GPR Examination of Multi-Year Seasonal Storm Impacts on Subsurface Depositional Architectures on a Beach in Grand Marais, MI

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Research Questions

- What are the subsurface architectures?
- Where subsurface structures are being preserved?
- Are sediment packages correlative between survey lines?
- Are current storm disruptions mapped and preserved in sediment packages?
- Are previous storm disruptions mapped and preserved in sediment packages?

Abstract

The shallow subsurface of Grand Marais headland beach, located along the southern shore of Lake Superior, Michigan, was imaged using ground penetrating radar (GPR) to determine how seasonal storm impacts are manifested in subsurface depositional architectures. This study was designed to evaluate the implications of the 1883 emplacement of a jetty system that allows for accumulation of sand from the westerly Grand Sable dunes, which would otherwise be transported further east as a result of longshore drift. Due to the jetty and previous research, there is an indication that the beach is growing.

GPR data were acquired during spring, fall, and winter seasons over the course of two consecutive years (2016-2017) to determine if and where subsurface structures are being preserved. Images were subsequently used to determine the annual changes in beach architecture. Emphasis was placed on evaluating the nature of unconformities, formed by strong winter storms, given their suitability for subsurface correlation.

The 250 MHz and 500 MHz GPR setups mapped lake-ward-sloping sediment packages, interpreted as former foreshore deposits bounded by horizontal units, which were the product of aeolian processes. The data reveals correlations between sediment packages located on three different shore-perpendicular survey lines, which were connected by a shore-parallel tie line. Features encountered in the data are depositional onlap and erosional truncation. The latter is the result of the seasonal storm impacts on the beach and/or changes in sediment availability.

The presence of the jetty has allowed for preservation of the shoreline facies, which would be minimal under natural erosional conditions. The patterns detected from the data provides insightful information on the effects of the seasonal storms on shoreline dynamics. Further seasonal data collection, would augment our knowledge of the depositional and erosional cyclic processes that are responsible for shoreline growth.

Introduction

The Grand Marais headland beach is located in the Upper Peninsula of Michigan along the southern shore of Lake Superior (**Figure 1**). The beach was imaged using ground penetrating radar (GPR) to determine the implications of seasonal storm impacts on shoreline dynamics which are manifested in subsurface depositional architectures. The 1883 jetty system was emplaced by the Army Corps of Engineer to create a Harbor of Refuge in Grand Marais. The emplacement of a jetty system disrupts the natural deposition of sediment by longshore current. Since the emplacement of the jetty system the sand accumulates on the west side of the jetty and erodes from the east side (**Figure 2**). The source of sand is from the westerly Grand Sable dunes, which would otherwise be transported further east as a result of longshore drift. The composition of the sand at Grand Marais is a medium to coarse grained quartz arenite, which is well sorted from wind transport. Grand Marais is subjected to intense storms which can quickly change the architecture of the beach and rework the sediment. GPR data were acquired during spring, fall, and winter seasons over the course of two consecutive years (2016-2017), in order to map the changes in the beach. Images of the subsurface structures were used to determine the annual changes in beach architecture.

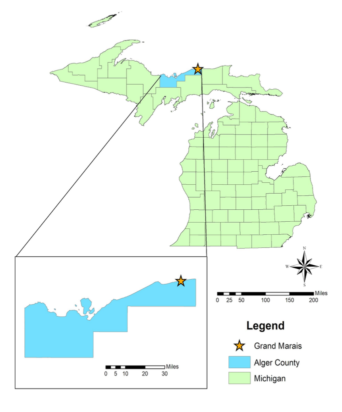


Figure 1: The star shows the location of Grand Marais, Michigan within Alger County; with respect to the State of Michigan.

Figure 2: Shows an aerial image of Grand Marais beach. The west side of the beach is accumulating and the east side of the beach is eroding.

Raw Data

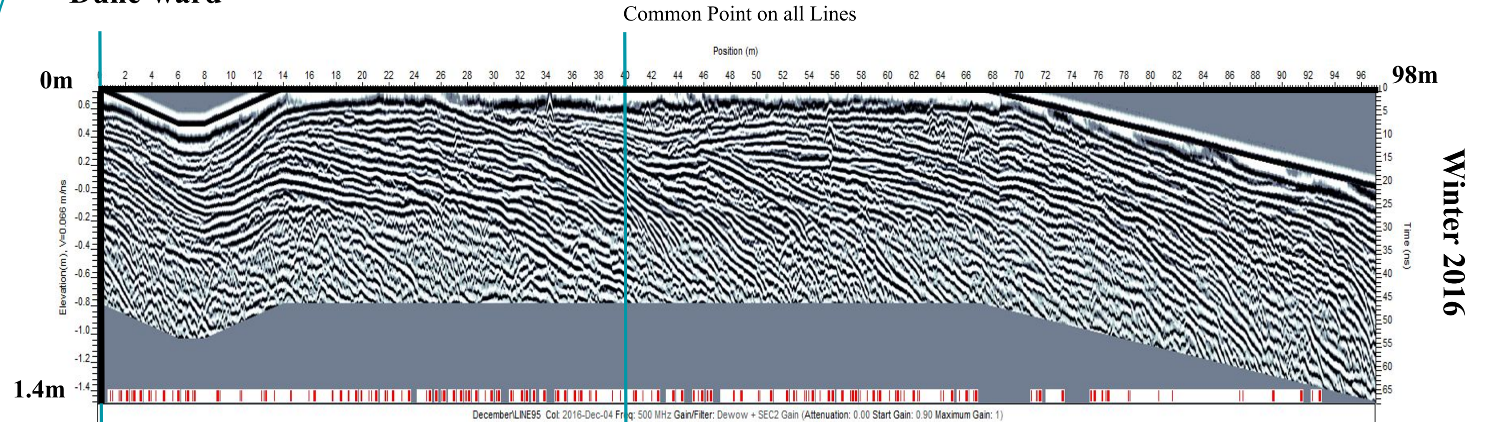


Figure 4A: This figure shows the uninterpreted line data collected Winter 2016 on the survey line closest the jetty. The teal lines represents common points on the jetty line over multiple seasons. See figure 4B, for interpretation.

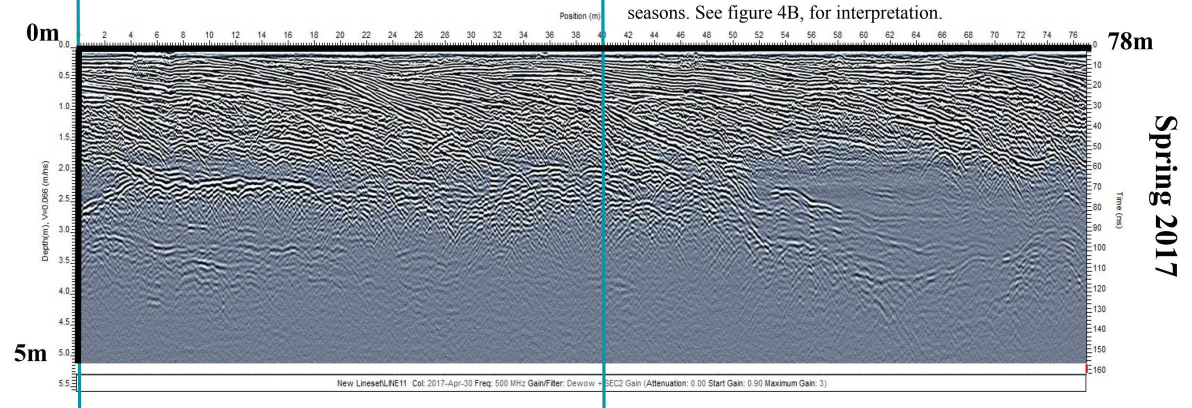


Figure 5A: This figure shows the uninterpreted line data collected Spring 2017 on the survey line closest the jetty. The teal lines represents common points on the jetty line over multiple seasons. See figure 5B, for interpretation.

GPR Data	Characterization	Interpretation
	Continuous Horizontal Lines	Continuous Deposition
	Short, Random, Chaotic Lines	Gravel Lag
	Random, Chaotic, Wavy Lines	Reworked Sediment
	In line or increasing angle and laying on top of a the previous line	Onlapping, Progradation

Table 1: Shows GPR features with corresponding interpretations.

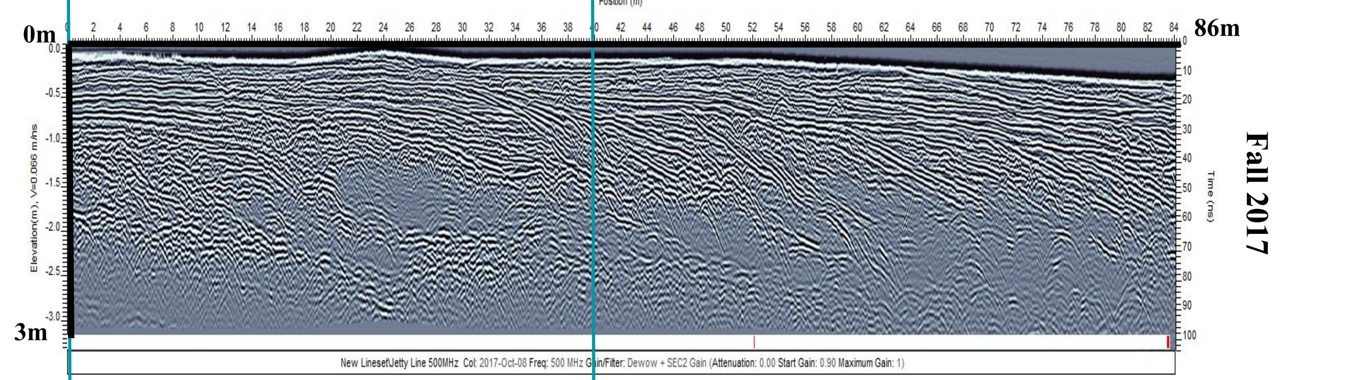


Figure 6A: This figure shows the uninterpreted line data collected Winter 2016 on the survey line closest the jetty. The teal lines represents common points on the jetty line over multiple seasons. See figure 6B, for interpretation.

From this point right, data was collected on the frozen Lake Superior.

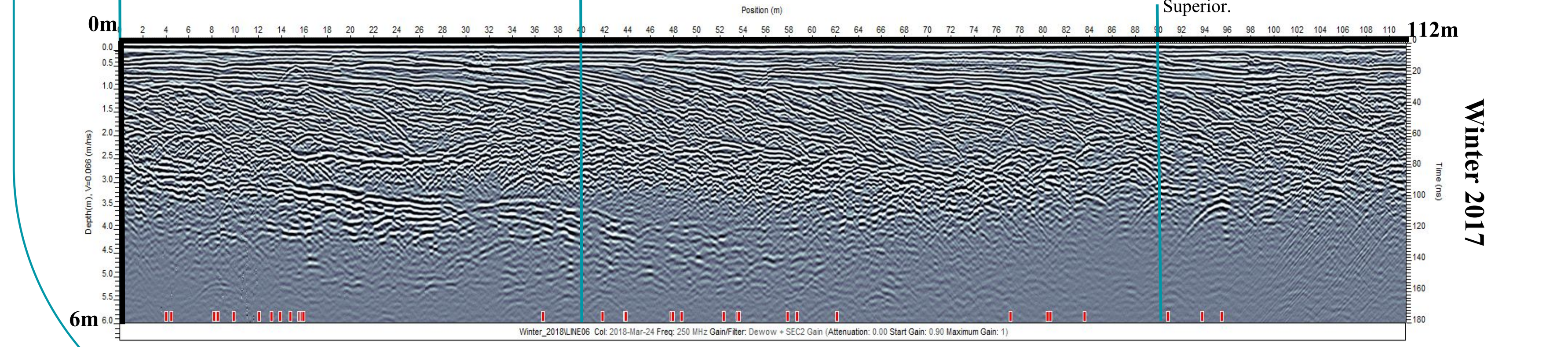


Figure 7A: This figure shows the uninterpreted line data collected Winter 2017 on the survey line closest the jetty. The teal lines represents common points on the jetty line over multiple seasons. See figure 7B, for interpretation.

Interpretations

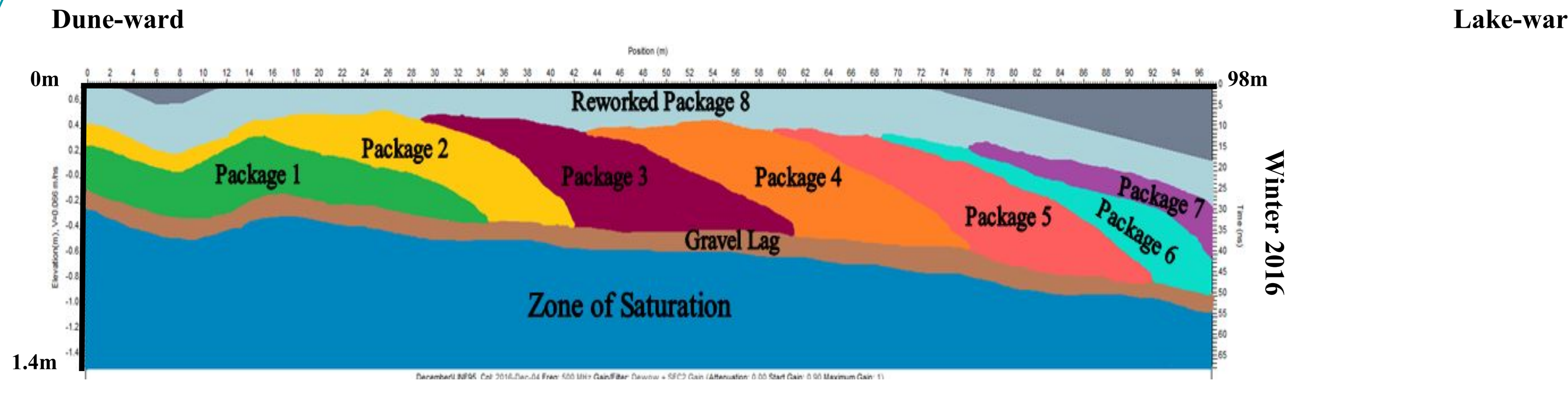
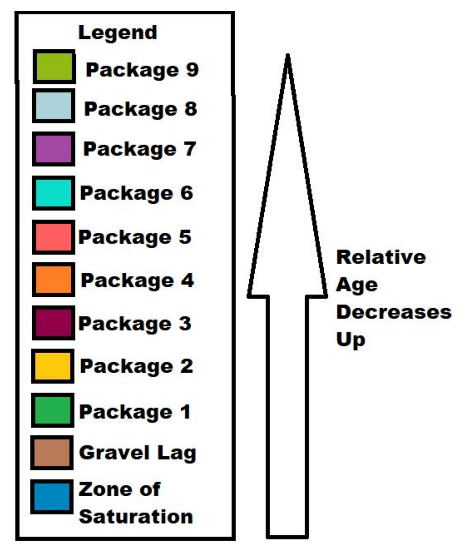


Figure 4B: Shows interpretation of the jetty line Winter 2016. A storm event reworked the top 0.2 meters of sand at Grand Marais, as indicated in package 8. The topography of the line is a result of the storm eroding sediment from some locations and depositing sediment in other locations. Relative age was determined based on the relationship between interpreted sediment packages.



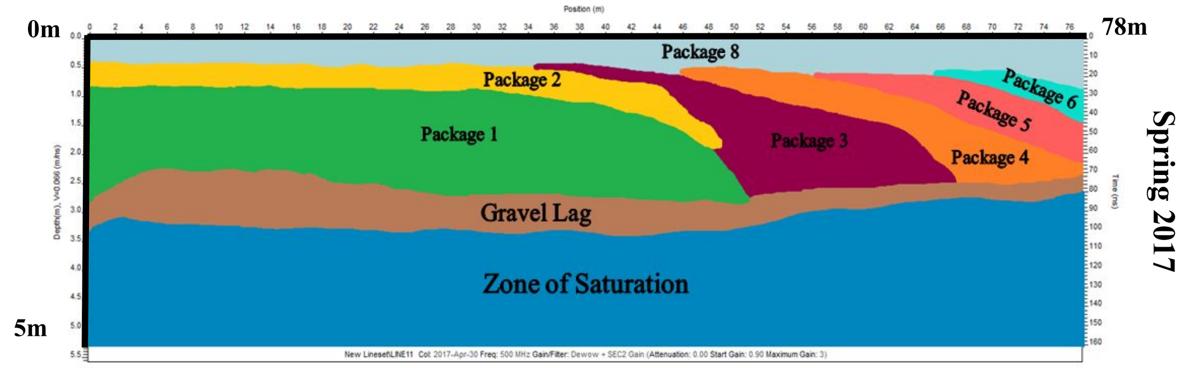


Figure 5B: Shows the interpretation of the jetty line Spring 2017. Based on the horizontal layering seen in figure 5A, back-filling sediment, wind, and tidal processes. The lowered water table allows for examination of deeper portions of the sediment packages. The contact between packages 1, 2, and 3 is chaotic would indicate preservation of an older storm event (reworked sediment) in the sediment pack 3.

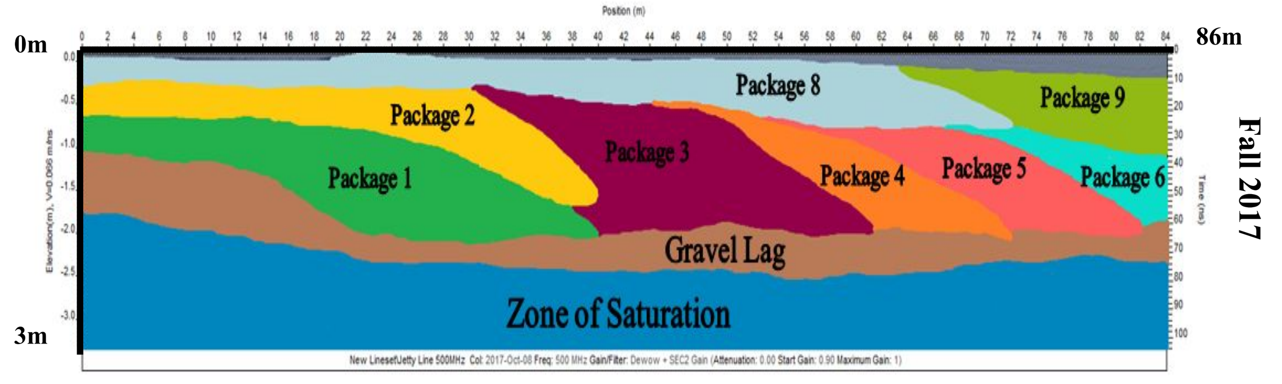


Figure 6B: Shows the interpretation of the jetty line Fall 2017. The topographic high located between 20 to 30 meters, appears to be an area where sediment is accumulating on the beach. The lowered water table allows for examination of deeper portions of the sediment packages. The contact between packages 1, 2, and 3 is chaotic which would indicate preservation of an older storm event (reworked sediment) in the sediment package 3. A similar contact is seen between package 6, 8, and 9.

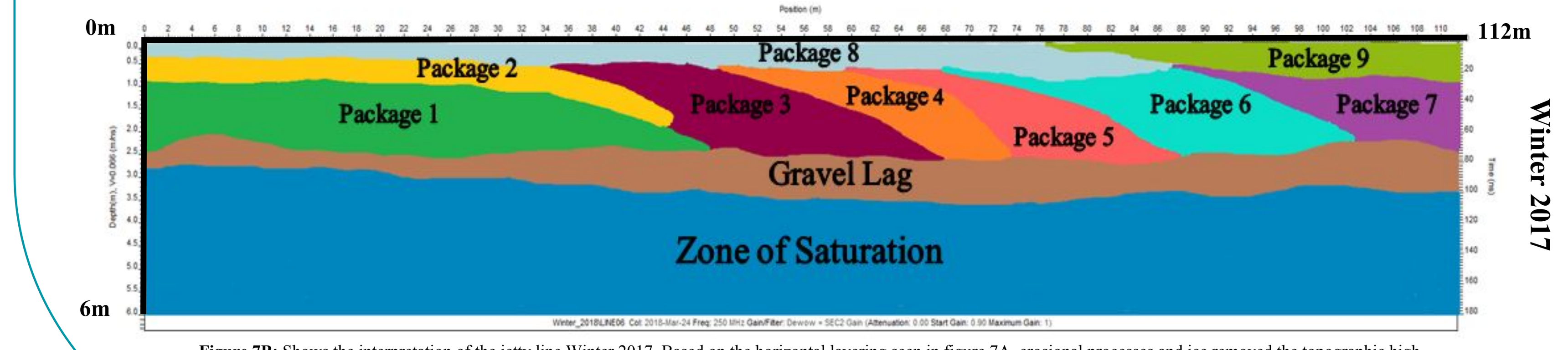


Figure 7B: Shows the interpretation of the jetty line Winter 2017. Based on the horizontal layering seen in figure 7A, erosional processes and ice removed the topographic high located between 20 to 30 meters. The lowered water table allows for examination of deeper portions of the sediment packages. The contact between packages 1, 2, and 3 is chaotic which would indicate preservation of an older storm event (reworked sediment) in the sediment package 3. More of package 7 and 9 can be examined due the increased length of the line from imaging over the frozen Lake Superior.

Data and Methods

Data Collection

- Survey design consisted of four GPR lines. Three transect lines varied in length and was collected perpendicular to shoreline. One transect line varied in length and was collected parallel to shoreline, midway along the other transects. **Figure 3**
- In the field lines were set up using a Brunton compass and GPS unit were used to measure the direction and location of the survey lines. The Brunton measured bearing of the each line was collected; perpendicular lines had a bearing of 5° and the parallel line had a bearing of 80°. GPS points were collected at the start and end of each survey line.
- Use of the calibrated 250 MHz and 500 MHz antennas GPR system.
- Each of the four lines were surveyed using both antenna configurations.
- Topography was collected on lines when there was visible topography on the beach, otherwise the beach was assumed to be horizontal.

Data Processing

- Topography files were created based on elevation that was collected in the field (when necessary). A slope calculation was conducted in Microsoft Excel based on measured elevations, to allow for smooth topography. Topography values were added to a Notepad file and saved as a .txt file in order to attach to the line file.
- GPR data was processed in EKKO_Project 4.
- Basic processing of Automatic Gain Control (AGC) and Dewow was added to each line in the dataset. Dewow was conducted to remove low frequency noise from the data.
- An average velocity calculation based on hyperbolas was conducted to convert from two-way time to depth, the average velocity was 0.066 m/ns.

Data Interpretation

- Subsurface sedimentary architectures were evaluated from finalized GPR images.
- Sediment packages and features were highlighted using photo editing software

Figure 3: This image shows the beach at Grand Marais, Michigan. The red lines indicate the survey lines where ground penetrating radar (GPR) data was collected. The pink points on the map indicate the start and end points of the survey line closest to the Jetty, the line which the data has been interpreted in the results section. The blue and yellow points indicate the start and end of survey lines 2 and 3, respectively. The green points indicate the start and end of the Tie Line, which is located approximately midway along the Jetty Line, Line 2, and Line 3.

Discussions and Conclusions

Grand Marais, Michigan's headland beach is growing based on the visual examination of GPR and satellite imagery. Further examination and interpretation has been done of the subsurface structures occurring on the survey line located closest to the Jetty system. In **Figures 4 – 7** the dunes of the beach are located on the left side of the image at 0 meters and the lake is located on the right side of the images, all images had a varying depths of collection based on the time-window that was imaged. **Table 1** shows the four recognized sedimentological lay features: 1) horizontal reflectors, 2) short, random reflectors, 3) chaotic, wavy reflectors, and 4) parallel angled reflectors. Horizontal reflectors were interpreted as continuous deposition. Short, random reflectors were interpreted as a gravel lag. Chaotic, wavy reflectors were interpreted as reworked sediment. Parallel angled reflectors were interpreted as progradational onlapping. **Figures 4A -7A** show progradational clinoforms from winter of 2016 to winter of 2017, which confirms that the beach is growing in the lake-ward direction. **Figure 4** shows that the first 0.2 meters of sediment was reworked due to a storm event. Similar features can be seen is sediment package 3, in **Figures 4-7**, which has been interpreted to be a previous preserved storm event. In **Figures 4-7** sediment package 2 is interpreted as a sedimentary wedge, due to a parallel reflectors.In **Figure 7** sediment packages 7 and 9 are examined due to imaging over the frozen portion of Lake Superior. All sedimentary packages show a progradational pattern in the lake-ward direction.

Since the implementation of the jetties in 1883, the beach at Grand Marais has been accumulating sediment due to longshore transport from Grand Sable dunes. By using the 500 MHz GPR, it was determined that the depositional architecture is exhibiting progradational clinoforms, a sedimentary wedge, onlap, and truncation. It was determined that the sedimentary architectures are being preserved, and growing in the lake-ward direction. Similar sedimentary packages can be seen on all survey lines however, the focus of this project was the jetty line. Current storm events that rework near-surface sediment can be imaged using GPR, as seen winter 2016. Previous storm events that reworked older sediment packages may be preserved in some conditions. Future work for this area would be continued seasonal examination of the beach using the predetermined survey lines, to determine and/or confirm the appearance of storm events in sedimentary reflectors. Sediment coring may help to confirm the depth to the water table and the presence of a gravel lag on the beach.

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