Evolution of a Barrier System in Response to Slow Sea Level Rise and Backbarrier Infilling: Plum Island, Massachusetts

Christopher J. Hein[1], Emily Carruthers[1], Duncan FitzGerald[1], Walter A. Barnhardt[2], and Byron D. Stone[3]

Search and Discovery Article #50235 (2009)
Posted December 31, 2009

*Adapted from oral presentation at AAPG Annual Convention, Denver, Colorado, June 7-10, 2009

[1]Department. of Earth Sciences, Boston University, Boston, MA (hein@bu.edu)
[2]Woods Hole Science Center, United States Geological Survey, Woods Hole, MA
[3]United States Geological Survey, Reston, VA

Abstract

Plum Island is part of the longest barrier chain in New England and subject of considerable sedimentologic and stratigraphic investigation during the past 40 years. New geophysical and sedimentological data combined with a chronology based on radiocarbon dates reveal that sediment supply, geological framework, and backbarrier processes controlled the early evolution of the Plum Island barrier system. Subsequently, the barrier built through aggradation and progradation during a regime of slow sea-level rise. Bedrock, glaciomarine clay, and till deposits form the underpinnings of the barriers in this region and the drainage of several rivers govern the extent of the backbarrier and dimensions of the tidal inlets. Glacio-isostatic rebound forced a regional lowstand of about -45 m at 10.5 kya. During the subsequent Holocene transgression, proto-Plum Island formed about 4 to 5,000 yrs BP from sediment sourced from the reworking of nearshore fluvial deposits combined with sand discharged by the Merrimack River. Evolution of the barrier was strongly influenced by backbarrier infilling, spit accretion and tidal inlet processes.

Sediment cores and Ground Penetrating Radar (GPR) data demonstrate that the barrier lithosome is 5 to 15 m thick and can be divided into three sectors:

1)A northern section dominated by channel cut and fills (depth: 8 to 10 m) associated with the Merrimack River Inlet.

2) A central section characterized by flat-lying to southerly dipping reflectors (thickness: 3-4 m) along the backside of the barrier fronted by seaward dipping clinoforms indicating southerly spit accretion and barrier progradation.

3) A southern third of the barrier is dominated channel migration and filling of the Parker River Inlet and southerly spit accretion influenced by nearby glacial till deposits.

Along the southern section of the island's length a complex inlet fill sequence is observed. The dominant southerly dipping sequences often contain several distinct sets of overlapping reflectors and are occasionally punctuated by cut and fill structures and smaller packets of northerly dipping reflectors. These features are interpreted to represent the processes associated with the migration and

eventual closing of the Parker Inlet. Using existing marsh stratigraphy and high resolution imaging of the paleo-Parker Inlet, this study models the effects of a diminishing tidal prism due backbarrier infilling, causing inlet shoaling and spit accretion.

References

Dougherty, A.J., FitzGerald, D.M., and Buynevich, I.V., 2004, Evidence for storm-dominated early progradation of Castle Neck barrier, Massachusetts, USA.: Marine Geology, v. 210, 123-134.

FitzGerald, D.M., van Heteren, S., Rosen, P.S., 1993, Distribution, morphology, evolution, and stratigraphy of barriers along the New England Coast: Technical report No. 16, Spring 1993.

FitzGerald, D.M., Rosen, P.S., and van Heteren, S., 1994, New England Barriers, *in* Davis, R.A., ed., Geology of Holocene Barrier Island Systems, Springer-Verlag, Berlin, Chap. 8, p. 305-394.

FitzGerald, D.M., Buynevich, I.V., Davis, R.A., Jr., and Fenster, M.S., 2002. New England tidal inlets with special reference to riverine-associated inlet systems: Geomorphology, 48, 179-208.

Hartwell, A.D., 1970, Hydrography and Holocene sedimentation of the Merrimack River Estuary, Massachusetts: University of Massachusetts, Cont. No. 5-CRG, Department of Geology. Series, 166 p.

Hayes, M.O., and Kana, T.W., eds., 1976, Terrigenous Clastic Depositional Environments: Tech. Report. No. 11-CRD, Coastal Res. Div., Columbia, S.C., University of South Carolina, 302 p.

Hein, C. FitzGerald, D., Barnhardt, W. and Ward, L., 2006, Holocene sedimentary evolution of the Merrimack Embayment, western Gulf of Maine: A Preliminary Draft Report for the Minerals Management Service, 5 January 2006, 30 p.

McCormack, C.L. 1968. Holocene stratigraphy of the marshes at Plum Island: Ph.D. Thesis, University of Massachusetts, 104 p.

McIntire, W.G., and Morgan, J.P., 1963, Recent geomorphic history of Plum Island, Massachusetts, and adjacent coasts: LSU Coastal Studies Set., no. 8. 44 p.

McKinlay, P.A., 1996, Bedrock contols on the evolution and stratigraphy of Coffins Beach, GloucesterMassachusetts: MS Thesis: Boston University, Boston, MA, 147 p.

Oldale, R.N., Wommack, L.E., and Whitney, A.B., 1983, Evidence of a postglacial low relative sea-level stand on the drowned delta of the Merrimack River, western Gulf of Maine: Quaternary Research, v. 33, p. 325-336.

Oldale, R.N., Colman, S.M. and Jones, G.A., 1993, Radiocarbon ages from two submerged strandline features in the western Gulf of Maine and a sea-level curve for the northeastern Massachusetts coastal region: Quaternary Research, v. 40, p. 38-45.

Rhodes, E.G., 1973, Pleistocene-Holocene sediments interpreted by seismic refraction and wash-bore sampling, Plum Island-Castle Neck, Massachusetts: US Army Engineer Waterways Experiment Station, Coastal Engineering Research Center, Coastal EngineeringTechnical Memorandum TM 40. 768 791.

Som, M.R., 1990. Stratigraphy and the evolution of a backbarrier region along a glaciated coast of New England: Castle Neck-Essex Bay, MA.: Boston University Geology Dept. unpublished Master's thesis.

Vallino, J.J., and Hopkinson, C.S., 1998, Estimation of dispersion and characteristic mixing times in Plum Island Sound Estuary. Estuarine, Coastal and Shelf Science, v. 46, p. 333-350.

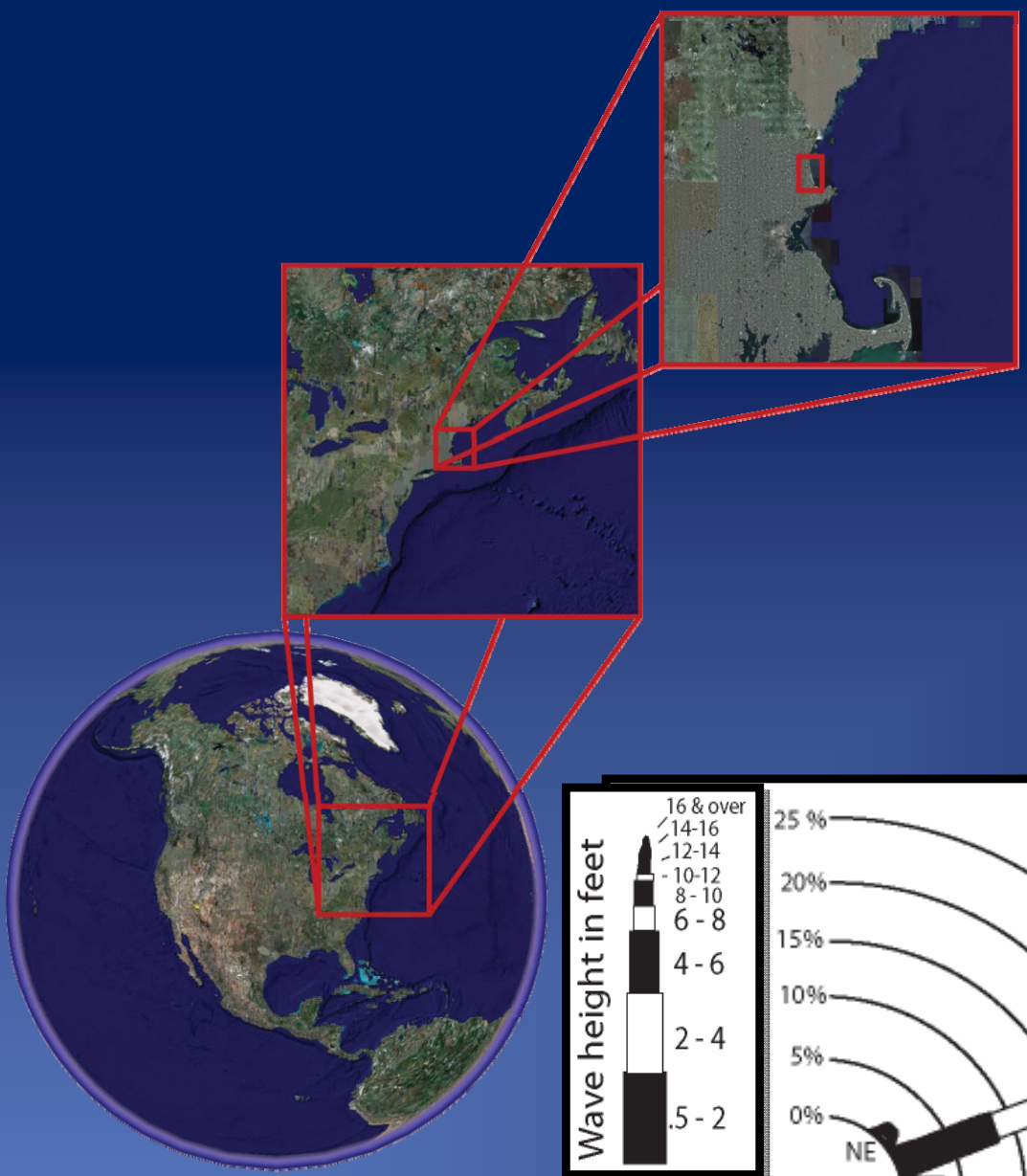
Evolution of a Barrier System in Response to Slow Sea Level Rise and Backbarrier Infilling: Plum Island, MA

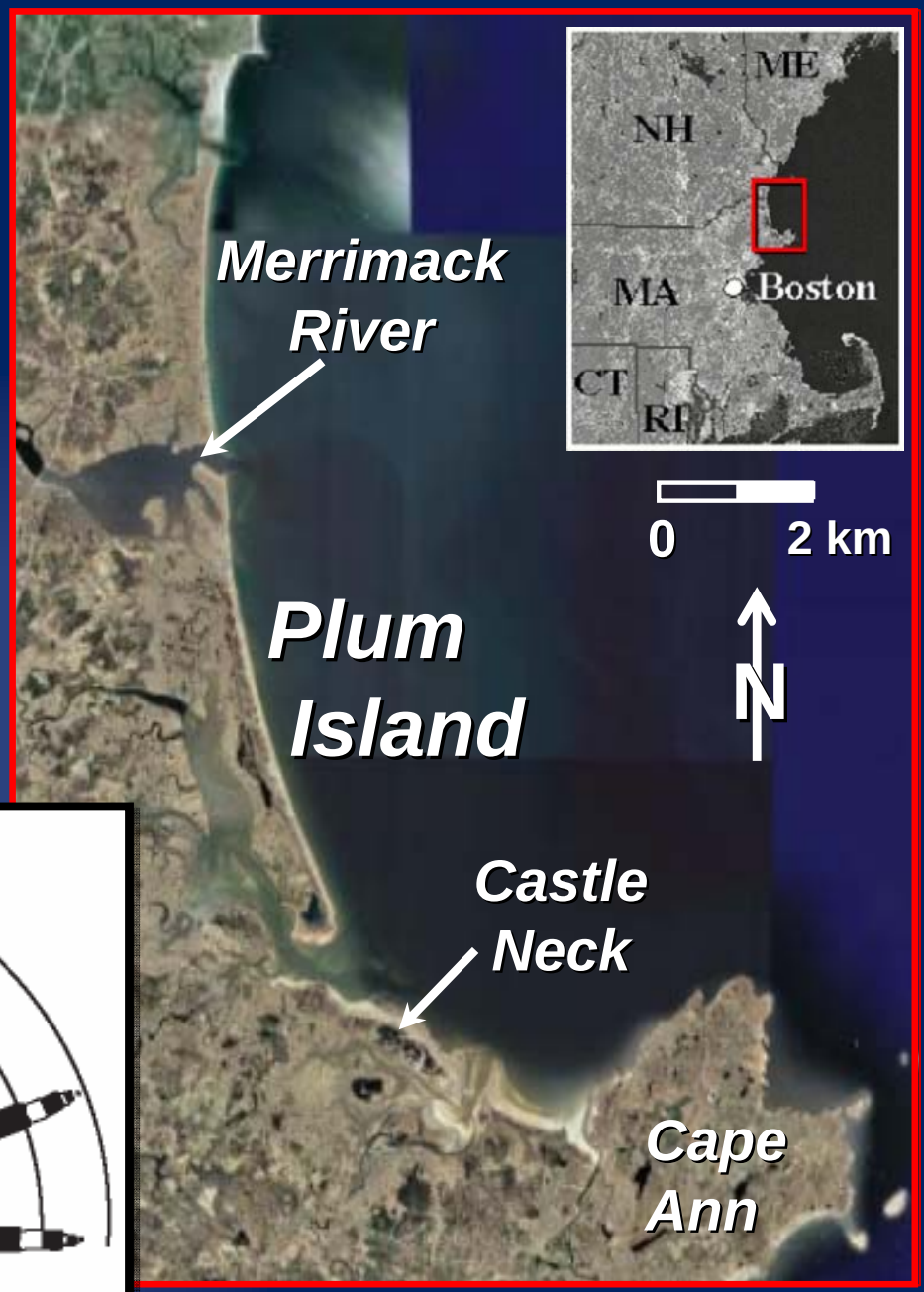
Christopher Hein (BU), Emily Carruthers (MIT/WHOI), Duncan FitzGerald (BU), Byron Stone (USGS), Walter Barnhardt (USGS)

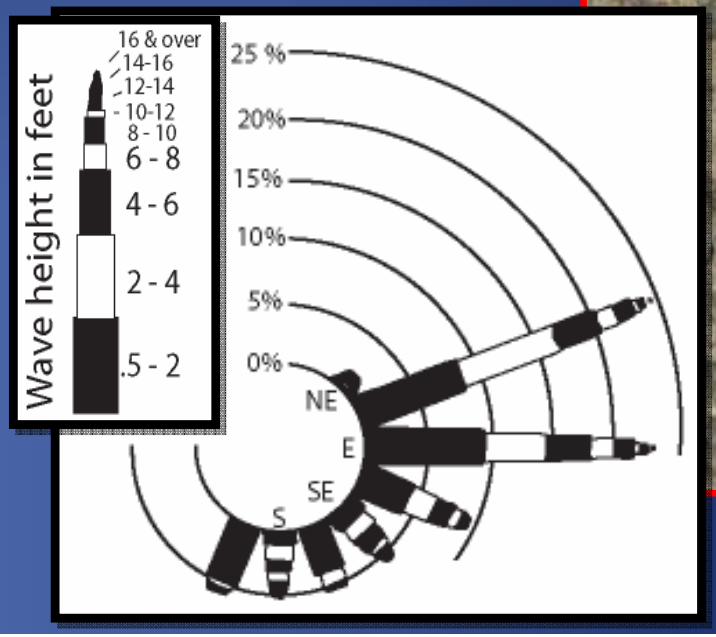
American Association of Petroleum Geologists
Annual Convention & Exhibition

9 June 2009

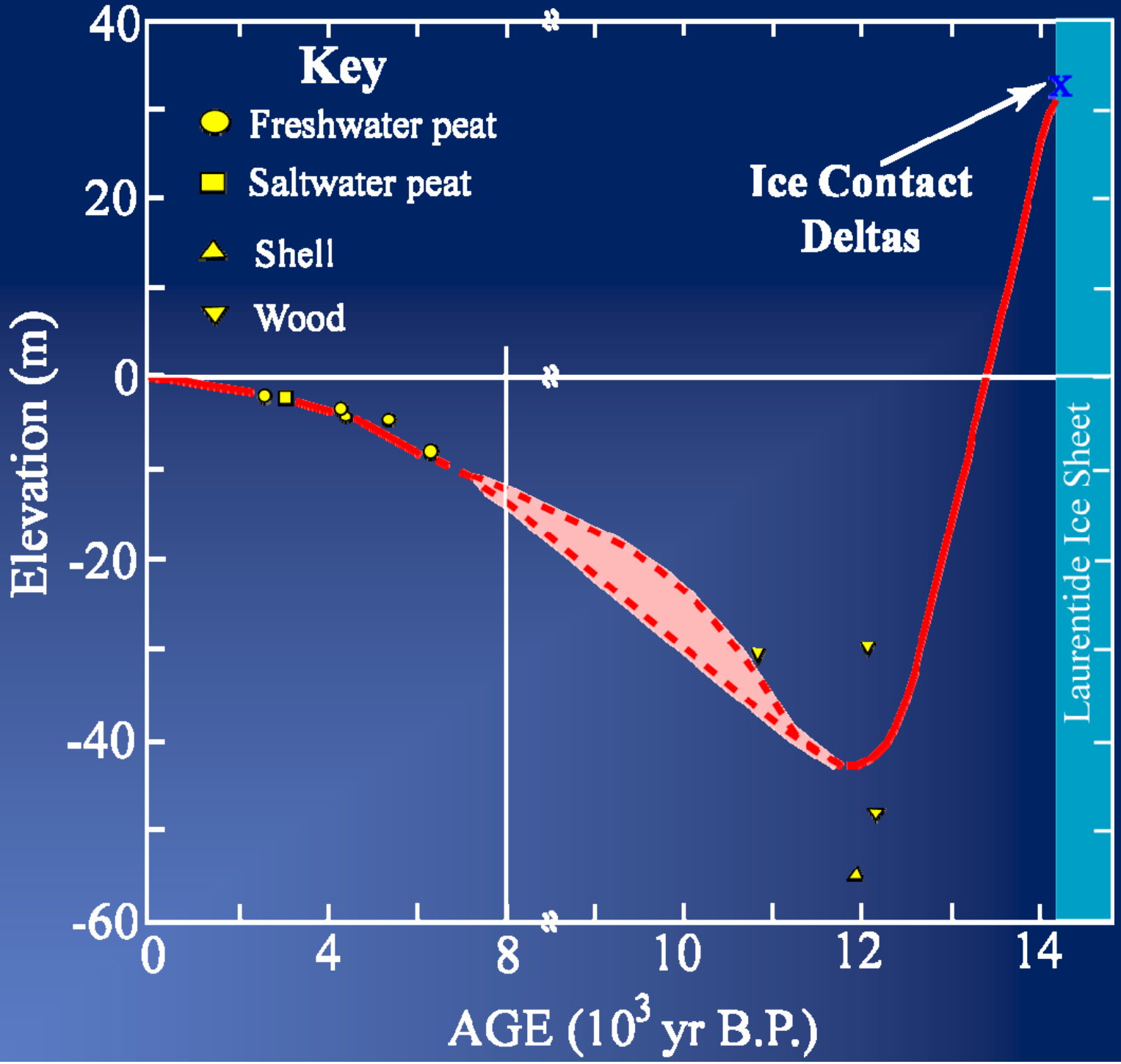
Study Area: Plum Island, MA





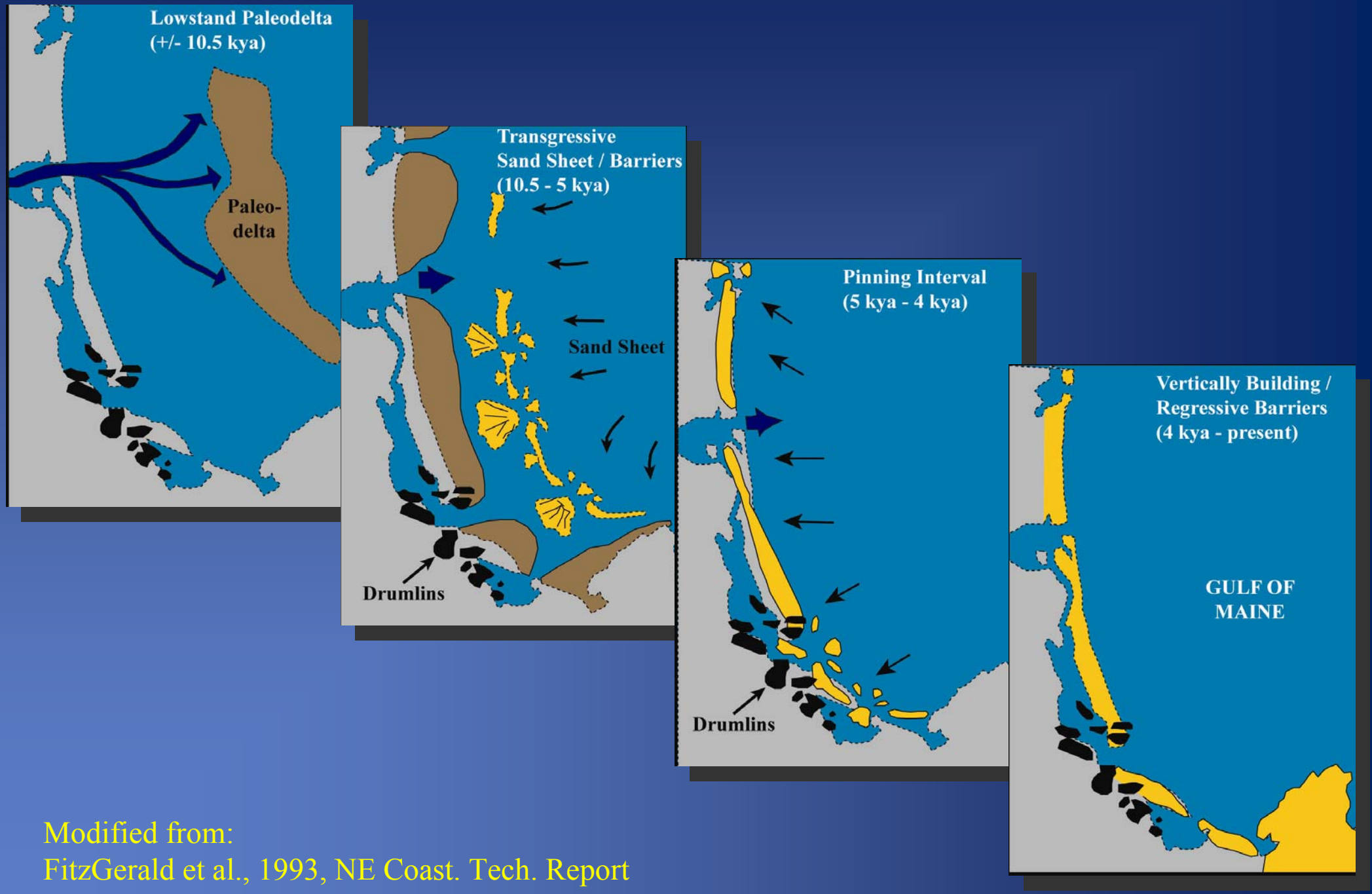


Massachusetts Post-Glacial Sea Level History



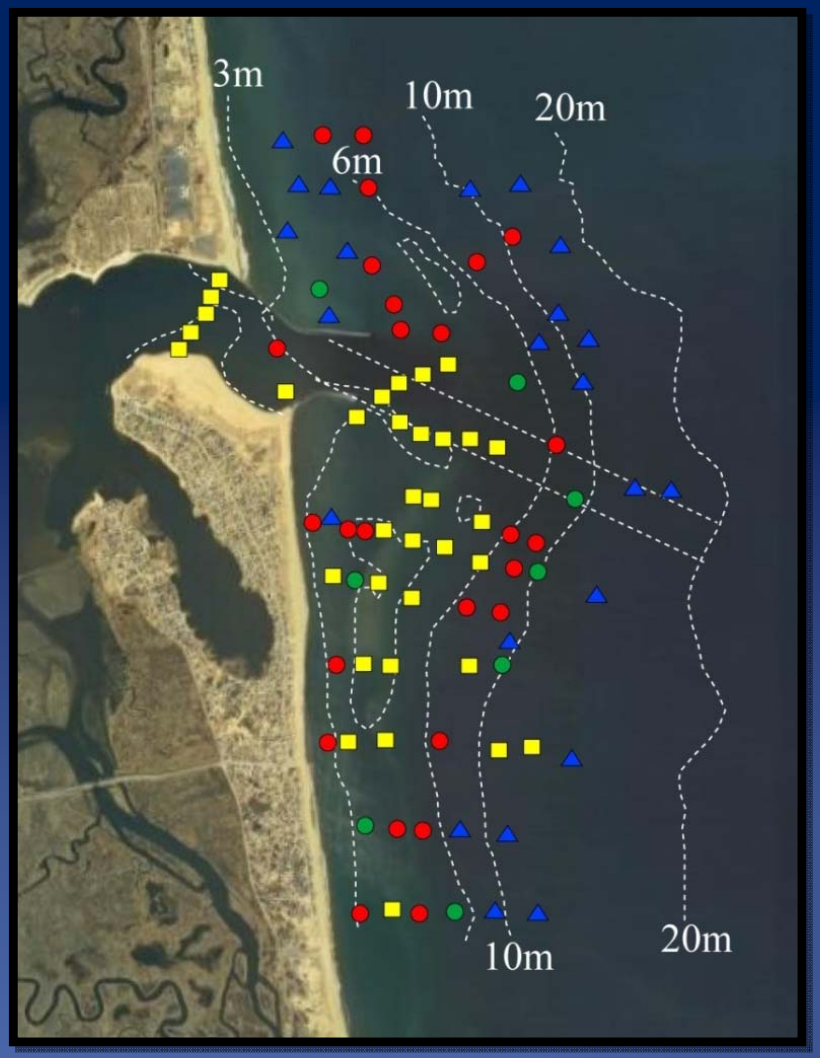
Modified from Oldale et al., 1993, Quat. Res.

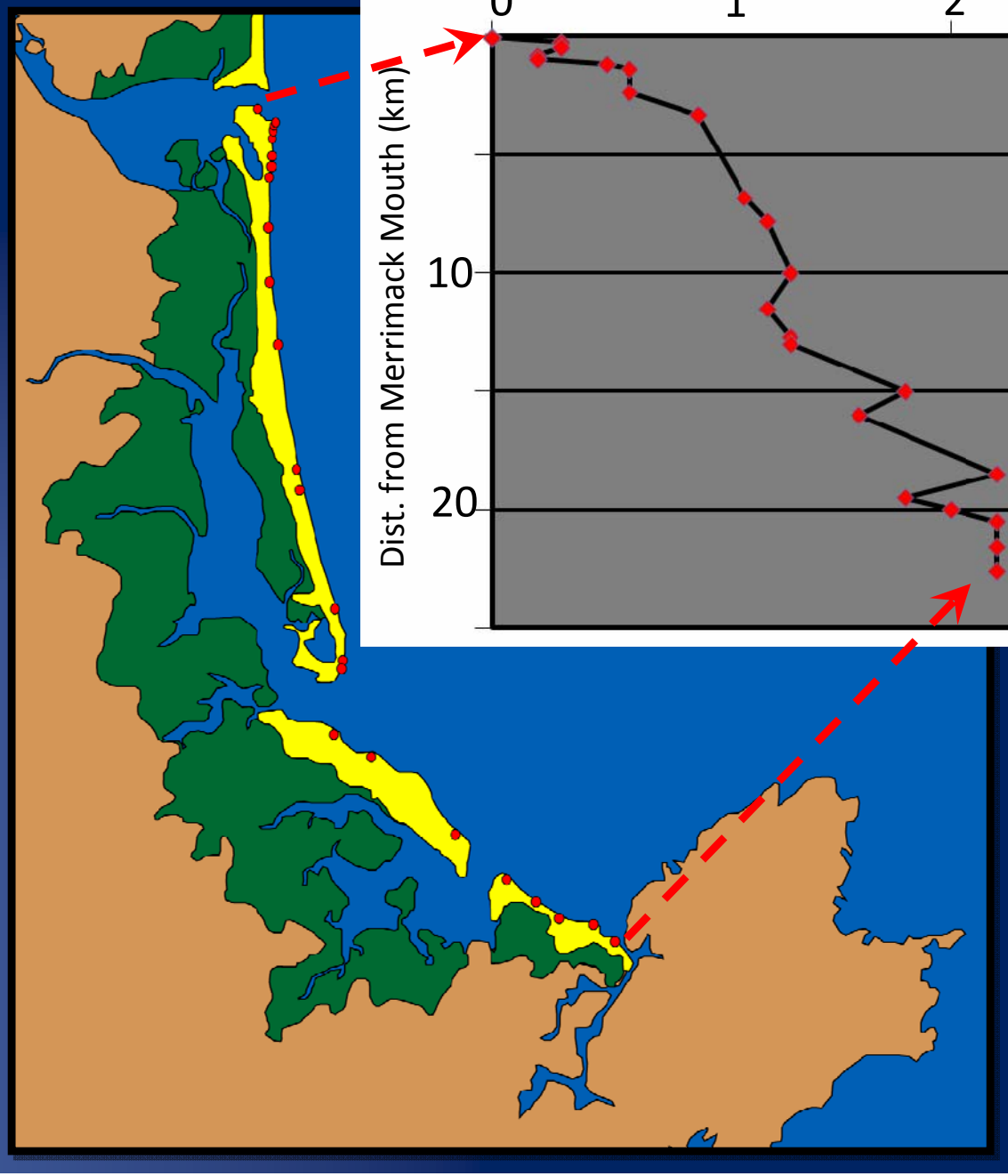
Sediment Sources: Reworking of Offshore Deposits



Modified from:
FitzGerald et al., 1993, NE Coast. Tech. Report

Sediment Sources: Riverine Sediments





- Very Coarse Sand and Gravel (<0 φ)
- Coarse Sand (0-1φ)
- Medium Sand (1-2 φ)
- Fine and Very Fine Sand (>2 φ)

FitzGerald et al, 1994

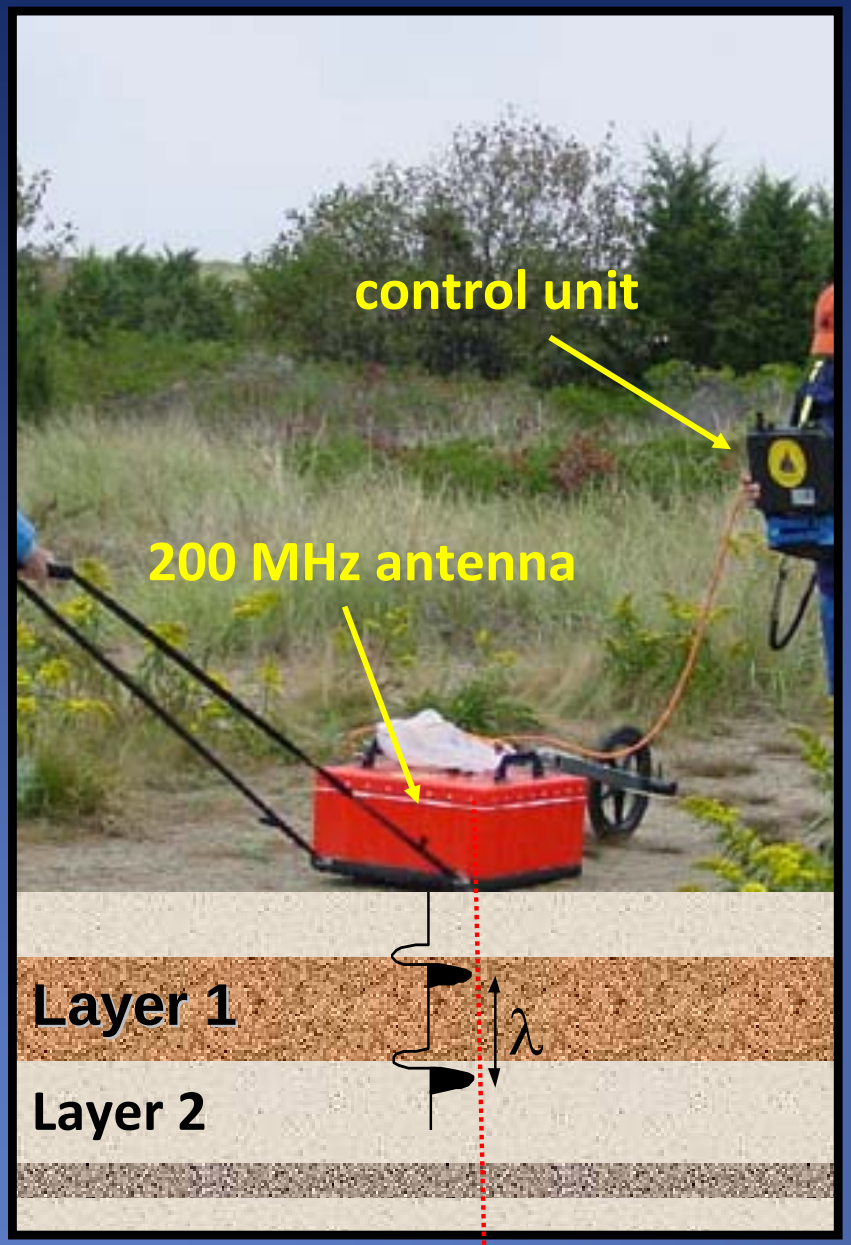
Data Collection

- 11 km of Ground Penetrating Radar, 200 KHz antenna (blue lines)
- 7 vibracores, max. 4 m depth (green dots)

- 9 Geoprobe cores, max. 15 m depth (red dots)
- 11 auger drill cores, max. 38 m depth (yellow dots)

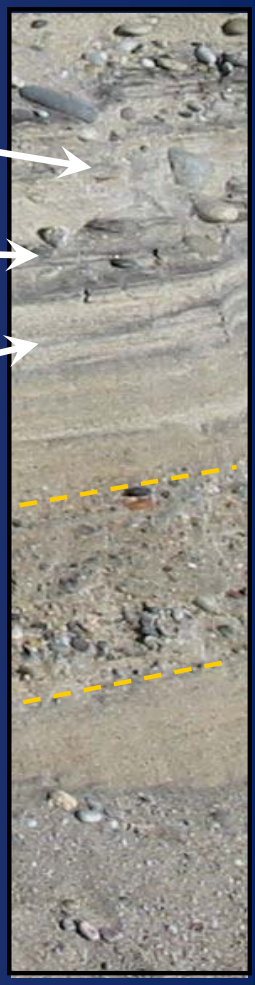
Ground Penetrating Radar

Antenna: 200 MHz; Range: 250 ns



Causes of reflection:

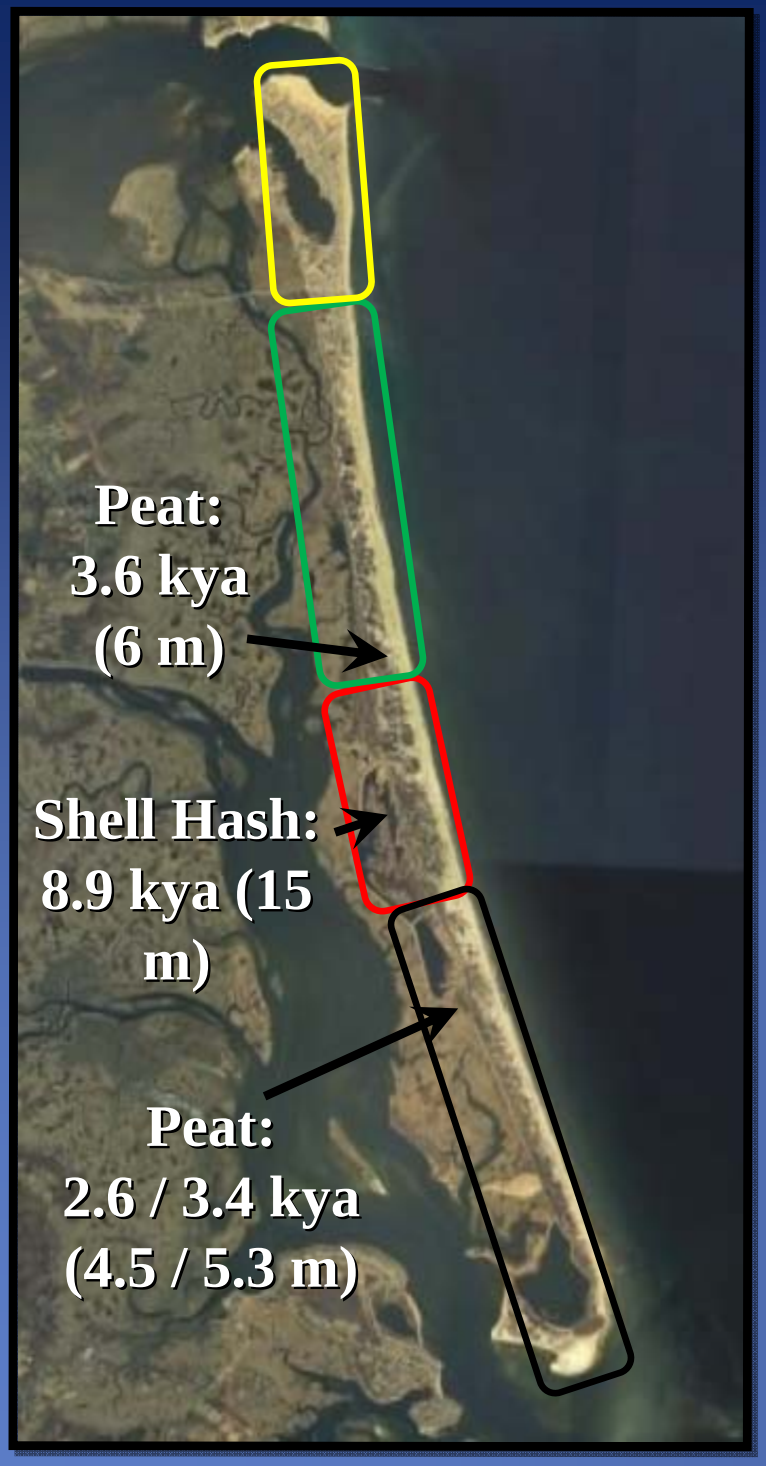
- Physical Structures
- Texture
- Composition (iron oxides, clays, organics)
- Moisture content
- Bulk density
- Porosity
- Temperature



Signal Loss:

- Saltwater, thick clay, metal

Evolution of Plum Island



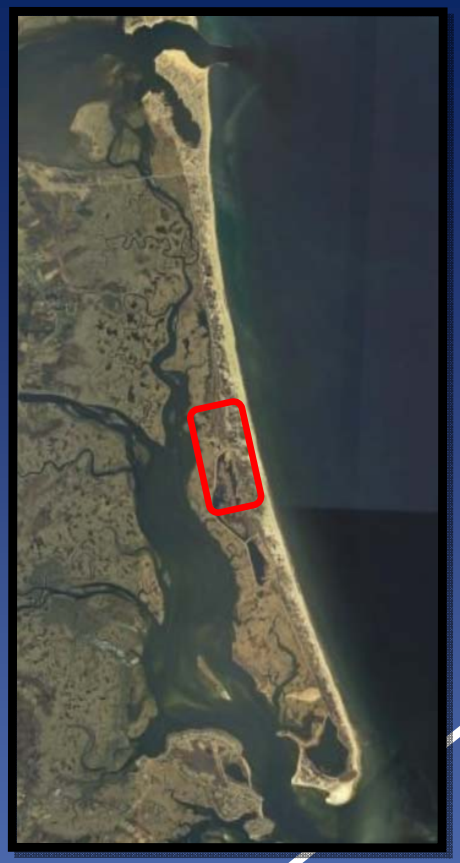
Modern Riverine Processes

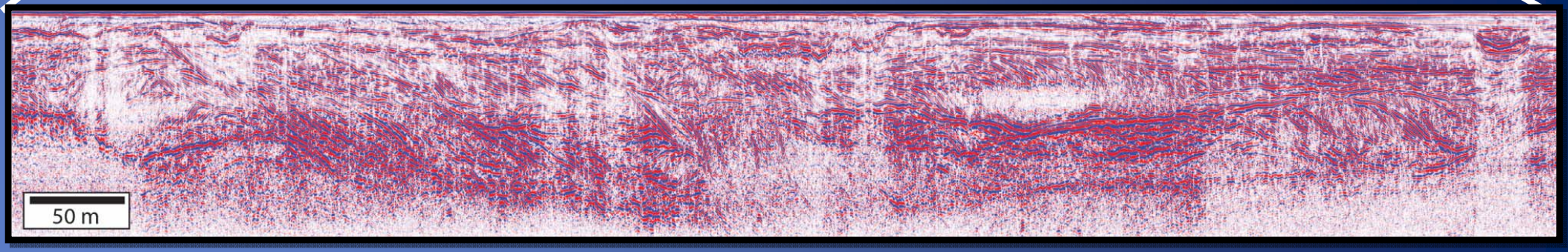
Southerly Spit Building

Inlet Fill

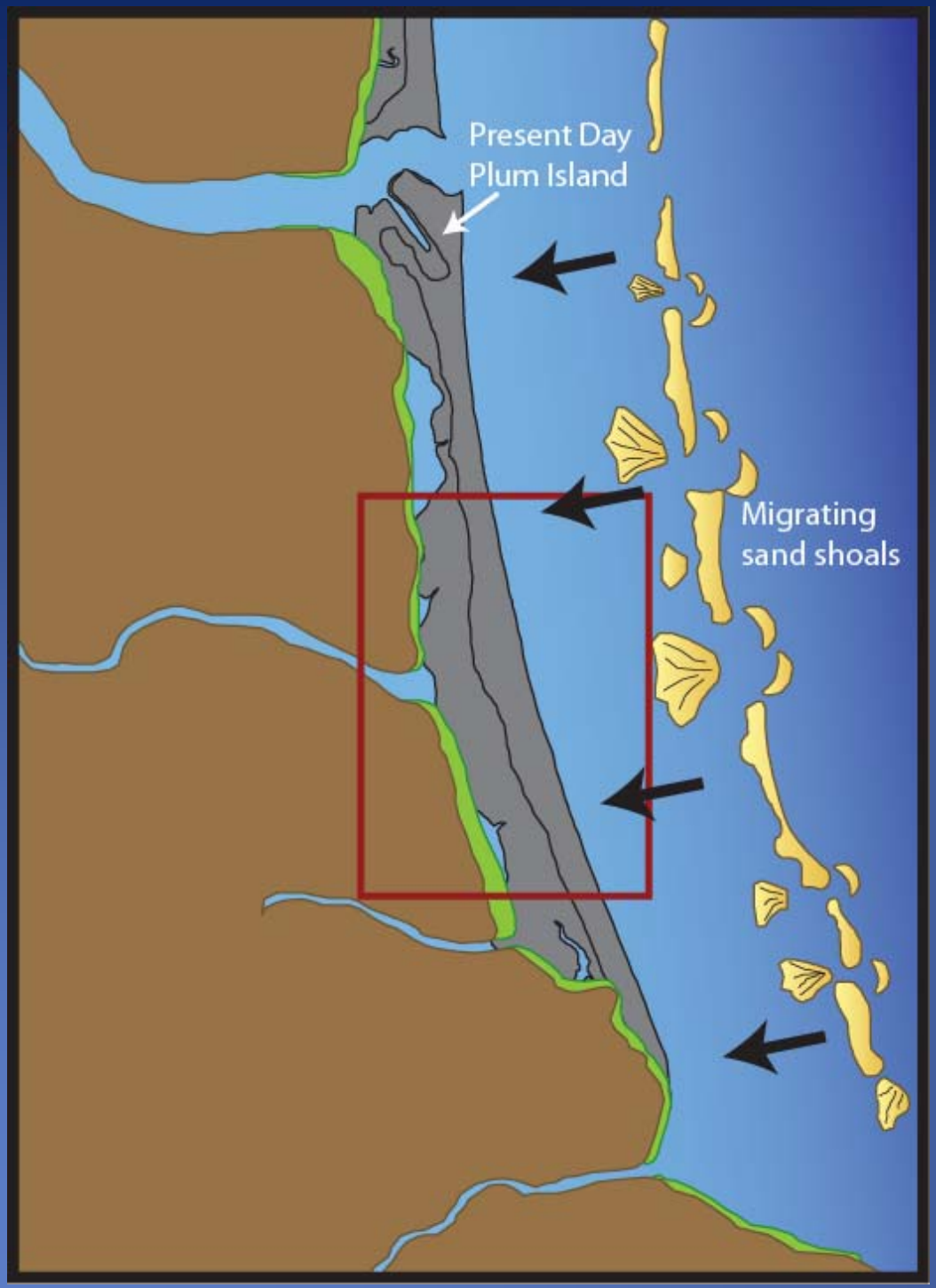
Southerly Spit Building

Evolution of Plum Island





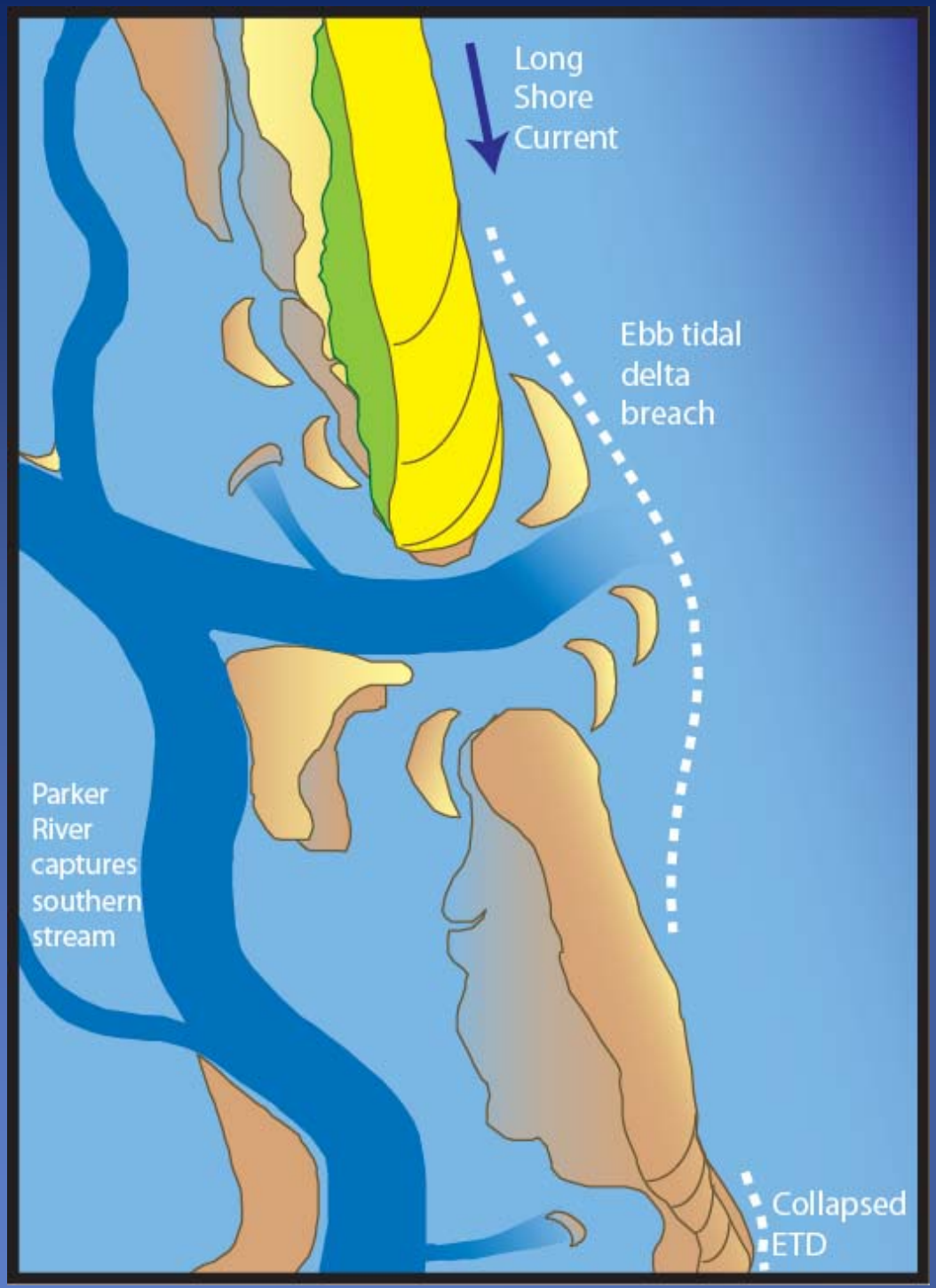
Evolution of Plum Island



Transgressive Migration of Sand Shoals

- Deltaic and braid-plain sediments deposited during regression
- Reworked onshore during transgression as sand shoals (12-4 Ka)
- Shallow shoals are pinned to glacial deposits
- Parker River maintains deep channel through proto-Plum Island

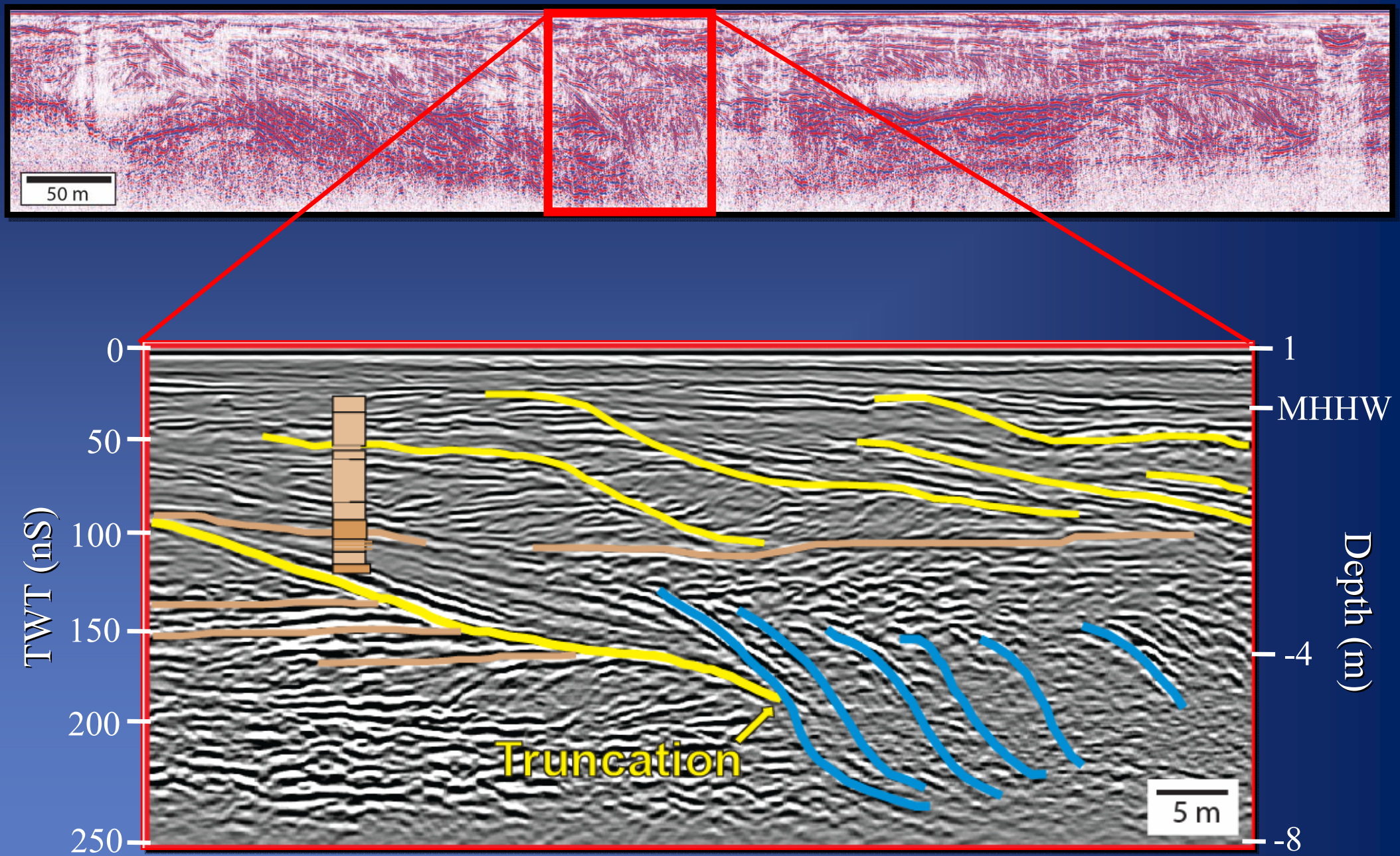
Evolution of Plum Island



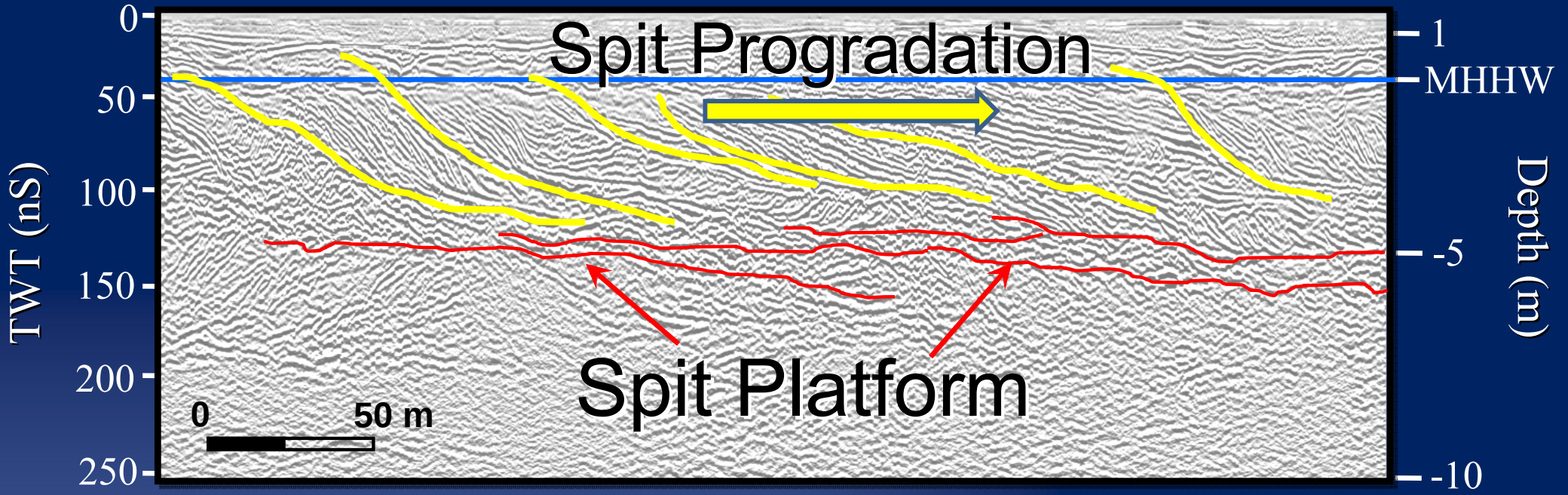
Paleo-Parker Inlet

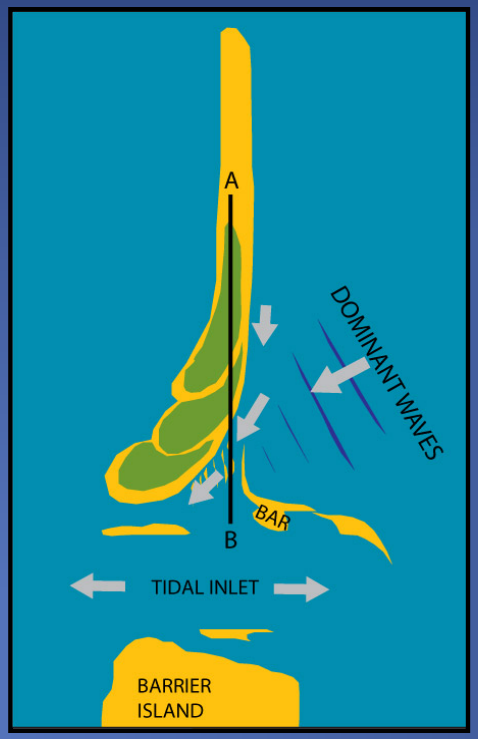
- Southerly longshore current forms southerly building spit
- Larger, open backbarrier (lagoon) yields larger tidal prism
- Inlet active in central Plum Island; positioned east of modern Parker River
- Evidence of active inlet system

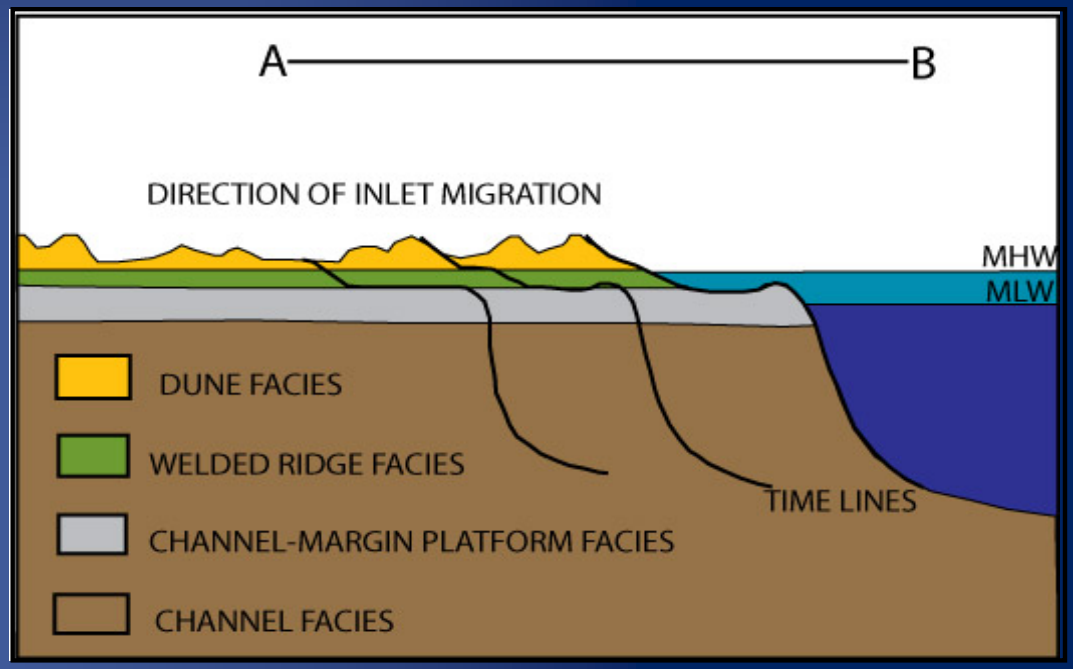
Evolution of Plum Island



Evolution of Plum Island

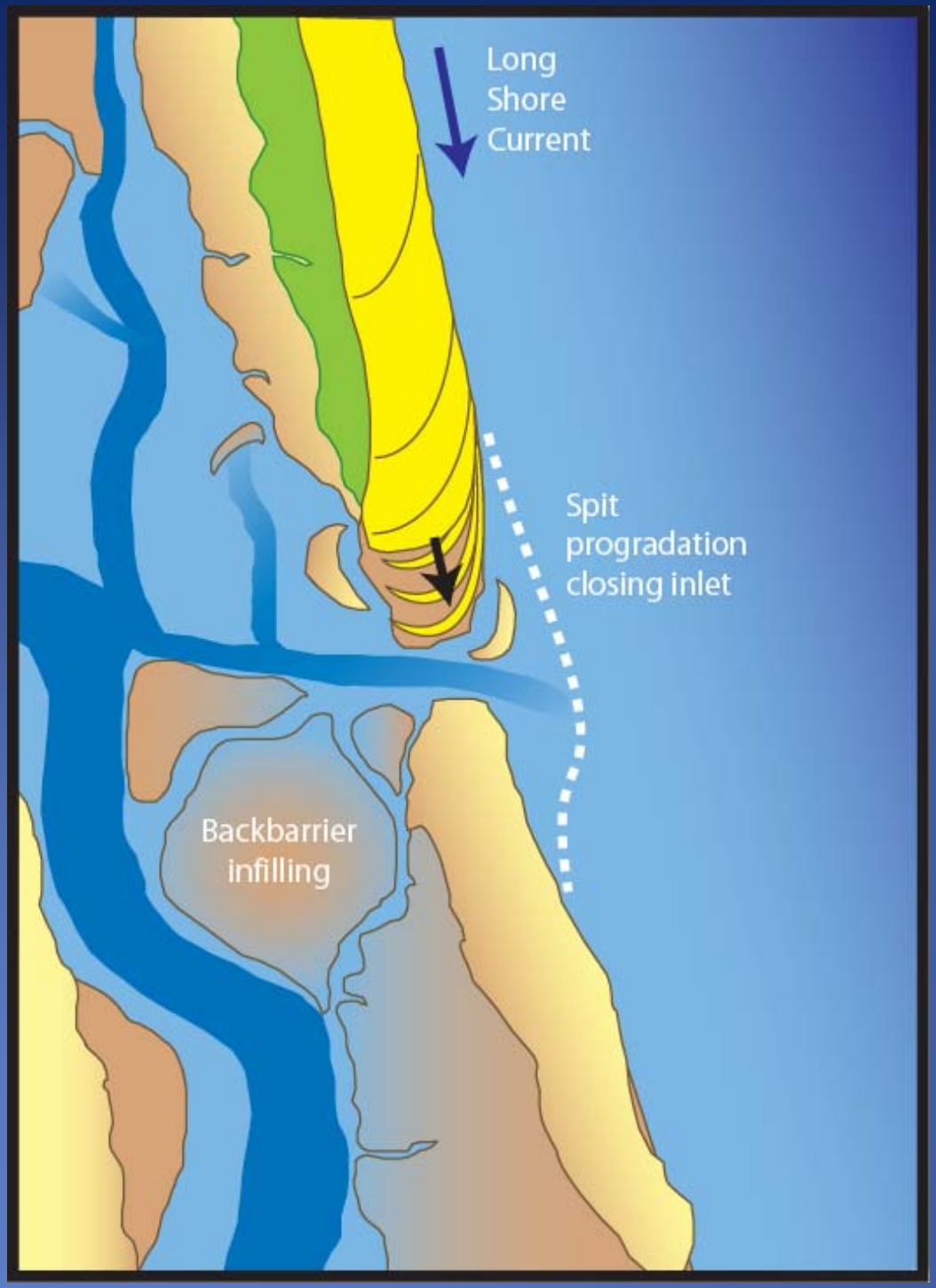






Modified from Hayes and Kana, 1976

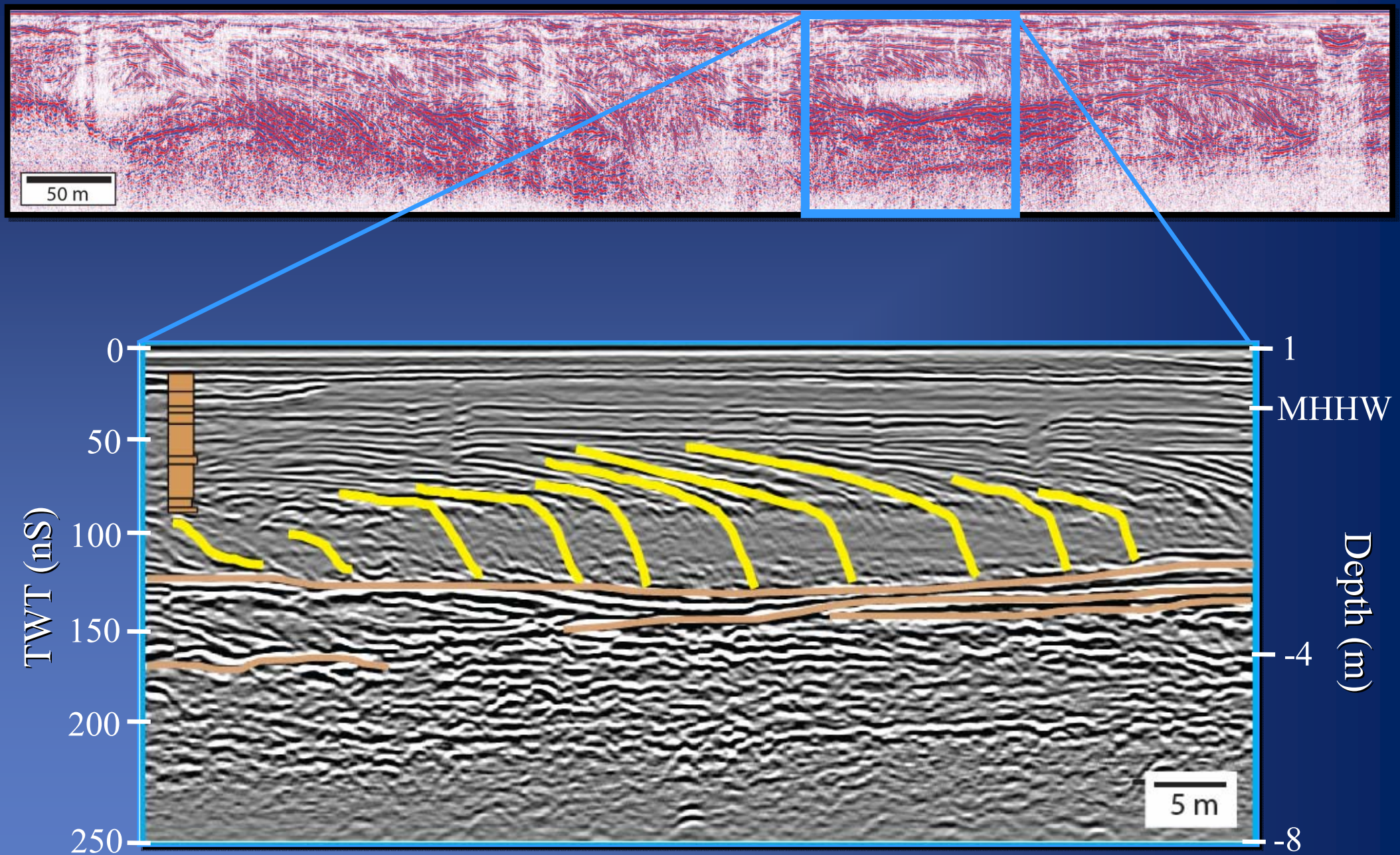
Evolution of Plum Island



Closure of Paleo-Parker Inlet

- Continued delivery of fine sediment to backbarrier causes reduction in tidal prism
- Paleo-Parker Inlet shoals and closes
- Rapid southerly spit building stabilizes central Plum Island and allows for vertical accretion

Evolution of Plum Island



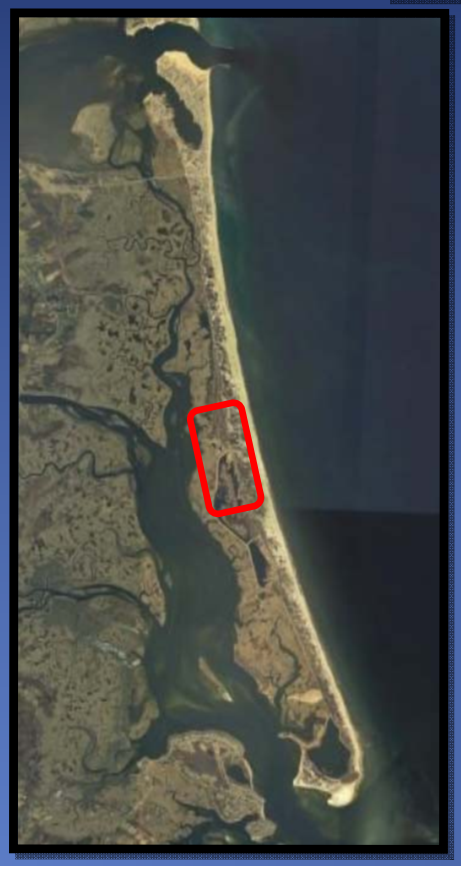
Evolution of Plum Island

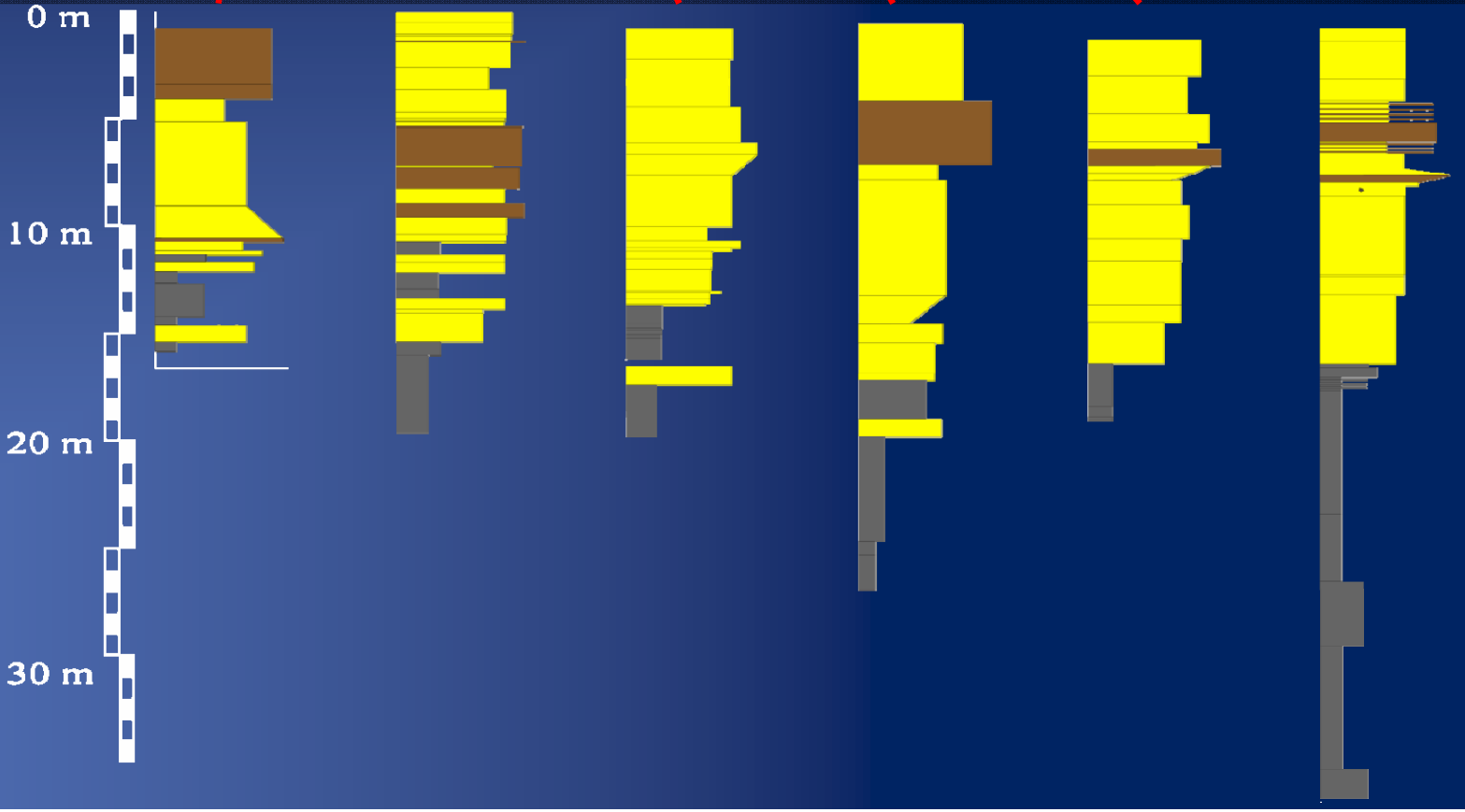
TP ~ 32 x 10^6 m^{3*}

TP >> 32 x 10^6 m^3

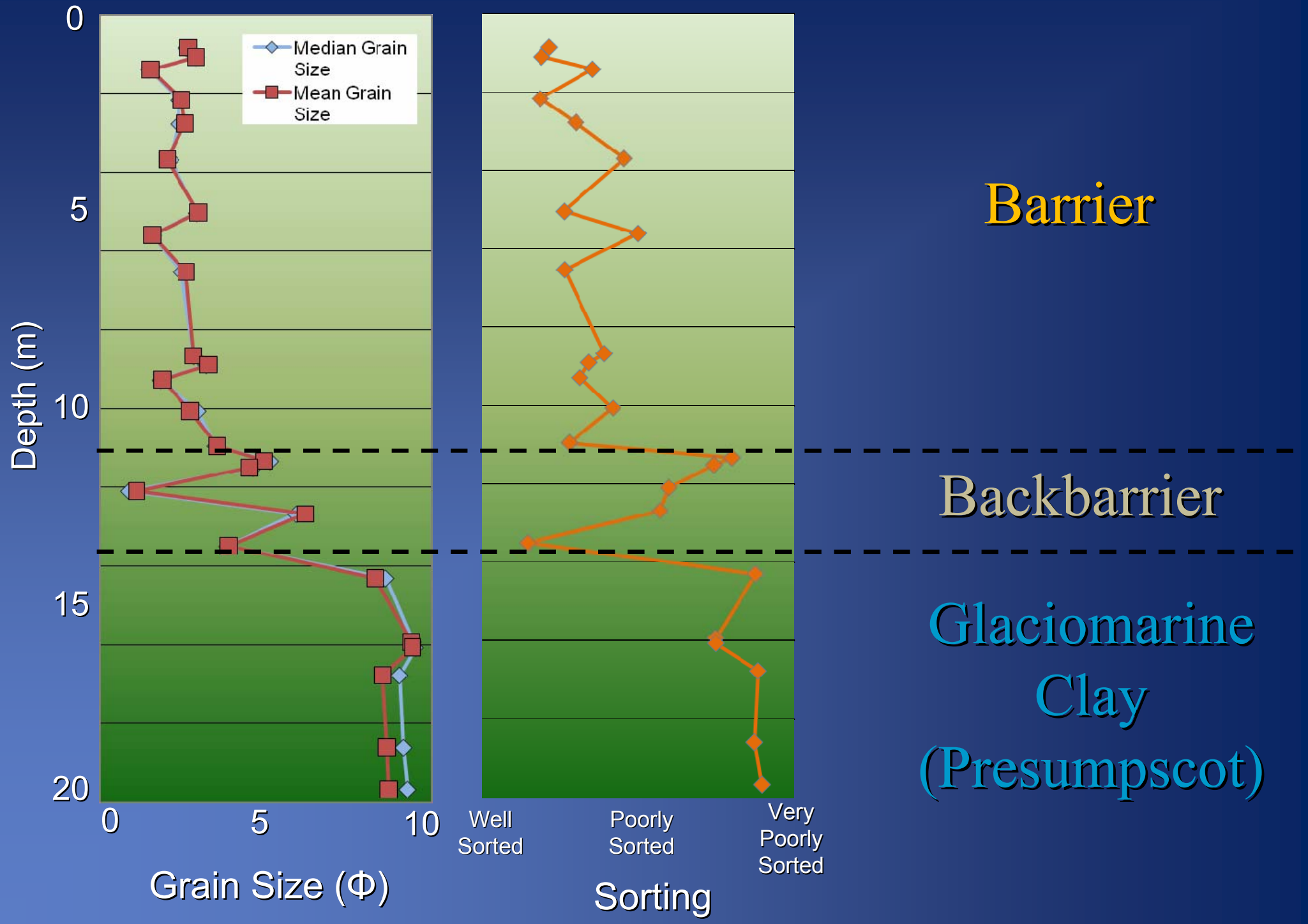
* - Vallino & Hopkinson, 1998, Estuarine, Coastal, & Shelf Science

Plum Island Stratigraphy

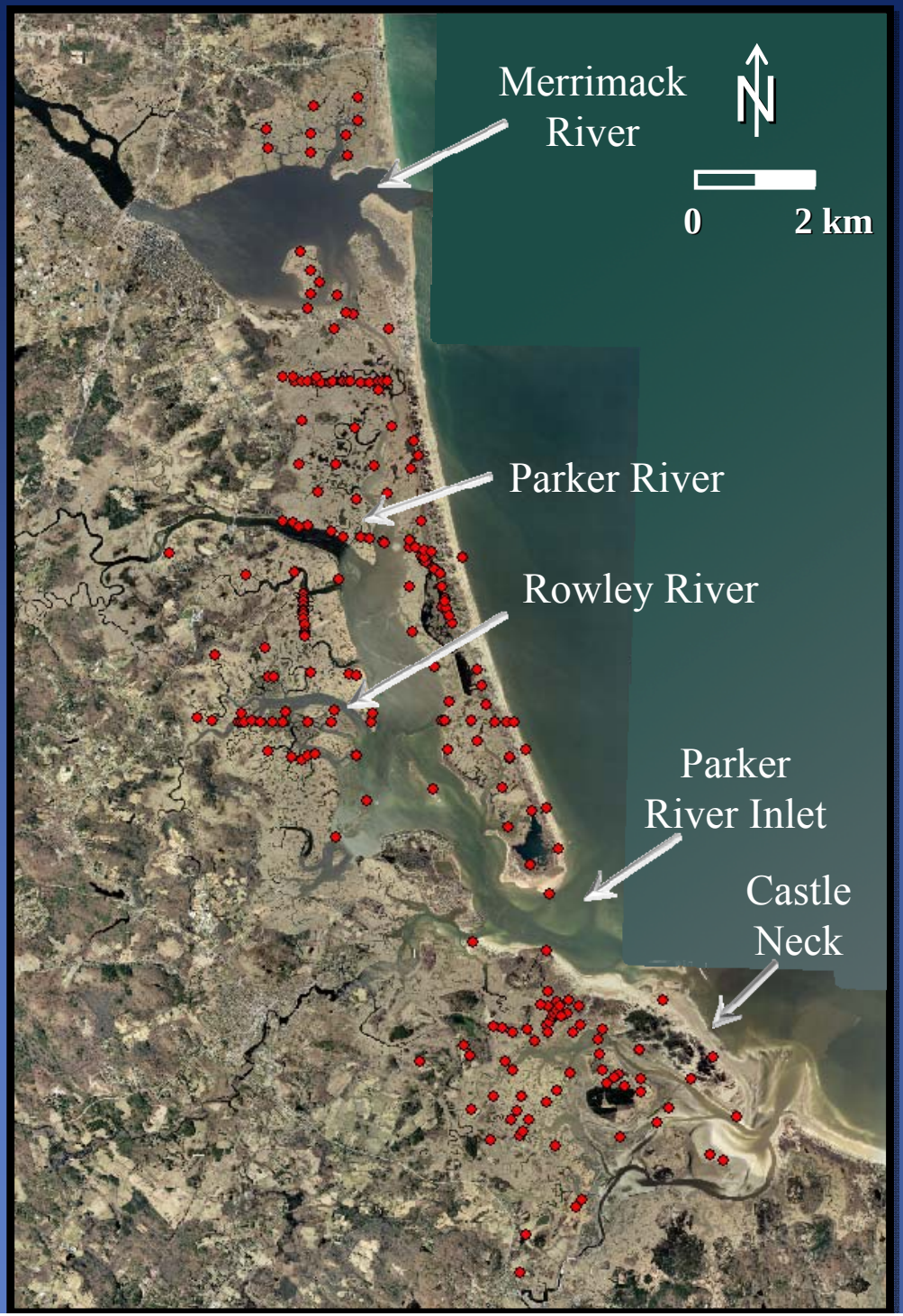




Plum Island Stratigraphy



Database



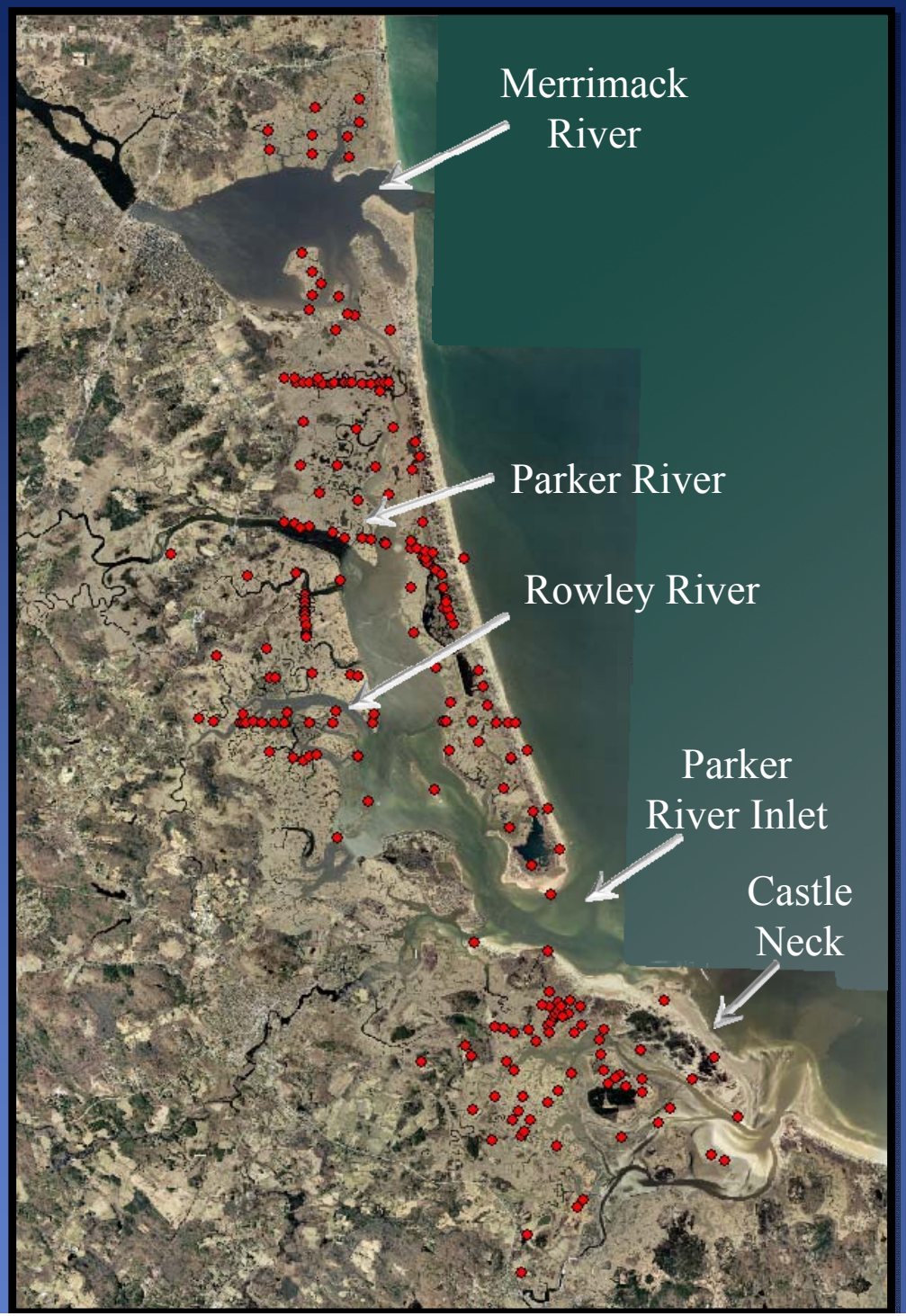
Stratigraphic Data Sources:

- McIntire & Morgan, 1963, LSU Technical Report
- USGS Water Supply Paper, 1963
- McCormick, 1968, Ph.D. Thesis
- Hartwell, 1970, ONR Report
- Rhodes, 1973, USACE Technical Memo
- Anderson-Nichols, 1987, unpub. cores
- Som, 1990, MS Thesis
- Mass. State Boring Data
- Hein et al., cores

Topographic / Bathymetric Data Sources:

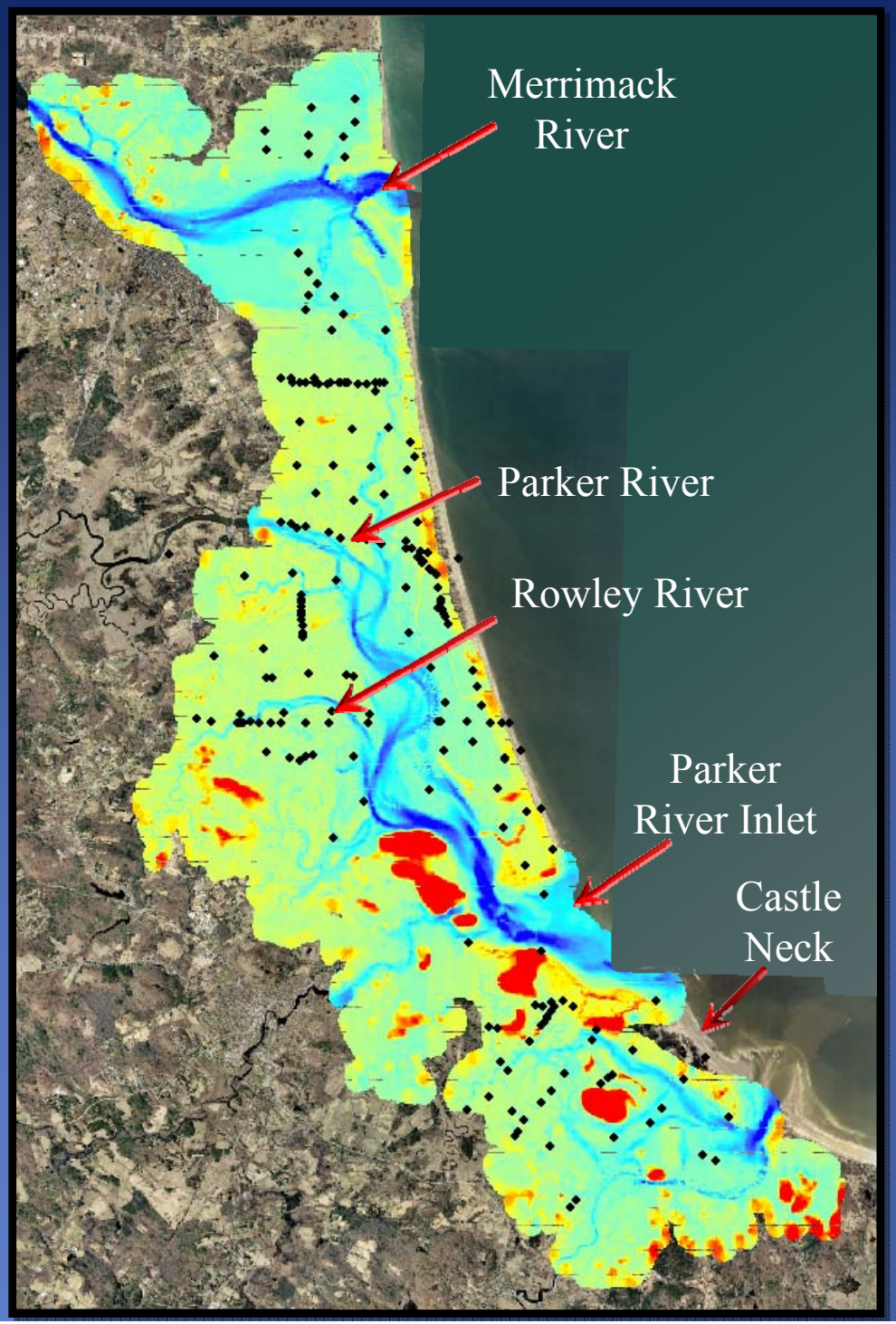
- US Coast & Geodetic Survey Hydrographic Survey Soundings (1953-1954)
- Mass GIS DTM Files (2003)

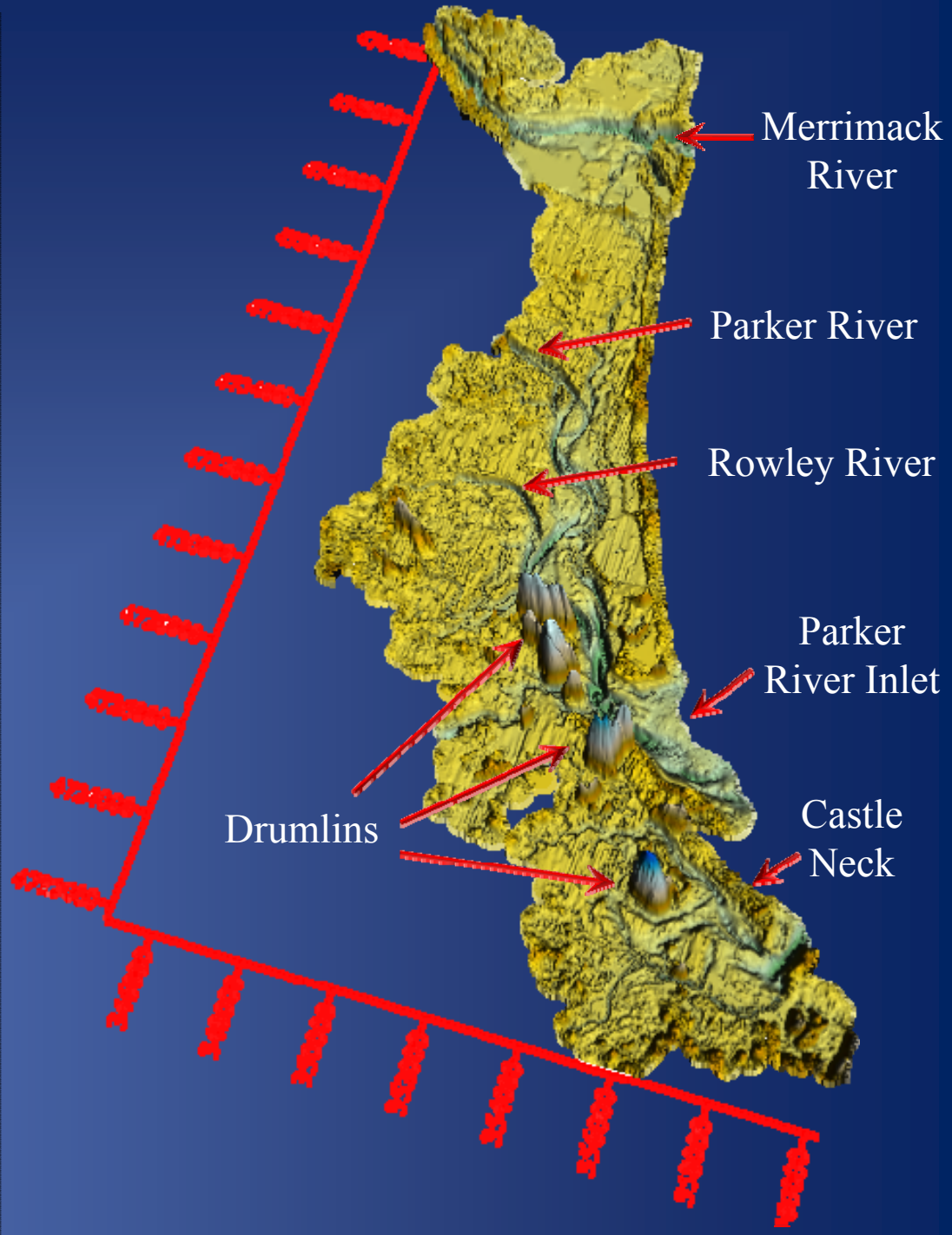
Database


Merrimack River
Parker River
Rowley River
Parker River Inlet
Castle Neck

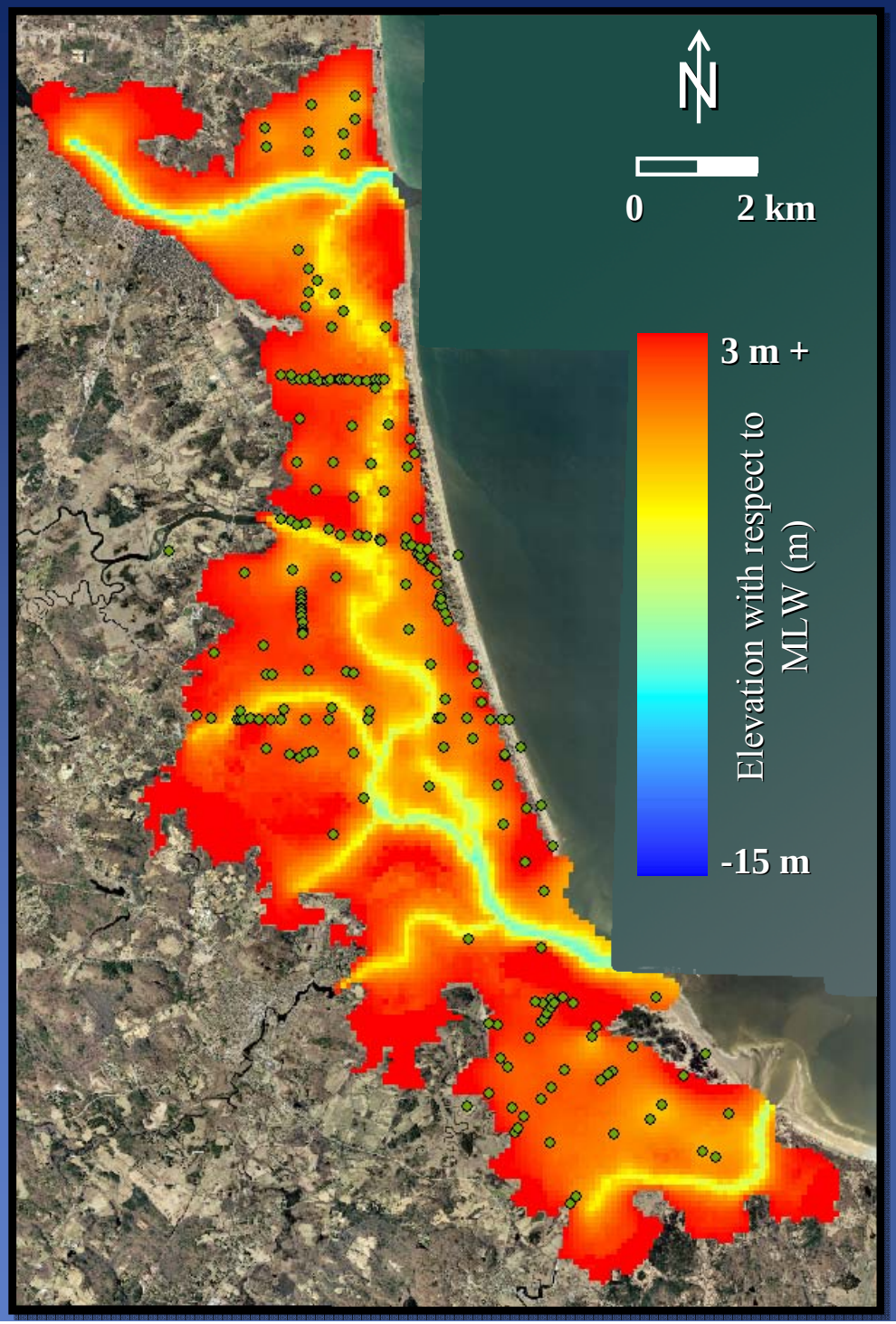

Backbarrier Boundary

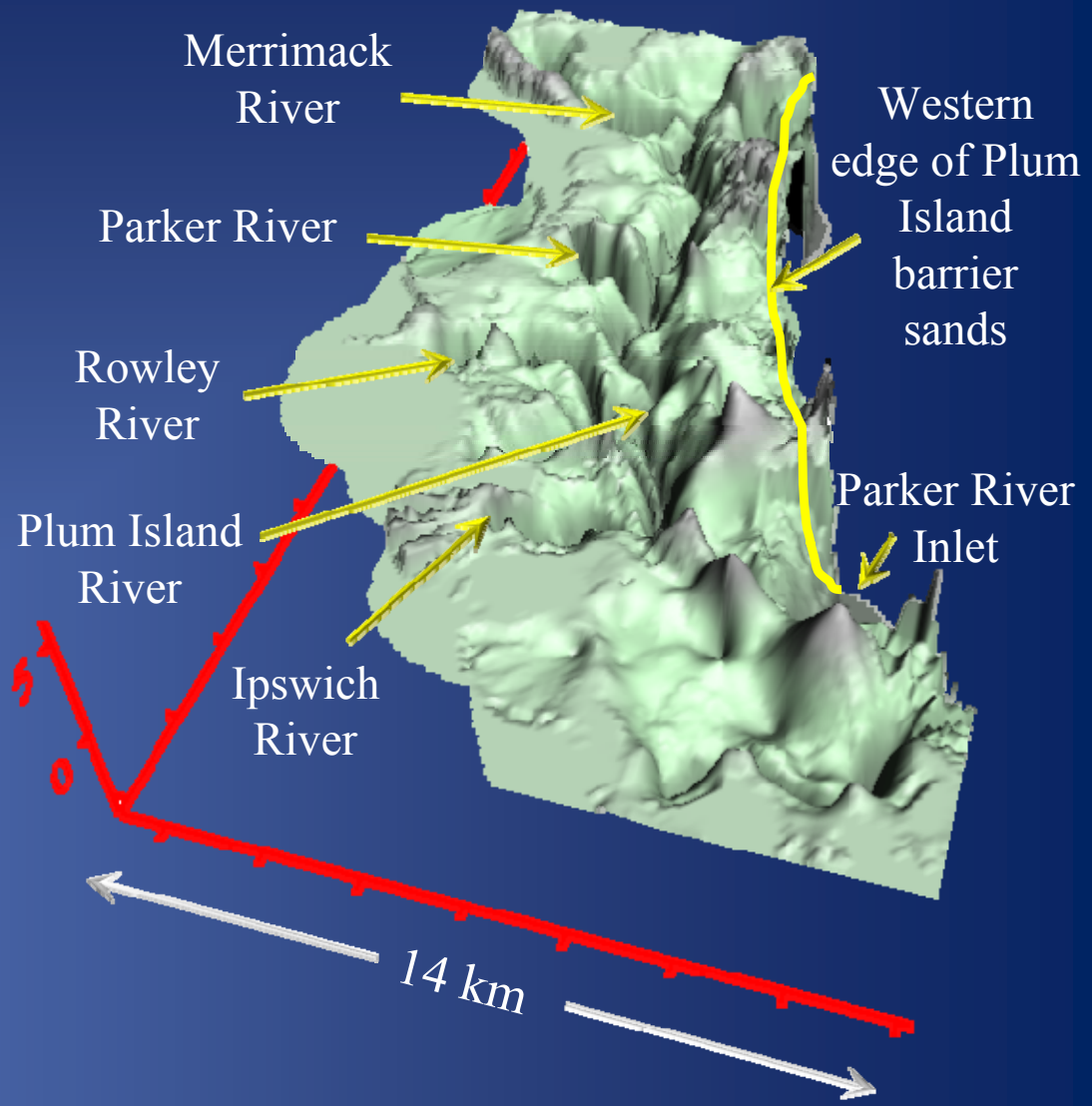
Plum Island Backbarrier



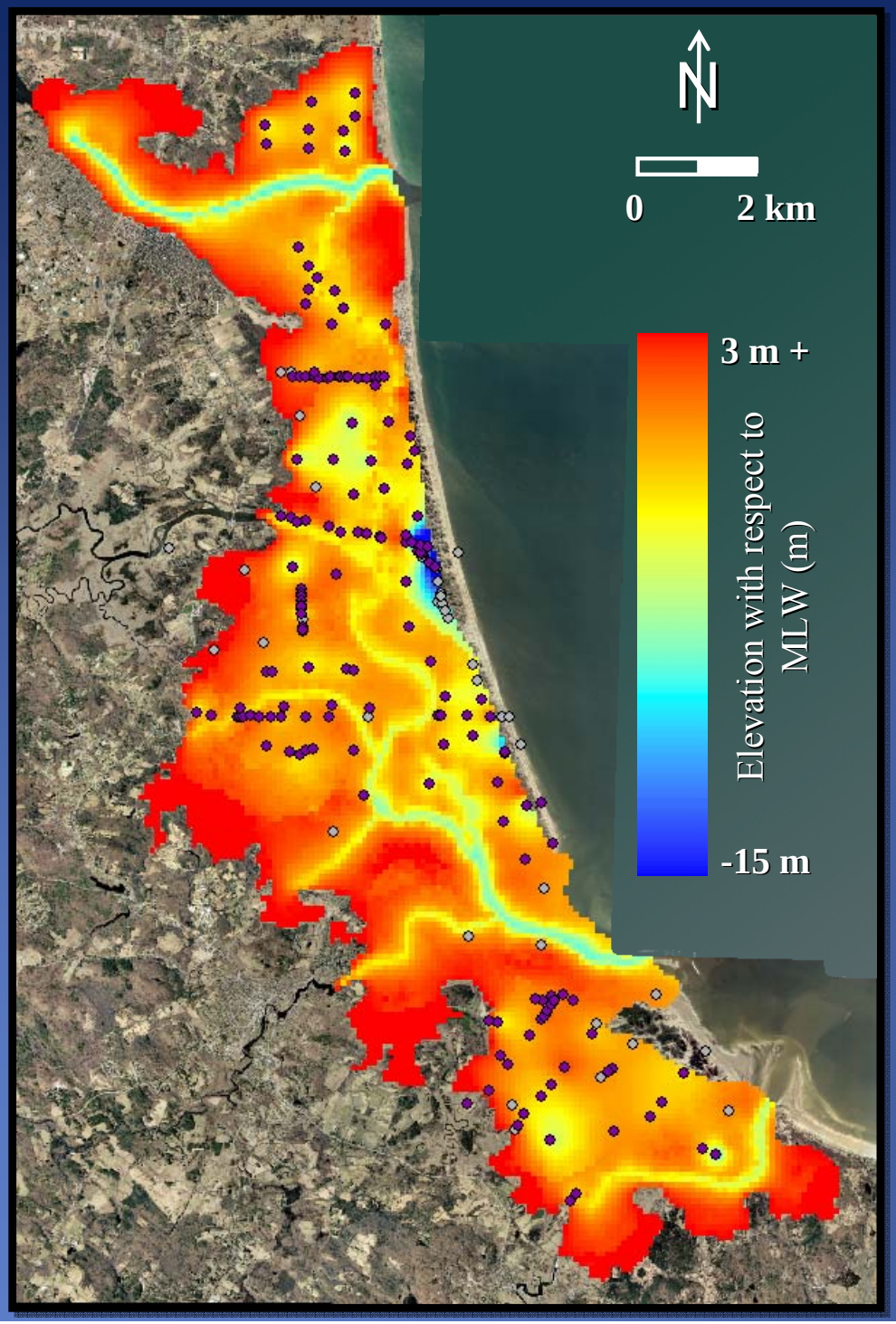


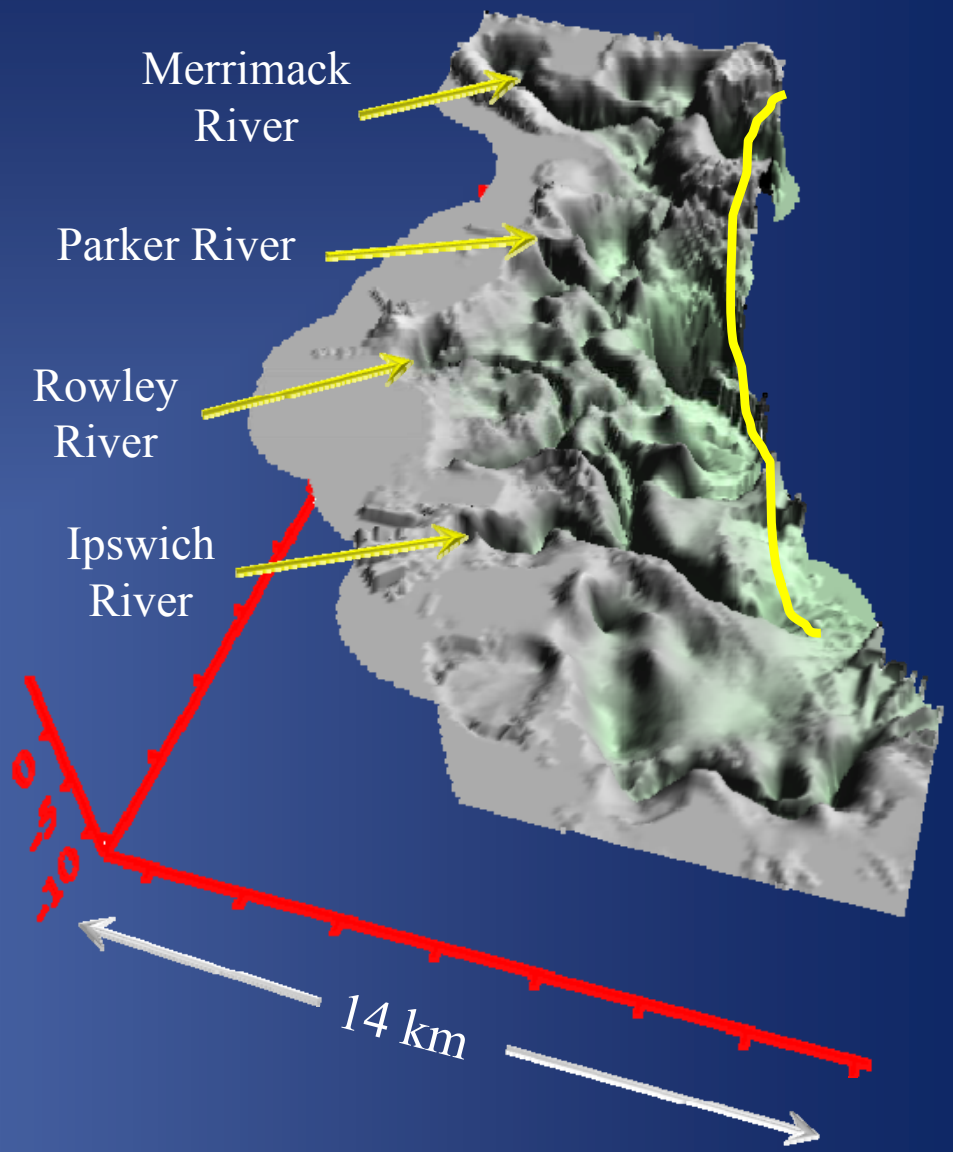
Plum Island Stratigraphy: Surface



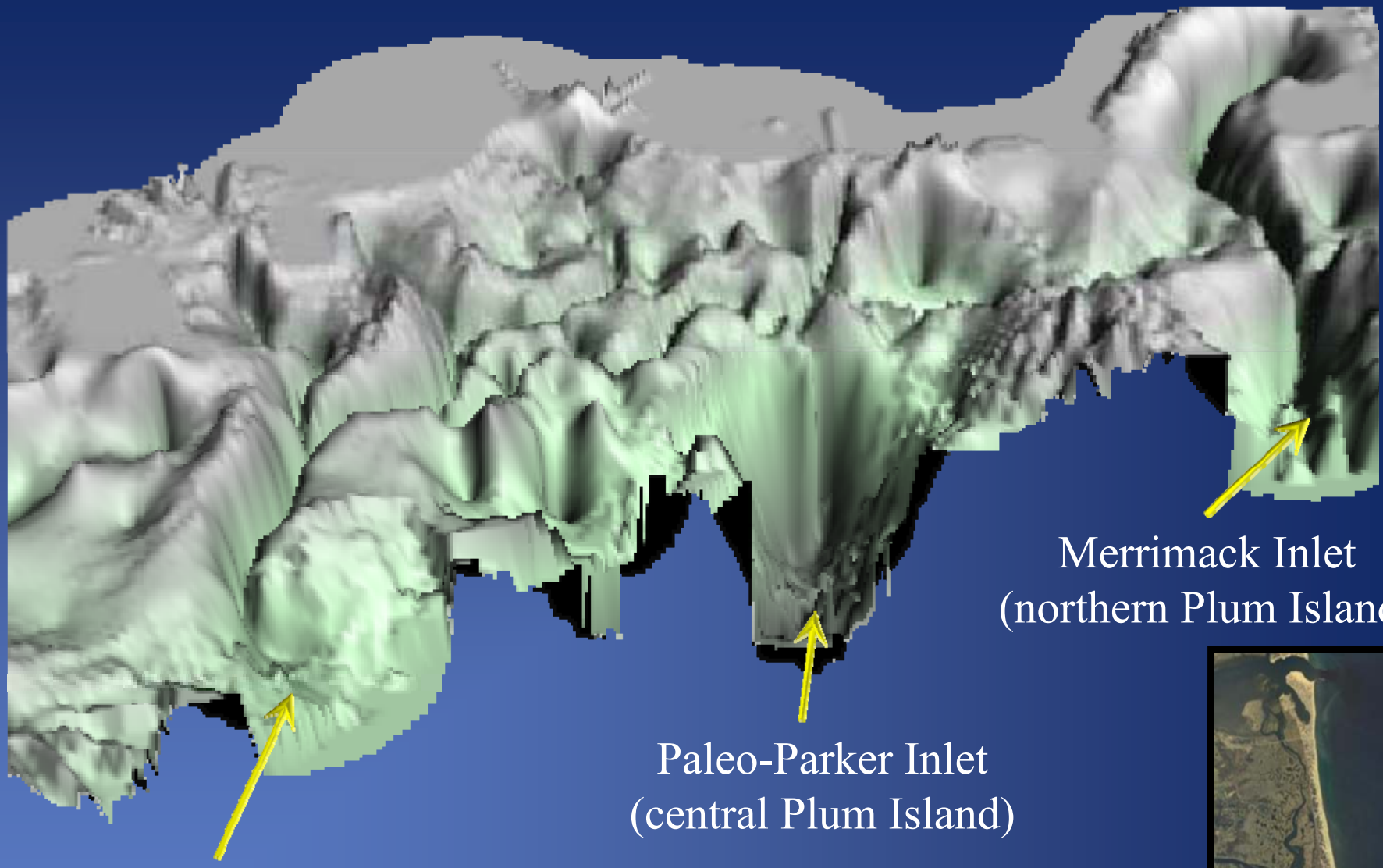


Plum Island Stratigraphy: Backbarrier Sediments





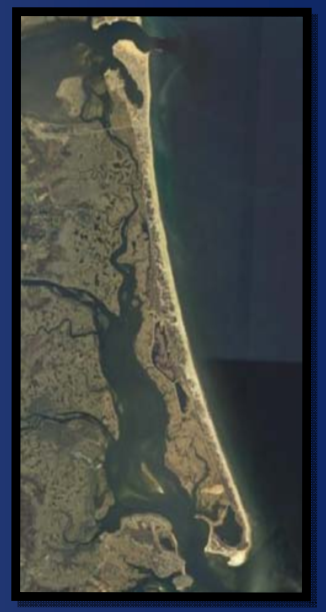
Plum Island Stratigraphy: Backbarrier Sediments



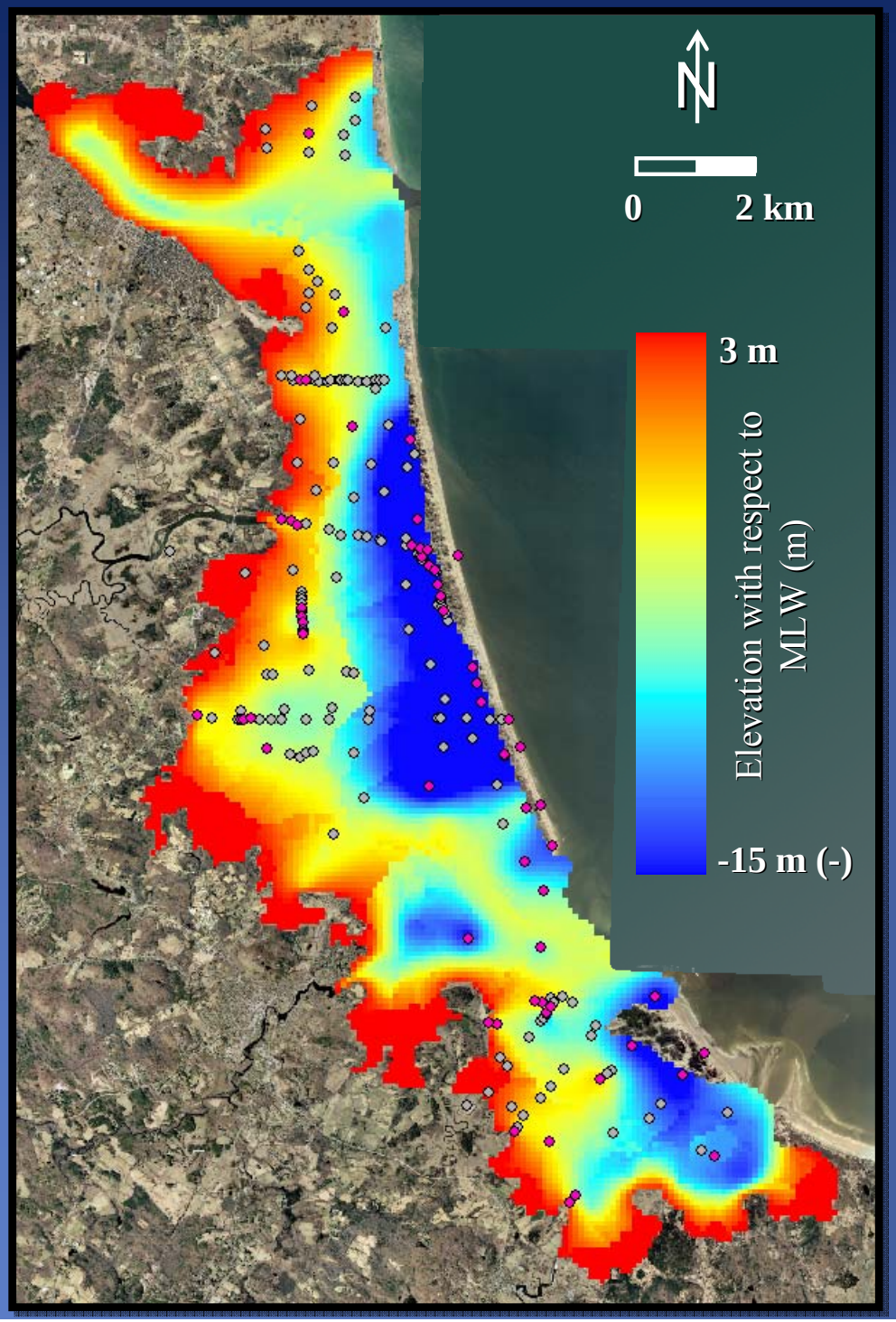
Merrimack Inlet
(northern Plum Island)

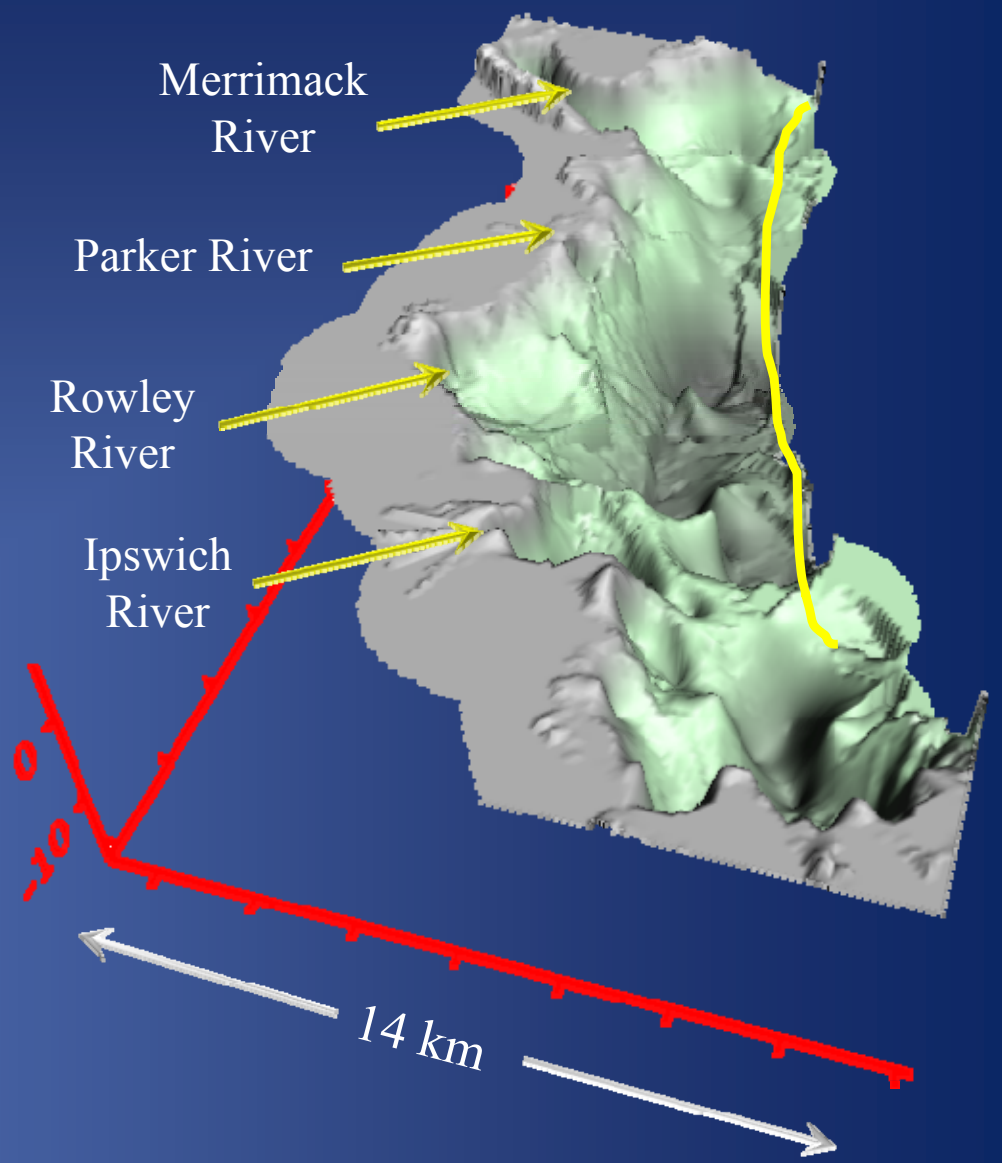
Paleo-Parker Inlet
(central Plum Island)

Parker River Inlet
(southern Plum Island)

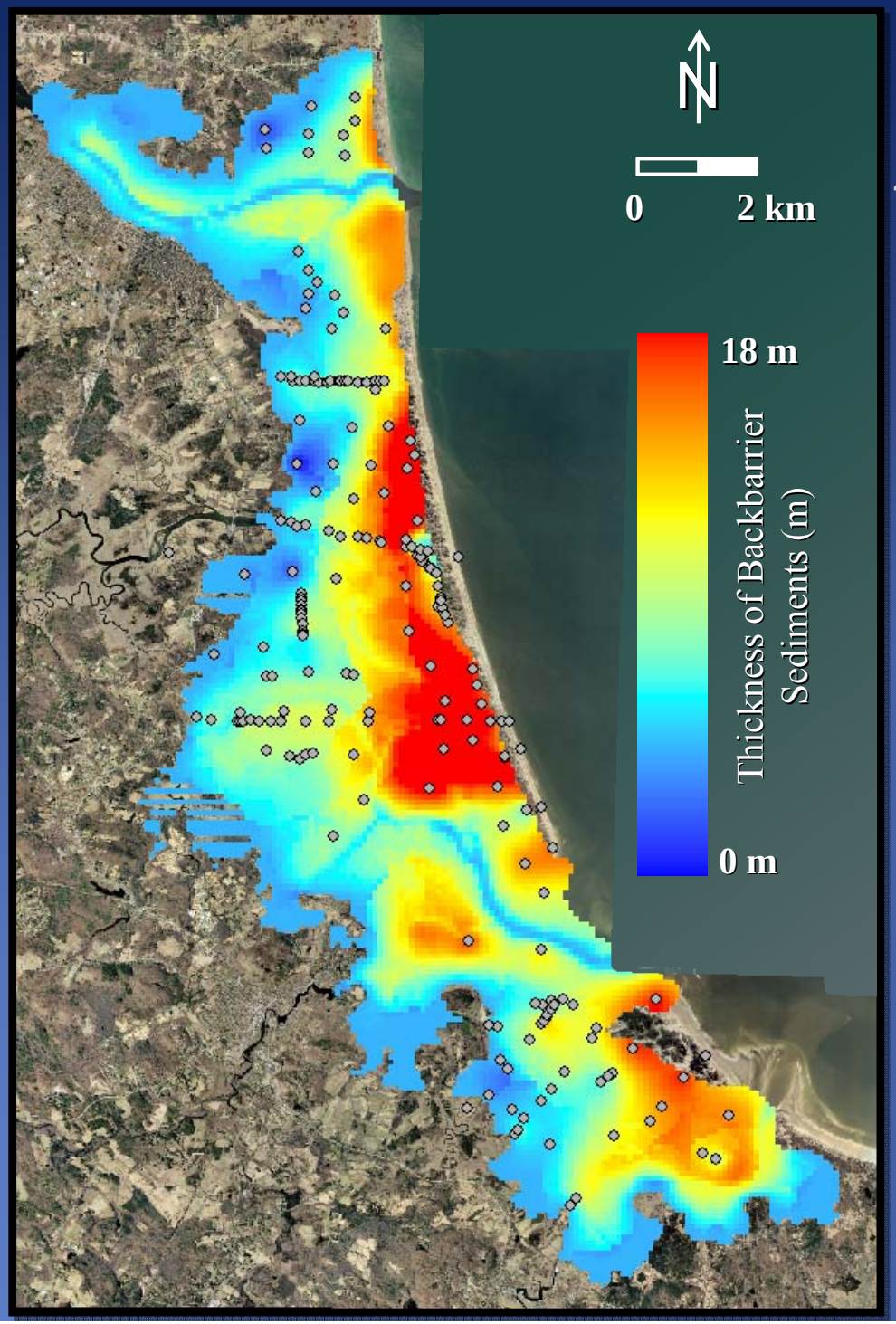


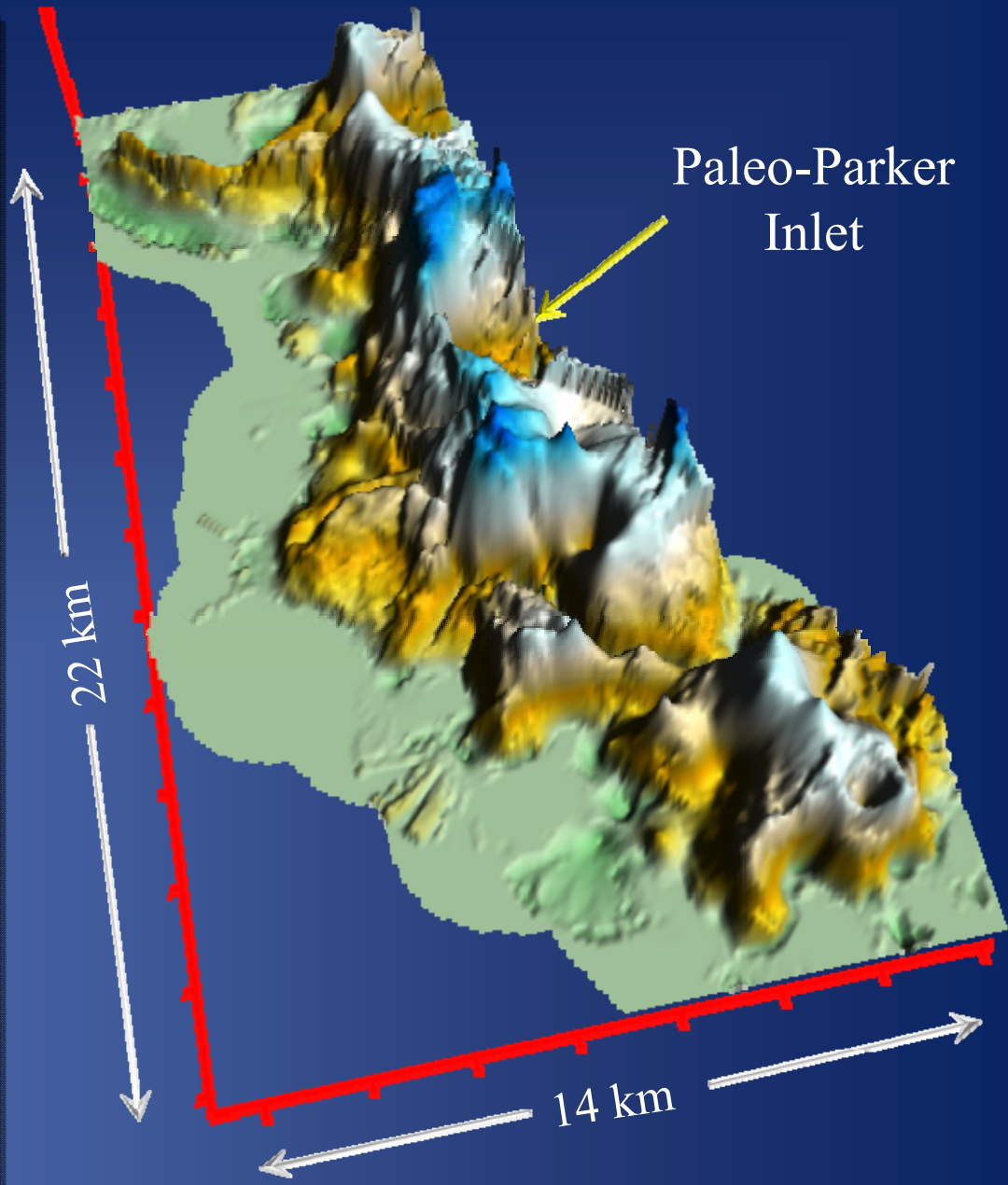
Plum Island Stratigraphy: Backbarrier Base





Backbarrier Sediment Thickness





NET VOLUME: 850 x 10^6 m^3

Sediment Reservoirs

(vol. x 10^6 m^3)

Other Reservoirs:

- Merrimack Paleo-delta: 1300
- Offshore Holocene Sand Sheet: 121

Data Sources:

- Costas et al., unpub.
- Dougherty, 2002, MS Thesis
- FitzGerald et al., 2002, Geomorph
- Hein et al., unpub.
- Hubbard, 1971, MS Thesis
- McKinlay, 1996, MS Thesis
- Oldale et al., 1983, Quat. Res.

ETD Volumes: inlet cross-sectional areas, O'Brien's Relationship, & Walton & Adams Relationship

Acknowledgements

Funding: NSF Graduate Research Fellowship Program, US Minerals Management Service, Geological Society of America Graduate Student Research Grant, Boston University Undergraduate Research Opportunities Program, Clare Booth Luce Foundation

Field / Lab Assistants: Mary Ellison, Carol Wilson, Christine Harrington, Ashley Bolbrock, Dr. Susana Costas, Nicholas Cohn, Nick Howes, Brandy Rinck, Stephanie Simms, Jeff Grey (USGS), Dr. Britt Argow (Wellesley College)

Parker River National Wildlife Refuge Staff