

GPR as a Tool to Investigate the Three-Dimensional Structure of the Subsurface at Robert Moses State Park.

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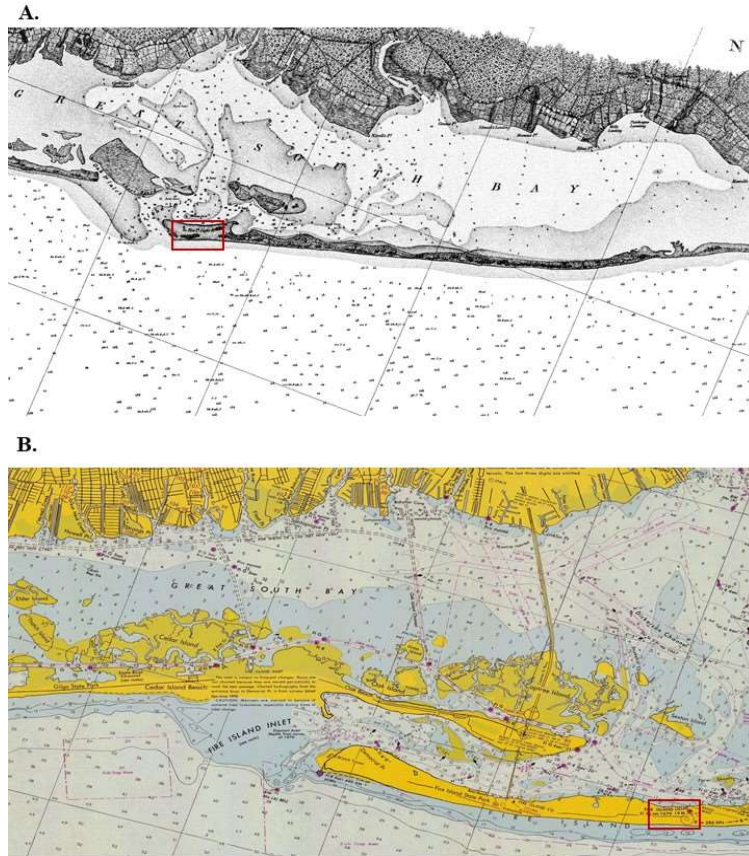


Figure 1. Bathymetric maps illustrating how Fire Island changes over time. Focusing on the western part of the Southern coast of Long Island. Cropped to emphasize the Fire Island lighthouse (in red) A) 1851 Map from a trigonometrical survey of the coast of the United States. B) 1970 Map from National Oceanic and Atmospheric Association (NOAA)

Barrier islands are not stagnant land masses. They continuously change over time as they are influenced by their environments and offer protection to the ‘mainland’ by taking the brunt of storms. Located at a distance of 3 to 8 km from the south shore, Fire Island is the barrier beach protecting Long Island, NY, and Robert Moses State Park (RMSP) is located at Fire Island’s westernmost tip. Fire Island changes shape as sediment is constantly deposited and eroded. Large erosional events, such as Nor’easters, are recorded within the local stratigraphy, while off shore currents transport sediment from the eastern end of the island westward. Figure 1 shows bathymetric maps that illustrate how much Fire Island changed between 1851 and 1970. There are times where erosional events are strong enough to breach the island. This can be seen in at the ‘Old Inlet’ near Smiths Point Park. This breach was opened during Superstorm Sandy in 2012.

Ground Penetrating Radar (GPR) is a geophysical surveying technique that allows for imaging of the subsurface. GPR allows the subsurface to be mapped as different layers transmit and reflect electromagnetic (EM) waves differently. A radio-frequency signal is sent out from a transmitter into the ground, hits a reflective layer, and then is received by a receiver. Reflectors on the radargrams record areas where there is a change in material. Using GPR at Robert Moses State Park allows us to analyze erosional surfaces that record Fire Island’s recent geologic history. Prior to this there have been numerous geophysical surveys at Robert Moses State Park. This project is focused on the Golf Course at RMSP. Over the course of four days GPR and topographic data were collected for this and a related project. For this project, we focused on setting up a 23x90 meter grid that allowed us to collect data from 24 vertical grid lines and 3 horizontal crosslines (Figure 2). Each of the main grid lines was one meter apart and 90 meters long. In addition, three crosslines were placed in areas that did not have obstructions and were different lengths. Such a

three-dimensional structure of GPR imagery gives a much fuller geometric perspective than possible with a single transect, making it possible to come to a much better understanding of the local stratigraphy. Although each grid line is not as long as some past transects in the area, the set of 24 parallel lines and 3 crosslines give a more detailed dataset. GPR data were collected using 25, 50, 100, 250, and 500 MHz antennas. It was important for us to use multiple antennas for the area because each antenna will give us different information about the subsurface. Lower frequency antennas will allow us to see less detail but see much deeper whereas a higher frequency antenna will show a much more detailed radargram with a loss in depth. A combination of multiple antennas will allow us to compare the reflectors that are seen in the radargrams. We are then able to use those comparisons to understand the geology of the reflectors. However, data collection on Fire Island is restricted due to anthropogenic and natural limitations. We were given permission to collect our data on the golf course with strict guidelines that we did not come in contact with the greens. We were also limited in that we were surrounded by thick vegetation. In addition, since our study location was a golf course, we had to understand that we would have anthropogenic traces within our radargram, such as shallow pipes. Overall, however, this was a very good location for our survey.



Figure 2. Maps showing the area in which data was collected. A) Map of Robert Moses State Park with survey area highlighted in red. B) Survey completed at Robert Moses State Park Golf Course, NY. The 23x90 meter grid is outlined in red. Data was collected from 24 gridlines running S-N at exactly 1 meter apart. An example of this is the blue line that represents the X=1 gridline. Data was also collected at 3 specific crosslines, Y=20 (Purple), 30 (Yellow), & 82 (Green) meters running W-E.

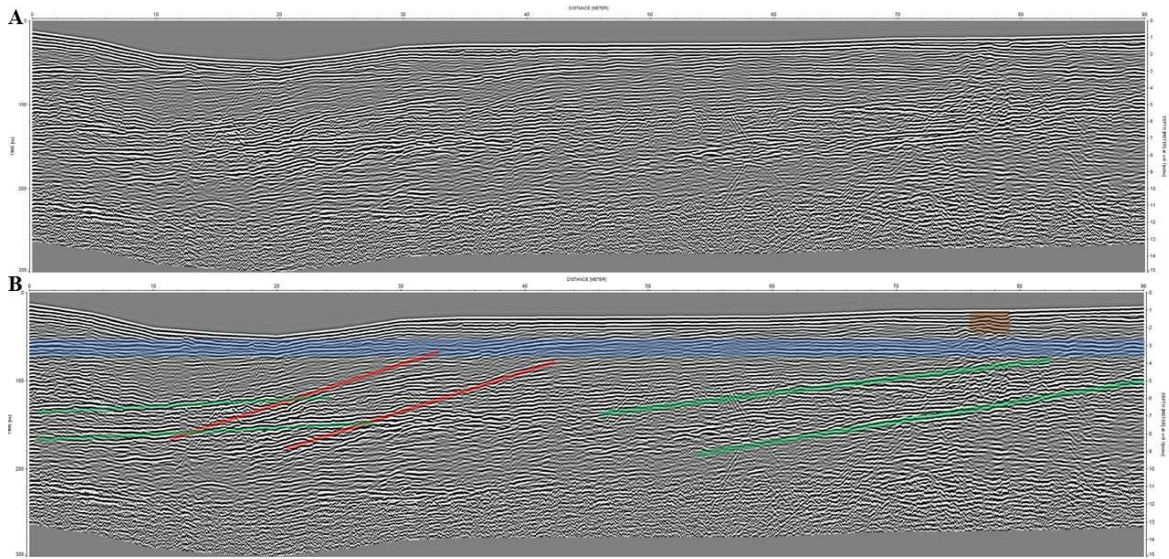


Figure 3. A) Example of GPR line collected during field work. This is data from the X=0 line of the grid. **B)** Initial results annotated from the X=0 grid line. The water table (blue) is prominent within the data along with an example of shallow anthropogenic feature (brown). Erosional (red) and depositional (green) environments can also be seen.

Within the radargram we are able to analyze and locate the water table, stratigraphy, and the fresh water lens, the area between the water table and the fresh-salt transition zone. The character of GPR reflectors depends on their thickness compared to the radar wavelength. Therefore, differences in the sharpness of radar reflectors at various frequencies allows us to better interpret their nature. Figure 3, above, is an example of an annotated GPR radargram.

Initial results show that with the correction for topography with an appropriate assumed radar velocity data there is shallow reflector that flattens out - we believe that this is the water table (Figure 4). The correction of topography tells us that that the shallow reflector is 1-2 meters below the surface. For this location this makes sense with the height above sea level.

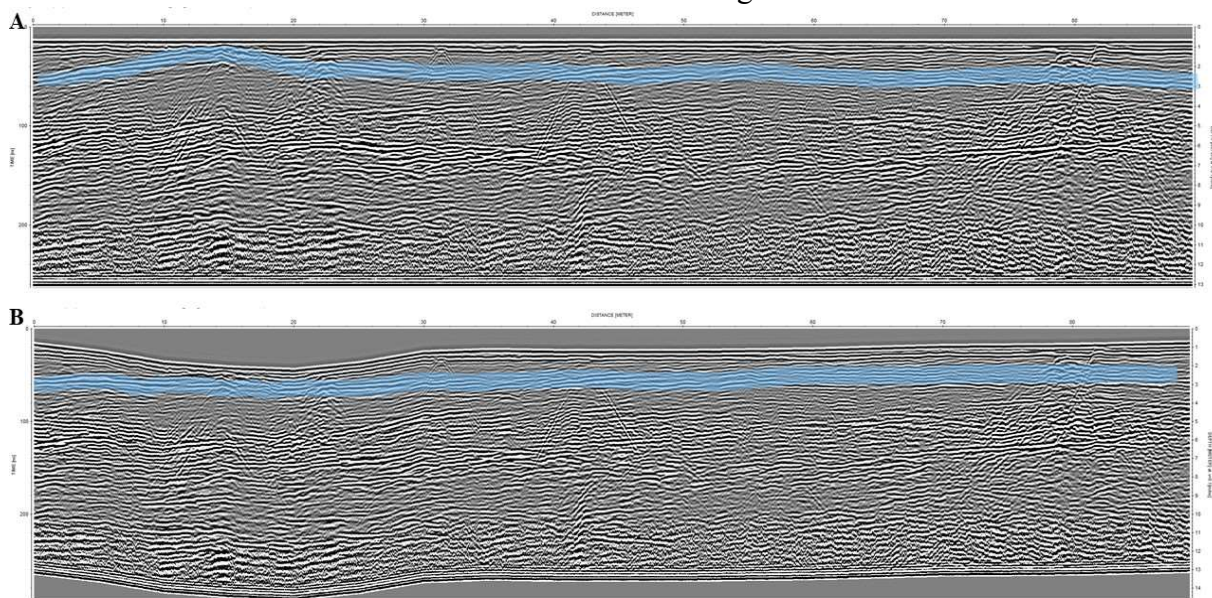


Figure 4. Example of the importance of topography correction for our GPR lines. The reflector that we interpret as the water table is highlighted in blue. A) X= 5 GPR line before topography correction. **B)** X=5 line after topography correction, showing us where the water table is located and flattening out.

The water table is more prominent in 250MHz data than in 500MHz data, suggesting that most of the transition in saturation occurs in a zone that is probably on the order of just 10cm thick. Another type of shallow reflector that we are aware of and are prominent within our data are shallow anthropogenic features. Below figure 5 shows what a shallow pipe looks like within a radargram and how it changes as we move across our grid. We know that this is a shallow straight pipe because the reflector is progressing linearly as it moves from the X=16 to the X=20 gridline.

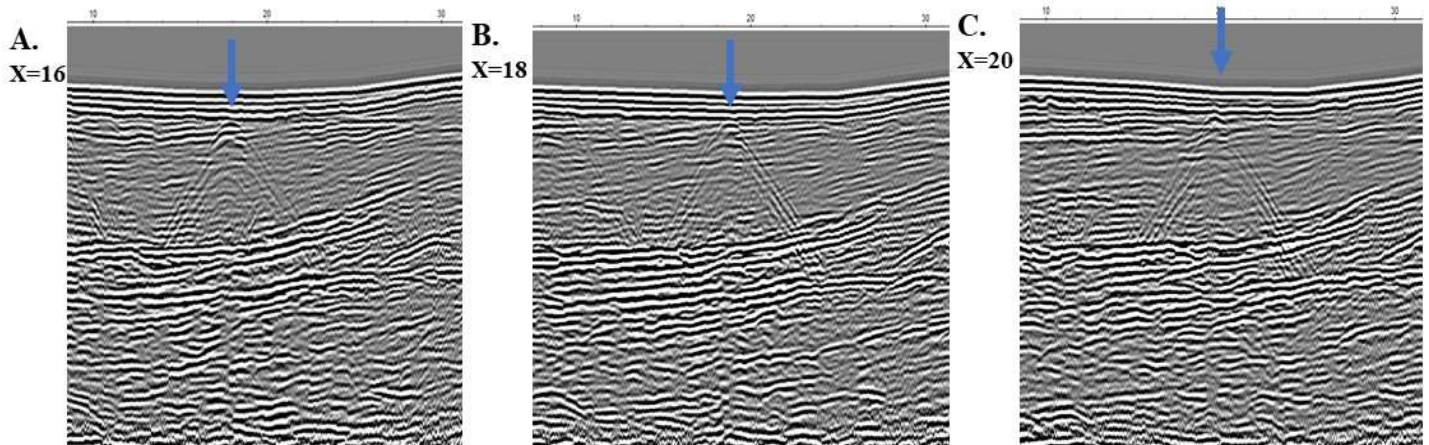
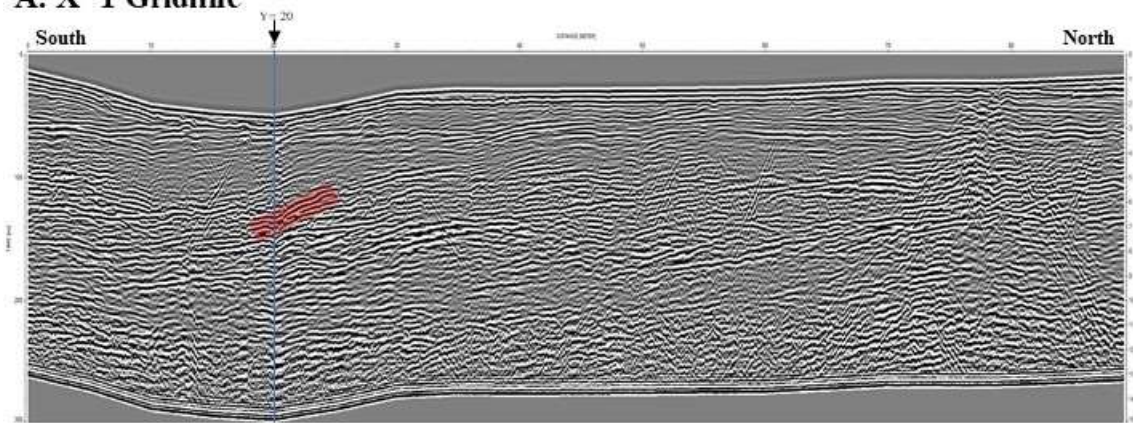


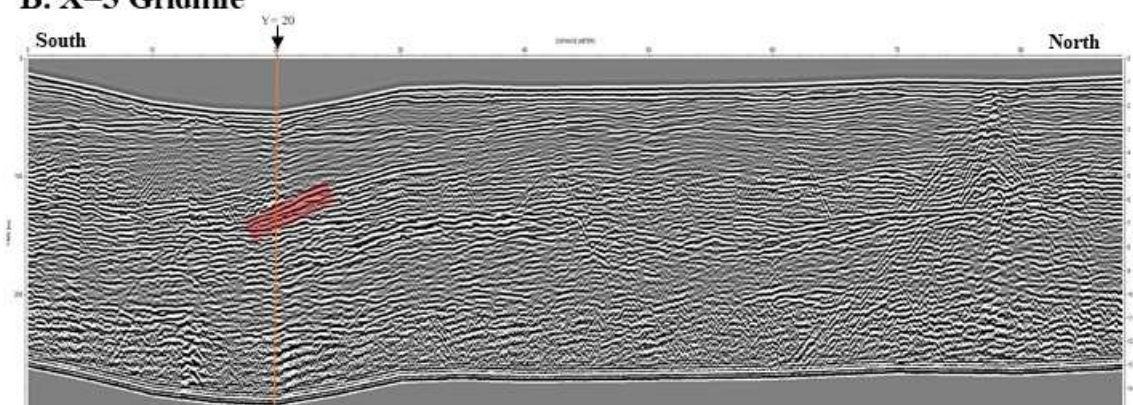
Figure 5. Example of shallow anthropogenic features that are present within our data. The blue arrow is pointing to a pipe as it moves across multiple lines. With an increase in the X, as we move across our grid, there is an increase in Y as the shallow pipe moves obliquely across A, B, and C. A) Part of the X=16 line, with the pipe at $\approx Y=18\text{m}$. B) Part of the X=18 line, with the pipe at $\approx Y=19\text{m}$. C) Part of the X=20 line, with the pipe at $\approx Y=20\text{m}$.

The 23x90 meter grid allows us to have a detailed 3-D imagery of the area. With 24 grid lines and 3 crosslines we are able to better understand the complex reflectors as we can correlate them across numerous lines. By looking at adjacent lines we have been able to find continuity in our features and understand the geometry of the reflectors. We have been able to identify reflectors on main gridlines that are continuous over adjacent lines and have been able to find those same reflectors on the crosslines. With the addition of the crosslines we are able to understand our reflectors in the third dimension. The longer gridlines give up an apparent dip of the reflectors in the plane of those long lines, which bear 209° - 029° . Likewise, the shorter cross lines (which bear 299° - 119°) give apparent dips along that plane. In the cross lines, most reflectors appear much closer to horizontal, so the cross lines are clearly much closer to strike. Figure 6 is an example of how reflectors can be identified over multiple gridlines and on a crossline. The apparent dip of the reflector seen in figure 6 is about 16.5° , which supports our belief that this is a past erosional surface. The apparent dip of a dipping layer as it appears on a radargram depends on the azimuth of the radar line as well as the true orientation of the layer. A stereographic analysis (Figure 7) tells us that the strike of this erosional surface (115° - 295°) is very close to the strike of our crossline ($Y=20$). By using two apparent dips in a stereonet we are able to determine the strike and dip of a reflector that we interpret to be an erosional surface with a dip of 17° towards the SSW. This is expected as Fire Island grows westward and the southern end of the island is eroded sporadically. It also helps us understand that in the past this was the South-West end of Long Island, with a bearing of 115° it is very similar to the bearing of the end of present day long island.

A. X=1 Gridline



B. X=3 Gridline



C. Y=20 Crossline

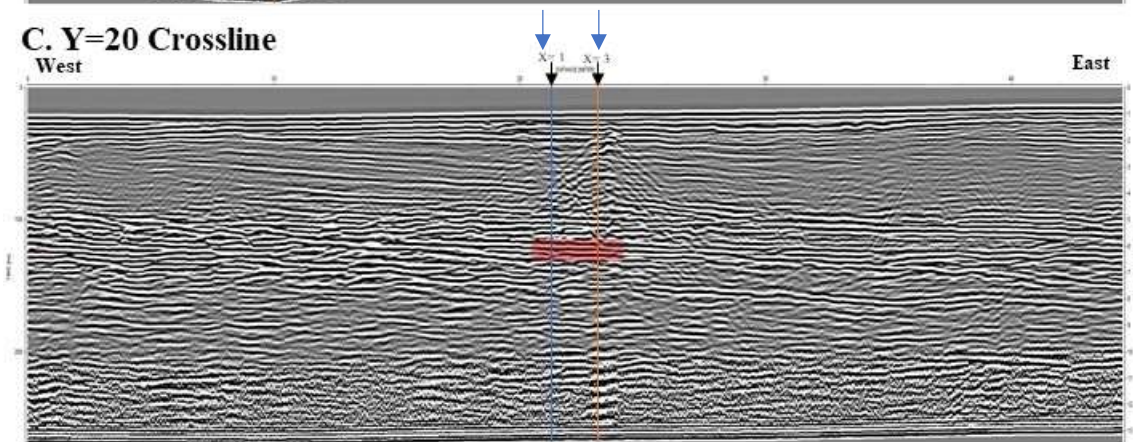


Figure 6. Example GPR lines showing a reflector (red) slowly varying across adjacent lines, as well as cutting through a crossline. Arrows indicate where lines intersect. The apparent dips of this reflector on the gridlines lead us to believe that it is an erosional surface. A) X=1 Gridline showing a steep reflector with an apparent dip of 16° . Highlighted in blue is where the crossline intersects the grid. B) X=3 Gridline showing a steep reflector with an apparent dip of 17° . Highlighted in orange is where the crossline intersects the grid. C) Y=20 Crossline highlighting the reflector seen in the above crossline. The reflector has an apparent dip of 1.2° . Highlighted in blue is where the X=1 grid line intersects the crossline, and in orange is where the X=3 gridline intersects the crossline.

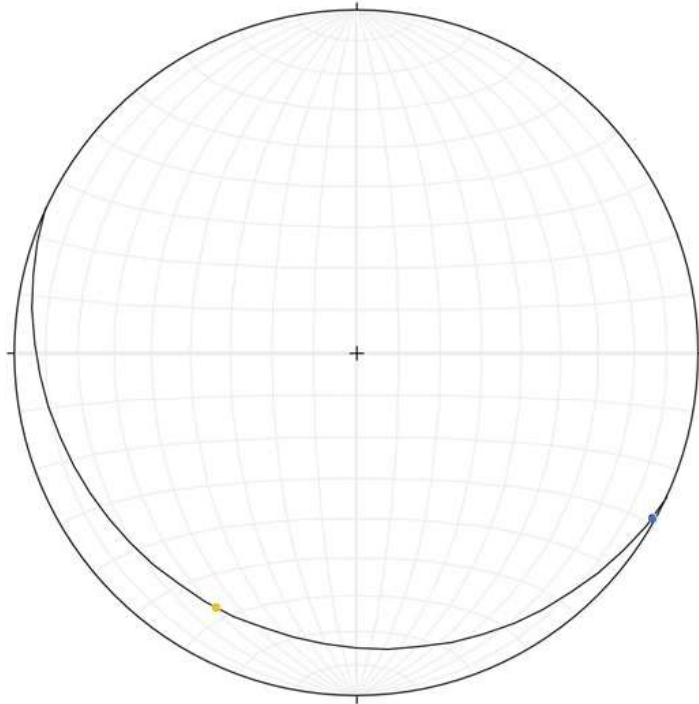


Figure 7. Stereonet of highlighted reflector in Figure 5. The yellow dot represents the reflector from the gridlines (209°,16.5°). The dot blue represents the reflector from the crossline (119°, 1.2°) . The black plane (115°, 16.5° S) represents the strike and dip of the reflector.

The next step in our work will be concentrated on ground-truthing the data. It is necessary to overcome the limitations of remote sensing - in this case the geophysics - to fully understand what we are seeing. The main way to do this will be to further understand what the reflectors are composed of and when they were deposited.

Previously GPR data were collected directly over an area where subsurface sediment was collected at Robert Moses field two picnic area. A very important part of this project will be to correlate drill hole data with GPR signal. Understanding the composition of the reflector requires an understanding of the cause of a reflector. The strength of a reflector depends on its radar reflectivity and the antenna used to image it. We will complete a grain size and mineralogical analysis to further enhance our understanding of the composition of reflectors. This will allow us to correlate the composition of the sediment to the radargram to give us a better understanding of what exactly the GPR data is telling us, giving us a baseline for other surveys that are completed in the area. We additionally will be able to look at past data collected in the area to use as a comparison to our data.

Understanding the age of reflectors will require the use of old maps of Fire Island. Past bathymetric maps give the depth of the sea floor at mean low tide. A comparison of that data with today's mean sea level can allow us to understand where the reflectors are located within the radargram. These can be used to identify ages of reflectors and give us a better understanding of

the timescale on which these large erosional surfaces occur. Another potential method to analyze the age of the reflectors would be optically stimulated luminescence (OSL). OSL is a dating technique that allows us to figure out how long a quartz grain has been buried. We may be able to use OSL to get dates of the lower portion of our drill hole data. However, there is the potential that the reflectors seen on the radargrams are too young to be dated with OSL.

Barrier Islands are dynamic systems that are constantly changing. GPR allows us to image the complex subsurface, giving us the tools necessary to piece together Fire Islands past. Using different frequencies allows us to understand the scale of the reflector, while using a grid allows us to understand reflectors in the third dimension. With our next focus on ground truthing, as we overcome the limitation of remote sensing, we will be able to understand more about the reflectors. Correlating drill hole data to GPR will allow us to understand more about what causes a reflector, and what our reflectors are made out of. While using bathymetric maps to find the ages of reflectors will help piece together a time line of when these large scale erosional events occurred. Overall, we are focusing on understanding what these reflectors are, what they are composed of and when they occurred.