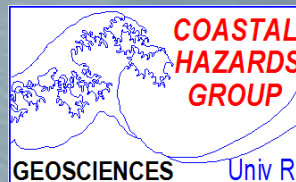


# **UNDERSTANDING COASTAL GEOLOGIC HAZARDS SEA LEVEL RISE and CLIMATE CHANGE in RHODE ISLAND**

**2<sup>nd</sup> National Workshop on Subaqueous Soils**

**9 August 2010**

**Jon C. Boothroyd, State Geologist,  
Rhode Island Geological Survey and Department of Geosciences,  
University of Rhode Island, Kingston, RI 02881,  
[jon\\_boothroyd@uri.edu](mailto:jon_boothroyd@uri.edu)**

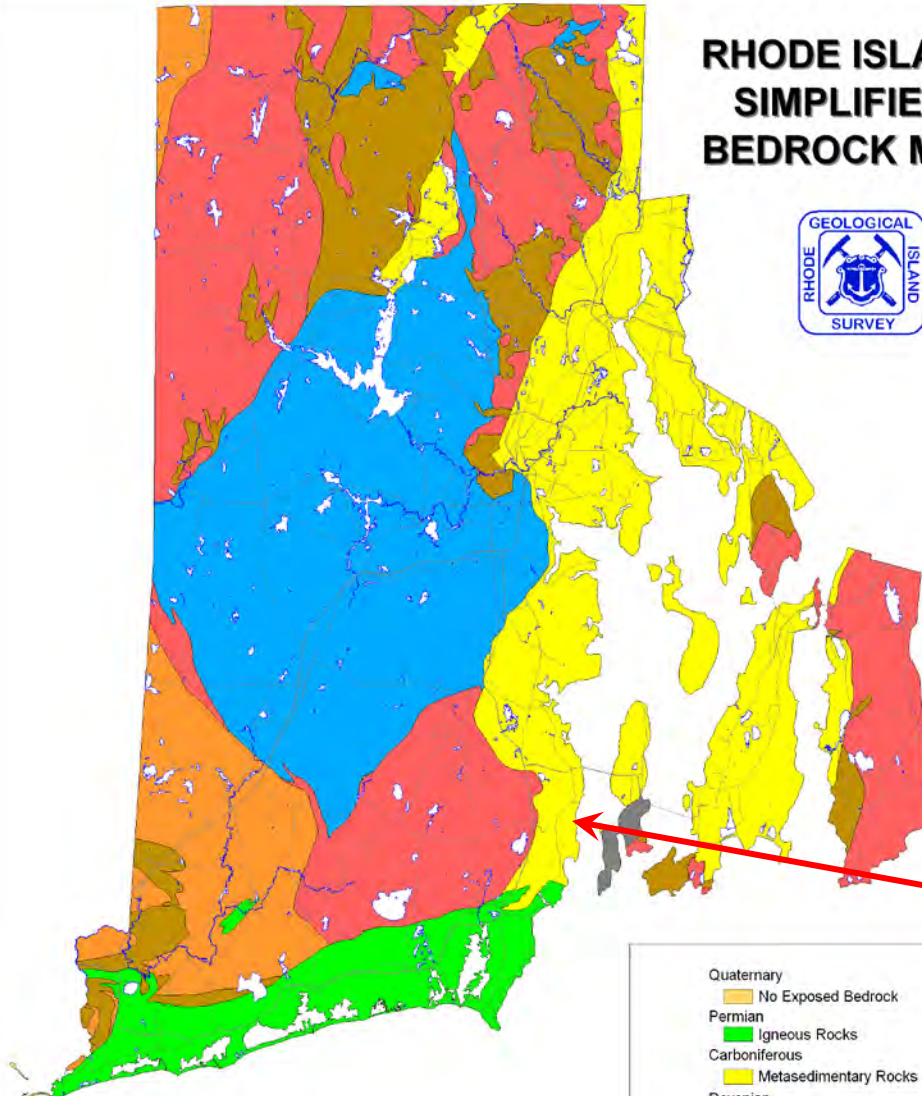


An aerial photograph of a coastal region, likely the Chesapeake Bay area, showing a large body of water in the center surrounded by land with a grid-like street pattern and some green spaces. The text is overlaid on this image.

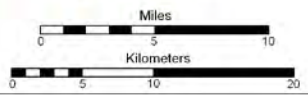
# ***A Little Background Information***

- **Bedrock Geology**
- **Glacial Geology**

# RHODE ISLAND SIMPLIFIED BEDROCK MAP



- Quaternary
  - No Exposed Bedrock
- Permian
  - Igneous Rocks
- Carboniferous
  - Metasedimentary Rocks
- Devonian
  - Igneous Rocks
- Cambrian
  - Metasedimentary Rocks
- PreCambrian
  - Igneous Rocks
  - Gneissic Rocks
  - Metastratified Rocks

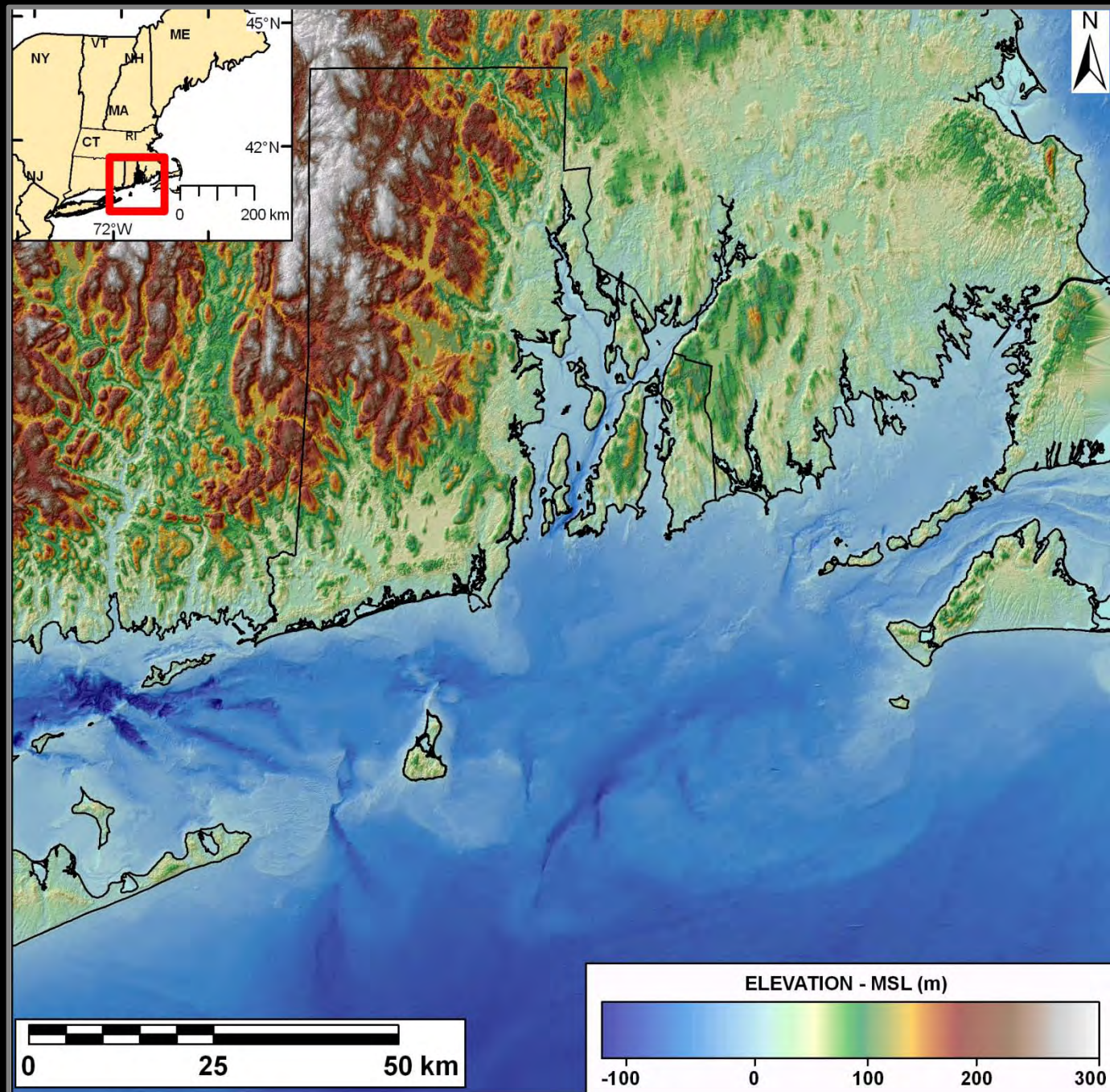


Modified from:  
Hermes, O.D., Gronet, L.P., and Murray, D.F. (compilers) 1994.  
Bedrock geologic map of Rhode Island.  
Rhode Island Map Series No. 1.  
University of Rhode Island, Kingston.  
Scale 1:100,000.



**You are  
here**

# Geomorphology of Southeastern New England



# Quaternary Geology Time Scales

- **QUATERNARY PERIOD** - **Last 2.6 million years** of geologic time
- **PLEISTOCENE EPOCH** – **All of Quaternary Period except last 11,700 years**
- **WISCONSINAN STAGE** – Last glacial age of the Pleistocene (**~70,000 years BP to 11,700 yrs BP**)
- **HOLOCENE EPOCH** – **Last 11,700 years** (including now)

# Geologic Time Scale

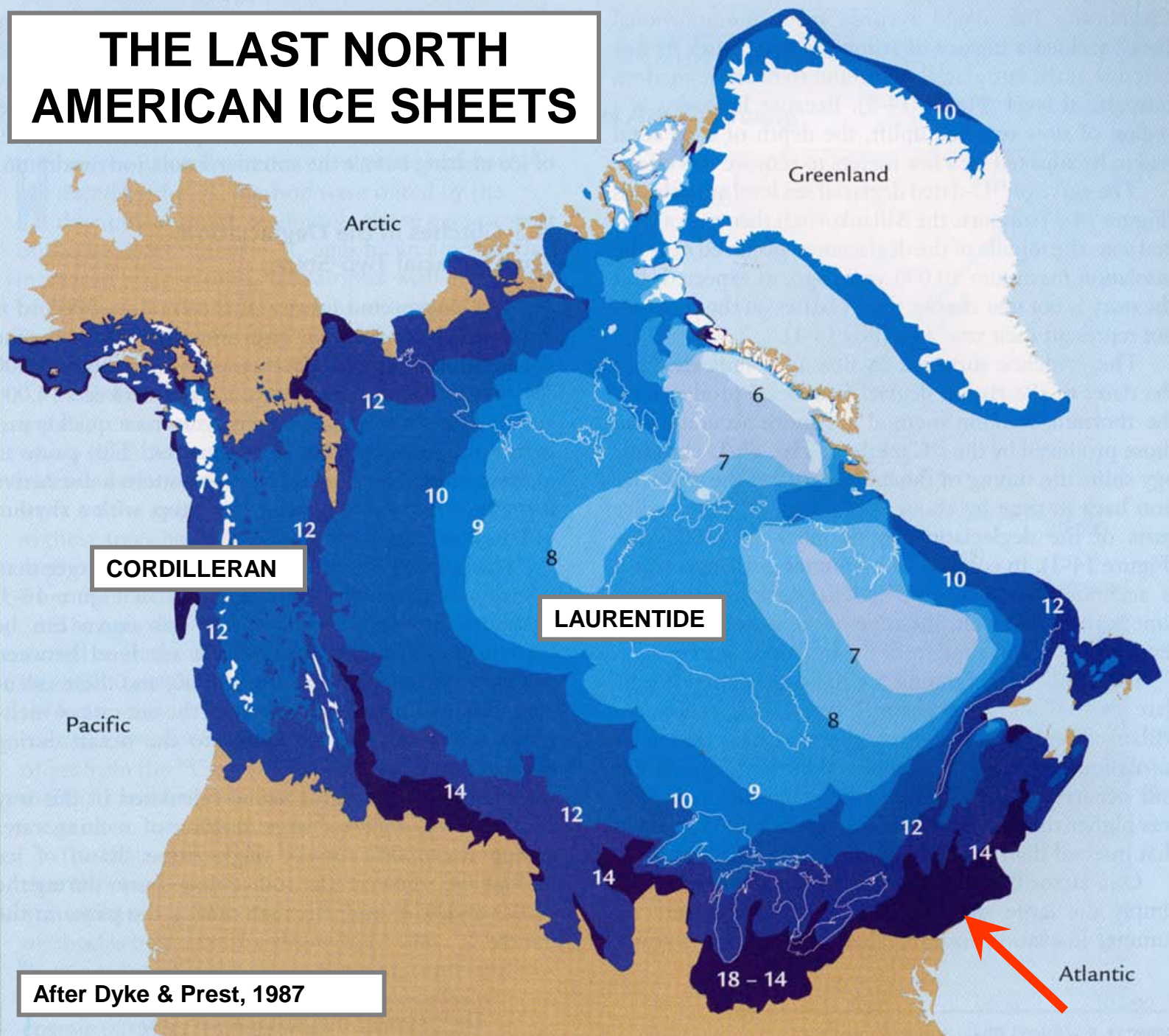
## Cenozoic – Last 65.5 my

Quaternary -  
Last 2.6 my



EONOTHEM / EON	ERATHEM / ERA	SYSTEM, SUBSYSTEM / PERIOD, SUBPERIOD	SERIES / EPOCH	Age estimates of boundaries in mega-annum (Ma) unless otherwise noted
Cenozoic (Cz)	Quaternary (Q)		Holocene	11,700 ±99 yr*
			Pleistocene	
	Tertiary (T)	Neogene (N)	Pliocene	2.588*
			Miocene	5.332 ±0.005
		Paleogene (P)	Oligocene	23.03 ±0.05
			Eocene	33.9 ±0.1
			Paleocene	55.8 ±0.2
				65.5 ±0.3

# THE LAST NORTH AMERICAN ICE SHEETS

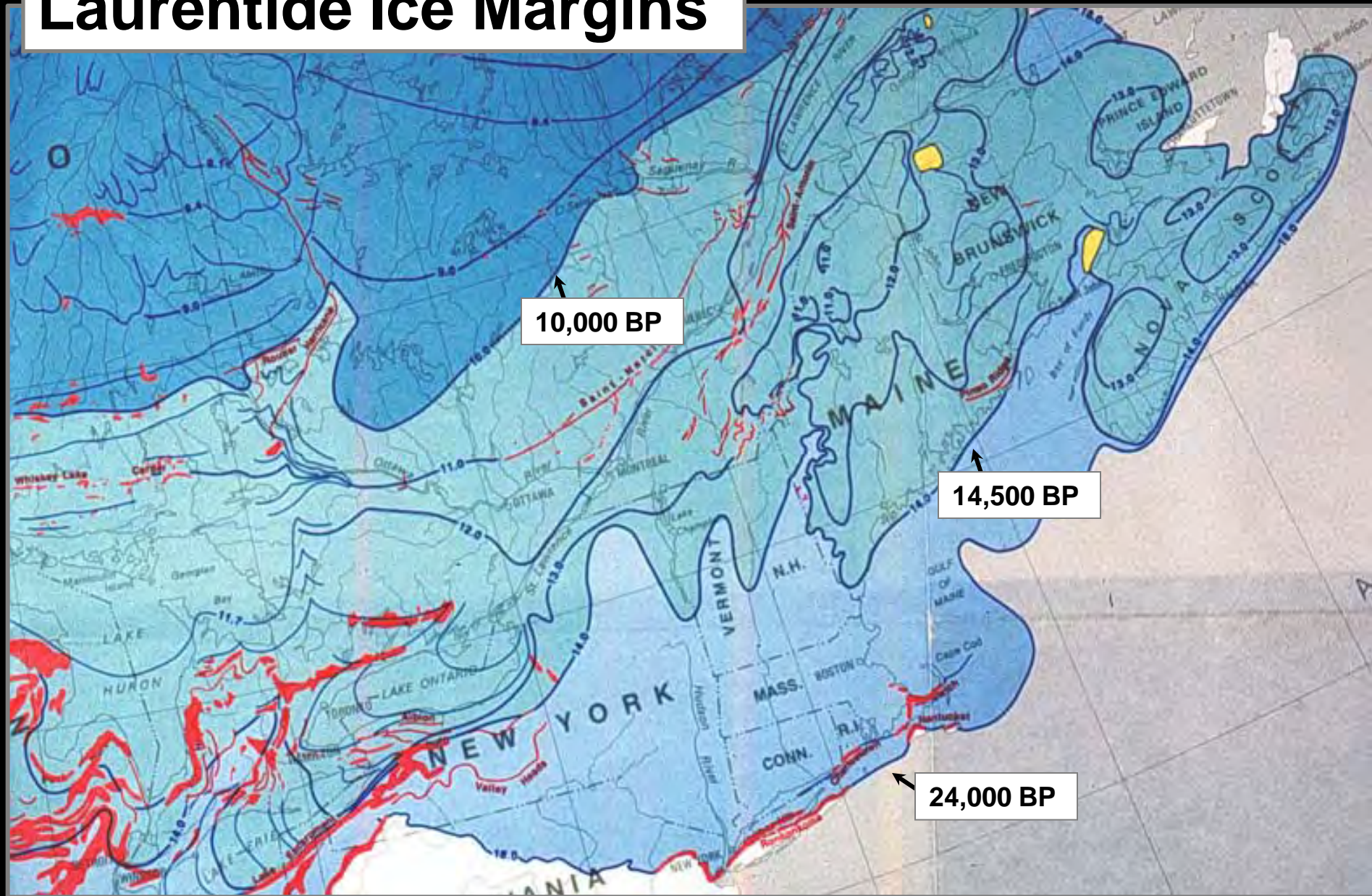


**CORDILLERAN**

**LAURENTIDE**

After Dyke & Prest, 1987

# Laurentide Ice Margins



After Dyke & Prest, 1987



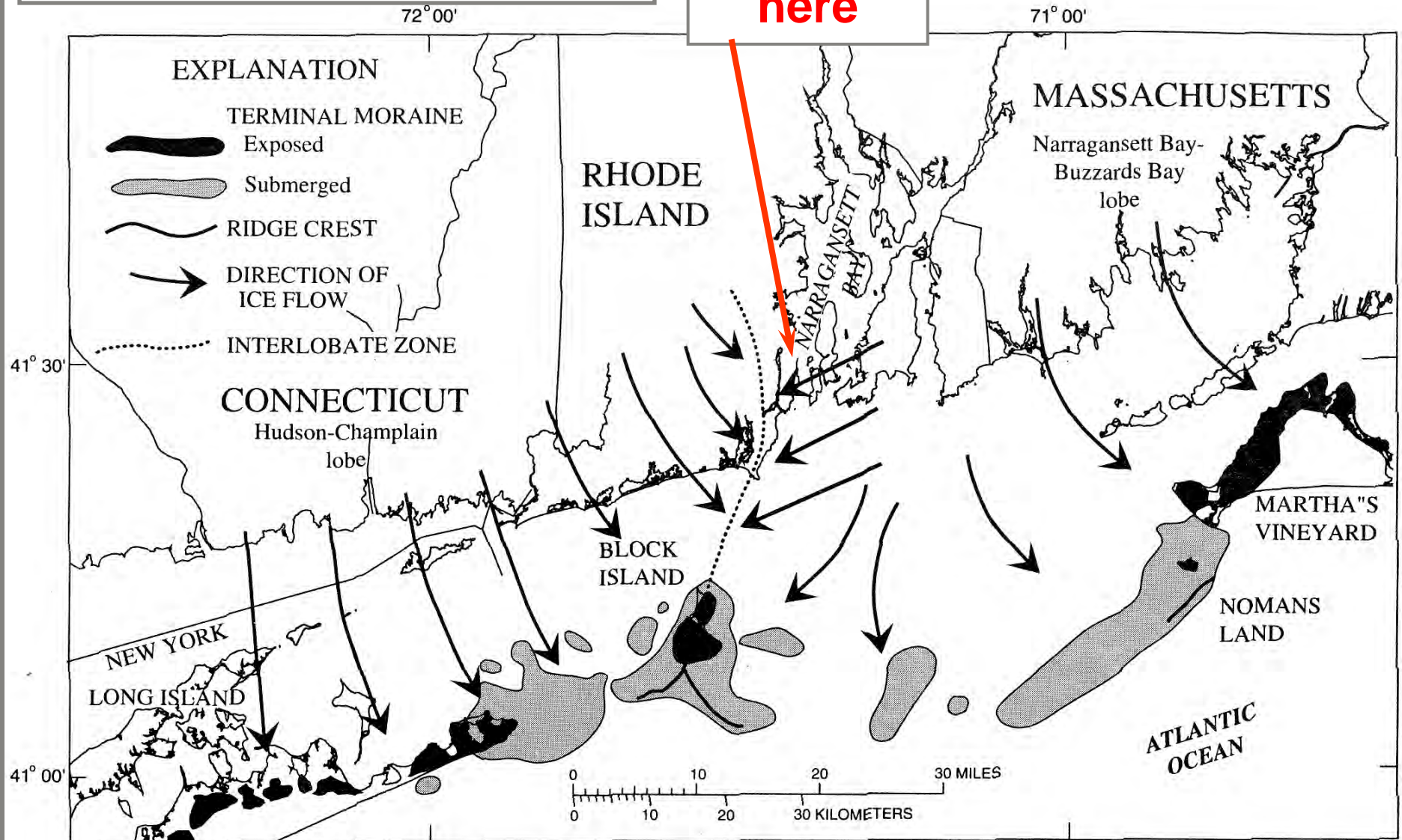
# MALASPINA GLACIER – Northeast Gulf of Alaska



**An Analog “The size of Rhode Island”**

# Ice Flow Directions

You are here



Base from U.S. Geological Survey, Digital Line Graphs, 1:100,000, 1983

Stone and Sirkin, 1996



# QUATERNARY DEPOSITS OF RHODE ISLAND

Granitic Till Upland

Thick Stratified Deposits

Narragansett structural basin

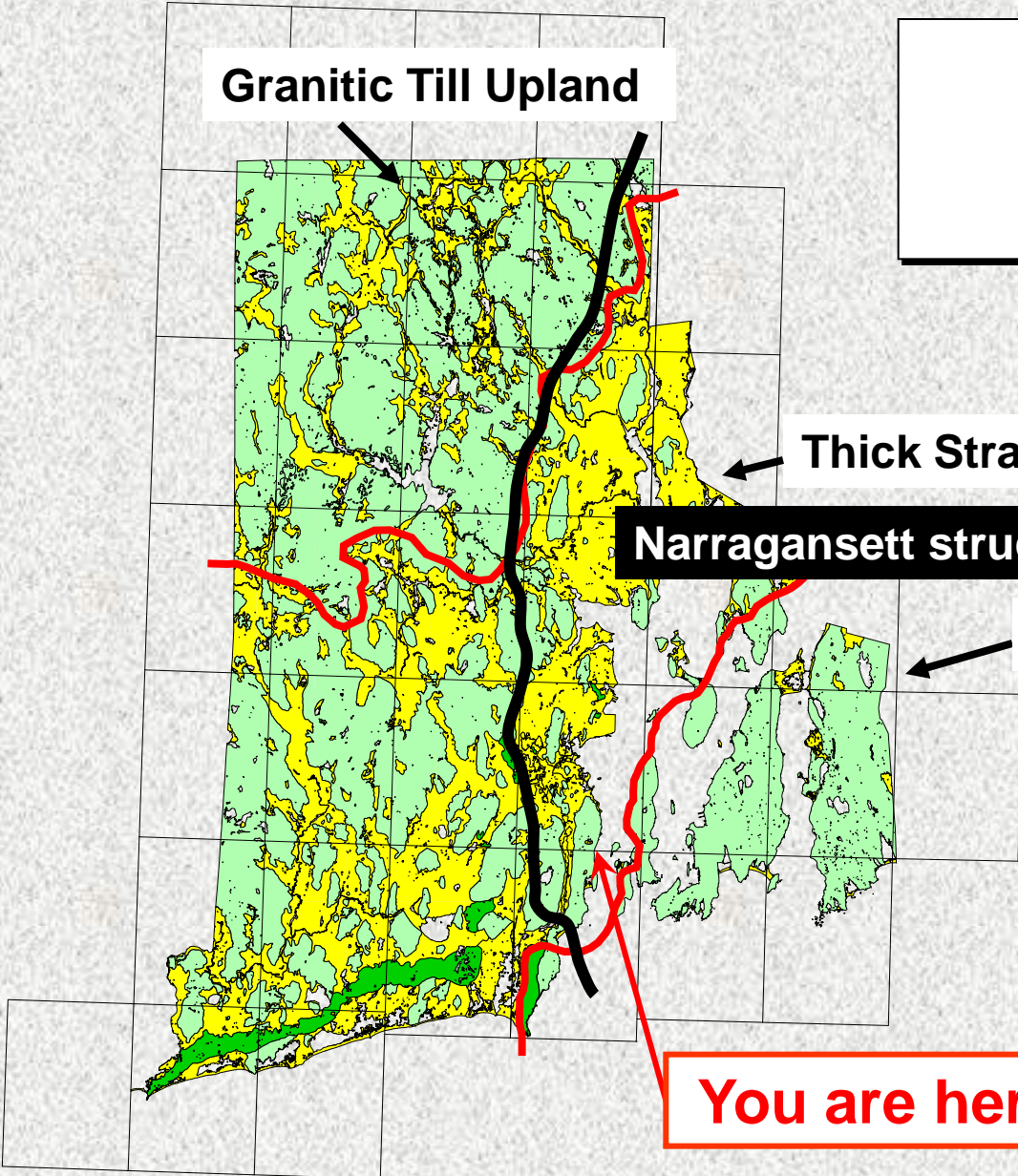
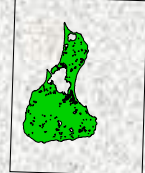
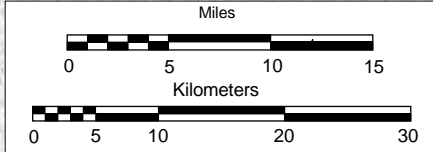
Compact Till Upland

You are here

Block Island Complex

**EXPLANATION**

- Stratified Material
- Till
- End Moraine - Till and Stratified Material



# GEOLOGIC FACIES -

Sediment with certain readily identifiable characteristics –

- Composition
- Color
- Particle size
- Sorting
- Stratification and structure
- Biologic content
- Plus others

May be discerned either in the field or laboratory.

# GEOLOGIC HABITATS -

Called **DEPOSITIONAL ENVIRONMENTS** by geologists

Places where geologic processes -

- Water
- Wind
- Ice
- Humans as agents

Deposit or modify geologic facies.

In a coastal setting, **GEOLOGIC HABITATS** may range from benthic habitats in 30 m water depth, through the intertidal zone, to the supratidal zone and perhaps across a barrier or upland habitat to the limit of storm-surge inundation.

# Braided River on a Delta Plain



**A GLACIAL  
DEPOSITIONAL  
ENVIRONMENT**

# Facies Deposited in a Glacial Lake Depositional Environment

**Imbricated Gravel  
Facies deposited  
on a delta plain** →

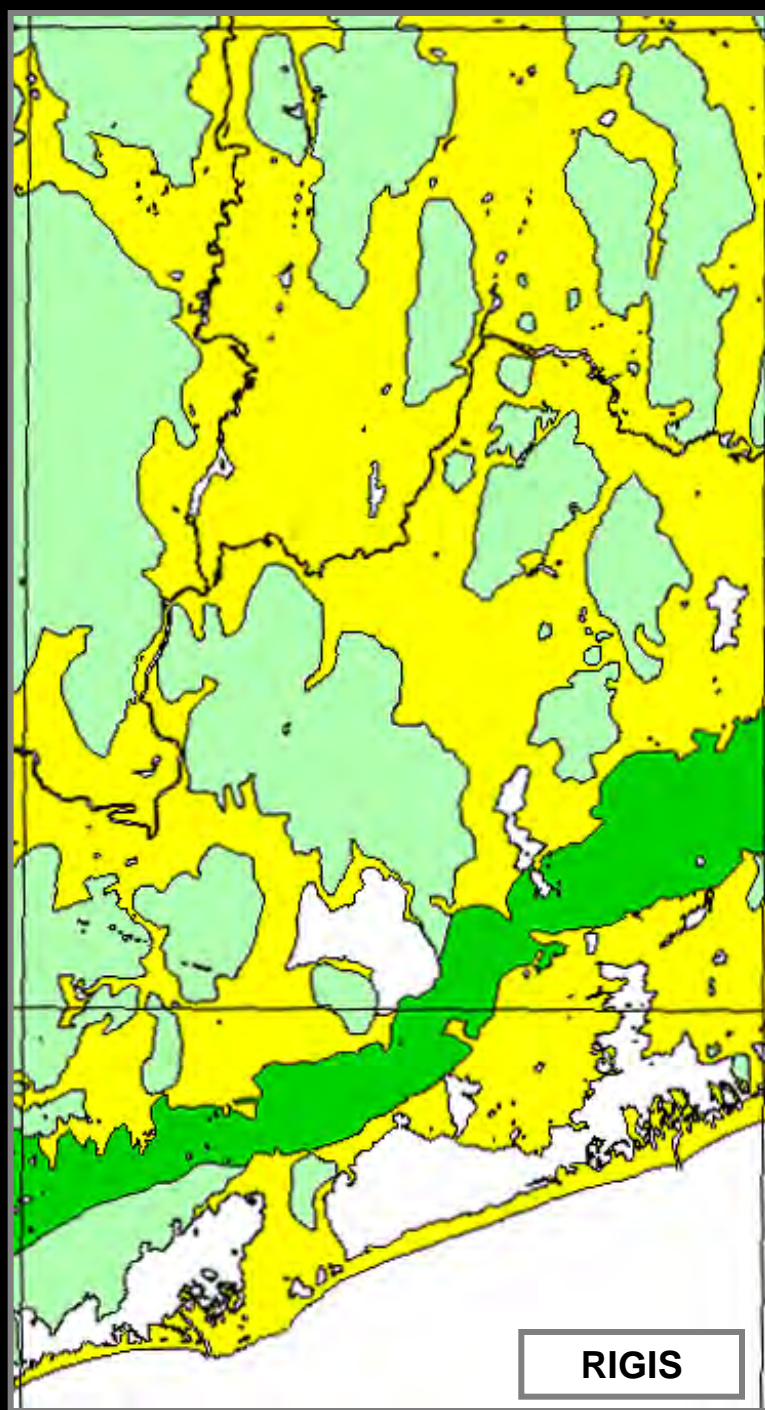
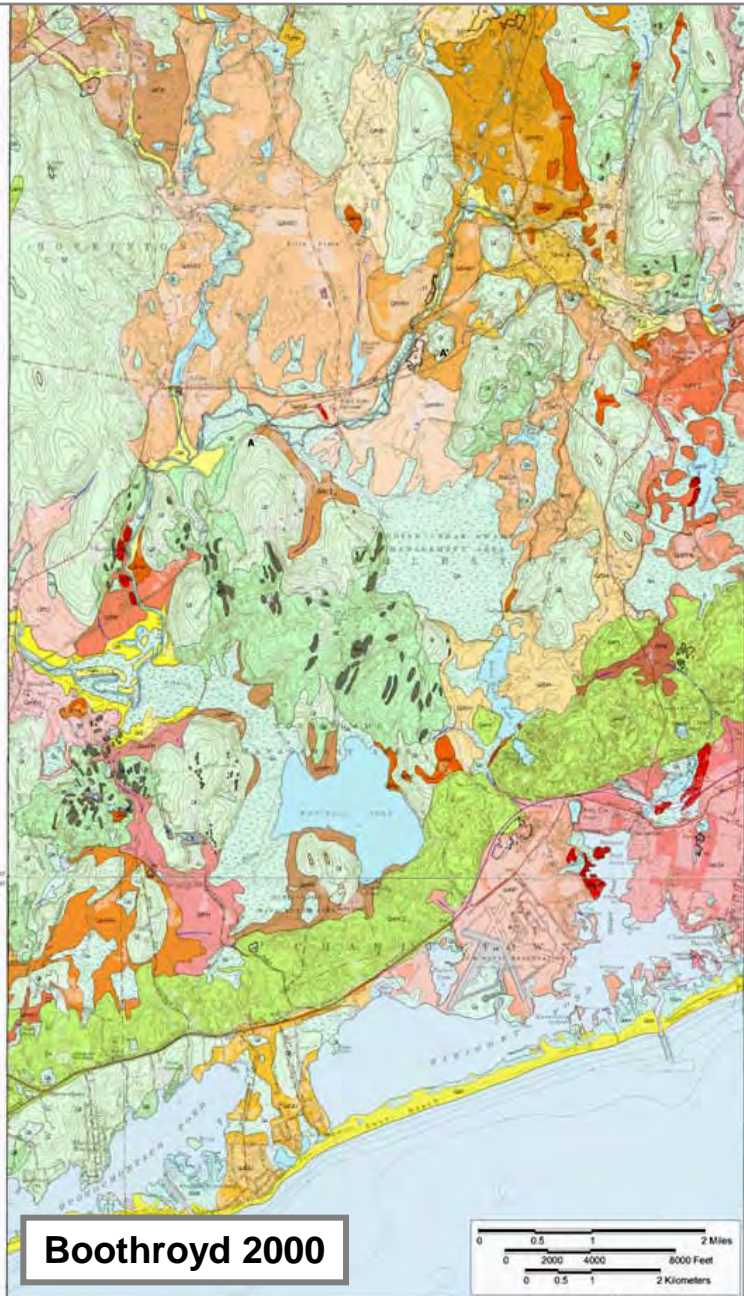
**Stratified Coarse-  
Medium Sand Facies  
deposited on a delta  
slope** →

8/10/2000 14:44

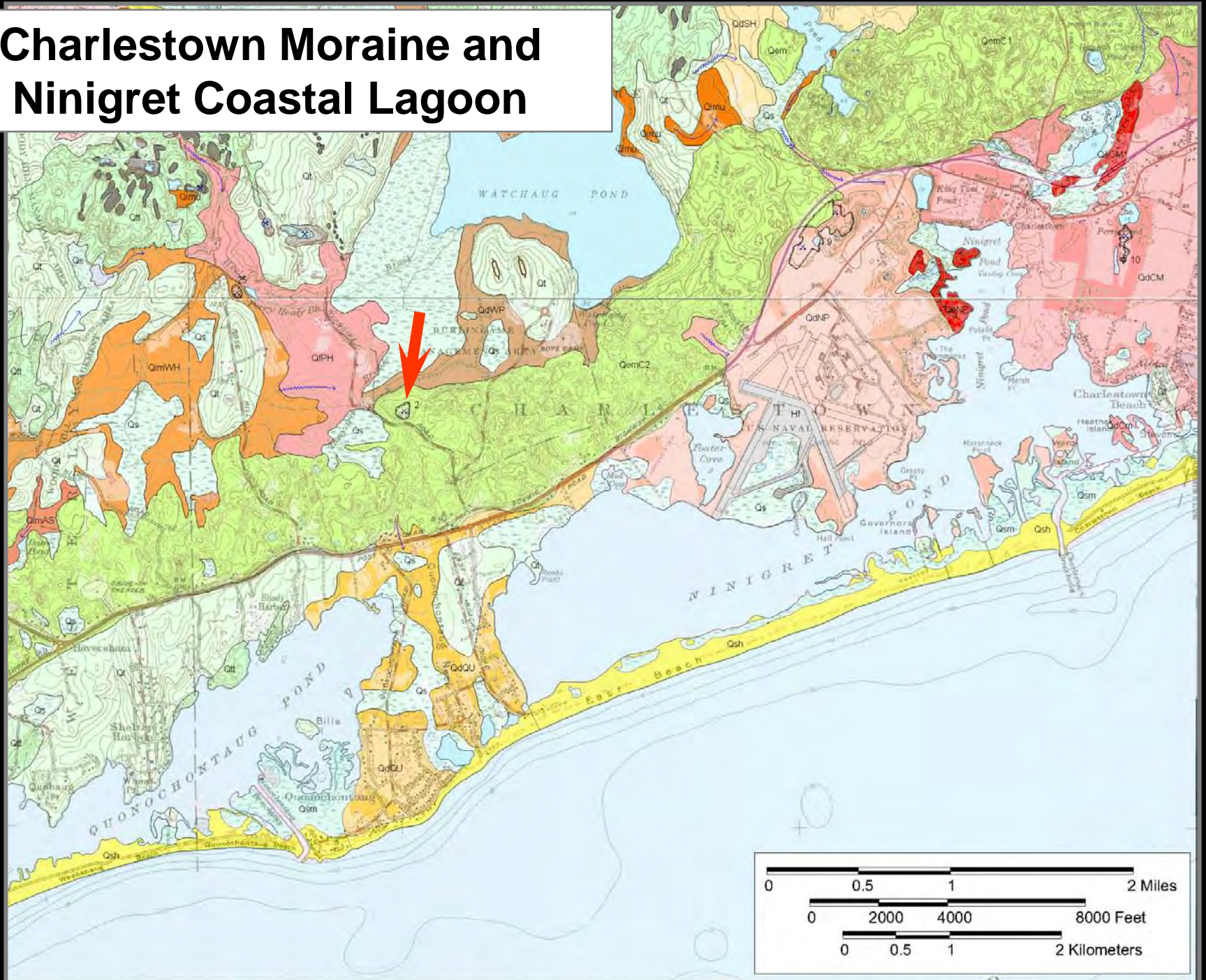




# Quaternary Map Detail



# Charlestown Moraine and Ninigret Coastal Lagoon



# Charlestown End Moraine

Silt - Eolian Mantle Deposit

Diamicton

Deformed Stratified Material

8/9/2000 14:53



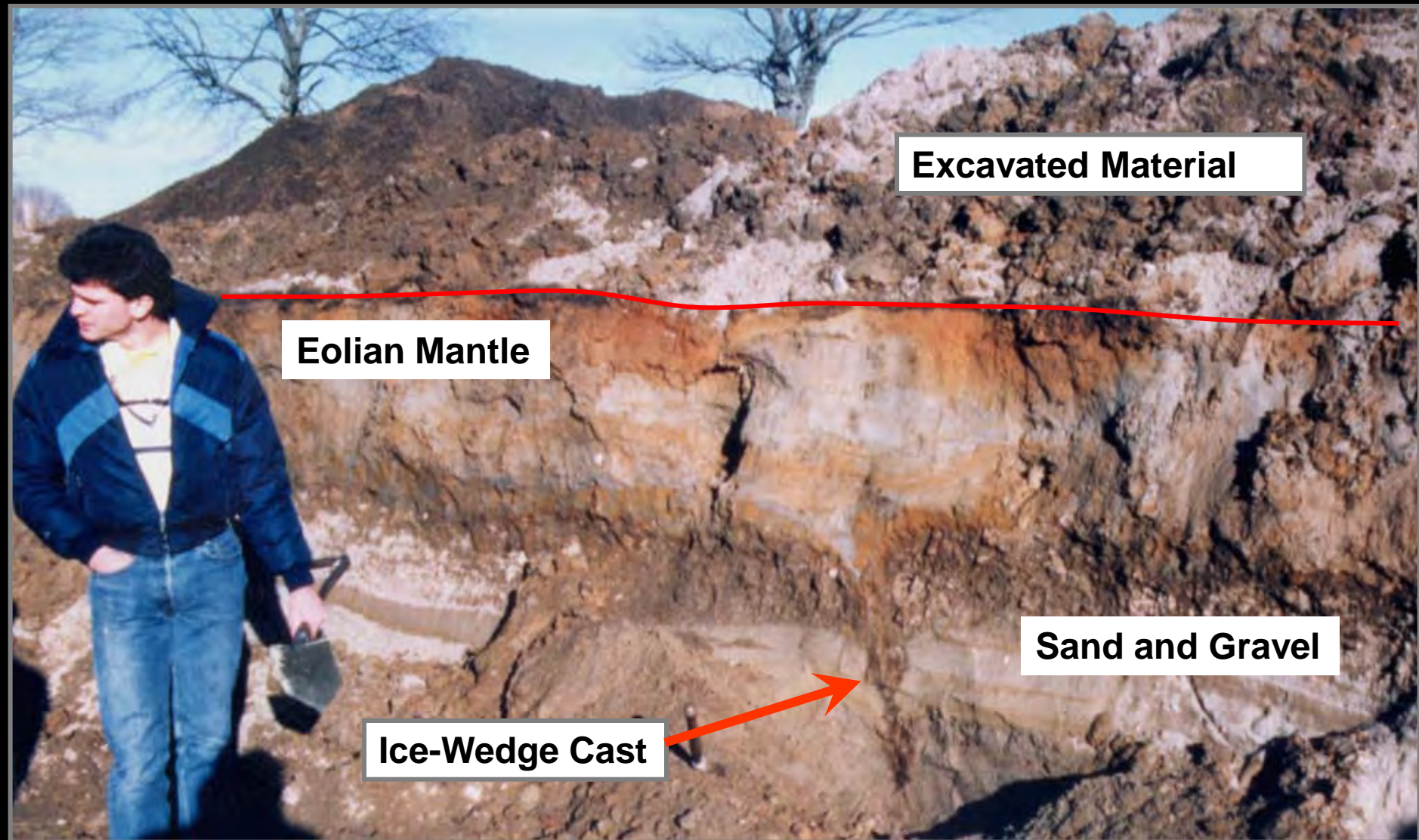
# Glacial and Post-Glacial Materials– Exeter RI

**Silt - Eolian Mantle Deposit**

**Sand and Gravel –  
Alluvial Fan Deposit**



# Ice Wedge Cast – Exeter RI

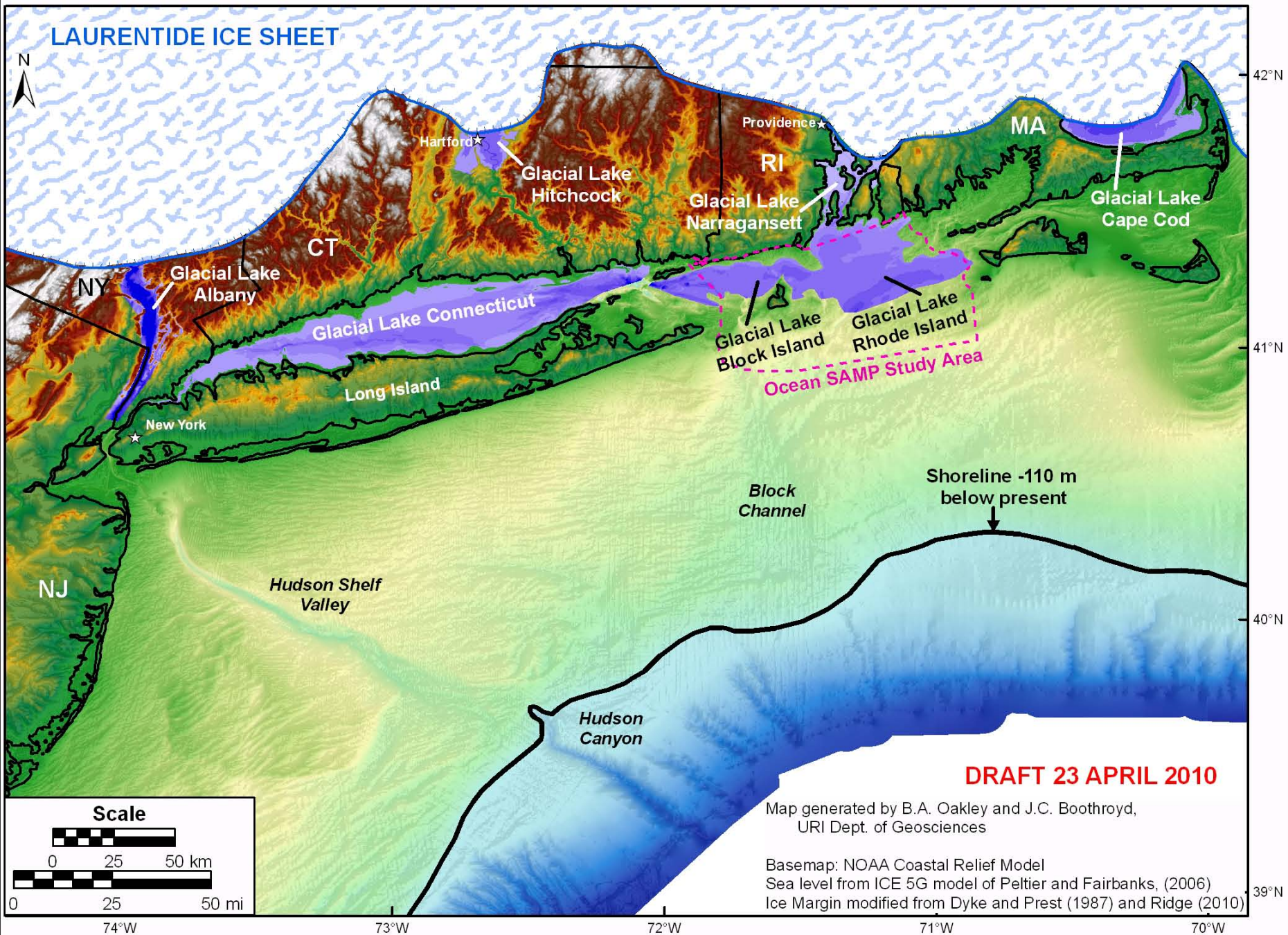


# Ice Wedge Cast – Exeter RI

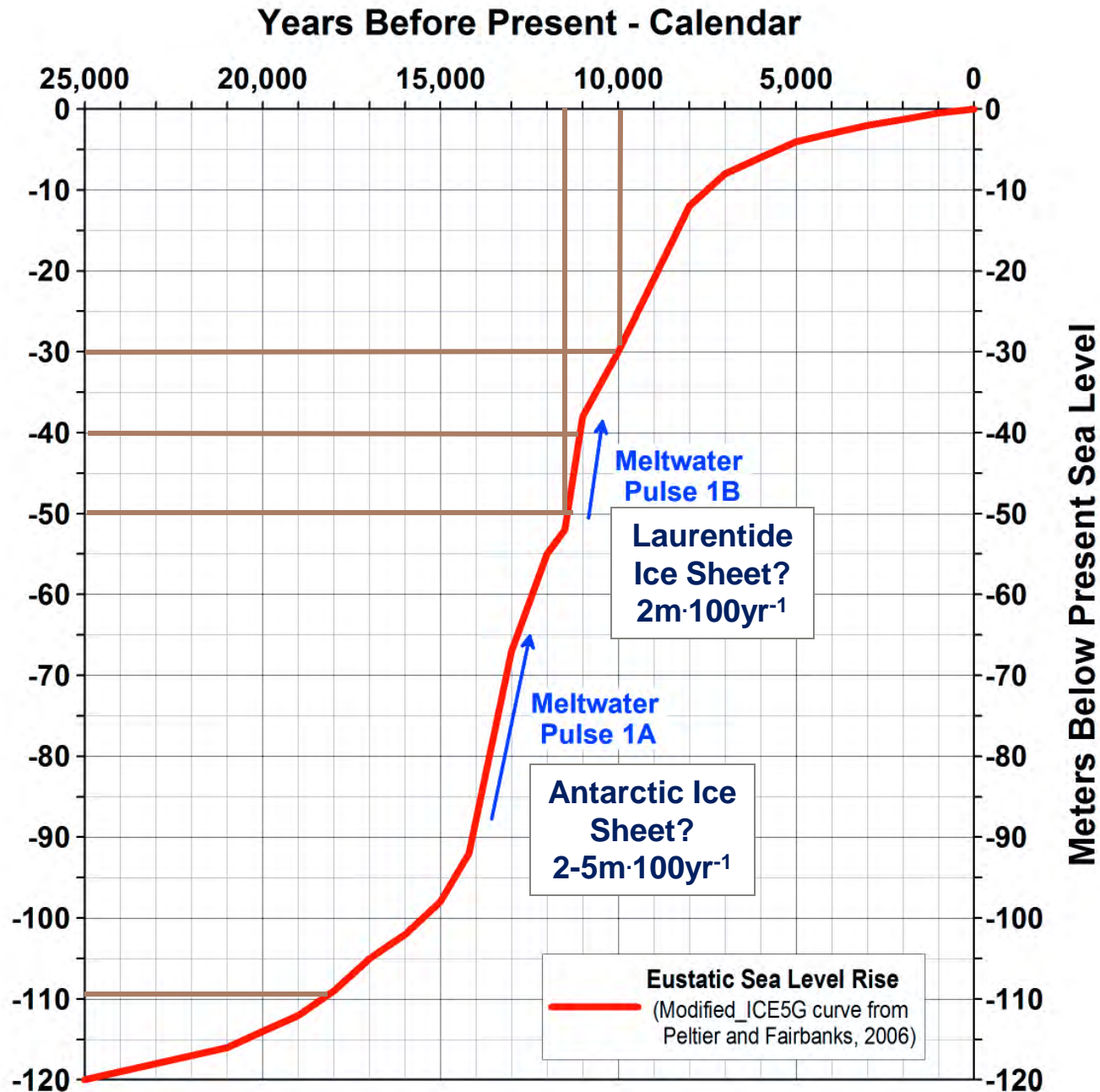
Eolian Mantle



# PALEOGEOGRAPHIC MAP OF THE SOUTHERN NEW ENGLAND CONTINENTAL SHELF 18,000 yBP



# Eustatic Sea-Level Rise

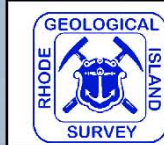
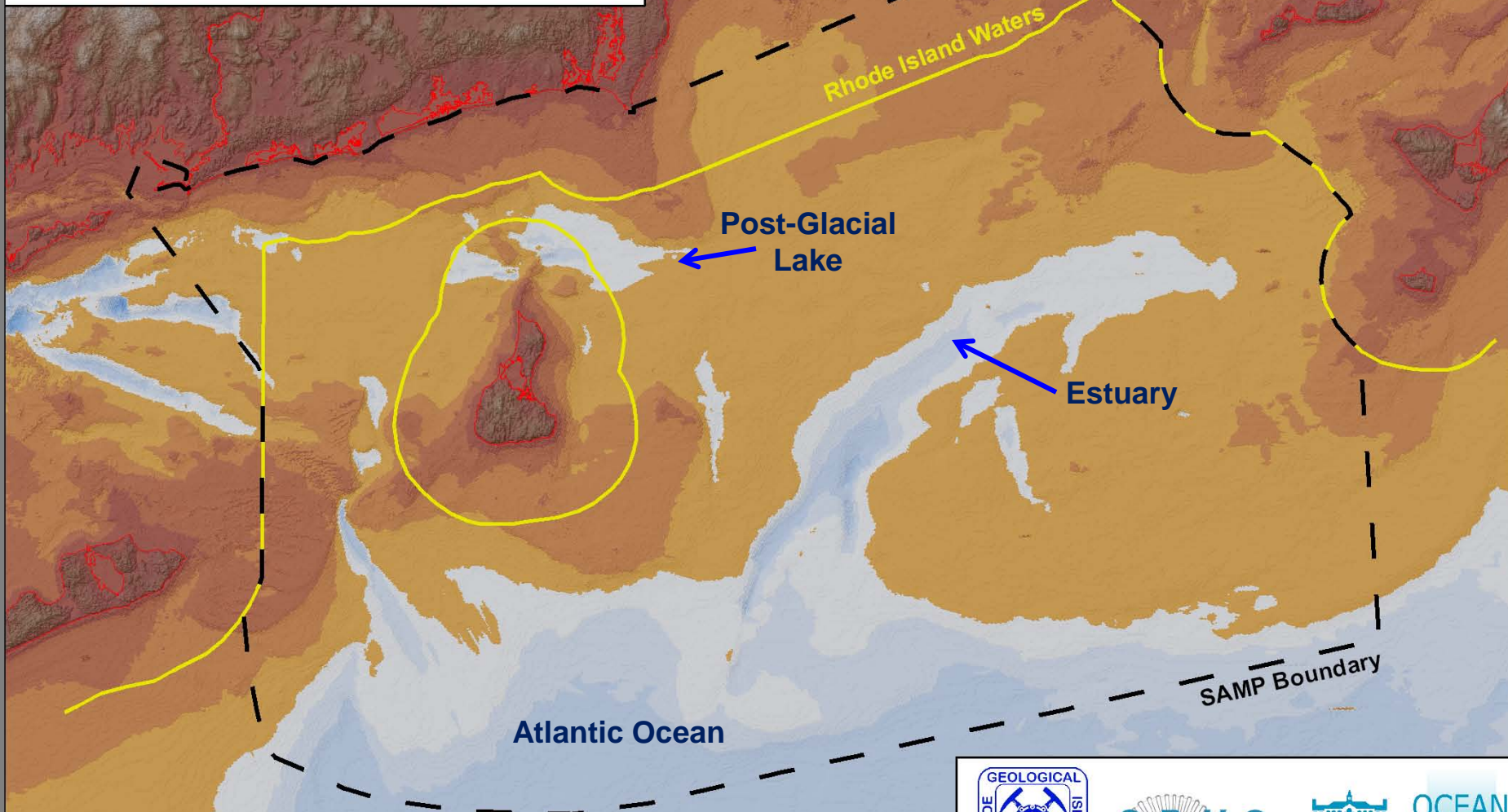




# SEA-LEVEL RISE: OSAMP AREA

- 40 m below present  
11,000 yBP

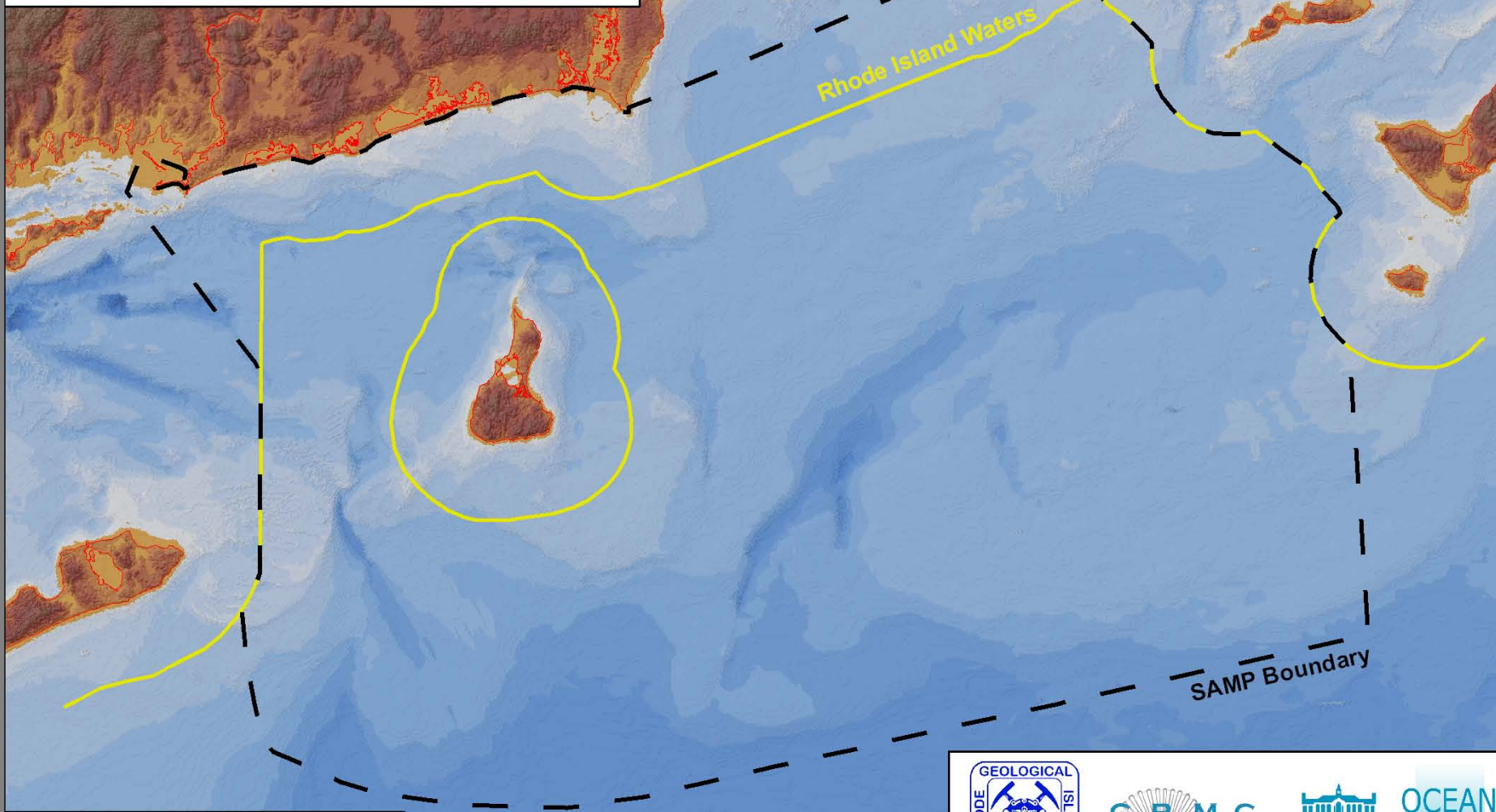
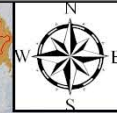
Sea level data from Peltier and Fairbanks, 2006  
Elevation data from P. Jordan, RI DEM  
Map created by B.A. Oakley, URI Geosciences



# SEA-LEVEL RISE: OSAMP AREA

- 5 m below present  
4,000 yBP

Sea level data from Peltier and Fairbanks, 2006  
Elevation data from P. Jordan, RI DEM  
Map created by B.A. Oakley, URI Geosciences



An aerial photograph of a coastal region, likely a bay or estuary. The water is a deep blue-grey color, and the surrounding land is a mix of brown and green, indicating a mix of urban development and natural vegetation. The land is fragmented by water channels and inlets. The text is overlaid on the water in the upper-middle section of the image.

***Now,  
We Need to Consider  
Coastal Processes Acting Today***

# The Sea Is Rising – But.....

**Narragansett Pier Seawall –  
Patriots Day 2007**



**WPRI.com  
16 apr 2007**

An aerial photograph of the Rhode Island coastline, showing the state's irregular shape and surrounding water. The image is semi-transparent, allowing text to be overlaid.

# ***When Contemplating Rhode Island Coastal Geologic Hazards***

## **One Must Consider:**

- **Extratropical Cyclones (“Nor’easters”)**
- **Hurricanes (Tropical Cyclones)**
- **and ..... Sea Level Rise**

An aerial photograph of the Rhode Island coastline, showing the state's irregular shape and the surrounding water. The land is a mix of urban areas with grid patterns and more natural, vegetated areas. The water is a deep blue-grey color.

## ***When Contemplating Rhode Island Coastal Geologic Hazards***

### **Which Give Rise to these Processes:**

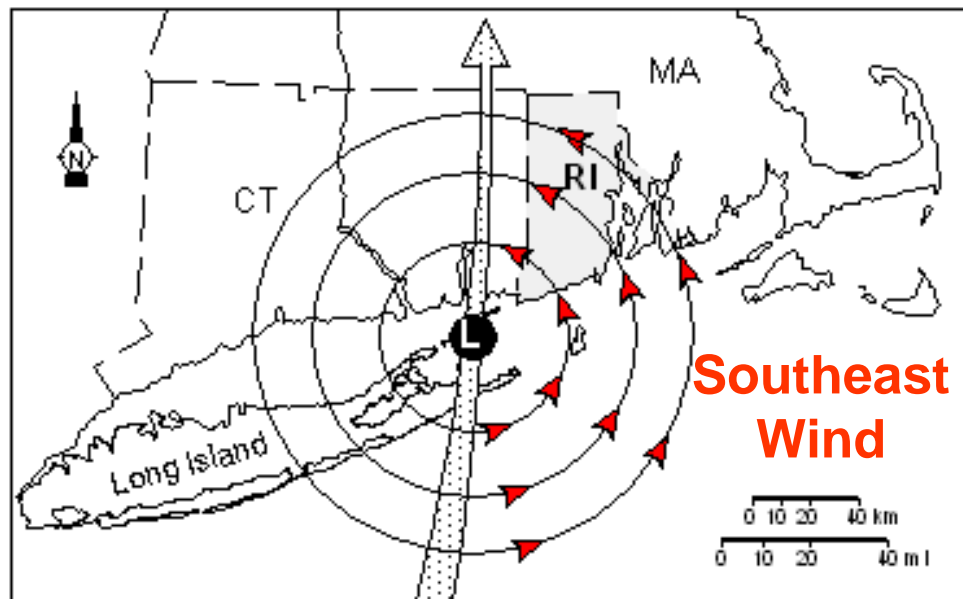
- **Frontal Erosion – from Breaking Waves and Swash**
- **Storm-Surge Overwash**
- **Elevated MHHW into the Future**

# ***When Contemplating Rhode Island Coastal Geologic Hazards***

## **The Scale of Processes are:**

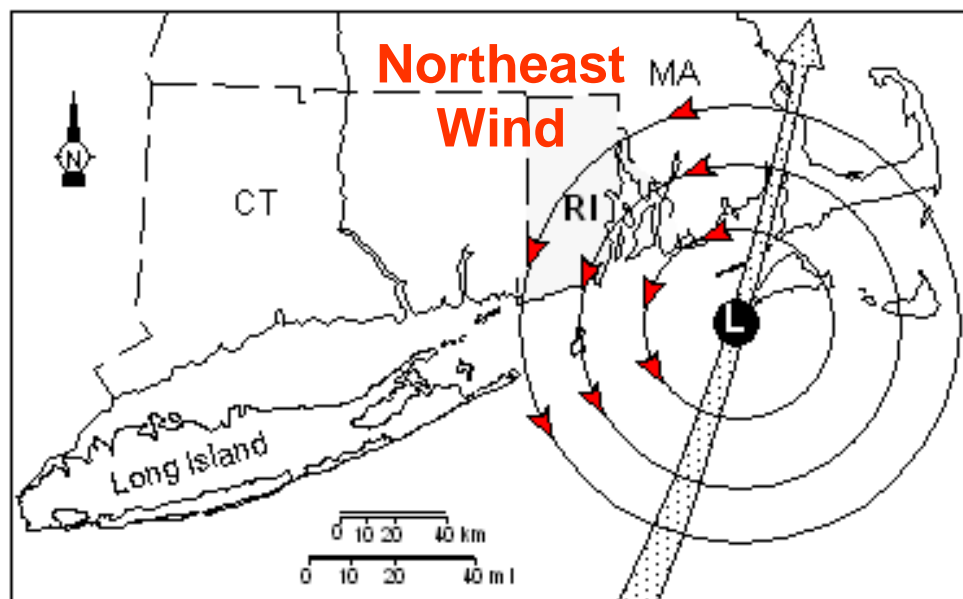
- **Breaking Waves –**  
1 to 3+ meters at shoreline, much higher at first break
- **Storm-Surge Overwash –**  
30 cm to 3+ m water depth across shore zone
- **Sea-Level Rise –**  
2.7-3.3 mm/year at present;  
could increase to 1-1.5 cm/yr

# HURRICANE and EXTRATROPICAL STORM PATHS and ASSOCIATED WIND PATTERNS



## PASSAGE TO THE WEST

- Maximum Onshore Wind
- Severe Storm-Surge Flooding



## PASSAGE TO THE EAST

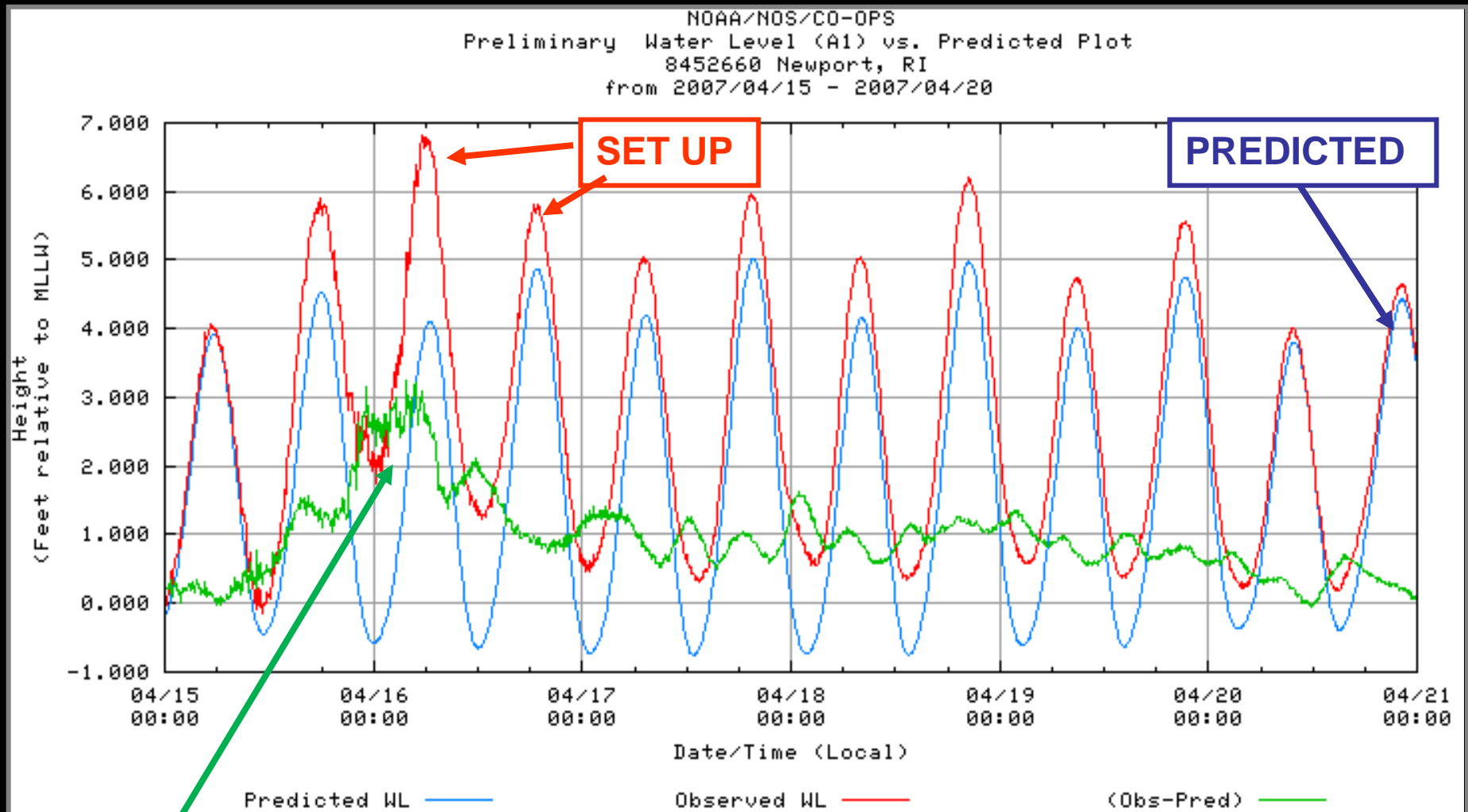
- Offshore Wind
- Minimum Storm-Surge Flooding

From Wright and Sullivan, 1982



# Patriots Day Extratropical Storm – April 2007

## Newport Tide Gauge



[http://tidesandcurrents.noaa.gov/  
data\\_menu.shtml?stn=8452660%20Newport,%20RI&type=Tide+Data](http://tidesandcurrents.noaa.gov/data_menu.shtml?stn=8452660%20Newport,%20RI&type=Tide+Data)

# Charlestown Beach – Blizzard 1978 – No Berm

CHARLESTOWN BEACH  
7 February 1978

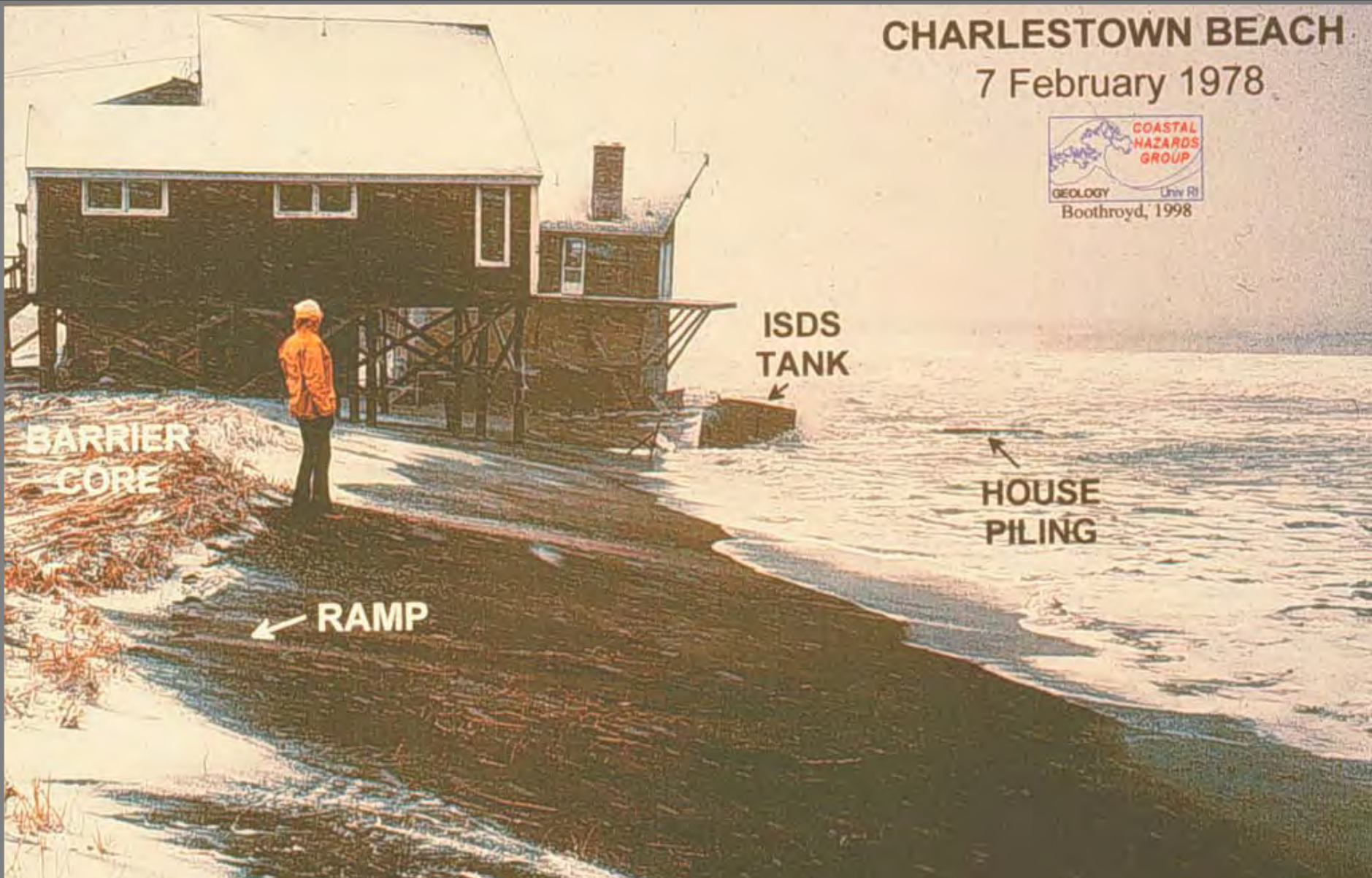


BARRIER  
CORE

ISDS  
TANK

HOUSE  
PILING

RAMP

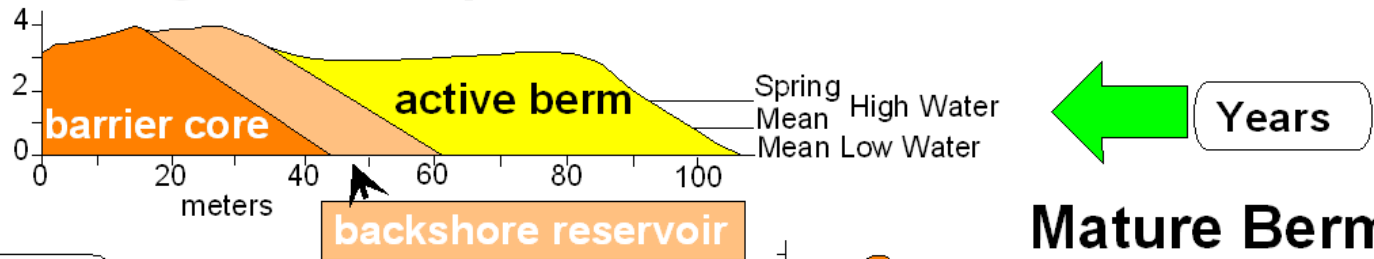


# Beach Cycles – RI Shore



Boothroyd and Galagan, 1999

## Long-Term Depositional

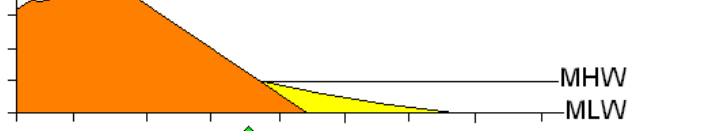


Hrs-10's Hrs

## Moderate Storm

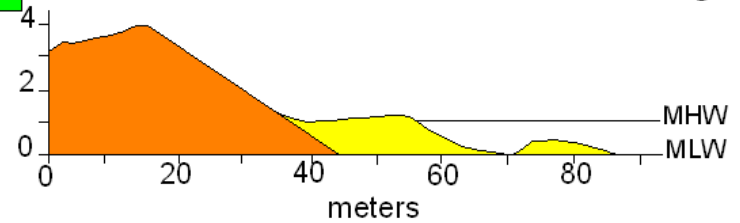


## Severe Storm

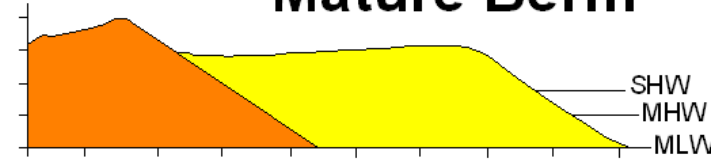


10's Hrs-Days

## Post-Storm Recovery

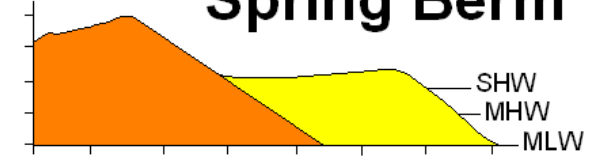


## Mature Berm



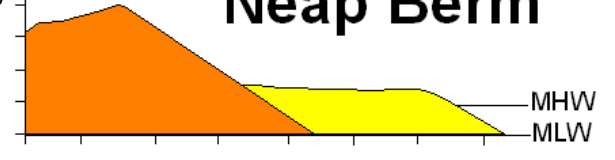
Months

## Spring Berm



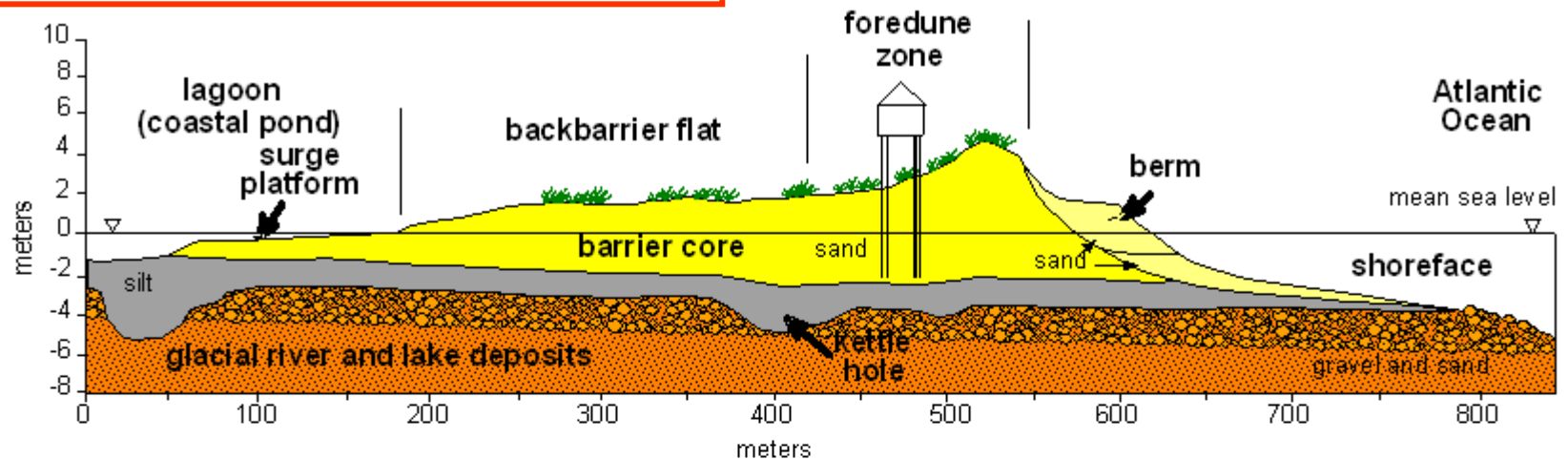
2 - 4 Weeks

## Neap Berm



4-7 Days

## Barrier Geologic Cross-Section



## Headland Geologic Cross-Section

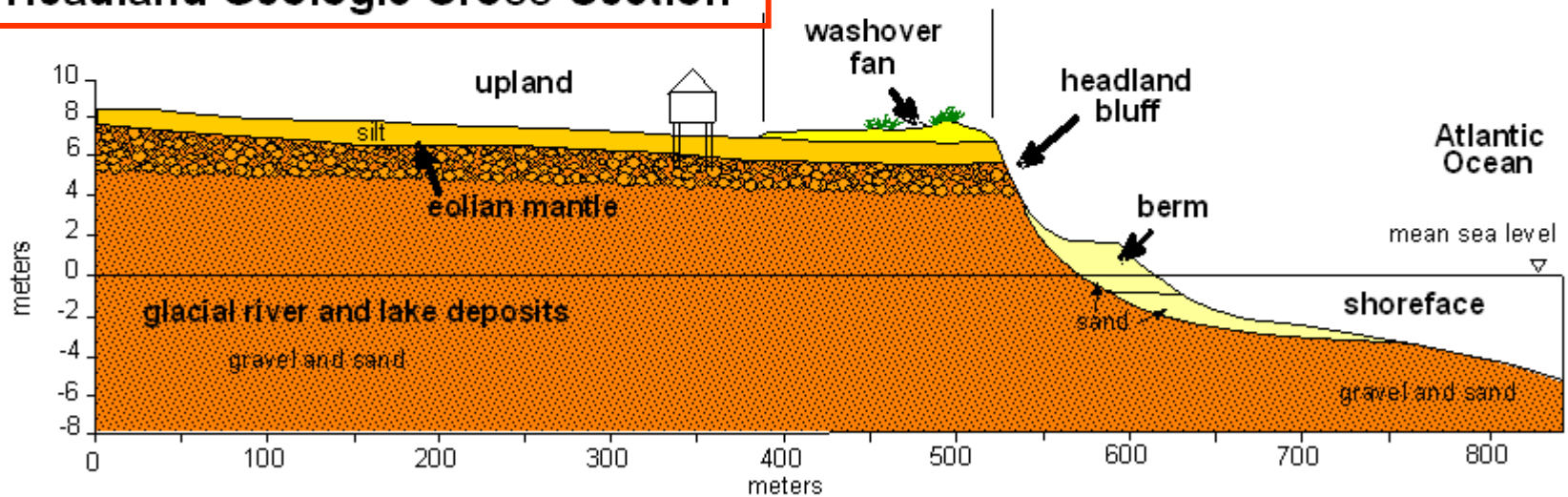
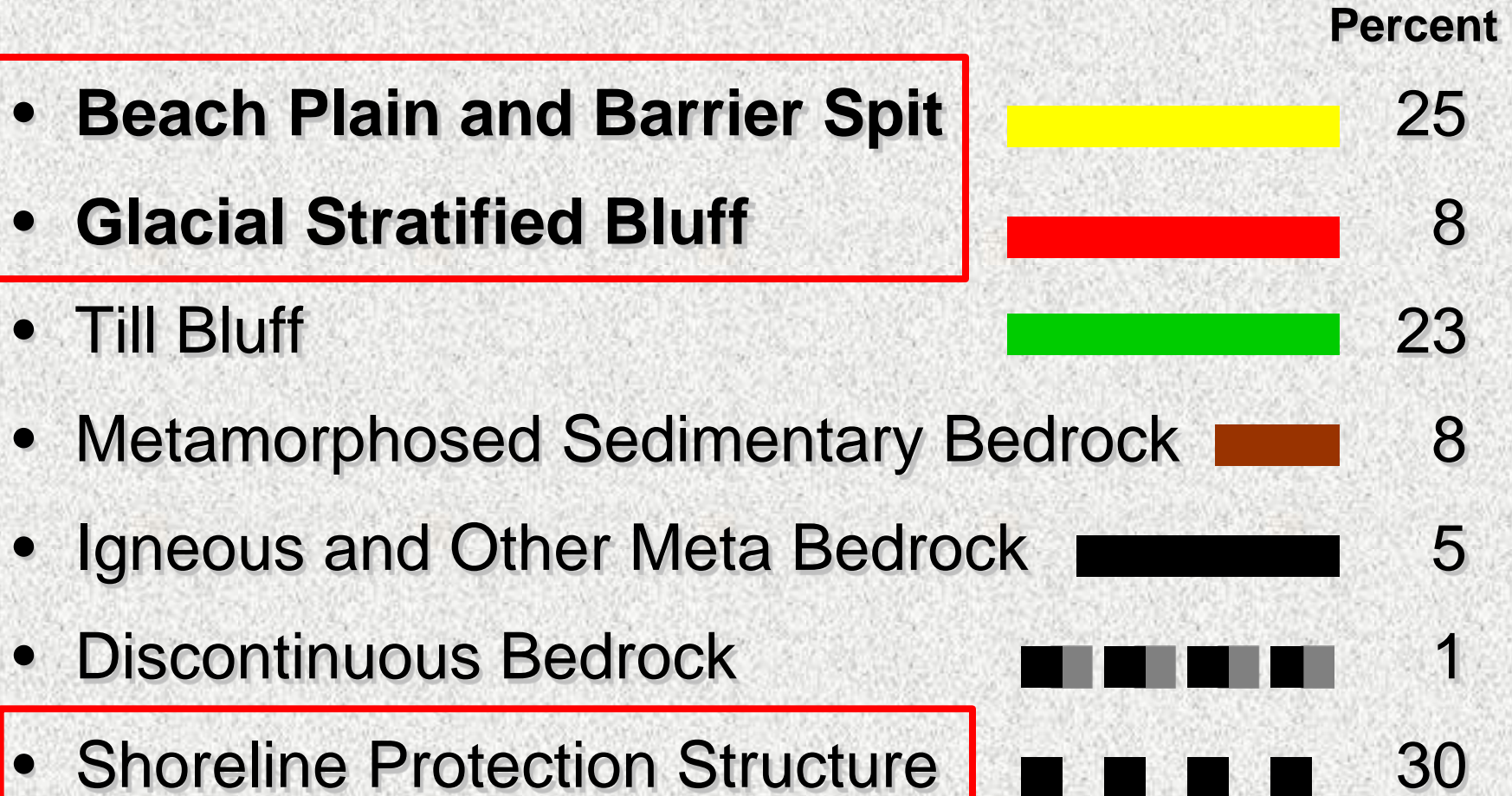


Figure 4-2

# GEOLOGIC SHORE ZONE TYPES



# Sediment Transport Pathways Charlestown – Green Hill Barrier and Headland

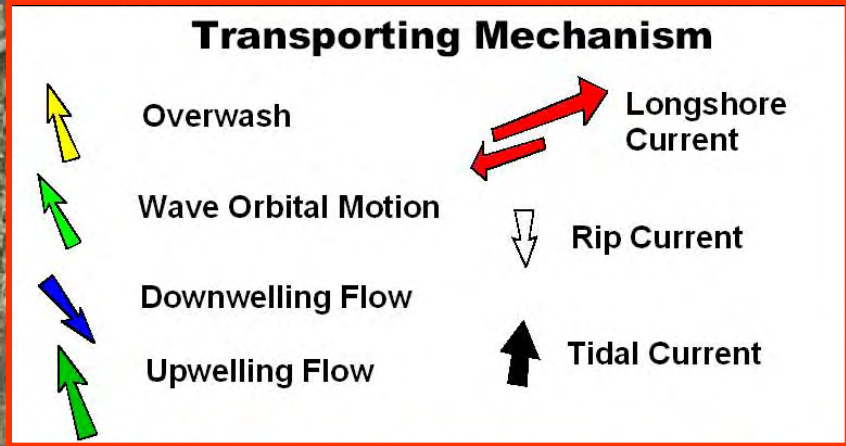
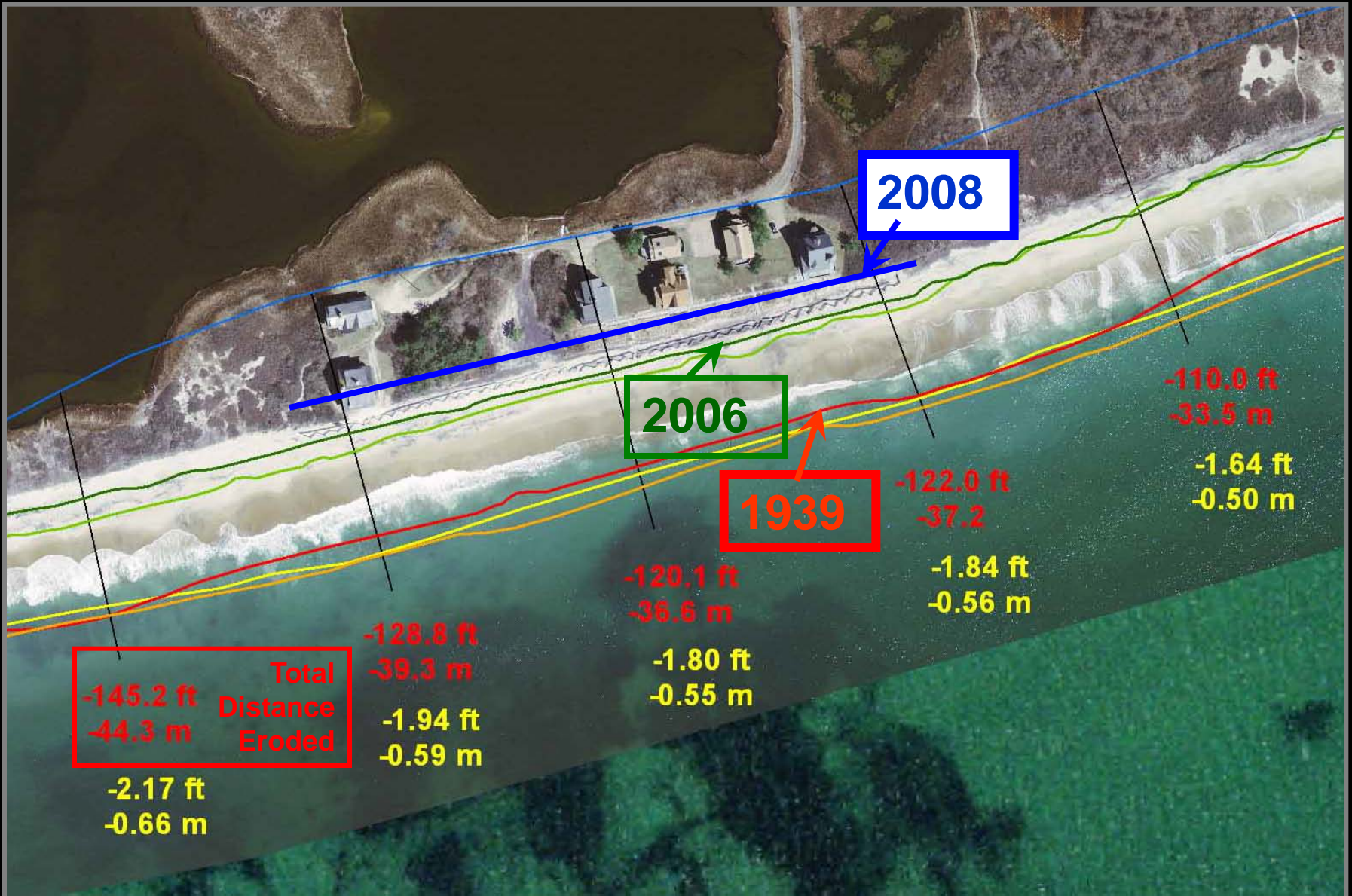


Image RIGIS

Image © 2008 TerraMetrics

©2008 Google™

# Frontal Erosion 1939-2008 - Browning Cottages, Moonstone Barrier



# Frontal Erosion - Browning Cottages





# Charlestown Beach – Overwash Processes Deposited 1 meter of sand in the road



11 Dec 1992

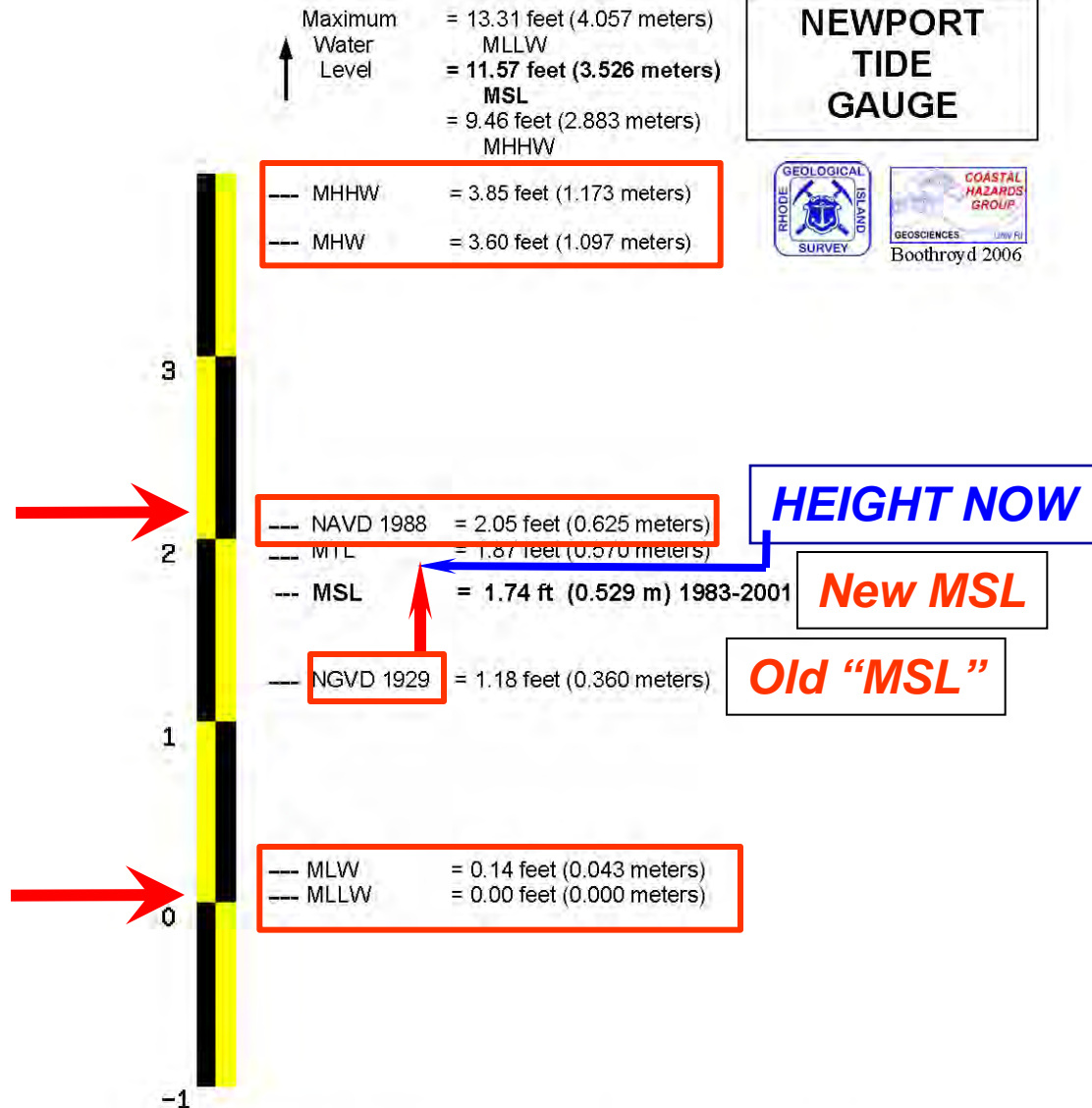
# Charlestown Barrier – Hurricane Bob 1991 Washover Fans



**Removal is a Bad Idea .....**  
**Barriers Naturally Retreat**  
**Landward and Upward**

**Aug 1991**

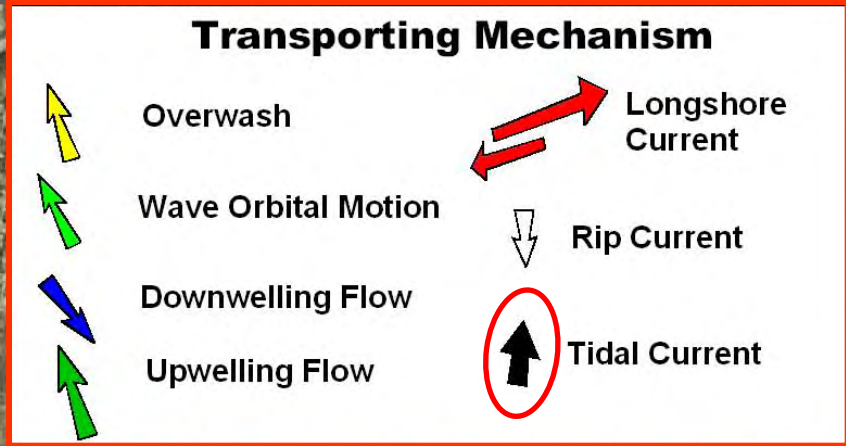
# Tidal Datums Newport



The NAVD 1988 and NGVD 1929 elevations related to MLLW were computed from Bench Mark, 845 2660 TIDAL 6, at the station.

Displayed tidal datums are MEAN HIGHER HIGH WATER (MHHW), MEAN HIGH WATER (MHW), MEAN TIDE LEVEL (MTL), MEAN LOW WATER (MLW), AND MEAN LOWER LOW WATER (MLLW) referenced on 1983-2001 Epoch.

# Sediment Transport Pathways Charlestown – Green Hill Barrier and Headland



# Tidal-Current Deposition into Coastal Lagoons – an Example

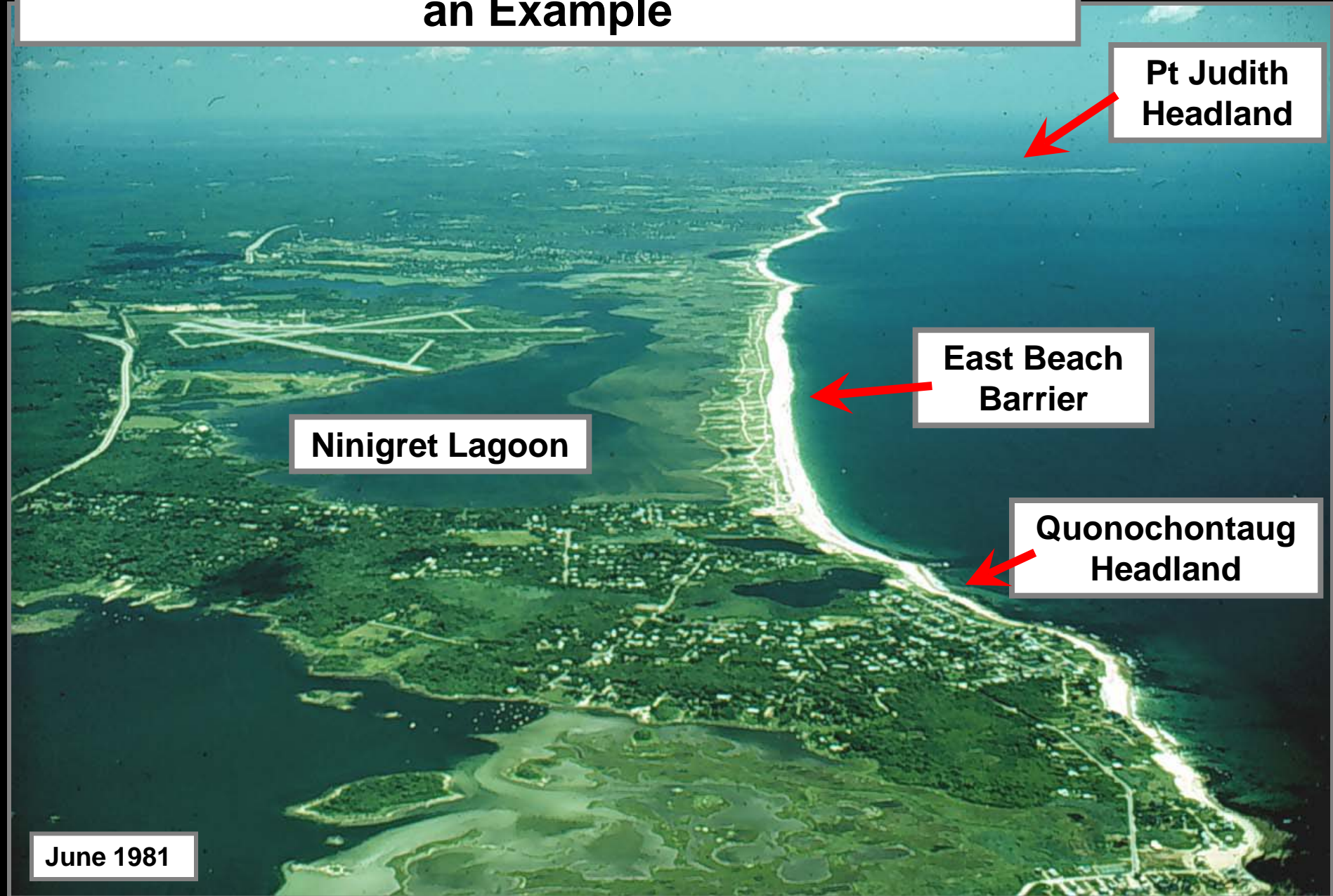
Pt Judith  
Headland

East Beach  
Barrier

Ninigret Lagoon

Quonochontaug  
Headland

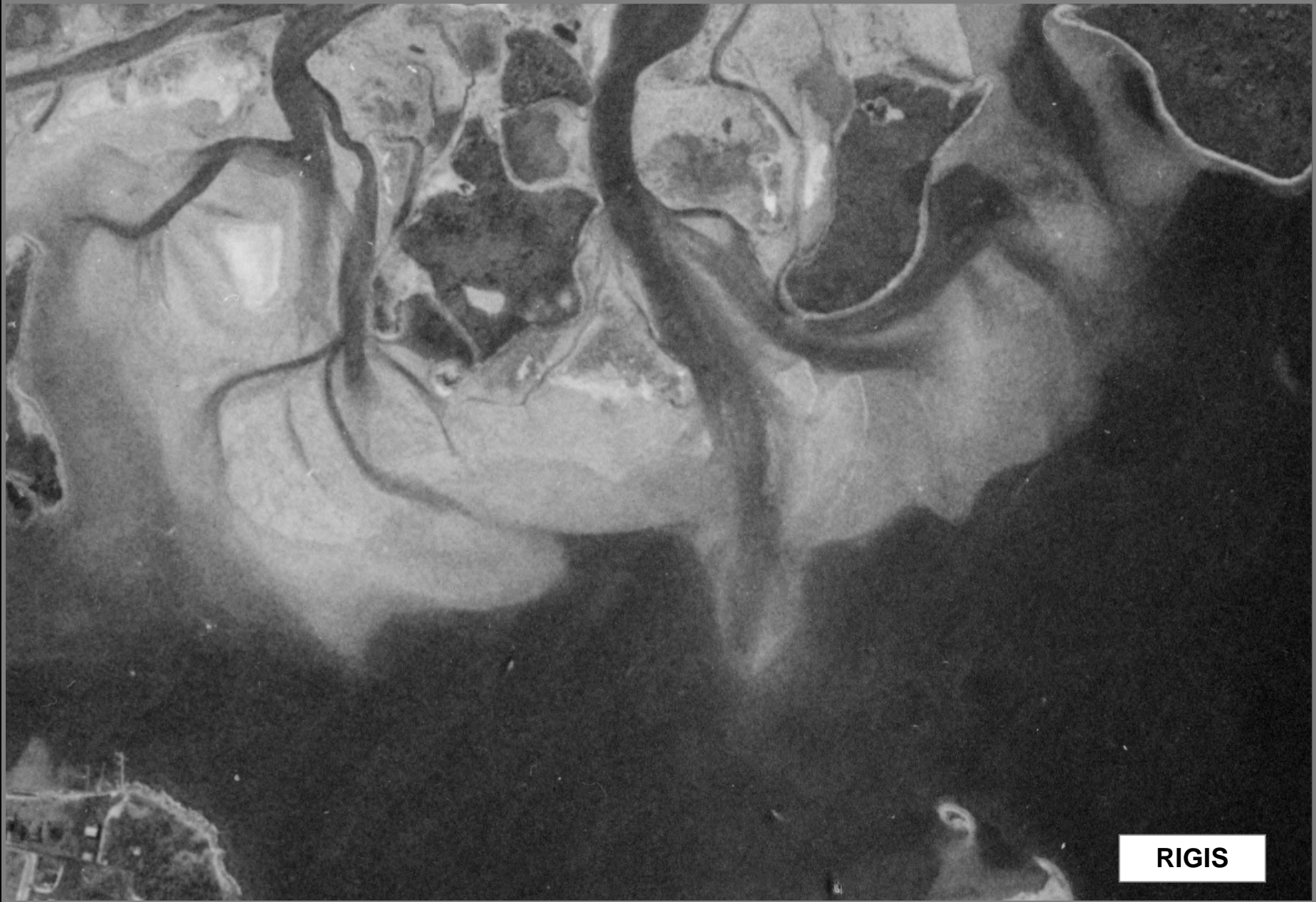
June 1981



# Ninigret Lagoon - 2004



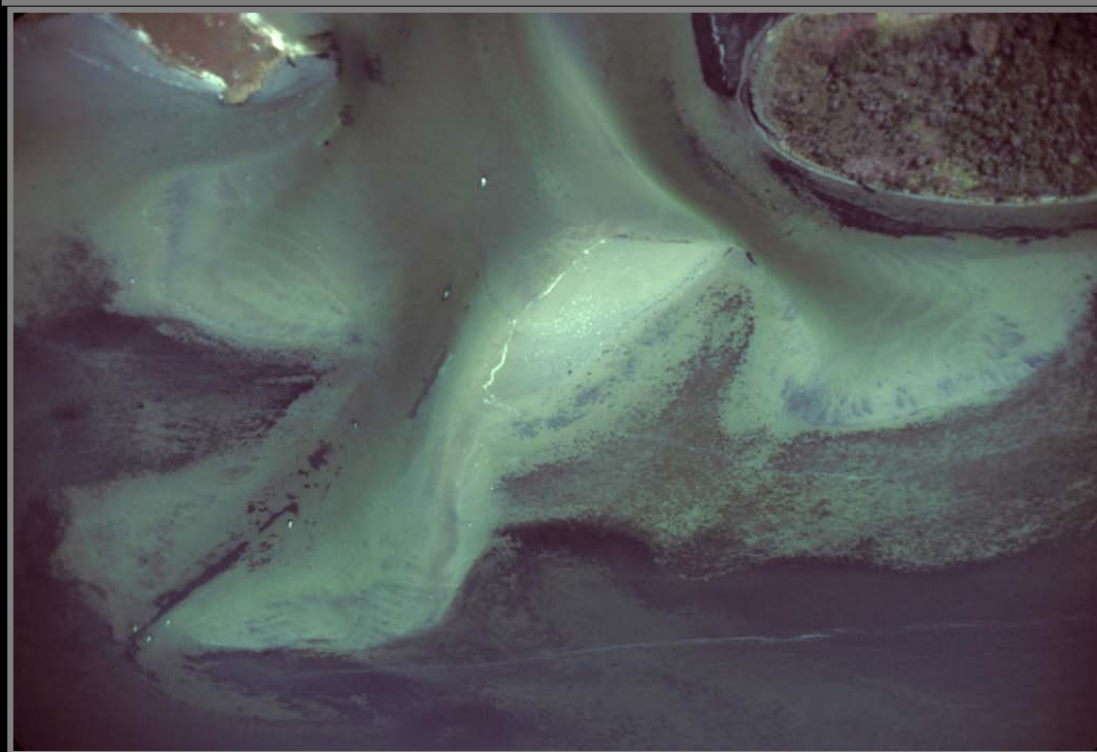
# Ninigret Flood-Tidal Delta - 1976



RIGIS



**17 Oct 1978**



**24 Oct 1982**



# Ninigret Flood-Tidal Delta 2004

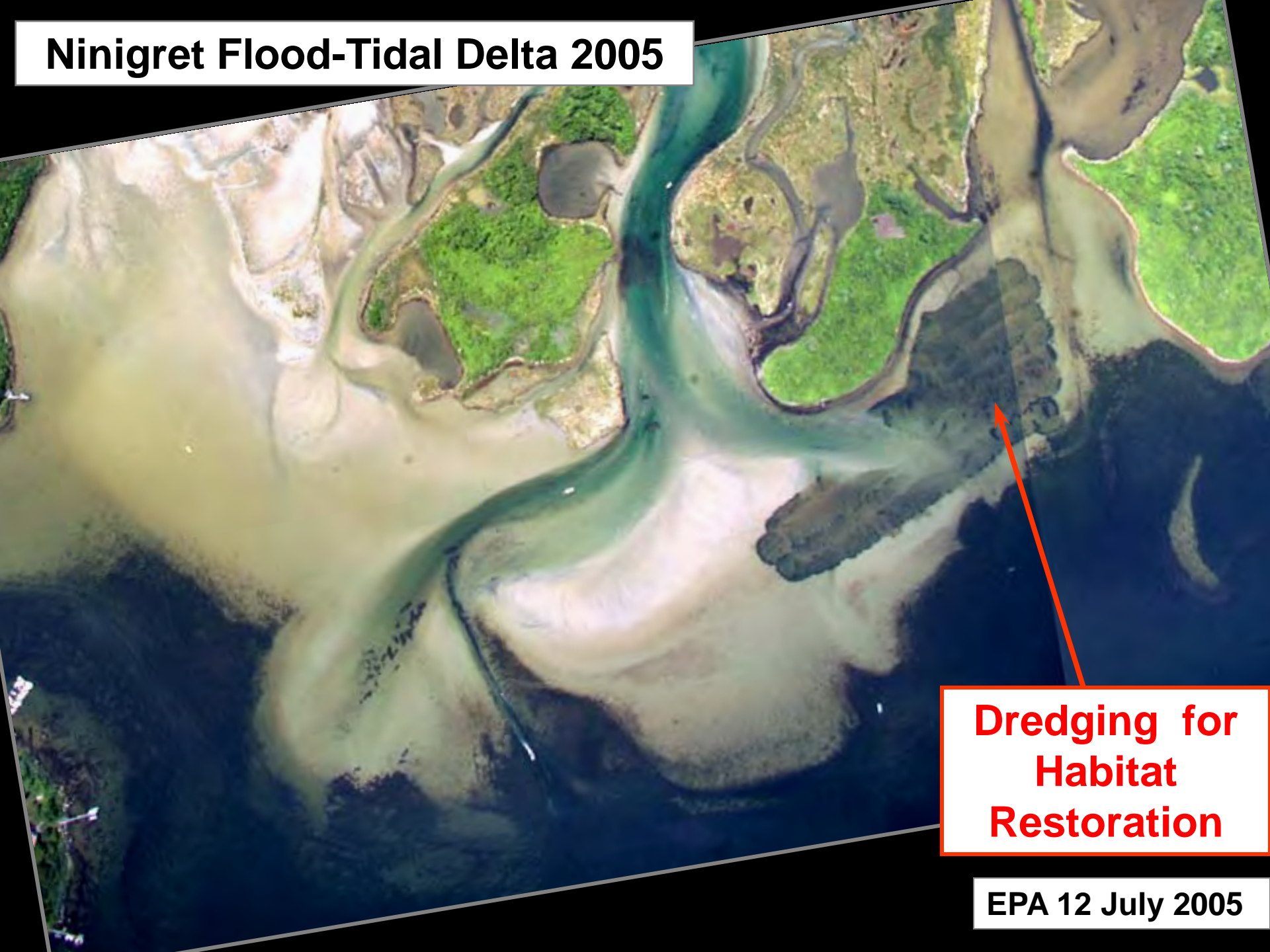


**Facies – Sand**

**Habitat –  
FTD Tidal Flat**

**RIGIS 2004**

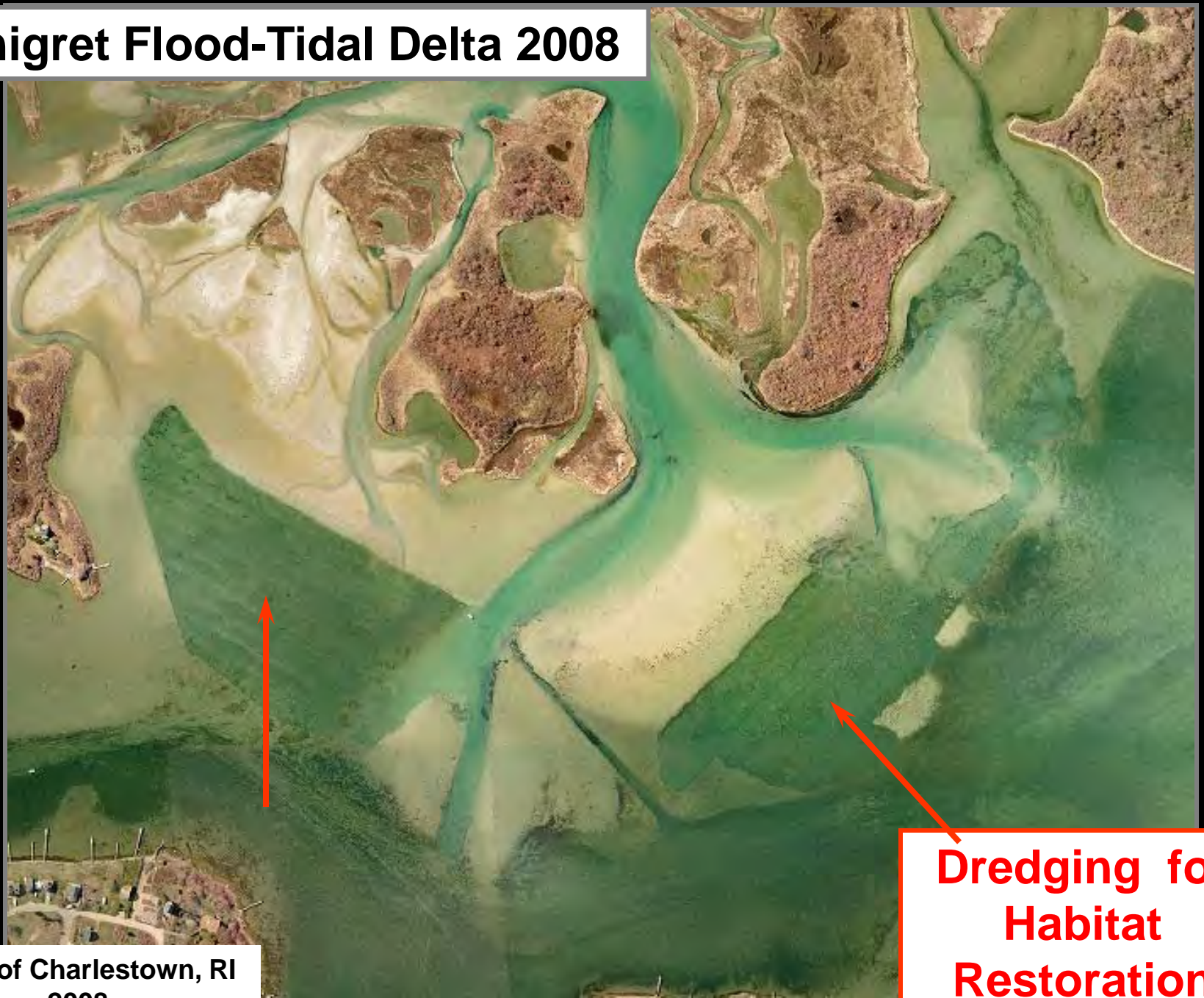
# Ninigret Flood-Tidal Delta 2005



**Dredging for  
Habitat  
Restoration**

**EPA 12 July 2005**

# Ninigret Flood-Tidal Delta 2008



Town of Charlestown, RI  
2008

**Dredging for  
Habitat  
Restoration**

# Ninigret Flood-Tidal Delta - 2010



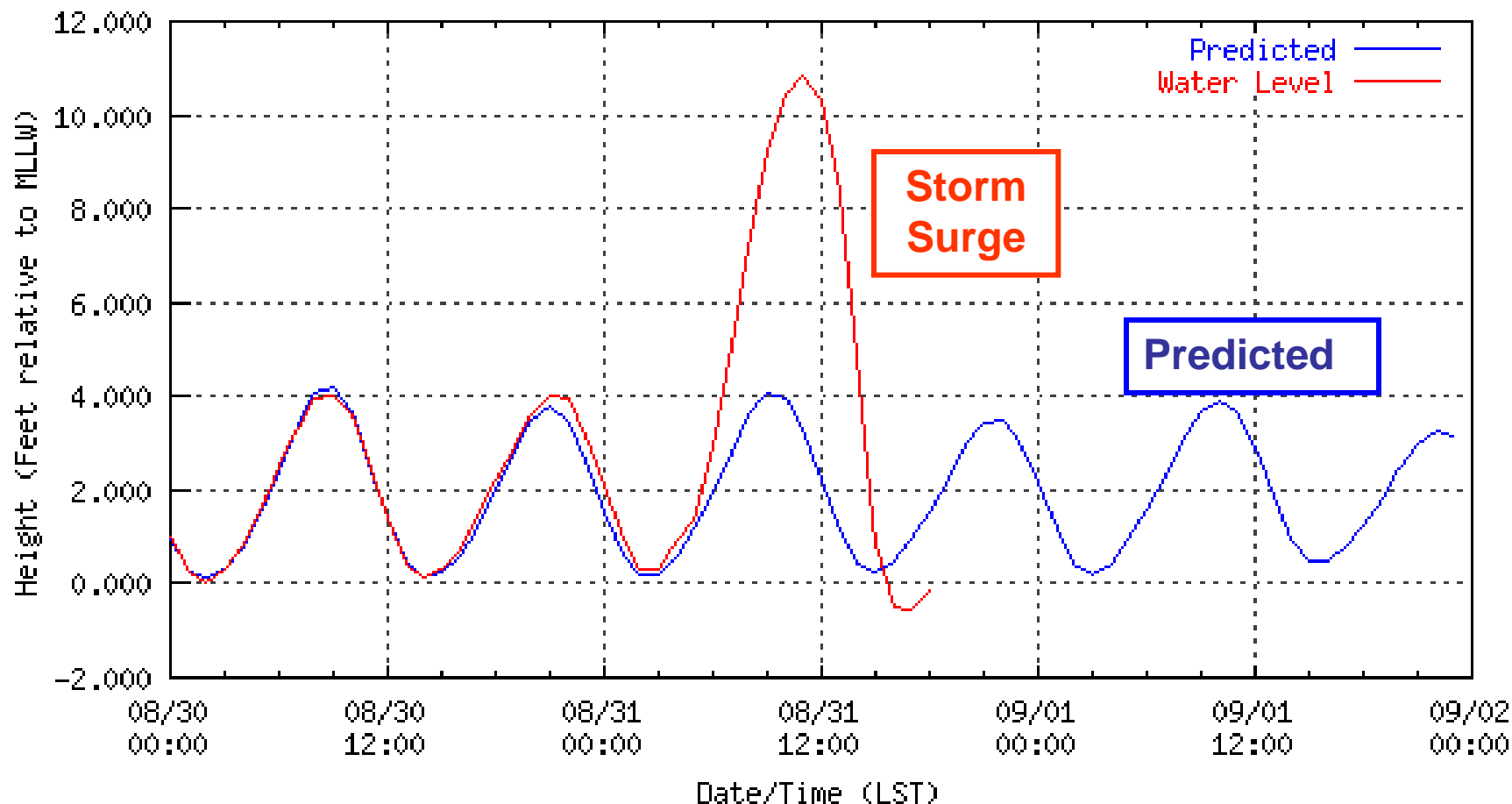
Google Earth

An aerial photograph showing a large, irregularly shaped body of water, possibly a bay or estuary, surrounded by land. The land is densely packed with buildings and infrastructure, indicating a developed urban or suburban area. The water is a dark blue-grey color, and the surrounding land is a mix of brown and green, suggesting a mix of built-up areas and vegetation. The overall scene depicts a coastal region that has been significantly altered by human development.

***Really Big Storms***

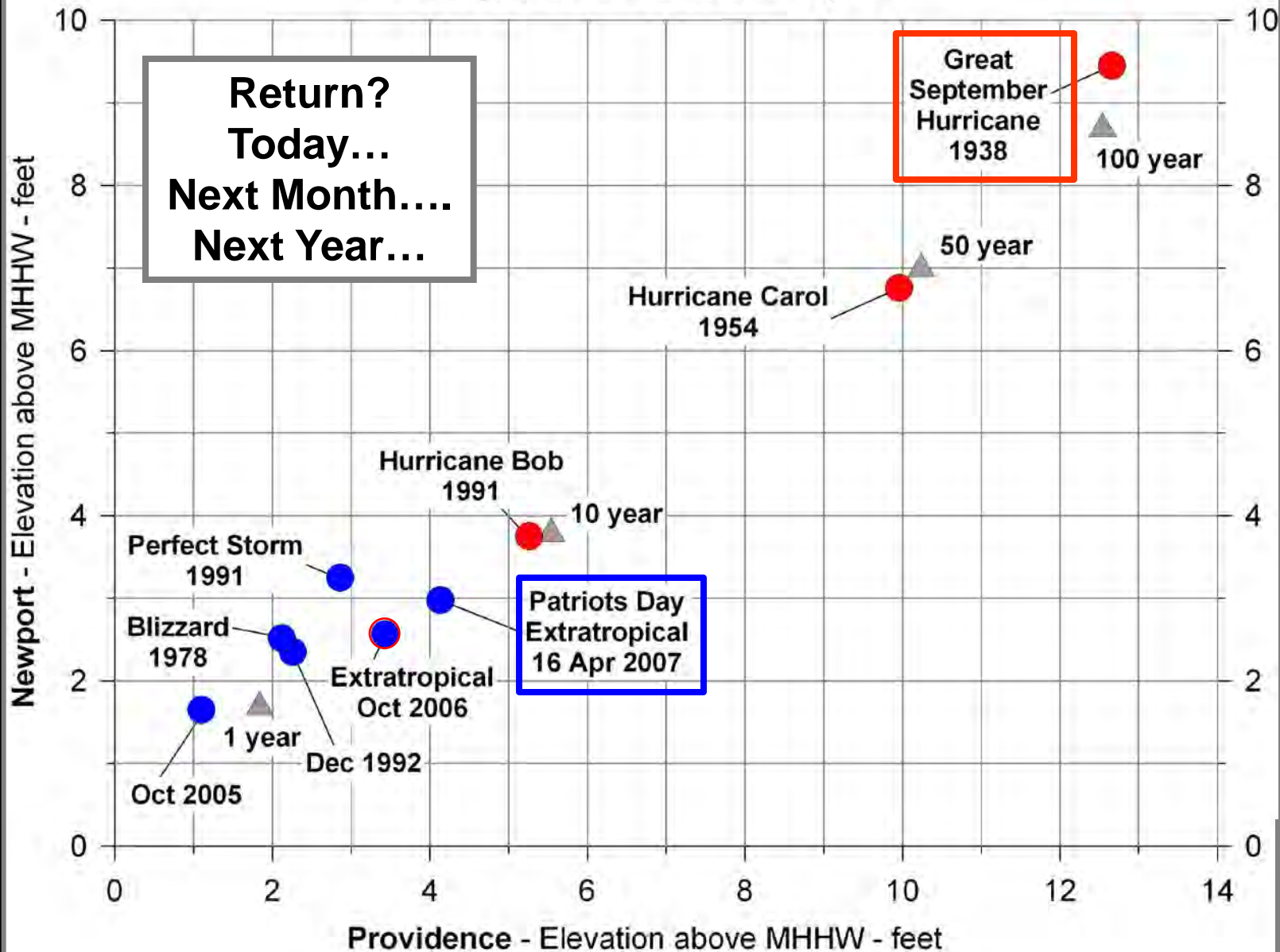
# Hurricane Carol - 1954

NOAA/NOS/CO-OPS  
Verified Hourly Height Water Level Plot  
8452660 NEWPORT, NARRAGANSETT BAY , RI  
from 08/30/1954 - 09/01/1954



[http://tidesandcurrents.noaa.gov/  
data\\_menu.shtml?stn=8452660%20Newport,%20RI&type=Tide+Data](http://tidesandcurrents.noaa.gov/data_menu.shtml?stn=8452660%20Newport,%20RI&type=Tide+Data)

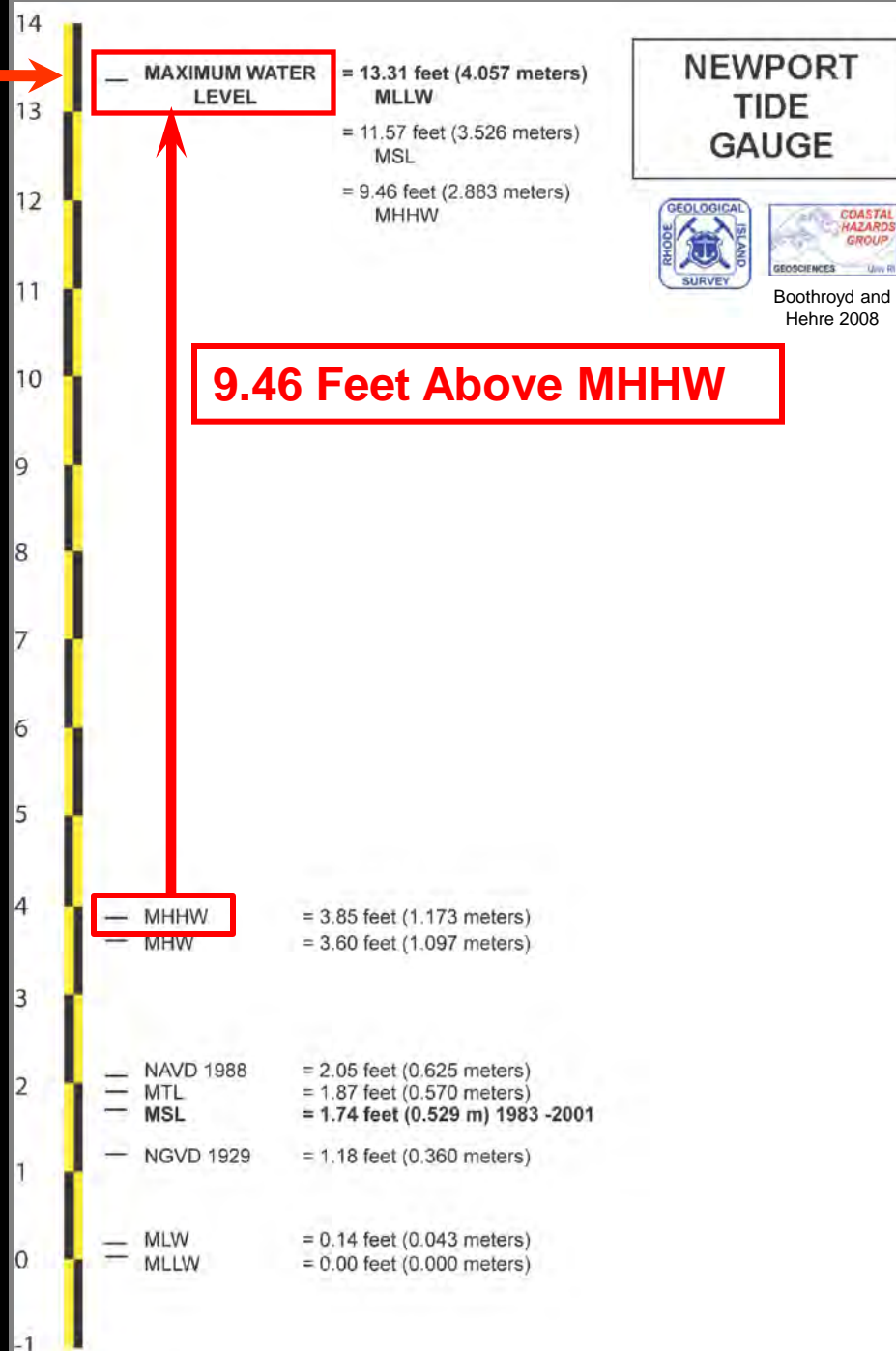
# STORM-SURGE ELEVATION Newport - Providence, RI



Adapted from  
NOAA;  
USACE 1988;  
Hehre 2007

**How High  
will the  
Water Be?**

**Tidal  
Heights  
Newport**





# Charlestown Barrier

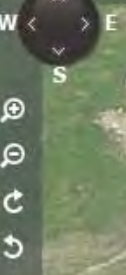


100 year Storm Surge plus Waves

04/17/2007 15:15



2D 3D Road Aerial



25 feet 10 m

© 2010 Microsoft Corporation  
Pictometry Bird's Eye © 2010 Pictometry International Corp  
Pictometry Bird's Eye © 2010 MDA Geospatial Services Inc.

bing

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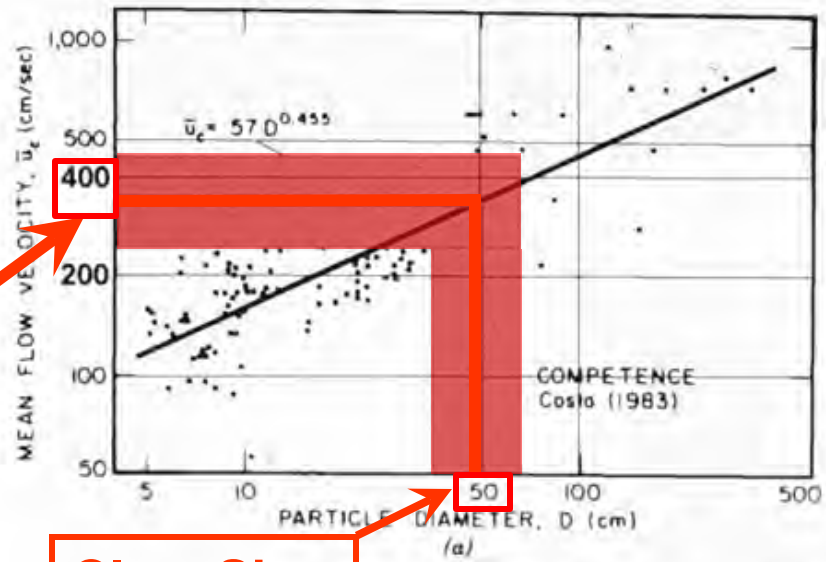
# The Towers – Narragansett Pier Headland - 1938



Providence Journal, 1938

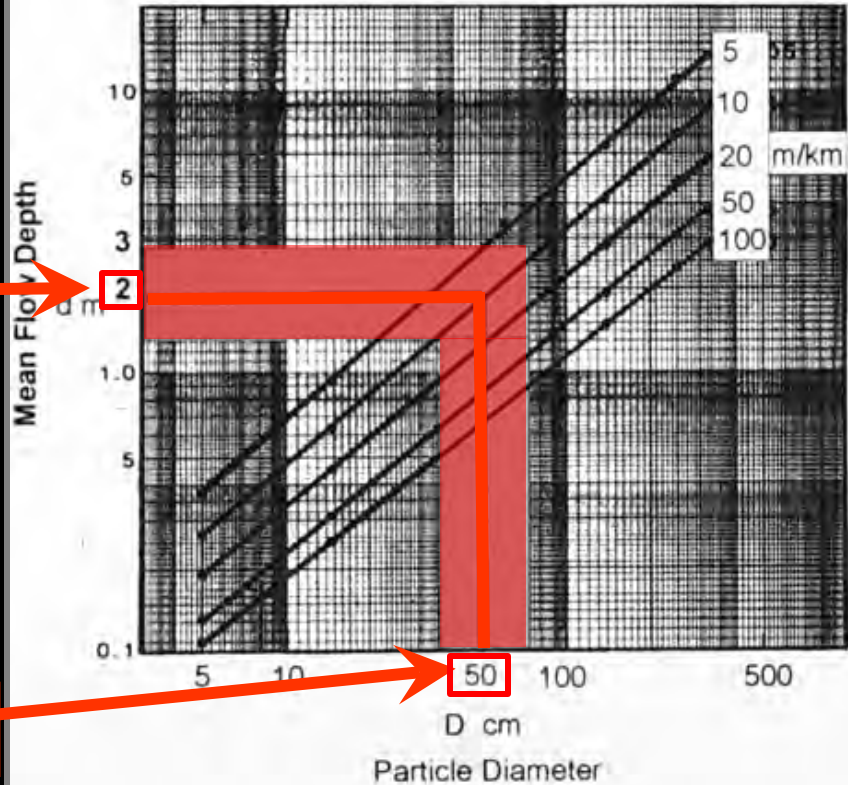
# CLAST MOVEMENT DIAGRAMS

Velocity



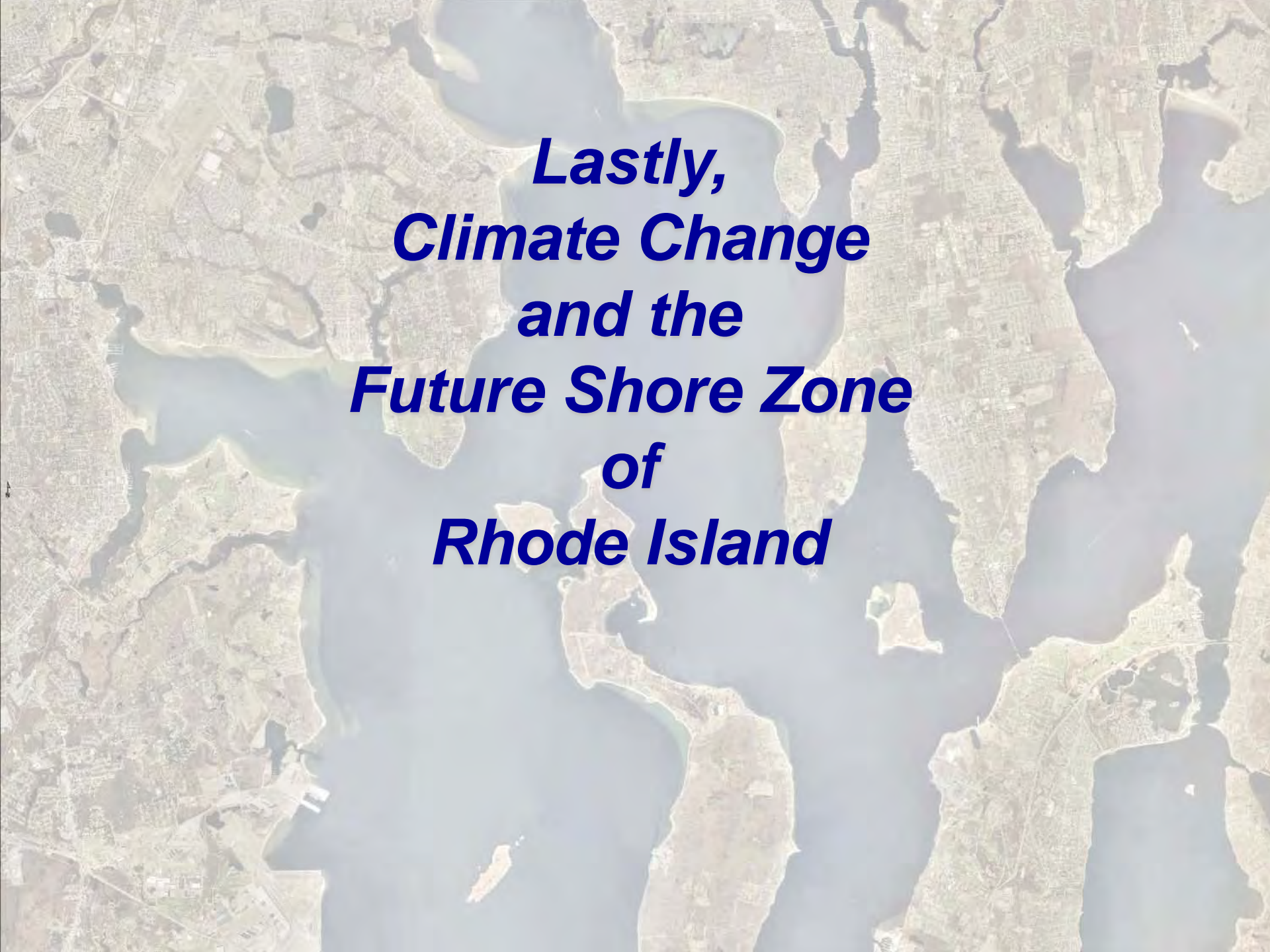
Clast Size

Depth



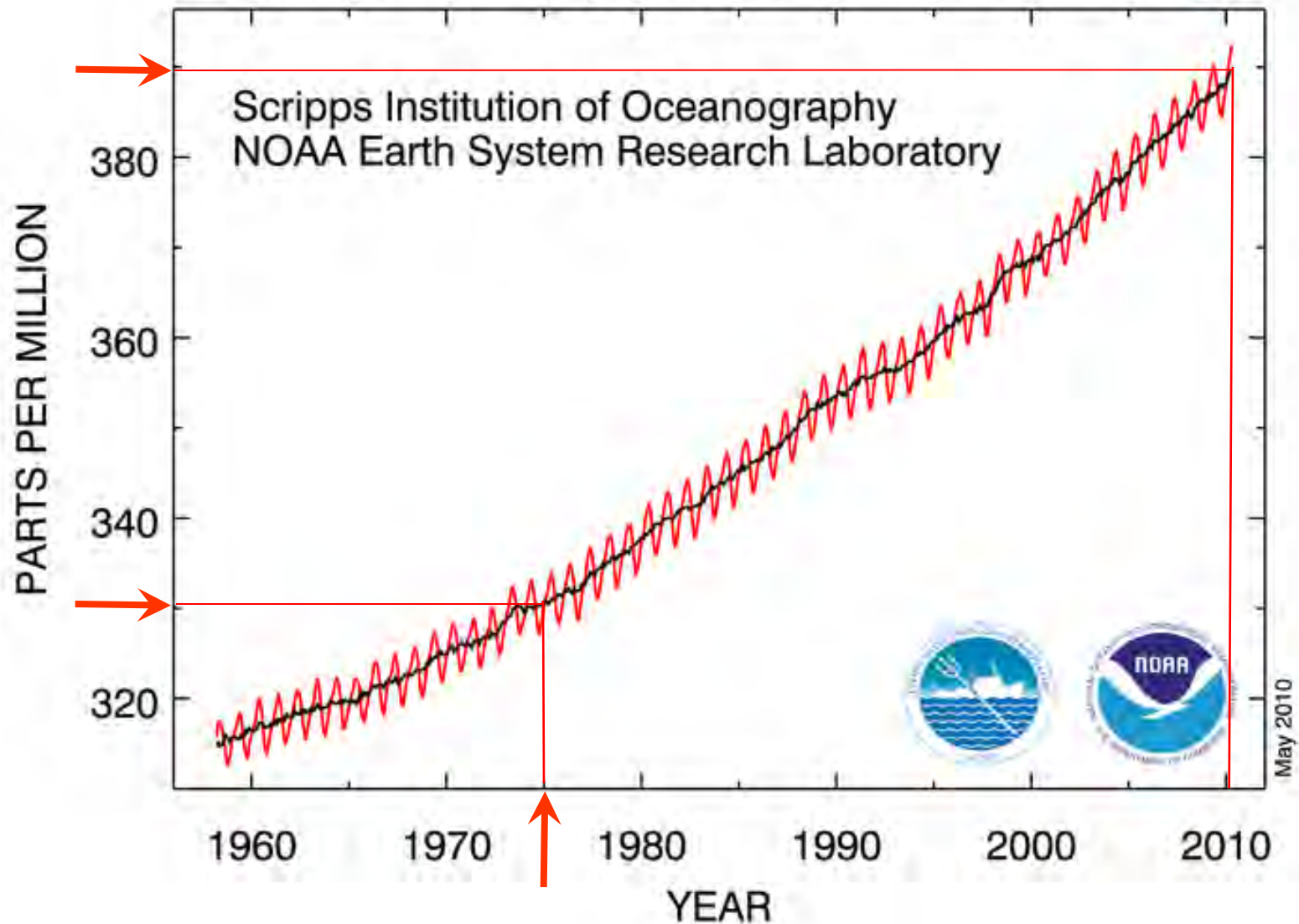
Clast Size

Costa, 1983

An aerial photograph of Rhode Island, showing its coastline and major water bodies like Narragansett Bay and the Pawcatuck River. A semi-transparent blue overlay covers the central and right portions of the map, serving as a background for the text.

***Lastly,  
Climate Change  
and the  
Future Shore Zone  
of  
Rhode Island***

# Atmospheric CO<sub>2</sub> at Mauna Loa Observatory



[http://www.esrl.noaa.gov/gmd/ccgg/trends/co2\\_data\\_mlo.html](http://www.esrl.noaa.gov/gmd/ccgg/trends/co2_data_mlo.html)

# Carbon Dioxide - CO<sub>2</sub> – Levels

## A Cause for Concern

Now 388+ ppm

Carbon Dioxide Levels Today are Higher than over the Past 650,000 Years

Atmospheric carbon dioxide record data sources: Keeling and Whorf (2004), Petit et al. (1999), IPCC (2001), Ahn et al. (2004).

Industrial CO<sub>2</sub> Levels

Pre-industrial CO<sub>2</sub> Levels

First Moon Landing

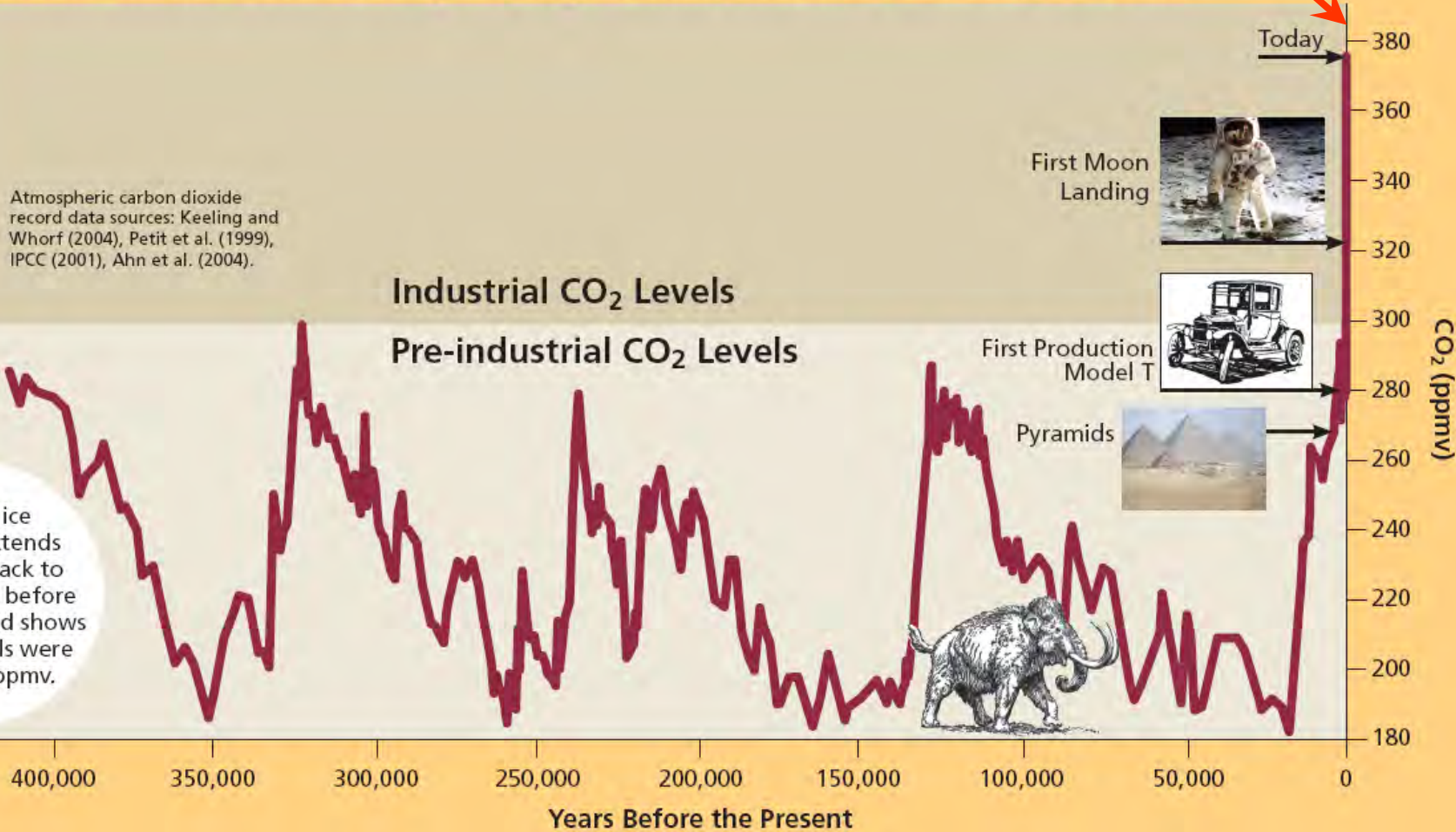


First Production Model T

Pyramids

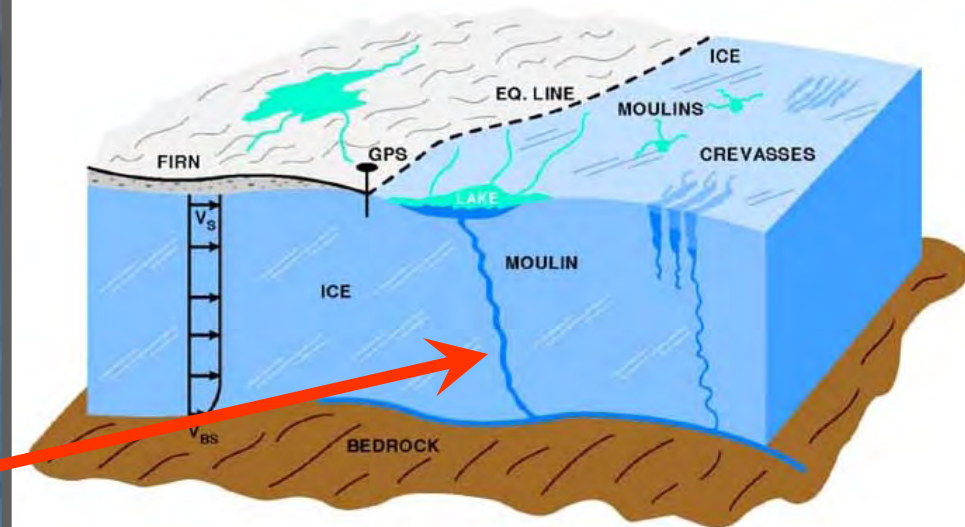


New Antarctic ice core data extends the record back to 650,000 years before the present and shows that CO<sub>2</sub> levels were below 300 ppmv.



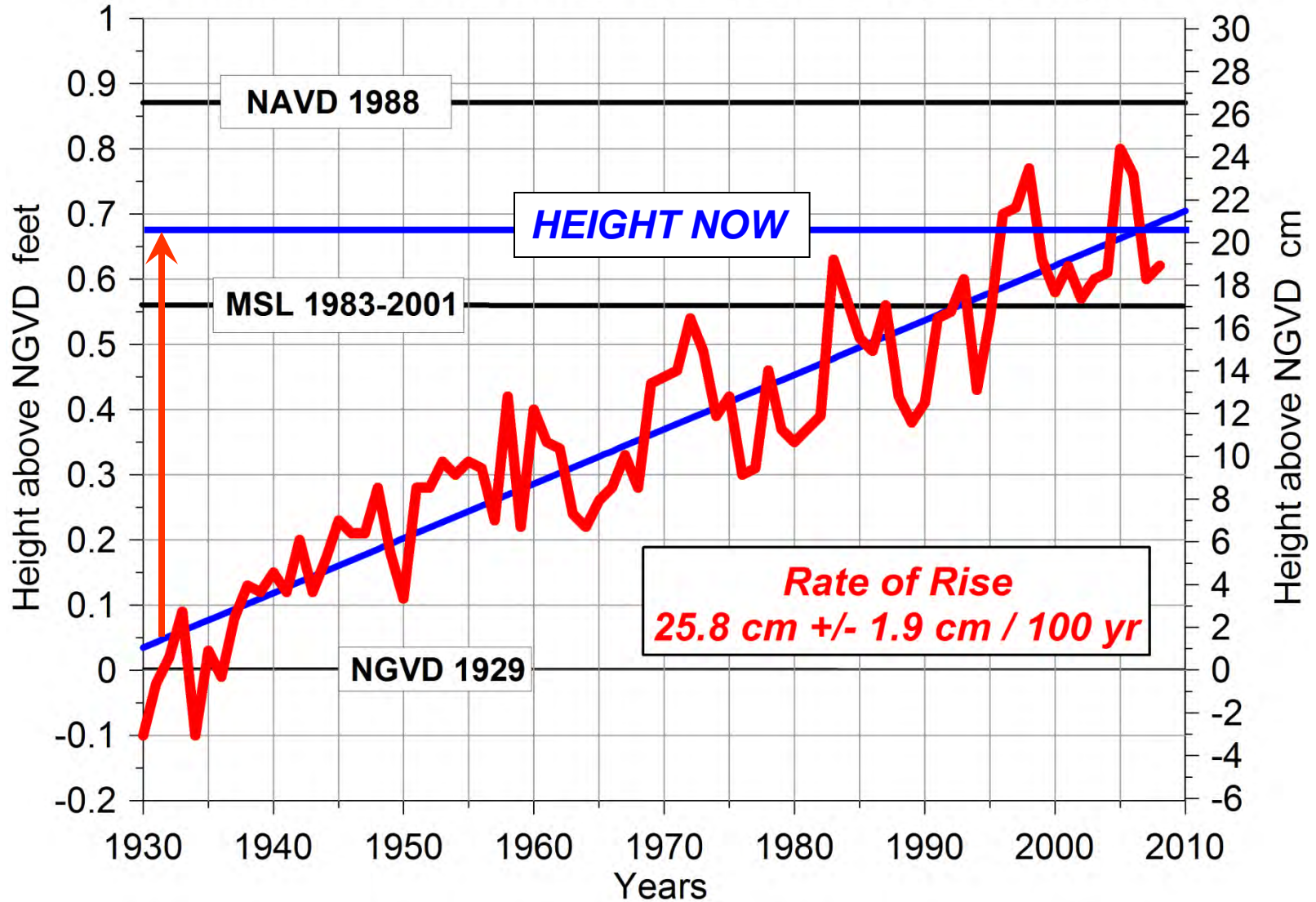
# Greenland Outlet Glaciers Changing from Polythermal to Warm Based

## A Key to Future Sea-Level Rise

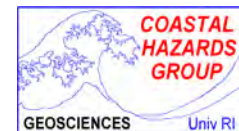
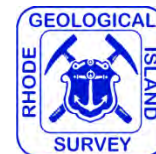




# HISTORIC SEA-LEVEL RISE - Newport, RI

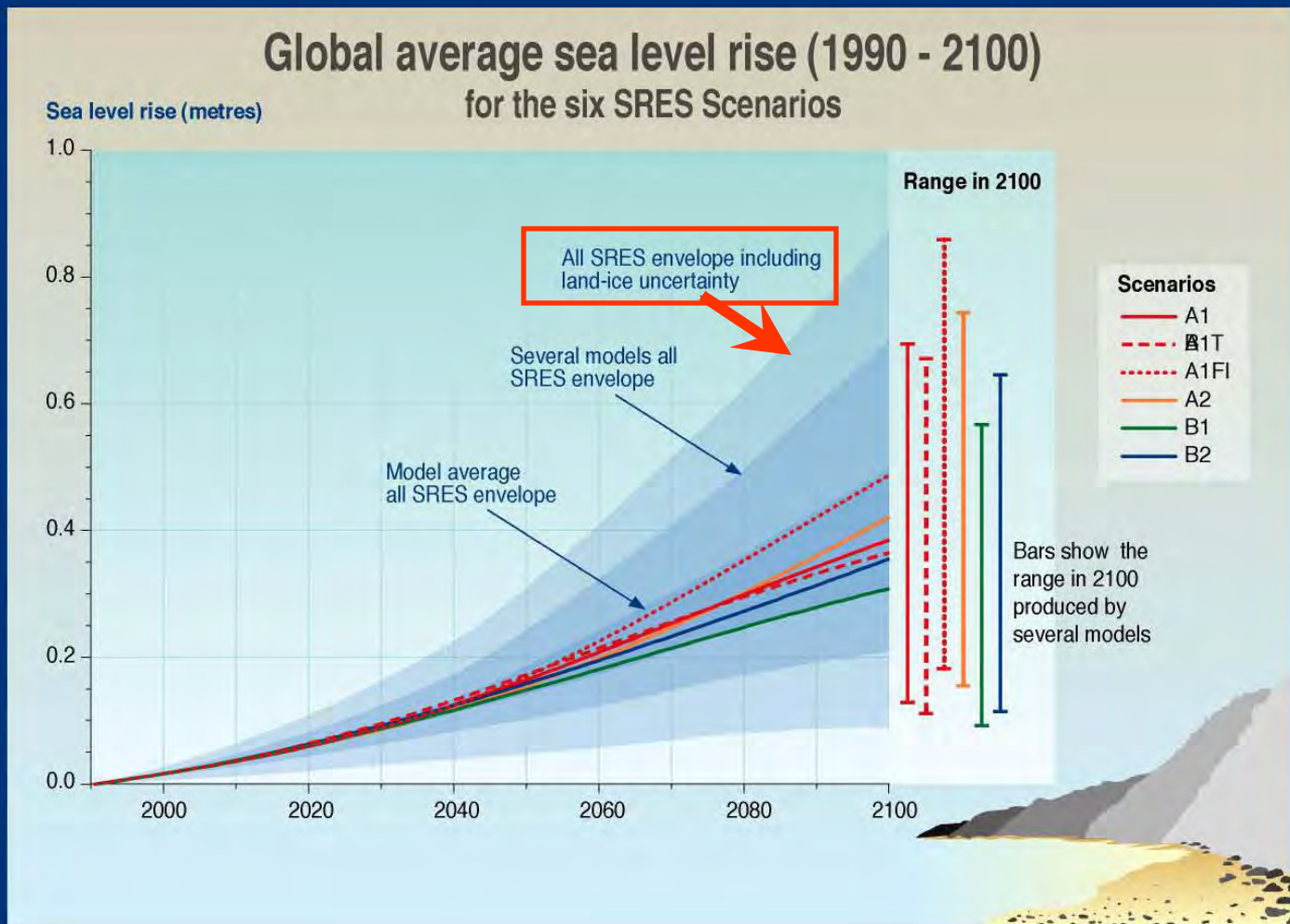


Adapted from: [http://tidesandcurrents.noaa.gov/sltrends/sltrends\\_station.shtml?stnid=8452660%20Newport,%20RI](http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=8452660%20Newport,%20RI)



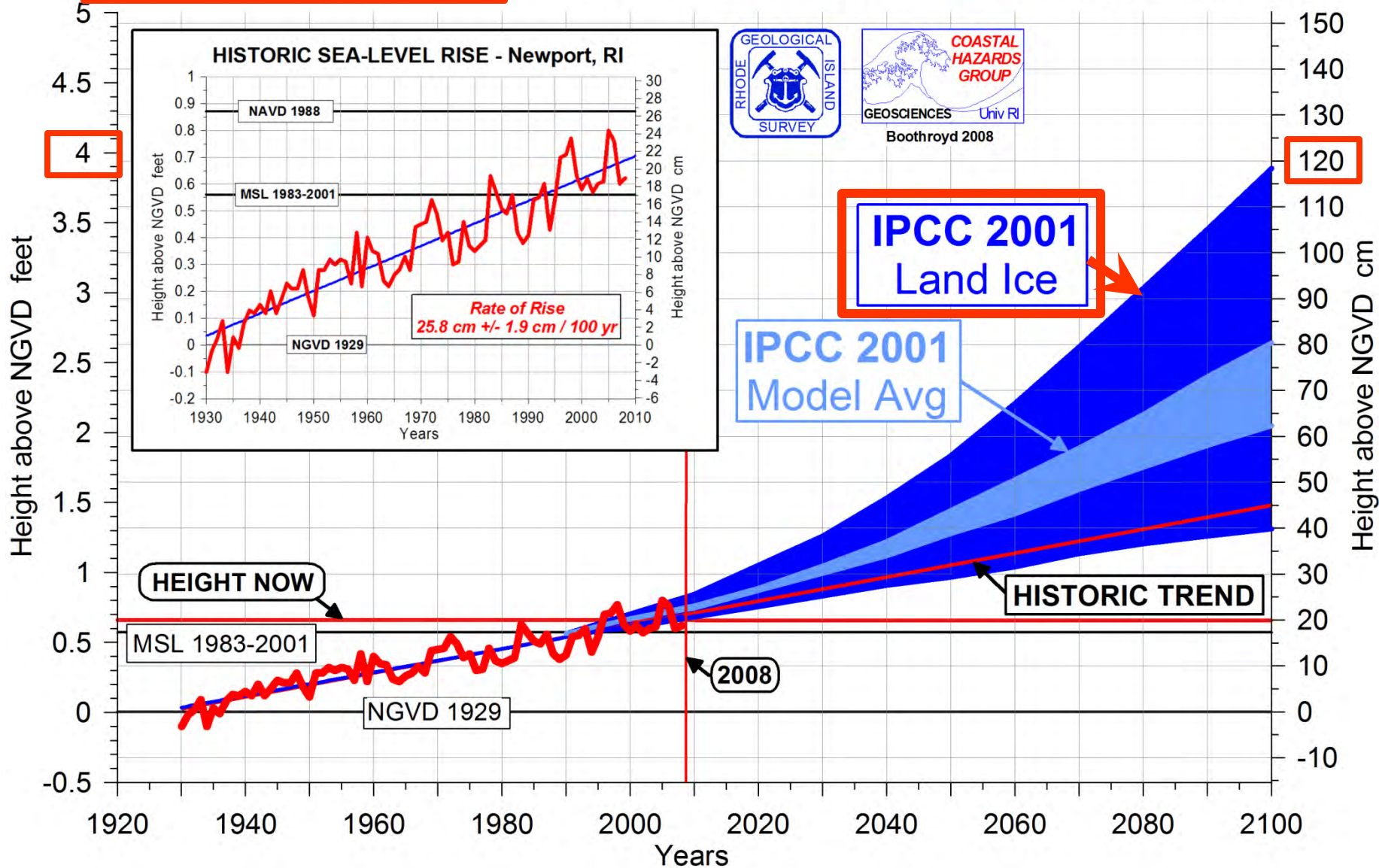
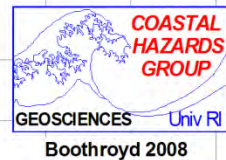
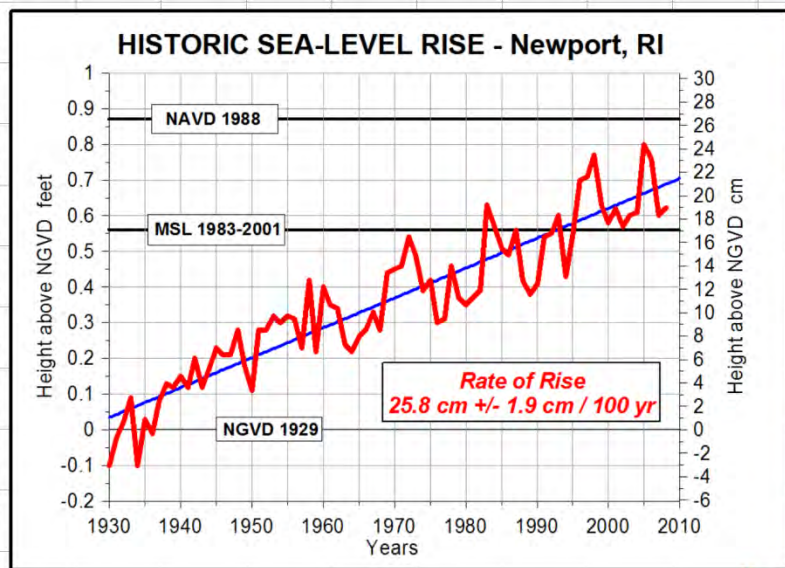
Boothroyd 2008

# IPCC Scenarios 2001



WG1 TS FIGURE 24

# ACCELERATED SEA-LEVEL RISE - Newport, RI



# Ninigret Lagoon - 2004

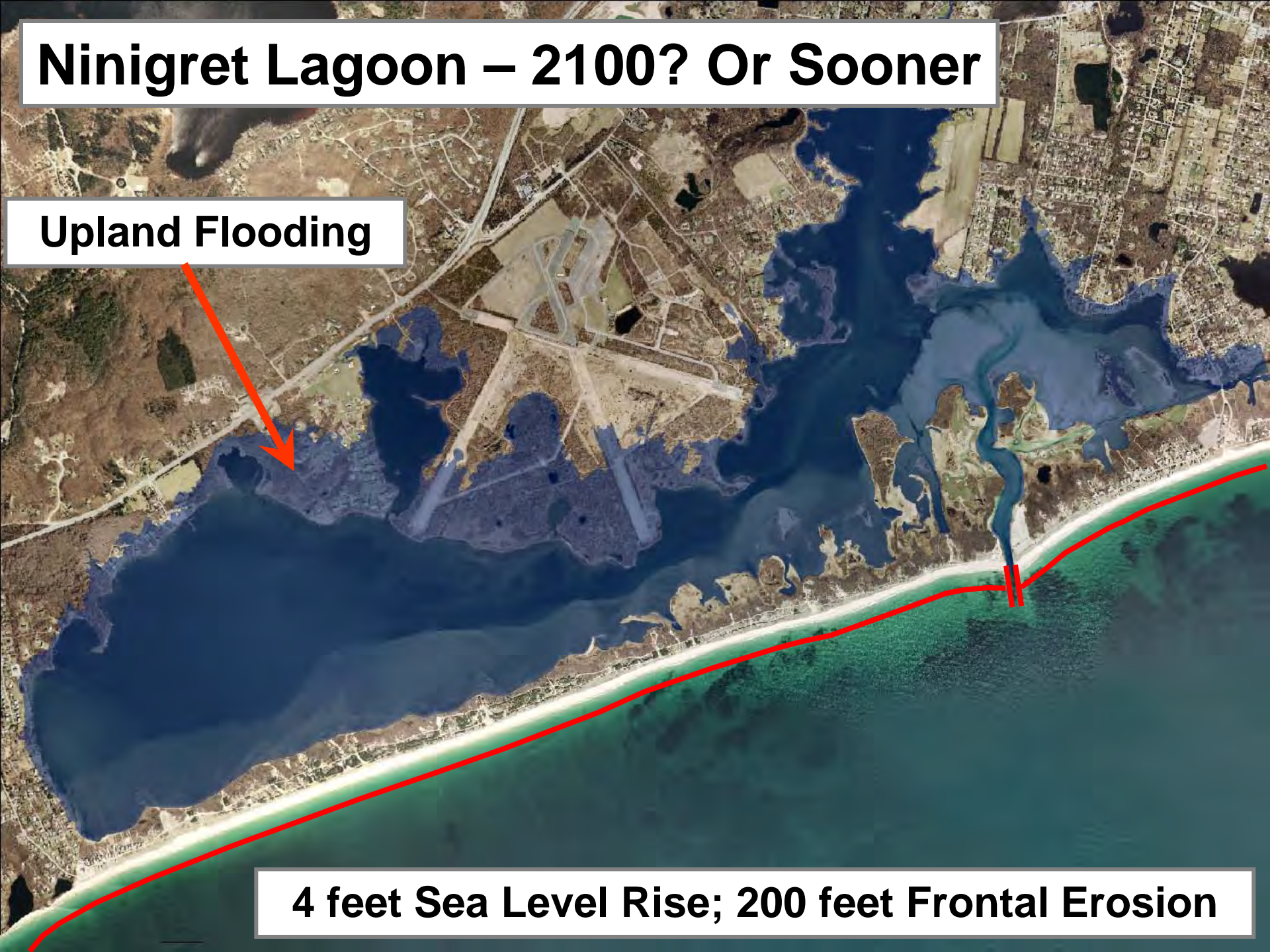


# Ninigret Lagoon – 2100? Or Sooner

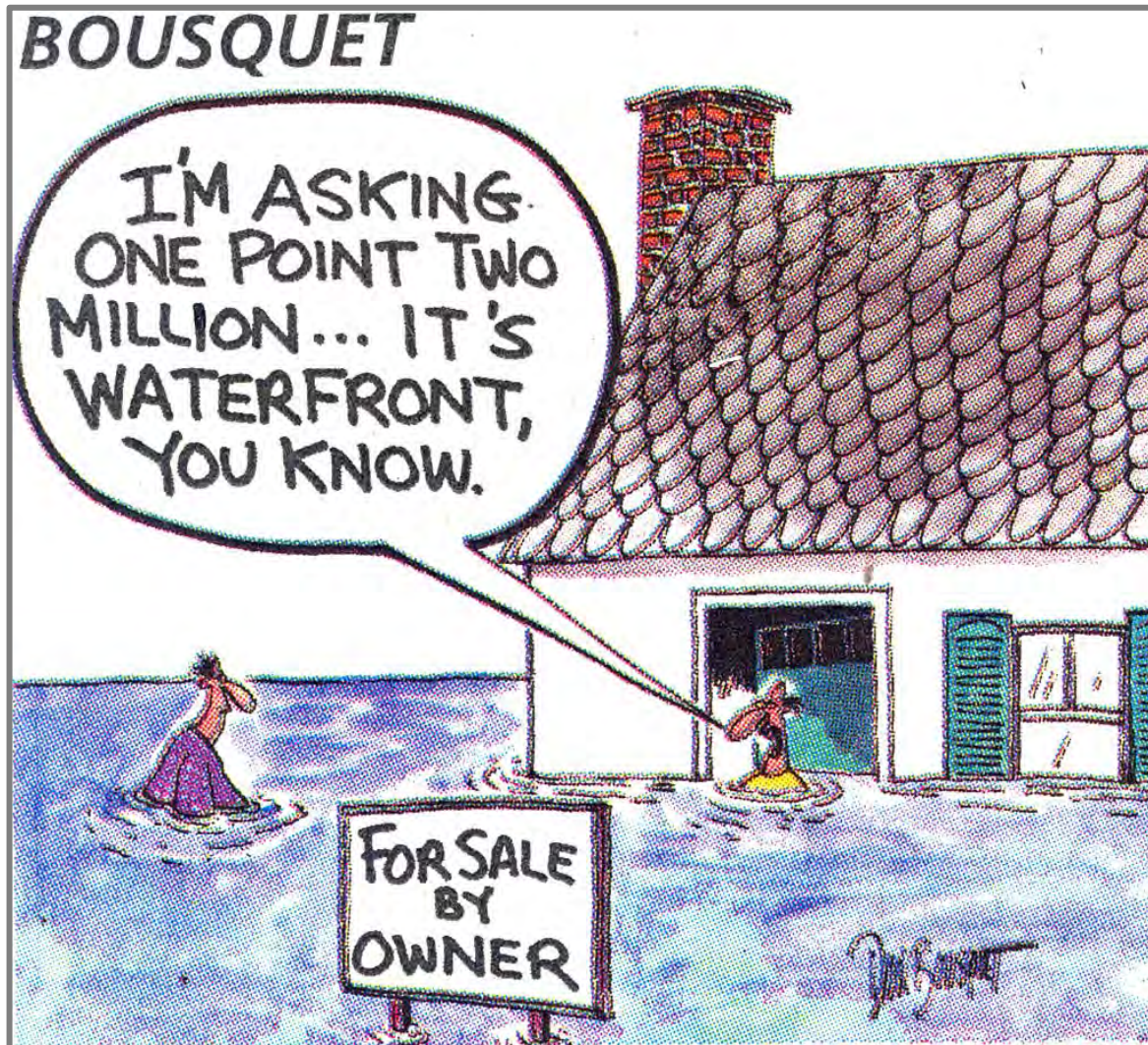
Upland Flooding



4 feet Sea Level Rise; 200 feet Frontal Erosion



# Coastal Rhode Island – A Common View of the Future



Don  
Bousquet,  
June 2008

# Middlebridge, South Kingstown, Coastal Lagoon: A Common View of the Future



OCT 28 2006

**End of Presentation**



# South Kingstown Town Beach – South Kingstown RI



09 March 1998

# South Kingstown Town Beach – South Kingstown RI



25 Oct 2005

BA Oakley

# South Kingstown Town Beach – South Kingstown RI



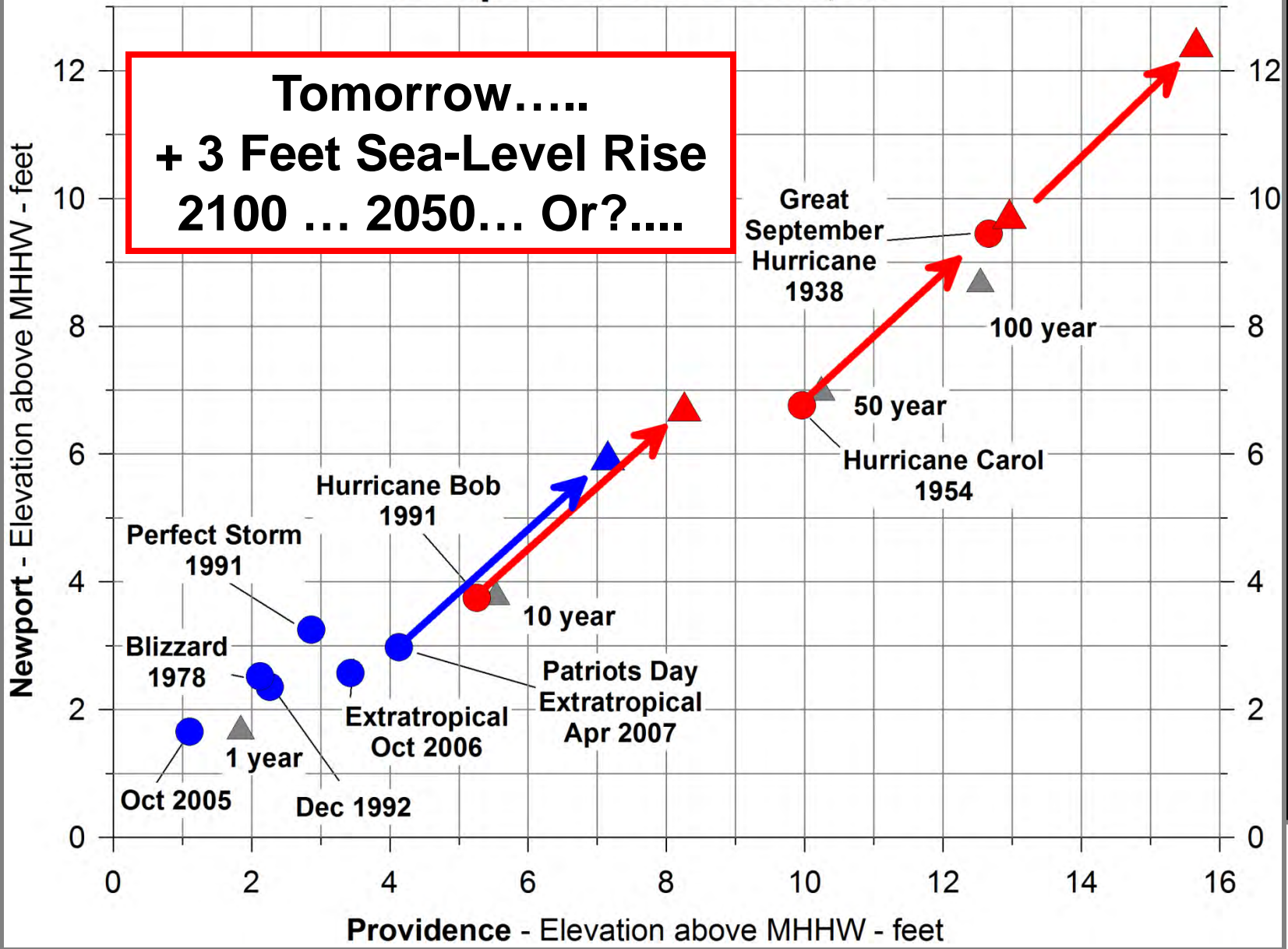
# South Kingstown Town Beach – South Kingstown RI





# PROJECTED STORM-SURGE ELEVATIONS

## Newport - Providence, RI



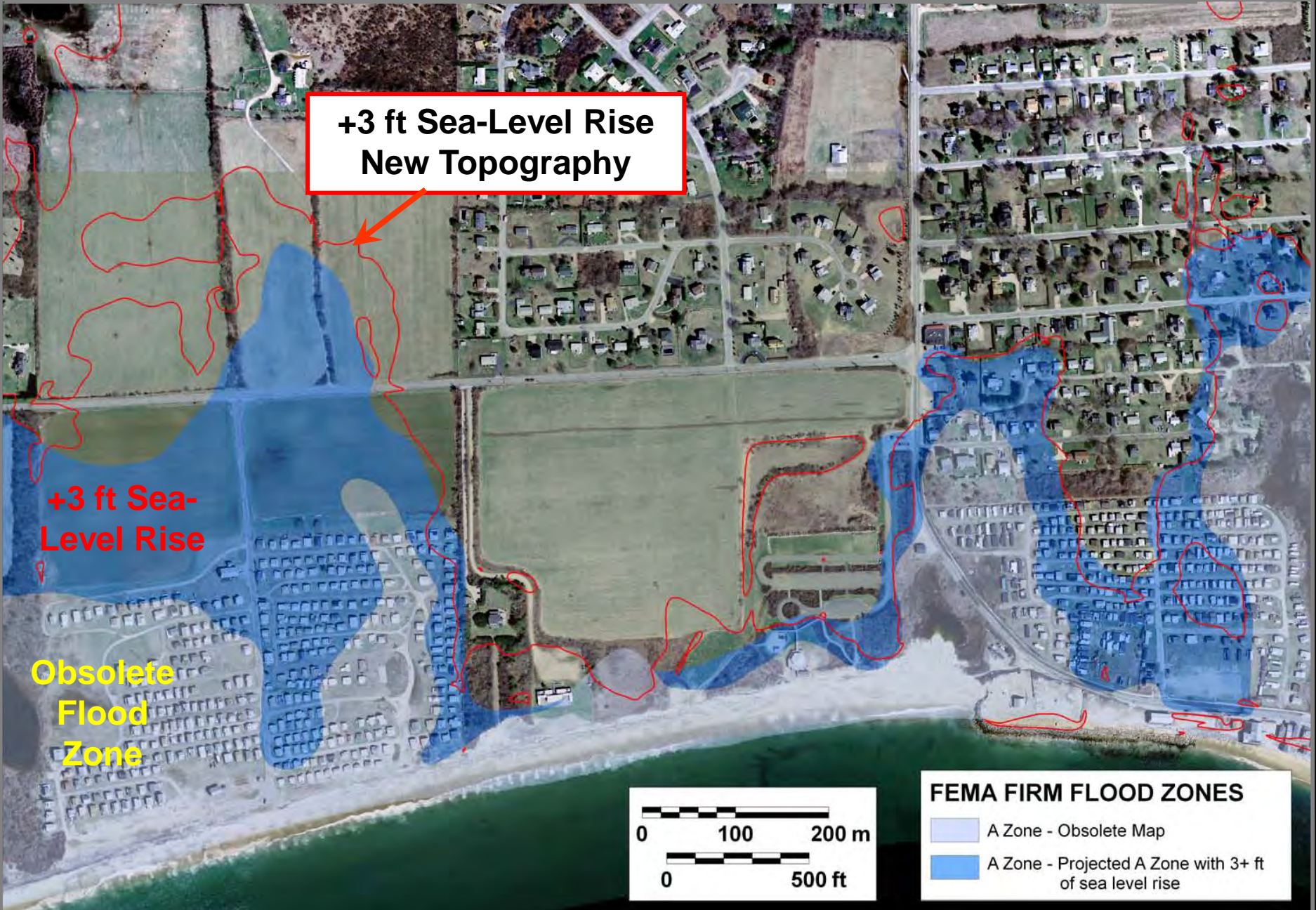
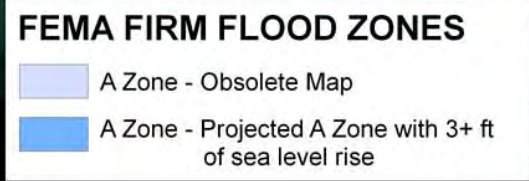
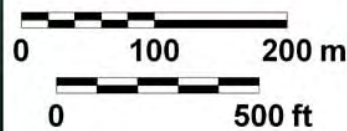
Adapted from  
NOAA;  
USACE 1988;  
Hehre 2007

# 100-Year Storm-Surge Inundation - Matunuck

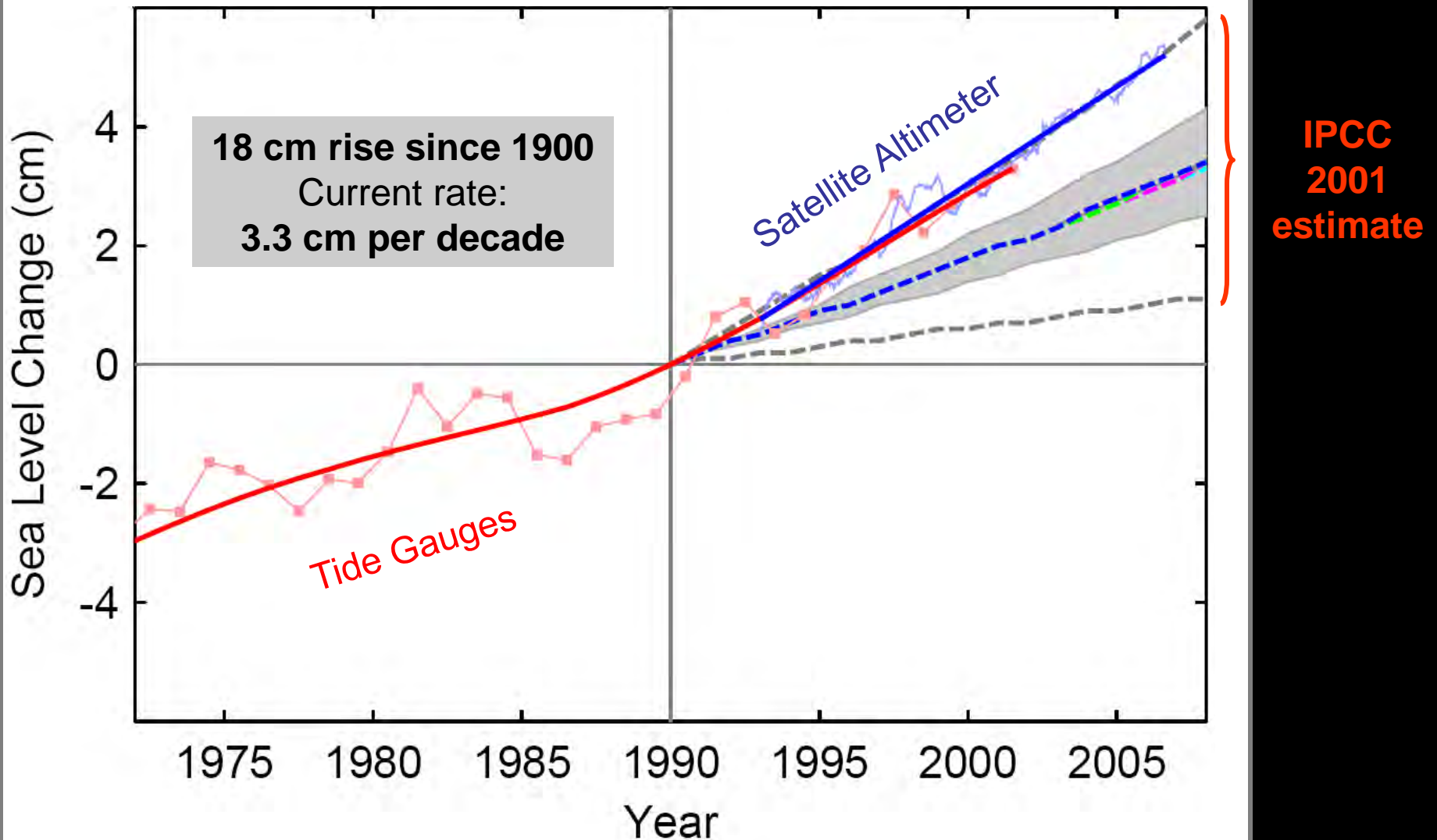
**+3 ft Sea-Level Rise  
New Topography**

**+3 ft Sea-Level Rise**

**Obsolete  
Flood  
Zone**

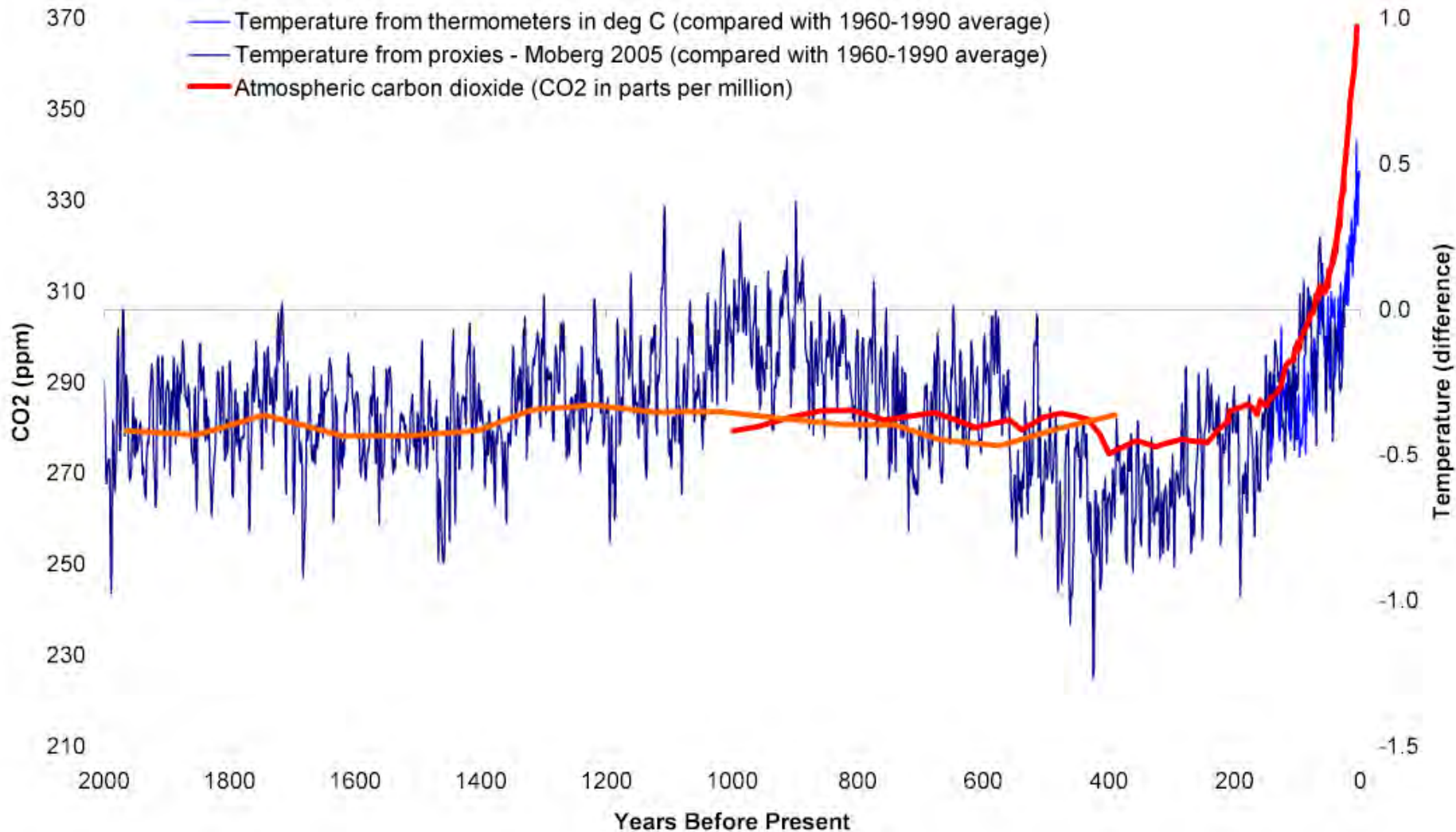


# Observed Global Sea-Level Rise





# THE HOCKEY STICK



# RHODE ISLAND POSSIBLE FUTURE CLIMATE

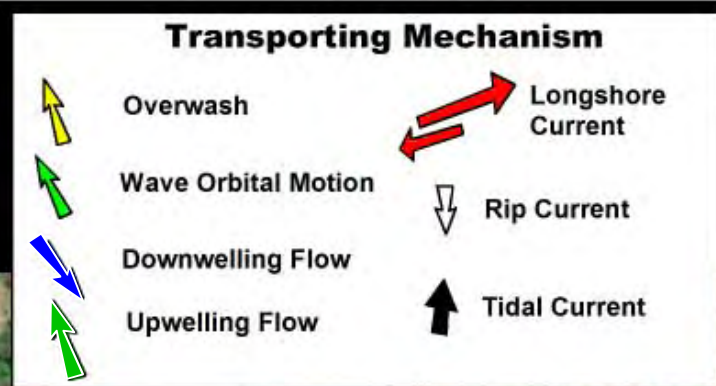


**Confronting Climate Change in the  
U.S. Northeast: Climate, Impacts,  
and Solutions, NECIA, 2007**

<http://www.northeastclimateimpacts.org/>



# SEDIMENT TRANSPORT PATHWAYS NARRAGANSETT COASTAL BARRIER



# NARRAGANSETT BEACH – Sand Transport Into Narrow River



# THE NARROWS – Flood-Tidal Delta and Narragansett Barrier Spit



# NARRAGANSETT BEACH – Sand Transport Into Narrow River



# NARRAGANSETT BEACH – Narrow River Ebb-Tidal Delta

Swash Bar

MAY 13 2007







# Ninigret Flood-Tidal Delta - 1981

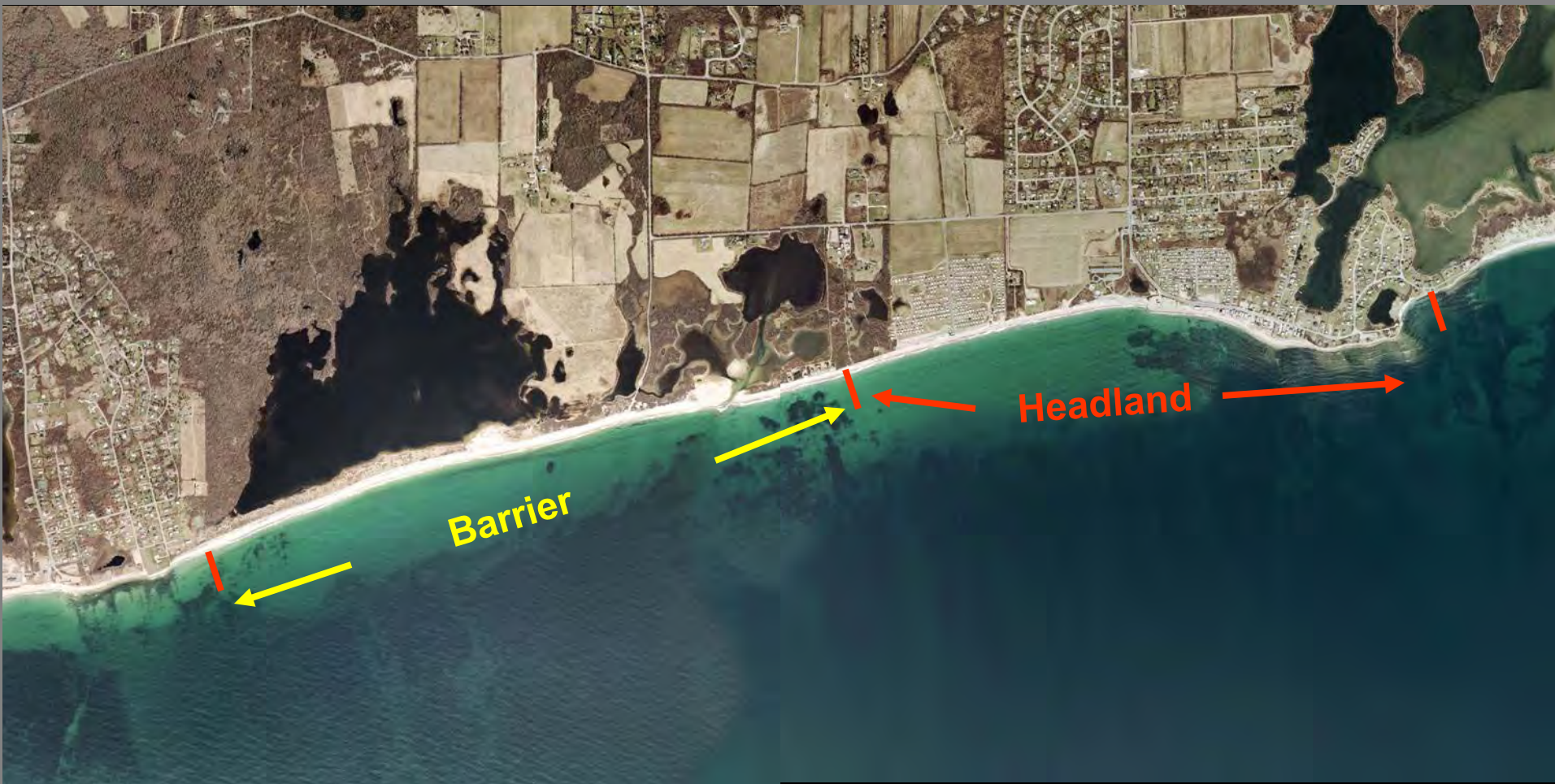


RIGIS

# Ninigret – Charlestown – East Beach Area

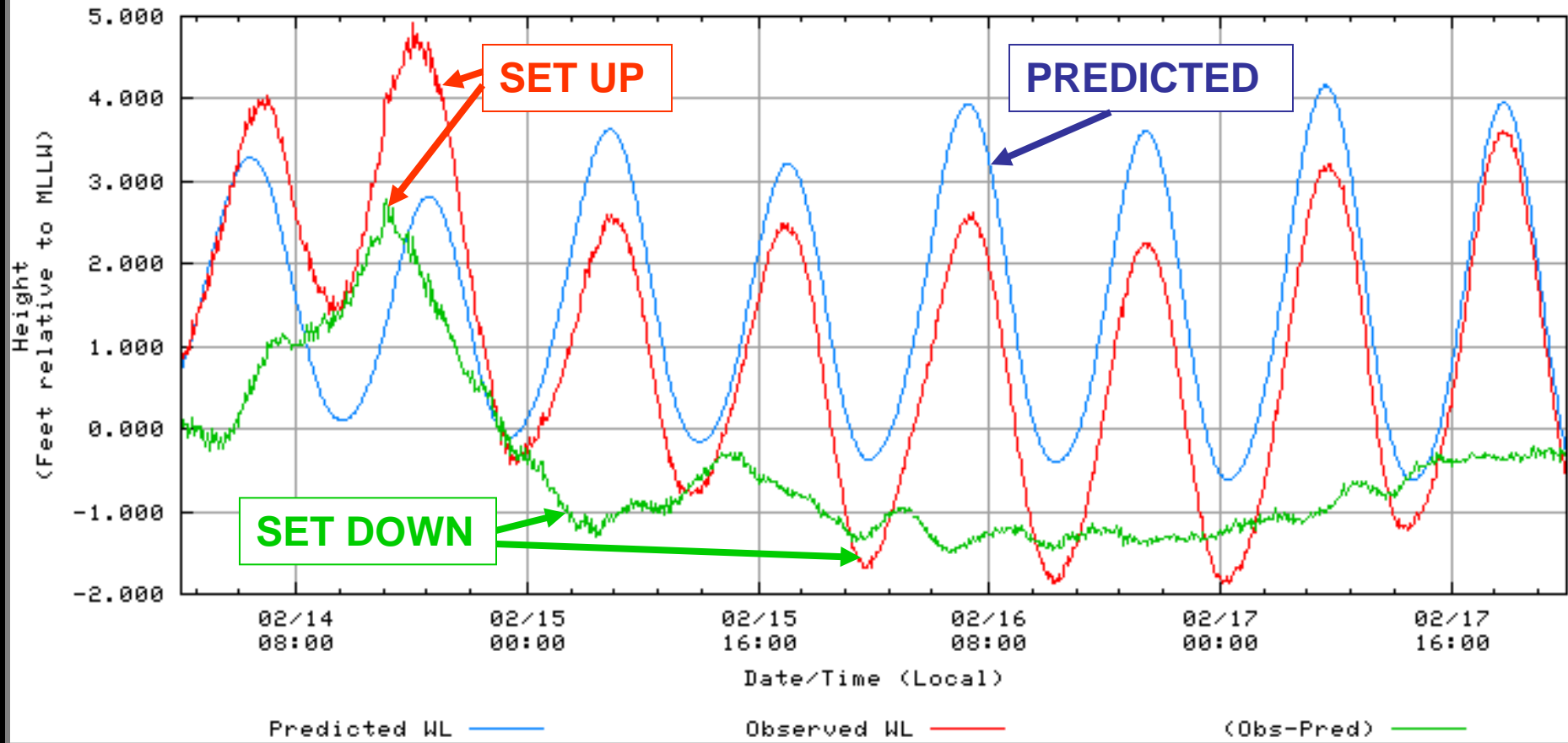


# Green Hill Headland to Matunuck Headland



# Valentine's Day Extratropical - 2007

NOAA/NOS/CO-OPS  
Preliminary Water Level (A1) vs. Predicted Plot  
8452660 Newport, RI  
from 2007/02/14 - 2007/02/17



# South Kingstown Town Beach

## An Eroding Bluff Shoreline

Profile Volume	$m^3 m^{-1}$
▲ 20 AUG, 1996	163.1
○ 10 MAR, 1998	86.7
● 02 MAR, 2005	45.3
Volume Change	- 117.8

Boardwalk

Washover Fan

Bluff

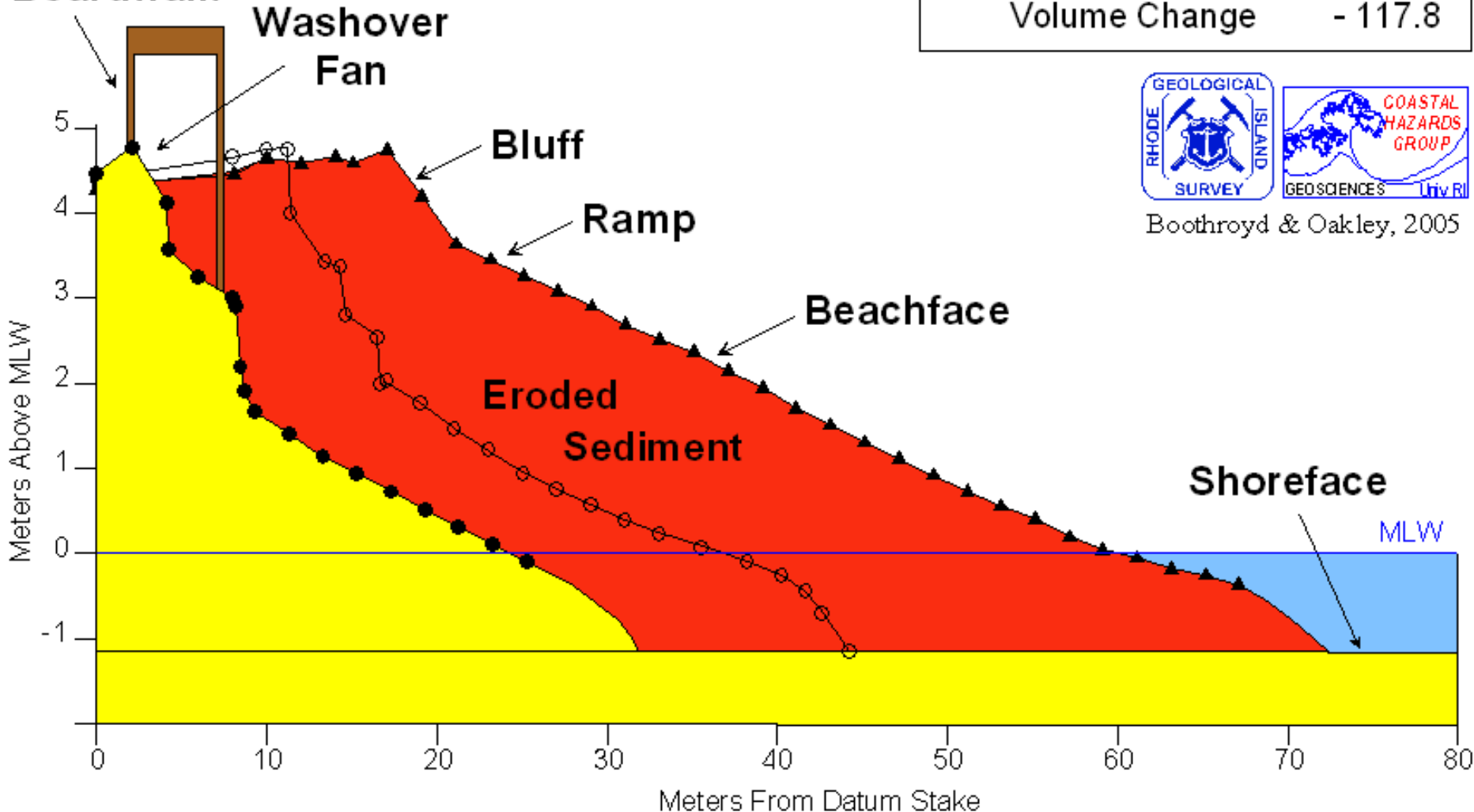
Ramp

Beachface

Eroded Sediment

Shoreface

MLW



Boothroyd & Oakley, 2005