Utilizing Ground-Penetrating Radar to Delineate Sedimentary Srtuctures: Birds Hill Esker Delta Complex, Manitoba, Canada

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ABSTRACT

Ground-Penetrating Radar (GPR) surveys were done at 4 sites in Birds Hill, Manitoba, Canada, to investigate sources of reflectivity of different geological units; to delineate interfaces between geological units; to interpret reflectivity patterns in terms of depositional processes, and to compare to previous studies in the area.

The Birds Hill esker–delta complex, which consists of two eastward oriented esker channels and a northward oriented ice-marginal channel, formed 12,000 years ago by the interaction of a glacial ice lobe and proglacial Lake Agassiz. Depositional features including a beach ridge, a spit, glaciolacustrine littoral sands, and glacio-fluvial sand and gravel, were surveyed using a pulseEKKO radar system from Sensors & Software Inc. Radar soundings were collected in reflection and CMP modes with 50, 100, and 200 MHz antennas. Results of the GPR survey data indicate that grain-size and mineralogy are less significant than structure and orientation of the deposits in generation of reflectors. Radargrams show patterns including horizontal and dipping reflections and diffraction hyperbolae that are associated with the common regional sediments: sands, gravel, diamict, and clays. Radar responses support previous geological interpretations and can be used to refine the position of geological boundaries. The results assist geological interpretation of the esker-delta complex and could be used by excavation companies to optimize extraction of sand and gravel.

INTRODUCTION

Surficial geology of the Birds Hill area formed about 12,000 years ago as a result of the interaction of a glacial ice lobe and proglacial Lake Agassiz. During the retreat of the ice lobe, melt water flowed out of the ice and into Lake Agassiz, depositing glacial debris in channels between the steep walls of ice. This debris consisted of sand and gravel that was sorted to generate the bedding observed today in the Birds Hill esker complex.

Continued retreat of the glacier caused deep-water conditions to engulf the region promoting the accumulation of silts and clays on sand and gravel ridges. Late stages of retreat allowed Lake Agassiz to begin to drain decreasing water depths in the Birds Hill area so that the highest parts of Birds Hill formed several small islands. At this time strong waves and currents modified the original shape of the Birds Hill esker complex. Material on windward flanks was eroded and redeposited as spits on the leeward side of the islands. The finer sands in the eroded material were carried further into deeper water proximal to the spits.

The final phase of the glacial activity in the area generated the Birds Hill esker complex comprising of two eastward oriented esker channels and a northward oriented ice-marginal channel (Matile, 1985). The esker channels are free of sediment gravity flows, indicating a strong meltwater current was able to flush these sediments from the channel. The esker channels have an eastward orientation which indicates that the complex was deposited in a lateral position on the front of the retreating ice lobe, defined by the orientation of the ice-marginal channel (Matile,1985).

Bedrock in the Birds Hill area consists of Precambrian granites, overlain by the Ordovician Winnipeg Formation and the Red River Formation (Matile, 1985). The Winnipeg Formation comprises poorly consolidated sandstone and is interbedded with shale. The Red River Formation is generally mottled dolomite to dolomitic limestone (Matile, 1985). The depth to bedrock in the area is variable such that in the northeast portion of the complex the bedrock depth is less than 5m, but within the main part of Birds Hill the depth is commonly 40m and greater (Matile, 1985).

Four sites were chosen for GPR surveys that would provide information on four different types of deposits. These areas were chosen based on interpretations by Matile (1985) and are: 1) a beach ridge; 2) glacio-fluvial glacial sand and gravel; 3) glaciolacustrine littoral sand; and 4) a spit.

METHOD

The pulseEKKO 100 radar system generates data by transmitting radiowaves that behave different in different geologic environments. This behavior is due tthe electromagnetic properties of the geologic materials, which are related to their composition and water content. Both of these variables control the speed and the attenuation of these electromagnetic waves (Reynolds, 1997). For example, geological materials exhibit a range of behavior such that there are materials (e.g. polar ice) that are transparent to radiowaves, and others that are considered opaque (e.g. water-saturated clay). The speed of radiowaves in any medium is dependent upon the speed of light in free space (c= 0.3 m/ns), the relative dielectric constant (a measure of electrical polarization resulting from an applied magnetic field), and the relative magnetic permeability (the proportionality of the magnetic field being proportional to the magnetic force generated by a current). The ground penetrating radar method and its accuracy relies on the variability of the subsurface to allow the transmission of radiowaves (Reynolds, 1997). The greater the difference of electromagnetic properties between adjacent materials: superior data output.

Two surveying modes: common offset reflection and common mid-point sounding (CMP), using 50, 100, and 200 MHz antennas, were used in this project.
The common offset mode reflection mode was chosen because it is a suitable mode for mapping underlying stratigraphy. It provides an accurate subsurface reflection profile that is similar to seismic data (Reynolds, 1997). Common offset radar reflection profiling involves moving two radar antennas with constant separation over the ground surface along the grid lines set up in the study area. The results are displayed on a laptop computer with travel time on the vertical axis and antenna position on the horizontal axis. This mode of data collection does not provide information on the velocities of different sub-layers, which is the reason for also using the CMP mode.

The CMP mode was used because it allows discrimination between different types of waves: 1) the airwave, travelling from the transmitter to the receiver through the air at the speed of 0.3m/ns; 2) the direct wave, travelling directly from the transmitter through the near-surface ground to the receiver with the velocity of the near-surface medium (V_1); 3) the reflected wave, traveling from the transmitter to the interface from which it is reflected to the receiver (traveling at the speed of radiowaves in the first layer); and 4) waves refracted along intervals at which the radiowave velocity increases with depth (Reynolds, 1997). This information is needed for profiling data versus depth profiles such that the velocity from the direct, and other reflected and refracted waves can be calculated (Annan, 1999). When using the CMP configuration of data collection, the transmitter and receiver are moved away from each other so that the mid-point between them stay at a fixed location.

The survey approach for this project was based in part on previous research and published literature on the application of ground-penetrating radar in investigations of stratigraphy, heterogeneity of sub-surface sediments, and Quaternary geologic processes. In particular, the procedures used by Van Overmeeren (1997) were followed in the Birds Hill area. Van Overmeeren used GPR to study unconsolidated Quaternary sediments and structures in The Netherlands. His work resulted in a stratigraphic interpretation method for hydrogeology.

CONCLUSIONS

Analysis of the GPR data from the four survey sites has generated the opinion: grain size and mineralogy are less significant in the generation of reflectors. Structure and orientation of sediments, regardless of size or lithology, generate stronger reflections. Furthermore, application of GPR to the Birds Hill area has shown that this geophysical tool compliments geologic information in the region. Survey data is comparable with van Overmeeren (1998) and sediments of Birds Hill share similar reflections with previously published radar facies. Information acquired in this study reveals the accuracy of the pulseEKKO 100 system from traces in survey site 4 matching up with adjacent quarry face. Additionally, data interpretation has proven the need for a smaller scale and more detailed map of the geology of Birds Hill.

The pulseEKKO 100 instrument is easy to work with. The ability of this system to generate quality data promotes the potential of this method in the Birds Hill area, as well as others regions across the province. The instrument is a major source of detailed information and would generate smaller scale maps that are greatly needed of the esker complex. Broad CMP surveys of the region and an increased collection of cores can a characterize relative velocities and dielectric constants of till, diamict, and gravel containing high carbonate content. Excavating companies in the area can use GPR to help delineate which sedimentary structures and faces in their quarries should be active. Additionally, companies can use GPR for the investigative purposes such as new quarry locations.

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