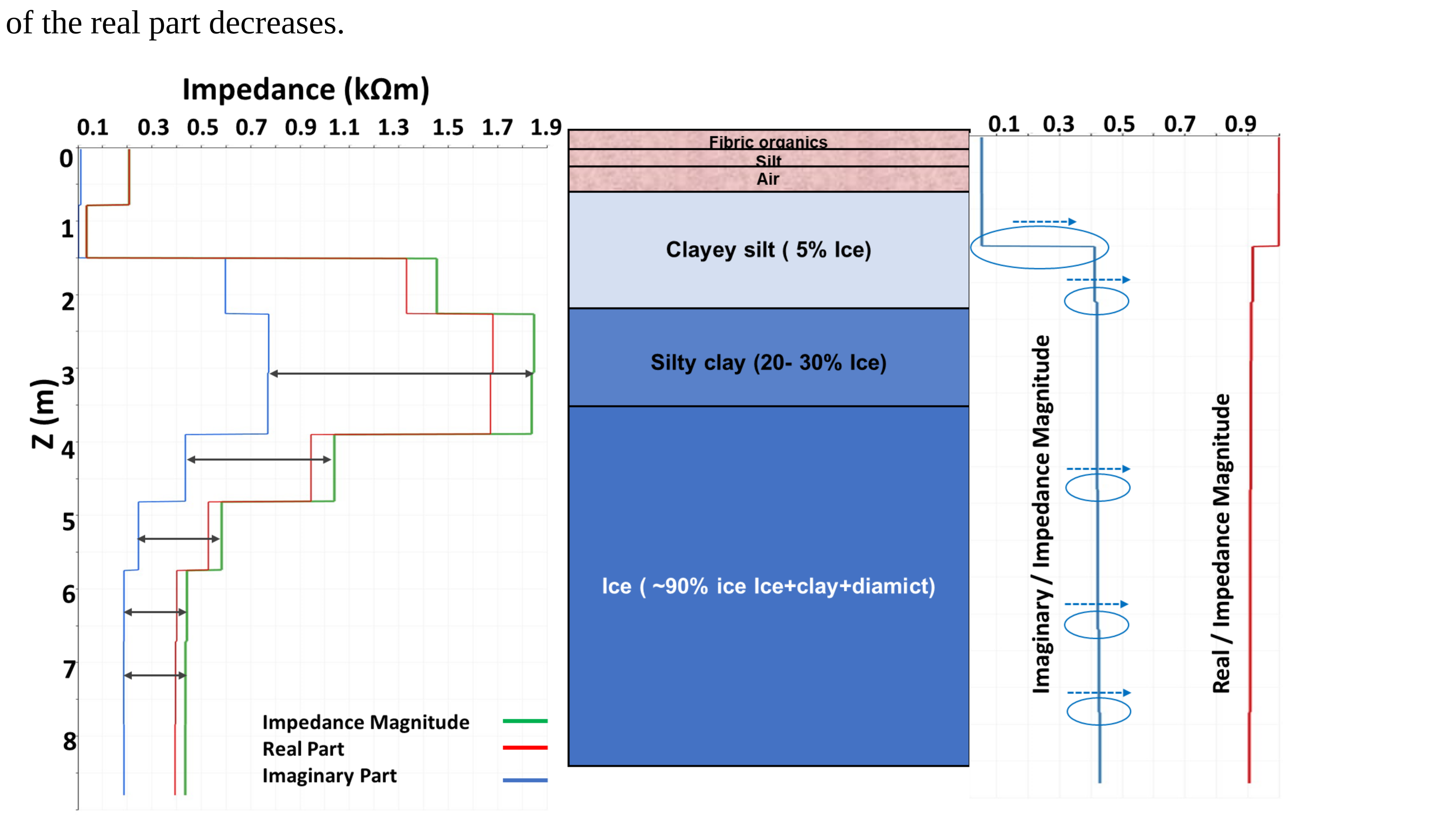


Figure 6: Impedance magnitude, real, and imaginary part (on the left side), and the change of real and imaginary part relative to impedance magnitude (on the right side) at 40 kHz (extracted for the borehole location).

Conclusion

Detecting ground ice with Electrical Resistivity Tomography (ERT) often encounters challenges due to resistivity overlap. To address this, our study employed Spectral Induced Polarization (SIP) methods, utilizing a frequency range from 1.46 Hz to 40 kHz to reduce the ambiguity. The SIP inversion at 40 kHz, combined with the Relative Frequency Effect (RFE) plot, effectively identified the ice core at the pingo site. These findings were further validated by borehole logs, which confirmed the results obtained through the SIP method. The next study will consider the full impedance spectra to enhance the accuracy of ice detection.

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