

APPLICATION OF GPR AND OSL IN INTERPRETATION OF DEPOSITIONAL HISTORY OF WESTERN PART OF FIRE ISLAND, NY

By

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Coastal areas are important sedimentary environments as they are directly influenced by climate change, sediment input and various human interventions. Studying the history of such environments can provide important information in predicting future behavior of coastal areas under the conditions of global climate change, storm surges and anthropogenic interventions. This is especially important at present times since coastal areas are attractive residential areas and spaces of increased human interest. Thus, their performance in various weather and climate settings has a direct impact on human lives and economy of such coastal areas.

South shore of Long Island is characterized by well-defined system of barrier islands and spits which is common on passive margins with adequate sediment source. Barrier islands and spits are sediment deposits parallel to the shore line and are built by longshore transport of sediment. This type of coastal environment is sensitive to storm surges and sea level changes as the islands will migrate landward or be breached as a consequence. The proximity of Long Island's south shore to the most populated metropolitan area in the country means that every disruption of this system comes at a large cost to the local and regional communities as witnessed in the aftermath of some recent storms. Mapping out the behavior of this system in the past can tell us a great deal about past climate and sediment transport and such knowledge would greatly improve our prediction for their behavior in the future. In pursuit of interpretation of these paleorecords one has to study sedimentology and geomorphology of such environments in detail and accompany it with geochronology in order to put time constraints on various past events (Reimann, Lindhorst et al. 2012).

The sedimentology of underlying sediments in a beach and barrier island setting can be assessed directly by observing the sediments in sediment sections if they exist or by coring. However, a noninvasive technique like Ground Penetrating Radar (GPR) gives us a good idea of subterranean sediment structures by using electromagnetic waves to image subsurface. It has been widely used to identify subsurface structures in coastal studies with great success (Bristow, Chroston et al. 2000, Havholm, Ames et al. 2004, Buynevich, FitzGerald et al. 2007, Lindhorst, Betzler et al. 2008, Mallinson, Burdette et al. 2008, Lindhorst, FÜRstenau et al. 2010, Fruergaard, Moller et al. 2015). Also, GPR enables surveying subsurface of large areas and exposing the places of special interest or features that point to a past event and need to be sampled later for dating or other analyses thus reducing the amount of invasive exploration.

Lately, the geochronology of coastal environments has been increasingly relying on luminescence dating. OSL or Optically Stimulated Luminescence dating provides a very good tool

in assessing the chronology of coastal sediments directly since it measures the deposition of sediment itself. OSL is a dating technique that uses the ability of some minerals to emit luminescence after they were exposed to ionizing radiation. Natural minerals have defects in their crystal lattice. In such places the orbitals of the atoms do not align well and electrons can have energies that are not allowed in the rest of the crystal. These places are called electron traps as they may contain negative charge vacancy that are attractive to electrons. When some minerals are exposed to ionizing radiation, it can excite electrons from valence band of an atom into a conduction band. Such electron can then be trapped in one of the defects. At room temperature these electrons can stay there for millions of years. As a consequence of ionizing radiation, valence band is missing an electron and this is called a “hole”. The more time a crystal is exposed to radiation the more “holes” are created. If crystal is then exposed to energy in the form of light or heat the electrons are freed from electron traps and get recombined in the electron “holes” within a valence band with a loss of energy that is emitted as luminescence (Wintle and Adamiec 2017).

The range of the method is ever expanding but it has been shown successful in dating very young sediments, decades (Madsen and Murray 2009, Costas, Reimann et al. 2012, Shen and Mauz 2012) up to several hundred thousand years (Cunningham 2014). Both ends depend on the sample collected and their depositional environment. Minerals that are used for dating are quartz and feldspar with quartz being the mineral of choice for most studies. Suitable settings for OSL dating are any deposits that were sufficiently exposed to sunlight prior to deposition: loess, aeolian sand, fluvial deposits, coastal deposits, proglacial deposits and even deep sea sediments. The technique basically measures the time that has passed since mineral grains, namely quartz, were last exposed to sunlight (Aitken M. 1998). It only measures the age of the last depositional event, as the reactivation of sediment, its transport and deposition will lead inevitably to exposure to sunlight and destruction or “bleaching” of previously acquired luminescence signal.

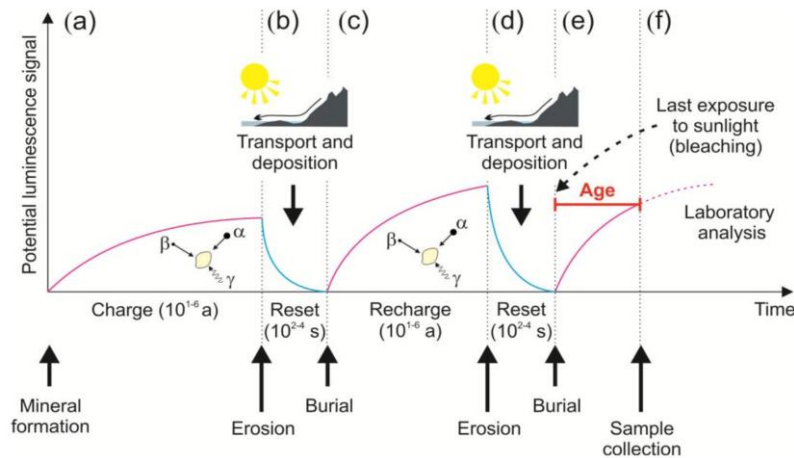


Figure 1. Diagram shows several cycles of deposition with subsequent reactivation of sediment and signal resetting. OSL can measure only the last depositional event (Mellet 2013)

Fire Island is a large thin barrier island parallel to the south shore of Long Island (Figure 1.), New York. The island is approximately 50 km long and between 160 and 400 m wide with the area of about 25 km². Robert Moses State Park is located on the western part of the Fire Island. Historic maps, GIS and satellite images demonstrate that Fire Island has experienced a remarkable change over the last 150 years with the most notable expansion of the island westward by about 7 kilometers to its present position (Itzkin 2016).



Figure 2. Fire Island shown in green. Robert Moses State park is the western most part of the Fire Island shown in white (U.S. Department of Interior, National Park Service, modified by Franz Gstättner).

The Park has been extensively studied with GPR as a part of a senior thesis study done by Michael Itzkin and Dan Davis (Itzkin 2016). They have covered the area of the Park with almost 5 km of GPR lines running the length of the park in the E-W direction and two lines crossing the island from ocean side to the South to the bay side on the North as well as a few shorter cross lines along the 5 km long GPR line as shown in Figure 3.

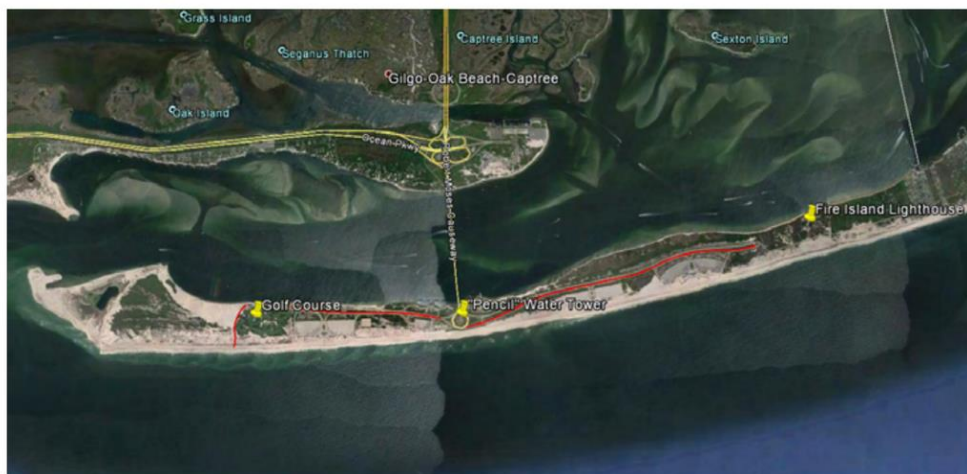


Figure 3. Current day satellite image of Robert Moses State park showing GPR lines shown in red. Robert Moses State Park Pitch and Putt Golf Course, the water tower and the Fire Island Lighthouse are marked with yellow pins (Itzkin 2016).

After processing, GPR lines running the length of the island showed shallow dipping beds extending westward with the dip angle of 4° which is indicative of prograding paleoshore as well as erosional surfaces and features suggesting past lobes of the island. GPR transect outlined in red going from the ocean side in the south to the bay side in the north (Figure 3.) clearly showed erosional and depositional surfaces as well as the water table and salt/fresh water boundary outlined in red and yellow in Figure 4. The depositional surfaces with the angle of 4° can be interpreted as past beach and the best explanation for the distinct erosional surfaces in the absence of more data is that they are erosional events of the past storms.

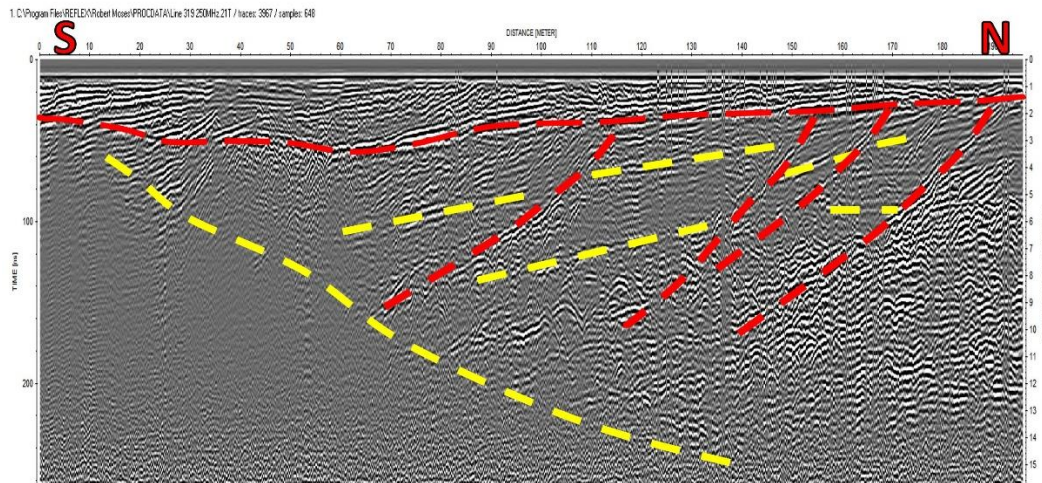


Figure 4. GPR line crossing the Fire Island at Robert Moses State Park. Ocean side is to the left.

This study provided some intriguing information about the subsurface of Fire Island and encouraged more GPR studies and eventually, sampling for OSL dating. The path that is outlined in red in Figure 3. and enlarged in Figure 5. and is crossing the island oceanside to bayside provided a good location for a more in-depth GPR investigation because of its location and accessibility.

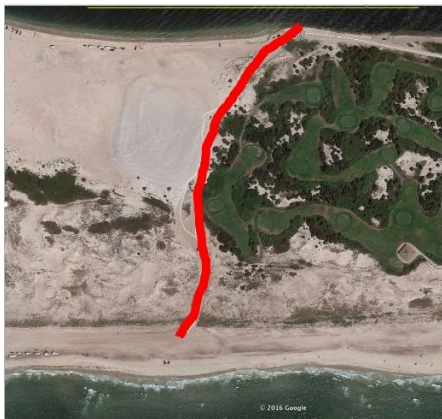


Figure 5. Outlined in red is a 500 m long truck path that crosses the Fire Island in the western part of Robert Moses State park from ocean to bay.

Several GPR lines were run the length of the path providing a crosssection of the whole island from ocean side to bay side. Radar images clearly outline the salt/fresh water boundary (Figure 6.). In addition they show shallow dipping beds of beach deposits and steeper erosional surfaces

as can be seen in Figure 7. These images were used to narrow down the area with multiple superimposed erosional and depositional surfaces that are of most interest for OSL sampling.

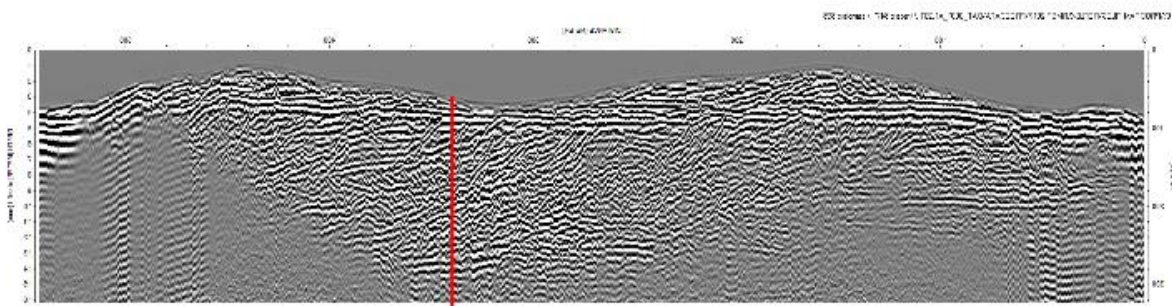


Figure 6. 500 m long GPR line at Robert Moses State Park spanning the island. Ocean side is on the left and bayside is on the right.

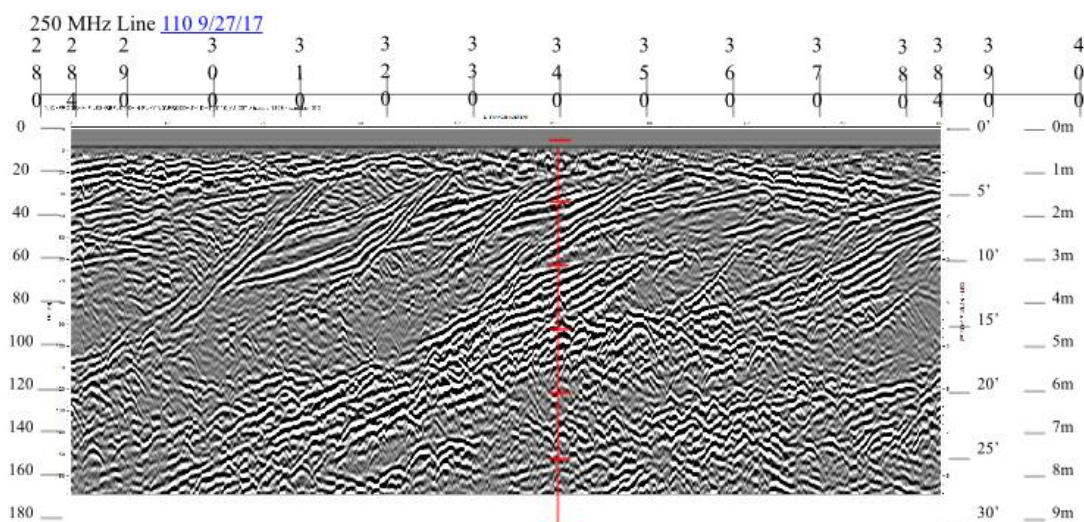


Figure 7. GPR image of the area chosen for sampling. Red line shows the position of geoprobe sample site.

Sampling for OSL has some challenges as the sample must not be exposed to light until it gets into the dark room conditions in the laboratory. Light is resetting luminescence signal and even brief exposure can reduce luminescence signal and result in underestimation of age. Short of sampling at night, one mostly uses different kinds of opaque pipes that are pushed into the sediment. Sampling at Robert Moses State park was attempted in several ways before finding an optimal sampling technique. First it was done by hand auger, a hand drilling tool for soil sampling. Auger can sample sediments up to several meters in 30 cm increments. In this case it was used with the split spoon attachment. One can take only relatively shallow samples with hand auger since there is a great chance of introducing more modern material as the bore hole gets deeper which would interfere with dating. In addition, it becomes increasingly problematic to pull the auger out of the sediment as it is pushed deeper underground so this sampling method was abandoned. Vibra-core is a device that uses vibrations to push aluminum pipe into the ground. This method of sampling was not successful in this setting as the vibrations of the core made the sand fall out of the aluminum pipe and a great portion of sediment was lost. Geoprobe is a truck-

mounted coring device that uses pushing rather than drilling to force a core into the ground (Figure 8.). The core is taken in 6 ft increments that are lined with transparent plastic sleeves. The plastic sleeves contain the sample and great care has to be taken when transferring them out of the metal core not to expose them to sunlight. Samples were collected with a geoprobe up to the depth of 7 meters at which point the probe was not able to go any deeper.



Figure 8. Geoprobe sampling at Robert Moses State Park, Oct. 2017.

The cores were taken to the OSL laboratory in the Department of Geosciences at Stony Brook University. Under dark room conditions a sample was taken from depth of 6.5 meters. Portion of sample was taken for water content assessment and portion for determining the dose rate of the surrounding sediment. Rest of the sample was sieved. Grain size 150-250 μm was further processed with HCl to get rid of carbonates, H_2O_2 to destroy any organic material, HF to dissolve feldspar and etch outer layer of quartz affected by alpha radiation. Finally, heavy liquid density separation was used to isolate quartz grains.

As stated earlier, OSL dating relies on the ability of quartz grains to produce luminescence after they absorbed ionizing radiation. Luminescence is emitted when such grains are submitted to light or temperature. The energy of light or temperature will force the trapped electrons to recombine and luminescence will be emitted. The luminescence emitted is proportional to the dose absorbed. The age is calculated from the dose that sample absorbed (also called the Equivalent Dose) divided by the dose rate of the surrounding sediment.

Age is calculated from formula

$$OSL\ age = \frac{Equivalent\ Dose\ D_e\ (Gy)}{Dose\ Rate\ \dot{D}\ (\frac{Gy}{a})}$$

In the laboratory, natural luminescence of the sample is measured but one does not know what is the dose that is responsible for that luminescence signal. In order to convert the luminescence measured into equivalent dose quartz grains are submitted to several steps in the dating procedure. Natural luminescence is measured first and in the process of measurement this natural luminescence the natural signal is erased. After that, several different radiation doses are given to the same sample and luminescence signal resulting from each dose is measured. The results are plotted on a luminescence vs. dose plot. The dose responsible for the natural signal is inferred from there (Figure 9.).

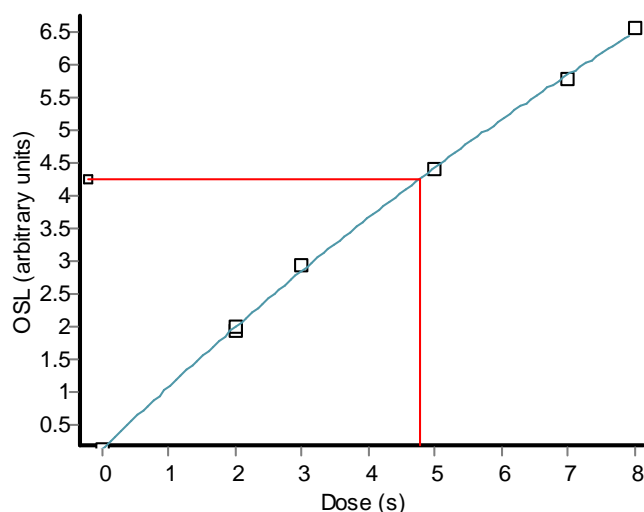


Figure 9. A simplified example of OSL signal vs. dose plot. Squares are the laboratory doses given to a sample. Red line is natural signal.

Robert Moses State Park samples are expected to give low equivalent doses as the sediment should be young, less than 200 years old. Dating young sediments is challenging because everything that usually affects equivalent dose will have a greater effect on young samples with low signal. For example, variation in sedimentary environment, choice of procedure such as preheat temperature or left-over signal from previous depositions can lead to severe underestimation or overestimation of equivalent dose. The low signal to noise ratio itself introduces larger uncertainties.

OSL on samples from Robert Moses State Park was measured on an automated Risø TL/OSL reader (Figure 10.). 6-10 mg of sample was placed on aluminum cups and loaded into the reader for measurement. Samples were stimulated with blue LED at 470 nm and 7.5 mm Hoya U-340 filter was used as detection filter. Preheat temperature was 200°C with the cut heat temperature of 160°C. Before each OSL measurement aliquots were submitted to infra-red (IR)

LED light to erase any possible feldspar contamination. Single-aliquot regenerative-dose (SAR) protocol was used for determination of the D_e (Murray and Wintle 2000). Aliquots with recycling ratios of $> 10\%$ from unity and test dose error over 10% were excluded from calculations. The regenerative dose signals were fitted by a linear function to obtain SAR dose response curve. The signal was calculated from the first 0.5 s of the OSL decay curve. Background signal from the last 5 seconds of the decay curve was subtracted from the initial signal. The suitability of the method was determined by dose recovery experiments on 24 aliquots. In these experiments sample's natural signal is erased and a known dose is given to it. This dose is treated as an unknown dose and sample is run through the procedure to recover the given dose.



Figure 10. Risø TL/OSL Reader in the OSL laboratory in Geosciences Department at Stony Brook University.

As expected, the D_e values from Robert Moses State Park sample are low but consistently around 0.1 Gy. The fact that the dose is so low gives us confidence that there was no residual signal from previous depositions as that signal would overwhelm the natural luminescence measured at this time.

The next step is to determine the dose rate of the surrounding sediment. Dose rate is determined from the concentrations of U, Th and K, and contribution from cosmic rays. Moisture content for the duration of burial is estimated and taken into account.

SUMMARY

The behavior and evolution of the beach and barrier island environment in the past has been studied around the world. Luminescence dating has been widely used in dating coastal sediments since they fulfill all the requirements for the technique. OSL has been proved very useful in dating young coastal sediments and with the latest advances in methodology (Murray

2000, Murray and Wintle 2003) and equipment (Duller 2008) the consensus is that it can be used with confidence (Madsen and Murray 2009). Some studies successfully showed the usefulness of combined use of Ground Penetrating Radar (GPR) for geomorphology and OSL dating for chronology (Havholm, Ames et al. 2004, Buynevich, FitzGerald et al. 2007, Mallinson, Burdette et al. 2008, Fruergaard, Moller et al. 2015). In North Carolina (Mallinson, Burdette et al. 2008) OSL ages were used to put constraints on paleo shorelines and relative sea level changes in the past ~80 ka years. Combined GPR and OSL were used to determine the change in storms frequency and intensity on the coast of Maine in the past 1500 years (Buynevich, FitzGerald et al. 2007). Two combined studies used GPR (Havholm, Ames et al. 2004) and OSL (Berger, Murray et al. 2003) to determine periods of past coastal dune stability and activity in the past ~1000 years.

Recent GPR study of Robert Moses State Park showed that this area of Fire Island exhibits distinctive geological features which can potentially be analyzed and dated to give a more comprehensive description of development of a barrier island. Fire Island has been covered by historical maps starting from 1852 (Itzkin 2016) and shows the evolution of the island in westward direction. The maps themselves are providing an independent age control on the OSL ages. Ultimately, the combined use of GPR and OSL would give better understanding of the depositional history of the island.

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