



USING RADAR STRATIGRAPHIC ANALYSIS TO IDENTIFY EROSION AND DEPOSITION IN THE DULUTH BAY BARRIER, LAKE SUPERIOR

Sean Morrison, Harry Jol, Ryan Alger
University of Wisconsin-Eau Claire



Abstract

The Duluth barrier protects the major Great Lakes shipping ports of Duluth, MN and Superior, WI from Lake Superior. The barrier is divided into Park Point and Wisconsin Point by a natural inlet. Over 2.5km of shore parallel and shore perpendicular ground penetrating radar (GPR) transects were collected and analyzed on both points. GPR uses electromagnetic (EM) waves to infer a subsurface image. Common midpoint surveys were collected and a near surface velocity of 0.08m/ns was calculated, allowing more accurate depth calculations. This study utilized a pulseEKKO 100 GPR system for data collection with 100 MHz antennae. Data was processed and plotted with Sensors and Software's EKKO Project. Radar stratigraphic analysis divides reflection patterns into radar facies based on changes in geometric characteristics. A major, continuous, undulating reflection is imaged between 4-6m depth and interpreted as an erosional surface created during a lower lake level. In shore parallel transects, facies are dominated by northward dipping reflections suggesting that littoral drift from the southeast feeds the Duluth barrier. Predominant radar facies in shore perpendicular transects are lakeward dipping inclined to sigmoidal reflections interspersed with subhorizontal reflections. The pattern is interpreted to be repeated storm deposition and non-storm deposition during progradation. Sigmoidal to inclined reflections are interpreted as erosional beach facies, subhorizontal reflections are believed to result from deposition in the surf zone. Radar stratigraphic analysis can aid in a better understanding of how erosion, littoral drift, and human activity have affected the Duluth barrier. Interpretation of the stratigraphic relationship between radar facies allows the evolution of the Duluth barrier to be reconstructed.

Introduction

The Duluth barrier is located on the western edge of Lake Superior (Figure 1). The NE-SW trending barrier is nearly 10km long making it one of the world's largest freshwater baymouth barriers (Loy, 1963). Separating the Duluth-Superior Harbor from Lake Superior, the Duluth Bay Barrier is breached by two inlets. A natural inlet near the SW end of the barrier separates Minnesota Point (known locally as Park Point) from Wisconsin Point, additionally an artificial inlet was constructed on the NE end of the barrier in 1870-71 and is spanned by the Aerial Lift Bridge. Due to the heavy shipping traffic, the Army Corps of Engineers has been charged with managing navigation channels in the harbor and through the inlets. Extensive amounts of dredging maintains a deep channel in the otherwise shallow water bay. The construction of jetties to protect both inlets from sediment infilling has blocked the movement of sediment along shore. Minnesota Point has a significant amount of residential houses, a large park, and a municipal airport. Erosion control measures are found through the area and include riprap on the bay side and sand fences on the lake side. Wisconsin Point on the other hand is almost entirely a state natural area and remains largely undeveloped. In addition, higher rates of the glacial isostatic rebound (GIA) in the northeaster Superior Basin (Mainville and Craymer, 2005) has caused rising lake levels in the Duluth area and the flooding of the Saint Louis

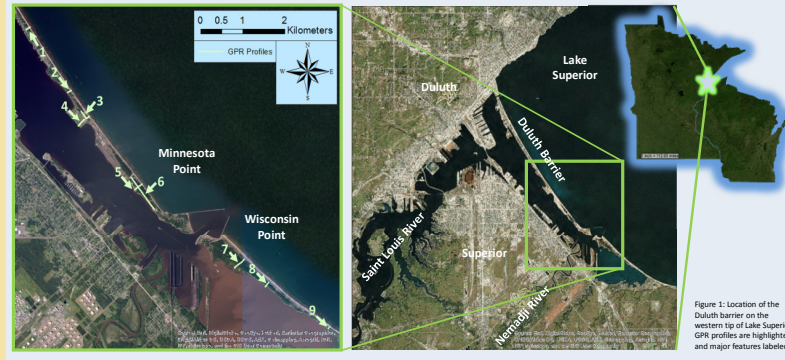


Figure 1: Location of the Duluth barrier on the western tip of Lake Superior. GPR profiles are highlighted and major features labeled.

Methods

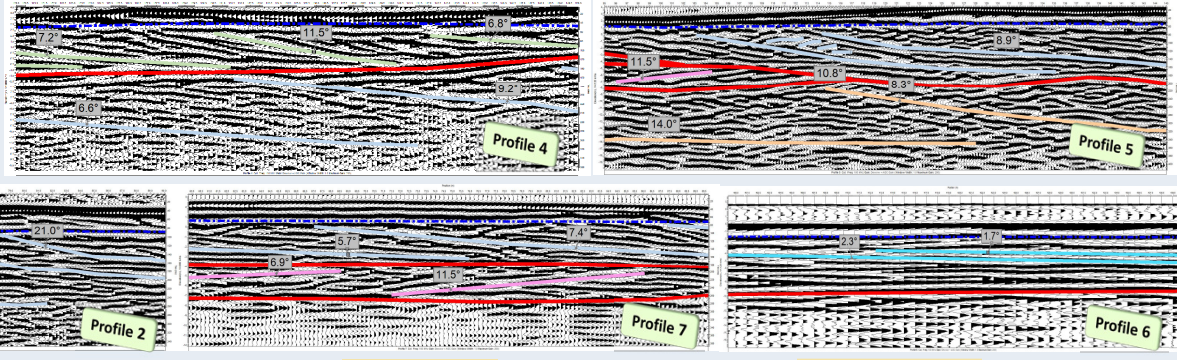
Ground penetrating radar (GPR) is a noninvasive method to image the shallow subsurface. GPR utilizes electromagnetic waves which reflect off changes in dielectric properties of sediments (Jol and Bristow, 2003). To understand the depositional history of the Duluth Bay Barrier, several shore parallel and perpendicular transects were collected along the length of the barrier (Figure 1). The GPR system used for this study was a pulseEKKO 100 with 100MHz antennae and a 1000V transmitter. For shore perpendicular transects data was collected in step mode with a step size of 0.25m and antennae separation of 1m. For shore parallel transects the data was collected in continuous mode with an interpolated step size of 1m and antennae separation of 0.8m. Common midpoint surveys collected in the field were analyzed to determine an average near surface velocity of 0.08m/ns. Relief measurements were collected using a Topcon RL-H3CL laser level to adjust the profile to reflect changes in topography. Processing and plotting of the data utilized Sensors and software's EKKO_Project and applied horizontal and vertical averaging, dewow filtering and automatic gain control. Radar stratigraphy was then used to identify radar facies (RF) which were interpreted by comparing identified radar facies to previous work in similar environments.

Results and Interpretation

Radar Facies Name	Location	Radar Stratigraphic Description	Interpretation
RF-A	Upper 1-3m on profiles 4 and 7.	Semi to non-continuous subhorizontal to sigmoid reflections.	Aeolian dunes.
RF-B	8-12m thick facies observed on profiles 1, 2, 4, 5, 7, 8 and 9. The upper boundary is the ground surface or a continuous reflection below RF-A. The lower boundary is non-continuous at a depth of 12m - 15m.	Lakeward (NE) dipping (5-21°) sigmoidal reflections with some intervening semi-continuous subhorizontal reflections. Several hyperbolic reflections are observed on profile 7.	A progradational sequence
RF-C	Observed only on profile 4 from position 0 to 280. The upper boundary is the ground surface and the lower boundary is a continuous subhorizontal bayward inclined reflection at a maximum depth of 3m.	The continuous reflection between RF-B and RF-C differentiates the two facies. Sigmoidal lakeward (NE) dipping (9-12°) reflections.	Progradation onto an already established barrier.
RF-D	Observed on profile 5 from position 0 to 80m. The upper boundary is the ground surface and the lower boundary is a continuous horizontal reflection at a depth of 4m.	Continuous horizontal reflections with several hyperbolic reflections.	Back-barrier aggradation, hyperbolics are buried objects (possible logs).
RF-E	Observed on profiles 5 and 7 with a continuous horizontal upper boundary at a depth of 4m and a continuous subhorizontal lower boundary at a depth of 7m.	Inclined bayward dipping (6-12°) reflections with some subhorizontal reflections.	Bayward dipping reflections are storm overwash deposits.
RF-F	Observed on profile 5. The upper boundary is a continuous subhorizontal to undulating reflection at a depth of 4-7m. The lower boundary is below the depth of penetration.	Sigmoidal, lakeward dipping (6-15°) reflections with intervening subhorizontal reflections.	A buried progradational sequence.
RF-G	Observed on profiles 3 and 6. The upper boundary is the ground surface and the lower boundary is a non-continuous to semi-continuous subhorizontal reflection at a depth of 8-10m.	8m thick facies of subhorizontal to inclined reflections with slight dip (1-2°) to the NW with a non to semi-continuous lower boundary.	Deposition of barrier sands primarily in the direction of longshore drift.

Select GPR Profiles

GPR profiles were selected to best exemplify the radar facies observed in all profiles. For shore perpendicular profiles (2, 4, 5 and 7) lakeward (NE) to the right. For shore parallel profiles (6) NW to the right. Colors correlate with radar facies in the above table.



Discussion

- The barrier is built upon a buried deposit. Due to changes in depth of penetration, the sediment of the buried feature differs from the barrier. Attenuation of the GPR signal likely stems from a concentration of fine grained sediments. Possible sources for the buried deposits are 1) lake sediment deposited during a higher lake level phase; 2) sediment deposited in a flooded river valley before the barrier formed; 3) deltaic sediments deposited during a lower lake level; 4) glacial or glaciofluvial sediment. Other researchers have proposed the barrier is built upon an underlying bedrock ridge, a terminal moraine, or a giant tree felled by the legendary Paul Bunyan (Colman, 2006).
- A historic inlet has been infilled with sediment (RF-F). The historic inlet is farther north than the modern inlet. Two scenarios could possibly explain the infilling of an inlet through the Duluth Barrier 1) the historic inlet may have resulted from the migration of a single inlet over time; 2) the historic inlet was naturally much larger than the current inlet and infilled with sediment, possibly due to the construction of jetties.
- Alternatively, RF-F may represent the former Nemaadi Delta built during lower lake levels and then buried by the prograding barrier.
- Overwash (RF-E) and buried objects deposits are localized near the southern, natural inlet. This suggests that the dominate process on the barrier is progradation with overwash processes playing a minor role in the Duluth Barrier.
- RF-C and RF-D both infill portions of the back barrier. RF-D is interpreted as dredge spoils (Alger et al., 2014) while RF-E is likely aggradation in the back barrier.
- Progradation is imaged as sigmoidal reflections within RF-B.
- High energy storm deposition is imaged as inclined reflections within RF-B. Low energy deposition is imaged as subhorizontal reflections.
- A slight dip to reflections within shore parallel profiles suggest longshore drift from the south. Additionally, a concentration of buried objects on the south end of the barrier indicates a southern sediment source, with buried objects getting washed ashore on the southern end of the barrier.
- Windblown dunes (RF-A) have built from the transport of sediment from the beach and onto the barrier crest. Field observations corroborate this interpretation.

Conclusion

The Duluth Harbor Barrier is one of the largest freshwater baymouth barriers in the world, however, little is understood about its depositional history. By carefully examining additional GPR data the results and interpretations propose several theories:

- The depth of penetration is dictated by a sediment change beneath the barrier, indicating the barrier is built upon a buried deposit of an unknown composition.
- The barrier is a progradational feature which has been exposed to depositional and erosional periods during net progradation.
- Longshore drift feeds the barrier with a sediment source to the south of the barrier supporting initial interpretations by Alger et al. (2014).
- Storm overwash deposits played only a minor role in the initial deposition of the barrier and do not affect the barrier after progradation becomes dominant.
- Discharge from the Nemaadi River has played a major role in the evolution of the Duluth bay barrier likely preserving the natural inlet and changes in the Nemaadi River channel influences the location of the inlet.

Future Work

The GPR investigation helps to better understand many of the littoral processes that shape the barrier, but many questions still remain:

- When did the barrier form?
- What is the barrier built on?
- How have storms and fluctuating lake levels influenced the Duluth Barrier?
- Can modeling demonstrate the sediment transport mechanism that built the barrier?

Further data collection is necessary to answer these questions. Dating either of sand grains with optical stimulated luminescence or wood fragments with radiocarbon dating is likely viable on the barrier. Coring could be used to collect samples and provide a detailed description of sediment changes in the barrier. With dating and coring a detailed model showing sediment transport mechanism and the influences of storms and fluctuating lake levels could then be developed.

Acknowledgements

We would like to thank the University of Wisconsin-Eau Claire (UWEC) Office of Research and Sponsored Programs (ORSP) Summer Research Experience for Undergraduates (SREU) for providing funding for this project. Additional collaboration was provided by Andy Beckenknecht from the University of Wisconsin-Superior (UWS) and Nigel Watturs and Steve Colman from the Large Lakes Observatory (LLO) at the University of Minnesota-Duluth (UMD).

References

Alger, R., Morrison, S., and Jol, H. 2014. Investigating the Subsurface of the Duluth Bay Barrier, Duluth, MN and Superior, WI. <https://doi.org/10.1002/eqe.2014>

Bayne, S., Jol, H.M., and FitzGerald, D.M. 2009. Coastal environments, in: Jol, H.M., ed., Ground penetrating radar (GPR) theory and applications. Elsevier, p. 299 - 322.

Colman, S. 2006. Duluth, Minnesota: Back to the future. GPR International Fall/Winter Symposium, Duluth, Minnesota, p. 3-10.

Jol, H.M., and Bristow, C.S. 2003. GPR in sediments: advice on data collection, basic processing and interpretation, a good practice guide in C.S. Bristow and H.M. Jol, eds., GPR in Sediments. Geological Society Special Publication 213, p. 5-7.

Loy, W. G. 1963. The Formation of the Duluth-Superior Harbor in Proceedings, Minnesota Academy of Science, v. 31, n. 1, p. 28-35.

Mainville, A., and Craymer, M.E. 2005. Present-day tilting of the Great Lakes region based on water level changes. Geological Society of America Bulletin, v. 117, p. 1070-1080.

McCullough, D.G., 1982. Barrier island and strand plain facies, in Scholle, P.A., and Sperrling, J., eds., Sediments Depositional Environments. American Association of Petroleum Geologists Memoir, 1982, v. 31, p. 247-260.

Van Weeren, S., Fitzgerald, M.C., McInerly, P.A., and Bayliss, L. V. 1998. Radar facies of proglacial barrier systems: coastal New England, USA. Sedimentology, v. 45, p. 181-202.