Radar Analysis of the Grand Island Tombolo, MI, USA: A Case Study for Coastal Landscapes

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Abstract

Coastal landforms along the North American Great Lakes record historic lake levels in their sedimentary structure. Grand Island is the largest island on the southern shore of Lake Superior. A 0.75km wide, 2km long sandy depositional feature, a tombolo, connects bedrock highs on the island. A ground penetrating radar (GPR) transect reveals the tombolo's internal architecture. The transect was collected with a pulseEKKO 100 GPR system with 100MHz antennae and 1.0m antennae separation with 0.5m step size. Velocity was determined to be 0.1m/ns after analysis of a common midpoint survey. A Topcon RL-H3CL laser level was used to collect topographic data to adjust the profile to changes in relief. Four radar facies were interpreted from the transect. Radar facies range from northward dipping inclined reflections, interpreted as strandplains, to sigmoid and hummocky reflection, interpreted as shoreface progradation during lake level rise, to continuous horizontal to inclined reflections, interpreted as shoreface progradation during lake level fall. The boundary between shoreface progradation during lake level rise and a buried strandplain is believed to result from historic Lake Superior lake level known as the Houghton Low.

Introduction

Lake Superior is one of the largest bodies of freshwater in the world (Johnston, 2012). Its immensity leads to our understanding that lake level in the basin mimics sea level when studying coastal landscapes. During the Late Holocene, several lake level fluctuations have occurred creating a varied suite of coastal landforms. Historic shorelines are preserved in coastal landscapes and wave cut bluffs and cliffs (Fig. 1). Lake Superior coastal landscapes evolve as lake level fluctuate, creating a unique opportunity to study how coastal landforms adapt in response to sea level changes. Sediment inputs cause coastal landforms prograde (build out from shore) (Ritter, et al., 2011). Though progradation during regression (relative sea level fall) is widely accepted, how, or even if, progradation during transgressive (relative sea level rise) occurs is not well understood (McCubbin, 1982). This poster seeks to provide insight into the subsurface stratigraphy of the Grand Island Tombolo in order to better understand its continuing formation. In order to achieve our objectives this study used GPR to provide a means of imaging subsurface stratigraphy to establish the depositional style of various radar facies with radar stratigraphic analysis. A GPR transect of the Grand Island Tombolo is interpreted using radar stratigraphic techniques and divided into four radar facies. Radar facies are interpreted as shoreface and strandplain deposits, the contact between which is interpreted as lake level.

Figure 1: Cliffs of Jacobsville Sandstone as seen along Pictured Rocks National Lakeshore.

Study Area

Grand Island, near the town of Munising, Michigan, is the largest island on the southern shore of Lake Superior (Fig. 2). The island is part of the Hiawatha National Forest, limiting present and future development to hiking and biking trails. Cliffs of Jacobsville Formation and the Chapel Rock Member of the Munising Formation sandstone (Fig. 1) rim Grand Island. A 2km long, 0.75km wide sandy tombolo connects eastern and western bedrock lobes (Fig. 2). A well-developed strandplain is present on the tombolo (Fig. 3 and 4). Strandplains are a specific kind of beach deposit forming from an interaction of wave deposition and windblown dunes creating a sequence of shore parallel beachridges (Ritter et al., 2012) and can be used to infer historic sea levels (Johnston et al., 2012). Sand is likely supplied from the erosion of nearby sandstone and glacial till. It is believed that wave refraction around bedrock lobes helps to concentrate and deposit sediment on the Grand Island Tombolo.

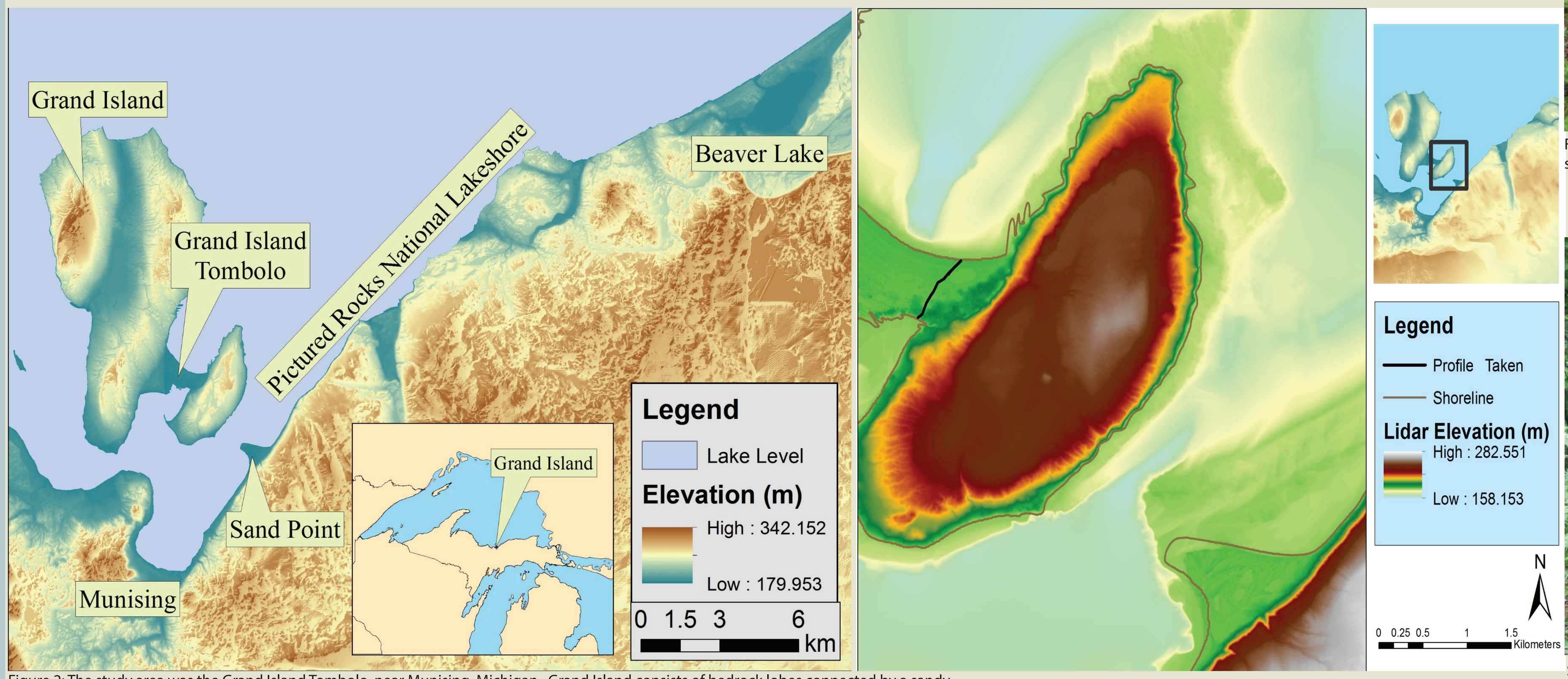
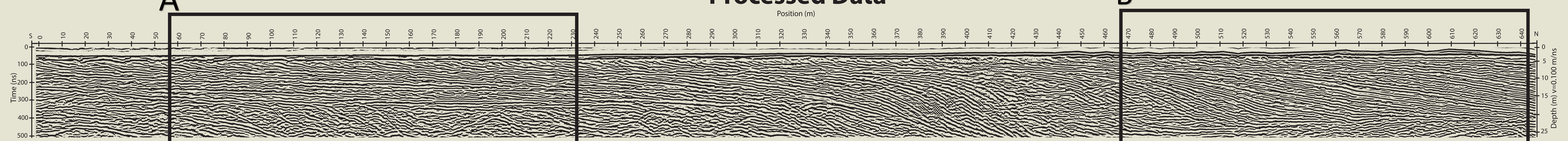


Figure 2: The study area was the Grand Island Tombolo, near Munising, Michigan. Grand Island consists of bedrock lobes connected by a sandy tombolo. Sand Point and Beaver Lake have been the sites of previous studies that were used to interpret data from this investigation.

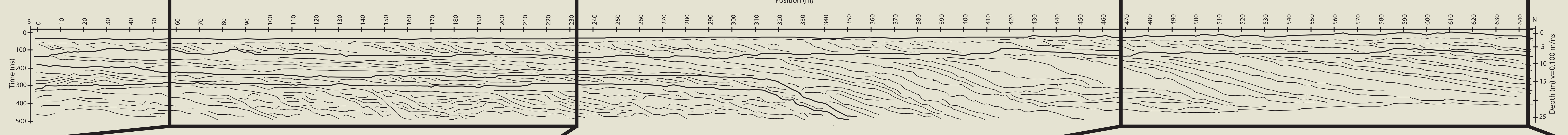
Figure 3: North end of the tombolo, this area is sandy and slightly higher than the south end of the tombolo.

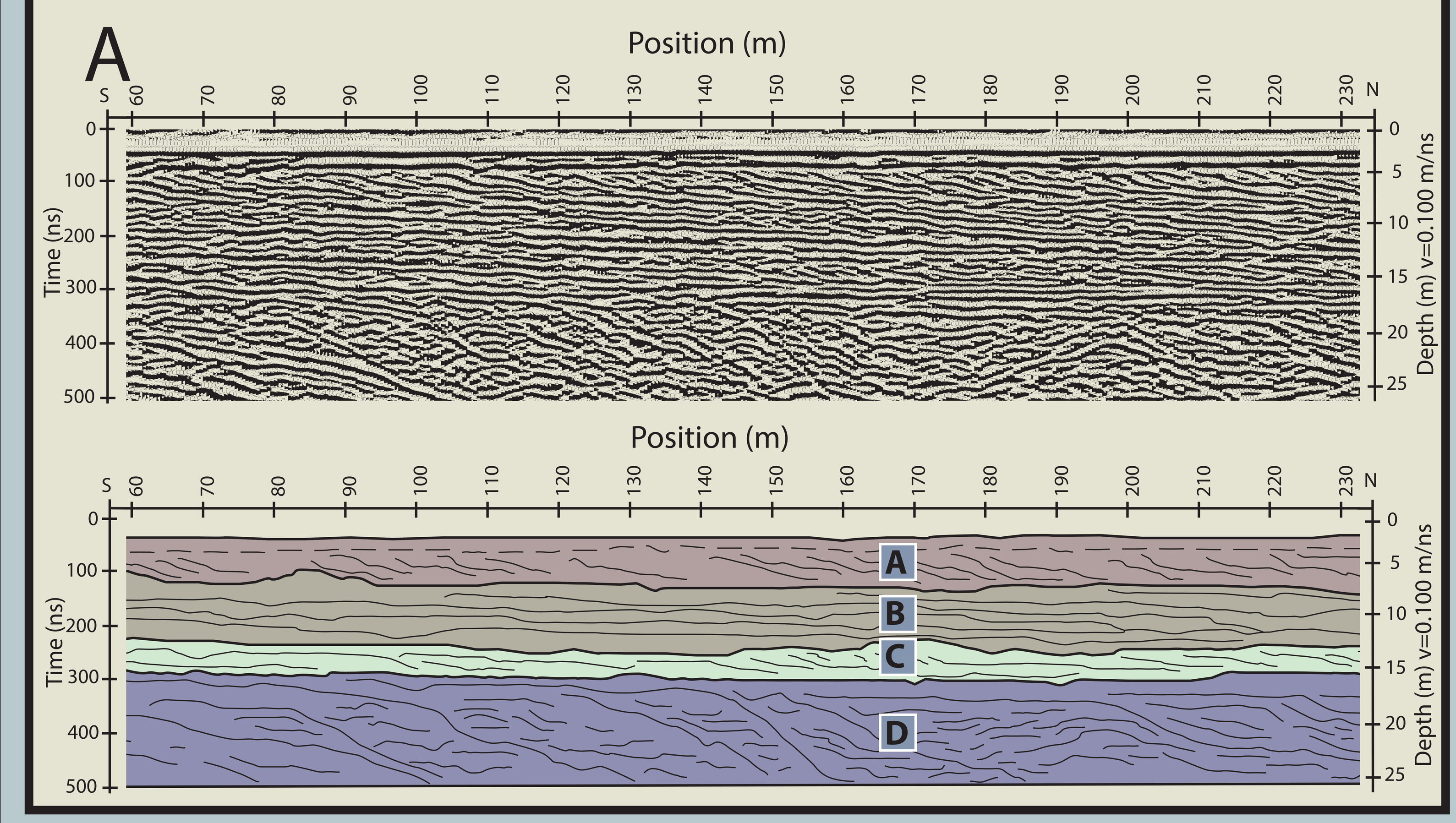
South end of the tombolo, this area is lower than the north end of the tombolo and is partially inundated.

Processed Data



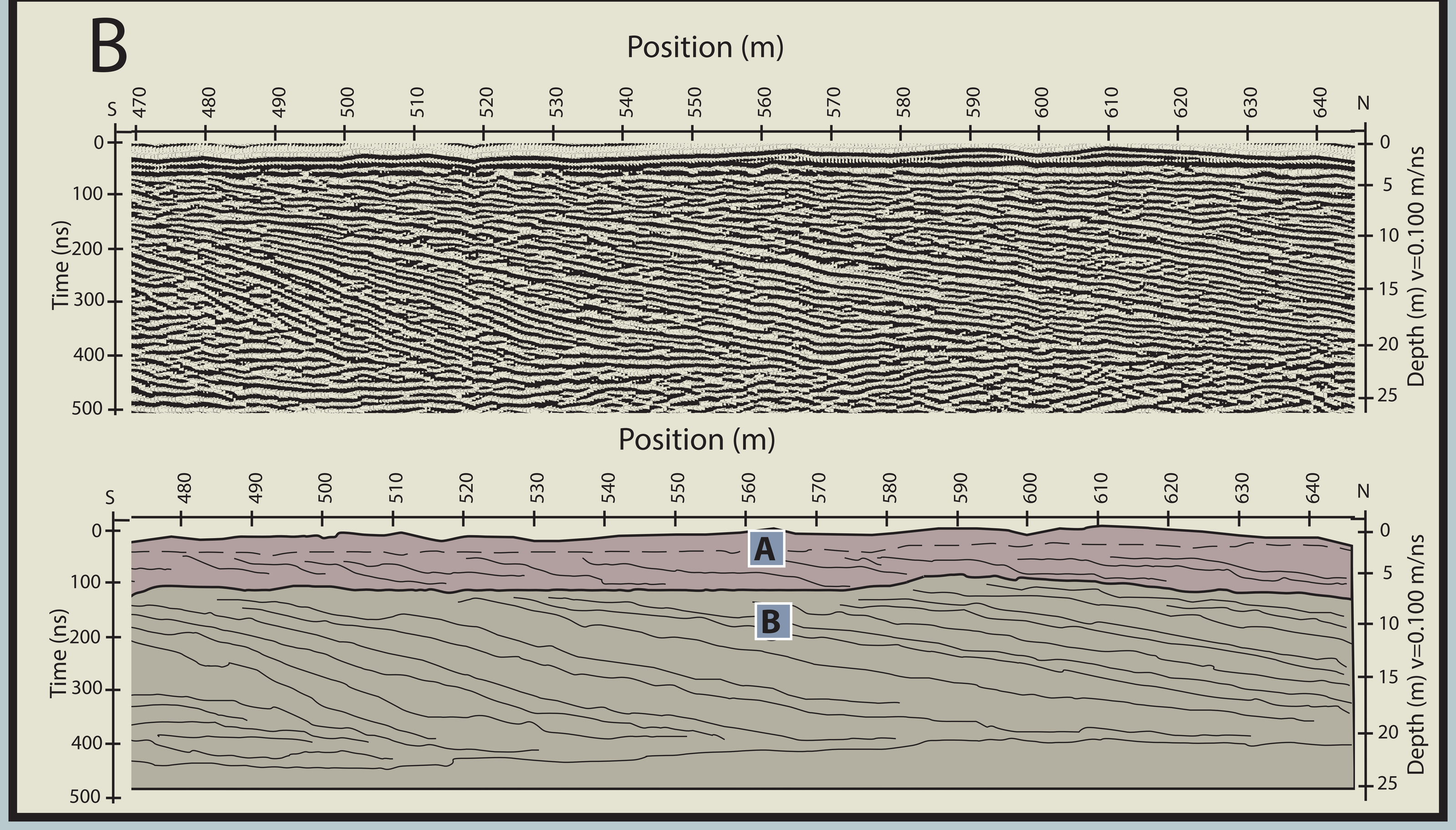
Interpreted Data





Results

Radar Facies	Radar Stratigraphic Description	Interpretation
A	The upper radar facies consists of northward dipping inclined reflections with a 3-5m thickness across the length of the profile, and downlaps lower facies.	The modern strandplain. This radar facies matches radar stratigraphic descriptions of other Lake Superior strandplains, (Johnston, et. al, 2007).
B	Concordant with lower reflections, a third radar facies with a thickness of 5-7m at the southern end of the transect and 20-22m at the northern end of the transect consists of continuous subhorizontal to inclined reflections.	Shoreface progradation during lake level regression. Subhorizontal reflections were deposited on top of the underlying deposits and grade to inclined reflections which are interpreted as clinoforms building out from the underlying deposit.
C	A thin, 2-4m, radar facies downlaps onto radar facies 1 and consists of northward dipping inclined reflections. This radar facies is only found on the southern portion of the transect.	A historic strandplain. Modern Lake Superior strandplains have been extensively studied and show lakeward dipping reflections with an average thickness of 5m (Johnston, et. Al, 2007) which match reflections observed in radar facies 2.
D	The deepest facies is below 16m and likely descends below the depth of penetration. This radar facies is composed of sigmoid and hummocky reflections which top lap above facies. Hummocky reflections are truncated by sigmoid reflections. Sigmoid reflections are 5-10m apart. The facies are found only on the southern part of the transact.	The lowest radar facies is interpreted as shoreface progradation during lake level transgression. Sigmoid lower reflections are interpreted as erosional surfaces, while horizontal hummocky reflections suggest aggradation (Larson, et al, 2007). Together these reflections represent periods of erosion and aggradation resulting in net progradation. Lake level transgression provided the erosive energy needed to form sigmoid reflections, while other unidentified processes episodically deposited sediment.



Methods

GPR is a noninvasive way to image the shallow subsurface using electromagnetic waves which rebound off subsurface reflectors (Fig. 6). A 700m shore perpendicular GPR transect across the Grand Island Tombolo used a pulseEKKO 100 GPR system with 100 MHz antennae (Fig. 5). Data collection used a step size of 0.5m and antennae separation of 1.0m. A topographic survey, using a Topcon RL-H3CL laser level, was also conducted to adjust profiles to changes in relief. A common midpoint survey indicated the velocity of the electromagnetic wave through the sediment to be 0.1 m/ns (Fig. 6). Profiles were processed with pulseEKKO software utilizing trace-to-trace averaging, down-the-trace averaging, dewow and automatic gain control and plotted using wiggle trace formatting.

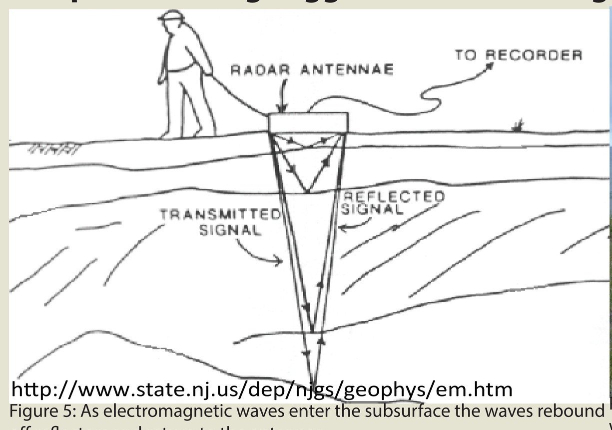
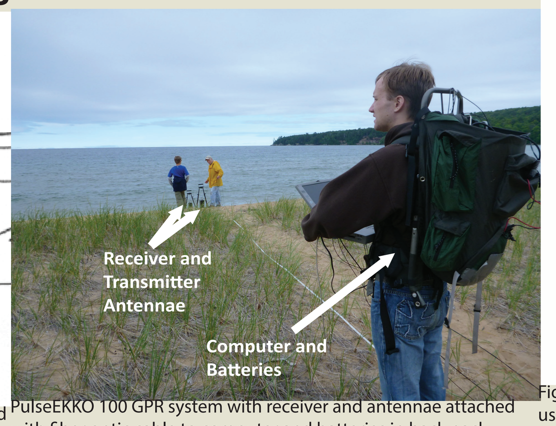


Figure 5: As electromagnetic waves enter the subsurface the waves rebound off reflectors and return to the antennae.



PulseEKKO 100 GPR system with receiver and antennae attached with fiber optic cable to computer and batteries in back pack.

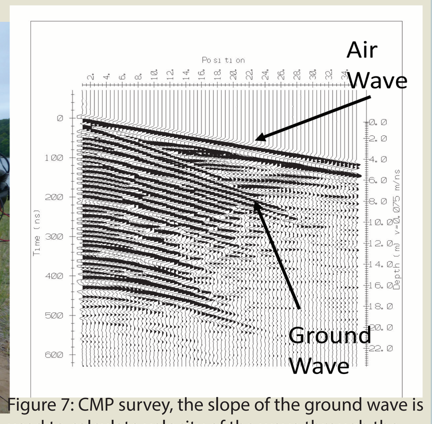


Figure 7: CMP survey, the slope of the ground wave is used to calculate velocity of the wave through the sediment.

Summary

Two lake level phases are believed to be preserved in the Grand Island Tombolo's stratigraphy. The historic strandplain, shoreface contact is interpreted as a historic lake level approximately 15m below the tombolo's surface. Contemporary lake levels are preserved as the contact between modern the strandplain and shoreface. This is supported by interpretation of historic lake levels based on a drill core collected by nearby Beaver Lake (Fisher, 1999) This core shows a sand unit beginning 14m below modern lake level that believed to represent the same lake level interpreted from our GPR transect.

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