Seafloor characterization through Acoustic backscatter imagery

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From hemp rope, to piano wire, to echo-sounding, to…

1905 - General Bathymetric Chart of the Oceans (GEBCO), First Edition
a series of printed sheets covering the globe at a scale of $1:10^7$

2003 - GEBCO Digital Atlas (GDA), Centenary Edition
including the first release of the GEBCO 1" bathymetric grid.

20XX - Expanded Atlas including seafloor characteristics
at the same resolution as the bathymetry, or better.

… techniques allowing full characterization of the bottom morphology and facies of the Earth's water bodies.

1. Why do we need bottom characterization?
2. How might we obtain this information?
3. What are the major challenges?

WHY?

Need to develop a global ocean management plan that integrates bathymetry, geology & geophysics, physical & biological oceanography, and fisheries habitats.

Immediate need for national EEZ plans (200 nm boundary)

Specific uses in:

- cable & pipeline route surveys,
- offshore drilling and mining surveys,
- dredging & disposal surveys,
- navigation channels & costal zone surveillance,
- fisheries habitats assessments,
- sonar modeling.

Data already collected in most swath bathymetry surveys.

HOW?

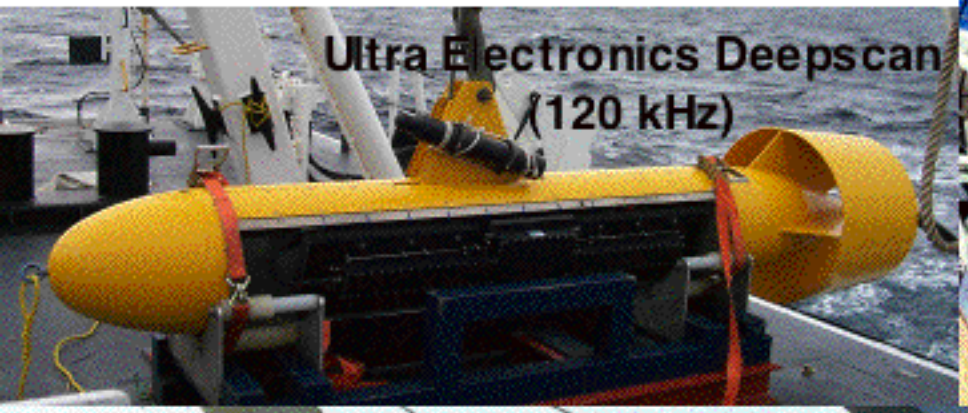
An echo-sounder measures the round-trip travel time of sound waves backscattered by surfaces or scatterers in the sound path.

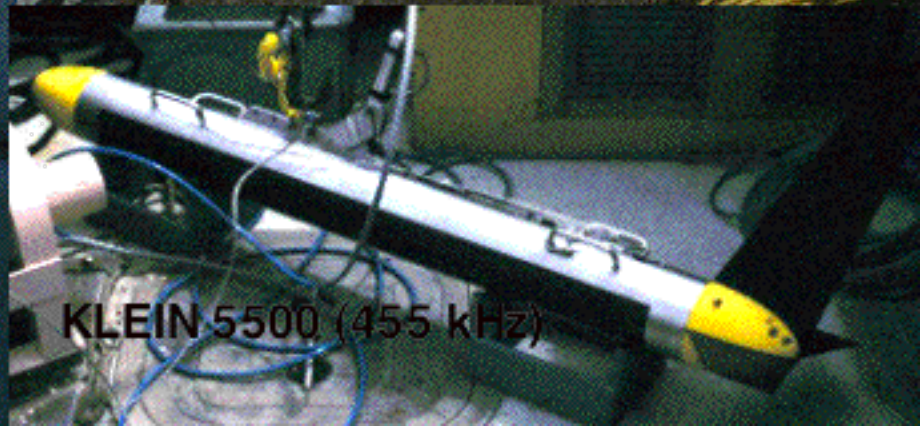
Each backscattered signal contains physical information that characterizes the scattering surface or volume, (acoustic impedance contrast, roughness, resonance highlights, …).

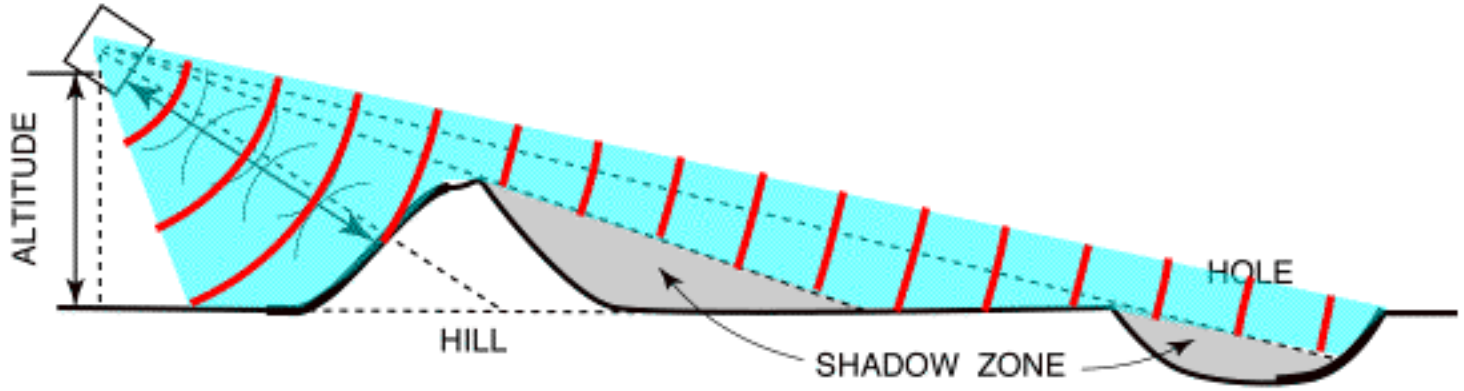
Approach: retain and analyze the backscattered echoes.

Tools include primarily swath(e) bathymetry sonars: sidescan sonars and multibeam echo-sounders.

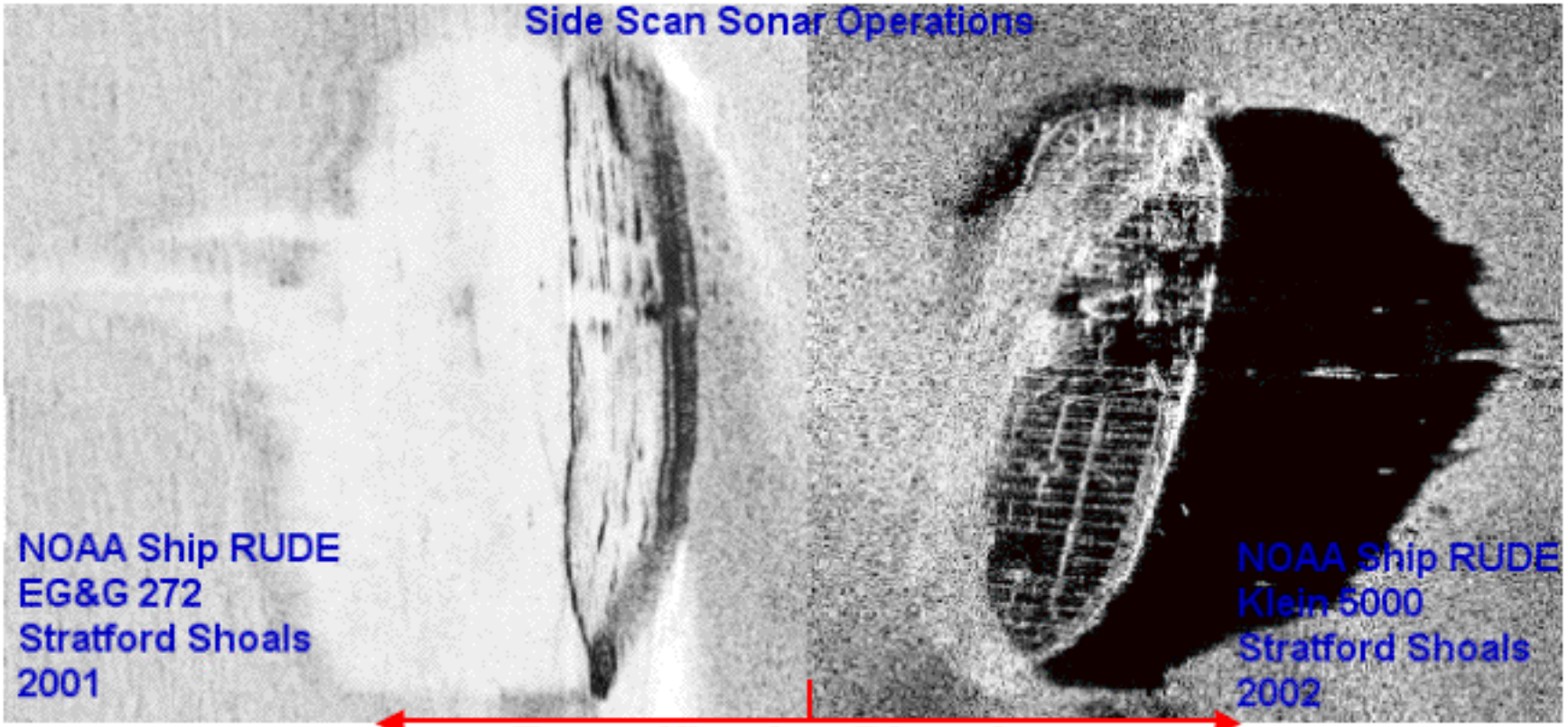
Towed Sidescan Sonars







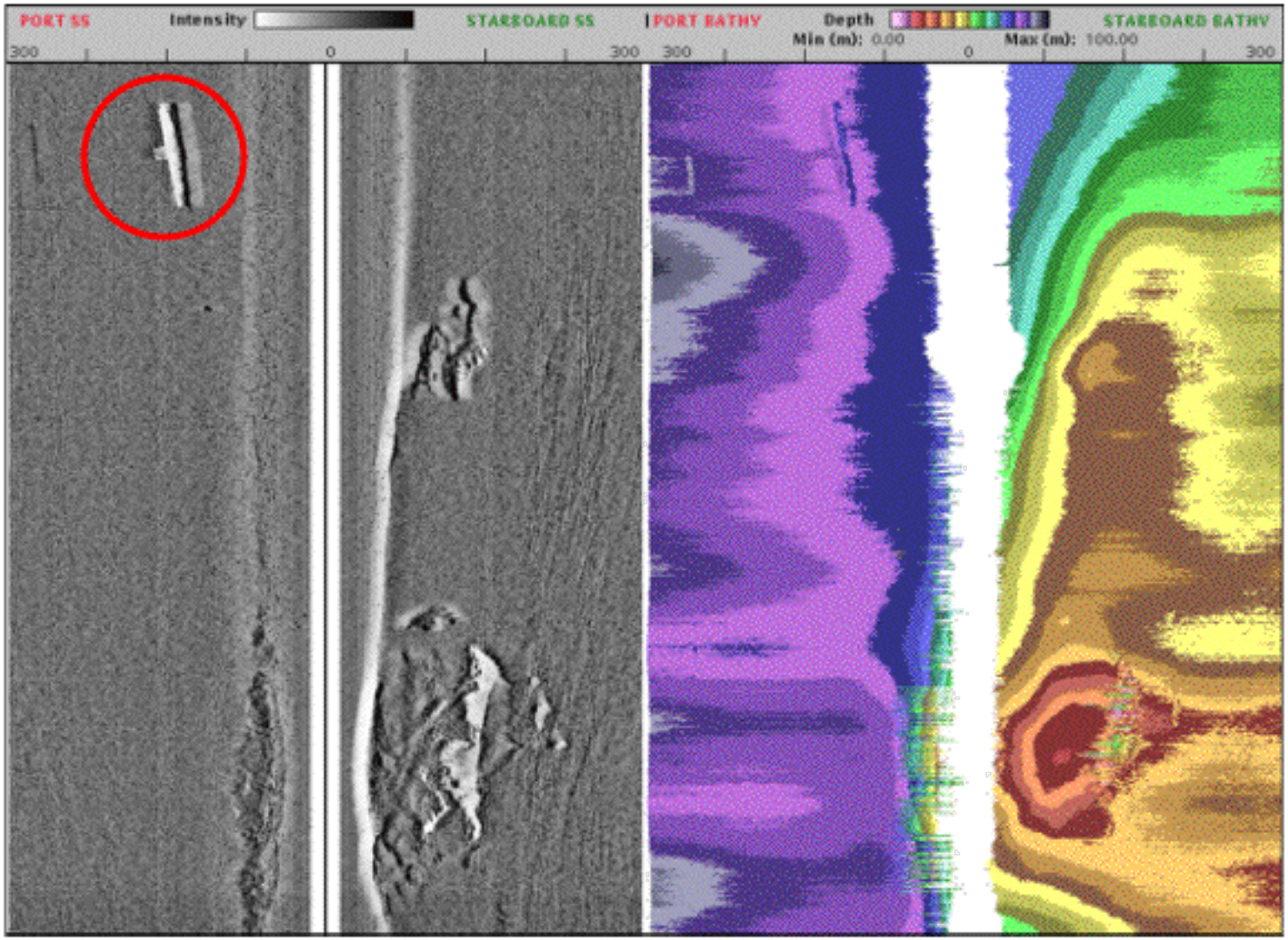
Side Scan Sonar Operations



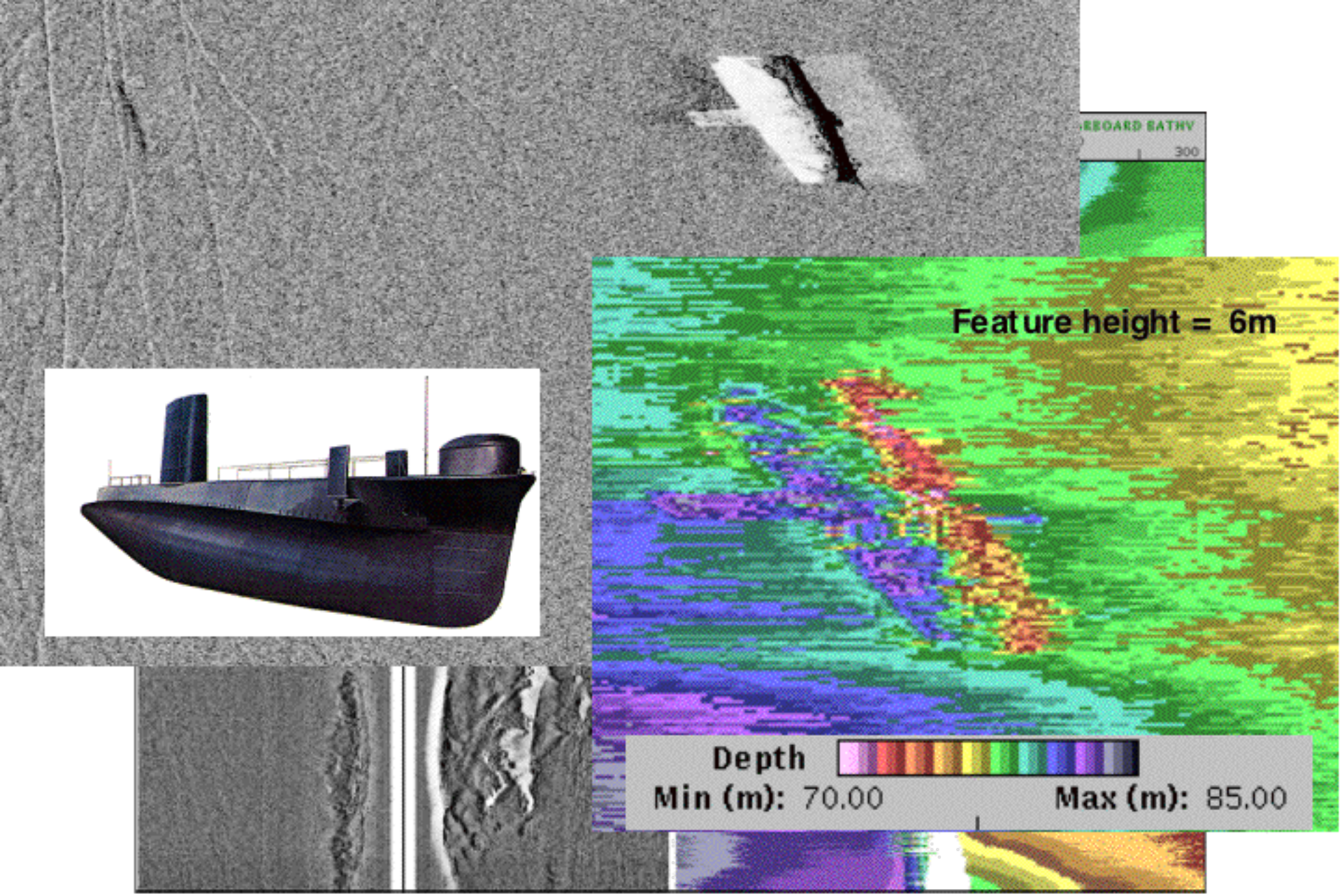
Ensonification Directions

High backscatter = Black

High backscatter = White

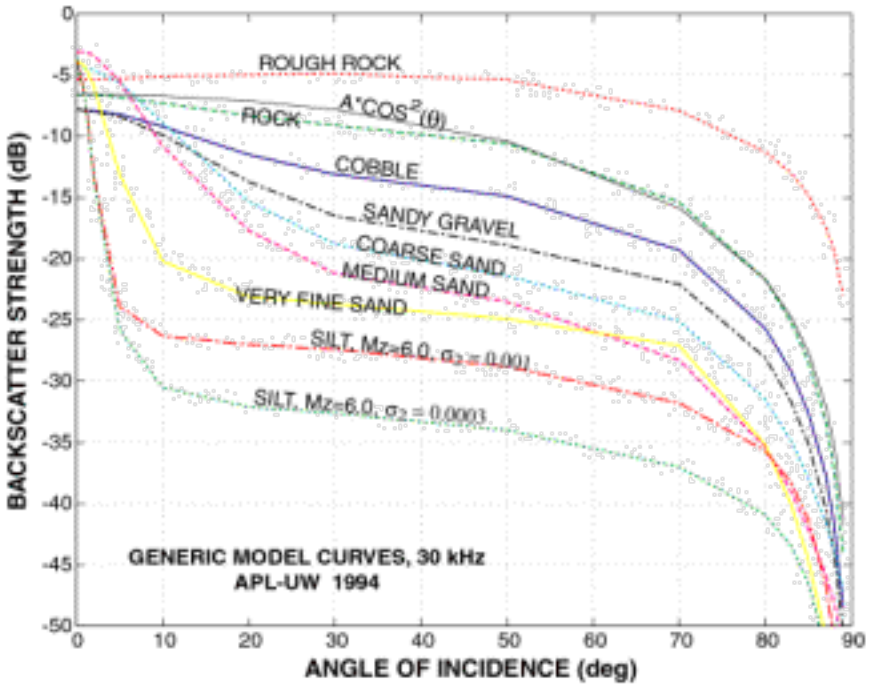


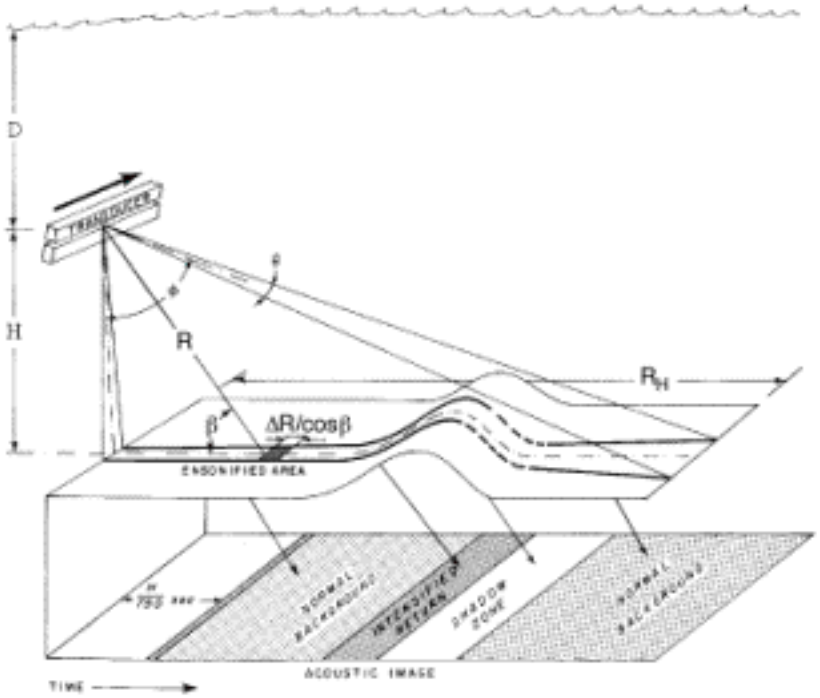
(A.D. Wilby, Proc. IEEE Oceans '00, 2000)



(A.D. Wilby, Proc. IEEE Oceans '00, 2000)

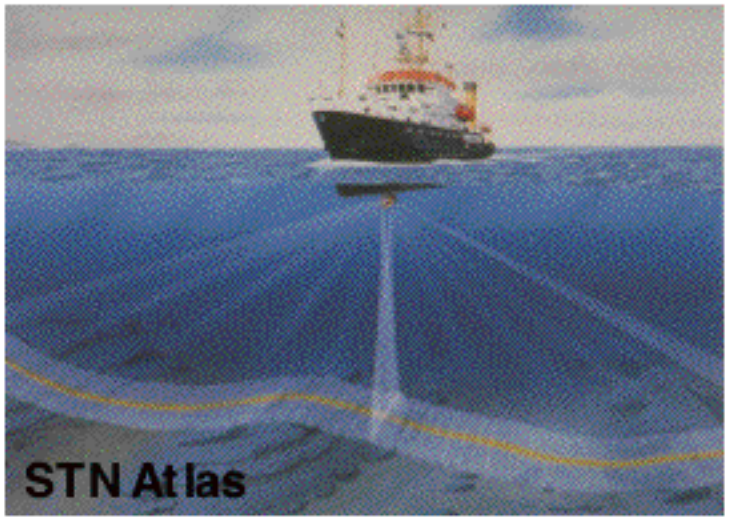
Are We Characterizing Sediment Type or Bottom Relief??

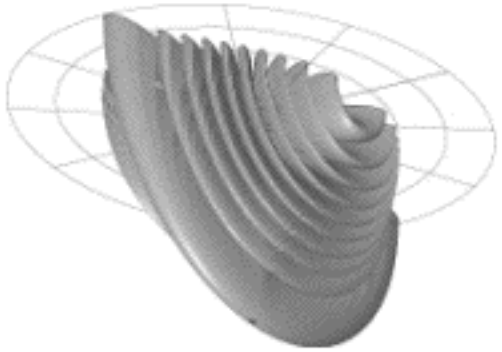




assumes flat, horizontal bottom

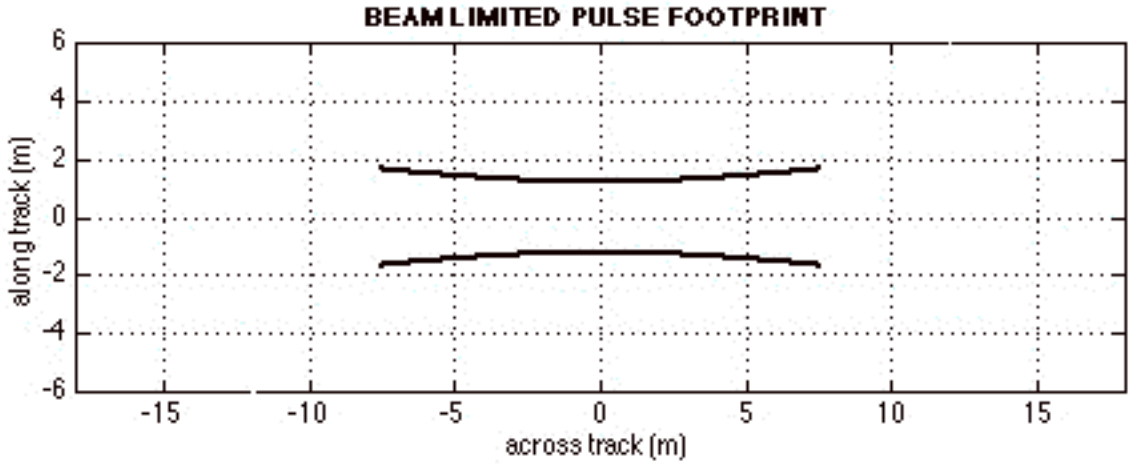
assumes well calibrated sonar system



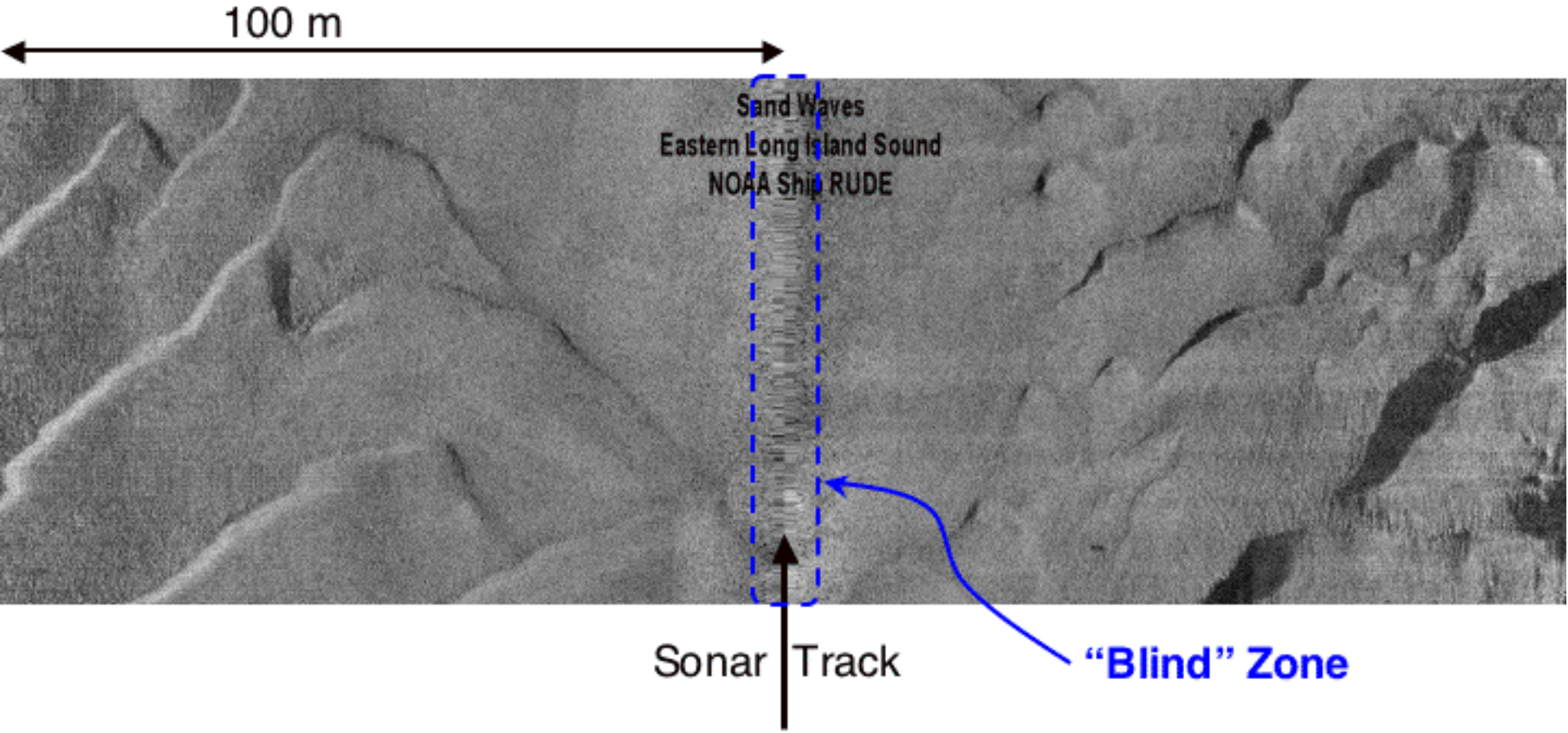


SOURCE

BOTTOM

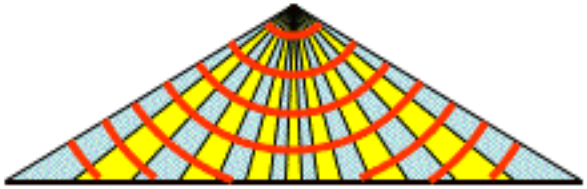


Klein 5000 (455 kHz) Multibeam Sidescan Sonar



Sonar Geometries for Swath Bathymetry

Multibeam Sonar



Sidescan Sonar

Transmit

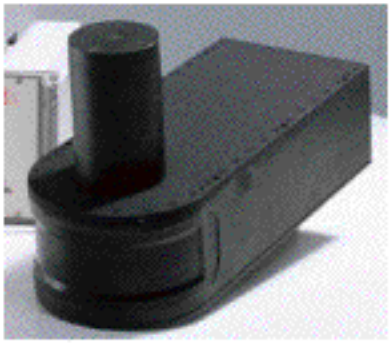
- Broad athwartships sector at single frequency, or
- Multiple sectors at different frequencies (yaw,pitch steering)

- Alternate port/starboard sectors at same frequency, or
- Simultaneous port/starboard at different frequencies
- Blind zone in center 8-30°

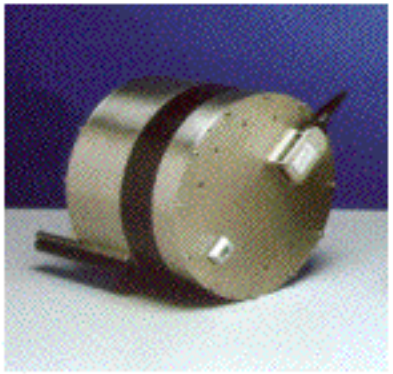
Receive

- Multiple beams formed simultaneously

- Same geometry as transmit

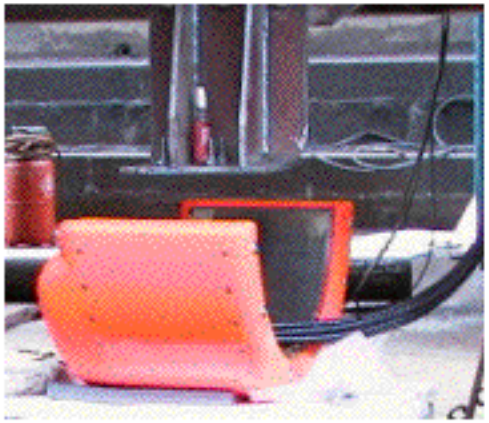


9001



8101

8111

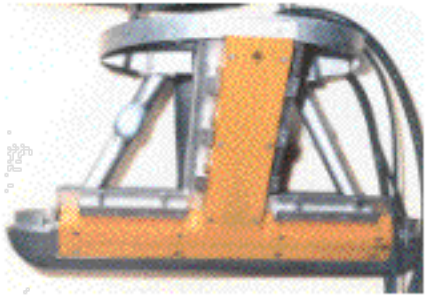


EM 1002

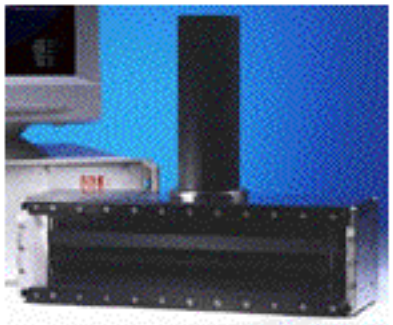
EM 3000

SB1180

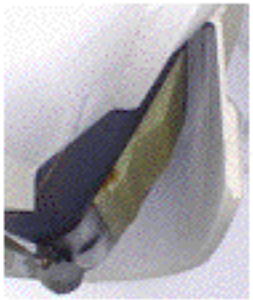
SB1050



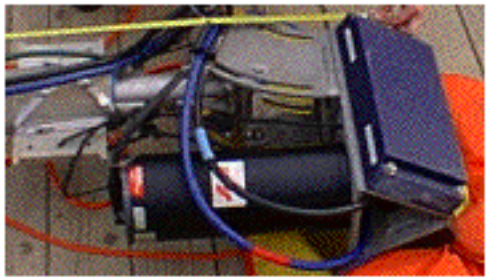
Hydrosweep MD



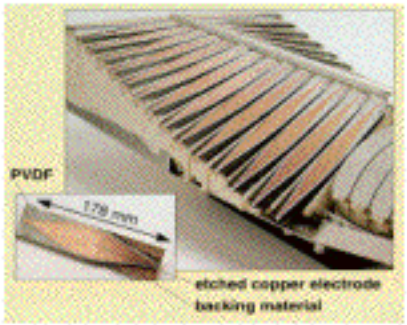
8125



FANSWEEP 20



SUBMETRIX 2000



ECHOSCAN

Multibeam Swath Bathymetry

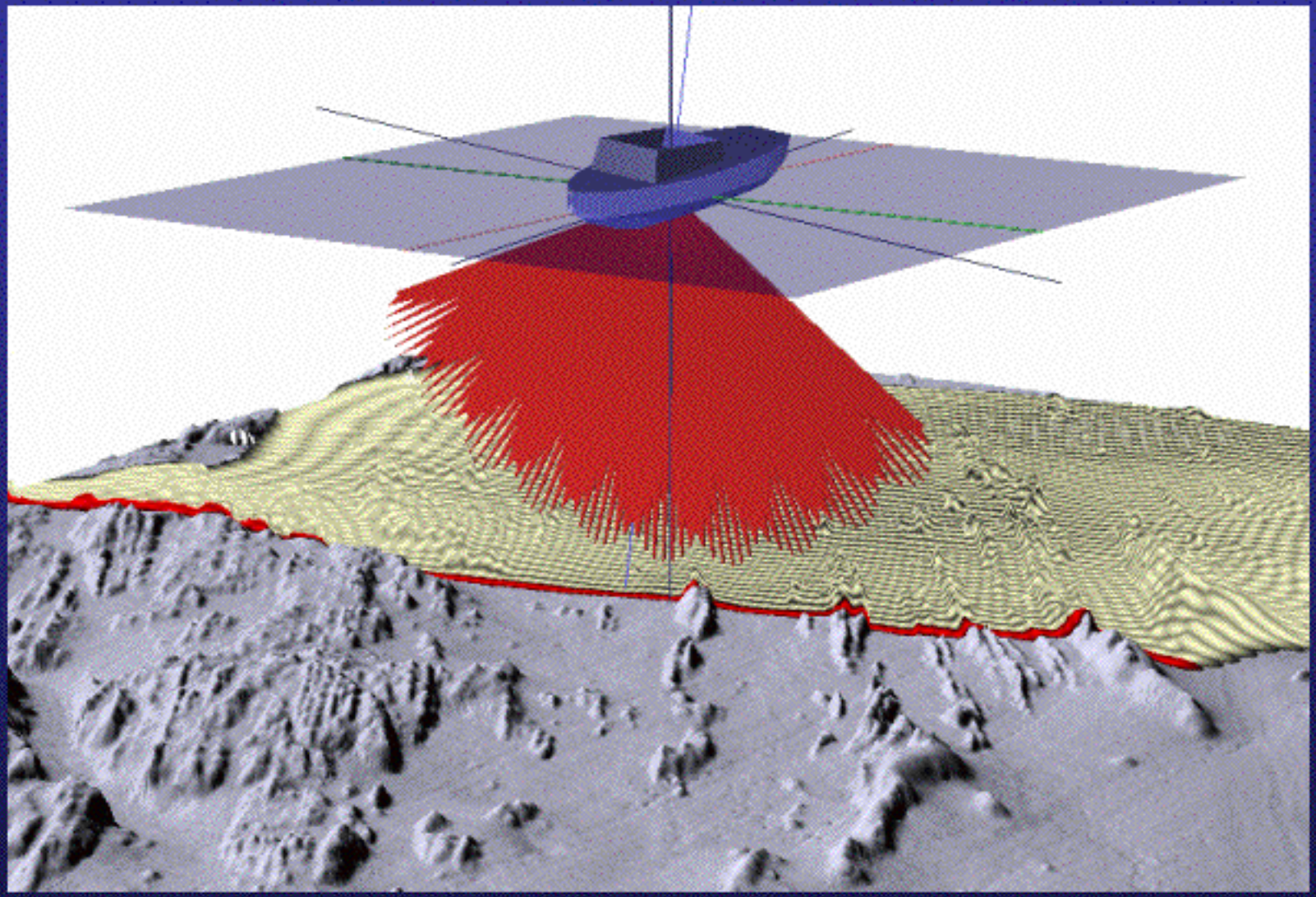
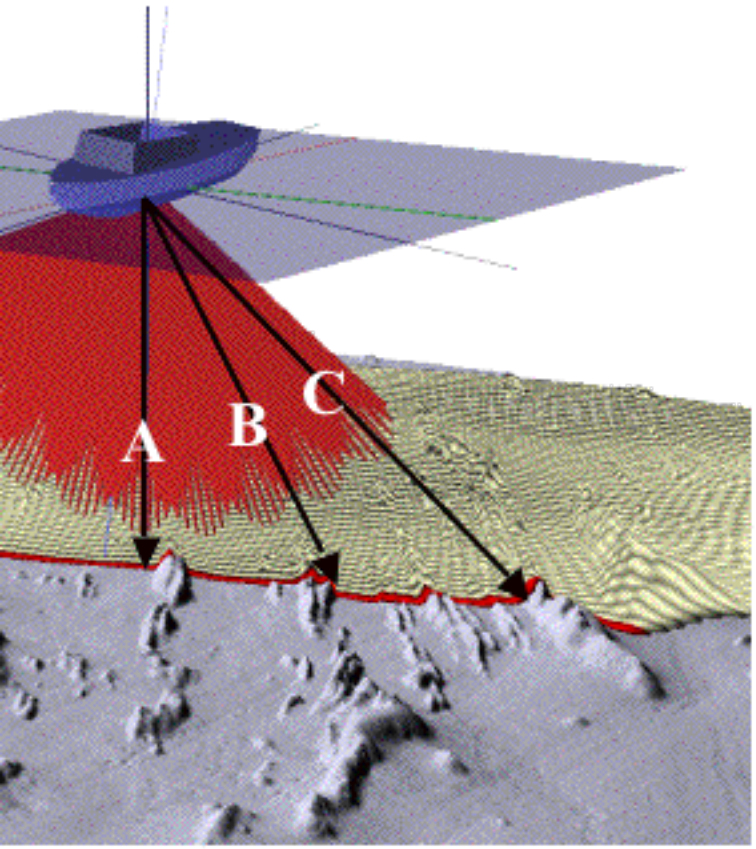


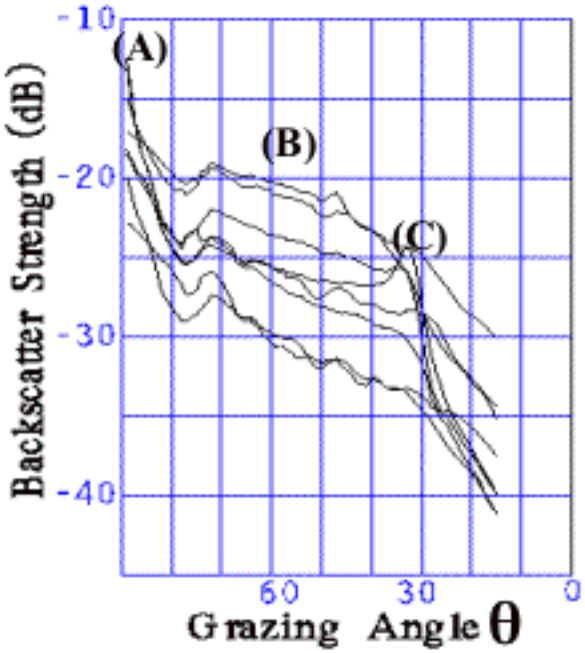
Image derived from theoretical sonar model interacting with artificial seabed DTM using *"SynSwath"* (J.E Hughes Clarke, OMG/UNB)

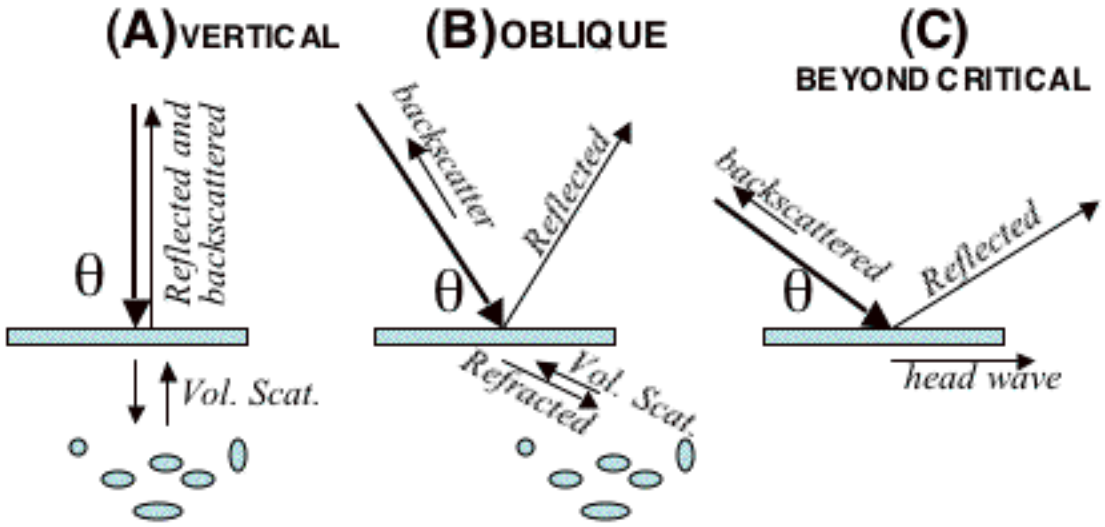
Bottom Backscatter Strength

Angular Dependence

(built into swath imaging geometry)

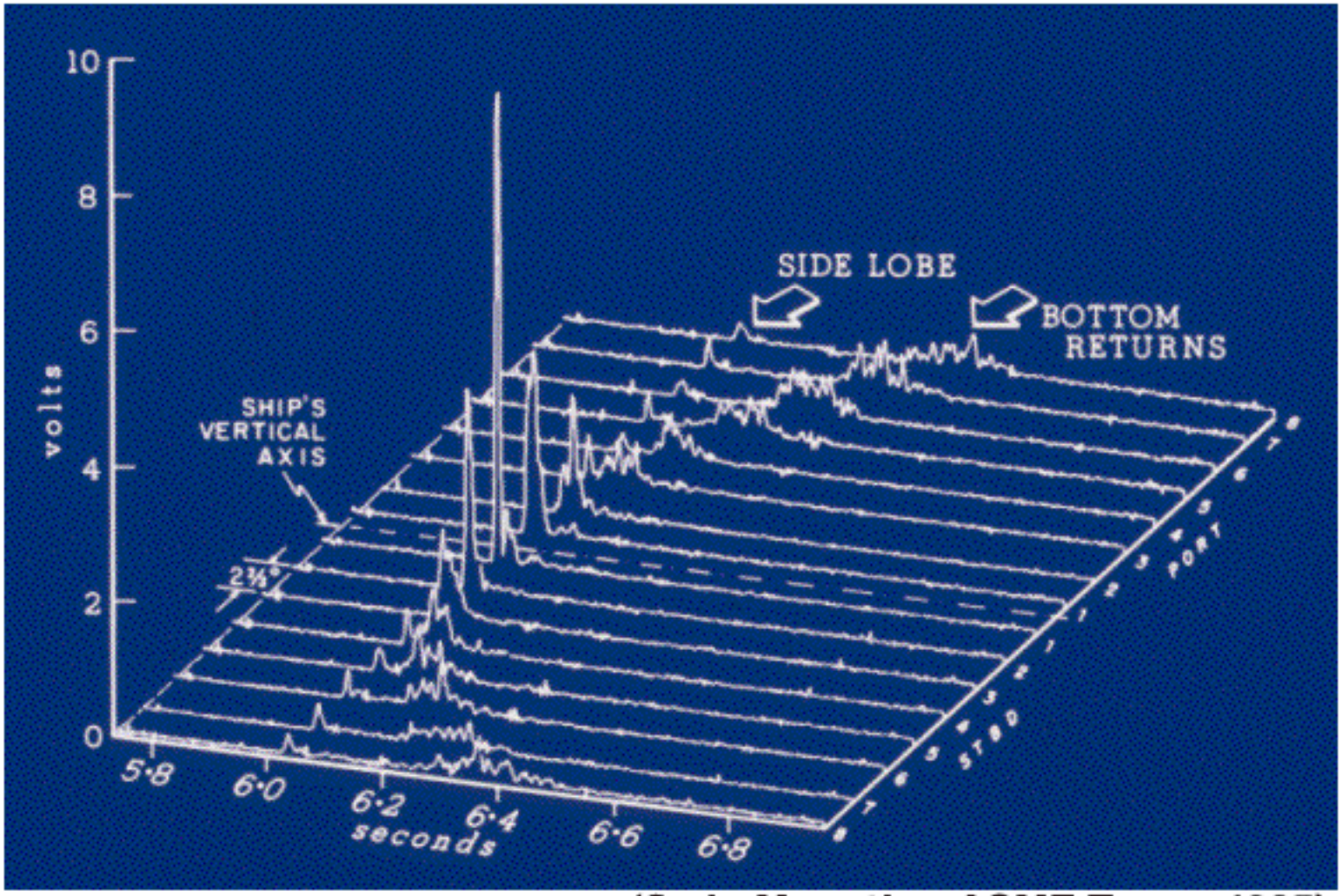






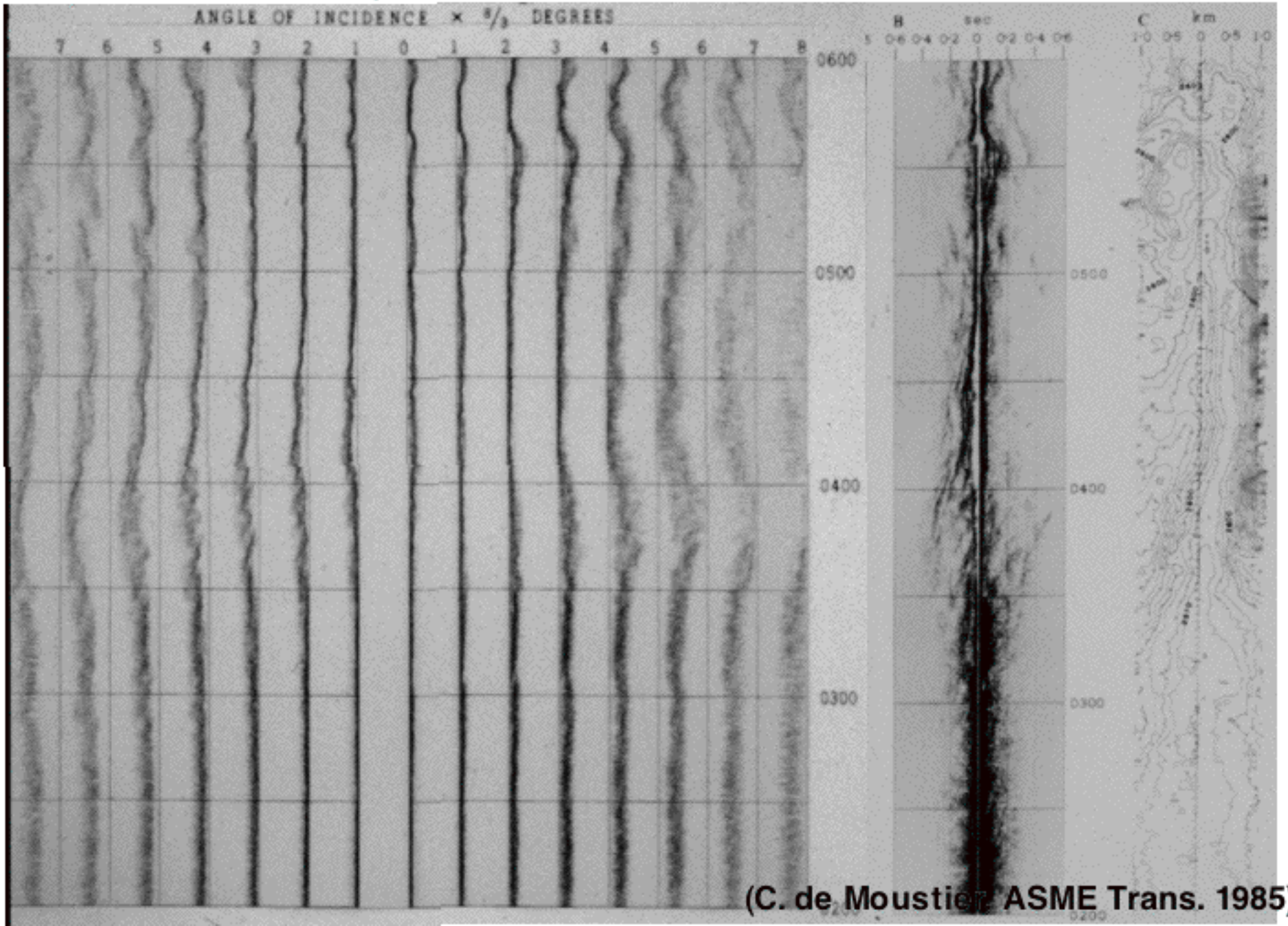
(J.E Hughes Clarke, OMG/UNB)

Backscattered Seafloor Echo Envelopes Received in The 16 Beams of the "SeaBeam Classic" (R/V T. Washington)



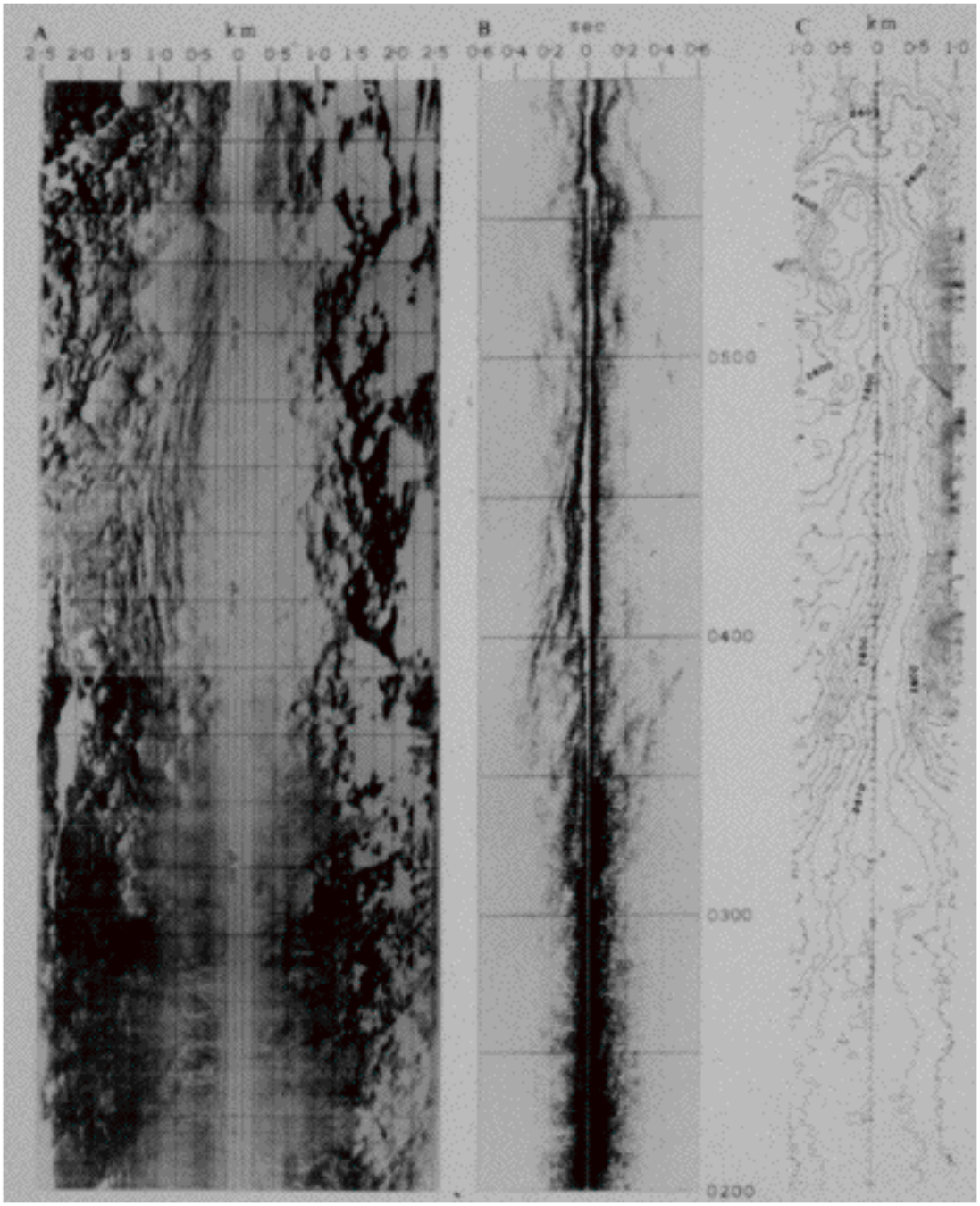
(C. de Moustier, ASME Trans. 1985)

Backscatter Image Construction - 16 Beam SeaBeam Classic



(C. de Moustier, ASME Trans. 1985)

(A) 30 kHz SeaMARCI near-bottom sidescan survey EPR-9°N 5 km swath



(C) concurrent SeaBeam Classic bathymetry and

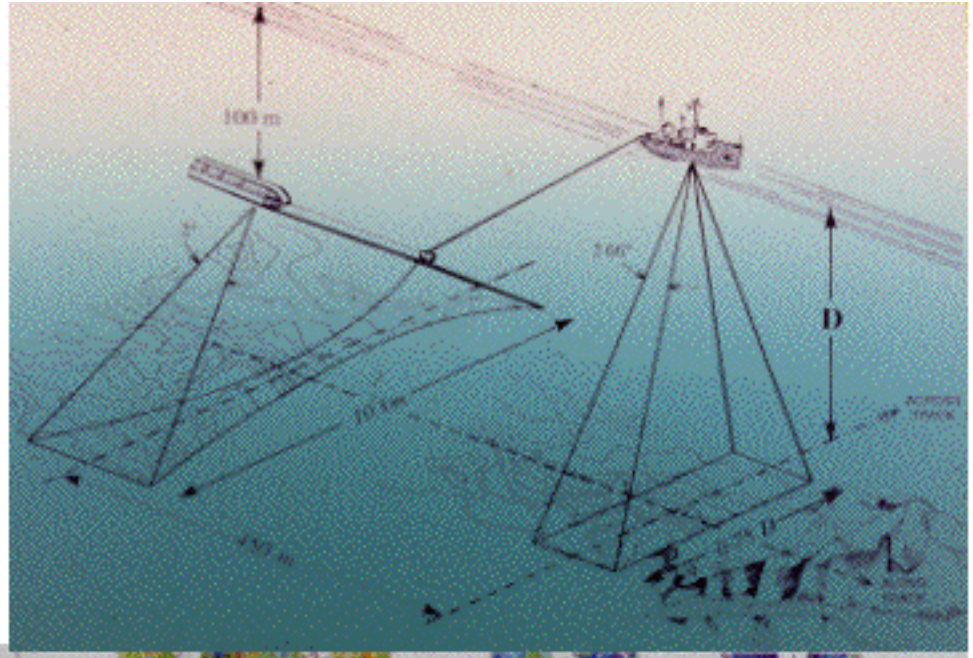
(B) acoustic imagery

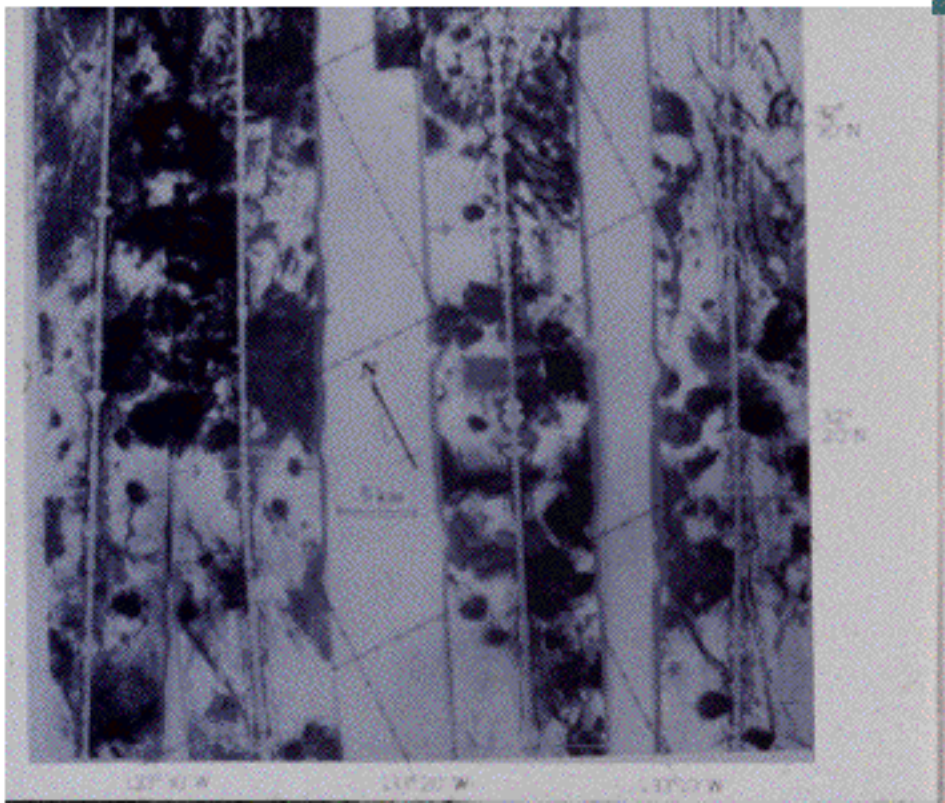
(C. de Moustier, ASME Trans. 1985)

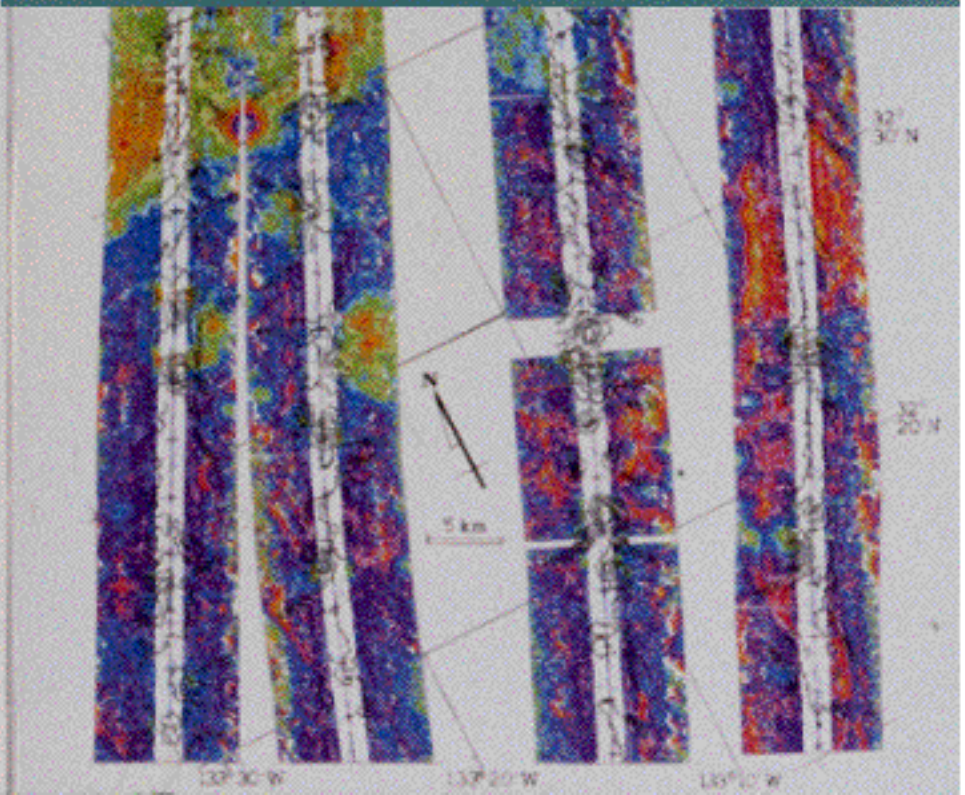
SeaMARCII:
Acoustic backscatter imaging & bathymetry

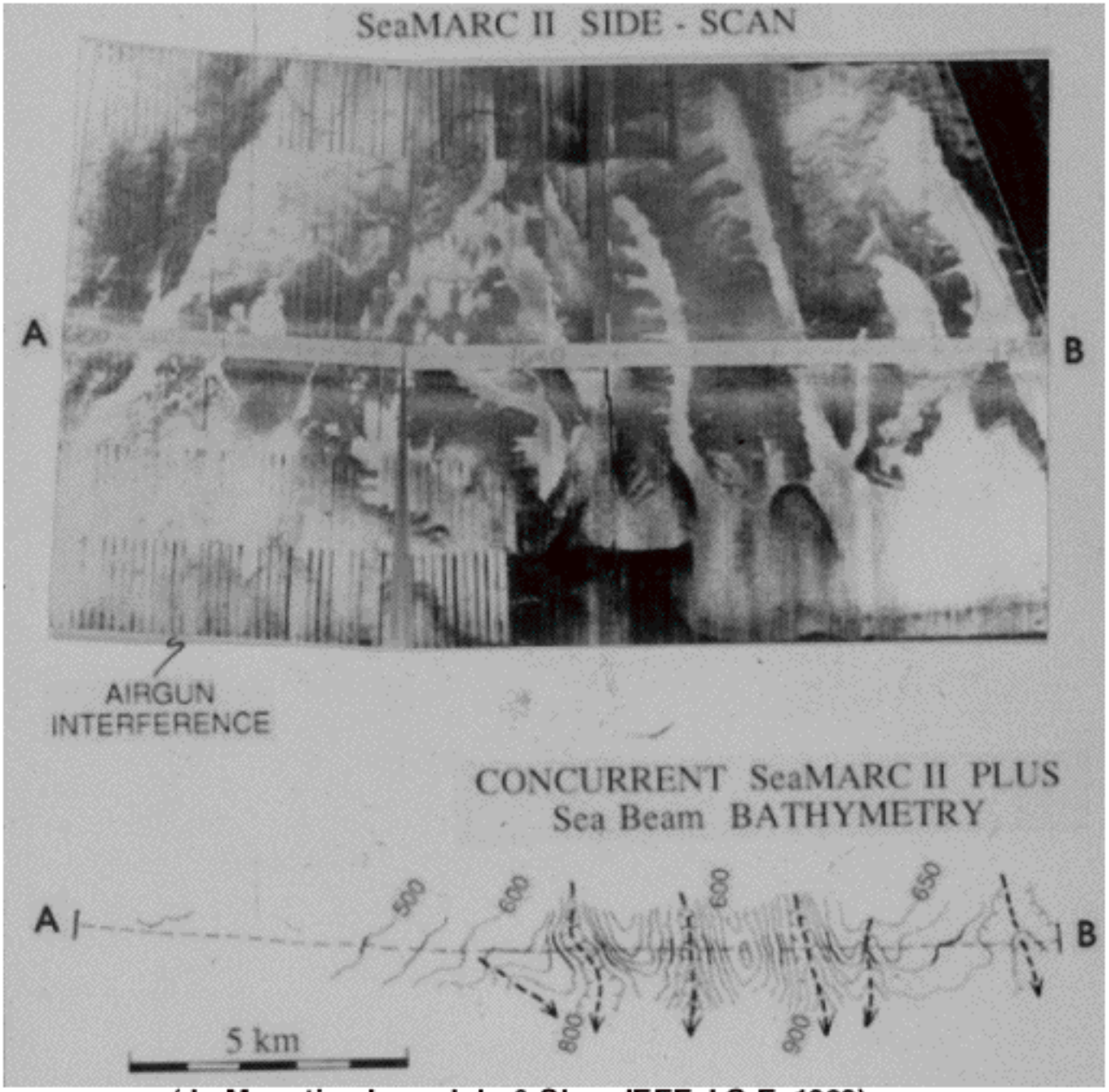
SeaBeam "Classic":
Nadir bathymetry gap filler

(de Moustier, Lonsdale & Shor, IEEE J.O.E. 1989)

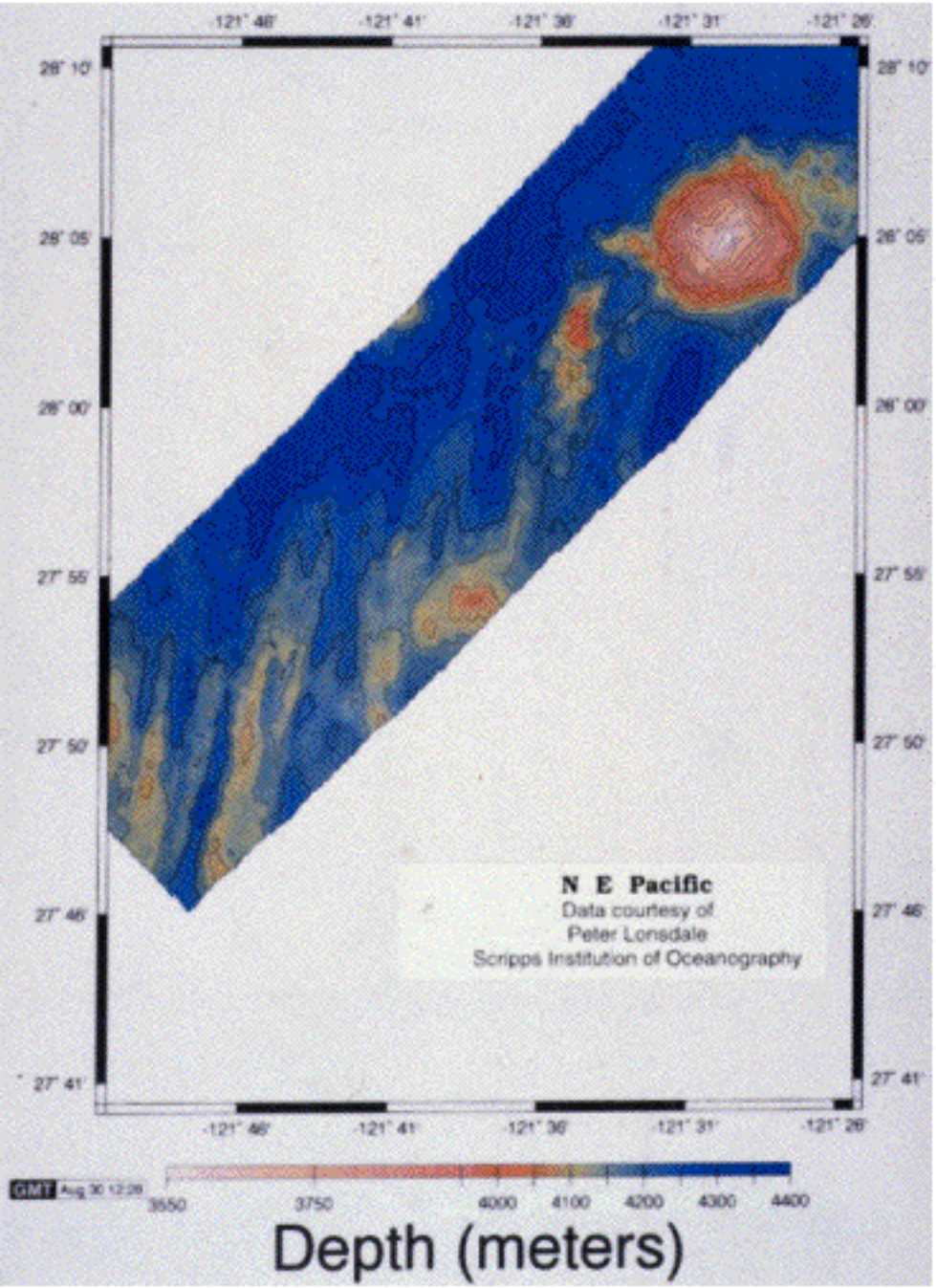


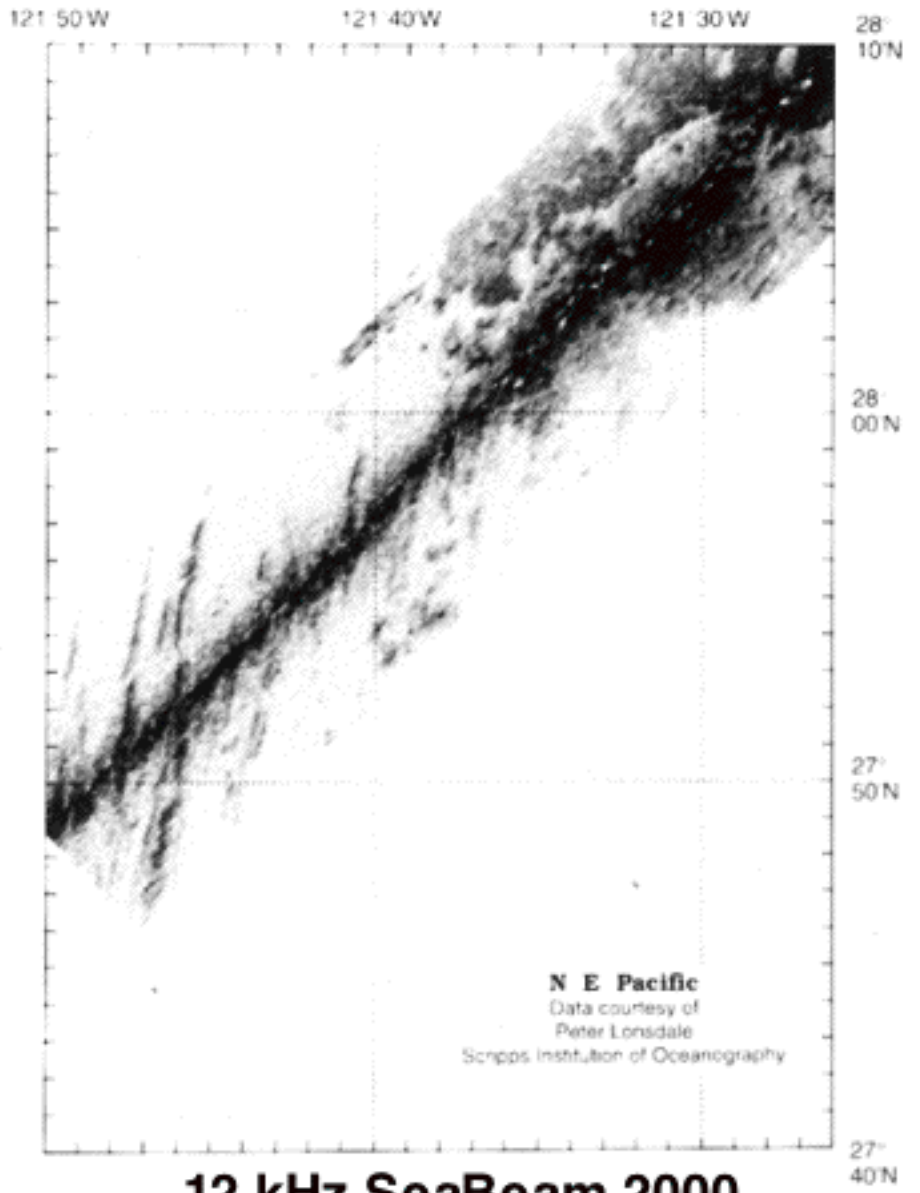




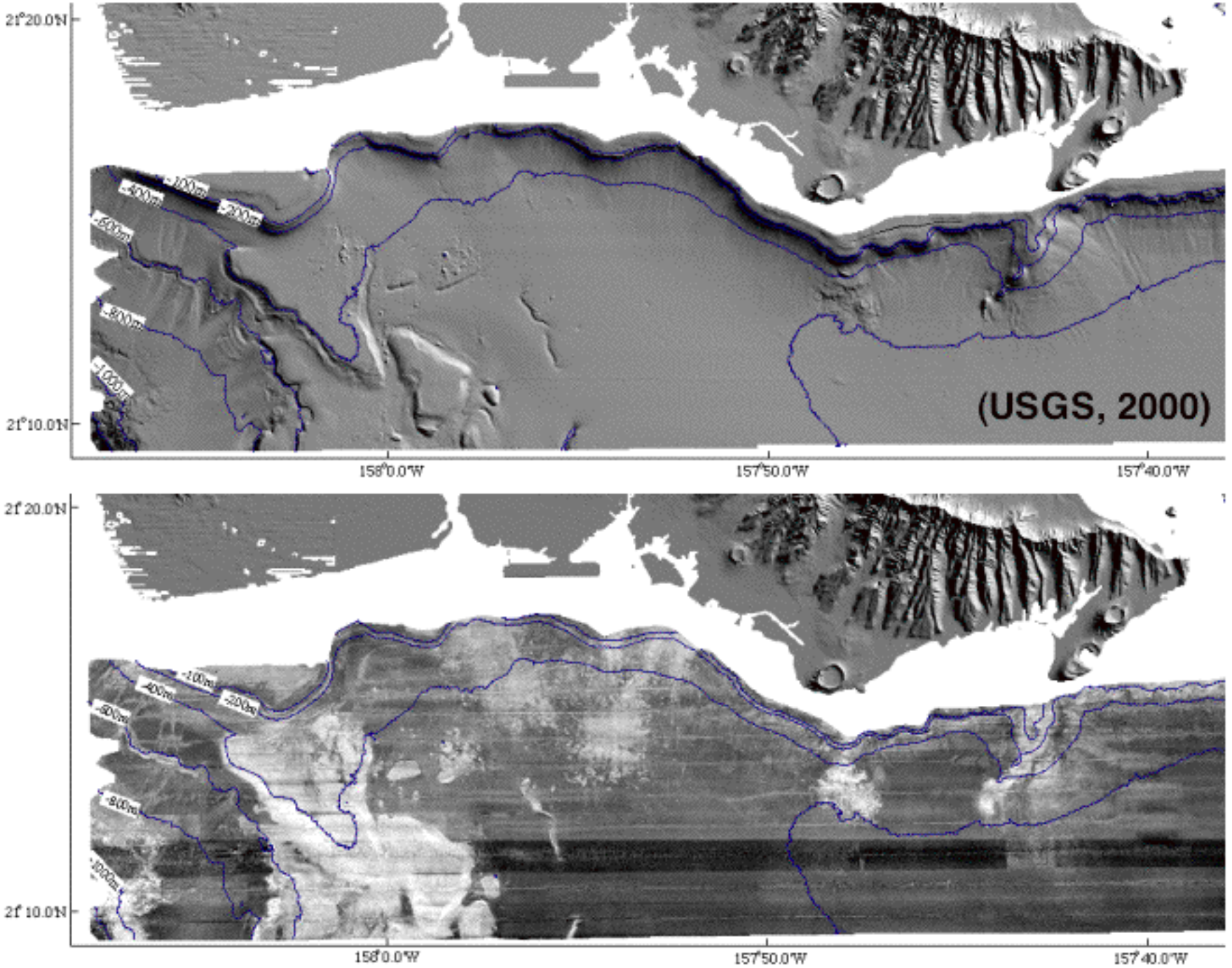


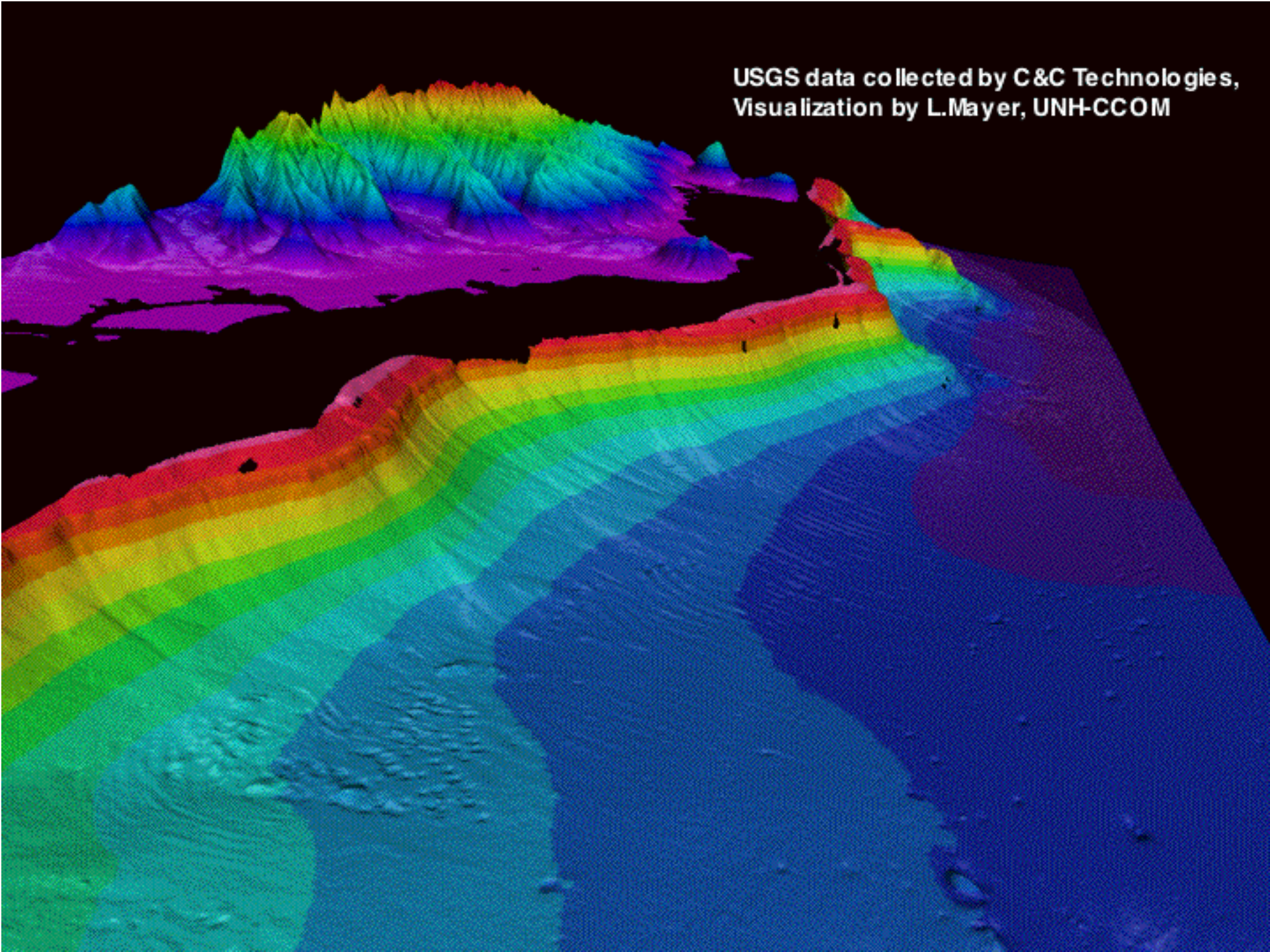
(de Moustier, Lonsdale & Shor, IEEE J.O.E. 1989)

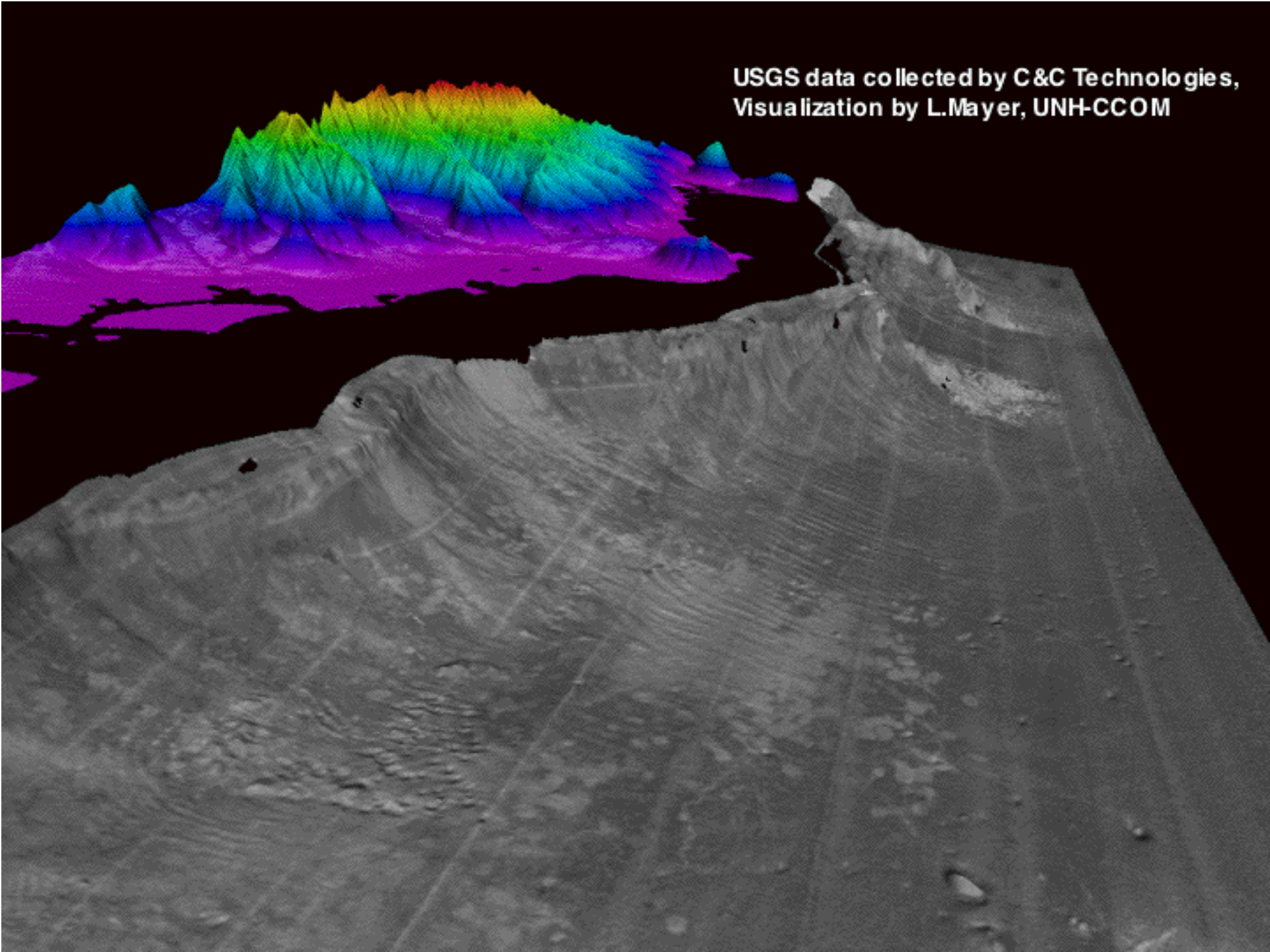




12 kHz SeaBeam 2000 (R/V Melville), 1992


21°20.0'N
21°10.0'N
158°0.0'W
157°50.0'W
157°40.0'W
-100m
-200m
-400m
-600m
-800m
-1000m
(USGS, 2000)


USGS data collected by C&C Technologies,
Visualization by L.Mayer, UNH-CCOM


USGS data collected by C&C Technologies,
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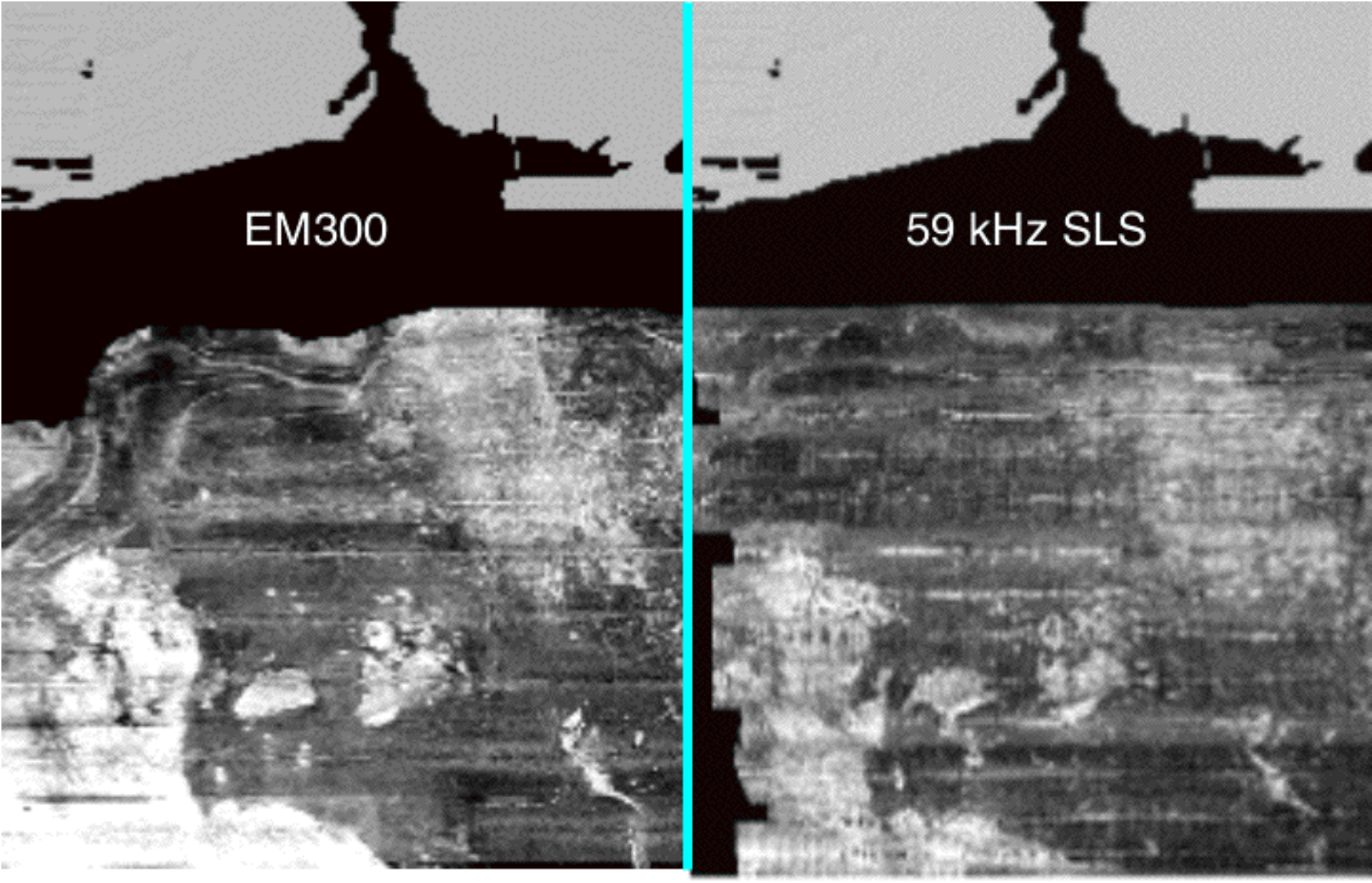


(Field & Torresan, USGS, 2000)

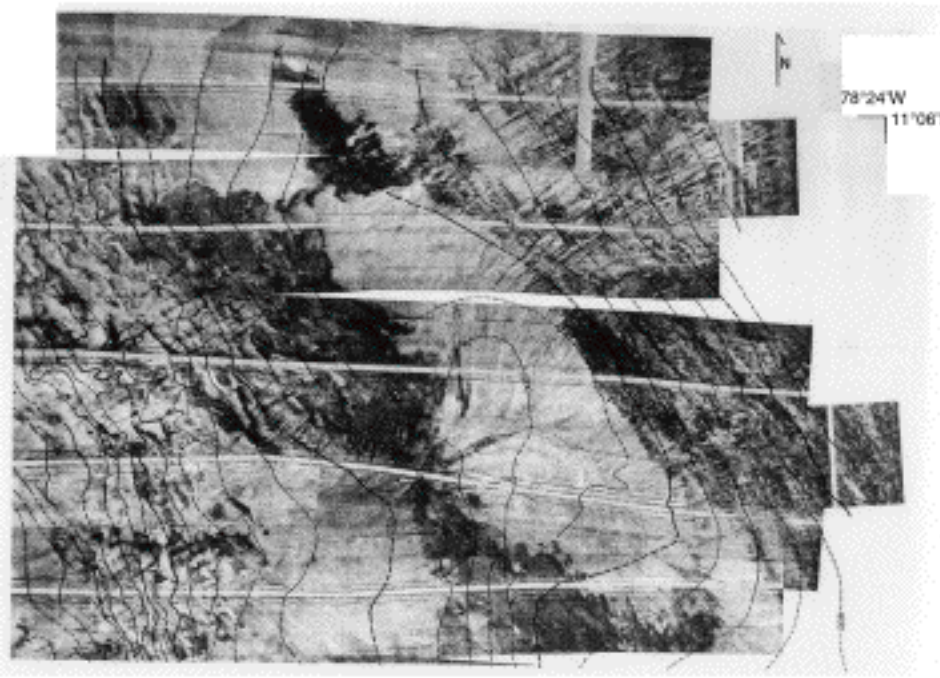
0 2 4 Kilometers

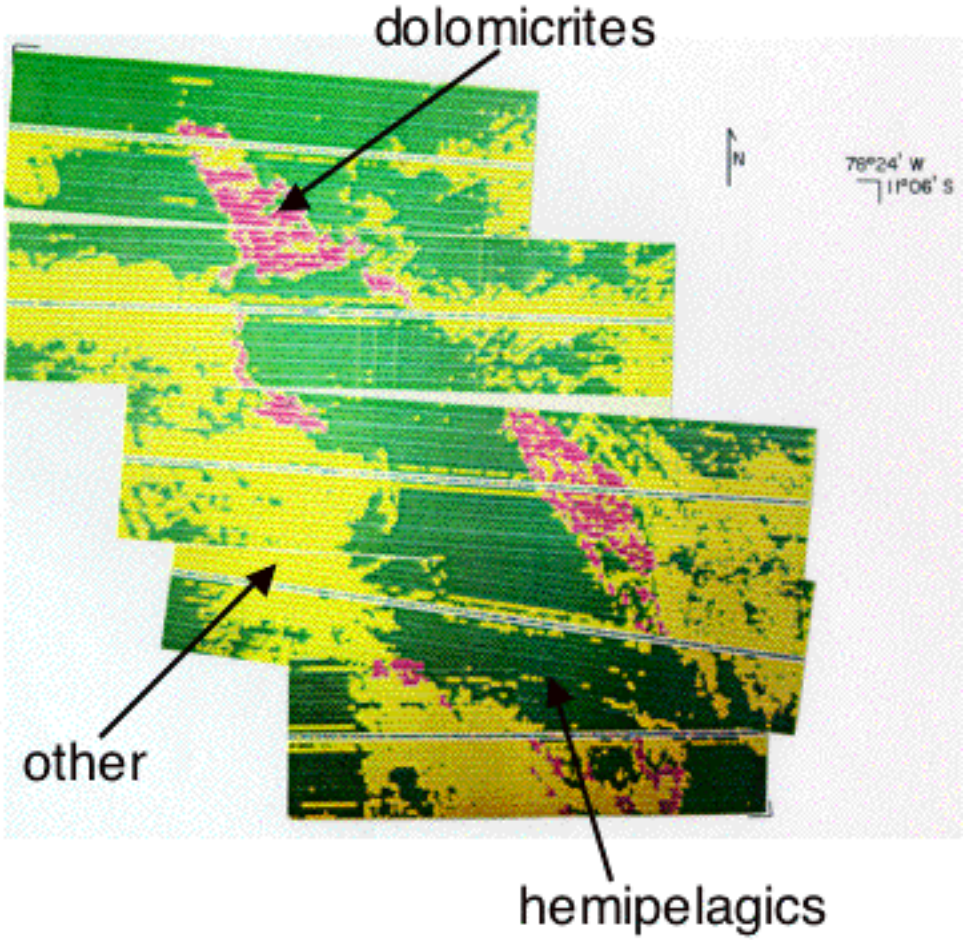
16 April 2003

4 Techniques for Extracting Bottom Characteristics From Acoustic Backscatter Measurements

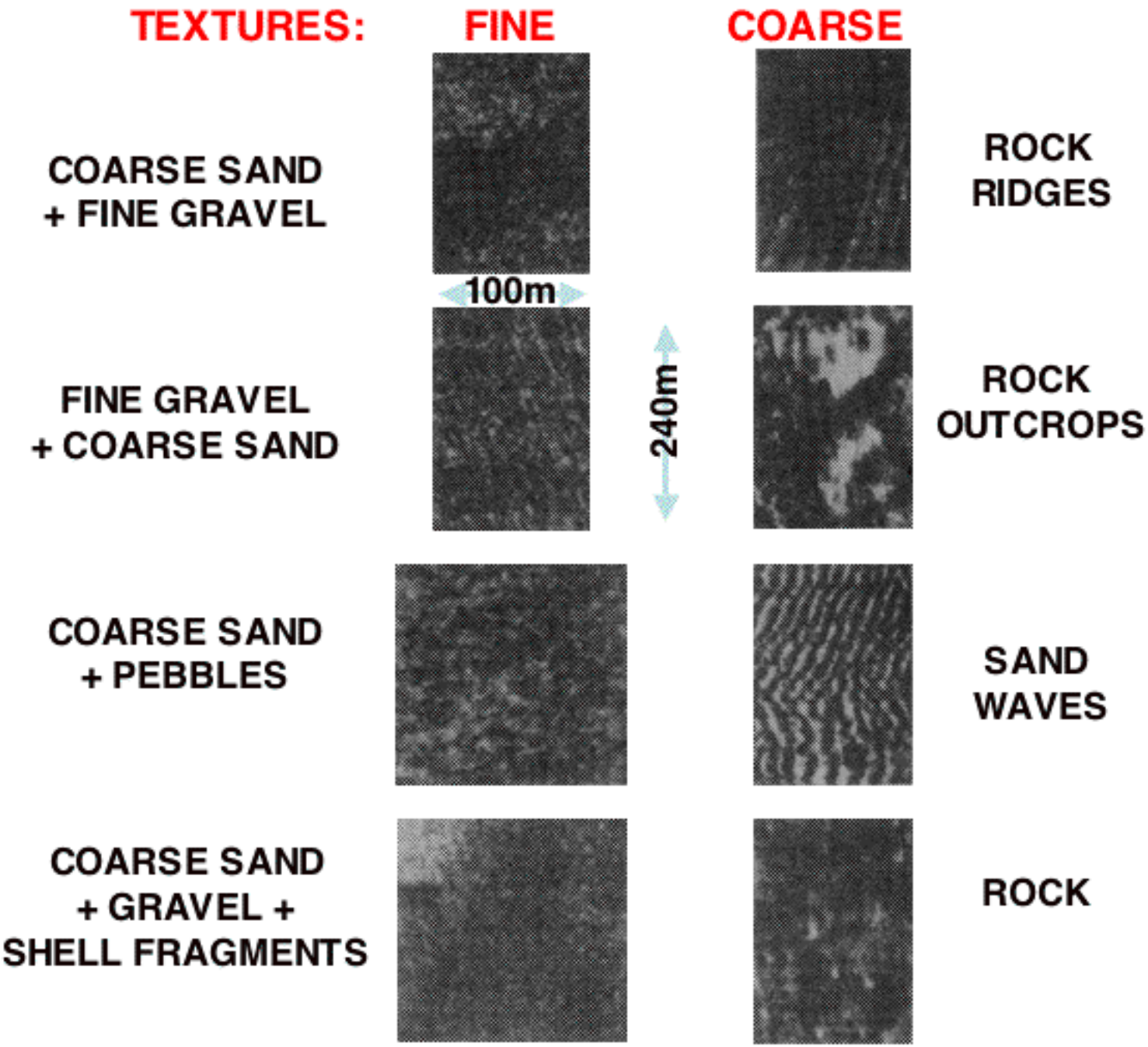
- Texture analysis (grey level co-occurrence matrices)
- Power spectral analysis (Pace discriminants)
- Angular dependence analysis
- Combined bathymetry and acoustic backscatter analysis.

SeaMARCII Sidescan data (11-12 kHz)
Lima Basin Sidescan & Textural Mosaics





(Reed & Hussong, J.G.R. 1989)



(Pace & Dyer, IEEE J.O.E.1979)

Averaged Power Spectra

$f(\phi, \theta, \tau, \Delta t, \Sigma A_i)$

F_o = 48 kHz
CW pulse: τ = 1ms
Receiver W~2kHz

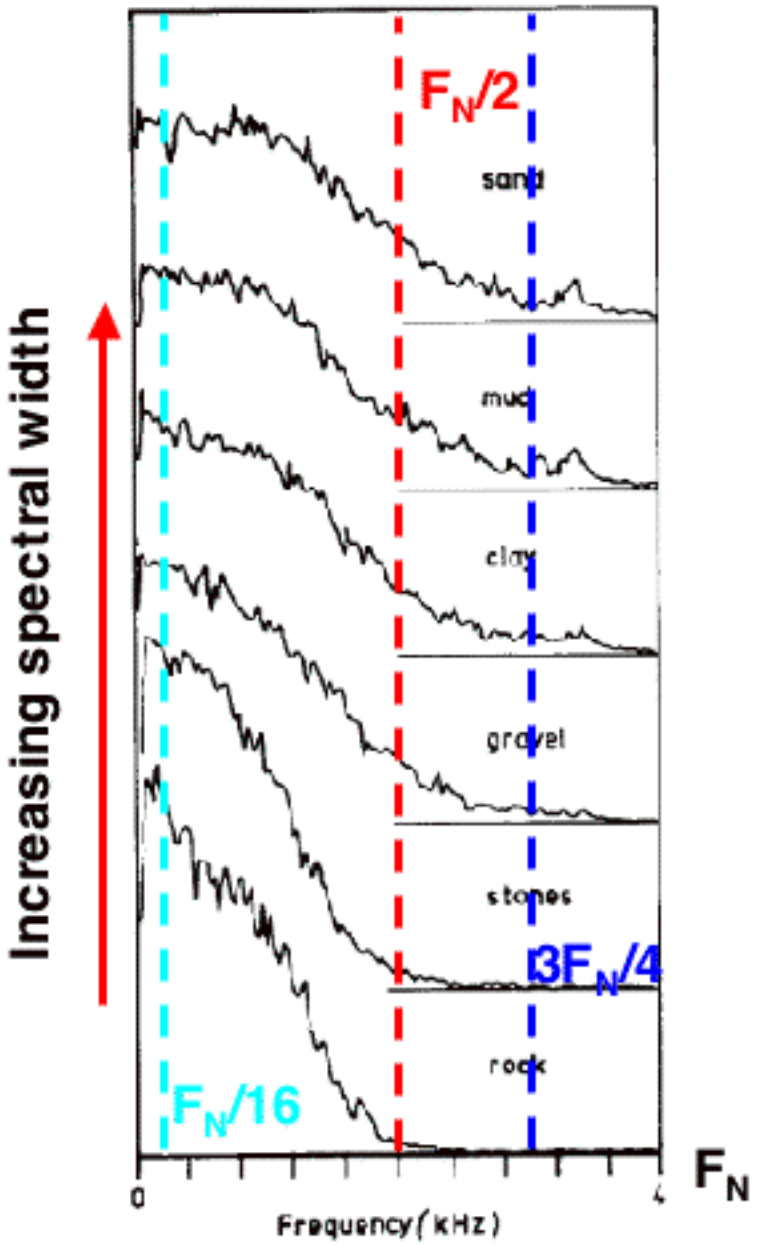
Ratios of areas under segments of the power spectra for specific frequency bands provide 3 discriminants:

$D_{f1} = A(0, F_N/2) / A(F_N/2, F_N)$

$D_{f2} = A(0, F_N/16) / A(F_N/2, F_N)$

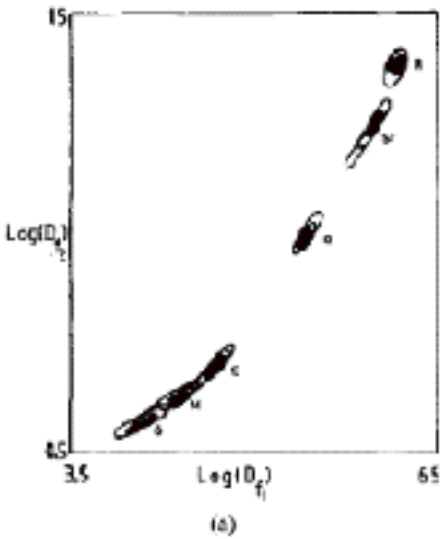
$D_{f3} = A(0, F_N/16) / A(3F_N/4, F_N)$

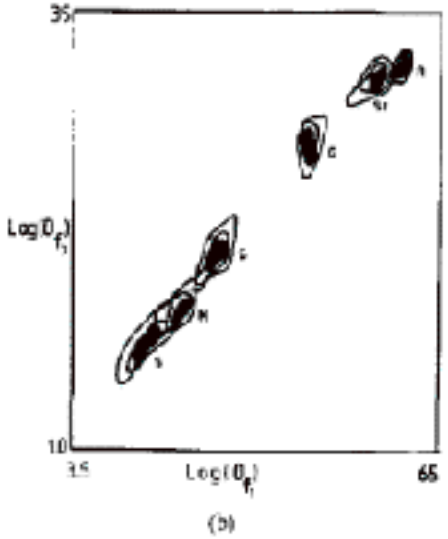
(Pace & Gao, IEEE J.O.E. 1988)

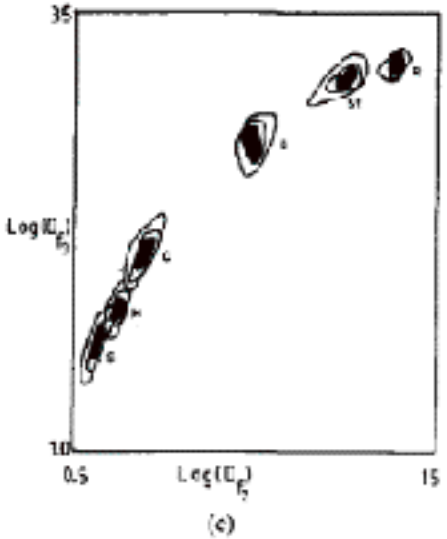


Averaged Power Spectra

S = sand
R = rock
G = gravel
C = clay
M = mud
St = stones

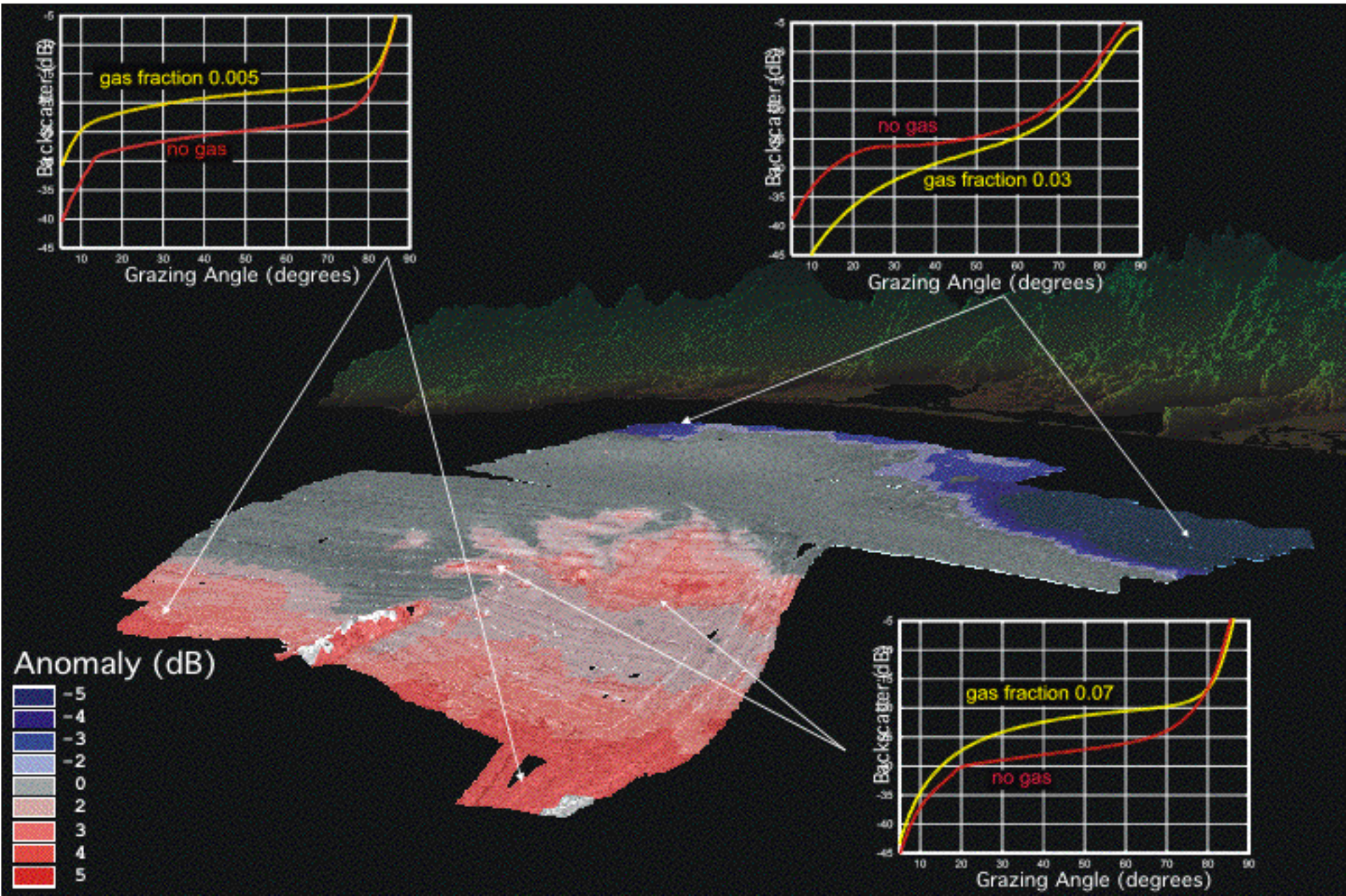




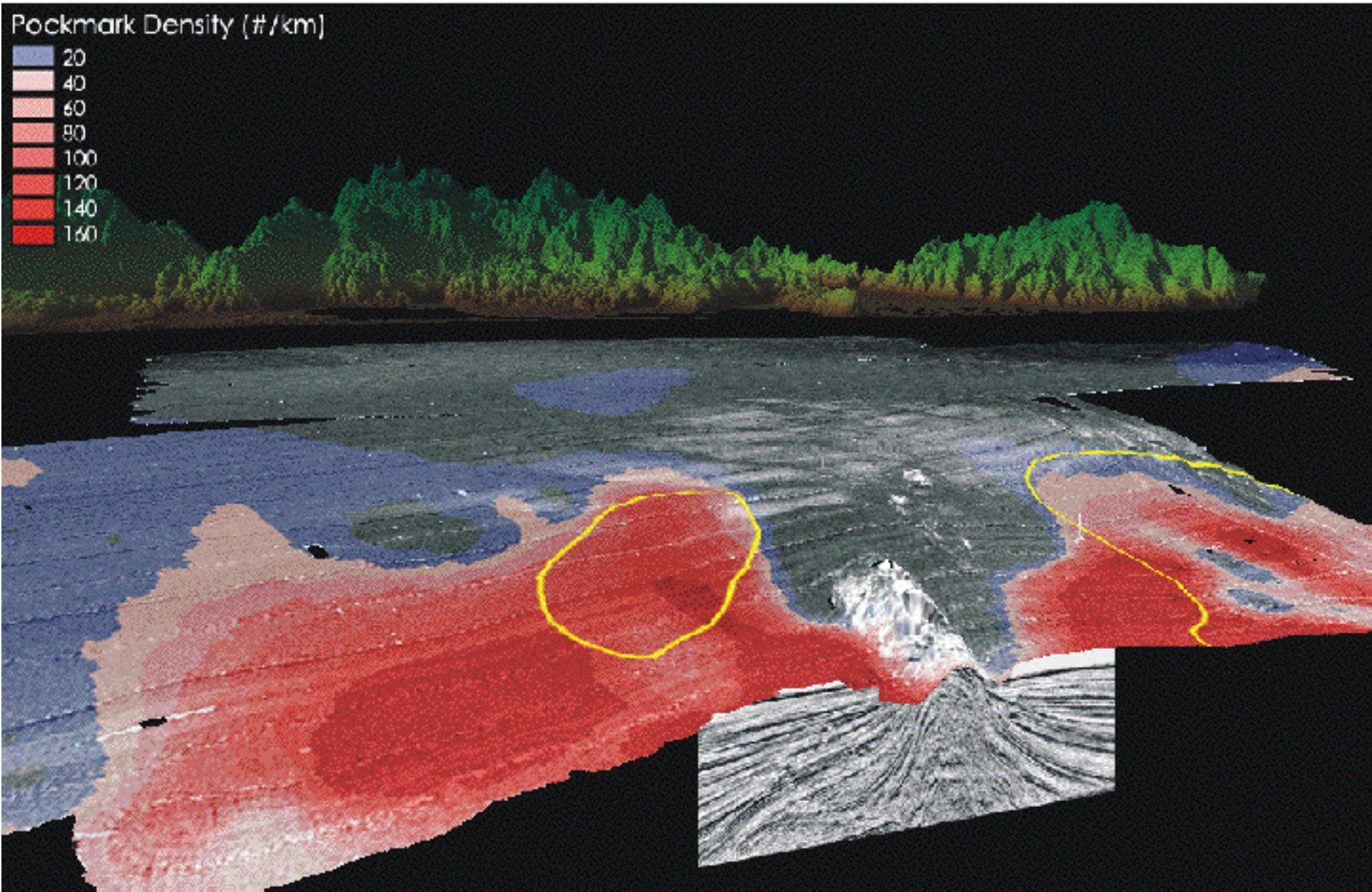


(Pace & Gao, IEEE J.O.E. 1988)

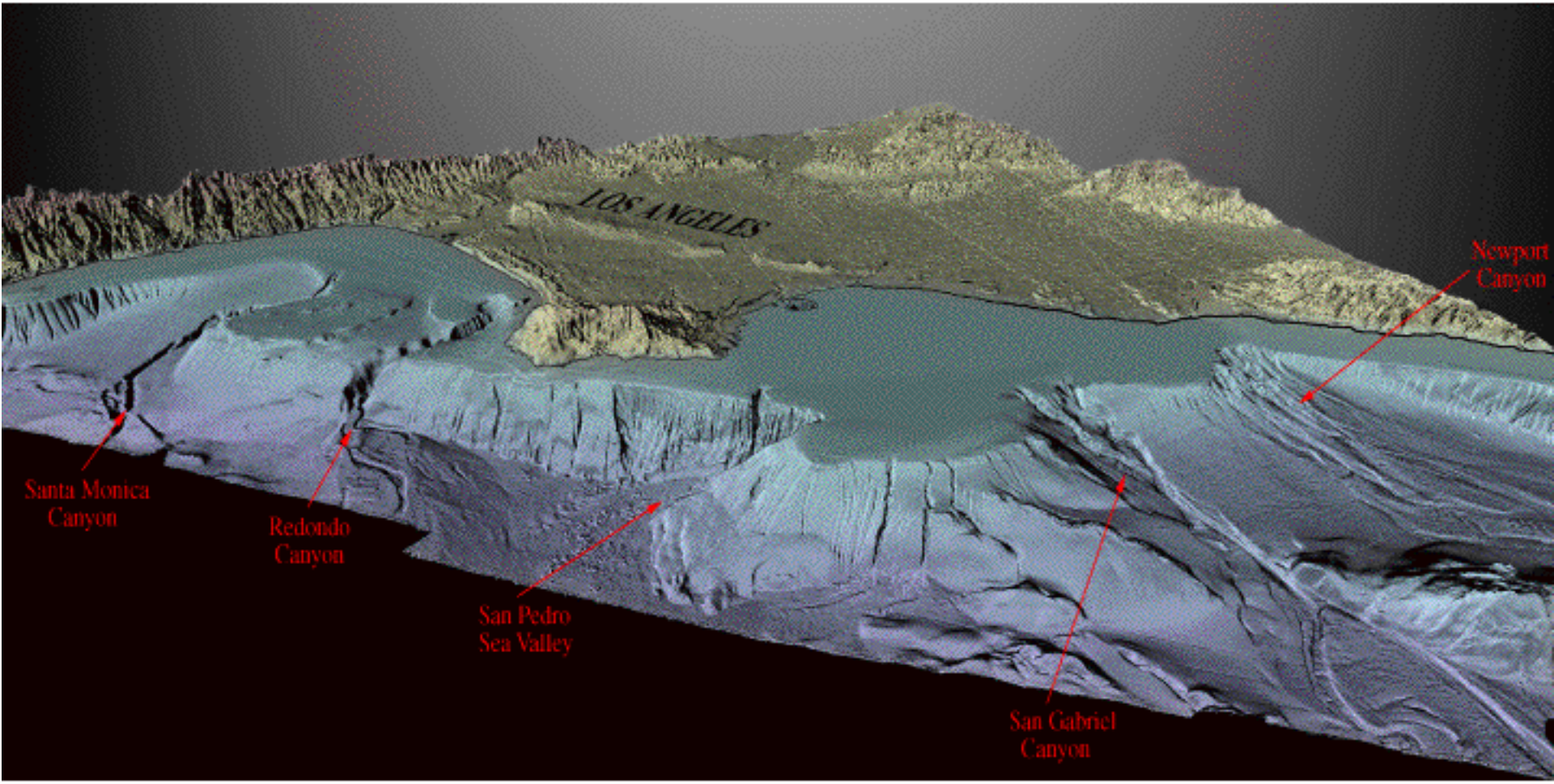
Inference of gas content in surficial sediments from the angular dependence of acoustic backscatter measured with a multibeam sonar (Fonseca et al., J.A.S.A. 2002)



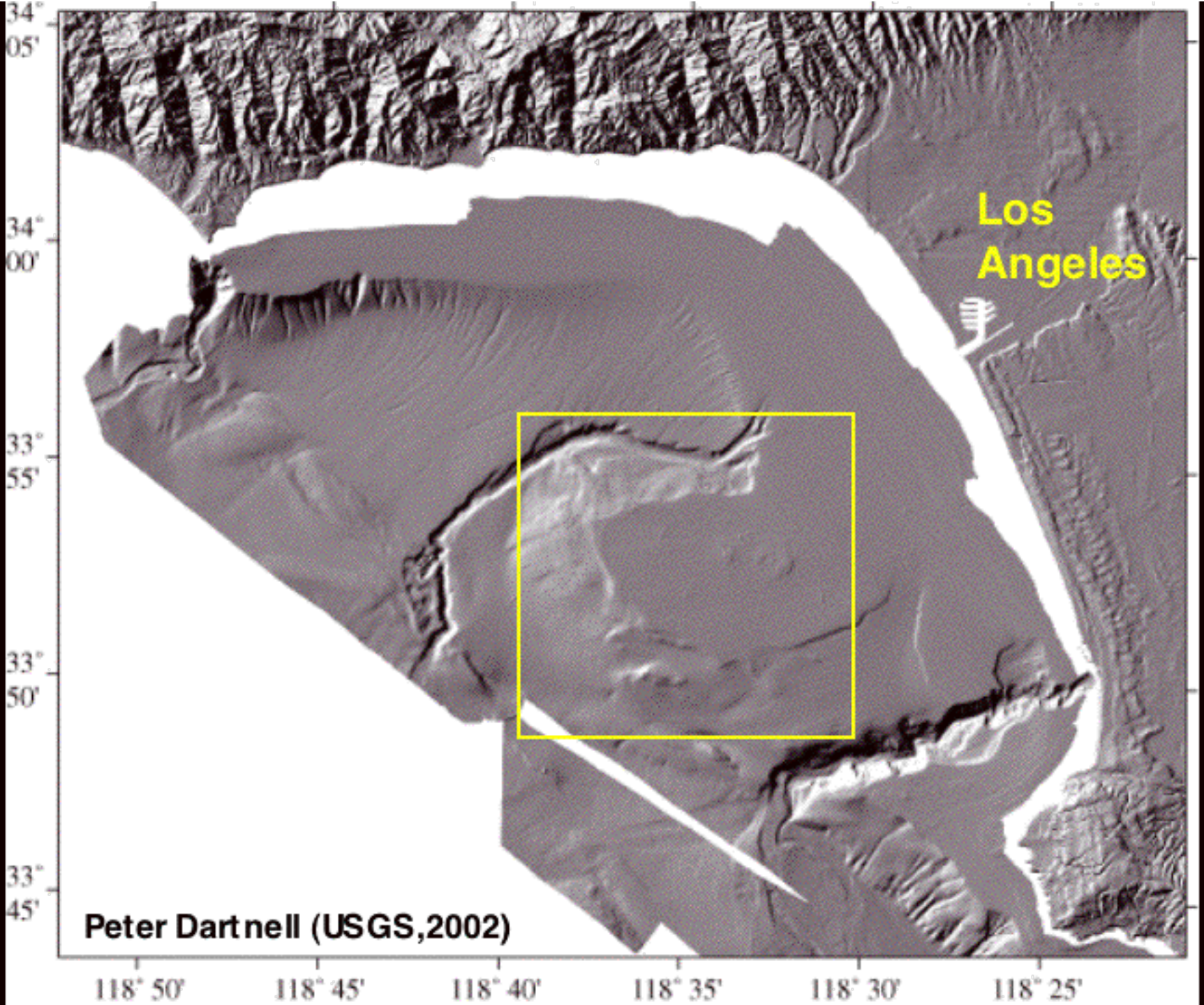
Interactive 3-D GIS to better understand relationship between backscatter anomalies and gas (Fonseca et al., J.A.S.A. 2002)

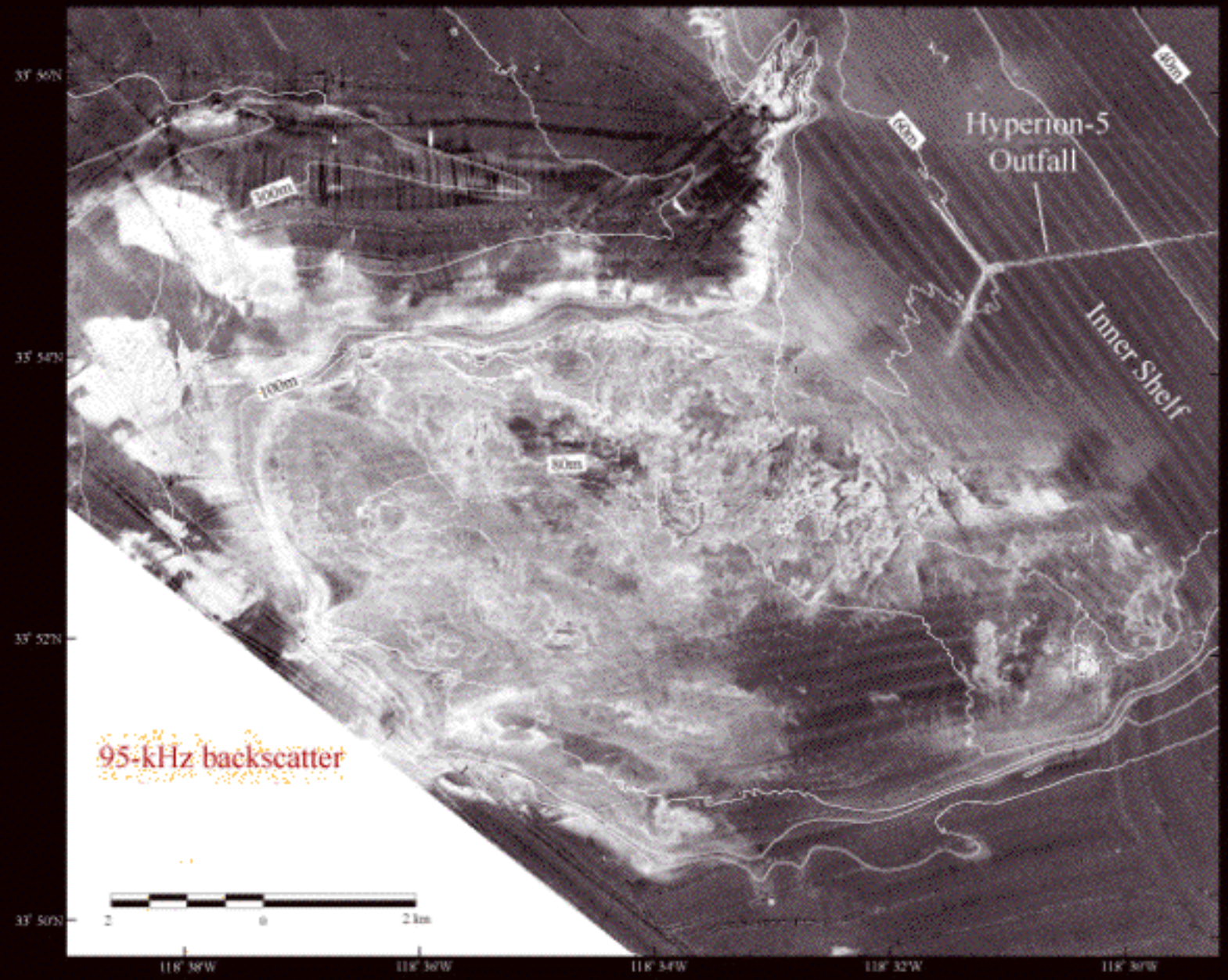


A new perspective → new insights

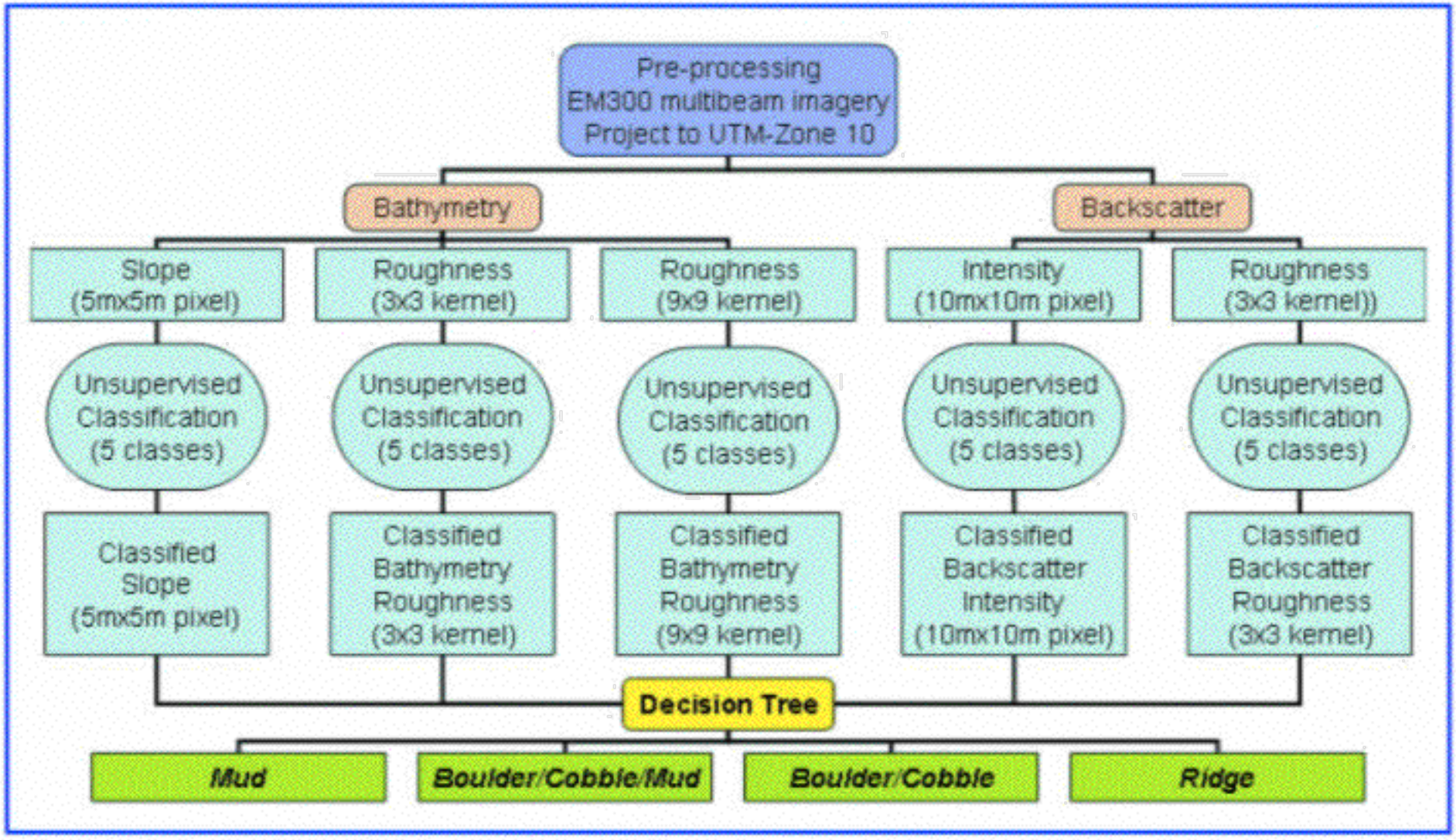


(J.V. Gardner et al., USGS ofr, 2001)

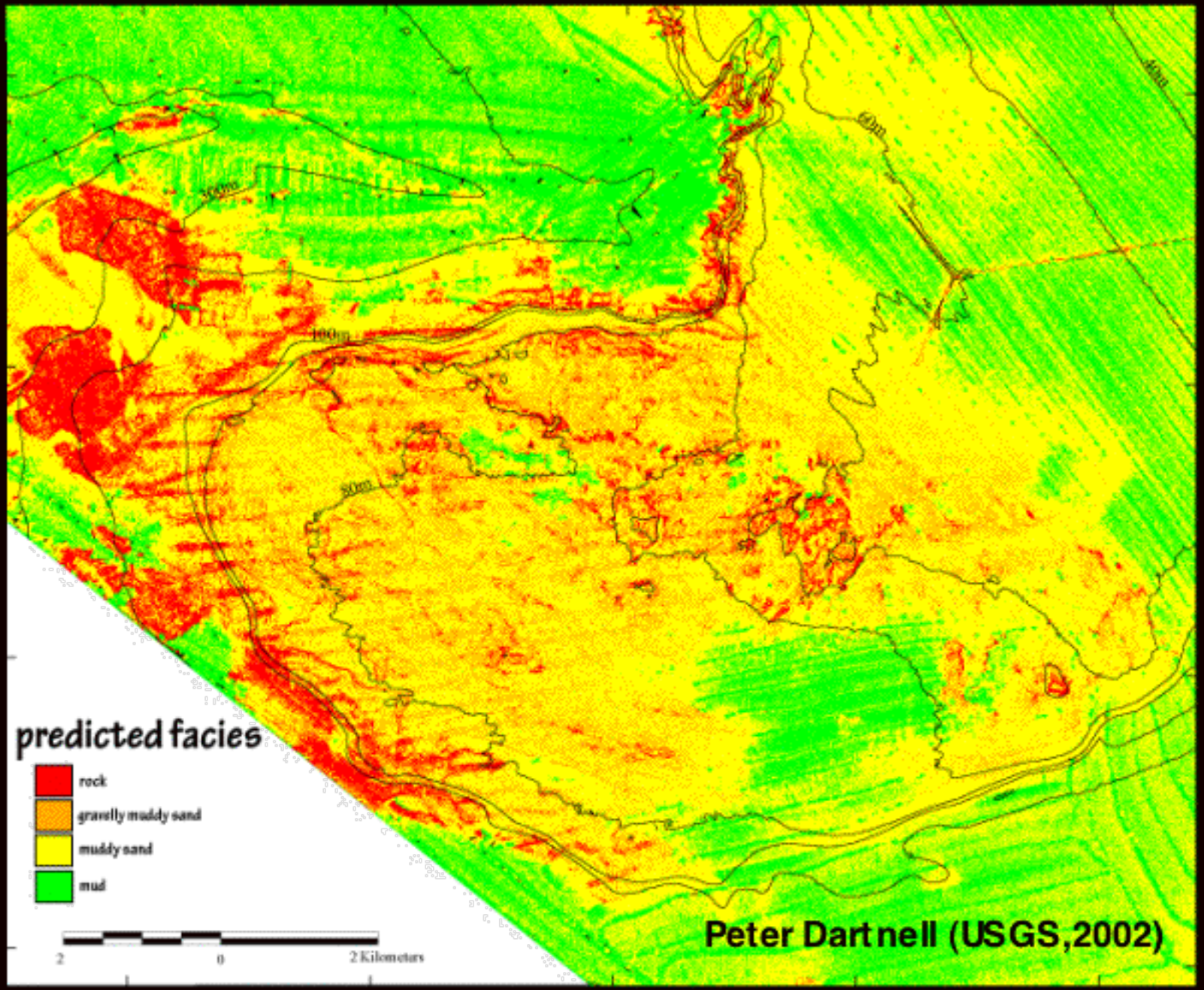

Los Angeles
Peter Dartnell (USGS,2002)
34° 05'
34° 00'
33° 55'
33° 50'
33° 45'
118° 50'
118° 45'
118° 40'
118° 35'
118° 30'
118° 25'

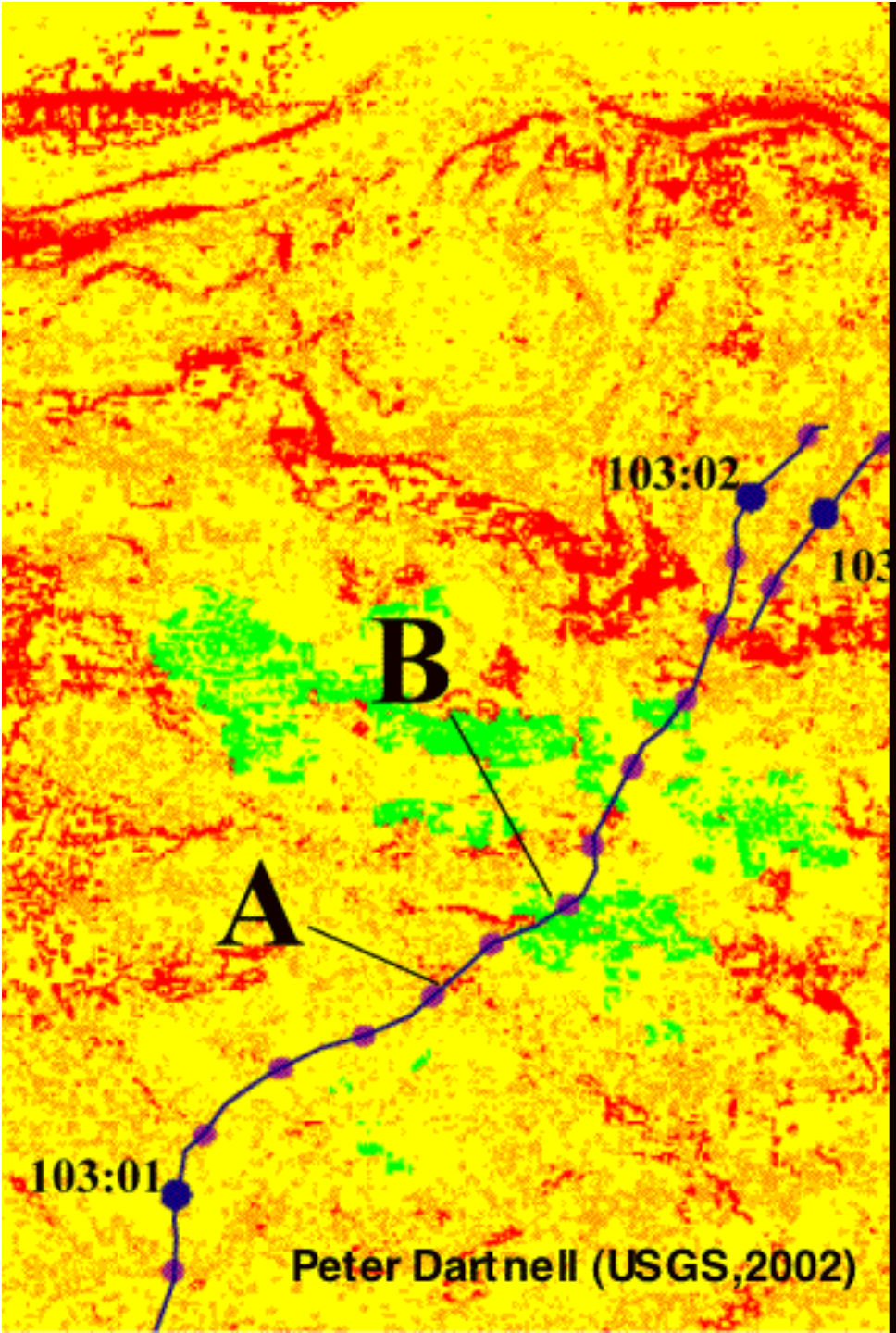


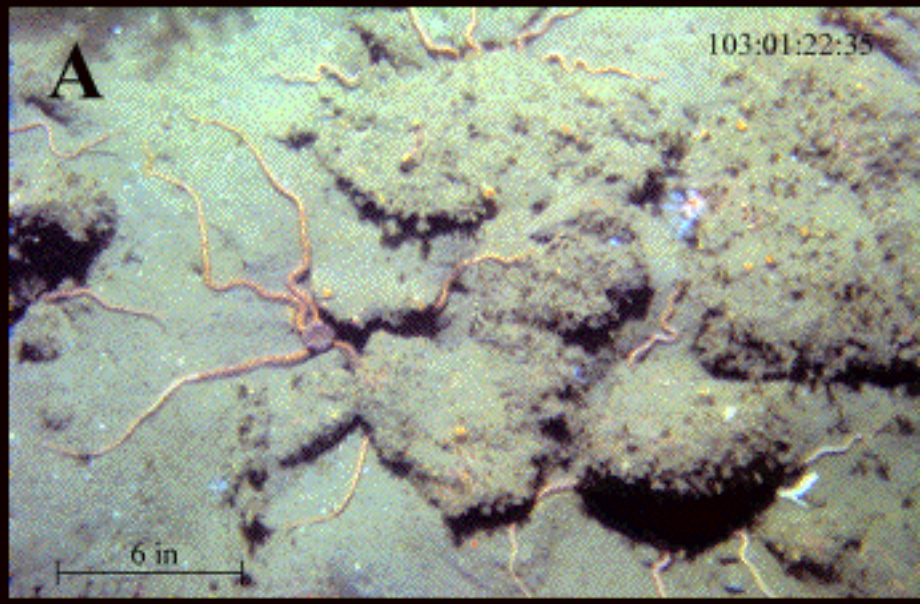
Peter Dartnell (USGS,2002)



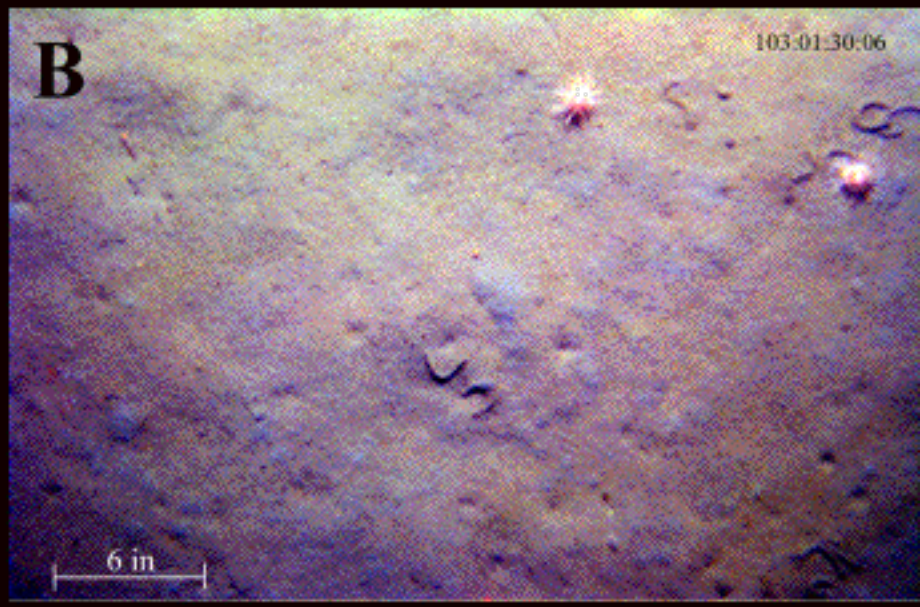
NOAA's adaptation of Dartnell's decision tree (2000)
Ovals = processes, rectangles = intermediate raster images


predicted facies
rock
gravelly muddy sand
muddy sand
mud
2
0
2 Kilometers
Peter Dartnell (USGS,2002)

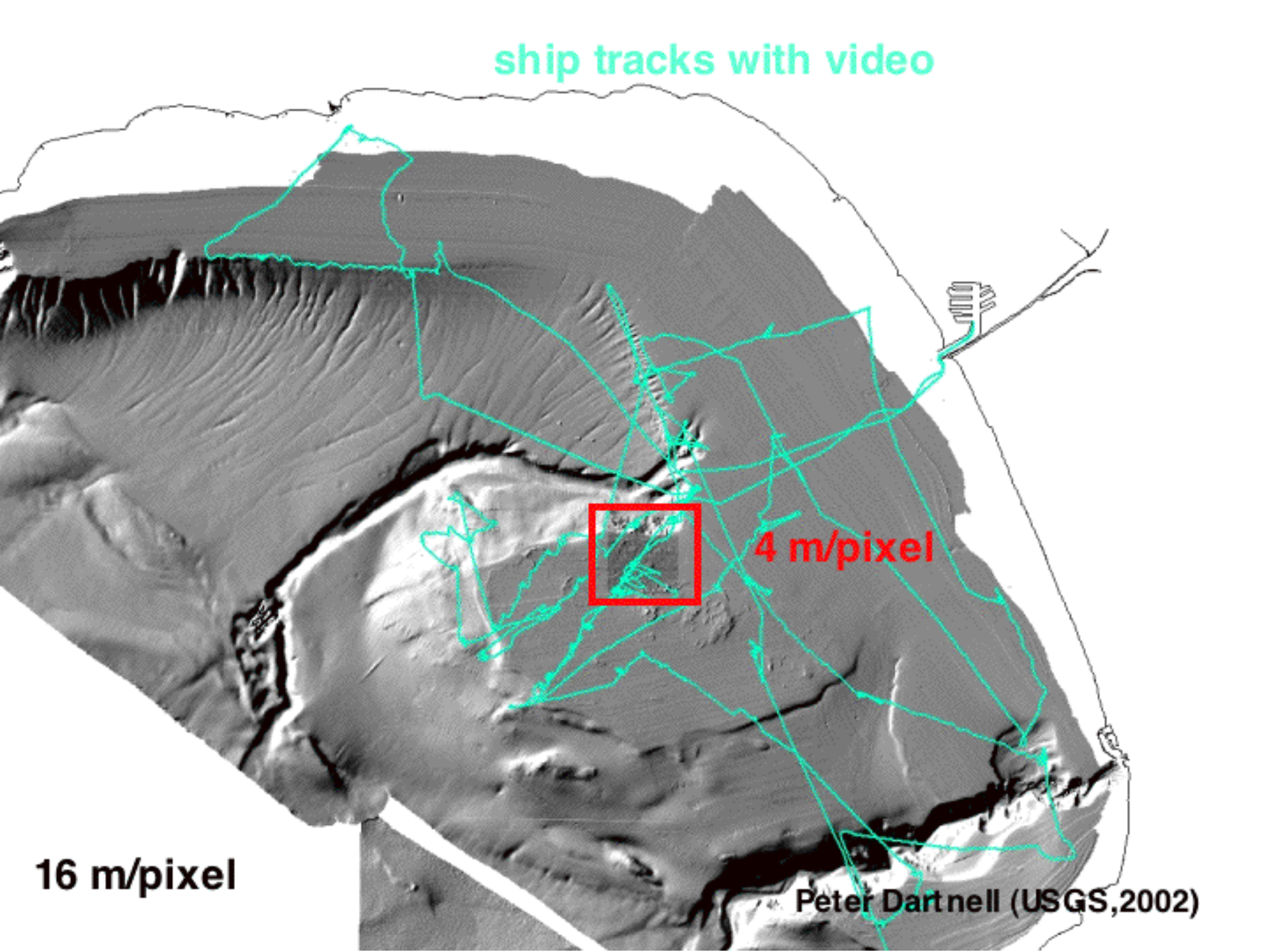


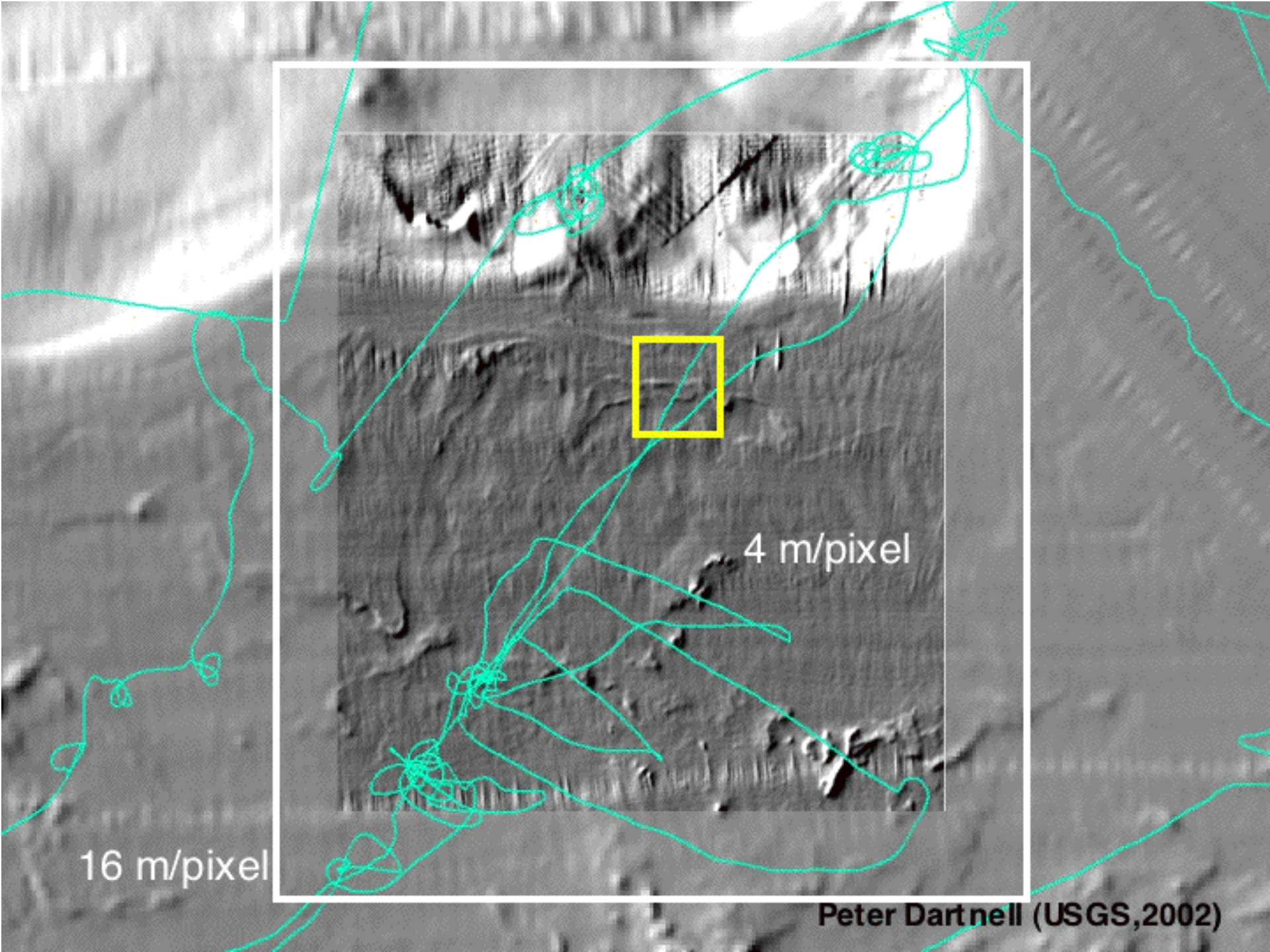


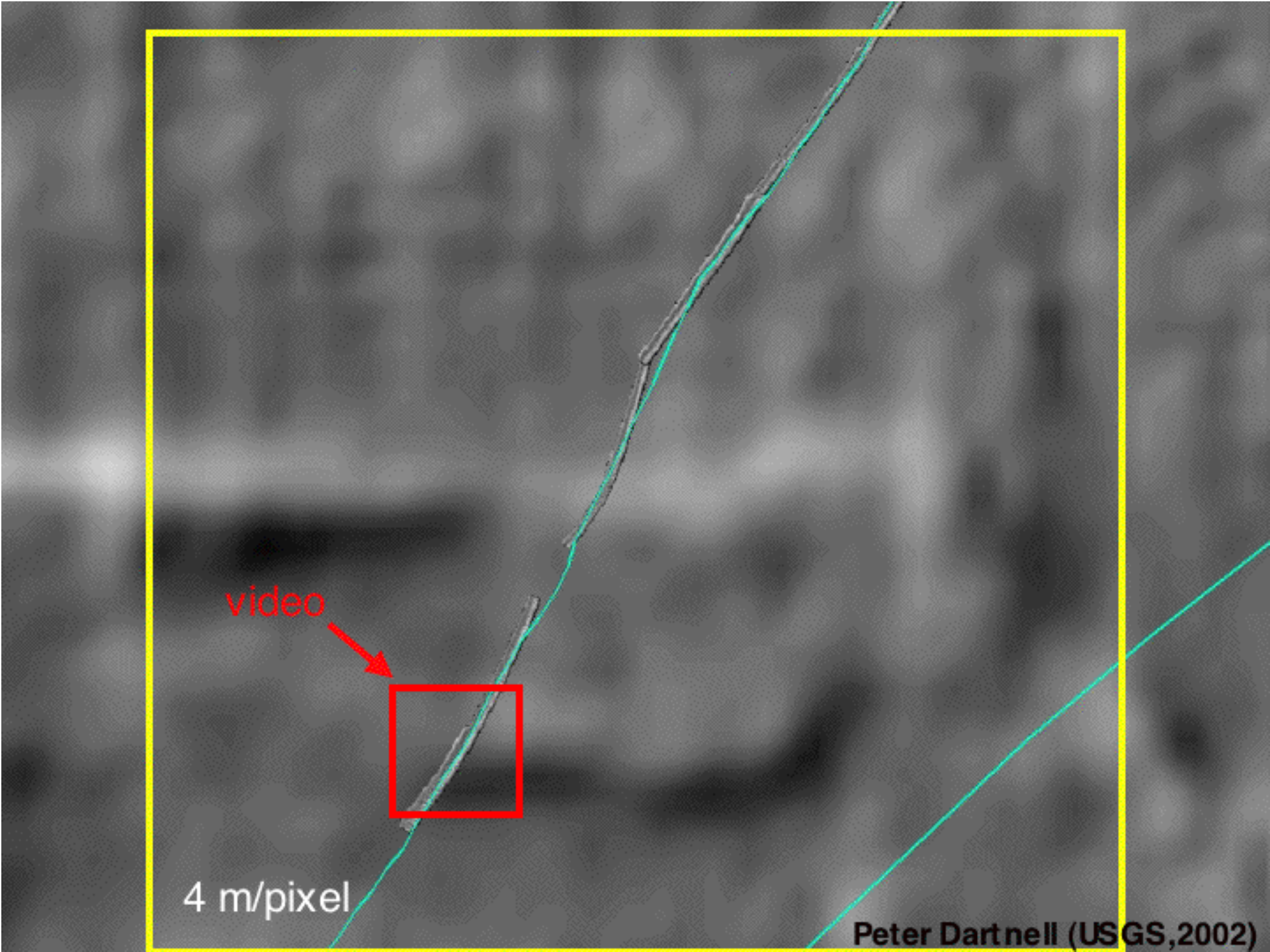
rock

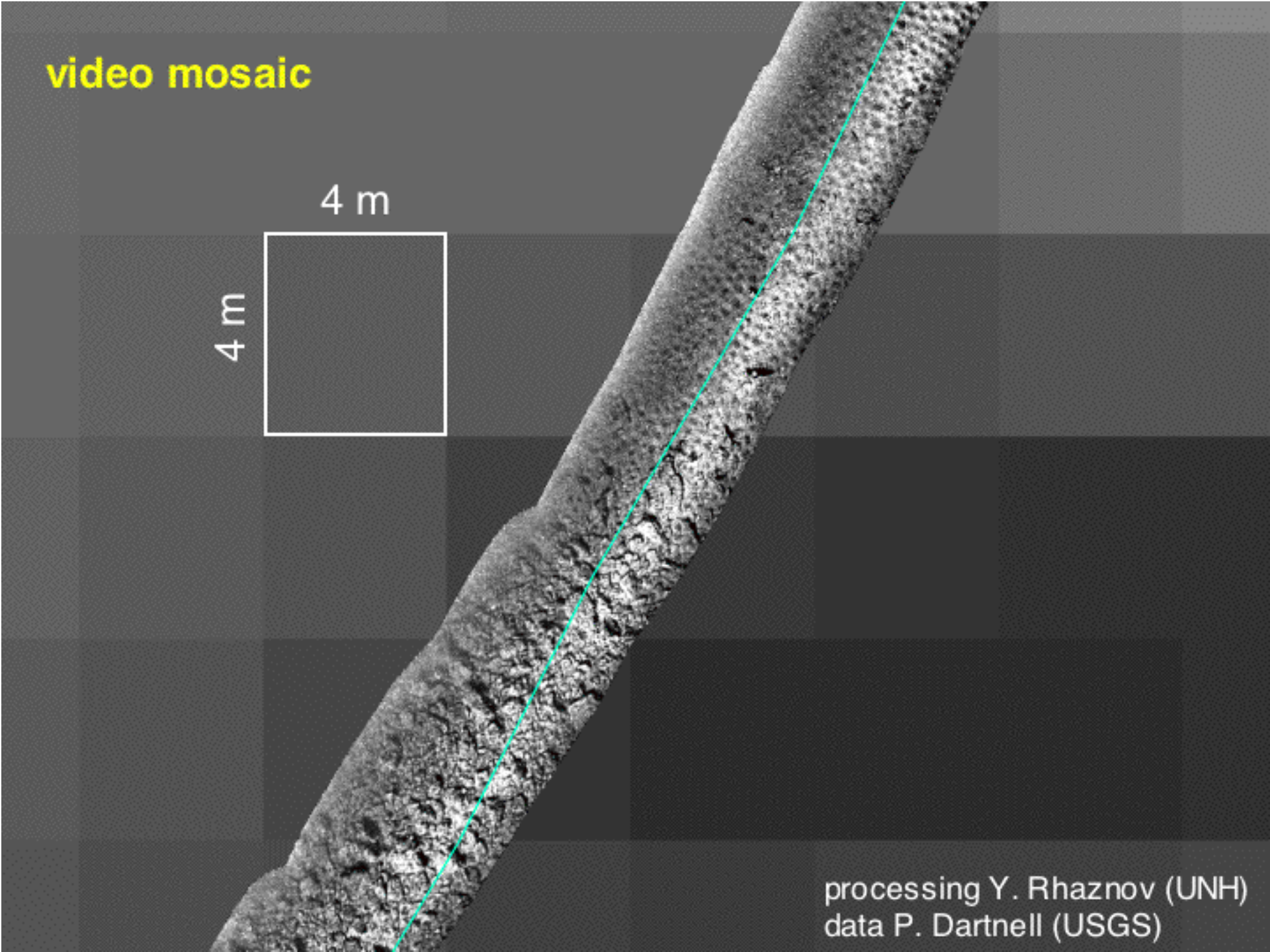


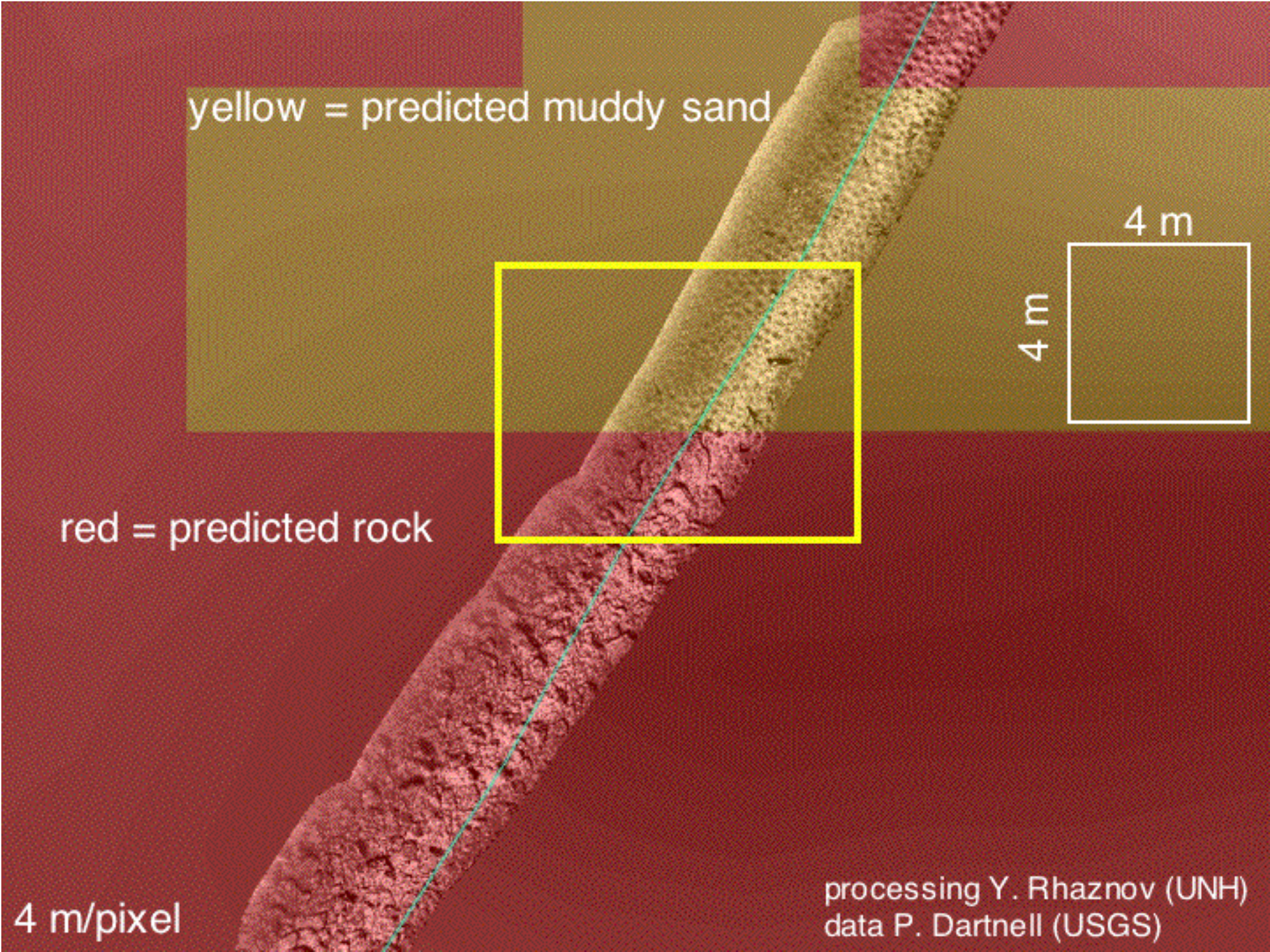
muddy sand

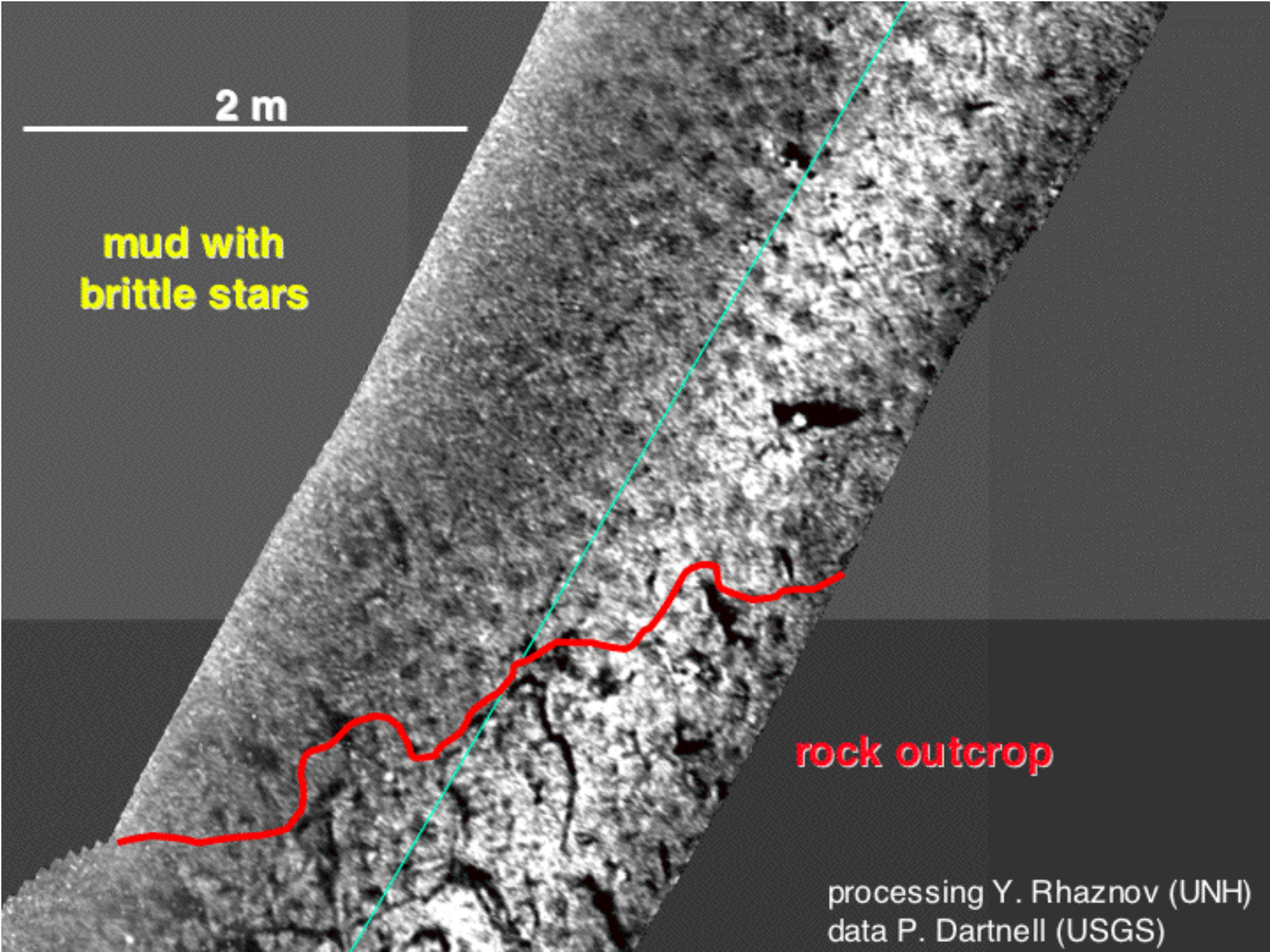

ship tracks with video
4 m/pixel
16 m/pixel
Peter Dartnell (USGS,2002)


4 m/pixel
16 m/pixel
Peter Dartnell (USGS,2002)


video
4 m/pixel
Peter Dartnell (USGS,2002)

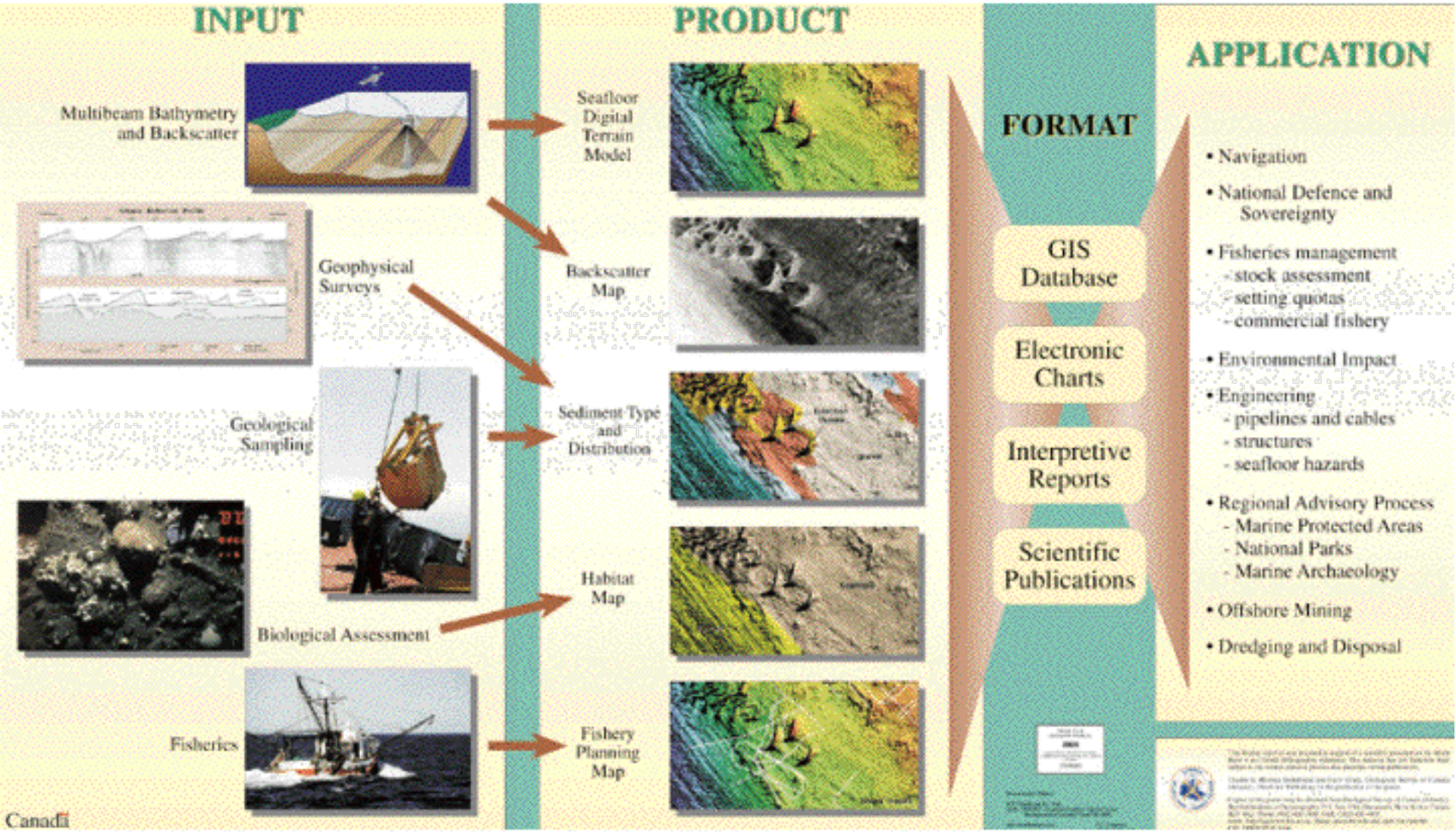

video mosaic
4 m
4 m
processing Y. Rhaznov (UNH)
data P. Dartnell (USGS)


yellow = predicted muddy sand
4 m
4 m
red = predicted rock
4 m/pixel
processing Y. Rhaznov (UNH)
data P. Dartnell (USGS)


2 m
mud with
brittle stars
rock outcrop
processing Y. Rhaznov (UNH)
data P. Dartnell (USGS)

Canadian SEAMAP Initiative

A knowledge base for ocean management in the 21st century



Geological Survey of Canada (Atlantic), Natural Resources
Canadian Hydrographic Service, Fisheries & Oceans
National Defence, Route Survey Section; Marine Environmental Sciences, Fisheries & Oceans

Major Challenges Ahead

- Accurate sonar calibration
  for absolute acoustic measurements
- Data management (archive and distribution)
- Impact of anthropogenic underwater acoustics
  on marine organisms (particularly marine mammals)

From hemp rope, to piano wire, to echo-sounding, to…
… back to hemp rope