Interpretation of the Duluth-Superior Barrier System: Analysis through models and ground penetrating radar data

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Abstract

Barrier Island geomorphology is a complex subject due to the various coastal environments and associated processes where barriers form, including variations in sediment supply and sea level. The Duluth-Superior Barrier System (DSBS), home to the Duluth Seaway Port, has received little investigation from scientists. Past UW- Eau Claire research students collected ground penetrating radar (GPR) data from two spit components that compose the system. After a review that compiled models of formation and stratigraphy of previously studied marine and fresh water barrier systems, the study presents the interpretation of the DSBS through processing and analyzing previously collected GPR field data. Interpreting the stratigraphy to develop a geomorphic chronology of formation was influenced by the literature review. GPR systems record the return of electromagnetic energy reflected from the subsurface lithology and structure. These returns were stored as raw data and then processed using EKKO Project software to display the stratigraphy as 2-D and fence diagrams. Results of the study aid in better understanding the processes of formation and barrier type, Holocene lake level fluctuations, and an understanding of geomorphic processes occurring in the modern system. Research results pertaining to current geomorphic processes provide conservation groups with information to aid in habitat restoration of the area.

Introduction

The Duluth-Superior Barrier System (DSBS) is composed of a barrier spit that is divided by the St. Louis River, creating Wisconsin Point and Minnesota Point. The system is 10 km in length, making it one of the largest freshwater barrier systems in the world (Krantz et al., 2013).The barrier is located in Duluth, Minnesota and Superior, Wisconsin and encapsulates the Duluth Seaway Port. The St. Louis Estuary and DSBS are home to fragile dune and forest ecosystems. Human activity has caused pollution, flooding, and erosion in the area (Stirrat, 2016). By studying the formation of this barrier system and applying present day models of Padre Island, Texas and Eldeburgh, England, I will gain understanding of the sedimentation patterns in the area. Research findings will be shared with the Wisconsin Department of Administrative Coastal Management Program, the Wisconsin Department of Natural Resources, and the St. Louis River Alliance to aid in land and habitat conservation.

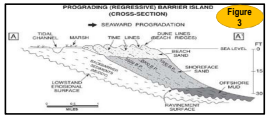
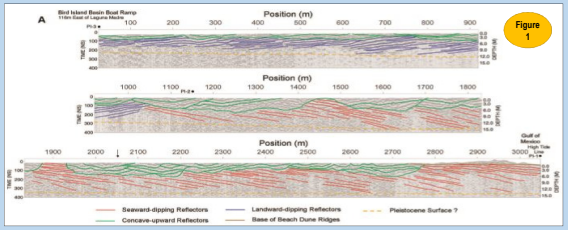


Figure 3. Cross sectional view of the morphology of a progradational sequence (Davis, 1994).

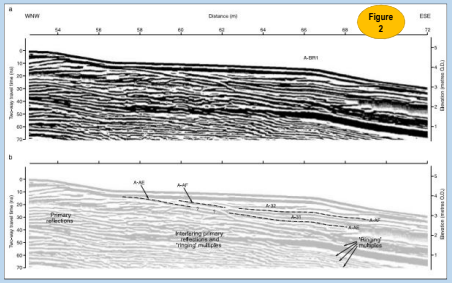
Methods

Ground penetrating radar (GPR) data and a literature review of present day barrier formation models (Garrison et al., 2010; Neal et al., 2002; Barlaz,1983) were the primary sources used to build my interpretation of the DSBS formation. Aerial photographs of the DSBS through the past 78 years were used to aid in understanding my interpretations. GPR data used for this project was collected during previous research campaigns. GPR systems record the return of electromagnetic energy reflected from the subsurface lithology and structure (Jol et al., 2003). The strength of the reflected signals are proportional to the difference in the dielectric constants of the sediments (Jol et al., 2003). These differences allow the user to see the stratigraphy (layer of sediment) of the subsurface in a non-invasive manner. Data was collected using a PulseEKKO 100 GPR system with a 100Mhz frequency antennae and 0.25m interval step method. Topographic data was collected for each transect using a TopCon RL-H3CL laser level. The raw data was processed using EKKO Project software. During processing, multiple datasets were merged as one, and topographic data was added as an attachment. AGC (automatic gain control) was used during processing to enhance the display of the stratigraphy. The output of processing yields two dimensional (2-D) images of the subsurface (Jol and Bristow, 2003). The 2-D images are compared to present day models of GPR studies conducted on other barrier systems.

Studies performed at Padre Island, Texas and Eldeburgh, England provided similar GPR profiles to the DSBS.



The Padre Island GPR profiles revealed seaward dipping clinoforms, landward dipping clinoforms, and concave-upward forms (Figure 1; Garrison et al., 2010). The seaward dipping clinoforms were interpreted to indicate progradation (seaward migration of the shoreline; Garrison et al., 2010). Landward dipping reflections were interpreted to form from washover channels and the concave-upward reflections are the washover deposits (Garrison et al., 2010). The growth of the shoreline was due to a large sediment supply provided by the Rio Grande River through longshore drift (Garrison et al., 2010).



Likewise, Eldeburgh, England profiles revealed dominant seaward dipping clinoforms along with landward dipping clinoforms (Figure 2; Neal et al., 2002). The seaward clinoforms had dips of 6-7 degrees and were interpreted to form from progradation (Neal et al., 2002). The landward dipping clinoforms were interpreted to form from storm overwash.

Discussion

From viewing the GPR lines and comparing them along side models, the Duluth-Superior barrier system has formed predominantly by progradation (Figure 3) of the shoreline and surficial aggradation by wind processes. Both the Wisconsin and Minnesota Point spits display aeolian (wind blown) dune deposits on the upper 0-5m of the lines. These dunes most likely formed by coastal wind processes. A section of Wisconsin Point displays landward dipping reflections similar to Padre Island. These reflections are interpreted as storm washover deposits.

Growth of the shoreline was provided by a sediment supply from the south shore (north shore lacks sand) through littoral drift (Barlaz,1983). This interpretation is supported by aerial photographs comparing the present day shoreline compared to its position in 1939. The Wisconsin Point Spit very clearly displays progradation of the shoreline towards Lake Superior (Figure 4). The Minnesota Point GPR profile displays lakeward dipping clinoforms indicating progradation, but the aerial photograph shows that the shoreline has eroded and water level has rose (Figure 5). Jetty construction is the most plausible cause for erosion, and rising lake levels can be associated with isostatic rebound. Future research to prove these points can be done through finding the date of jetty construction and viewing aerial photographs from that time period and onward.

Minnesota Point Morphology

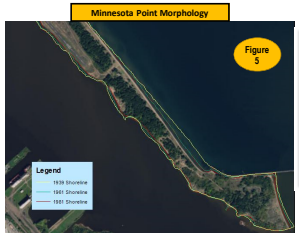


Figure 5. Aerial photograph of Minnesota Point shoreline at present time. The yellow line indicates the past shoreline in 1939. It can be seen that the shoreline has receded.

Wisconsin Point Morphology

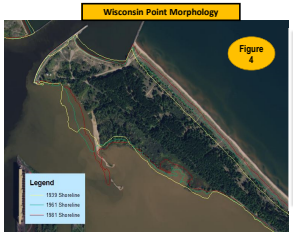
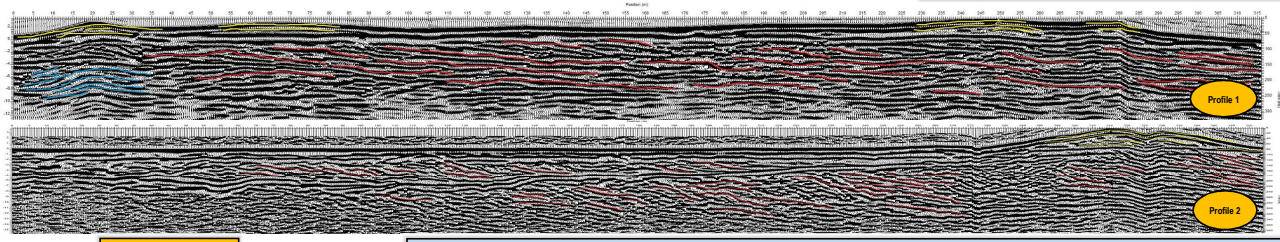


Figure 4. Aerial photograph of Wisconsin Point shoreline at present time. The yellow line indicates the past shoreline in 1939. The shoreline has prograded (grown) towards Lake Superior to the NE.

Results

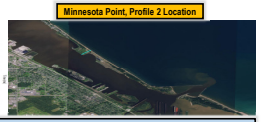
GPR field data was collected from both Wisconsin Point and Minnesota point. The Wisconsin Point transect (Profile 1) is 315 meters in length and displays lakeward dipping sigmoidal reflections, landward dipping reflections, and subparallel continuous reflections. The Minnesota Point transect (Profile 2) is 355 meters in length and displays lakeward dipping sigmoidal reflections and wavy subparallel continuous reflections.

Observation	Interpretation
Lakeward Dipping Sigmoidal Reflection	Progradation Sequence
Landward Dipping Reflection	Washover Deposit
Subparallel Continuous Reflection	Aeolian Dunes



Wisconsin Point, Profile 1 Location

Minnesota Point, Profile 2 Location



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References

Barlaz, D.B., 1983, Sedimentation in the Duluth-Superior Harbor, Lake Superior: , p. 1–123.

Davis, R.A., 1994, Geology of Holocene barrier island systems: Berlin, Springer-Verlag.

Garrison, J.R., Williams, J., Miller, S.P., Walker, E.T., Mcmanahan, C., and Zang, X., 2010, Ground-Penetrating Radar Study of North Padre Island: Implications for Barrier Island Internal Architecture, Model for Growth of Progradational Microtidal Barrier Islands, and Gulf of Mexico Sea-Level Cyclicity: Journal of Sedimentary Research, v. 80, p. 303–319, doi: 10.2110/jsr.2010.034.

Jol, H.M., and Bristow, C.S., 2003, GPR in sediments: advice on data collection, basic processing and interpretation, a good practice guide, in Bristow, C.S. and Jol, H.M., eds., GPR in sediments: Geological Society of London, Special Publications 211, p. 9–27.

Jol, H.M., Lawton, D.C., and Smith, D.G., 2003, Ground penetrating radar: 2-D and 3-D subsurface imaging of a coastal barrier spit, Long Beach, WA, USA: Geomorphology, v. 53, p. 165–181. (accessed December 2016)

Krantz, A., Pingel, A., and Jol, H.M. Subsurface Investigation of a Barrier Spit: Wisconsin Point: http://subsurfacevisualizationofaspoint.weebly.com/introduction.html (accessed December 2016).

Neal, A., Pontee, N.I., Pye, K., and Richards, J., 2002, Internal structure of mixed-sand-and-gravel beach deposits revealed using ground-penetrating radar: Sedimentology, v.49, p. 799–804, doi: 10.1046/j.1365-3091.2002.00468.x

Simenson, D., Alger, R., and Jol, H., 2013, A GPR Investigation of the Duluth Barrier: A GPR Investigation of the Duluth Barrier, https://duluthbarriergpr.wordpress.com/ (accessed December 2016).

Stirrat, H., 2016, Implementation plan for the St. Louis River Estuary Habitat Focus Area: https://www.habitatblueprint.noaa.gov/wp-content/uploads/2016/04/FINAL-Implementation-Plan-for-the-St-Louis-River-Estuary-HFA_ImpPlan.pdf (accessed January 2017).

Yale, K., 1997, Regional stratigraphy and geologic history of barrier islands, west central coast of Florida: , p. 1–160, http://palmm.digital.flvc.org/islandora/object/usf%3A63424#page/4/mode/2up (accessed February 2017).