Georadar Analysis for Geomorphic Evidence of Prehistoric Breaches at Nahant Tombolo, Massachusetts, USA

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Introduction

Located along a mesotidal glaciated coast, the Nahant tombolo is a 2km-long, 170 m-wide sandy barrier with a mean elevation of 2.5m (figs. 1 and 3). This barrier most likely formed during the Mid-Late Holocene, around 5,000 years ago, when the relative rate of sea level rise decreased. The tombolo is anchored to a rocky headland along Lynn Shore (north) and the bedrock island of Little Nahant (south). The shoreline position of this tombolo has been relatively stable for almost a century, since the building of the Carney Causeway. All barriers in the area are transgressive (fig. 2) and its unclear how anchoring of the tombolo to rocky headlands has inhibited, if any, its shoreward migration.

Long beach (fig. 1) is a dissipative, drift aligned beach with fine to medium grained sand. Long beach, including the low tide terrace and foreshore is 105m wide. The low dune field is 25m wide, backed by a 40m wide parking lot and road. The sand composing the barrier is most likely derived from the reworking of a submerged offshore Holocene paleo-delta and from the Saugus River.

In the late 1830's the Carney Causeway was constructed on top of the tombolo to provide access to the town of Nahant. The tombolo is backed by Lynn Harbor, which opens into Broad Sound and contains several maintained navigational channels (fig. 3). Because the tombolo protects the adjacent mainland and provides access to the town of Nahant, understanding its vulnerability to storm surges is important, considering the prospect of increasing storm activity and rising sea level.

This study is an attempt to identify and locate past storm breaches and therefore potentially vulnerable locations using Ground Penetrating Radar. GPR was conducted continuously along a walkway built on the dune crest, between the Nahant Causeway and Long Beach (Fig. 1).

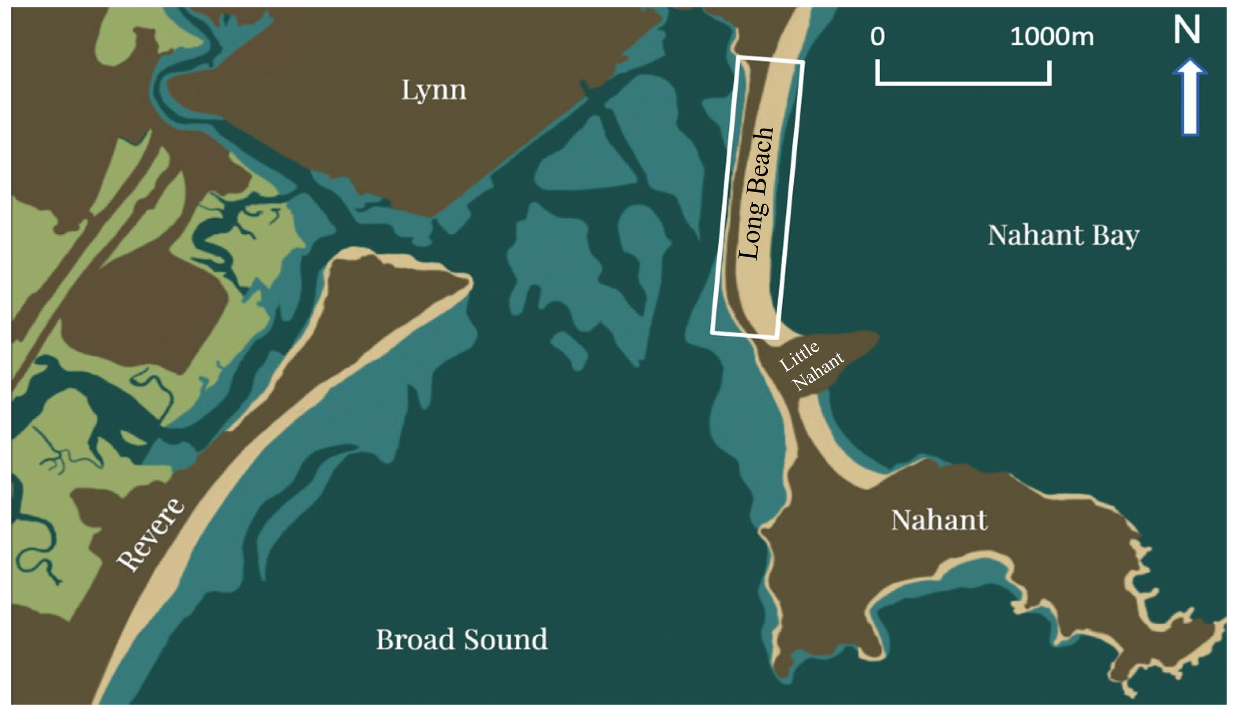

Figure 1: Locus map of the Nahant tombolo. The tombolo shelters Lynn Harbor and coastal portion of Lynn and Revere. The stretch investigated is mark by the white rectangular outline.

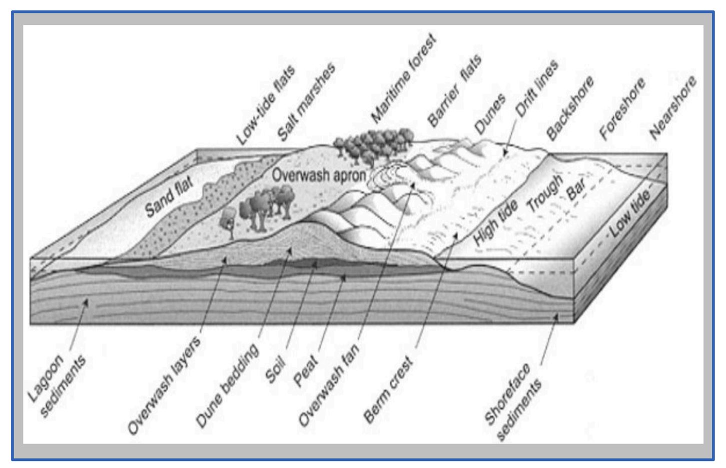

Figure 2: Diagram of a transgressive barrier illustrating the stratigraphic facies expected beneath the dune ridge. The GPR survey ran along a paved walkway built on top of a transverse dune ridge, comparable to the one shown here.

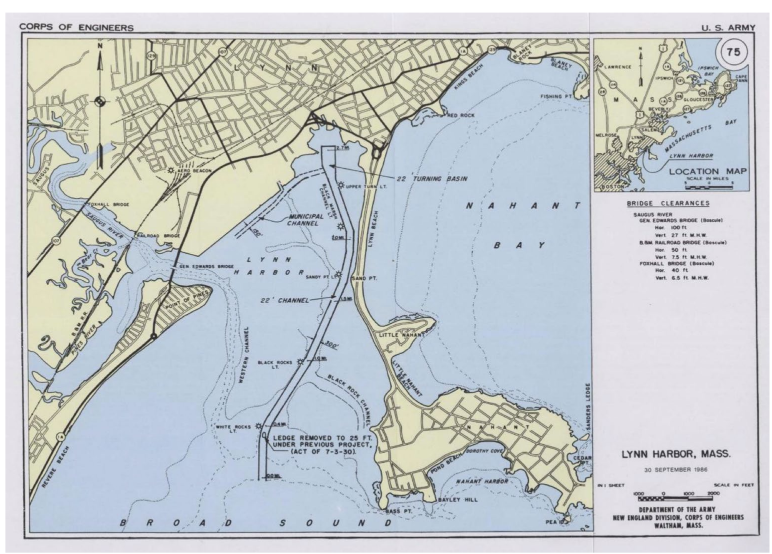

Figure 3: Dredged channel locations in Broad Sound. The Carney causeway was built in 1883 on top of the tombolo to provide access to the town of Nahant. Presence of the causeway and related protective barriers, and rocky headland no doubt have aided in stabilizing the barrier. (Map obtained from Army Corps of Engineers.)

Methodology

GPR was run continuously parallel to shore along the walkway overlying the dune crest, with a sampling rate of 200 scans per second.

Three-component GPR system used included:

- SIR 4000 control unit, 350 MHz antenna (for necessary depth range), and a survey wheel (for distance of path length)

Data collection properties included:

- System auto gain, depth range of 5m and 8m, dielectric constant of 4.0, for penetration of sand-dominant subsurface sediment
- Raw data was minimally processed using Radan, optimizing the displayed radar facies present.

Processing routines included:

- Background removal, color transform, band-pass filtering, amplitude correction, and time zero correction
- Radar facies were identified and compared to previously described radar facies defined by Fitzgerald et. al. (2000; fig. 4) and Van Heteren et al (1998).

Identification/Interpretation based on:

- Two dimensional characteristics, reflection patterns, such as shape, dimensions, and continuity (fig.4).
- No cores were taken to verify the observed GPR facies.

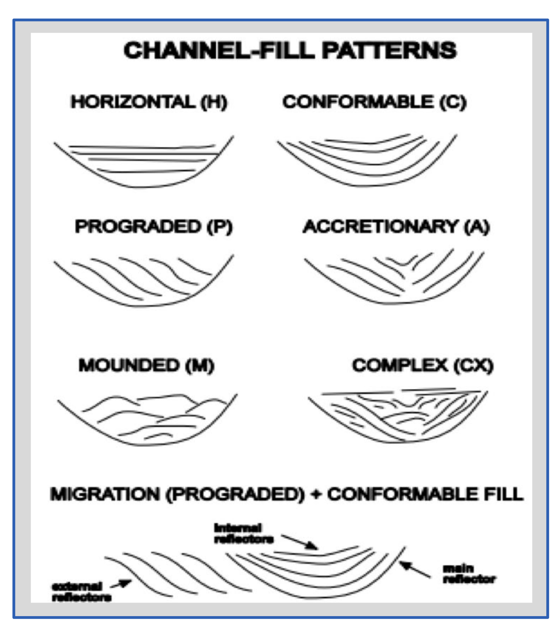

Figure 4: Radar facies of paleo-tidal channels drawn by Fitzgerald, et al. 2000, modified from Heteren et al. 1979 after Mitchum et al. 1977.

Results

Figure 5: Google Earth satellite image of the Nahant tombolo. Letters correspond to possible historic breaches (fig. 6) identified in this GPR study. This and other imagery do not indicate the presence of recent overwash deposits related to the breaches, suggesting that the breaches produced little overwash or deposits pre-dated formation of the navigation channel, which was dredged in 1932.

Most of the area beneath the barrier, was composed of horizontal facies (fig. 7). However, in three locations (figs. 5 and 6) the facies were disrupted by parabolic reflectors that are a few meters in width and depth.

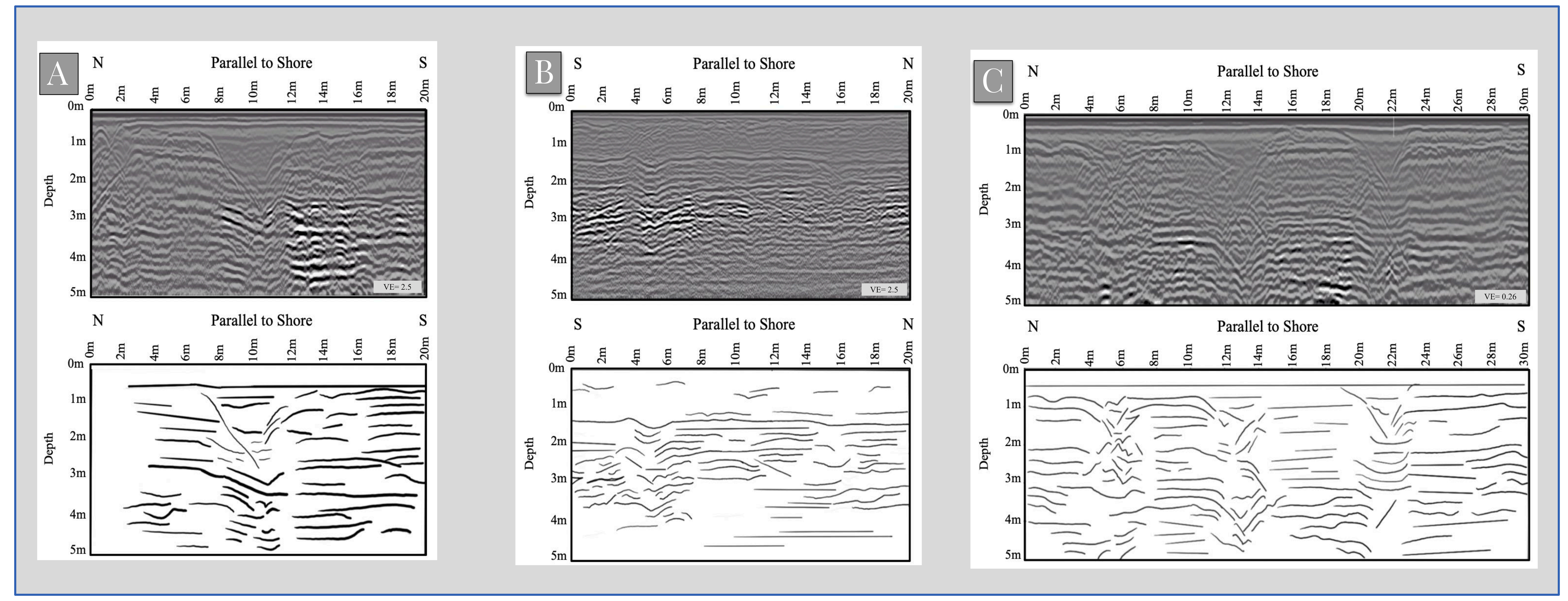

Figure 6: Breach locations obtained from GPR, indicating multiple prehistoric breaching events. Locations are marked in figure 5. Area A breach is 5m wide and is 3m deep. Area B breach is 2m wide and 2m deep. Area C breach has two breaches; the first (on the left) is 5m wide and 5m deep, second (on the right) is 2m wide and 4.5m deep.

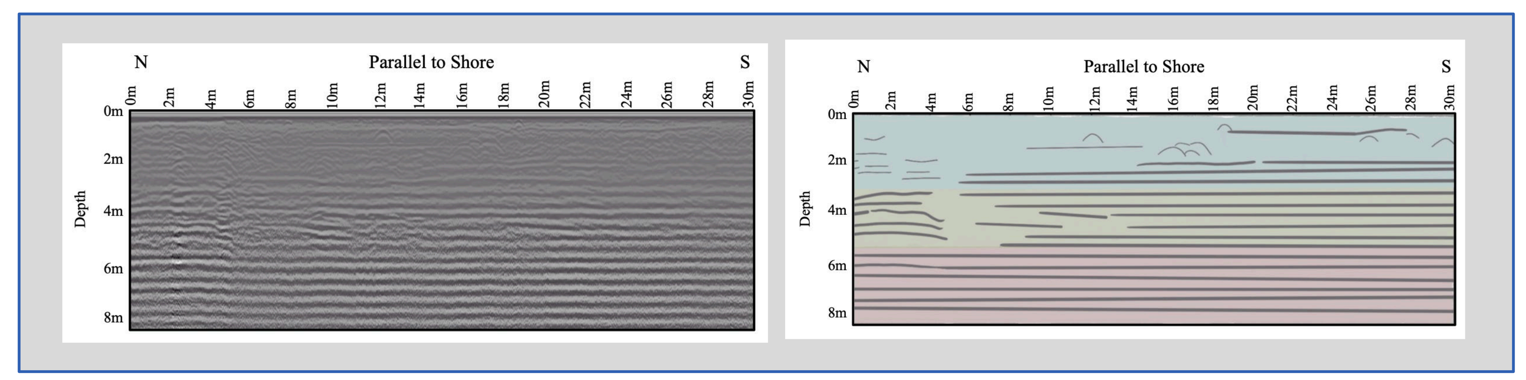

Figure 7: Typical GPR profile along the barrier of Nahant. The lowermost facies is characterized by horizontal reflectors.

Discussion

For most of the barrier, the facies observed were those seen in figure 7. These are interpreted as lagoon deposits (depth below 5m), overlaid by overwash deposits (depth between 3-5m), further overlaid by dune deposits (depth between 0-3m). Lagoon deposits contain continuous, horizontal, even parallel reflectors or attenuated reflection free deposits. Outwash deposits are discontinuous ranging from horizontal to sigmodal reflectors, with amplitudes ranging from 3-5m. Dune deposits are characterized by chaotic, discontinuous reflectors, with amplitudes ranging from 3-5m with varying dips.

At sites A, B, C (figs. 5 and 6) the GPR reveals three to possibly four very narrow breach channels clustered midway along the tombolo. None of these channels seem to be connected to recognizable overwash or tidal delta deposits either behind or in front of the tombolo. These breaches occur where the navigational channel is closest to the tombolo and the backshore platform is narrowest. Location of at least one possible breach is near the site of utility piping, which are characterized by high amplitude discontinuous, concave upward reflectors.

Possible paleochannels were identified by u-shaped discontinuities reflectors, with sizes ranging from 2-5m wide and 2-5m deep. The radar facies were compared to those (fig. 4) mapped by FitzGerald et al. (2001) along the Duxbury barrier, a similarly anchored and oriented barrier spit, south of Boston. The Nahant breach channels are much smaller, than the Duxbury channels which ranged from 60 to 285m wide, and depths of 3 to 6m. Our channels are much smaller in width, and most likely filled rapidly never surviving to form tidal inlets. The widening of Lynn Harbor into Broad Sound would decrease the tidal prism required to maintain the breach for any length of time.

Radar channel facies (fig. 6) identified along the Nahant tombolo are suitably vague and interpreted as complex (A), prograding (B), and complex or basin fill (C). Channel B contains noticeable south dipping reflectors that appear to support infilling by southerly-directed alongshore transport.

Conclusion

Possibly three to four small breaches are clustered along the mid-section of the tombolo. The dimensions of the GPR facies is at least an order of magnitude or more smaller than channel facies measured by previous authors, indicating that these were probably small short-term breaches that infilled rapidly. The chaotic facies may not be related to breaching but rather digging during construction of the adjacent bathhouse and related utilities.

Breaches are also located where the dredged navigational channel runs closest to the tombolo (figs. 1 and 3), which many increase vulnerability.

This study entailed GPR subsurface analysis only and would have benefited greatly from the addition of core data to better understand the internal stratigraphy and composition of the tombolo.

Channel fill patterns obtained from previous studies may not be comparable as the dimensions of comparison are considerably variable.

References

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