Sensing the ocean's depth

Today we will learn about:

1. Systems to probe map ocean depth.

2. Systems to study ocean bottom type.

3. Systems to study sub-bottom composition.

4. Learn about sound propagation in sediments.

5. Example: USGS survey in the GOM

Before we start:

0. Demonstration – acoustic nebulizer.

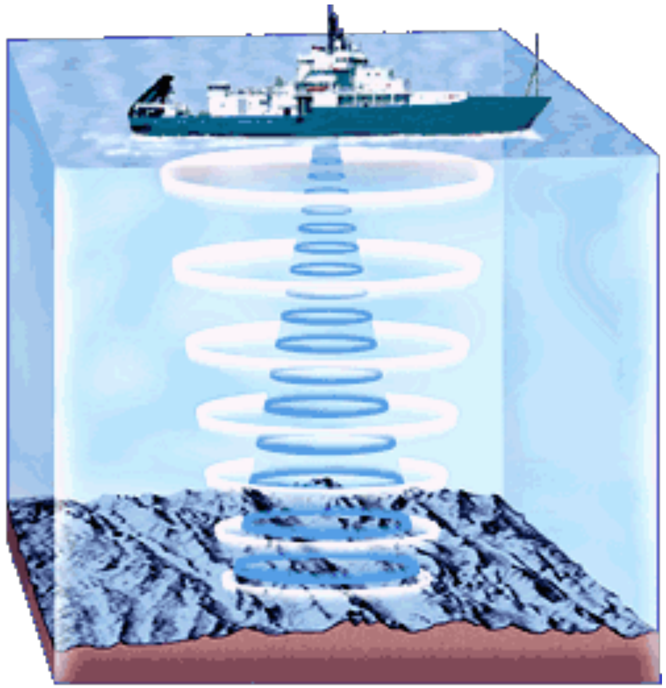
1. Presentations for next week?

2. Homeworks?

3. Blogs?

Systems to map ocean depth

Simplest concept: time of return of an acoustic signal from the bottom (echo sounder):

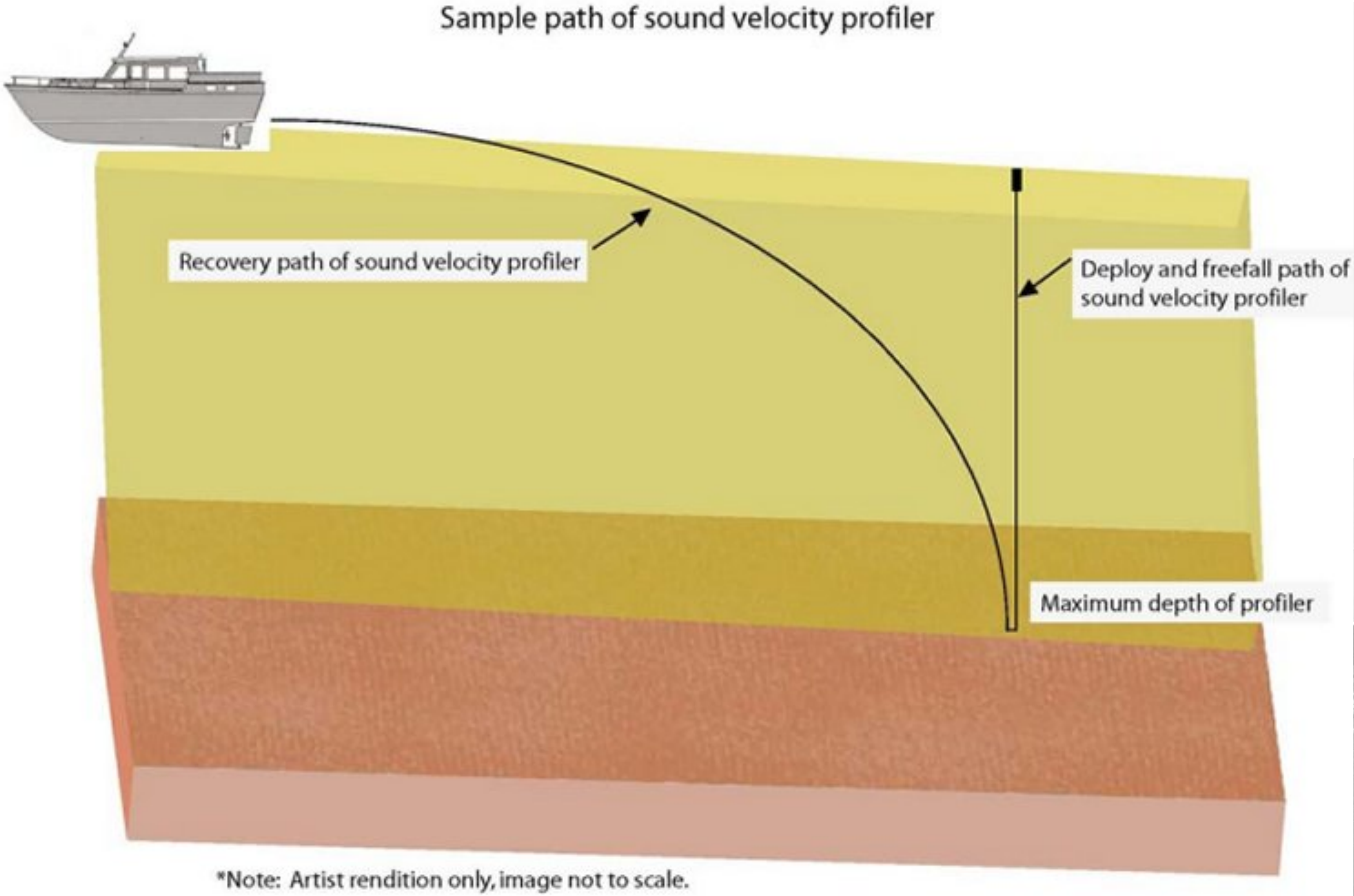


Typical: 12-200KHz (higher for shallower applications)

www.divediscover.whoi.edu/tools/sonar-singlebeam.html

Need to know the sound speed: $z = \frac{1}{2}\int_0^T c(z)\,dt = \frac{\overline{c}T}{2}$

Uncertainty ? How can we minimize it ?

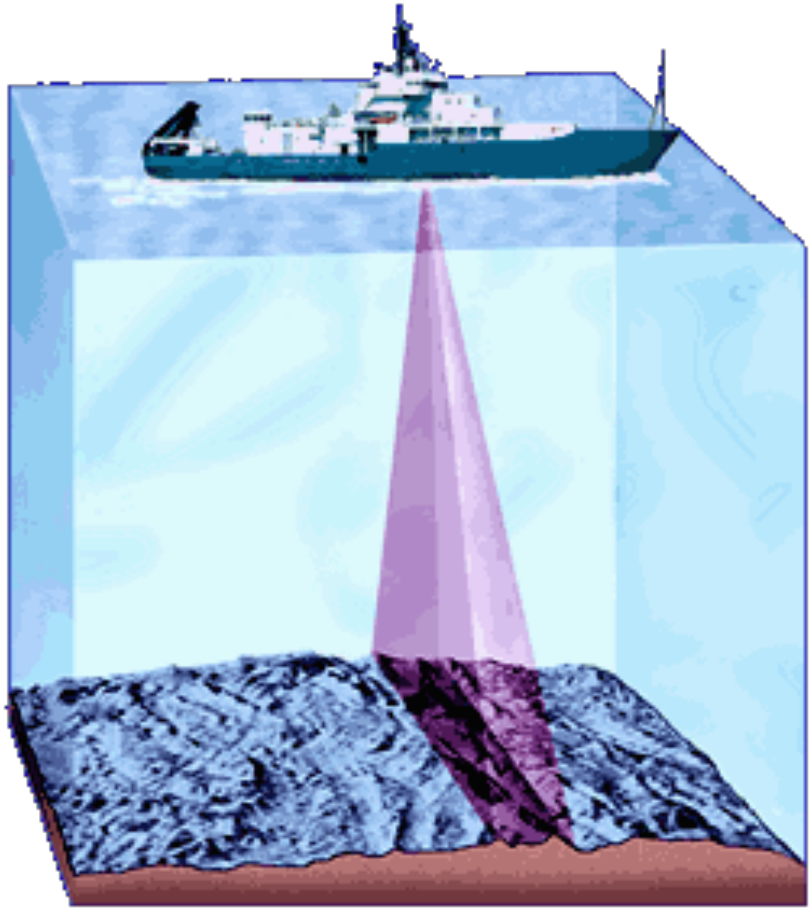


www.nauticalcharts.noaa.gov/csdl/svp.html

Operates on the "sing-around" sound principle, and contain a transducer head and a reflective plate a known distance apart.

Systems to map ocean depth

More advanced: multi-beam (up to 120 beams).



Swath width ~ 2 x depth

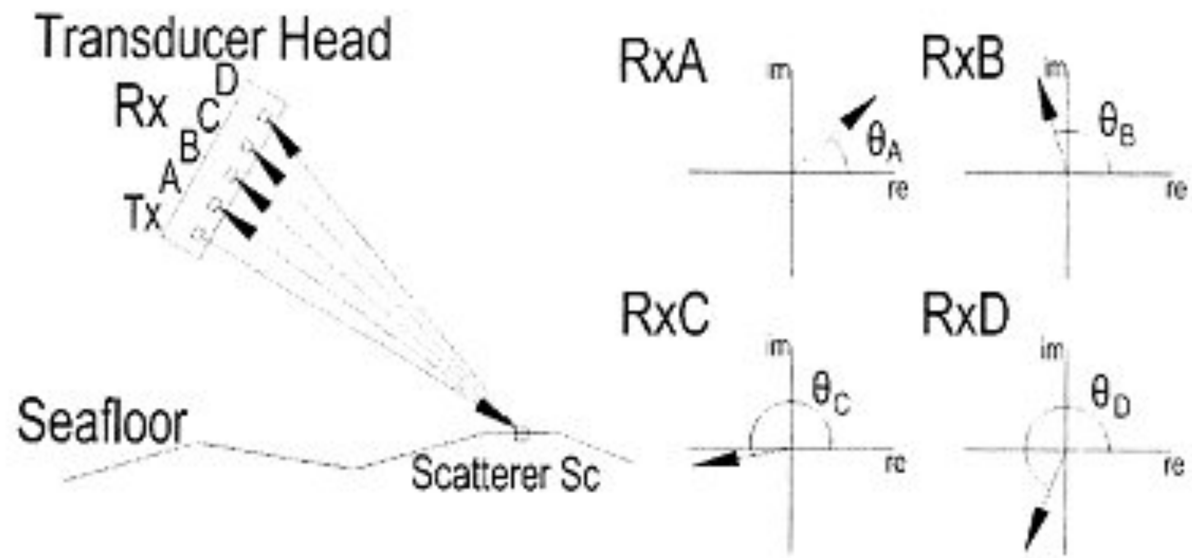
Compensation for ship movement

www.divediscover.whoi.edu/tools/sonar-multibeam.html

Need to know the sound speed: $z = \frac{1}{2}\int_0^T c(z)\,dt = \frac{\overline{c}T}{2}$

Systems to map ocean depth

More advanced: Phase differencing bathymetric SONAR (or interferometric SONAR)



www.nauticalcharts.noaa.gov/csdl/PDBS.html

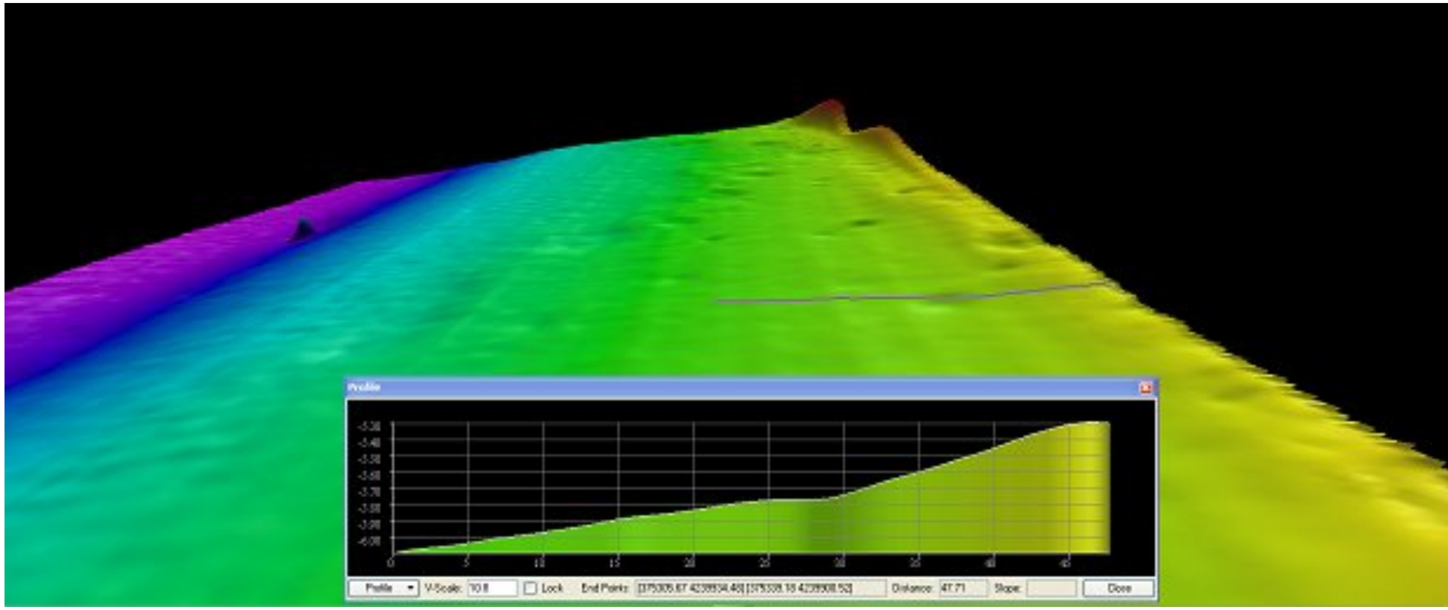
Phase is measured at each of several receive elements which are spaced at precisely known distances. The angle from which the return originated is calculated using differences in the phase as measured at each element and range is obtained from travel time ->3D modeled sea floor.

Comparison of systems obtained from the same vessel:

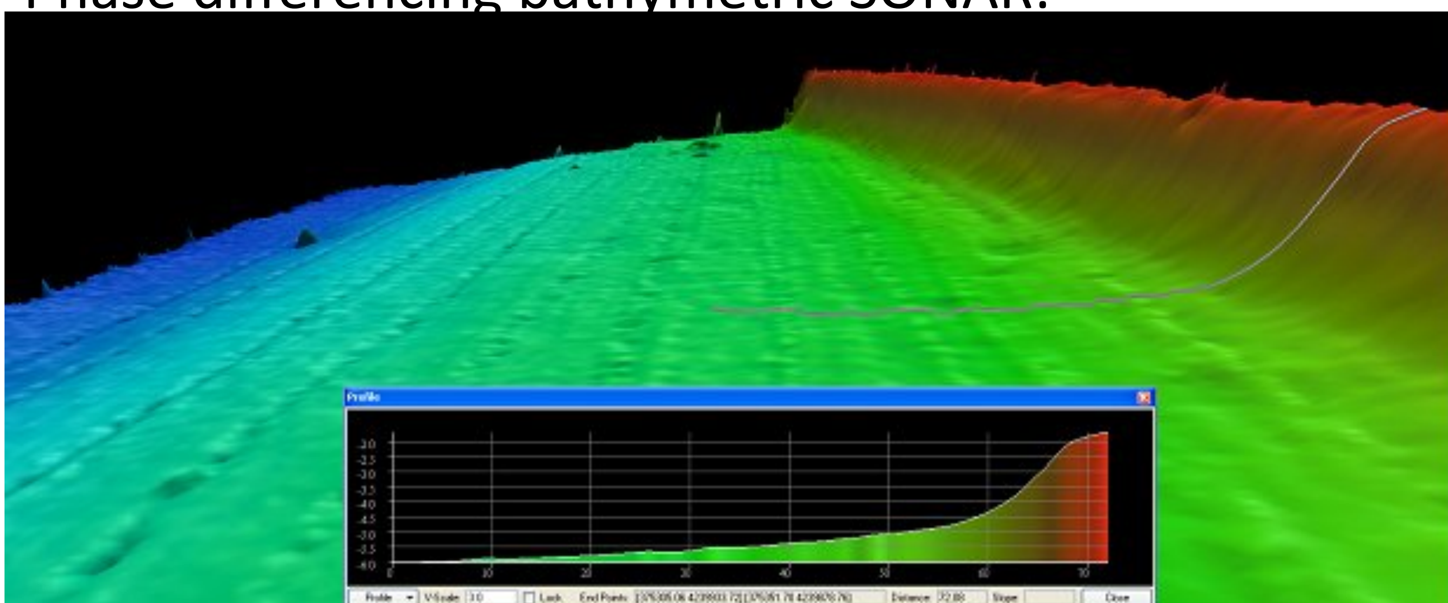
PDBS provides data closer to shore and places not accessible to vessel.

PDBS has lowest accuracy in NADIR (~10cm offset).

Multi beam:



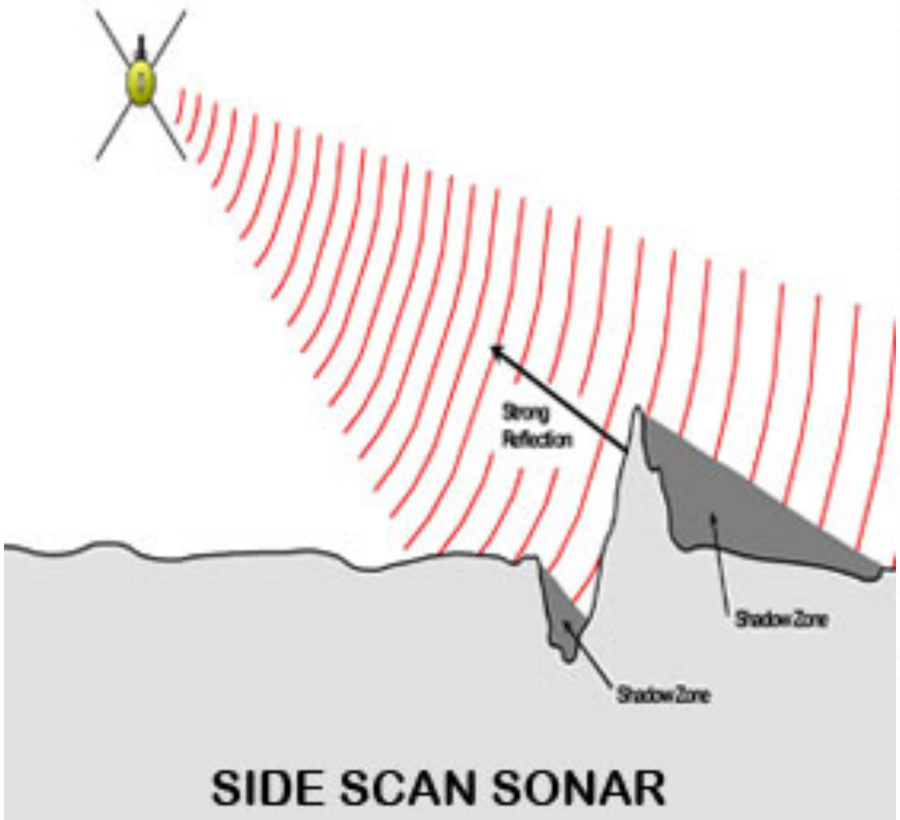
Phase differencing bathymetric SONAR:

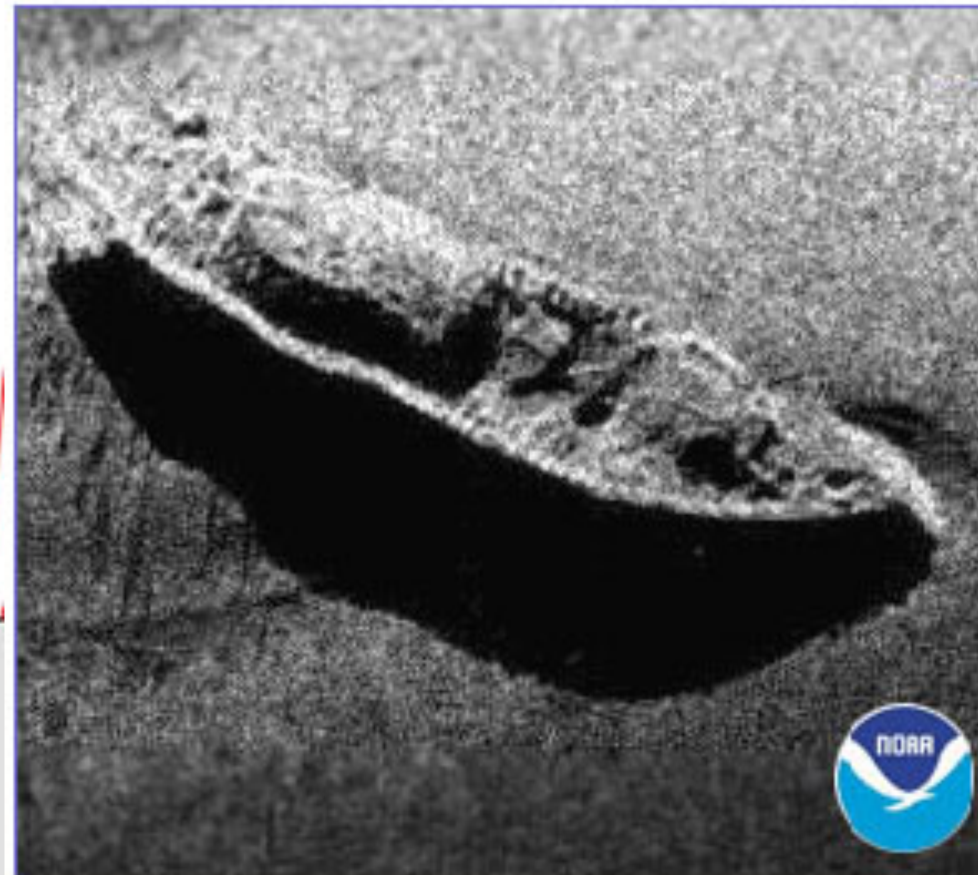


www.nauticalcharts.noaa.gov/csdl/PDBS.html

Systems to image the bottom acoustically

Side-scan sonar: measuring strength of return to a towed platform from a scanning SONAR (~100m).



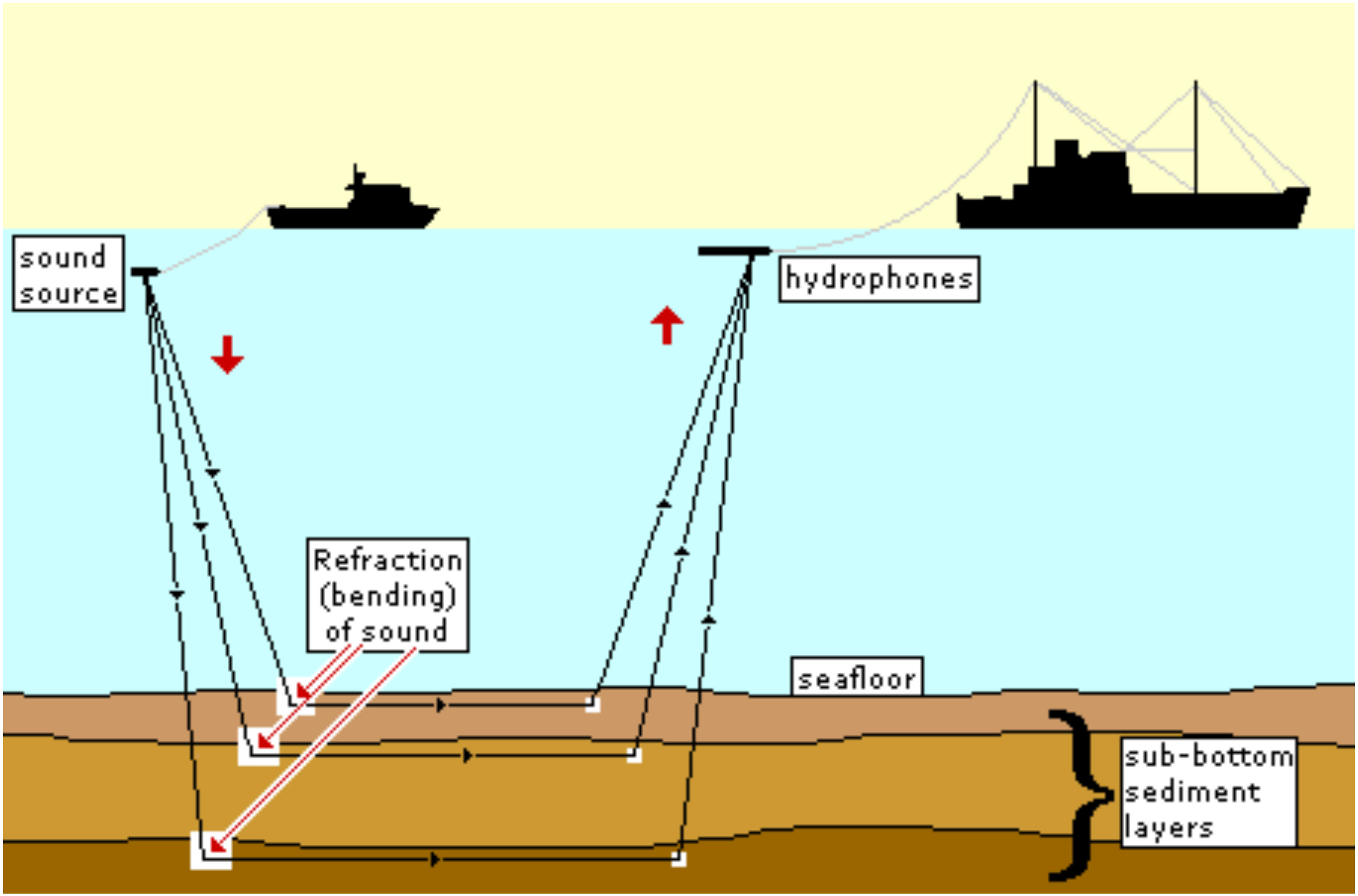


www.nauticalcharts.noaa.gov/hsd/SSS.html

white: strong return. Black: shadow

Systems to image within the bottom acoustically

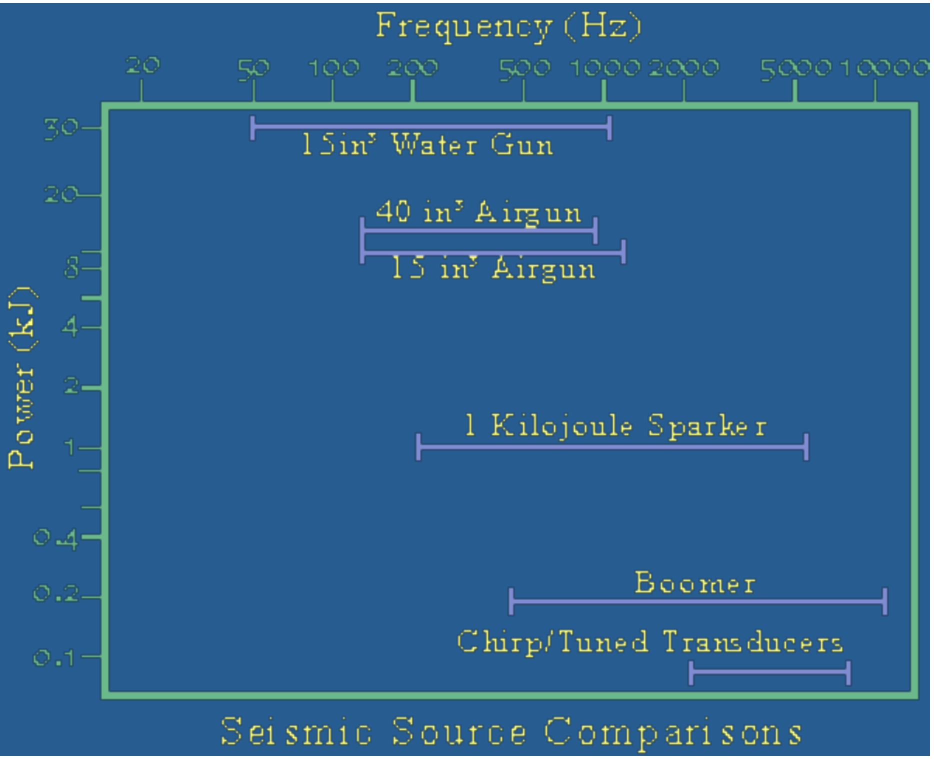
Seismic profiling.



Systems to image within the bottom acoustically

Seismic profiling, sources:

Vary in power and in frequency:



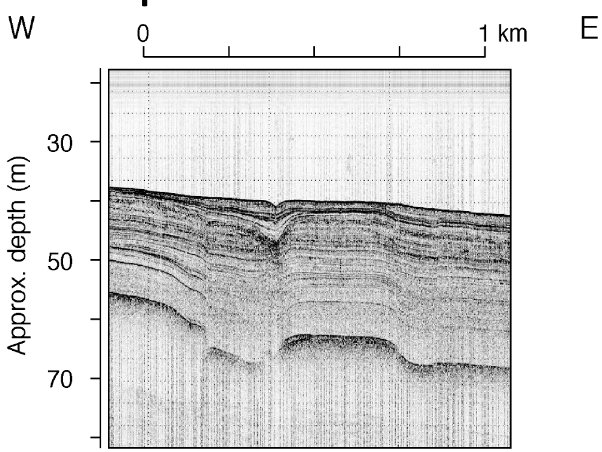
Water gun	**20-1500 Hz**
Air Gun	**100-1500 Hz**
Sparker	**50-4000 Hz**
Boomer	**300-3000 Hz**
Chirp systems	**500 Hz-12 kHz** **2 - 7 kHz** **4 - 24 kHz** **3.5 kHz and 200 kHz**

woodshole.er.usgs.gov/operations/sfmapping/seismic.htm

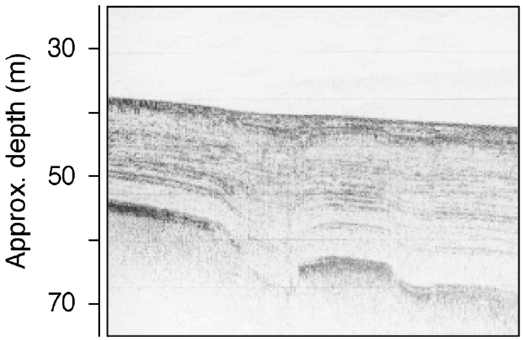
Systems to image within the bottom acoustically

WIKI: An air gun consists of one or more pneumatic chambers that are pressurized with compressed air at pressures from 14 to 21 MPa (2,000 to 3,000 psi). The air gun array is submerged below the water surface, and is towed behind a ship. Air gun arrays are built up of up to 48 individual air guns with different size chambers, to create the optimum initial shock wave with minimum reverberation.

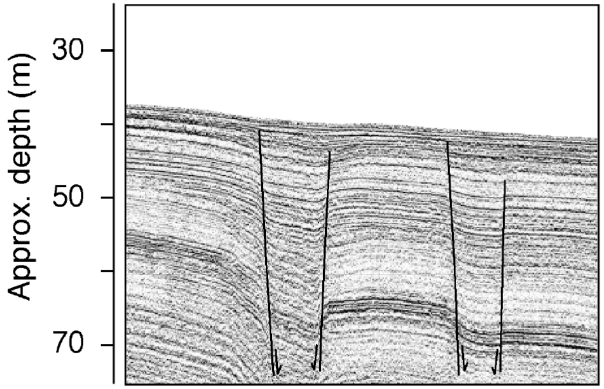
Comparison at the same location (Bear Lake):



Chirp 2-24Hz



Chirp 3.5kHz



Boomer

woodshole.er.usgs.gov/operations/sfmapping/seismic.htm

Applications of these technologies for bottom mapping in the Gulf of Maine by USGS

134 km^2 of inner shelf mapped using:
1. interferometric sonar (bathymetry and backscattering)-234 kHz
Width of swath is generally 7-10 times the water depth. Did not use b_b.
2. Side-scan sonar (backscatter). dual frequency (100/500 kHz).
Backscattering is an acoustic measure of roughness of the seafloor.
topographic highs/ lows can be interpreted based on acoustic shadows.
3. Chirp (3.5-12 kHz) seismic-reflection profiling (stratigraphy/structure).

Focus: 5-40m isobath.

Deployed simultaneously from R/V Rafael (25ft vessel)

18 days of survey + ground validation (samples, pictures).

GPS and tidal calibration (OPUS, National Geodetic Survey)

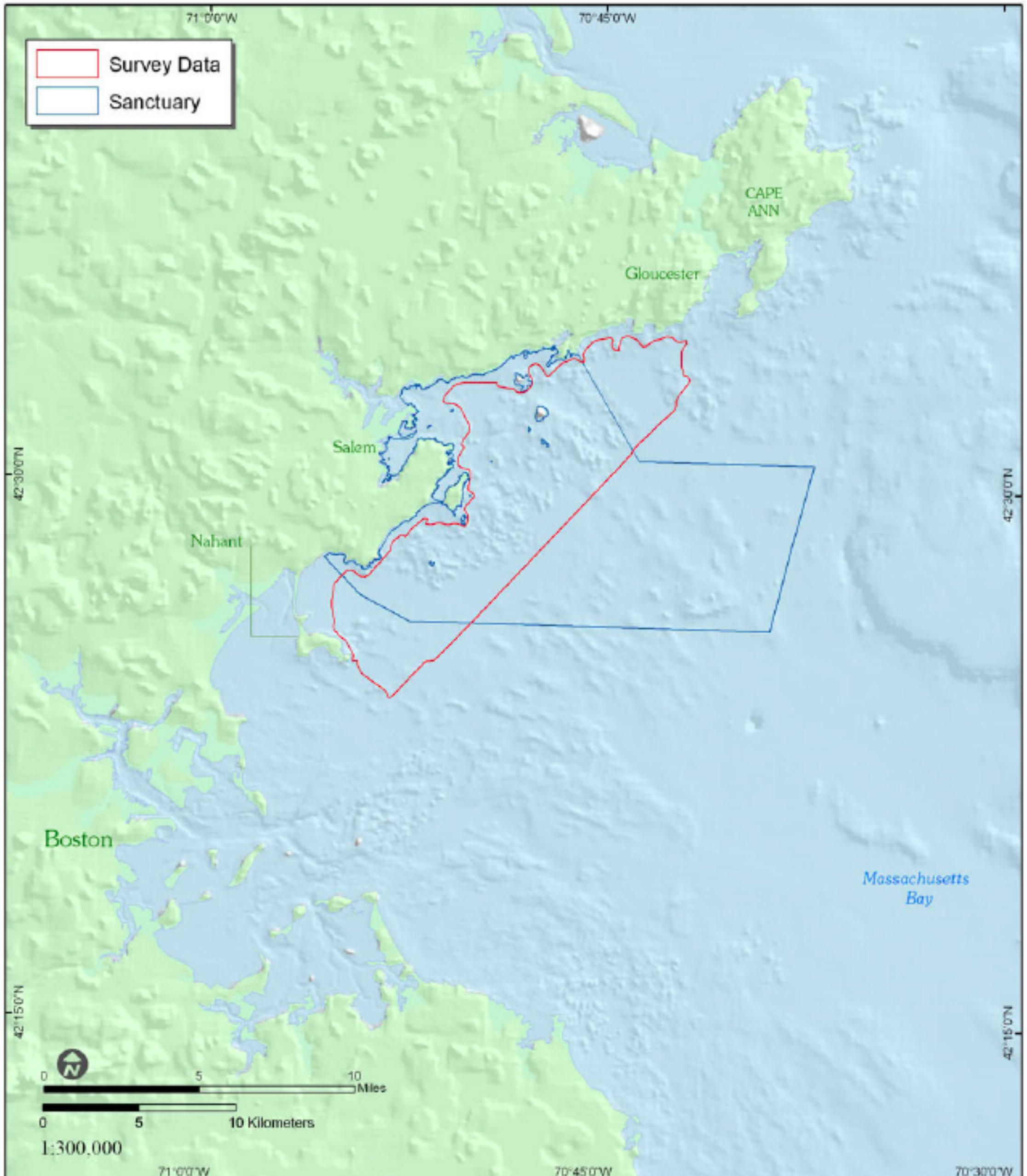


Figure 1.1. Map showing the location of the survey area (outlined in red) offshore of northeastern Massachusetts between Nahant and Gloucester, including part of the South Essex Ocean Sanctuary (blue line).

Figure 3.1. Photograph of the USGS research vessel Rafael.

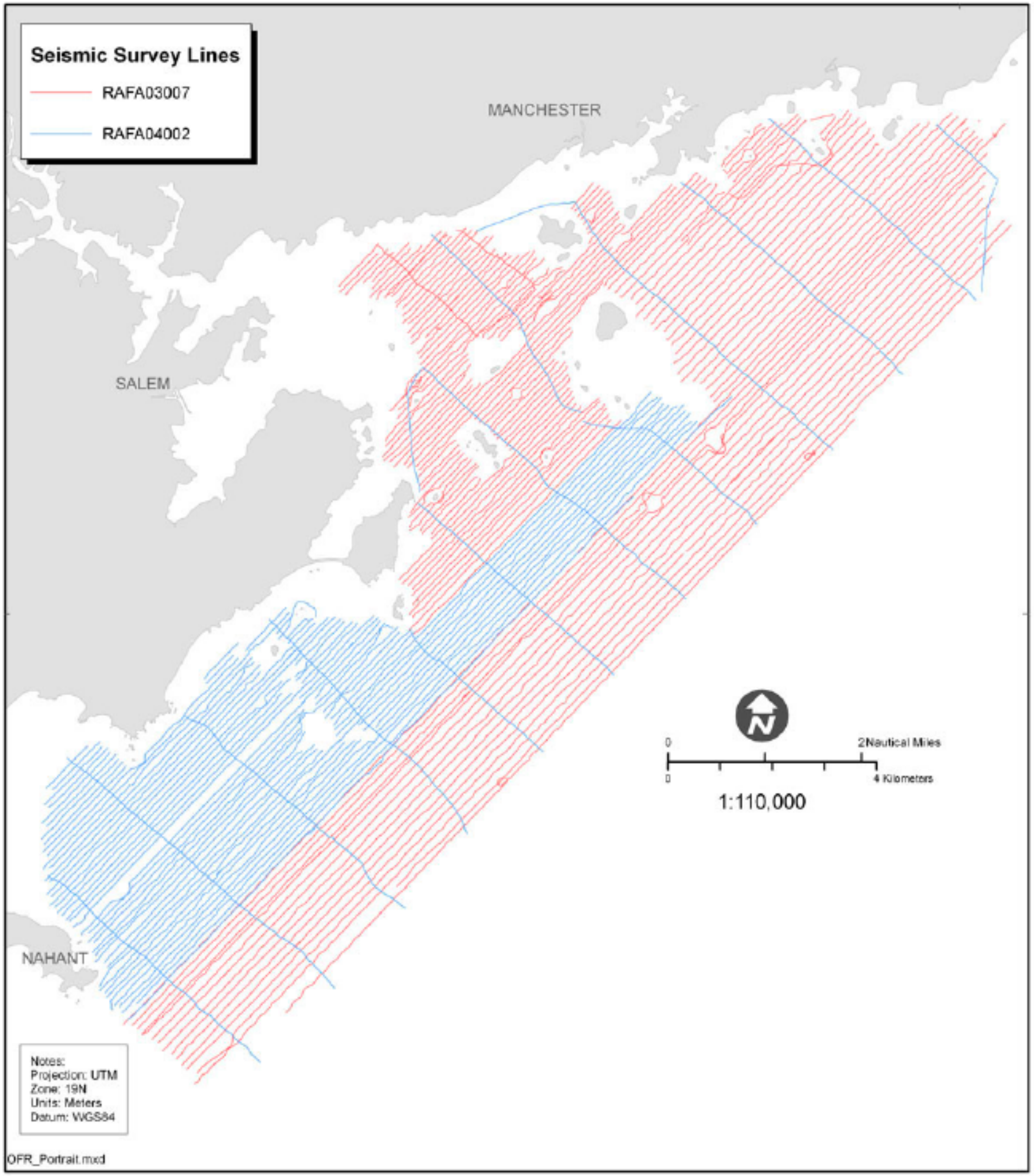


Figure 3.4. Map showing tracklines of seismic-reflection profiles in the survey area.

Figure 3.6. TOP: Photograph of Mini SEABOSS and winch on the deck of the RV Rafael. BOTTOM: Components of Mini SEABOSS viewed from below: A) forward video camera, B) downward video camera, C) video light, D) digital still camera and housing, E) strobe light, F) parallel laser for scale, G) laser for ranging, H) junction block, I) van Veen grab sampler, and J) multi-conducting cable.

Applications of these technologies for bottom mapping in the Gulf of Maine by USGS

Data analysis:

Use two different approaches to depict seafloor geology:

1) multivariate analysis – bottom classification

Loose correlation between water depth, backscatter intensity, and the slope of the seafloor.

Classify into 3 general classes: ledge, cobble/boulders, and sand/silt.

2) physiographic zones

Qualitative method than the multivariate approach described above, and relies heavily on geologic interpretation.

Nearshore Basins, Rocky Zones, Nearshore Ramps, Shelf Valleys, and *Bay-Mouth Shoals.*

3) Bottom Sediment Texture (samples). No correlation with bottom depth.

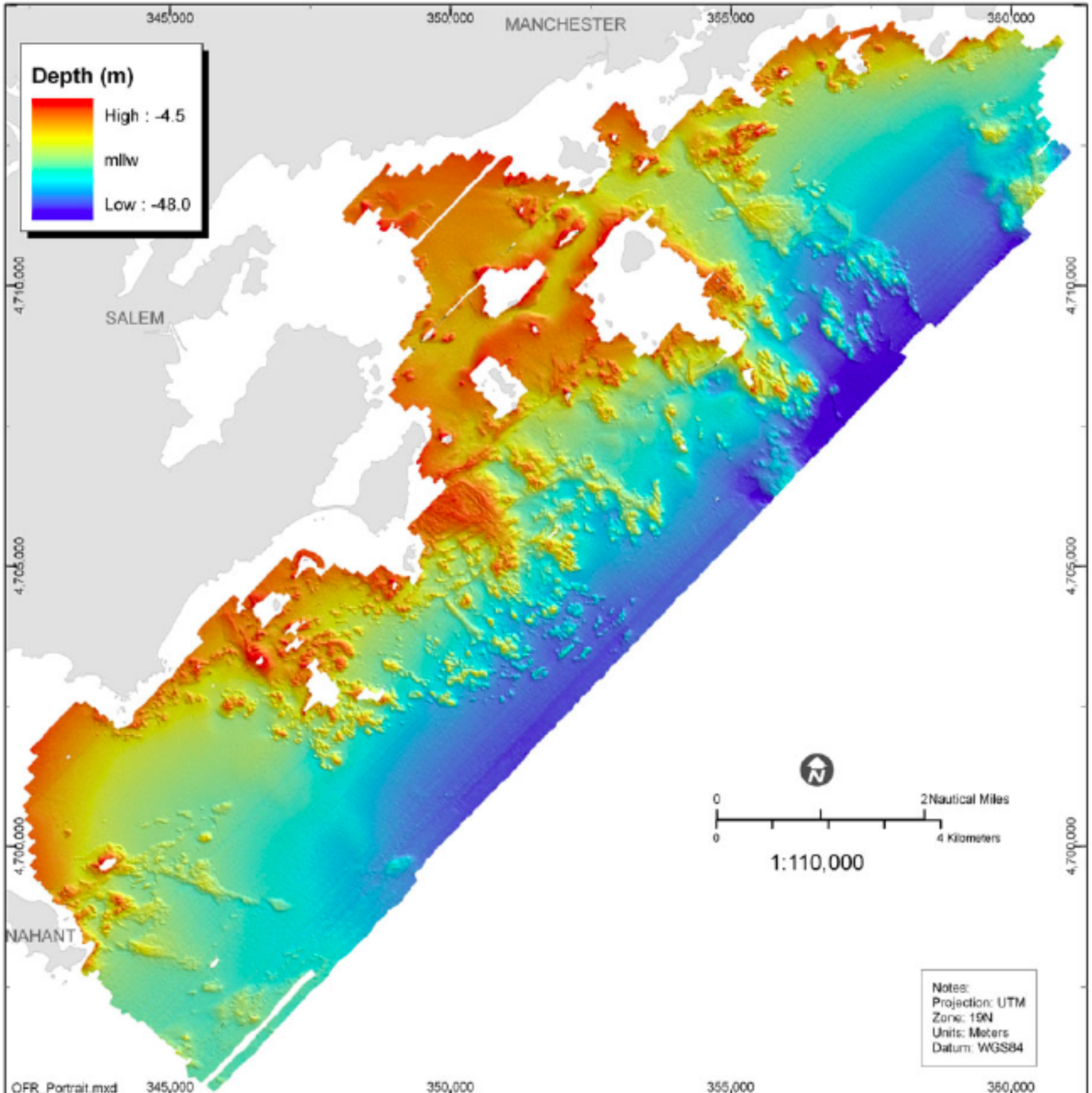


Figure 3.2. Shaded-relief map of seafloor topography offshore of northeastern Massachusetts between Nahant and Gloucester.

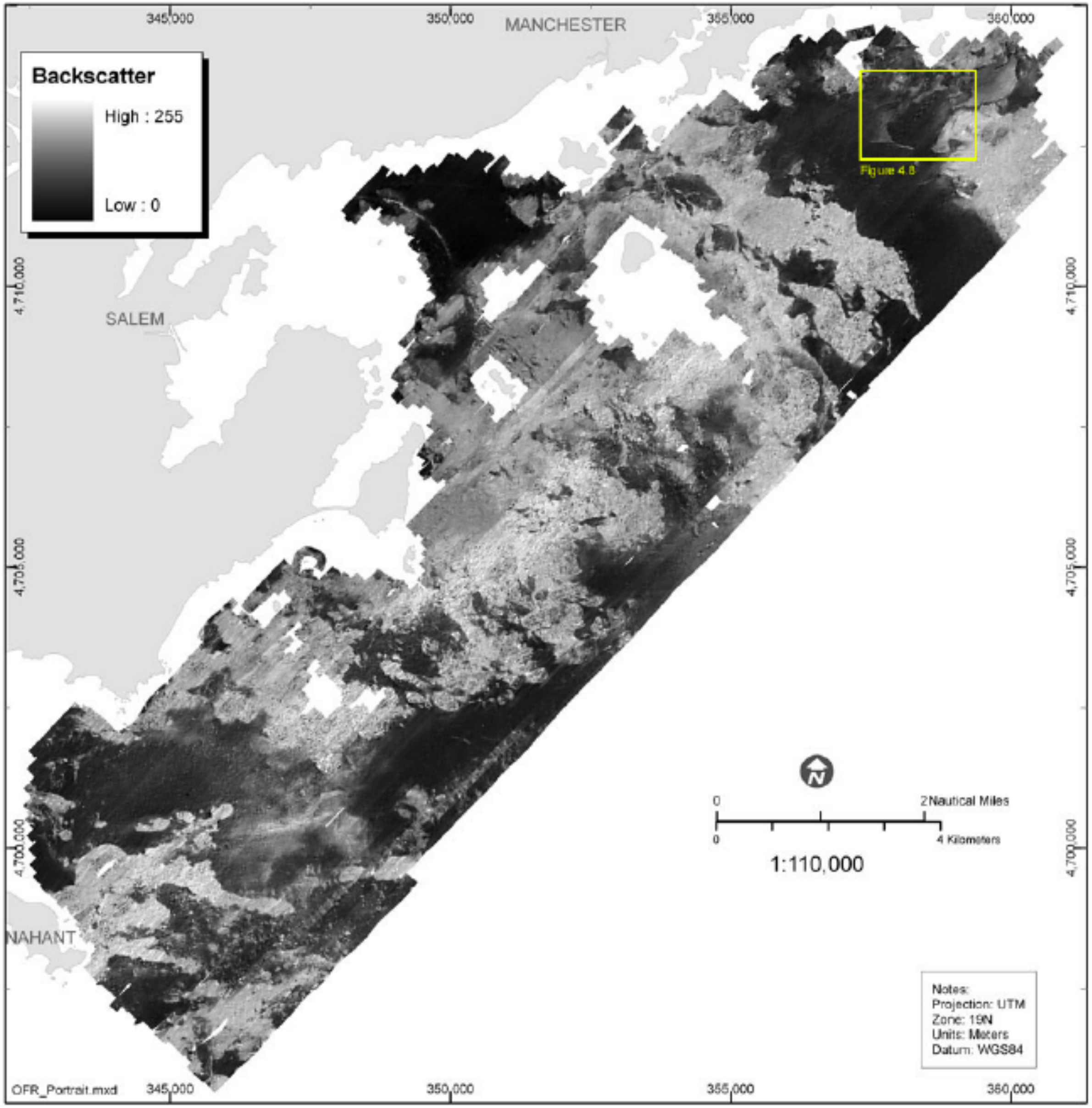


Figure 3.3. Map showing acoustic backscatter intensity offshore of northeastern Massachusetts between Nahant and Gloucester. Backscatter intensity, as recorded with sidescan sonar, is an acoustic measure of the hardness and roughness of the seafloor. In general, higher values (light tones) represent rock, gravel and coarse sand. Lower values (dark tones) generally represent fine sand and muddy sediment. Yellow box (upper right) indicates the location of Figure 4.8.

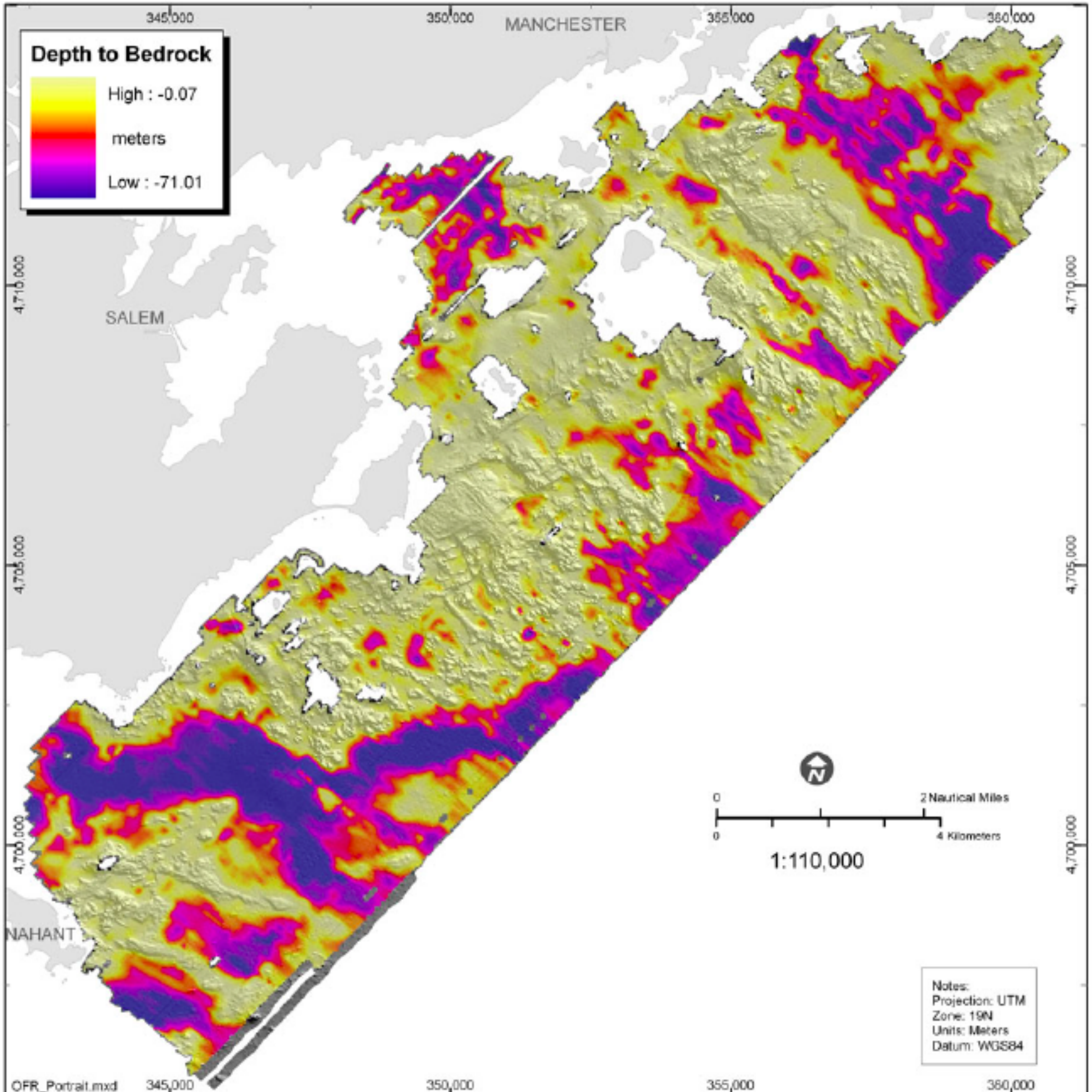


Figure 3.5. Isopach map of total sediment thickness in the survey area. Gridded values were interpolated from closely spaced seismic-reflection profiles shown in Figure 3.4.

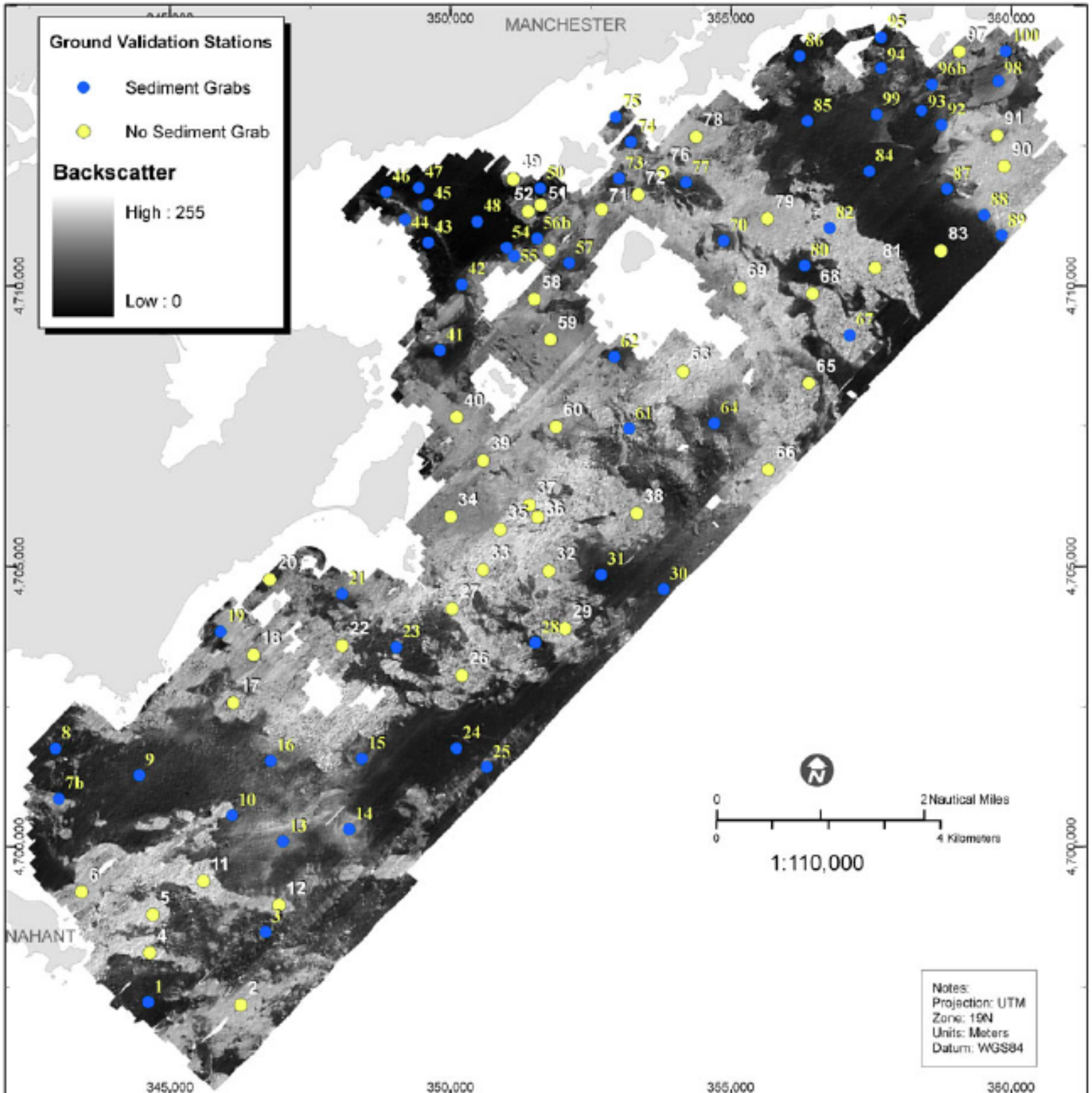


Figure 3.7. Map showing bottom sample locations and video transects overlain on a map of acoustic backscatter from sidescan sonar. Each numbered circle indicates a station where multiple photographs, video, and/or samples were collected.

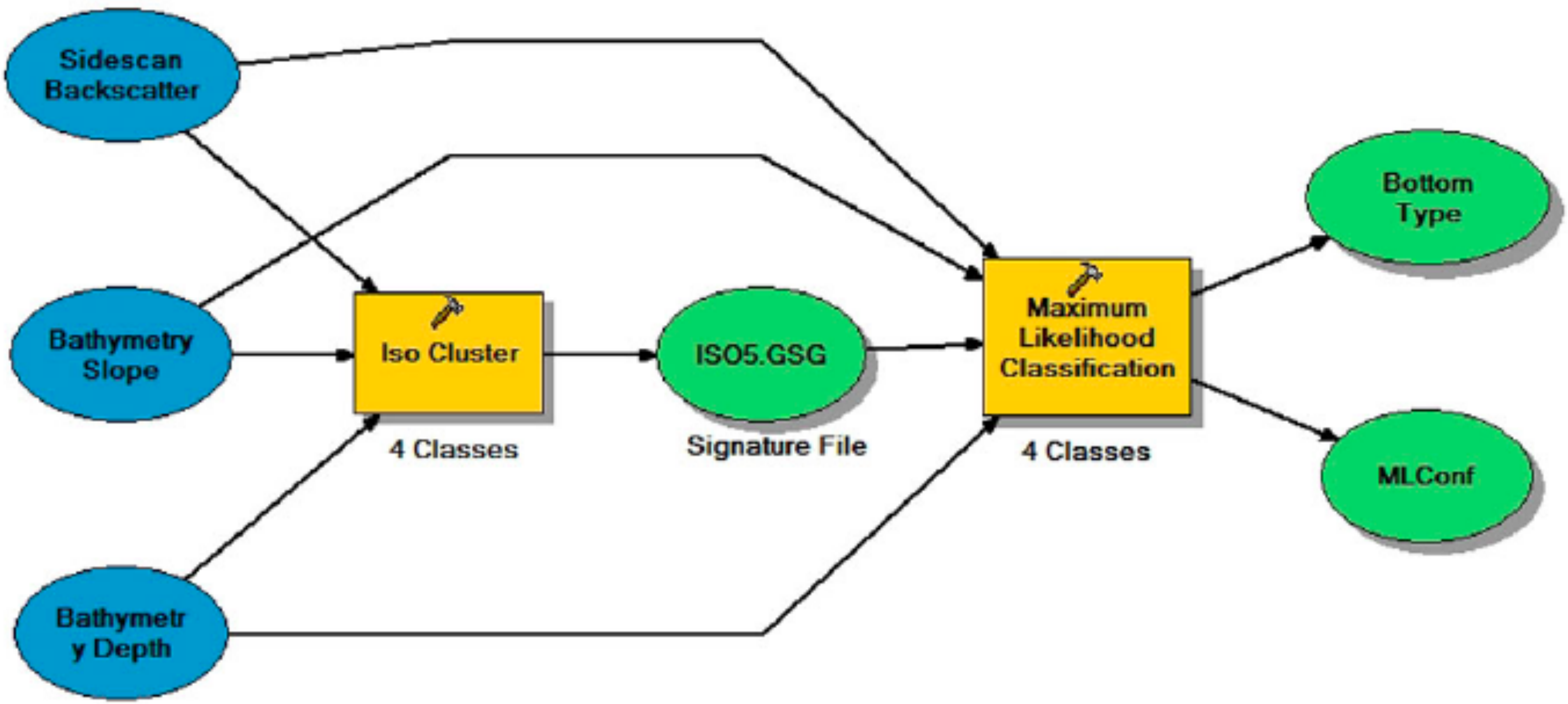


Figure 4.2. Model builder schematic of multivariate analysis, showing input data (depth, slope, acoustic backscatter) and processing steps used to create map in Figure 4.3.

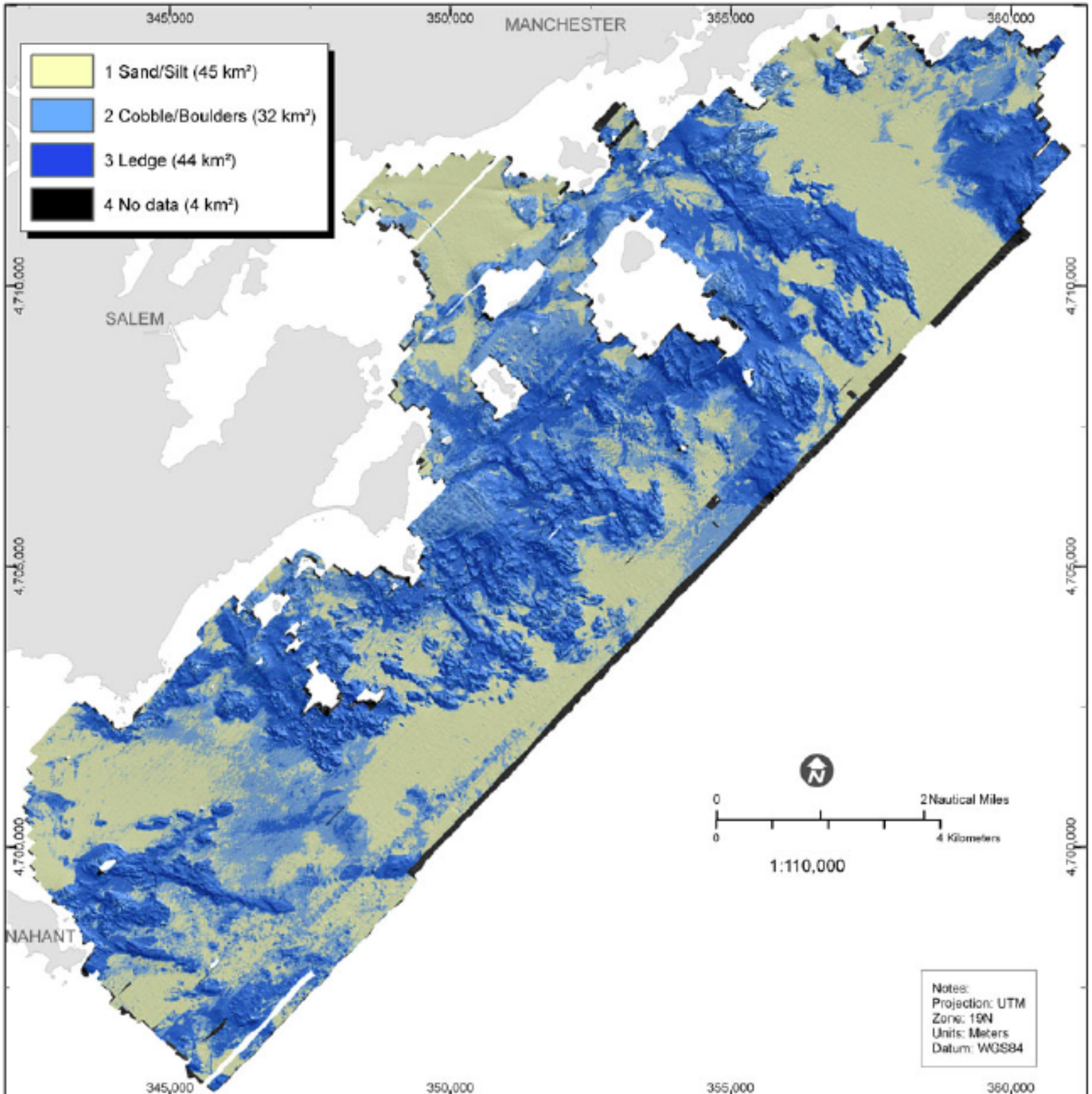


Figure 4.3. Map of generalized bottom type generated by multivariate analysis of seafloor properties.

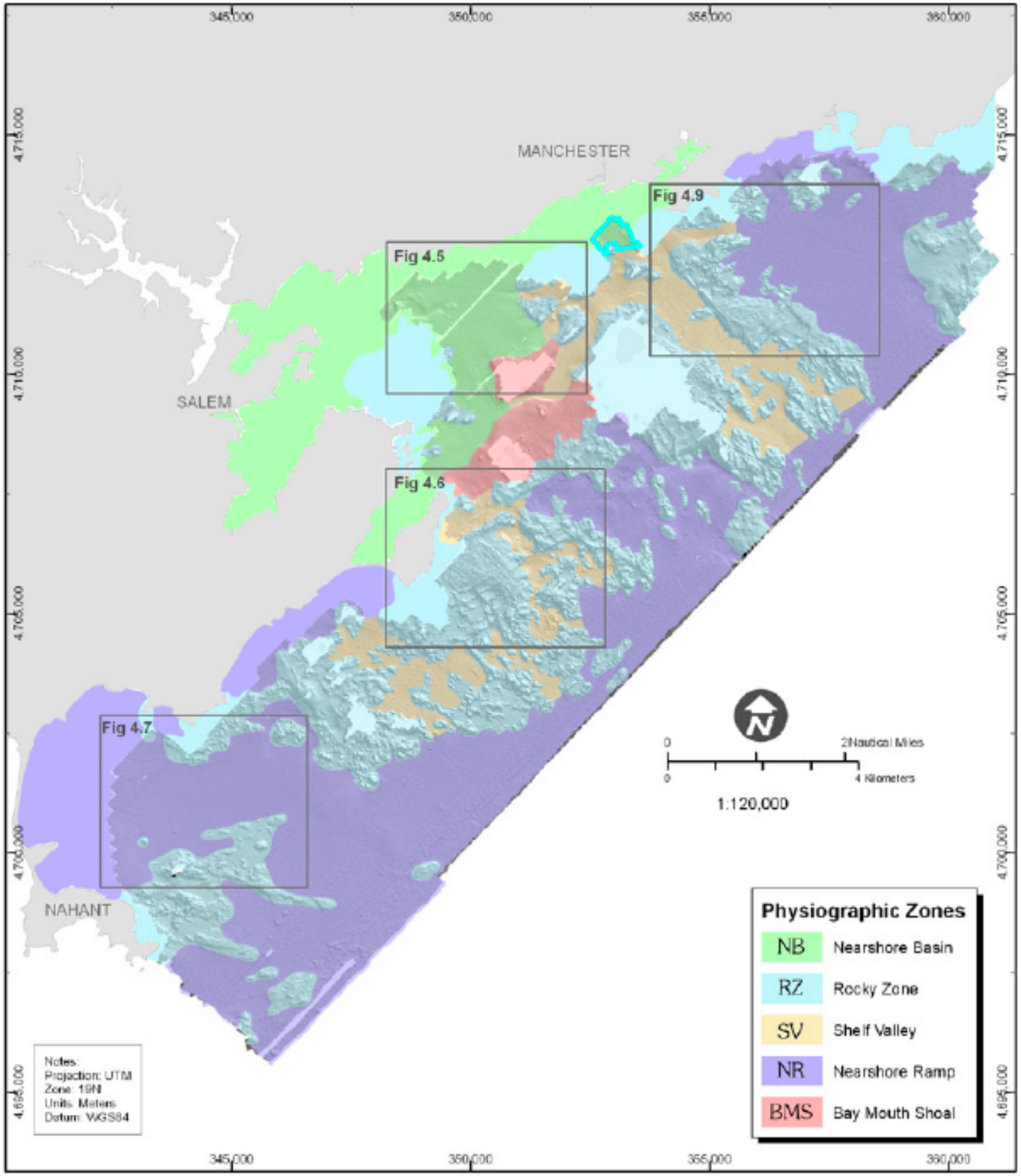


Figure 4.4. Map depicting the physiographic zones of the inner continental shelf. See text for description of zones. Index boxes show locations of inset maps in Figures 4.5, 4.6, 4.7, and 4.9.

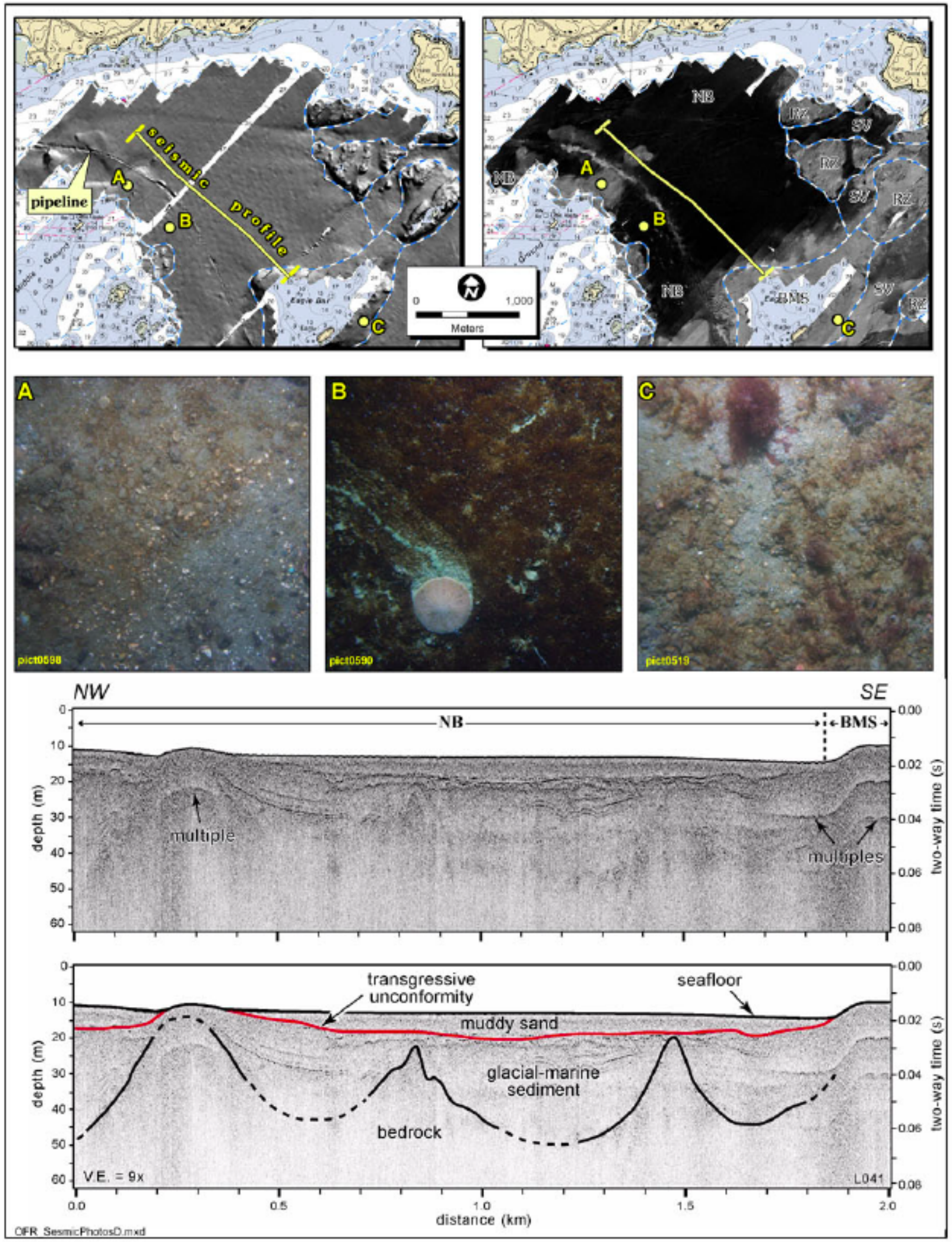


Figure 4.5. Maps of seafloor topography (upper left) and backscatter intensity (upper right) in Salem Sound. Both maps are overlain on NOAA-NOS nautical chart #13275. Dashed lines show boundaries of physiographic zones, which are based on seafloor topography and dominant substrate properties. See Figure 4.4 for location of maps. Bottom photographs A-C (middle) and seismic-reflection profile (bottom) are indicated by yellow circles and line, respectively. The distance across the bottom of the photographs is approximately 50 cm.

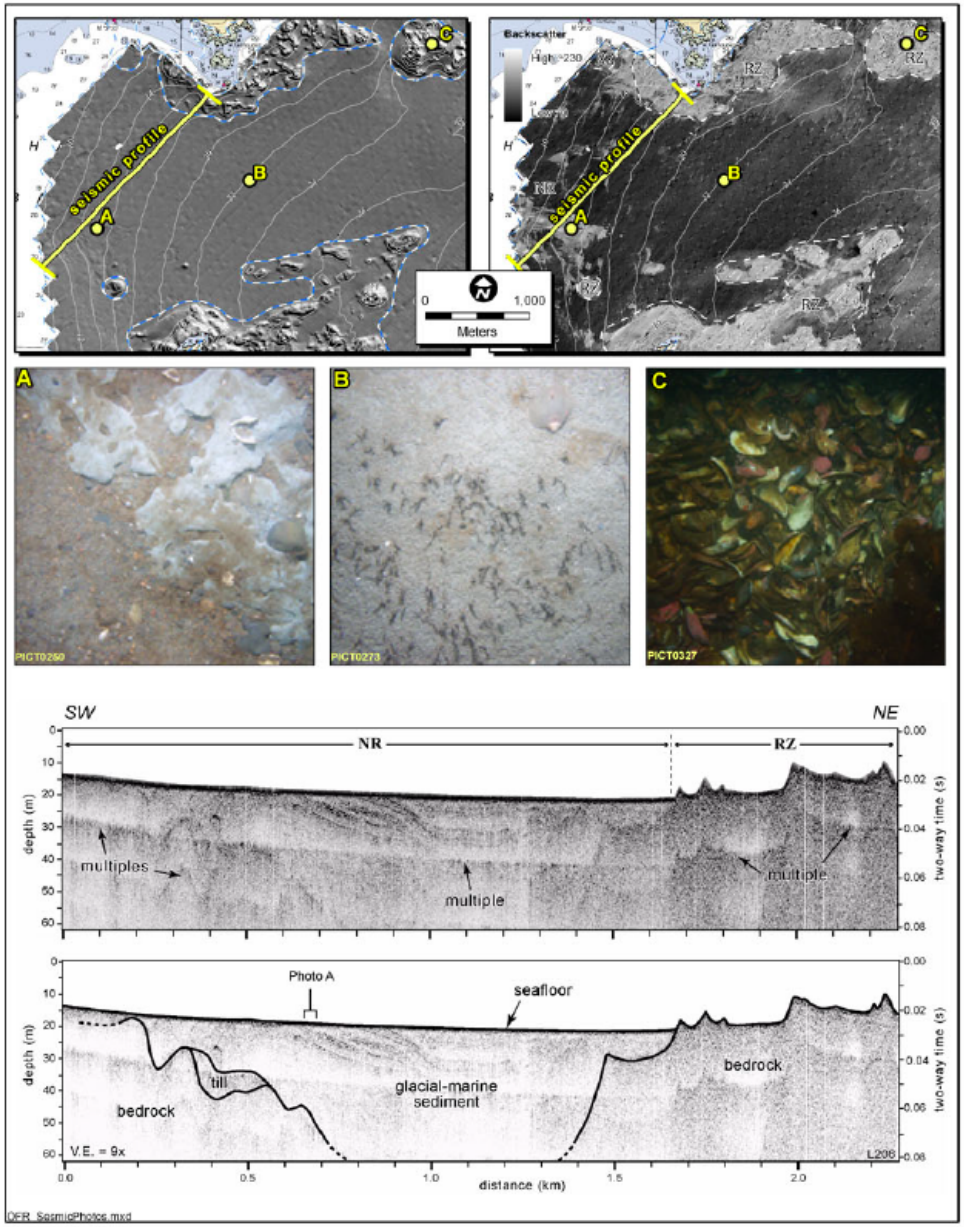


Figure 4.7. Maps of seafloor topography (upper left) and backscatter intensity (upper right) in Nahant Bay and approaches. Both maps are overlain on NOAA-NOS nautical chart #13275. Contour interval is 2 m. See Figure 4.4 for location of maps. Dashed lines show boundaries of physiographic zones, which are based on seafloor topography and dominant substrate properties. Bottom photographs A-C (middle) and seismic-reflection profile (bottom) are indicated by yellow circles and line, respectively. The distance across the bottom of the photographs is approximately 50 cm.

Example: sorted sediments (interferometric sonar)

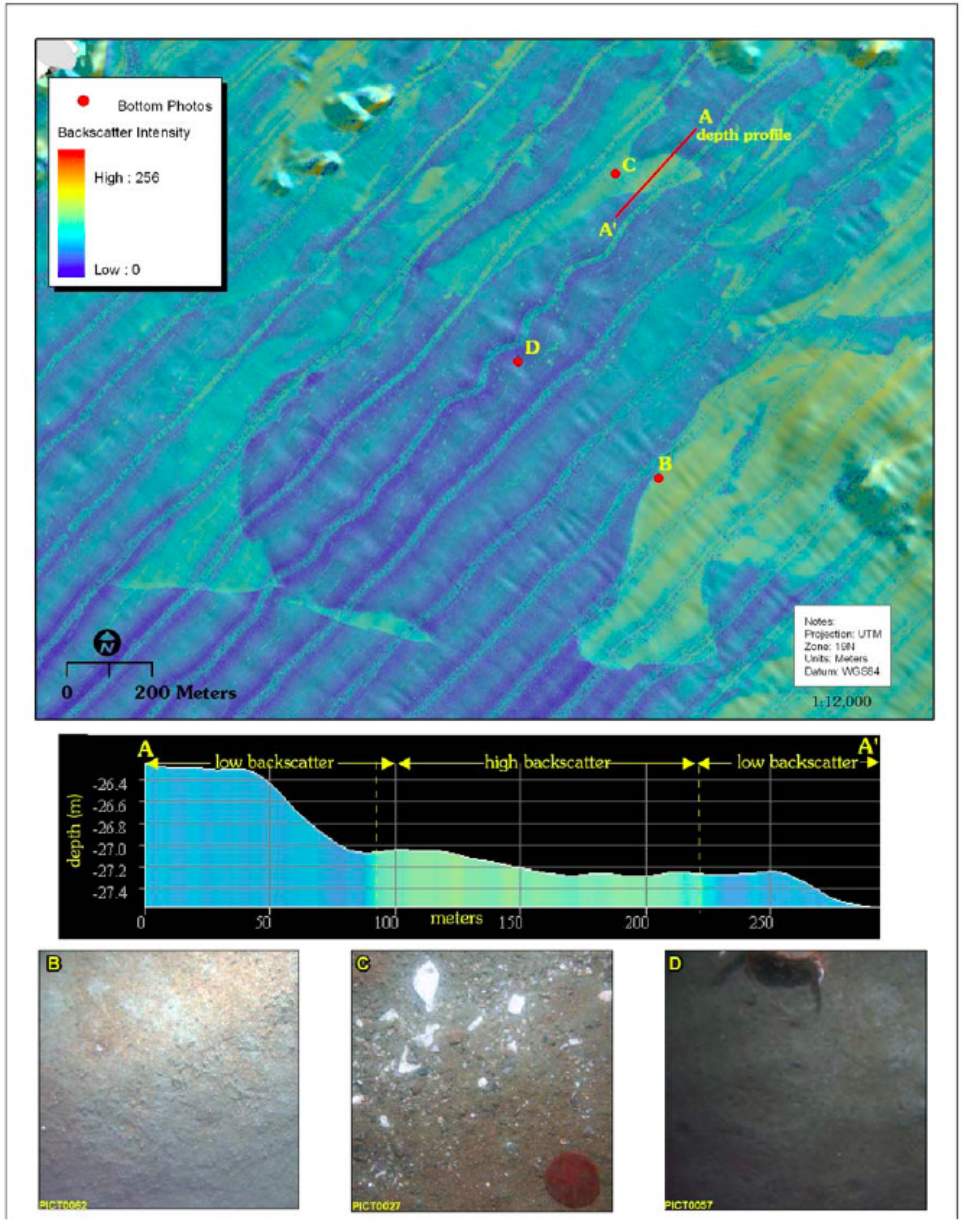


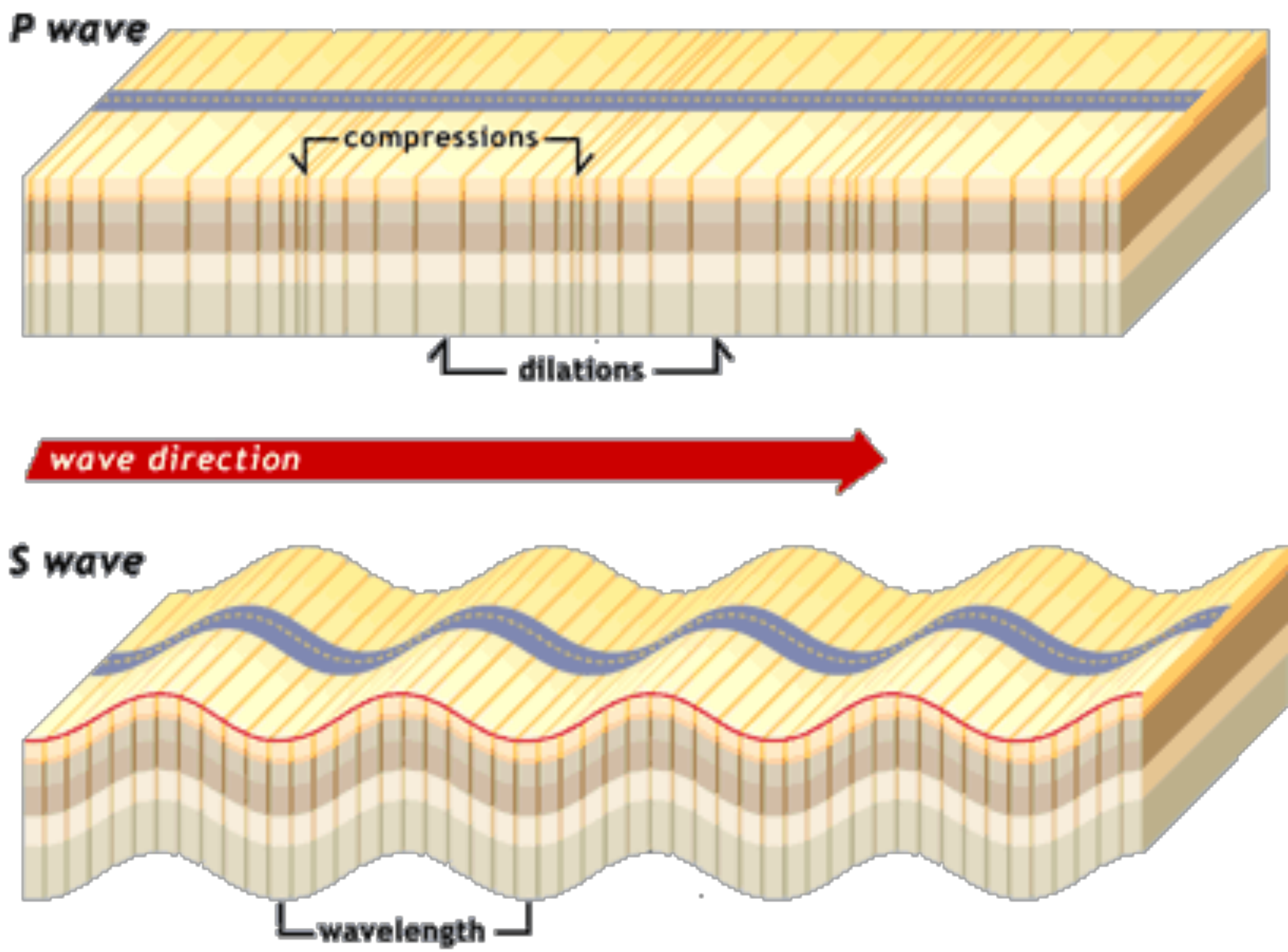
Figure 4.8. Map of seafloor topography colored by backscatter intensity in the northeastern part of the study area. Depth and backscatter data in this map were collected simultaneously by the pole-mounted interferometric sonar, ensuring precise navigation. The depth profile (A - A') crosses a sorted bedform in the upper part of the map; color coding on the profile shows high backscatter material on the floor of a shallow depression and high backscatter on adjacent, slightly elevated areas of the seafloor. Parallel stripes that trend SW-NE are artifacts of data collection. Bottom photographs B-D are indicated by red dots on the map. See figure 3.3 for location.

Seismic waves (waves propagating within the sediment):

$$v_p = \sqrt{\frac{K + (4/3)\mu}{\rho}}$$

$$v_s = \sqrt{\frac{\mu}{\rho}}.$$

K-bulk modulus
μ-shear modulus



Which is faster?