THE MEASUREMENT AND ANALYSIS OF BATHYMETRY, MORPHOLOGY, AND SEDIMENT THICKNESS

Ron Macnab

Geological Survey of Canada (Retired)

OUTLINE OF PRESENTATION

- Principles and practice of:
  - Echo-sounding
  - Seismic reflection and refraction
- Database and GIS tools
- Test of Appurtenance
- Foot of Slope
- 2500 metre isobath
- Gardiner Line
- Case studies and examples
- Discussion, Q & A

MEASURING THE DEPTH OF WATER: PRINCIPLES, PRACTICES, AND PROBLEMS

In the Article 76 context, water depth is necessary:

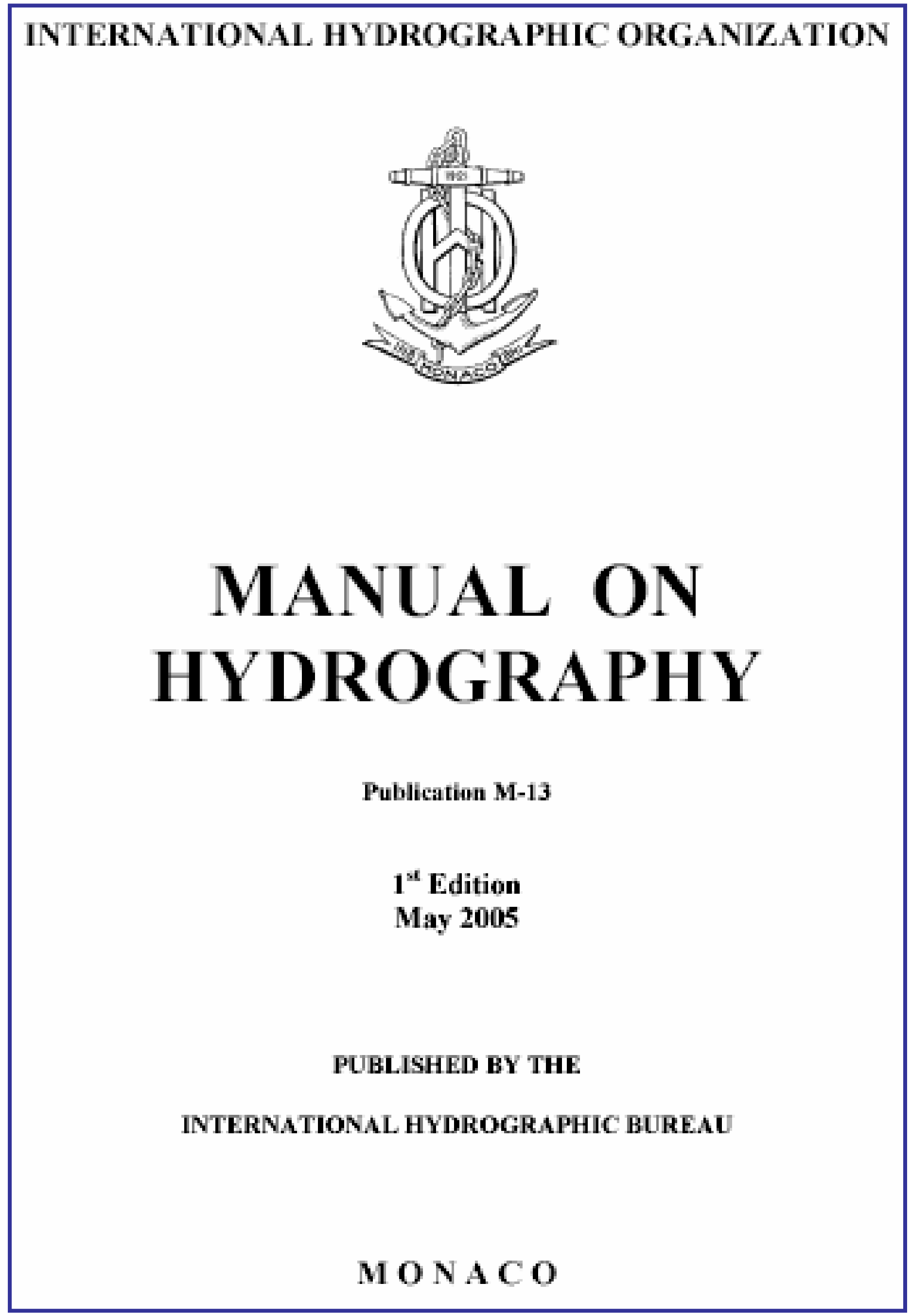
- To locate the *Foot of the Slope* (primarily a morphological exercise)
- To locate the *2500 m Isobath* (primarily a bathymetric exercise)

"THE BLUE BOOK"

Continental Shelf Limits: the Scientific and Technical Interface

- **Chapter 9 (Tony Laughton & Steve Shipman)**
  - *Historical Methods of Depth Measurement*
- **Chapter 10 (John Hughes Clarke)**
  - *Present-Day Methods of Depth Measurement*
- **Chapter 11 (David Monahan)**
  - *Interpretation of Bathymetry*

IHO MANUAL ON HYDROGRAPHY


INTERNATIONAL HYDROGRAPHIC ORGANIZATION

MANUAL ON HYDROGRAPHY

Publication M-13

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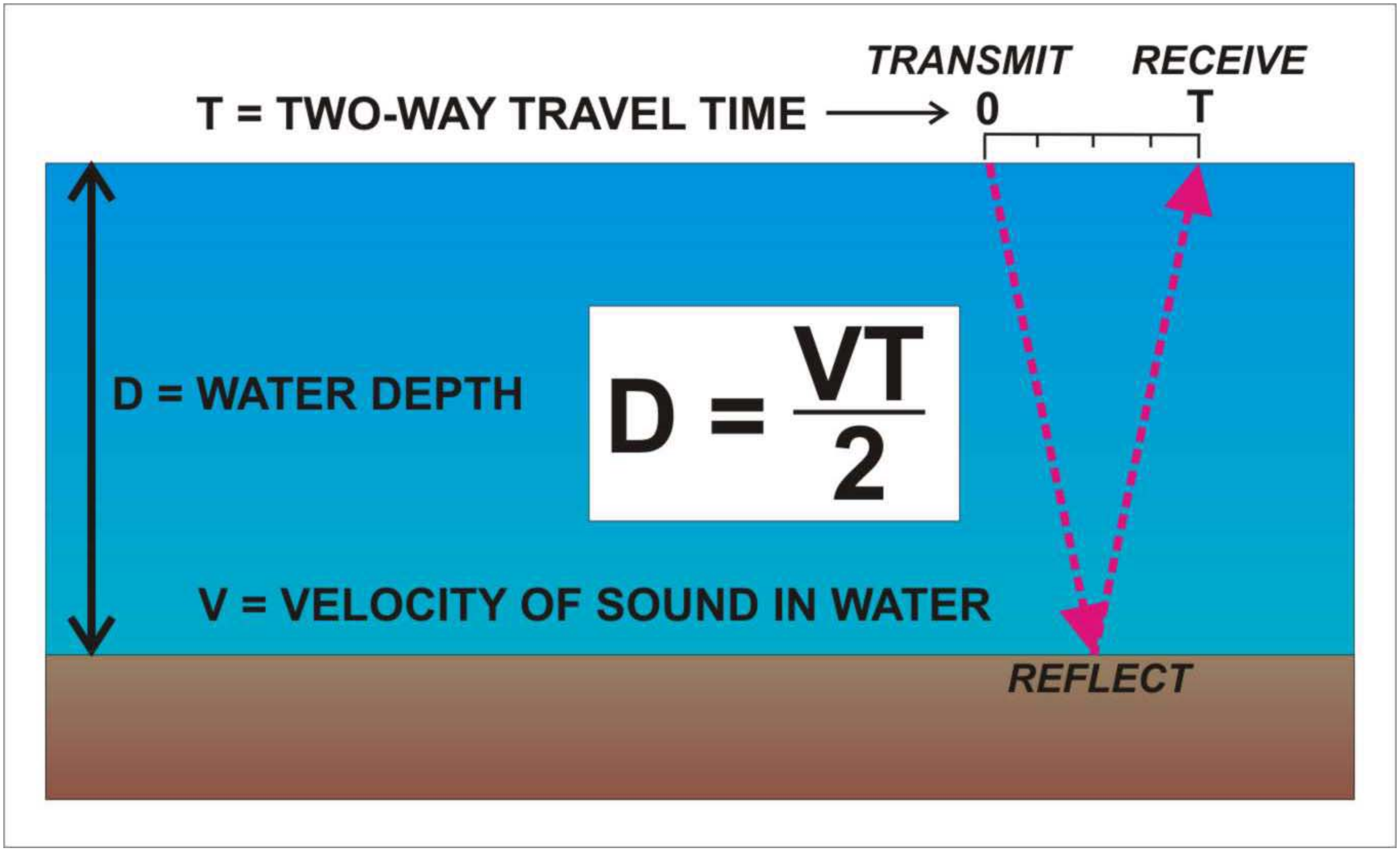
INTERNATIONAL HYDROGRAPHIC BUREAU

MONACO

THE MEASUREMENT OF DEPTH IS ACTUALLY A MEASUREMENT OF ELAPSED TIME



THE VELOCITY OF SOUND IN SEAWATER IS VARIABLE

- Function of Temperature, Salinity, Pressure
- Varies from the sea surface to the sea floor
- Varies from one location to another
- Varies from one season to another
- <u>These variations must be taken into account because they can introduce significant errors in the measurement of depth</u>

CORRECTING FOR VARIATIONS IN SOUND VELOCITY

- Refer to published Tables of Corrections
- Measure sound velocity in situ:
  - *Observations of Temperature, Salinity, Pressure throughout the water column*
  - *Direct measurement of velocity profile*
  - *Acoustical techniques*

POSITIONING TECHNIQUES IN MARINE SURVEYING

- Databases used for determining OCS limits may represent a mix of historic and modern observations.
- Most likely, these observations will have been collected with navigational systems that have evolved over the years.
- It is important to understand the principles and limitations of early navigation systems, in order to assess the suitability of historic observations for Article 76 purposes.

POSITIONING MARINE SURVEYS: HISTORIC METHODS I

Discussed in Cook & Carleton, Chapter 7:

- Astronomic observations
  - Intermittent
  - Sun - accurate to 3 km
  - Stars - accurate to 2 km
- Deduced reckoning (DR)
  - Continuous - based on course & speed made good
  - Subject to many and varied errors
- Land-based radionavigation
  - Continuous – accuracy within tens to hundreds of metres
  - Circular – measuring distances to known points
  - Hyperbolic - measuring time differences between signals
  - High frequency - short range, high accuracy
  - Low frequency - long range, low accuracy

POSITIONING MARINE SURVEYS: HISTORIC METHODS II

Discussed in Cook & Carleton, Chapter 7:

- Transit satellite
  - Periodic
  - Accurate to 100 m
- Inertial
  - Integration of horizontal and vertical accelerations
  - Subject to many and varied errors, particularly drift
- Integrated systems
  - Combining best of DR, radionavigation, Transit, inertial
  - Continuous
  - Accuracy - tens to hundreds of m

POSITIONING MARINE SURVEYS: MODERN METHODS

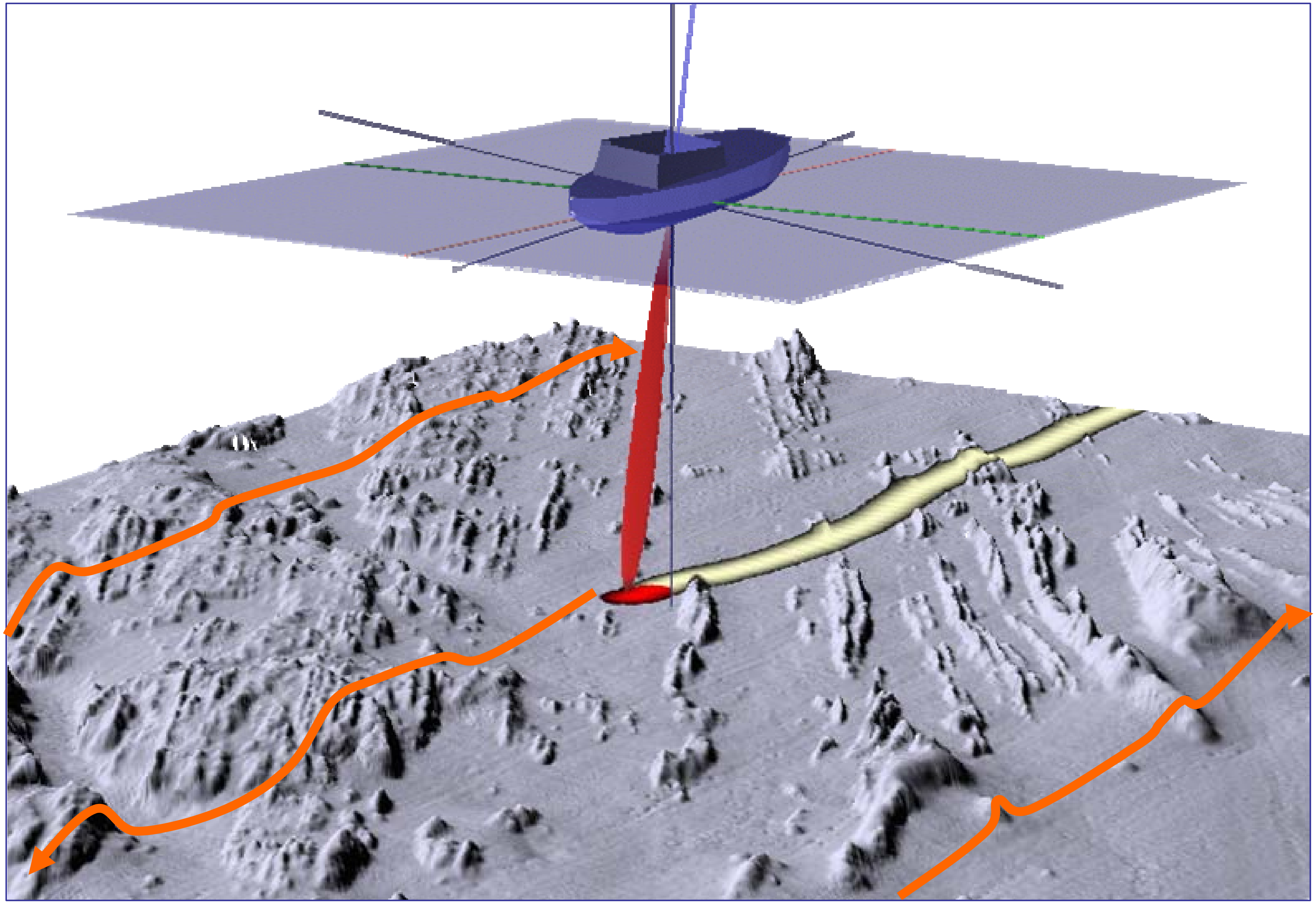
Discussed in Cook & Carleton, Chapter 8 - (GPS):

- Standard Positioning Service (SPS) – civilian
  - Coarse/Acquisition (C/A) code - 100 m hor, 150 m vert
  - Selective Availability (SA) - C/A signal degraded
  - SA removed May 2000 - accuracy improved to 12-15 m
- Precise Positioning Service (PPS) - encrypted, for military use
  - Precise (P) code - 16 m
- Differential GPS
  - Fixed reference station derives corrections for mobile receivers
    - Accuracy 1-5 m
  - Carrier phase measurements
    - Future potential for real-time navigation to the cm level

MAPPING THE DEPTH OF THE SEA: ACOUSTIC METHODS

- **Single beam**
  - *Depths at single points beneath the vessel*
- **Sidescan sonar**
  - *Bottom characteristics (not depths) to either side of vessel*
- **Multibeam**
  - *Multiple depths at points beneath and to either side of the vessel*

SINGLE (NARROW) BEAM MAPPING



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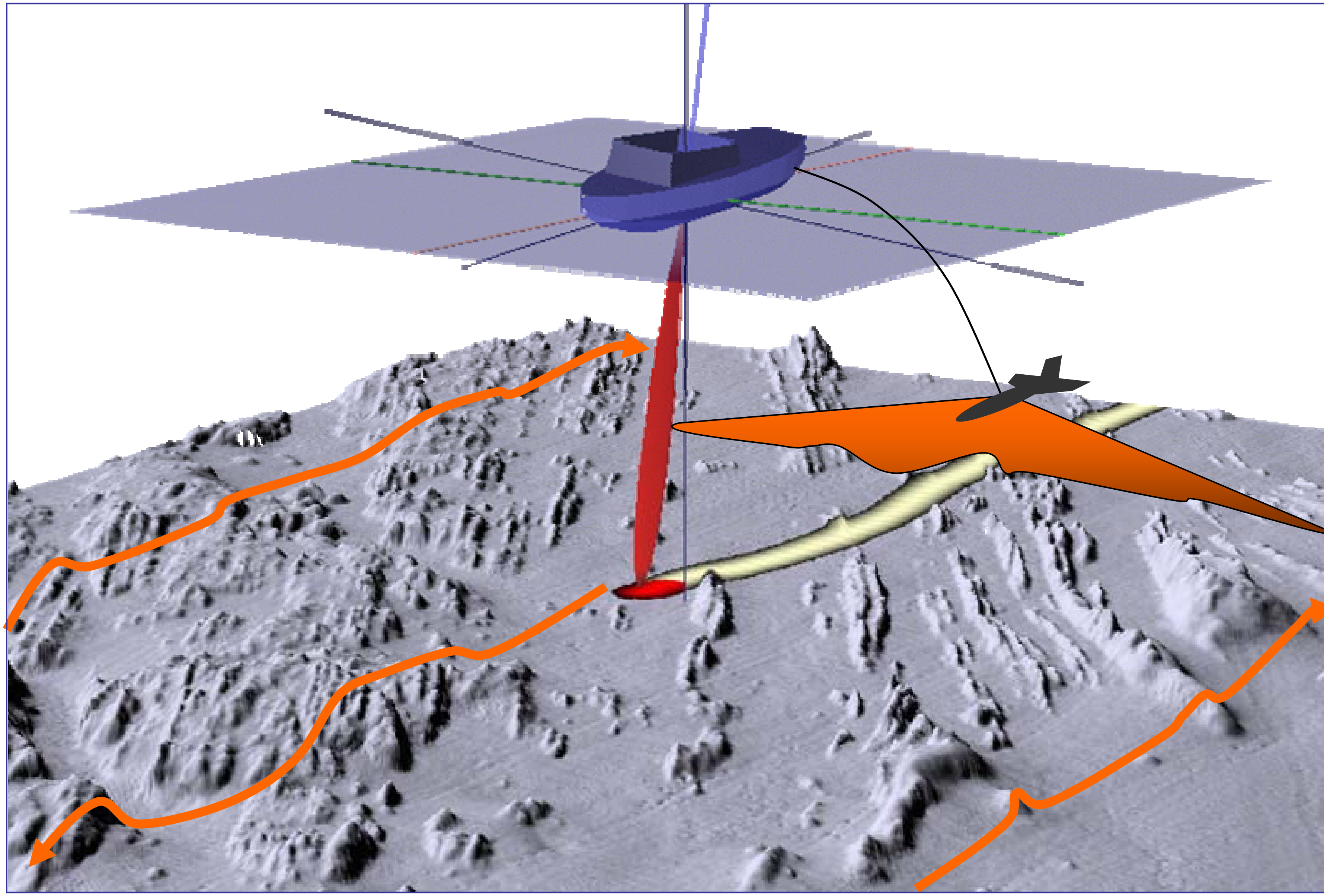
SINGLE (NARROW) BEAM WITH SIDESCAN SONAR



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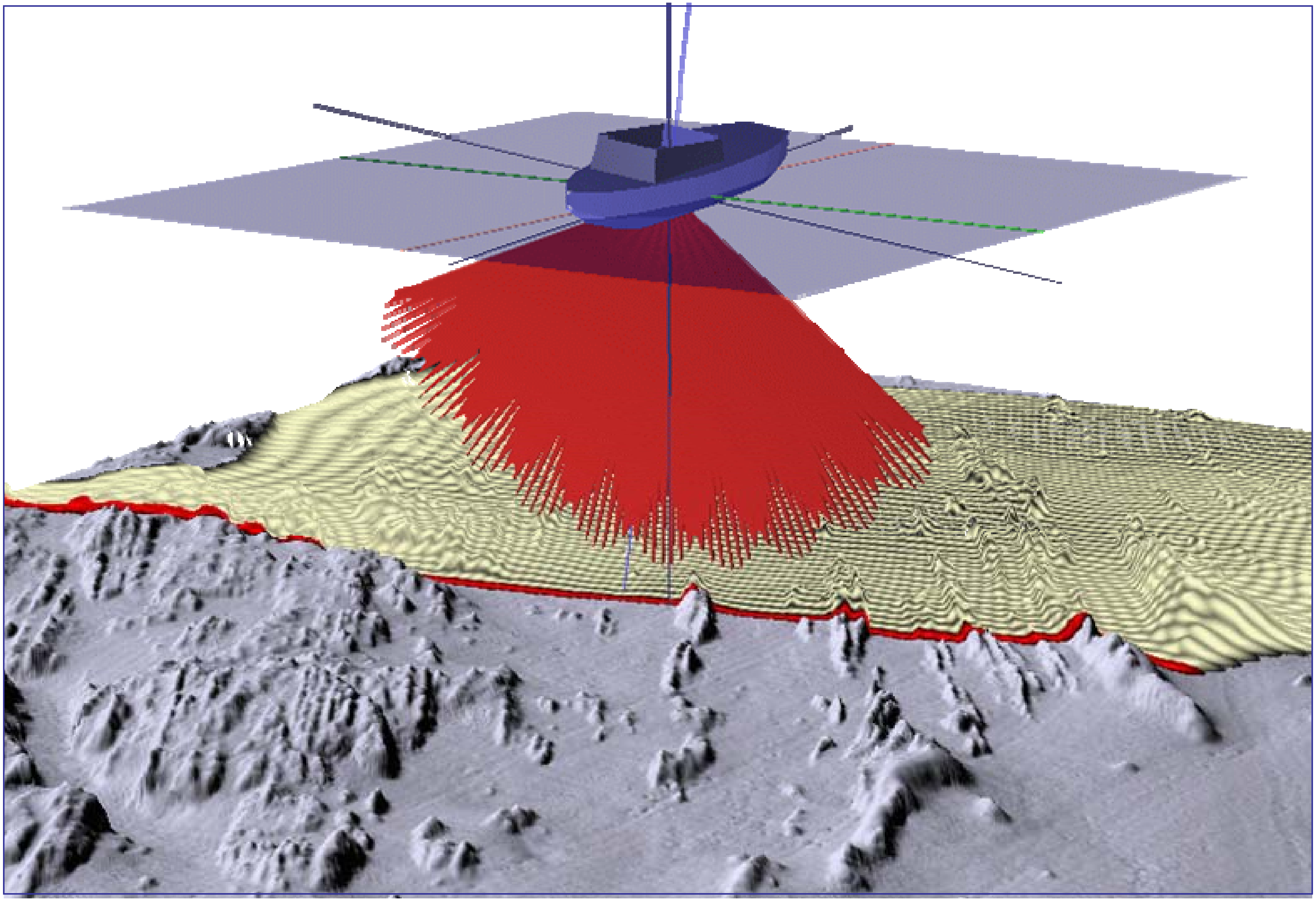
MULTIBEAM MAPPING



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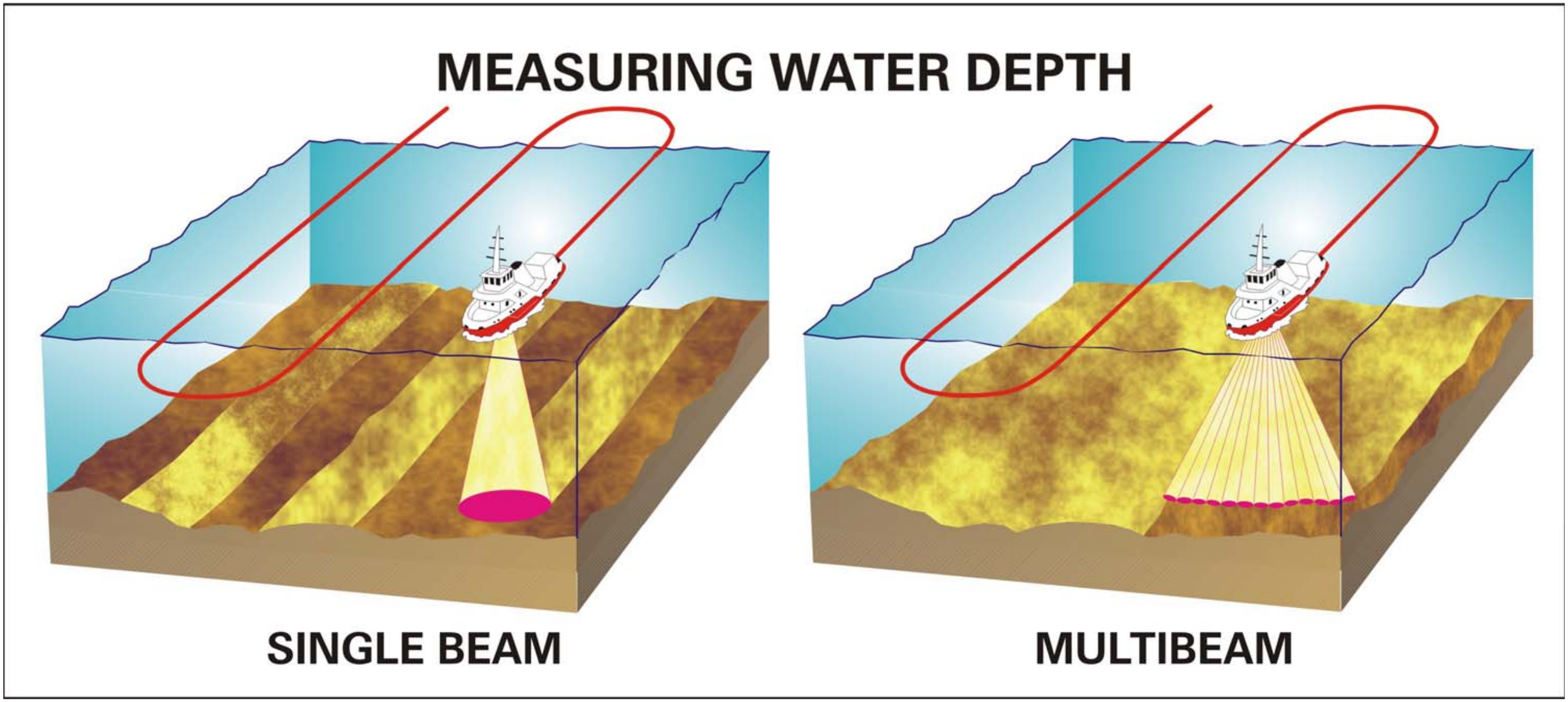
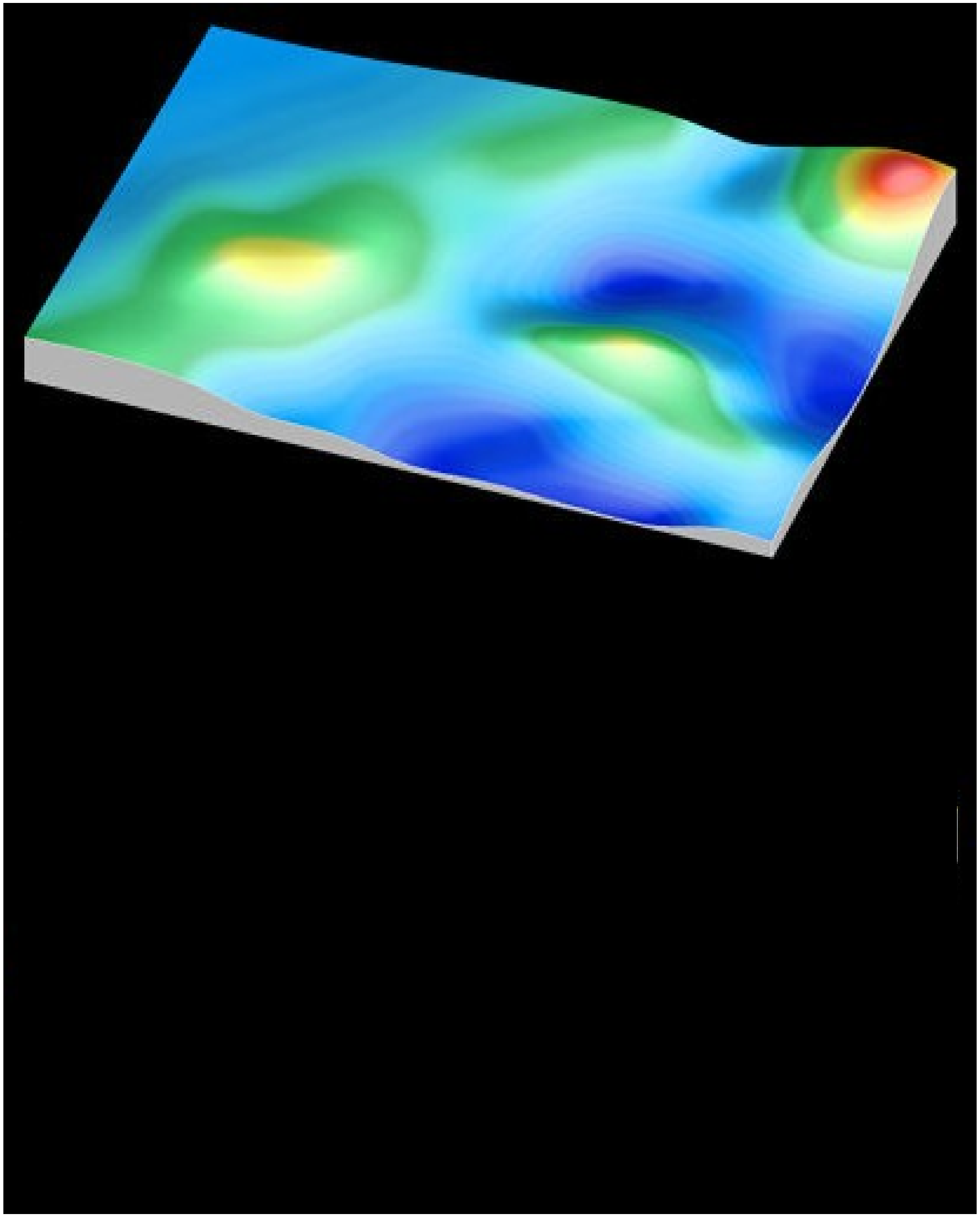
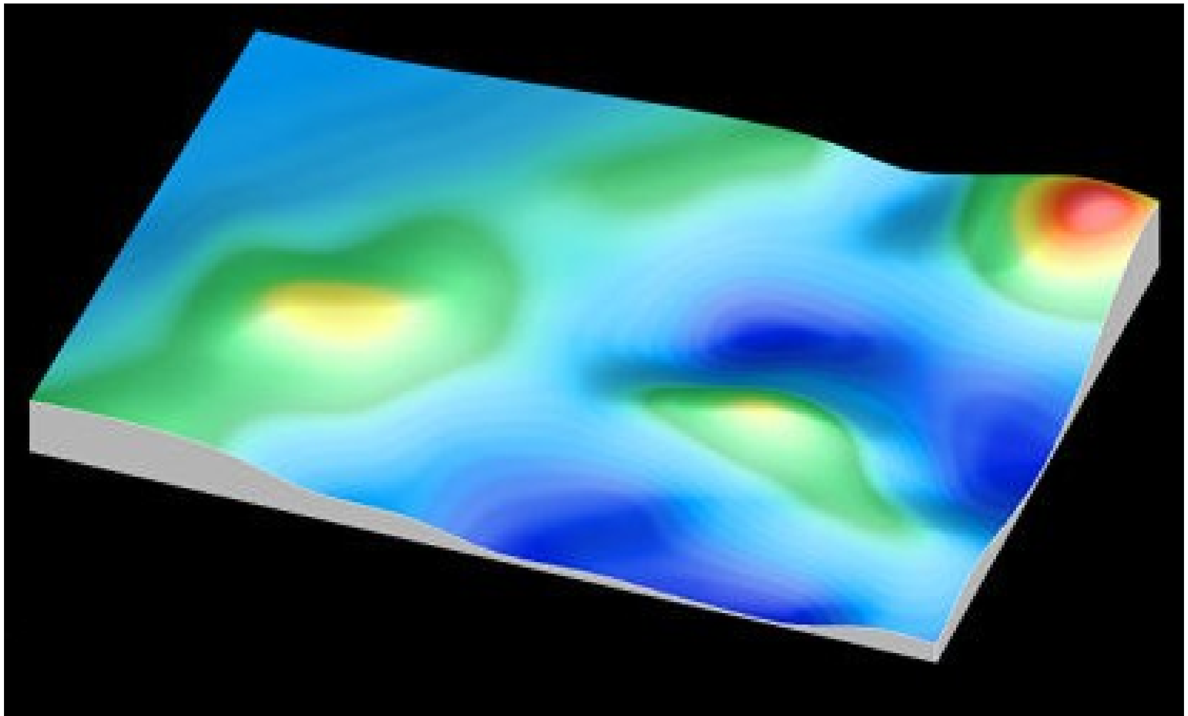
SINGLE (WIDE) BEAM VS MULTIBEAM





SEABED PORTRAYED FROM WIDE BEAM SOUNDINGS ALONG RANDOM TRACKLINES



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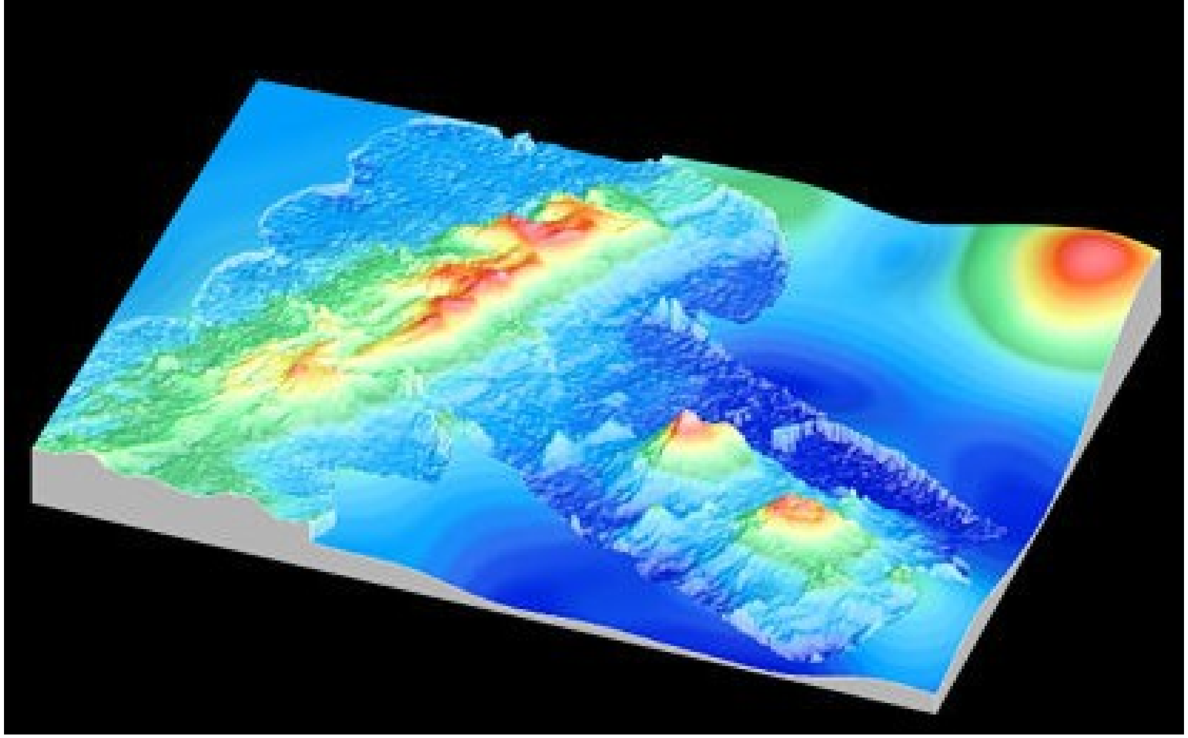
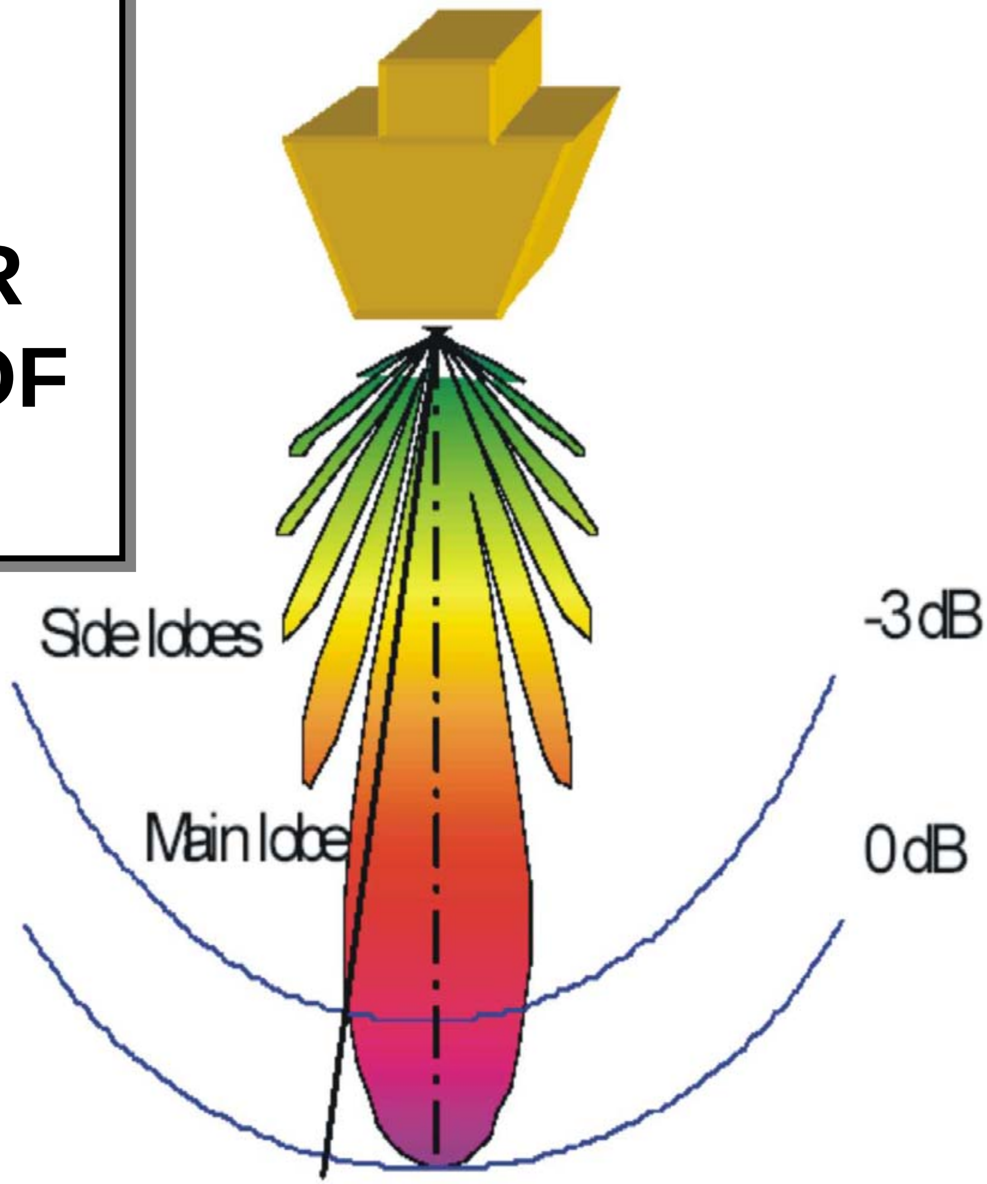


SAME SEABED PORTRAYAL, ENHANCED WITH MULTIBEAM SOUNDINGS

HOW BEAMWIDTH AFFECTS OUR PERCEPTION OF THE SEABED



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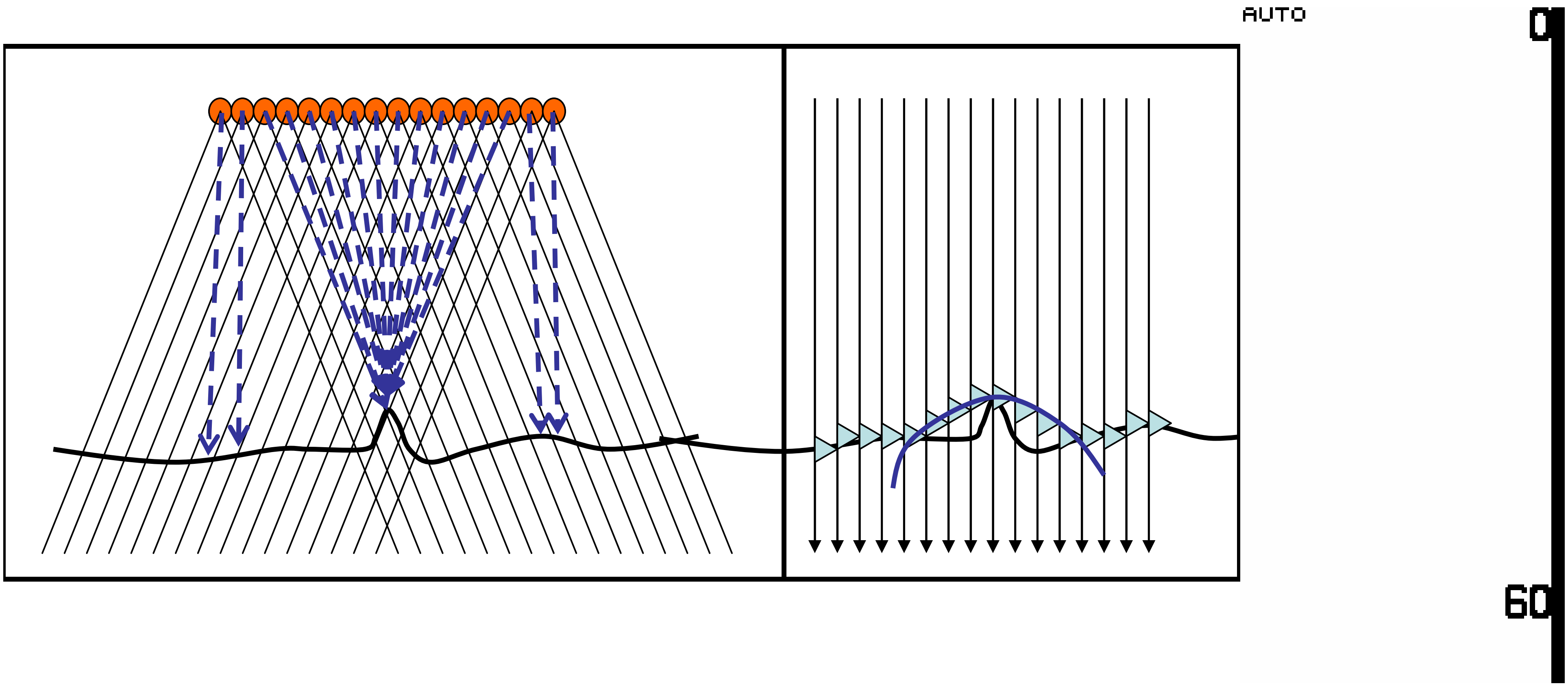
Hyperbolic Echoes



Bottom Minimum Wavelength

NOTE : as long as target below transducer,
does not bias the shallowest depth estimation

BUT : does significantly limit minimum resolvable horizontal Wavelength. A result of the projected beam width.

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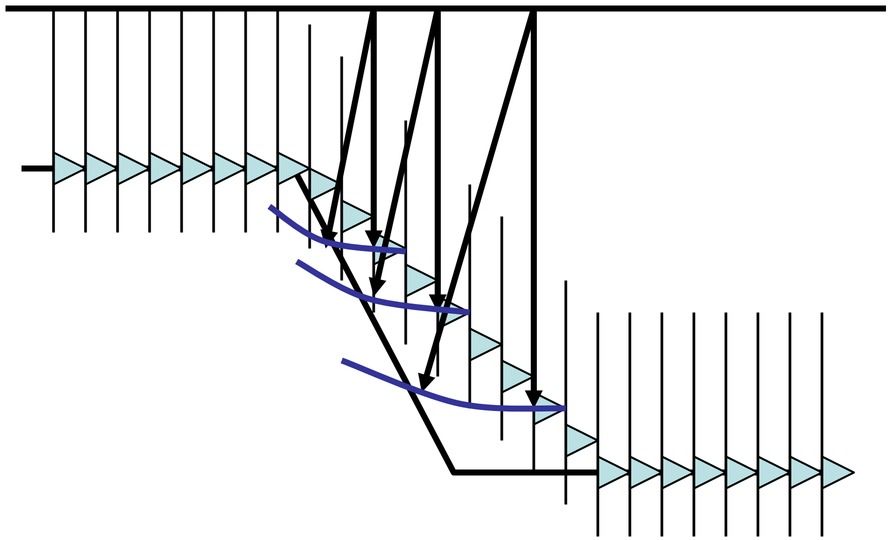
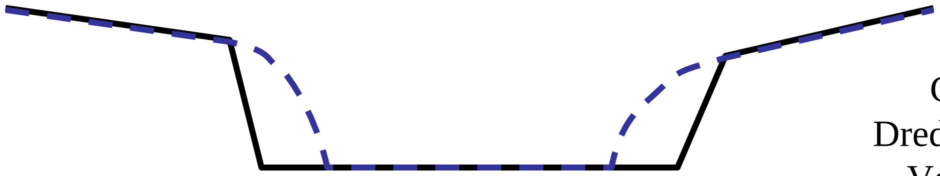


Bottom Slope Effect

Results in underestimation
of bottom slopes

Representation of a Trough (e.g.: dredged channel)



Can have consequences for
Dredge payment as underestimates
Volume of sediment removed.

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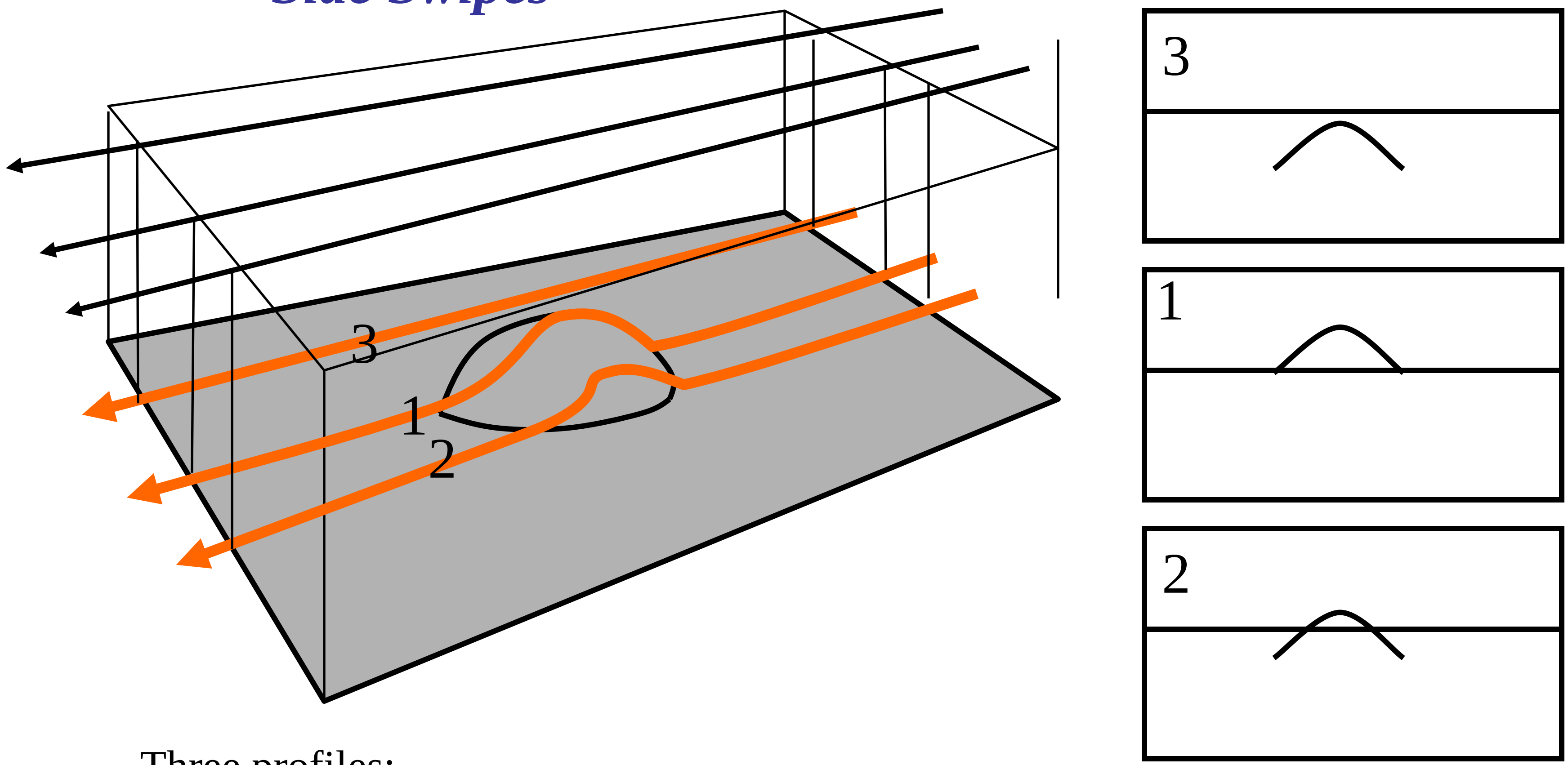
Side Swipes



Three profiles:

1. Directly over the target
2. Offset but over the target
3. Offset, never over the target

Note true elevation generally underestimated
And location imperfectly defined

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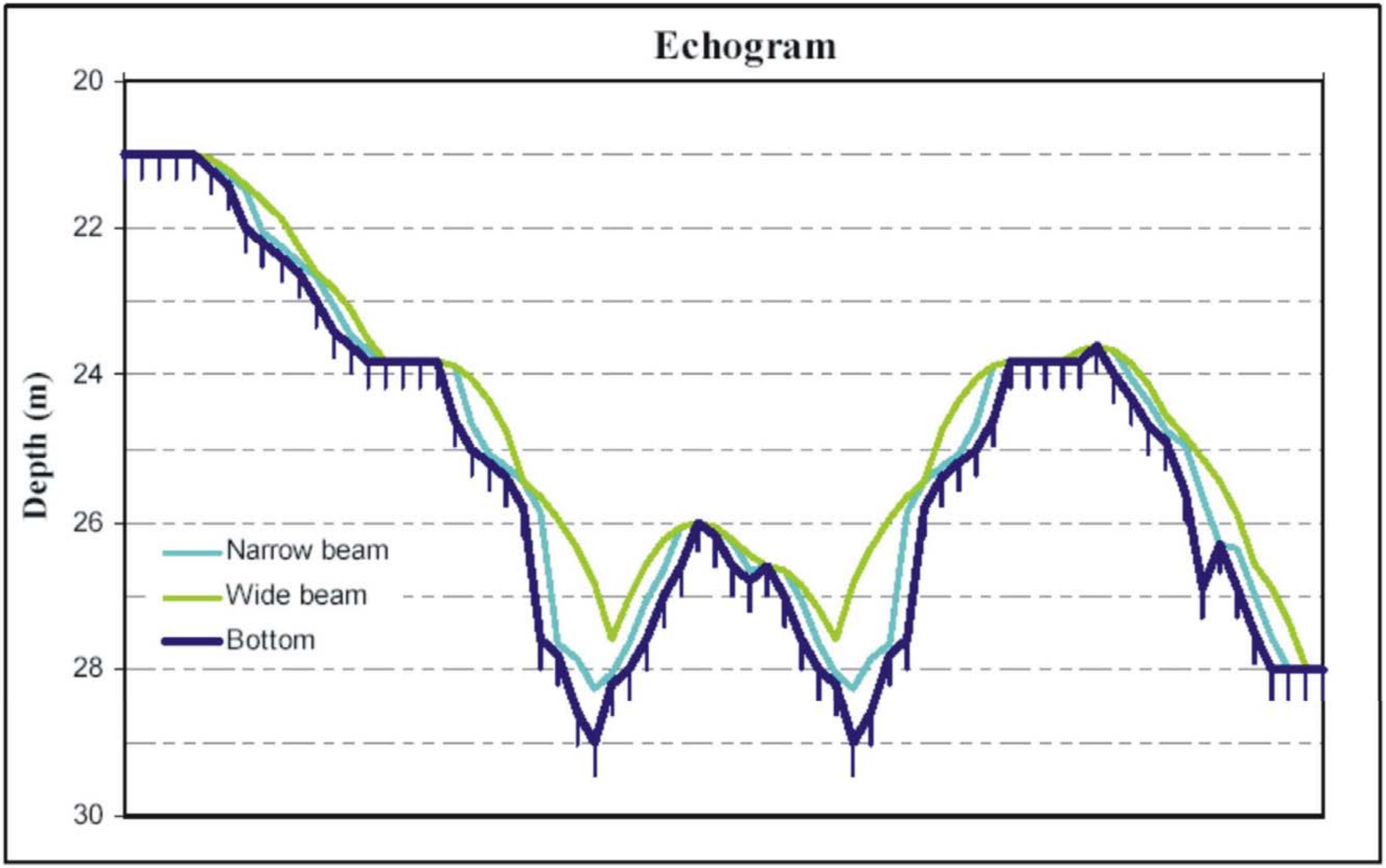
COMPARING NARROW- AND WIDE-BEAM PORTRAYALS OF THE SEABED



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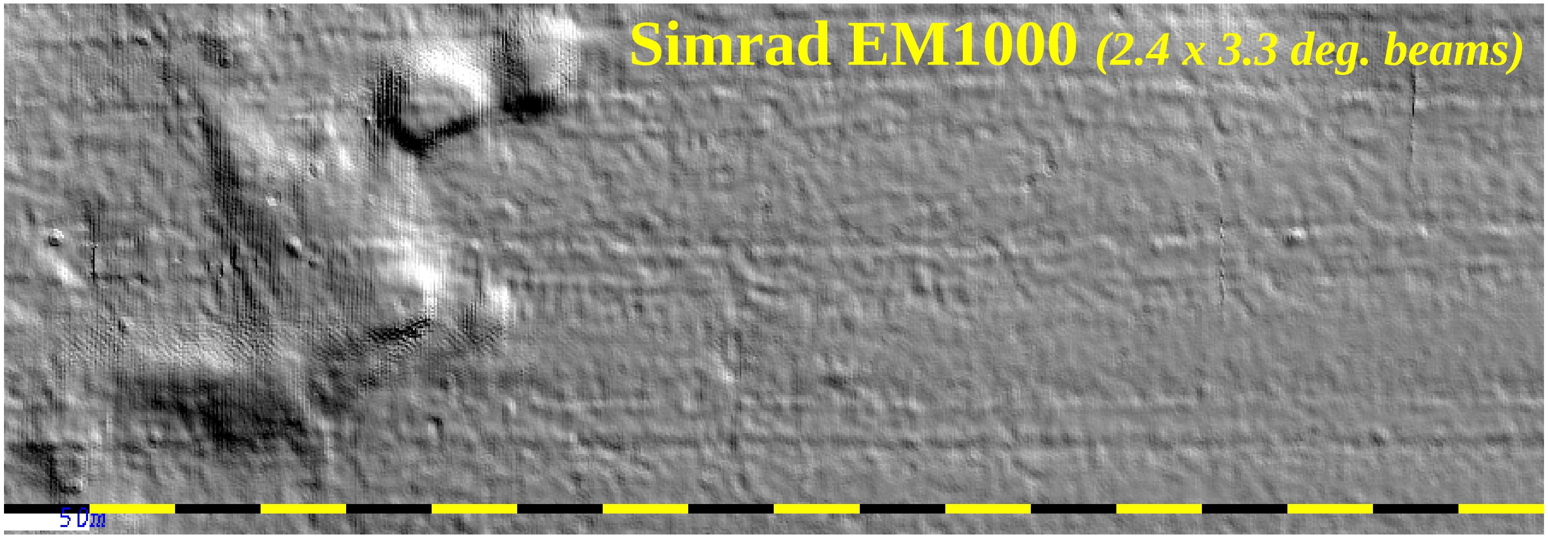
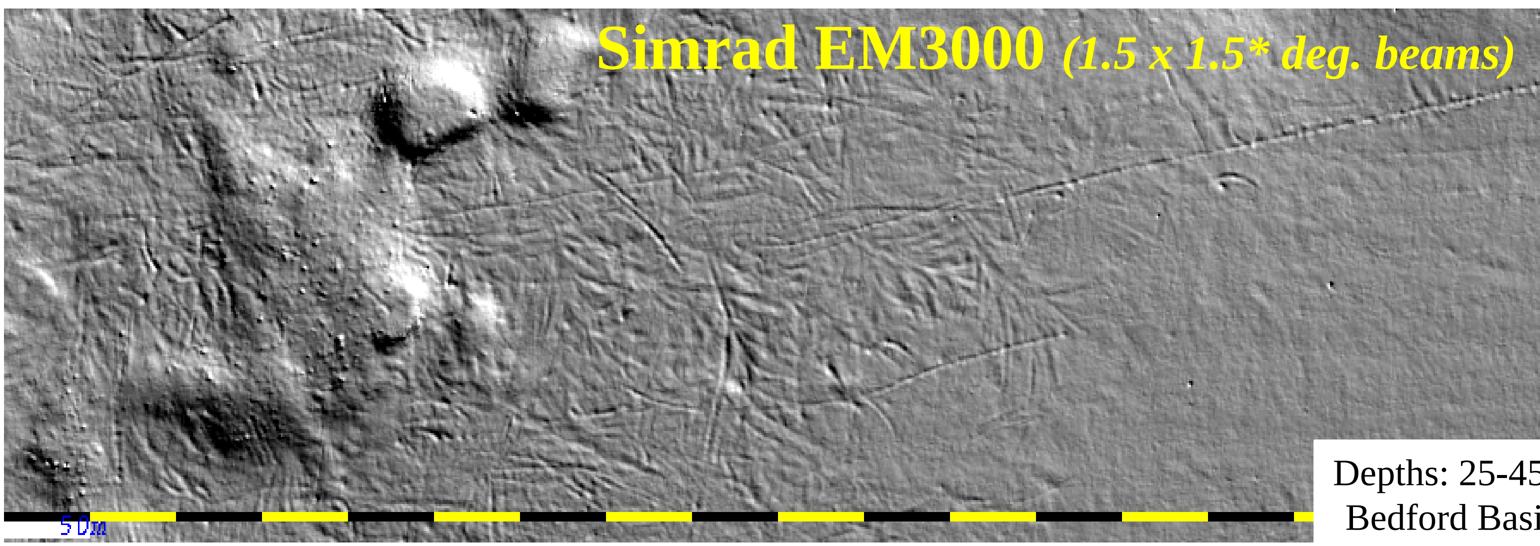
NARROW BEAMS = HIGHER RESOLUTION





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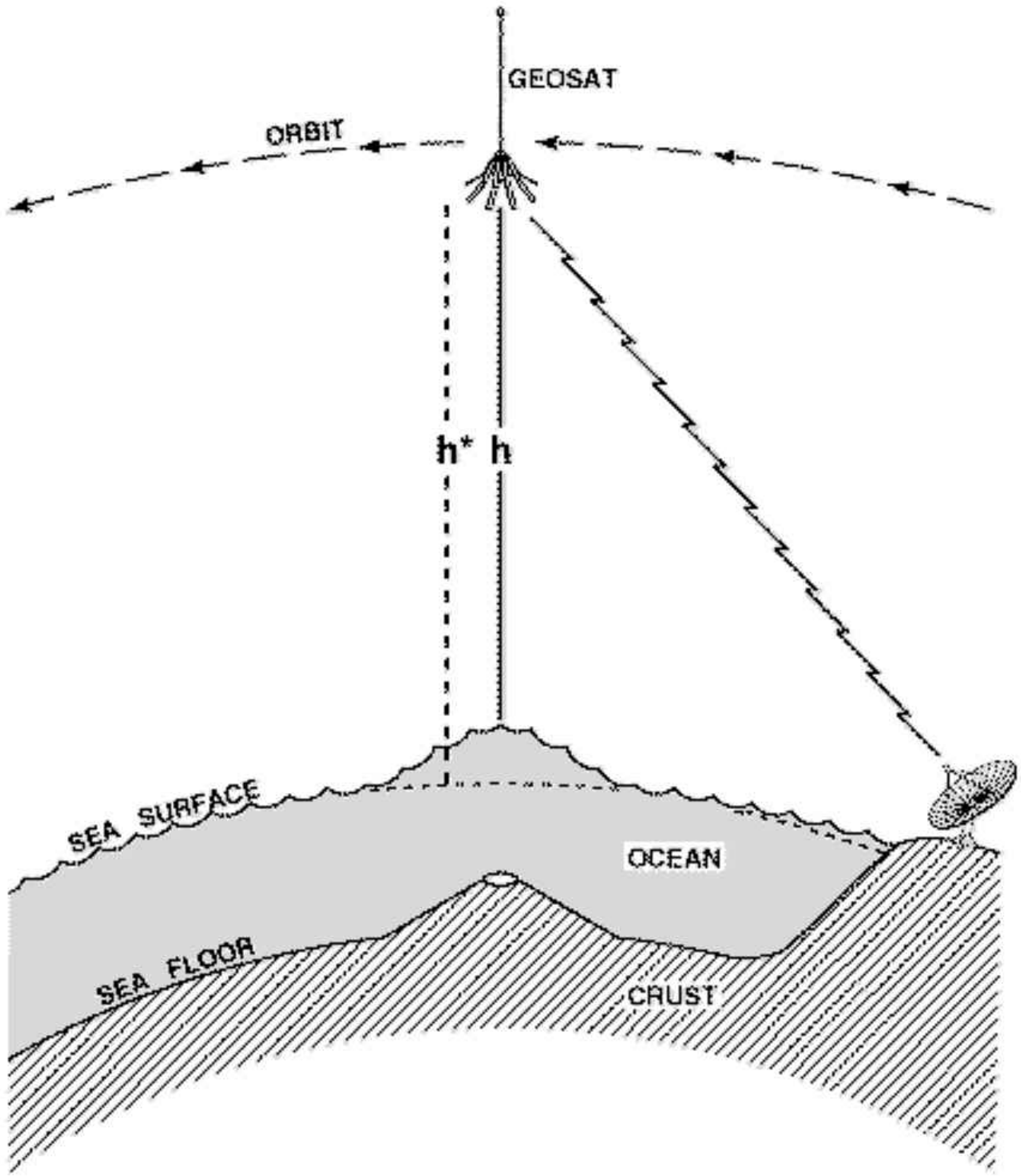
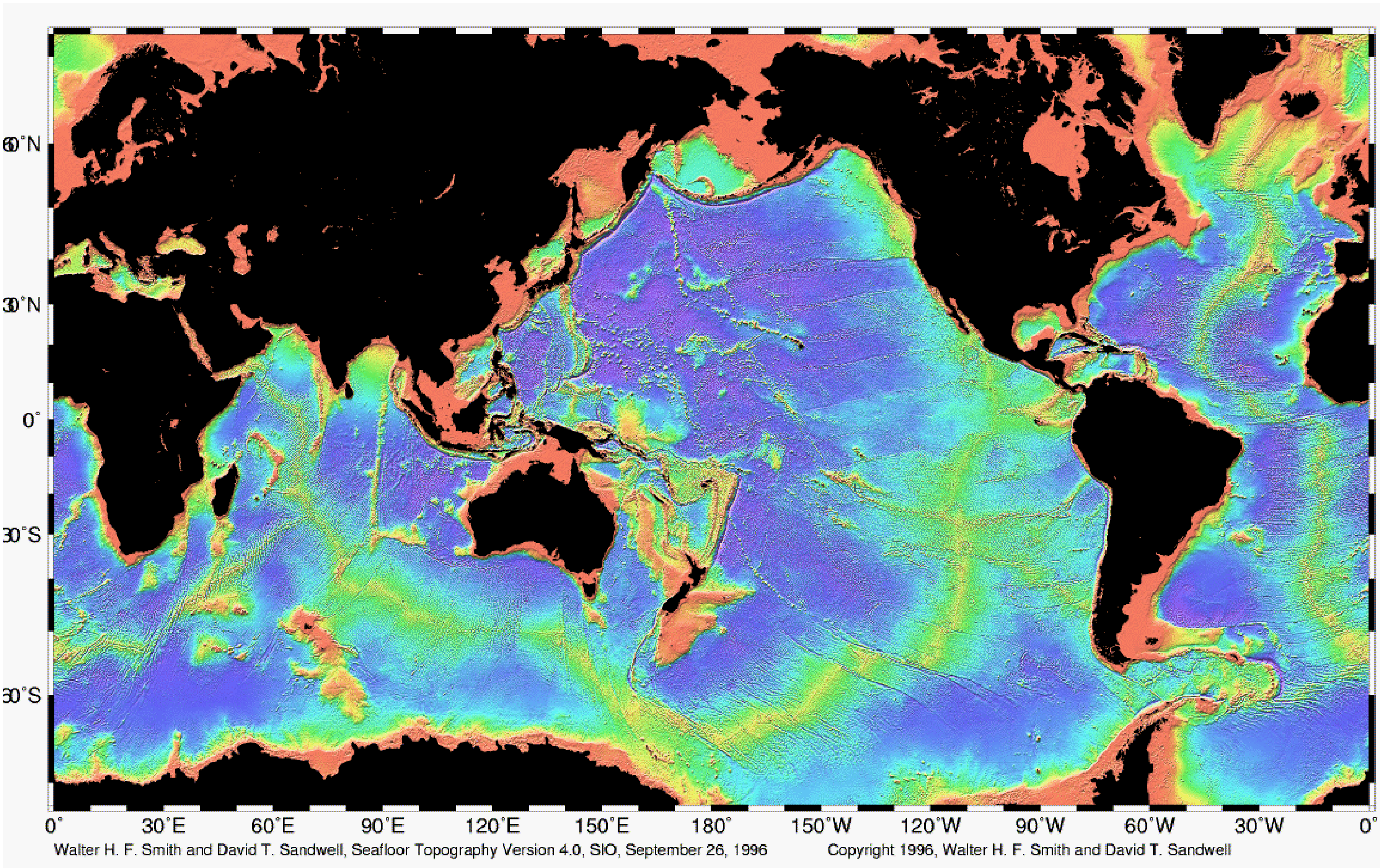
BATHYMETRY DERIVED FROM SATELLITE ALTIMETRY



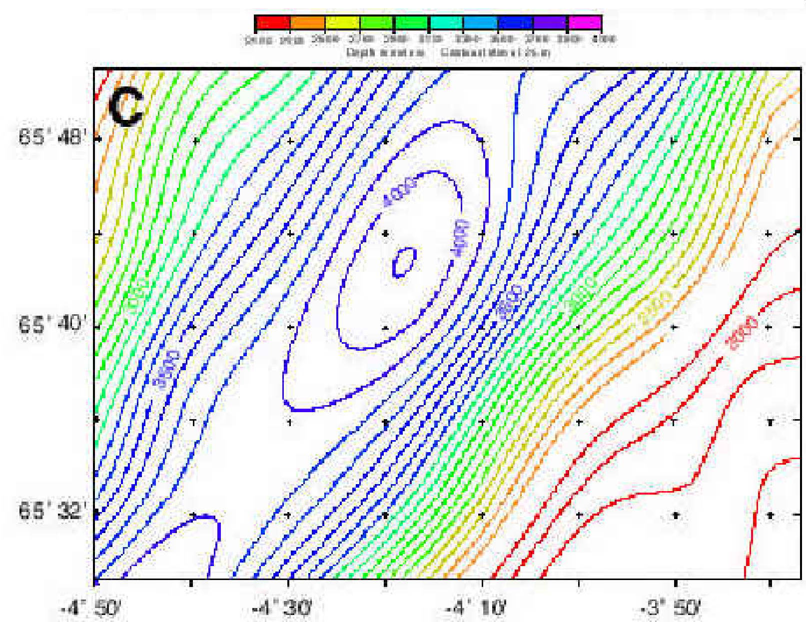
WORLD BATHYMETRY FROM SATELLITE ALTIMETRY



BATHYMETRY DERIVED FROM SATELLITE ALTIMETRY

- Bathymetric maps derived from satellite altimetry cover most of the globe. They are very useful for presenting regional views and for general analysis.
- These maps cannot resolve seabed features to better than about 8 km, with depth inaccuracies of 100s of metres. The CLCS has declared that it will not accept such maps in support of submissions.

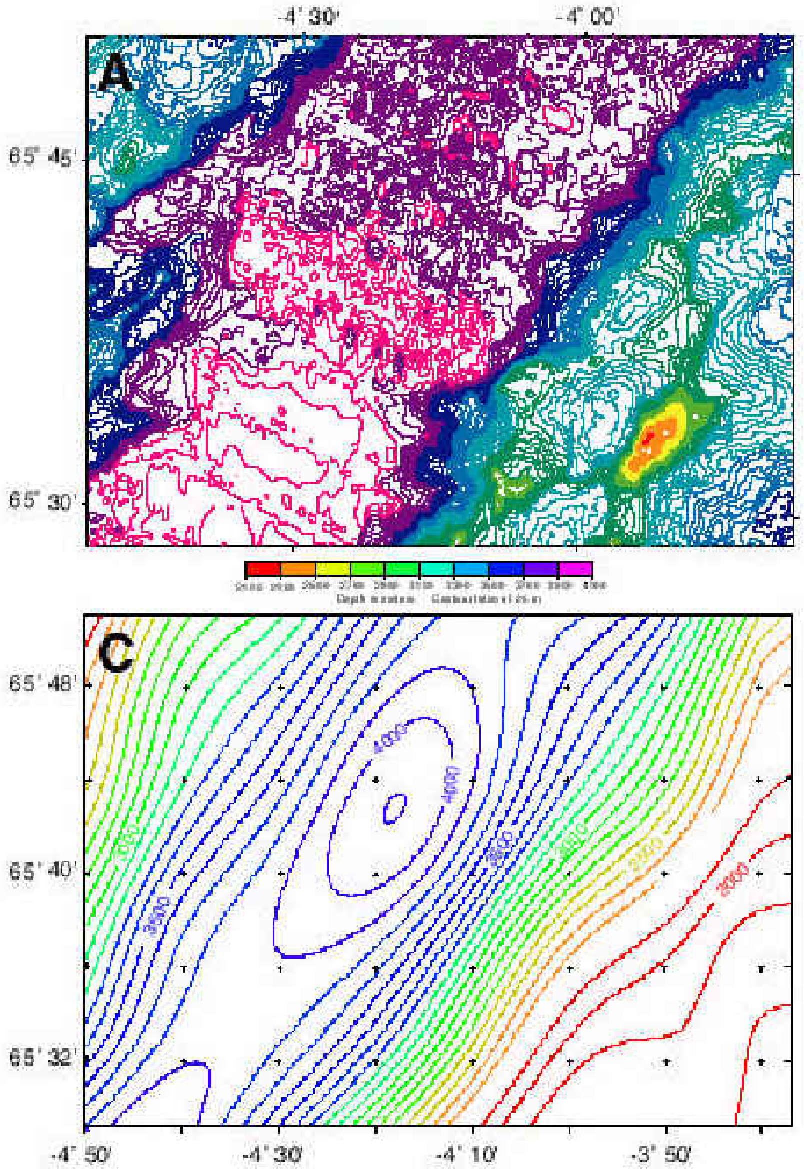
AEGIR RIDGE



DEPTHS DERIVED FROM SATELLITE ALTIMETRY

Peter Vogt, USNRL

AEGIR RIDGE



DEPTHS MEASURED WITH MULTIBEAM

DEPTHS DERIVED FROM SATELLITE ALTIMETRY

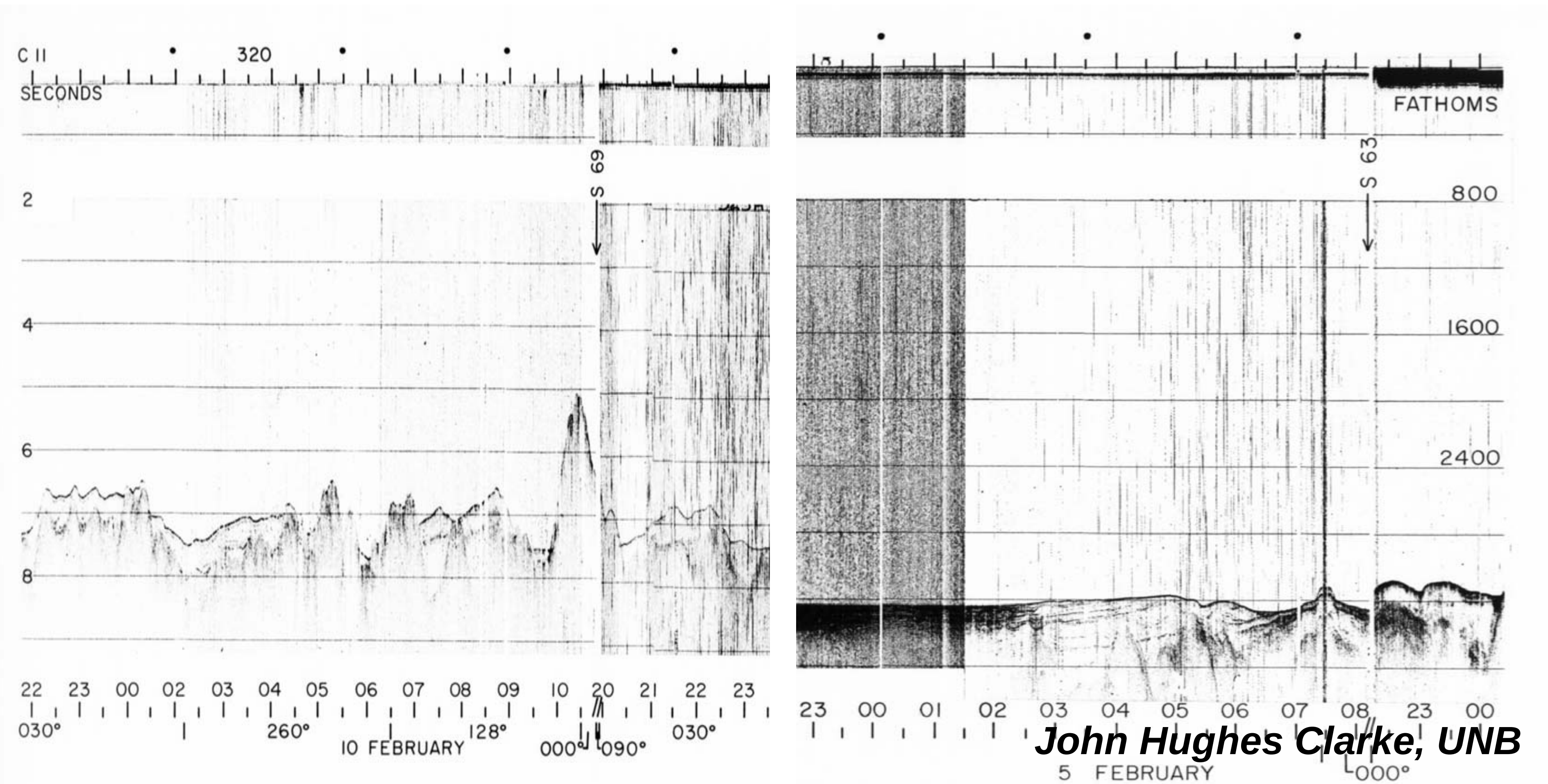
Peter Vogt, USNRL

BATHYMETRY DERIVED FROM SEISMIC MEASUREMENTS

Deemed acceptable by CLCS, but only as secondary data

Conventional annotation - TWT

Converted annotation - Depth



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MEASURING THE THICKNESS OF SEDIMENT: PRINCIPLES, PRACTICES, AND PROBLEMS

- In the Article 76 context, sediment thickness is needed to locate the Gardiner Line, i.e. the line where the thickness of sedimentary material is equal to 1% of the distance back to the foot of slope.
- Several considerations that apply to the measurement of bathymetry also apply to the measurement to sediment thickness, e.g. choice of frequency, acoustic propagation errors, etc.

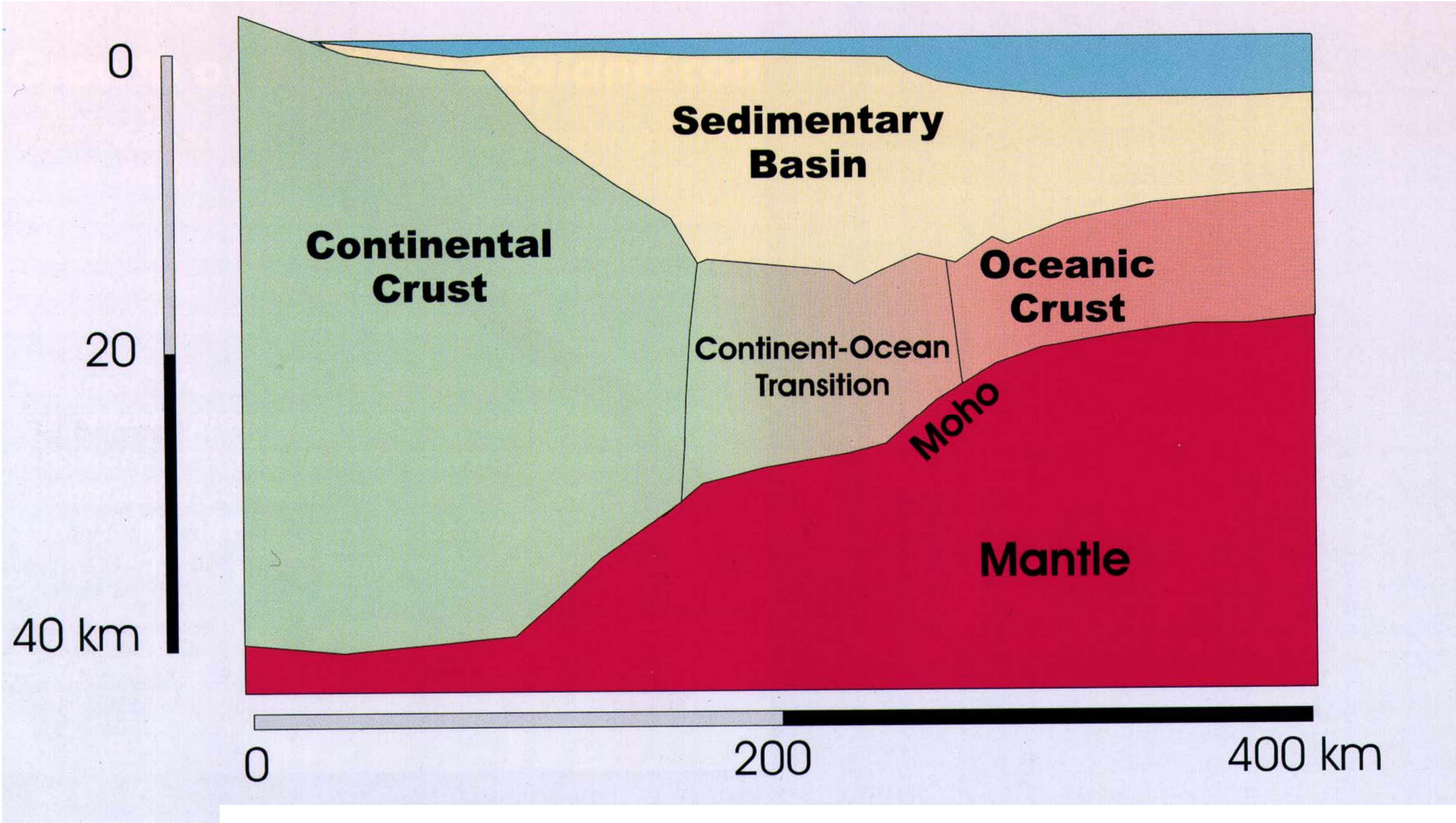
“THE BLUE BOOK”

Continental Shelf Limits: the Scientific and Technical Interface

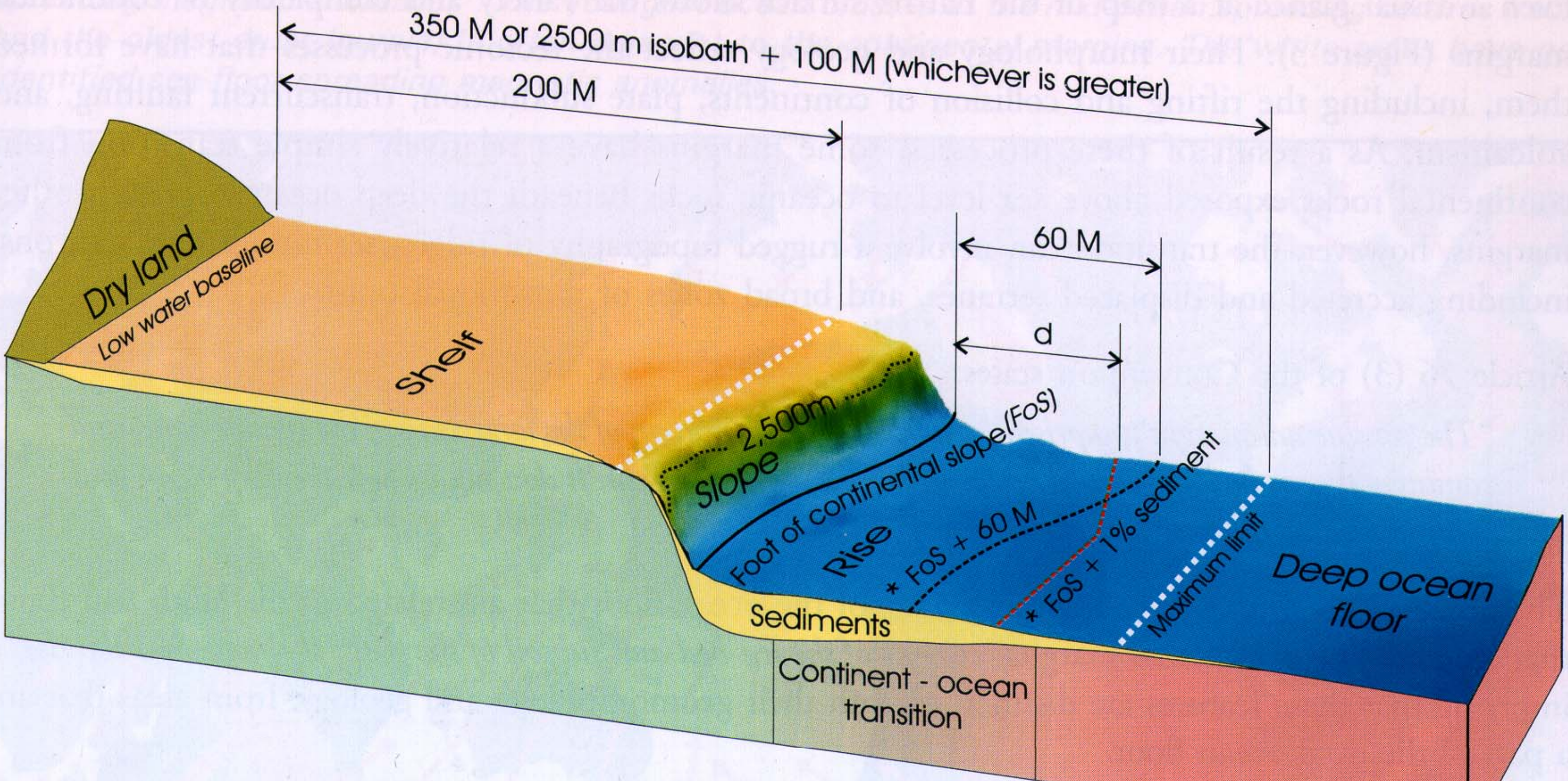
Chapter 12 (Kasuga, Nishizawa, Ohara, Kusunoki, and Katsura)

– *Seismic Reflection and refraction Methods*

A PASSIVE CONTINENTAL MARGIN



Extended Continental Shelf (UNCLOS article 76)



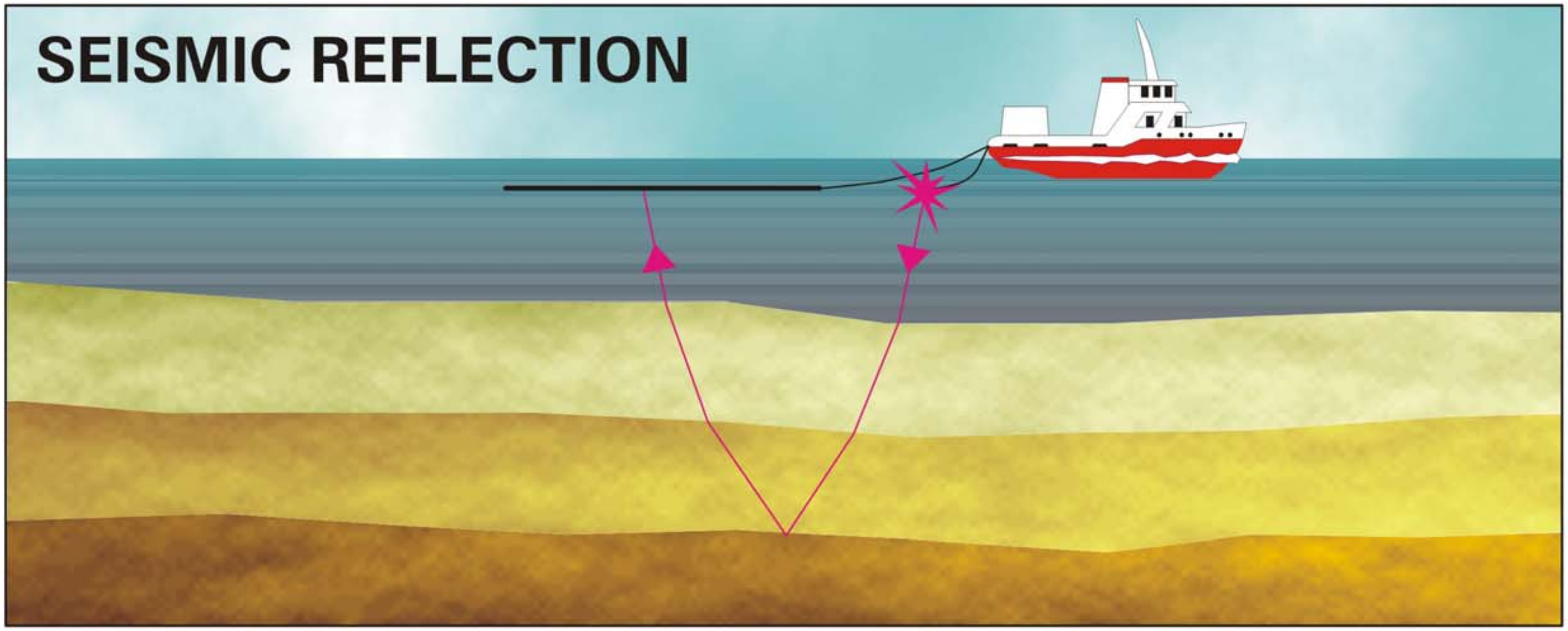
FoS = Foot of the continental slope

d = distance from 1% sediment thickness to foot of continental slope

* = extended continental shelf (whichever is greater)

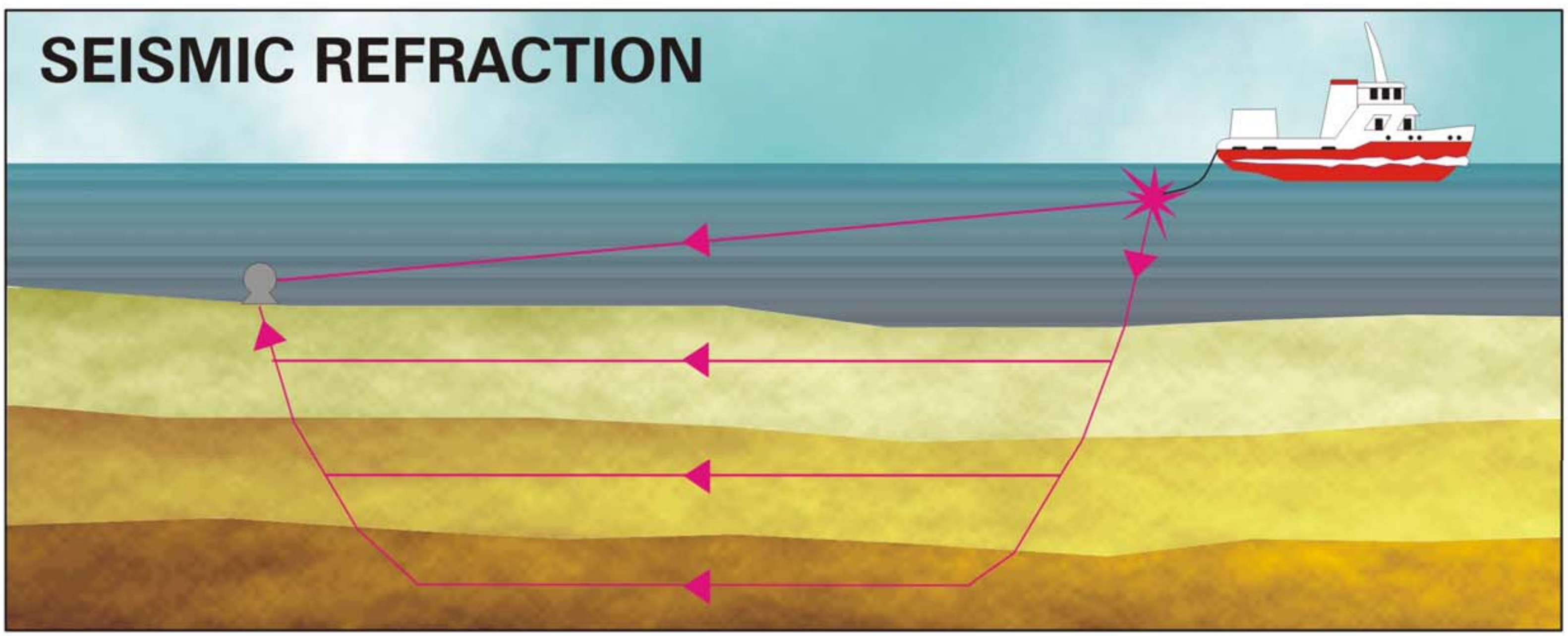
Figure 2 *Diagram summarising the formulae and constraints on the outer limits of the continental shelf from UNCLOS article 76 (modified from Kapoor and Kerr [4]).*

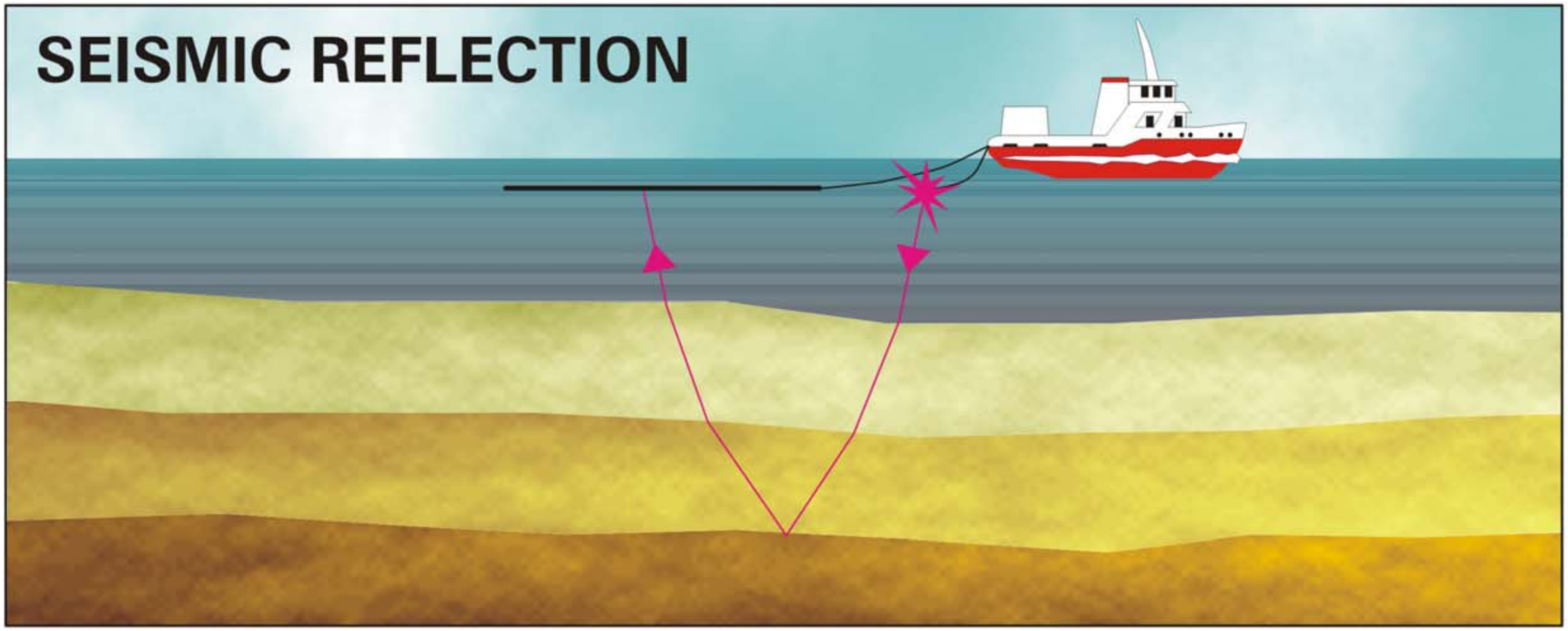
Wood et al. 2003

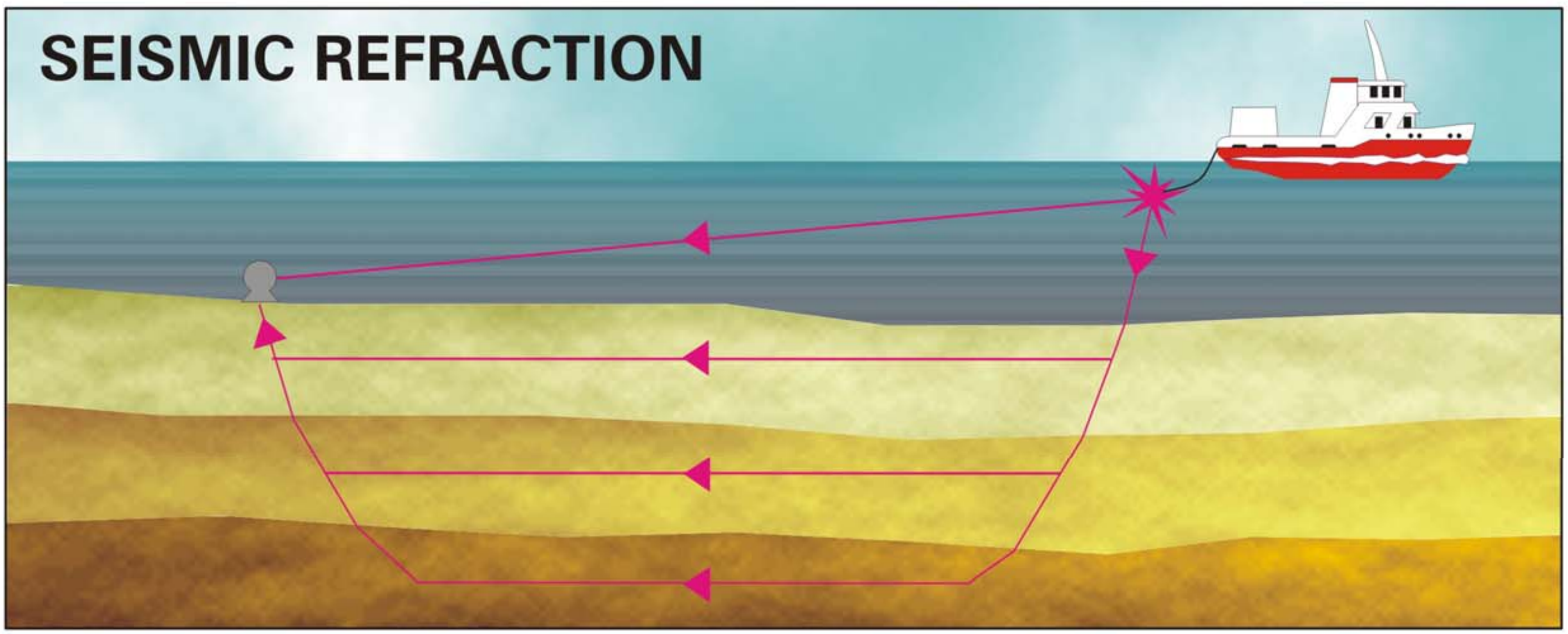


THE SEISMIC REFLECTION TECHNIQUE MEASURES THE TWO-WAY TRAVEL TIMES OF SOUND PULSES THROUGH SEDIMENT LAYERS THAT LIE BENEATH THE OCEAN FLOOR. BUT THOSE TRAVEL TIMES NEED TO BE COMBINED WITH THE SOUND VELOCITY FOR EACH LAYER IN ORDER TO YIELD VALUES OF SEDIMENT THICKNESS.

THE SEISMIC REFRACTION TECHNIQUE MEASURES THE HORIZONTAL TRAVEL TIMES OF SOUND PULSES THROUGH SEDIMENT LAYERS THAT LIE BENEATH THE OCEAN FLOOR. COMBINING THOSE TRAVEL TIMES WITH THE KNOWN DISTANCE BETWEEN SOUND SOURCE AND RECEIVER YIELDS THE SOUND VELOCITY FOR EACH LAYER.

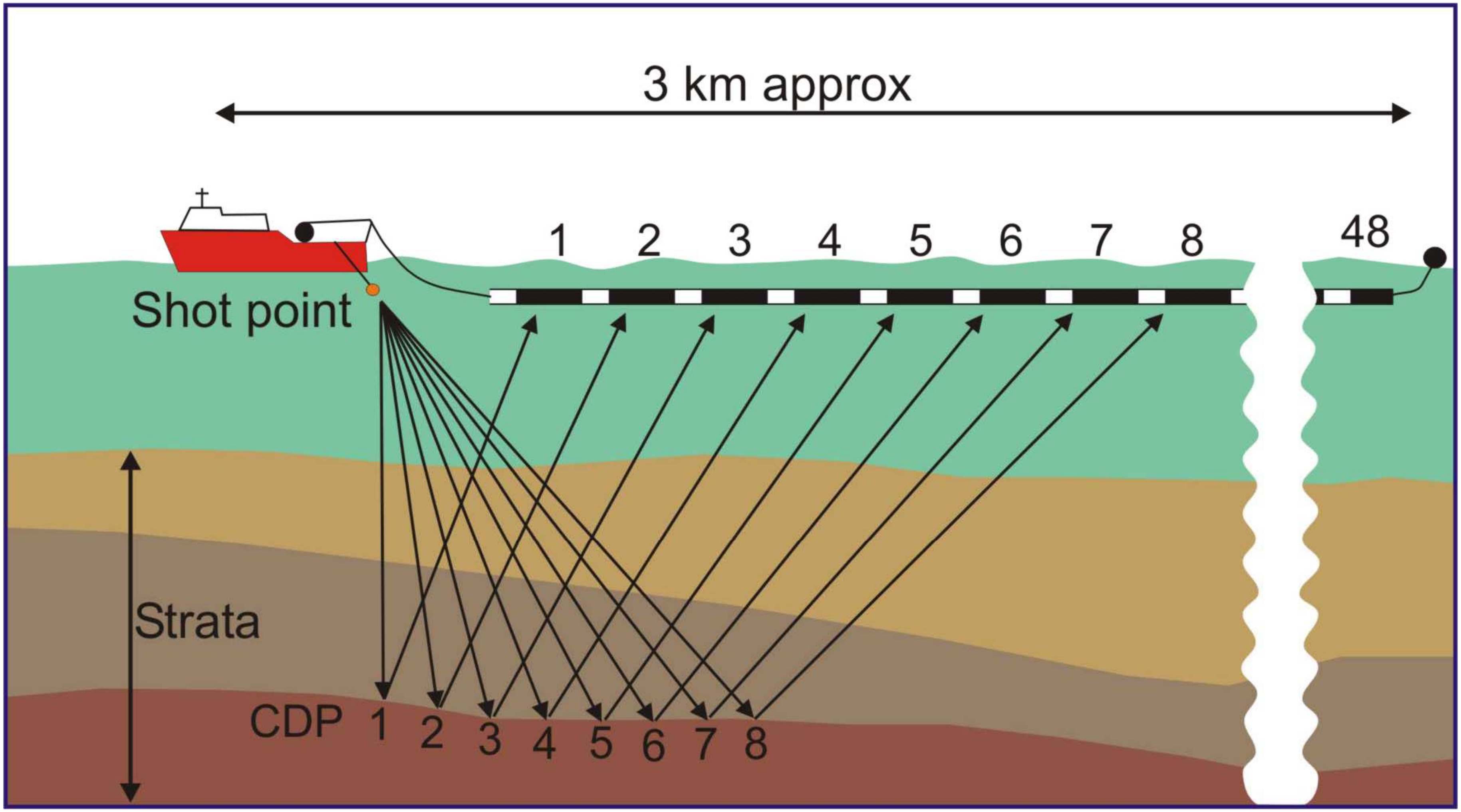



SEISMIC REFLECTION


SEISMIC REFRACTION

VELOCITY ANALYSIS

CALCULATING SOUND VELOCITIES IN SEDIMENT



Requires complex sensor configuration and extensive computer processing

MEASURING SEDIMENT THICKNESS FOR ARTICLE 76

- Single channel system will suffice if only depth to acoustic basement is being sought – this is cheap and simple to operate.
- Simple multichannel system will yield stratigraphic information in addition to depth to basement, but refraction experiments may be needed to calculate sound velocities – this is more expensive and complex.
- Industry multichannel system will yield detailed cross-section of sediment down to the basement – this is very expensive and may yield more information than is required.

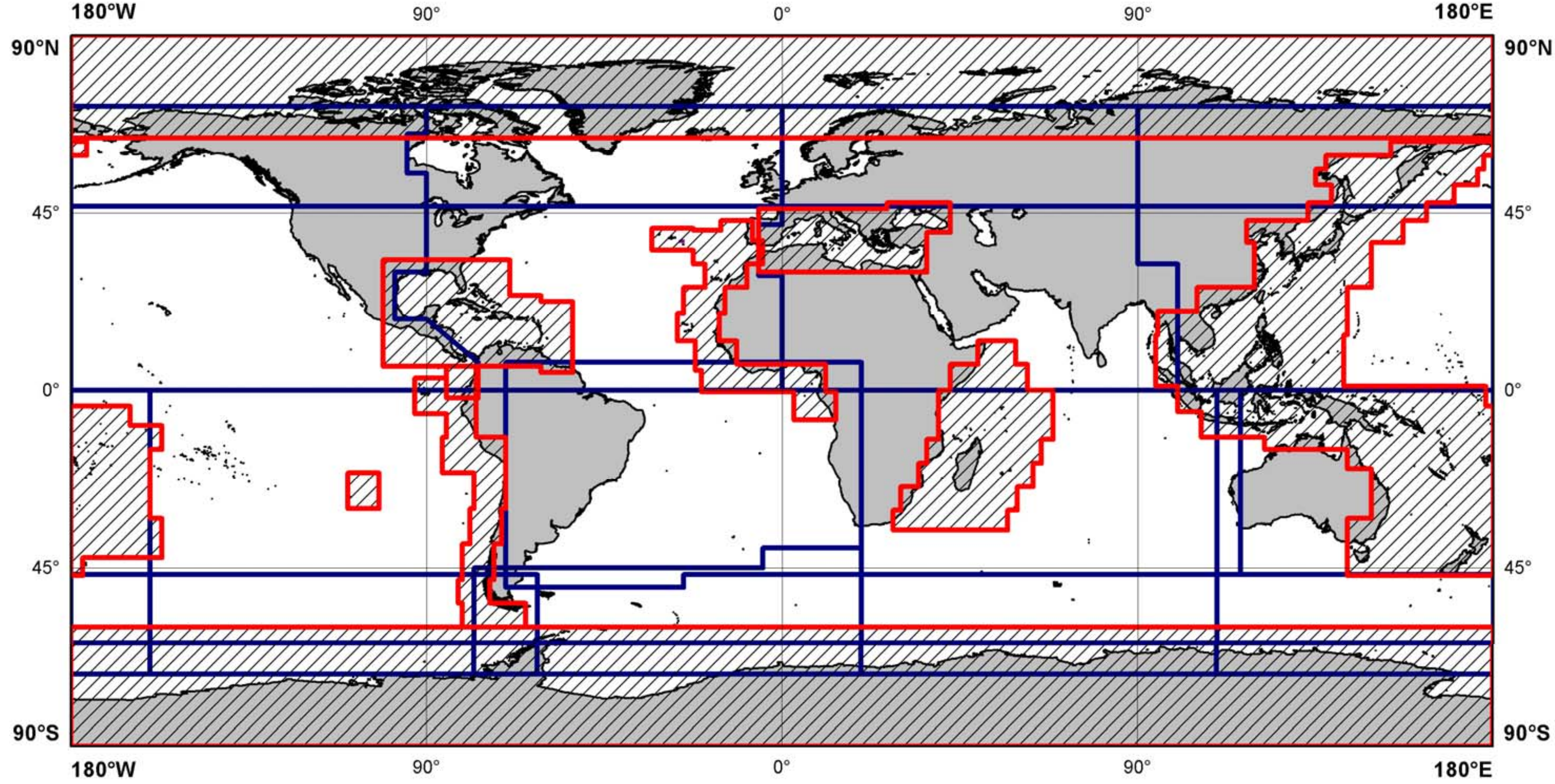
GATHER NEW DATA, OR USE EXISTING DATA?

Questions to ask when making the decision:

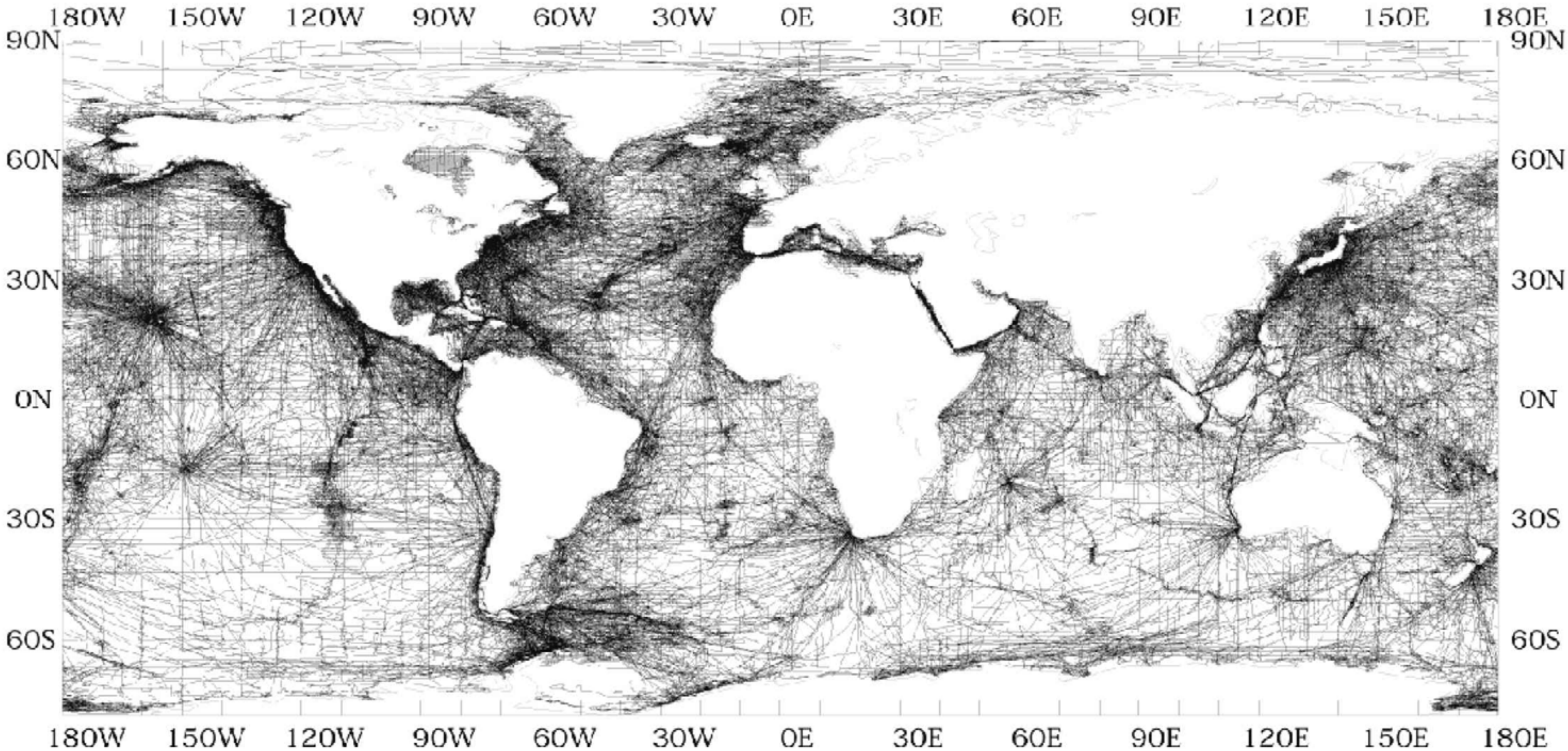
- Availability, coverage, and quality of existing holdings?
- Prospects for building a better article 76 case with new data?
- Time and effort to collect new data?
- Cost of collecting new data?

SOURCES OF EXISTING DATA

GEBCO (BLUE) AND IBC (RED) SHEETS



GLOBAL TRACKLINE HOLDINGS AT NGDC



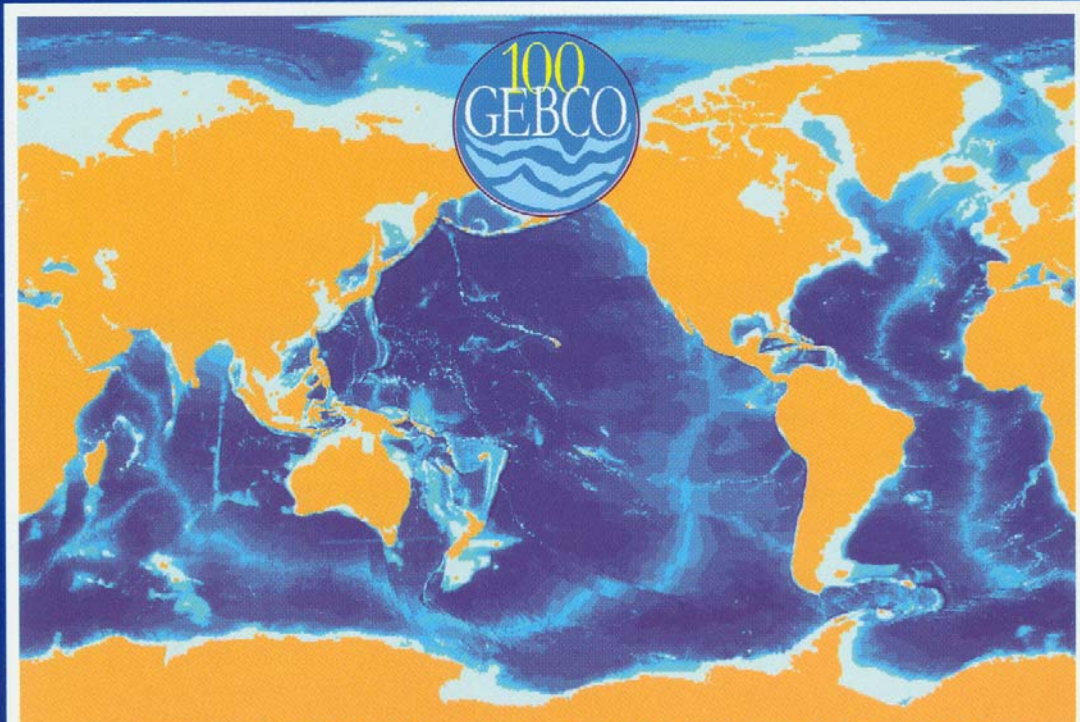
MARINE
TRACKLINE GEOPHYSICS

Worldwide Bathymetry, Magnetics and Gravity
with GEODAS Database Management System

CD-ROM data set and accompanying GEODAS software produced by

U.S. DEPARTMENT OF COMMERCE,
National Oceanic and Atmospheric Administration,
National Environmental Satellite, Data, and Information Service,
National Geophysical Data Center

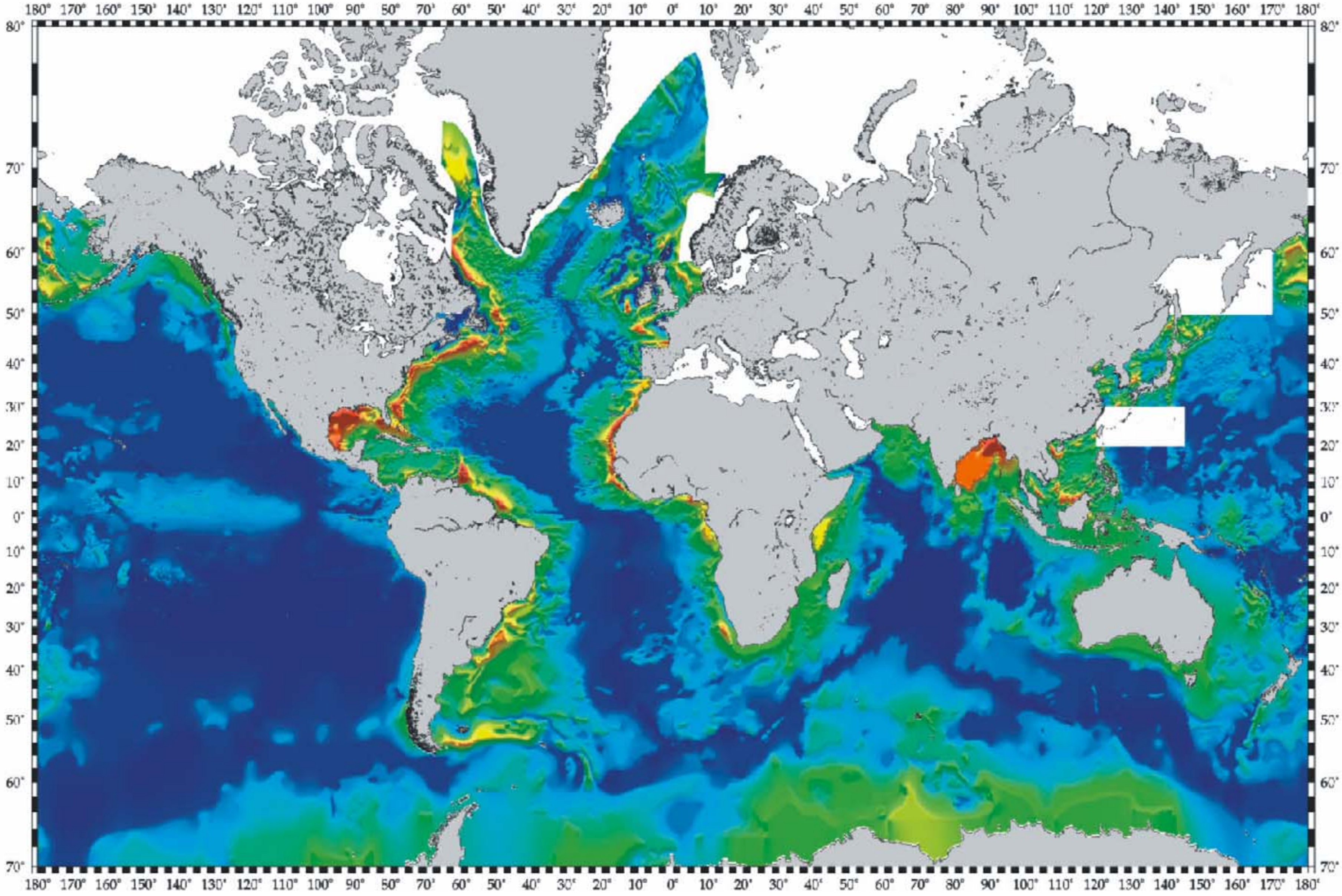
GEBCO DIGITAL ATLAS



GENERAL BATHYMETRIC CHART OF THE OCEANS

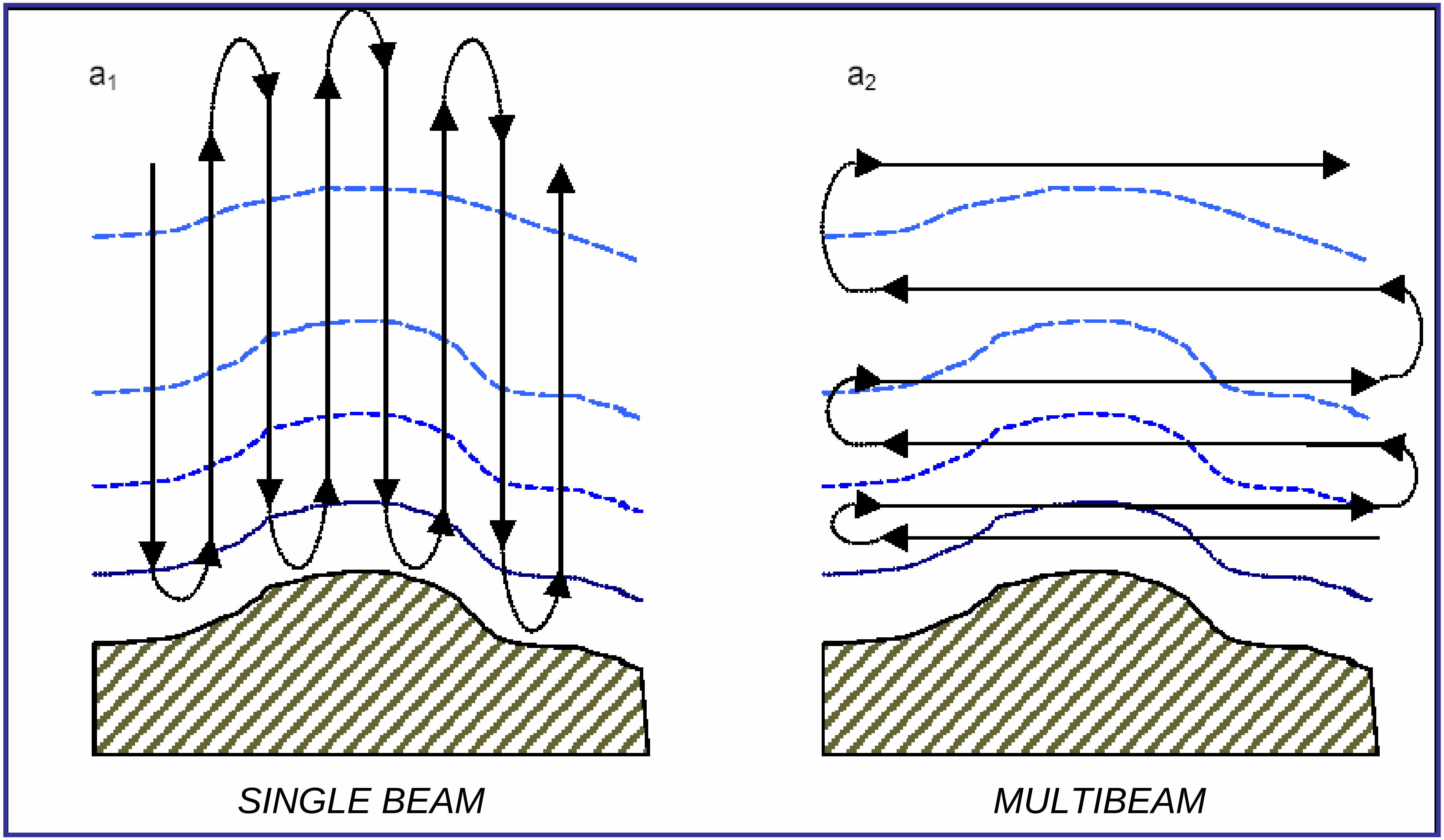
1903 - CENTENARY EDITION -2003

GLOBAL SEDIMENT THICKNESS GRID – NGDC



BASIC SURVEY DESIGN

GET EXPERT HELP!



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DATABASE AND GIS TOOLS

- Proprietary tools exist for archiving and managing the geo-referenced data sets that are needed for Article 76 work. These tasks are common to many geographic and geoscientific endeavours, so the tools are common and well developed.
- Fewer proprietary tools exist for analyzing these georeferenced data sets for Article 76 purposes and for visualizing the outcome. These tasks are unique to Article 76 and hence represent a smaller market for software developers. Some coastal States have developed their own tools in house.
- A coastal State should seek expert advice in the selection and procurement of these tools, taking its unique circumstances into account: there is no ‘one size fits all’ solution.

THE TEST OF APPURTENANCE

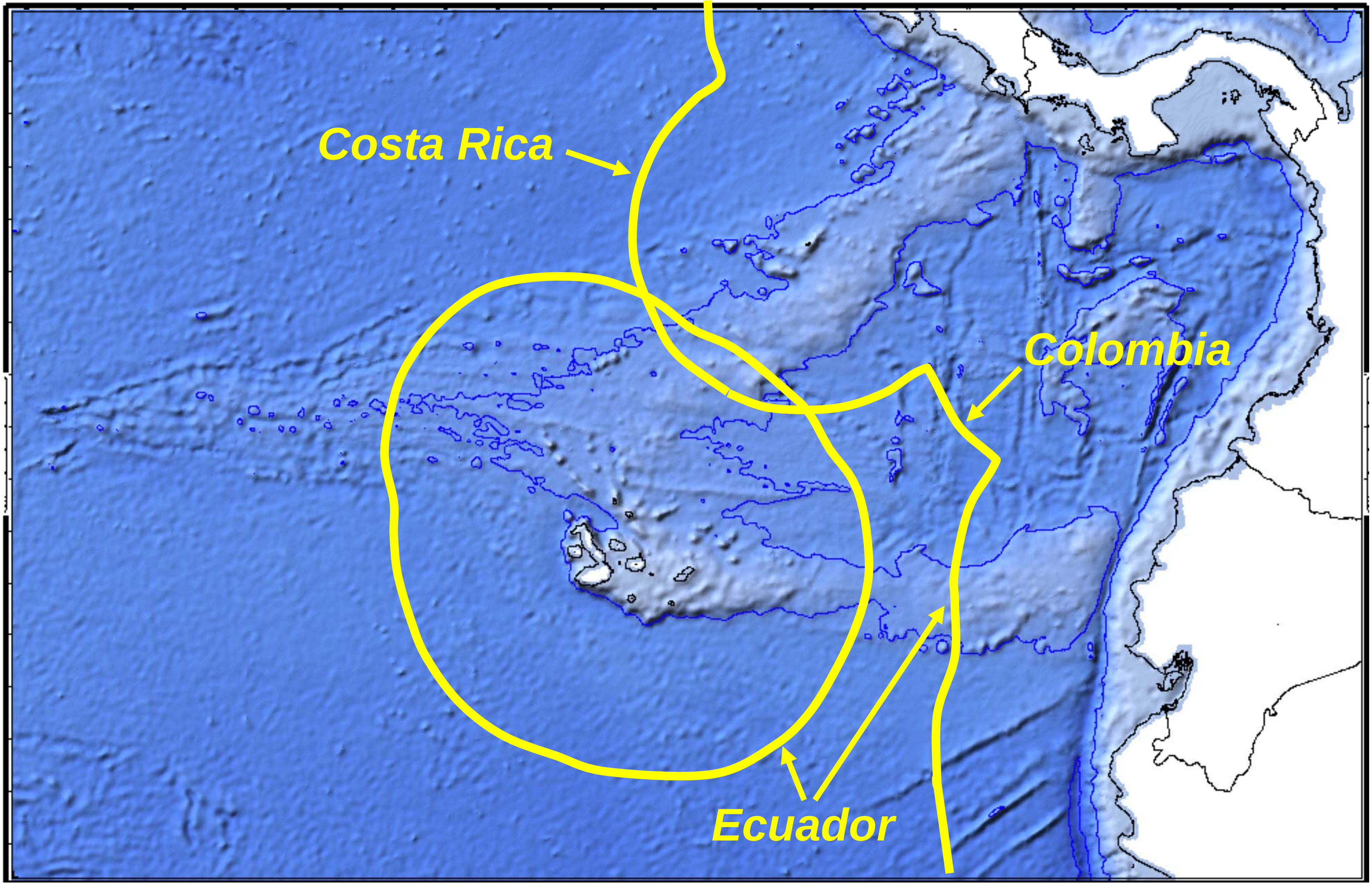
- The submitting State must demonstrate that a portion of its continental landmass extends beneath the sea and comprises a genuine ‘natural prolongation’
- The CLCS seems to prefer a geomorphological definition of the natural prolongation
- There may be some scope for invoking ‘evidence to the contrary’, e.g. geological or geophysical information, in defining the natural prolongation

SOME ILLUSTRATIONS OF THE TEST OF APPURTENANCE

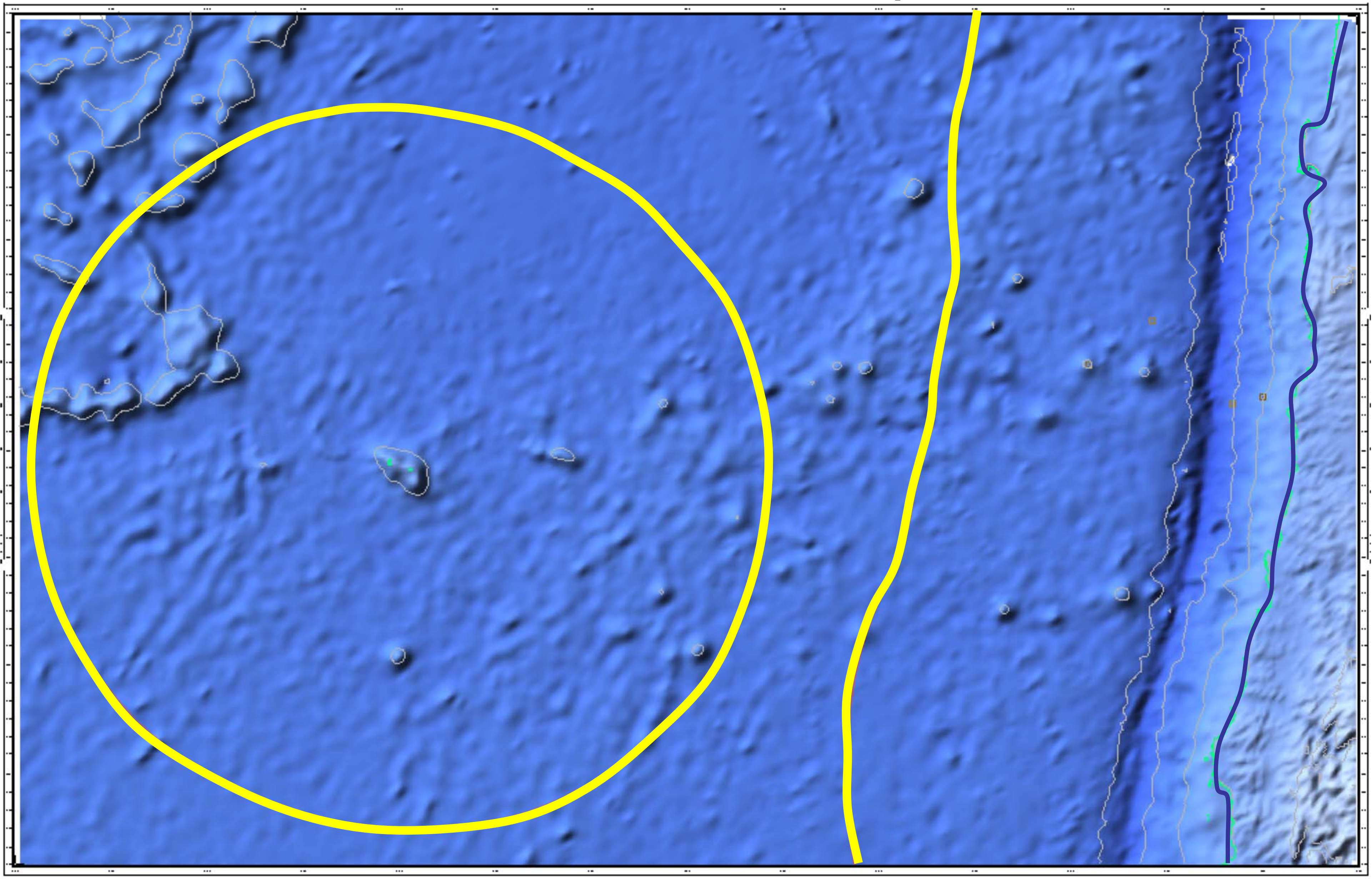
Islands located beyond the continental EEZs of their parent States:

- Ecuador and the Galapagos Islands
- San Felix and San Ambrosio Islands, Chile
- Azores and Madeira Islands, Portugal
- Trinidade and Martin Vaz Islands, Brazil

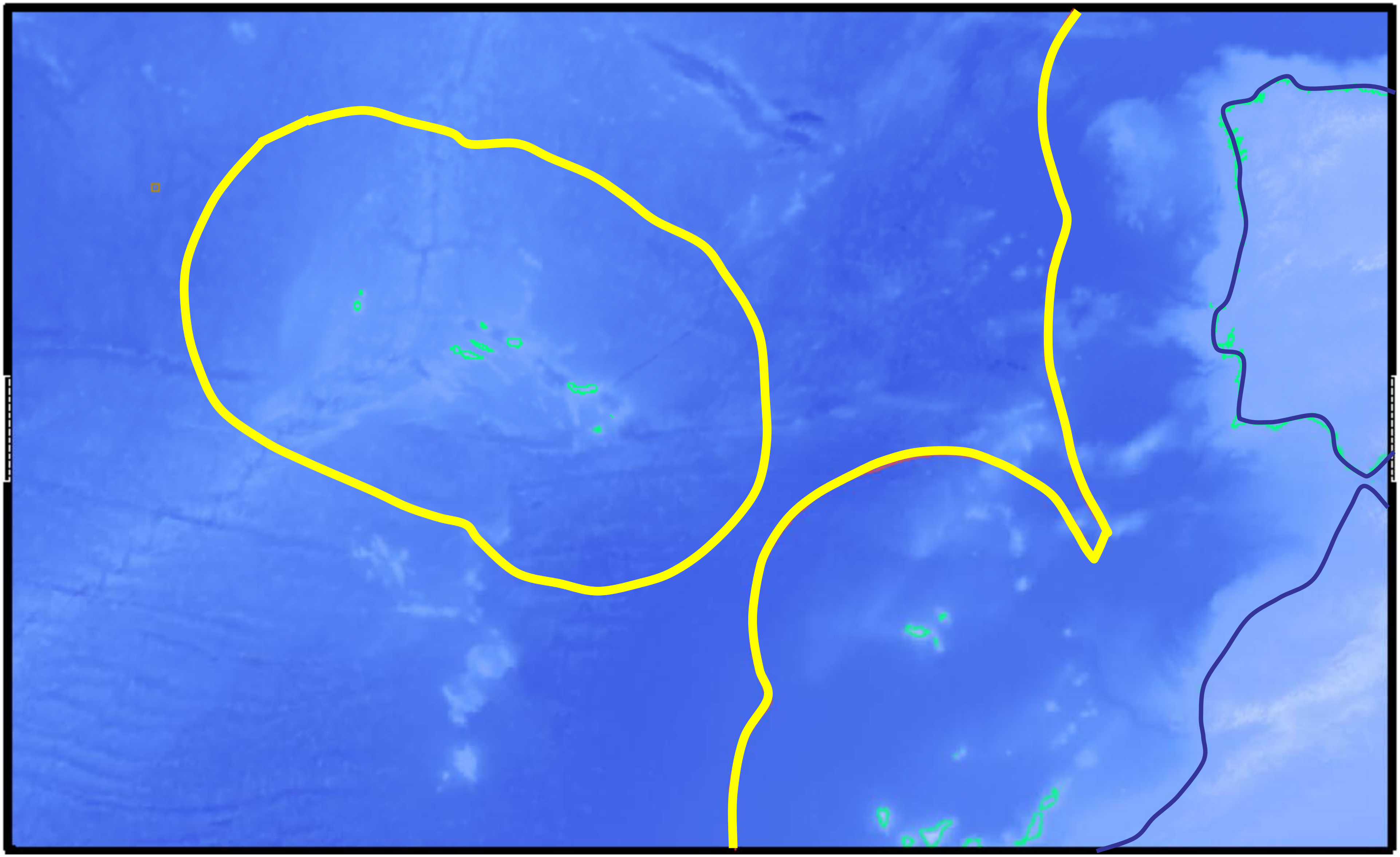
ECUADOR AND THE GALAPAGOS ISLANDS



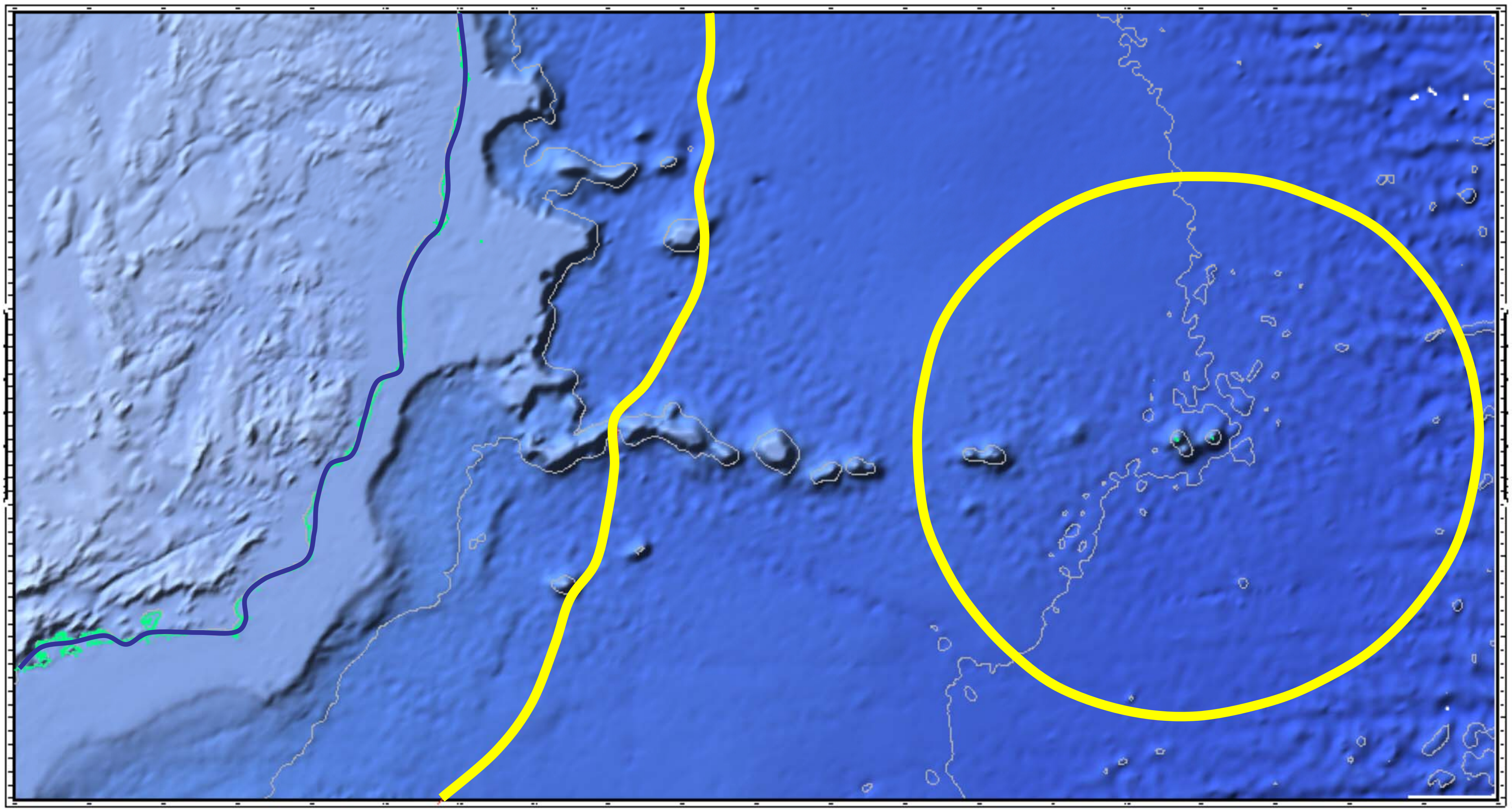
SAN FELIX AND SAN AMBROSIO ISLANDS, CHILE



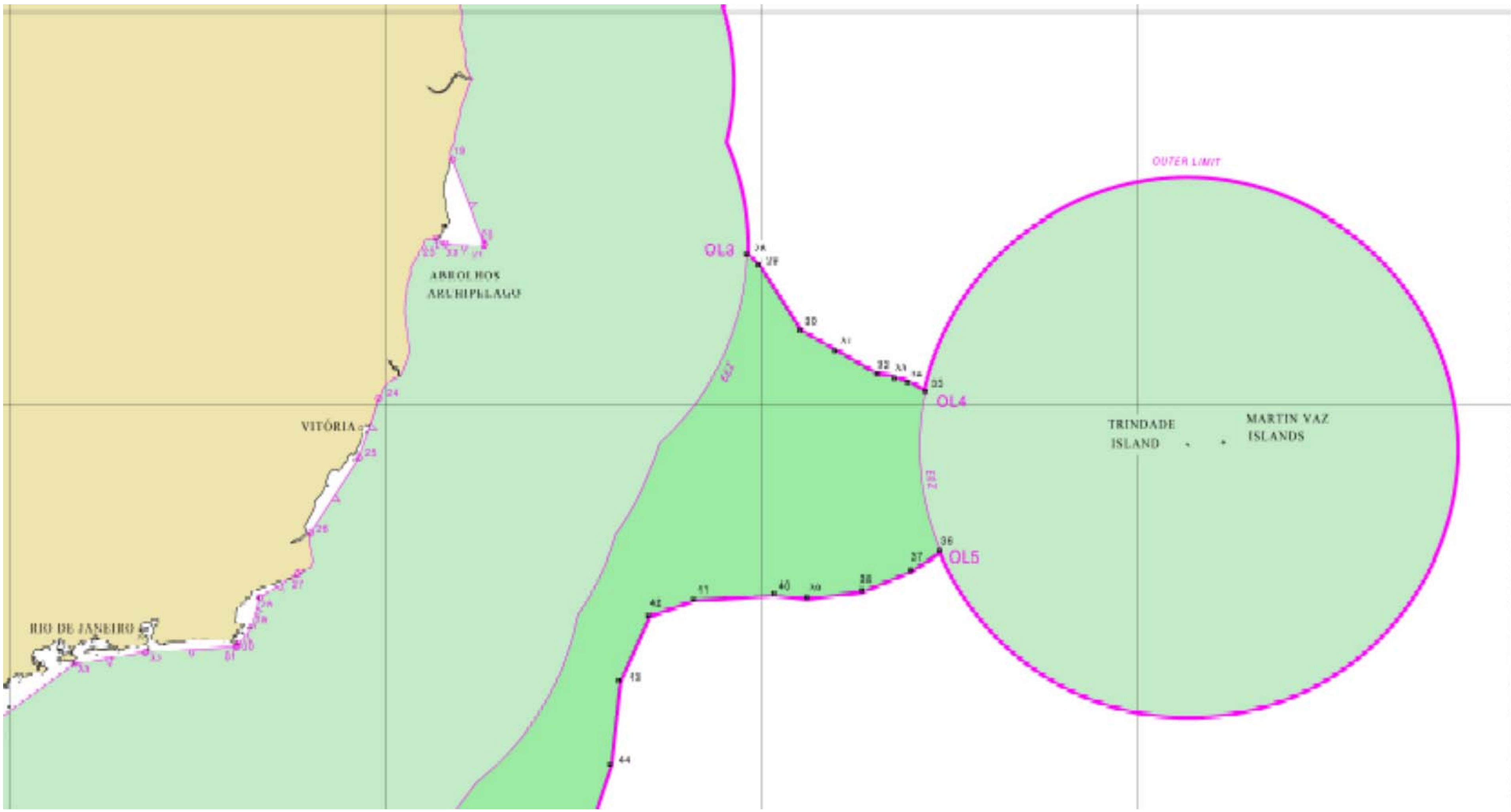
AZORES AND MADEIRA ISLANDS, PORTUGAL



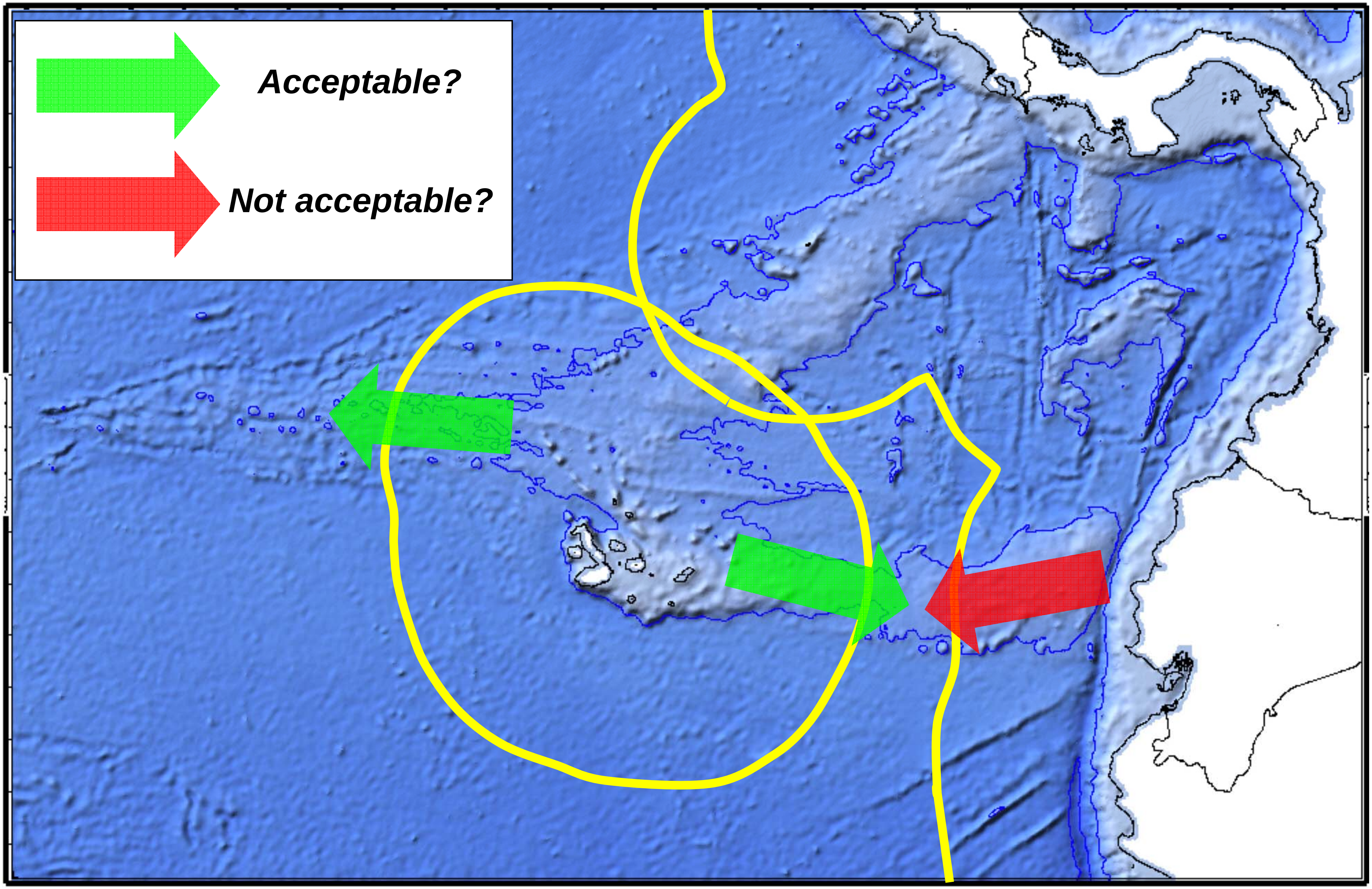
TRINIDADE AND MARTIN VAZ ISLANDS, BRAZIL



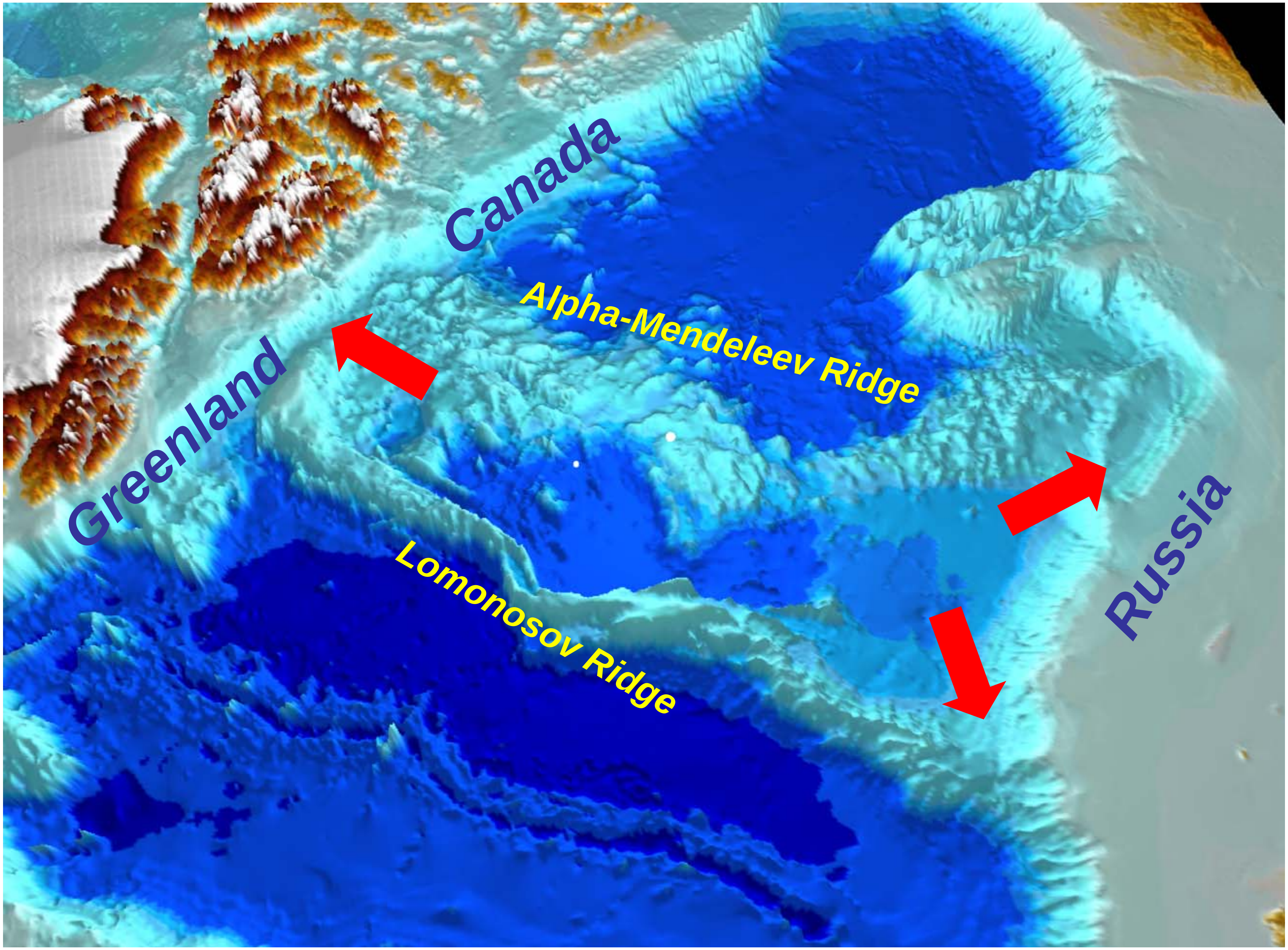
TRINIDADE AND MARTIN VAZ ISLANDS, BRAZIL: CLAIMED OCS LIMIT



NATURAL PROLONGATIONS AND THE TEST OF APPURTENANCE OFF ECUADOR



THE ARCTIC OCEAN: MORPHOLOGICAL BREAKS IN NATURAL PROLONGATIONS

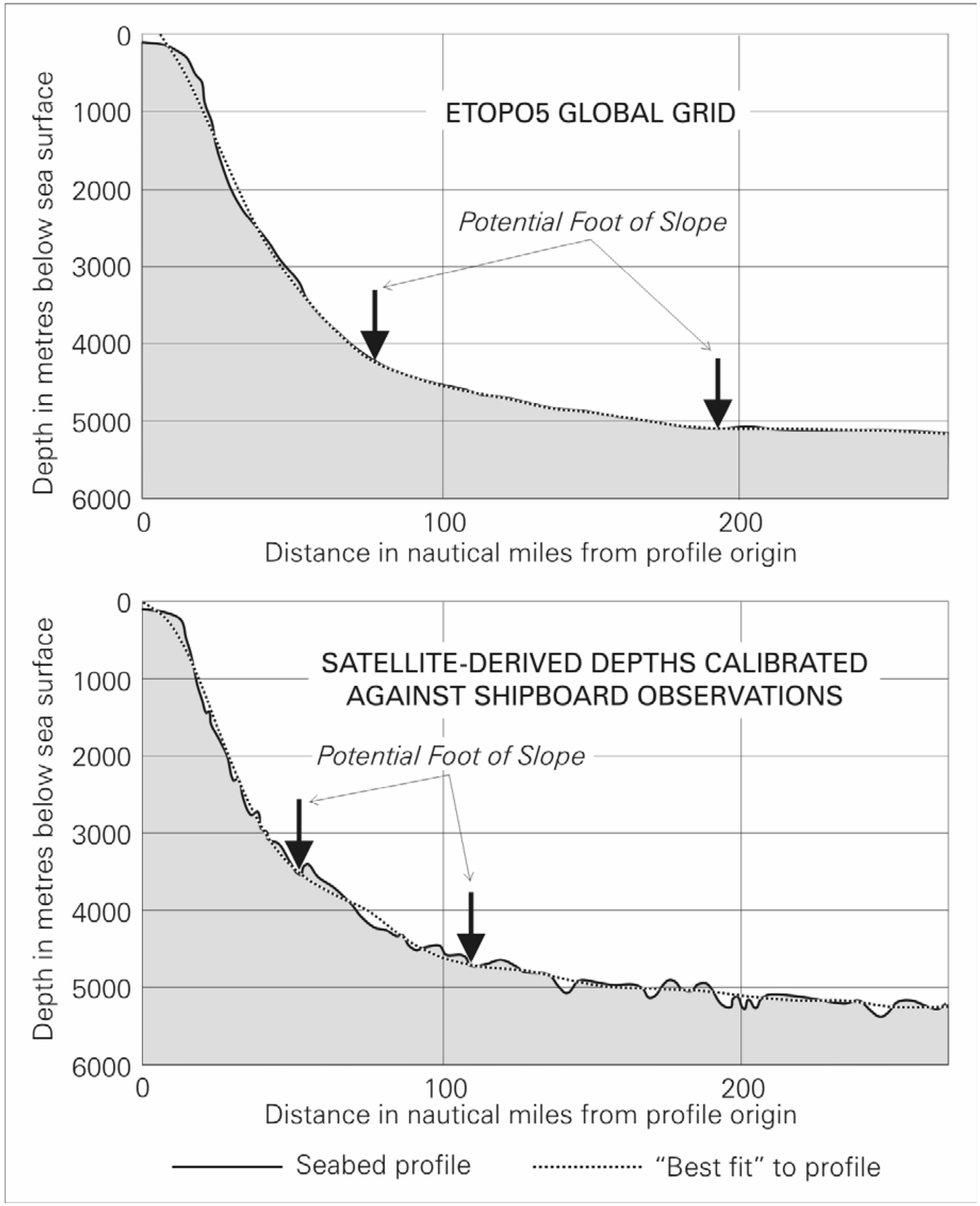


THE FOOT OF THE SLOPE

- The point of departure for the two Formula Lines of Article 76
- Defined as the point where the seabed undergoes a maximum change of gradient
- Not unambiguous: the FoS point may be difficult to determine with any precision, or there may be multiple contending points to choose from
- Important to document carefully the choice of FoS point and reasons why it was selected, in case of a query or challenge by the CLCS

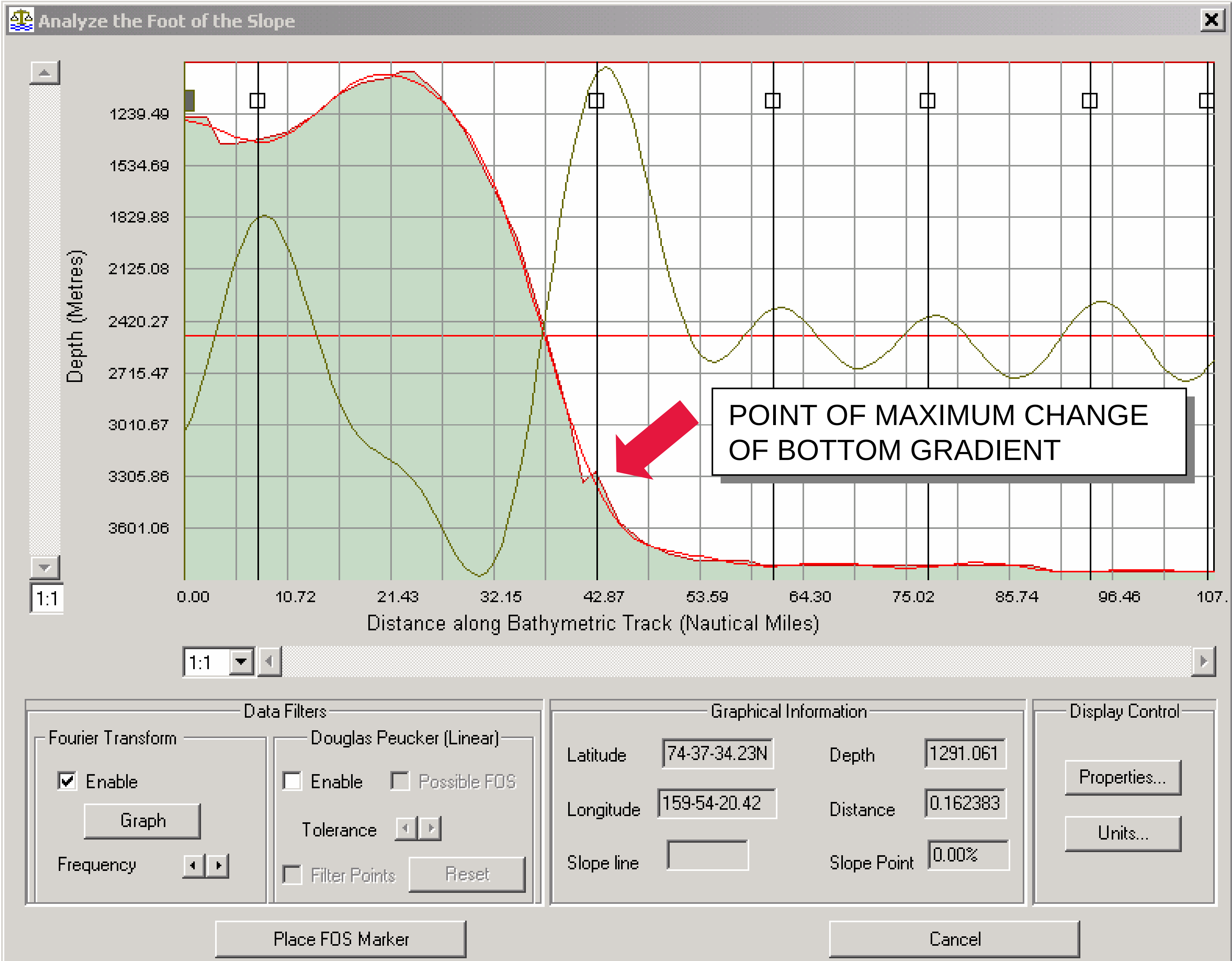
AMBIGUITIES IN LOCATING THE FOOT OF SLOPE

Two databases describing the same section of the seafloor: note multiple FOS choices in each profile, lack of agreement between profiles



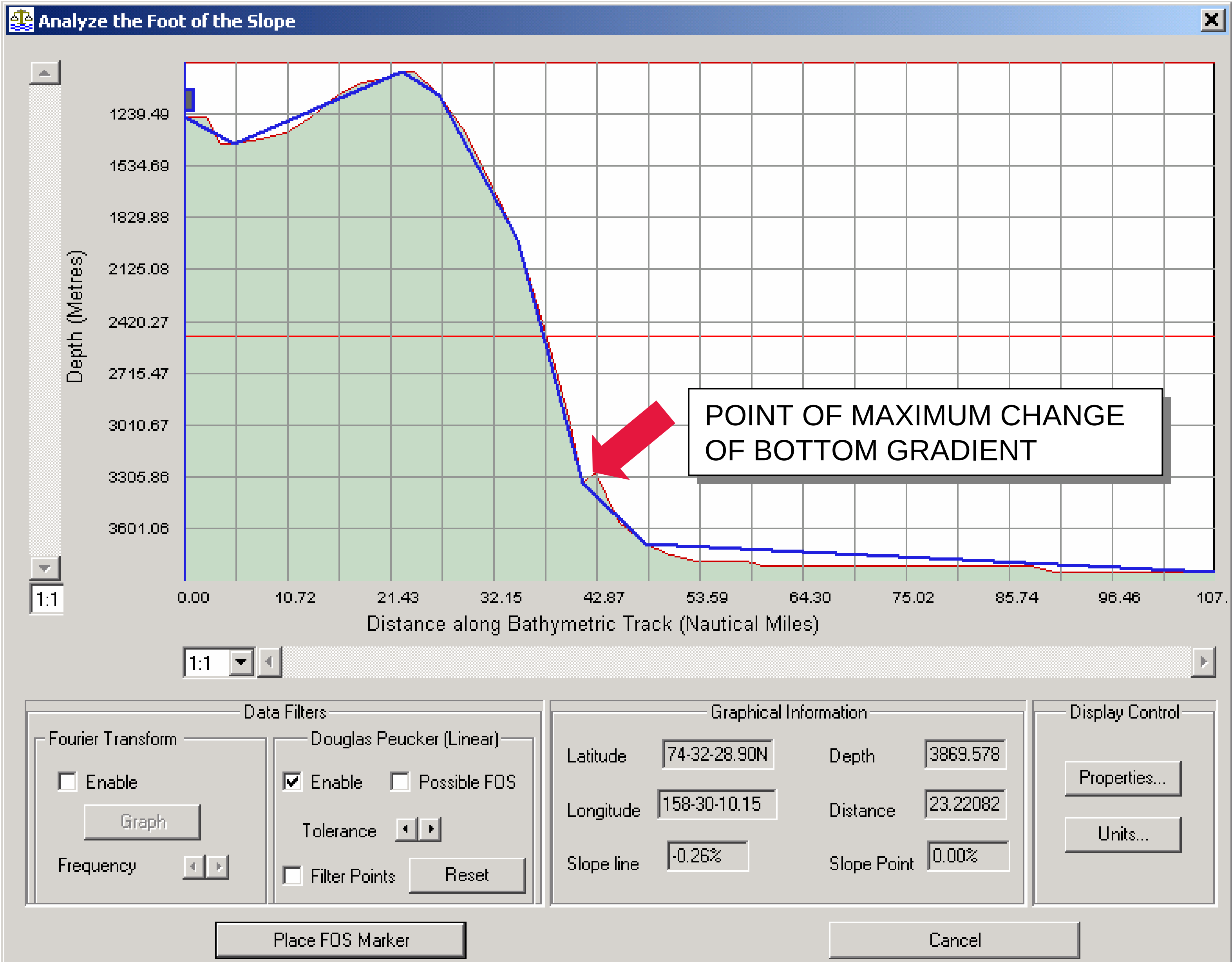
LOCATING THE FOOT OF THE SLOPE

Fitting a smooth curve to the bathymetric profile

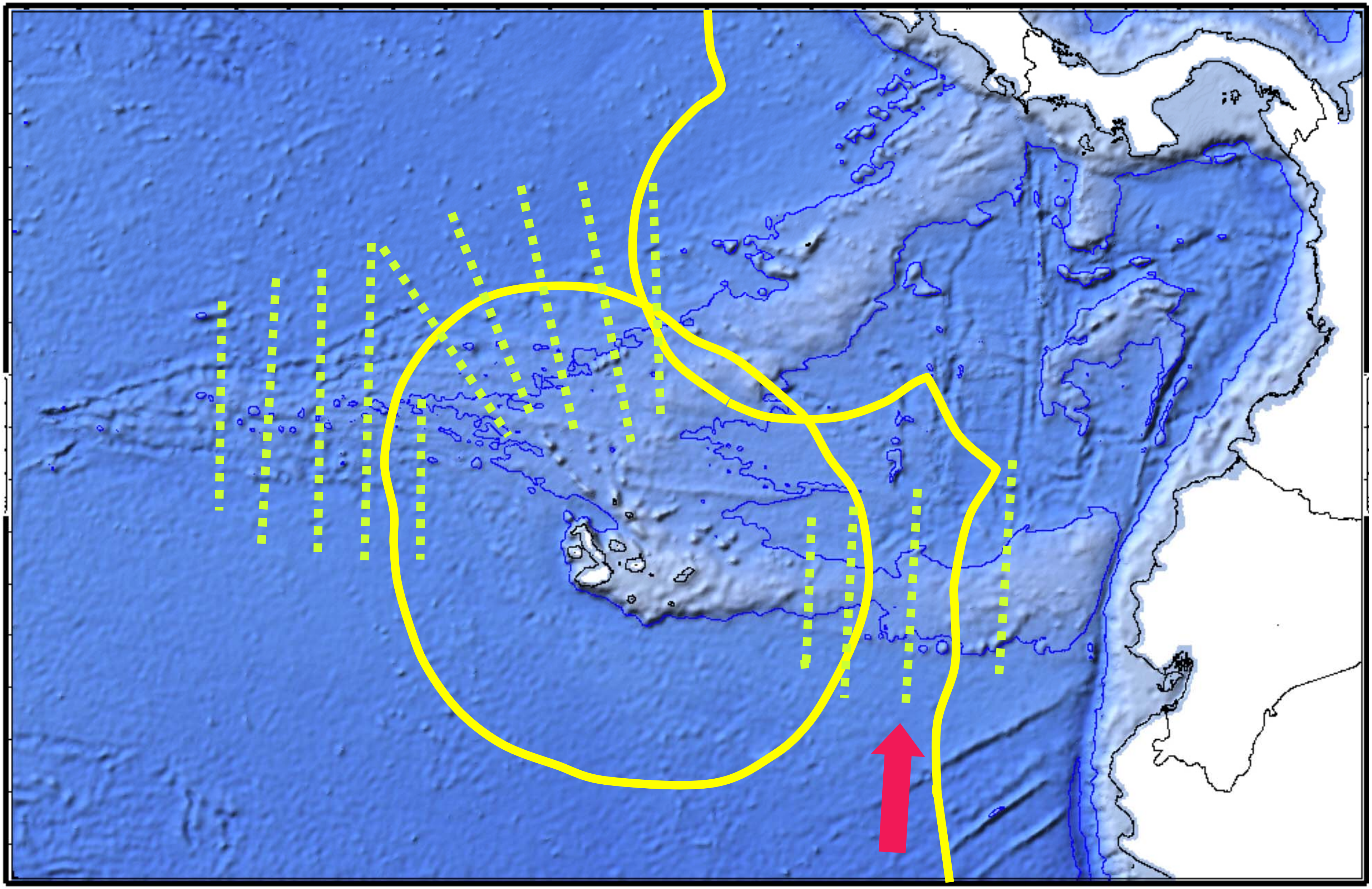


LOCATING THE FOOT OF THE SLOPE

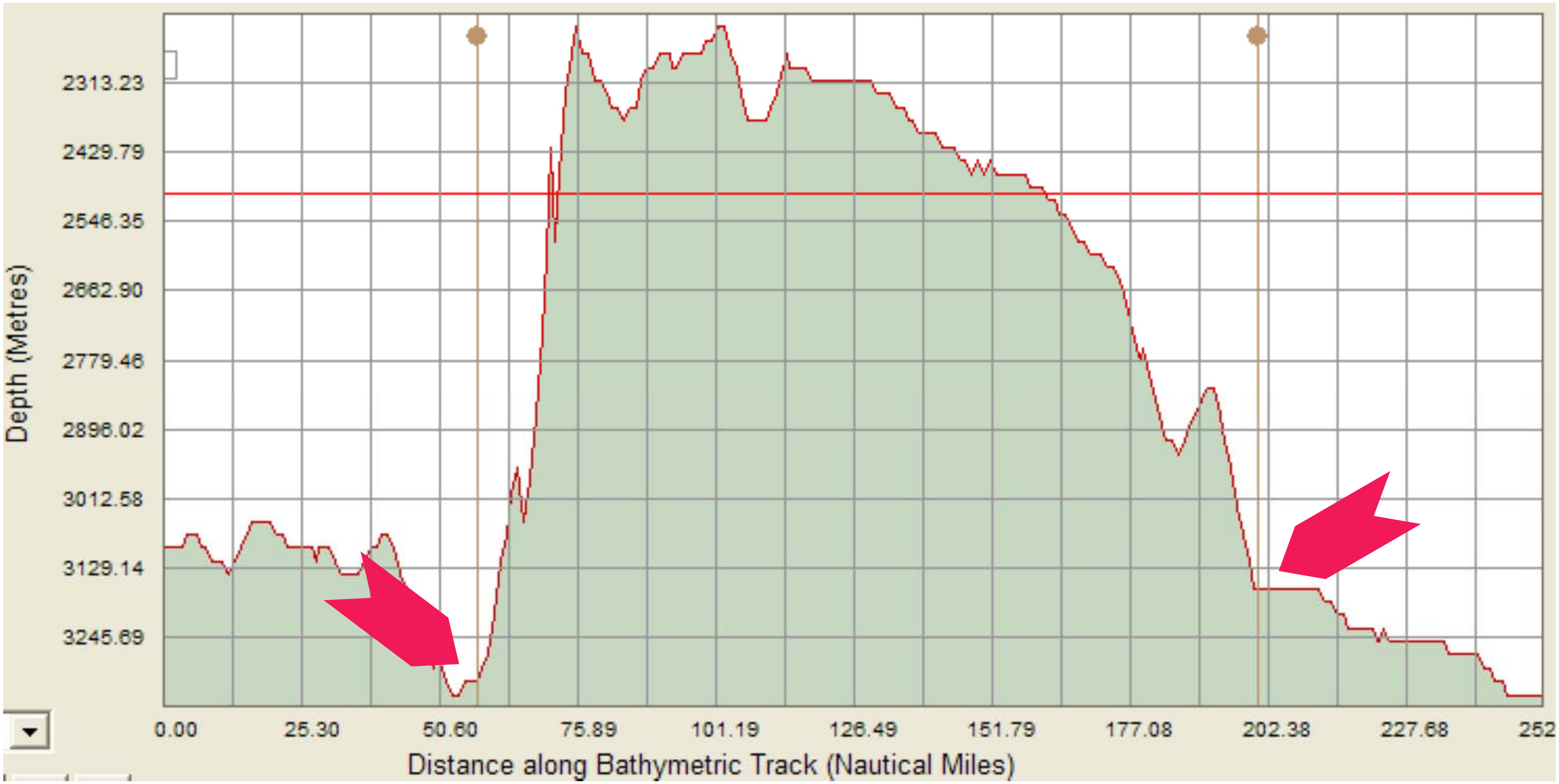
Fitting straight lines to the bathymetric profile



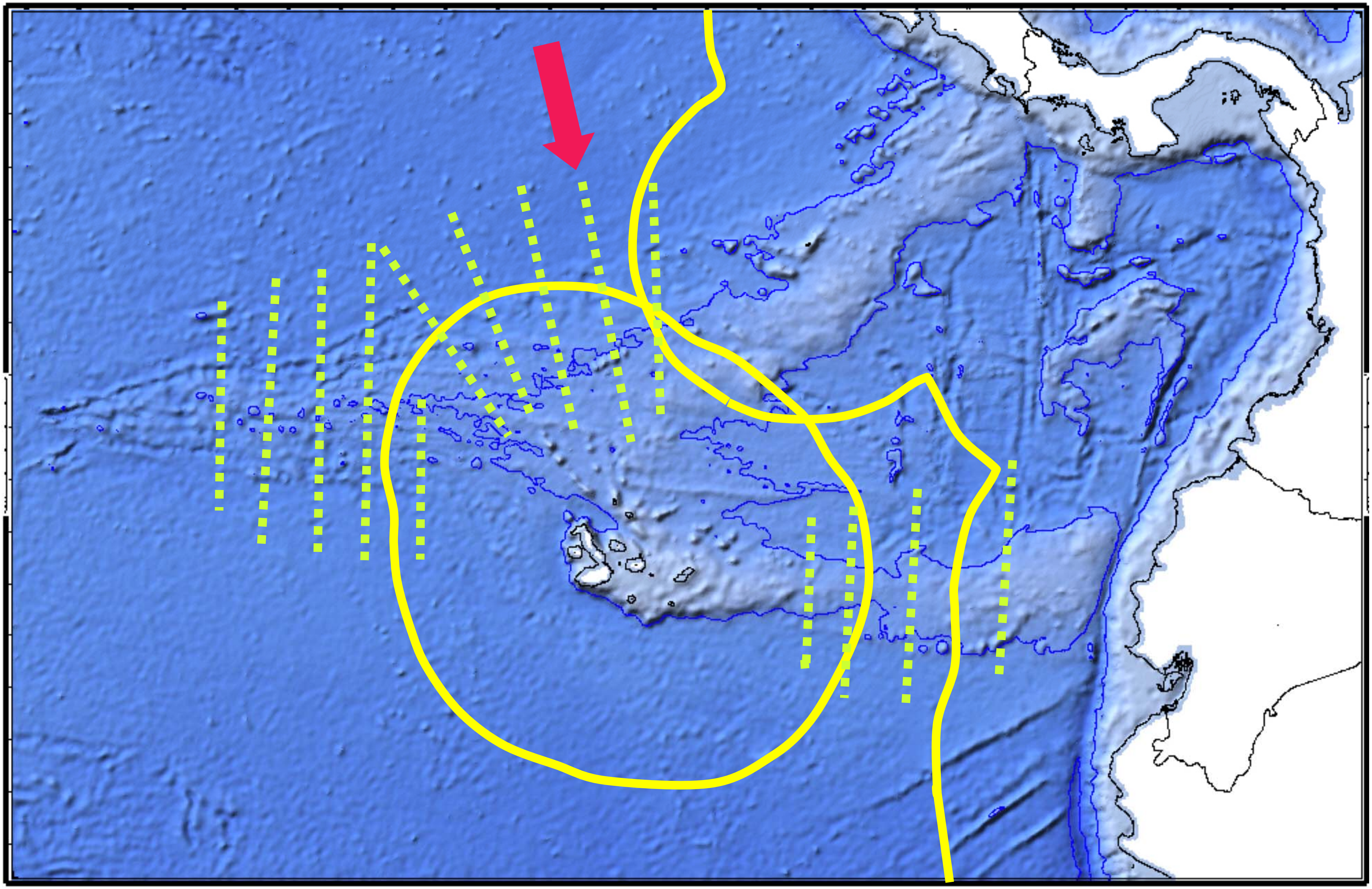
POSSIBLE FOS PROFILES OFF ECUADOR AND THE GALAPAGOS ISLANDS



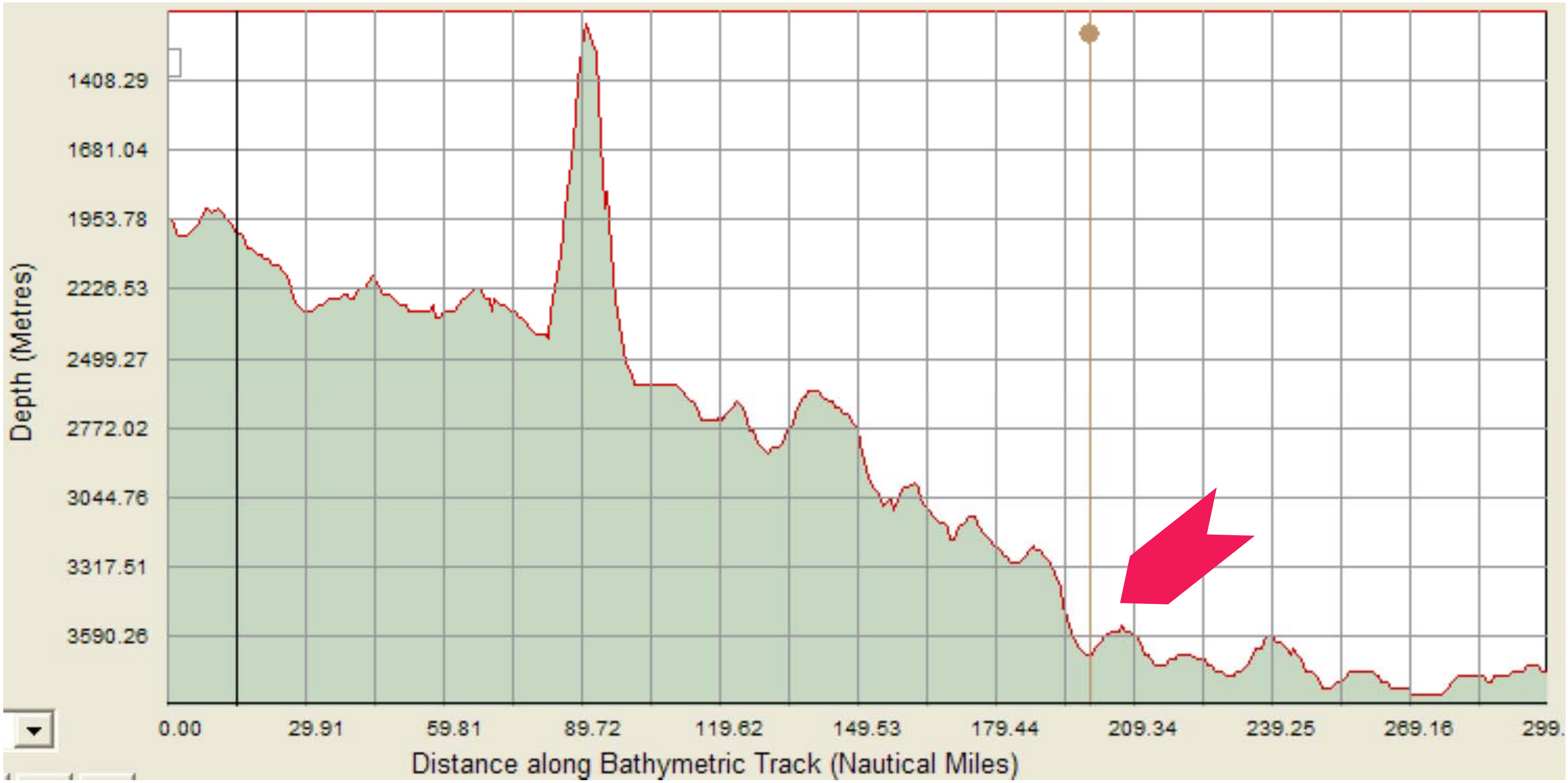
BATHYMETRIC PROFILE AND FOOT OF SLOPE POINTS, CARNEGIE RIDGE



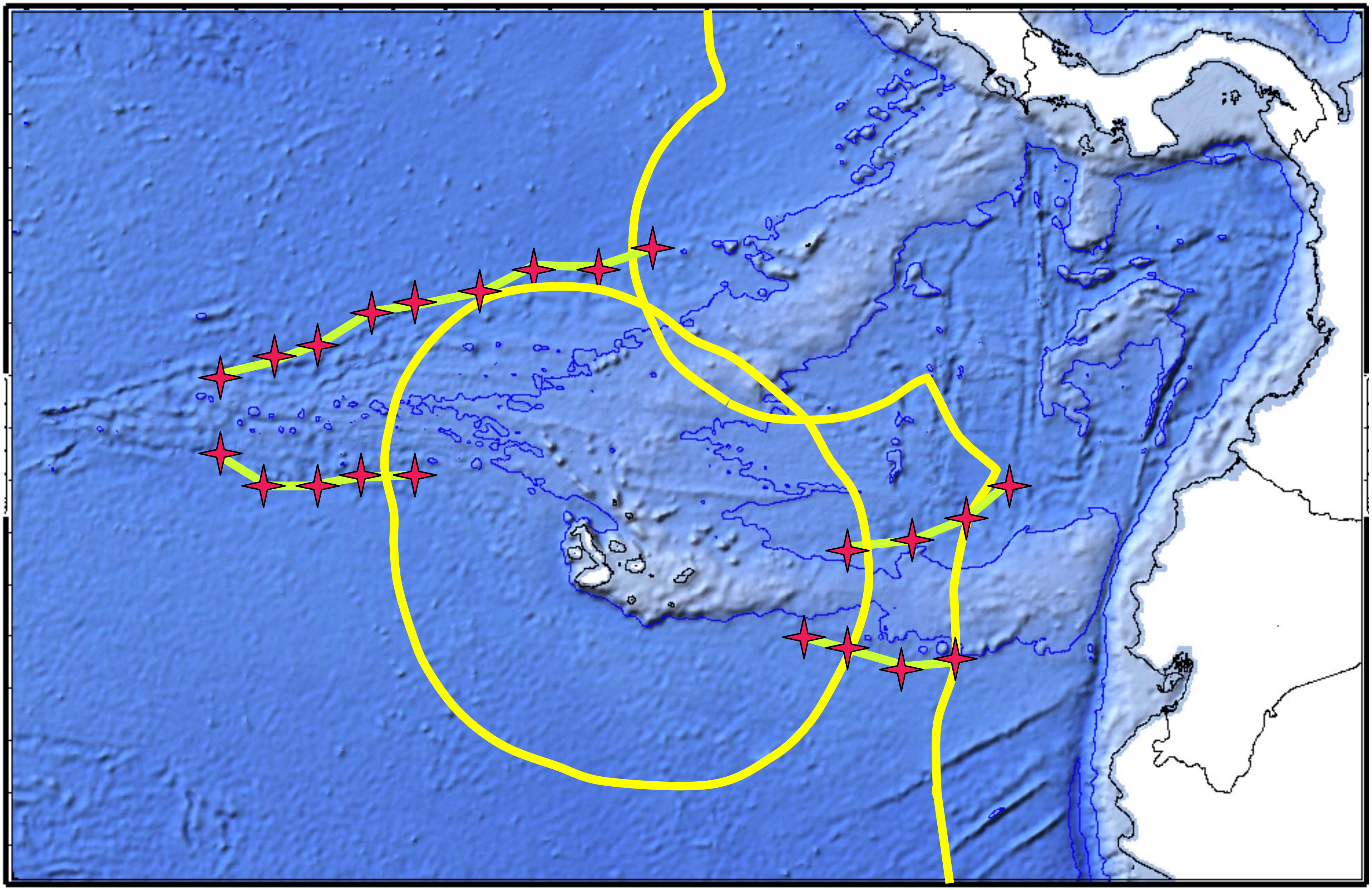
POSSIBLE FOS PROFILES OFF ECUADOR AND THE GALAPAGOS ISLANDS



BATHYMETRIC PROFILE AND FOOT OF SLOPE POINT, COLON RIDGE



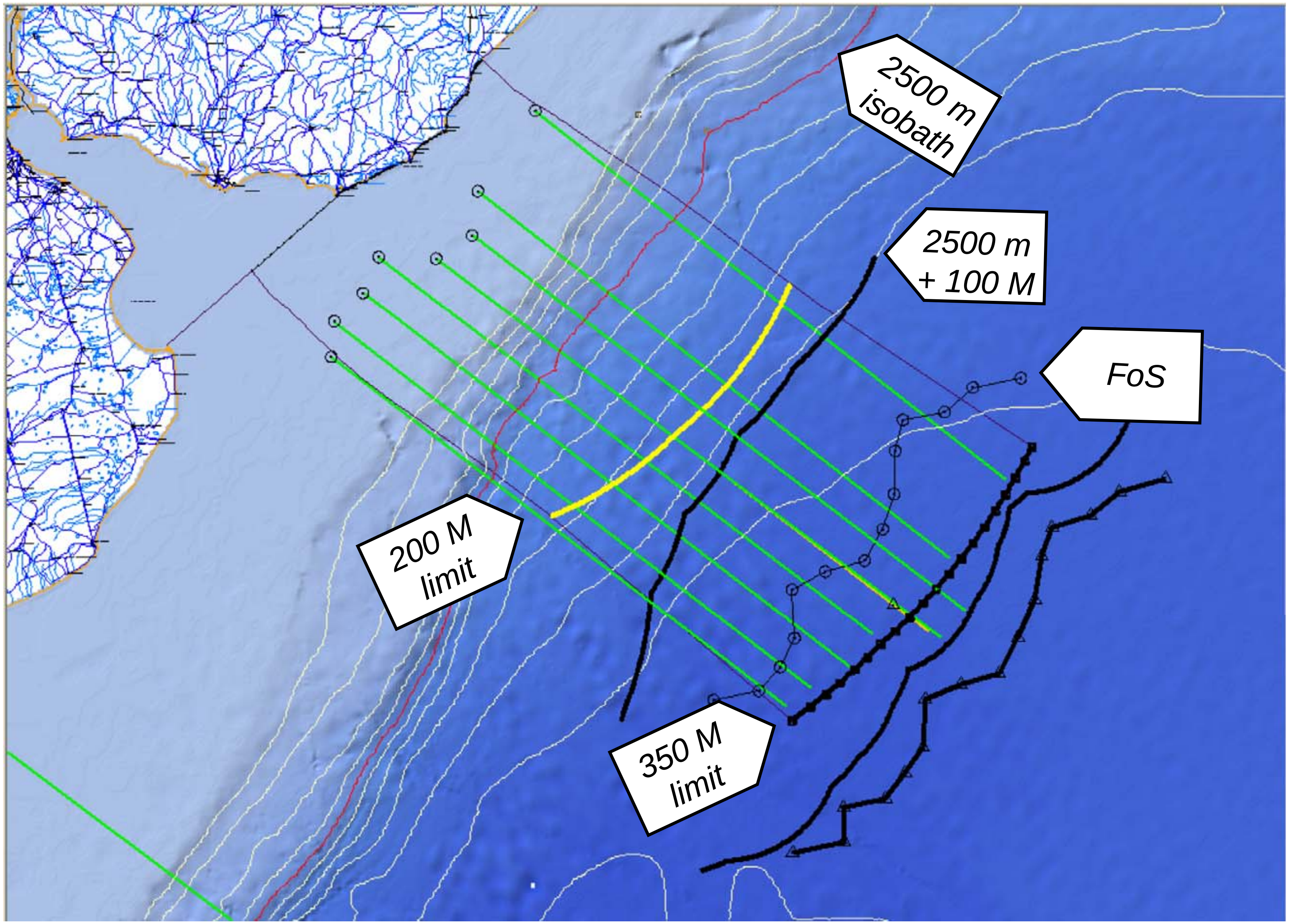
POSSIBLE FOS POINTS AND LINES



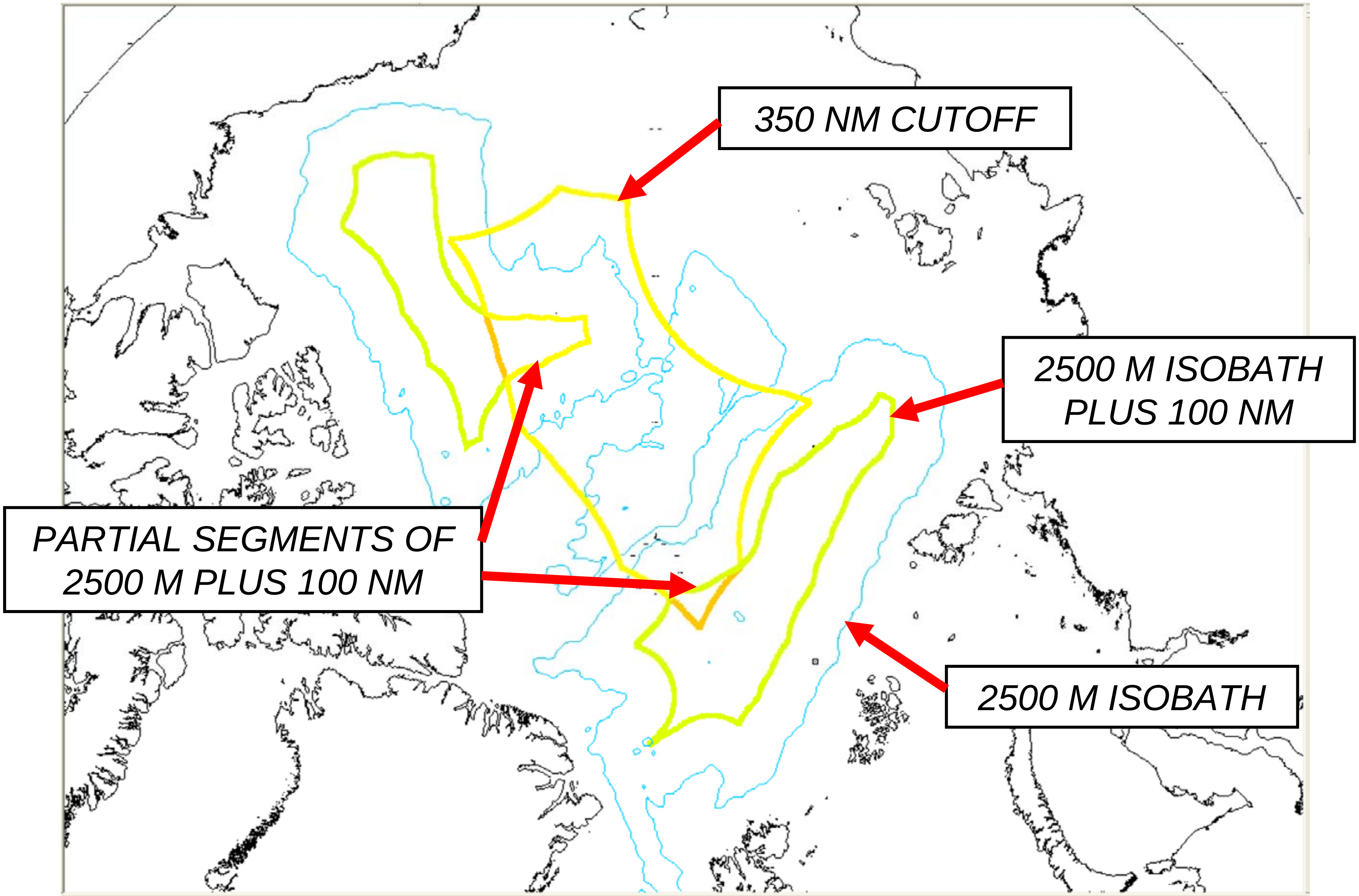
THE 2500 METRE ISOBATH

- Key to constructing one of the constraint or cutoff lines of Article 76
- Requires more measurement accuracy than does the determination of FoS points
- May apply only partially or not at all, depending on the configuration of the seabed adjacent to the submitting coastal State

2500 M ISOBATH NOT APPLICABLE



2500 M ISOBATH PARTIALLY APPLICABLE – THE ARCTIC SITUATION



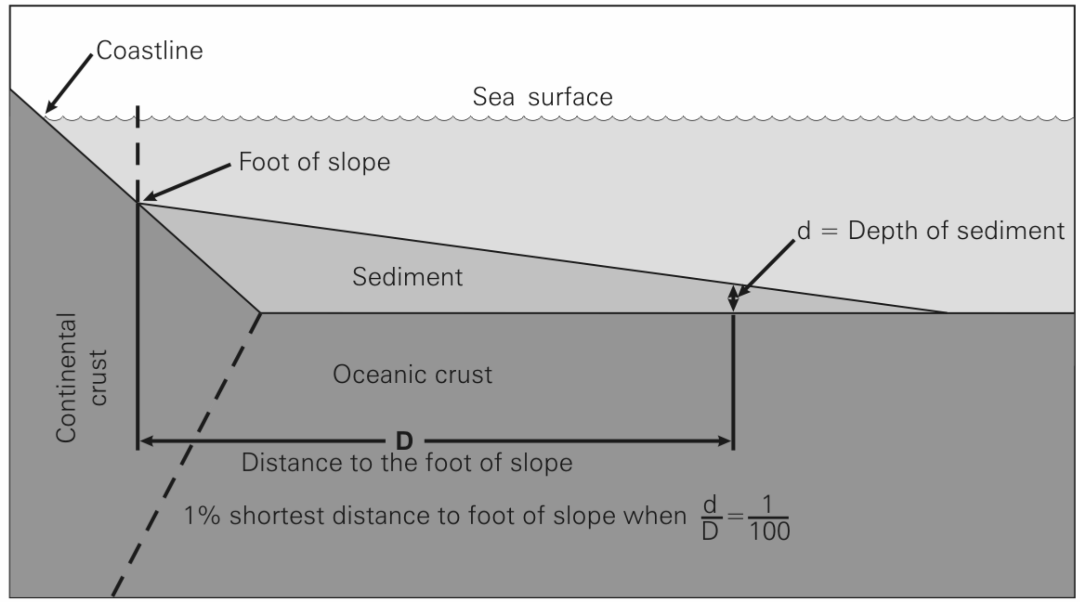
THE GARDINER LINE

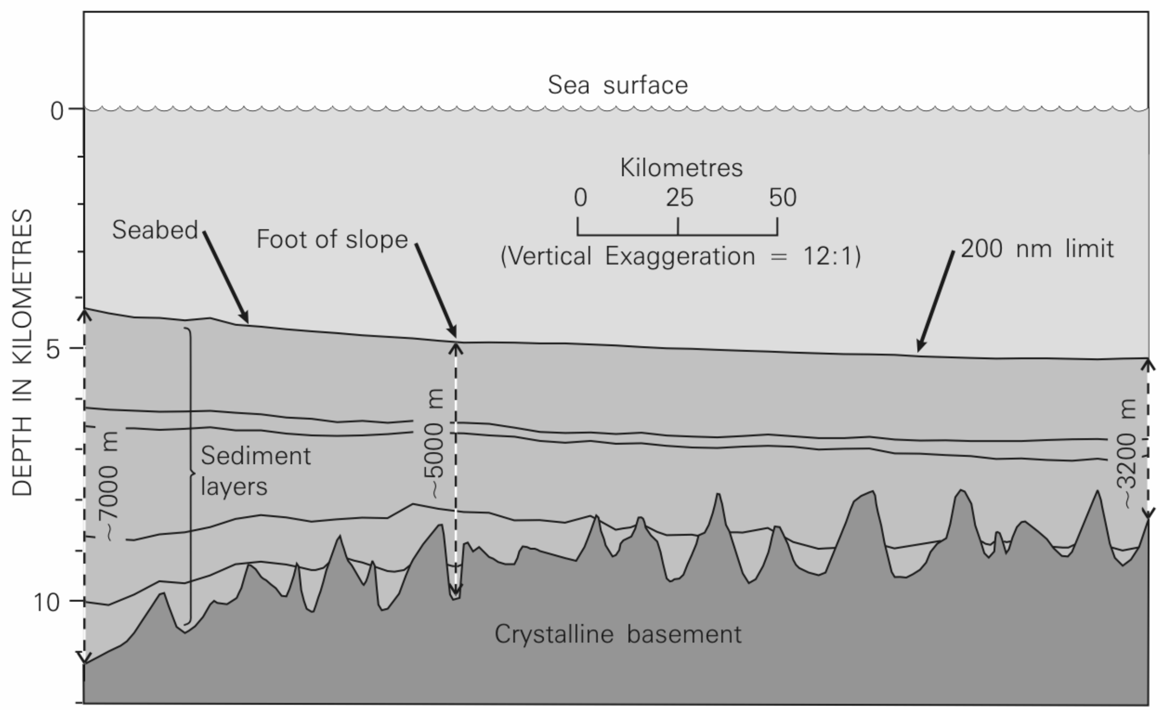
- The point where sediment thickness is equal to 1% of the distance back to the FoS
- One of the Formula Lines of Article 76
- An attempt to devise a criterion that could be applied consistently to the sedimentary material lying beneath the seabed adjacent to a submitting State
- Based on simplifying assumptions that bear little relationship to physical reality

AMBIGUITIES IN LOCATING THE GARDINER LINE

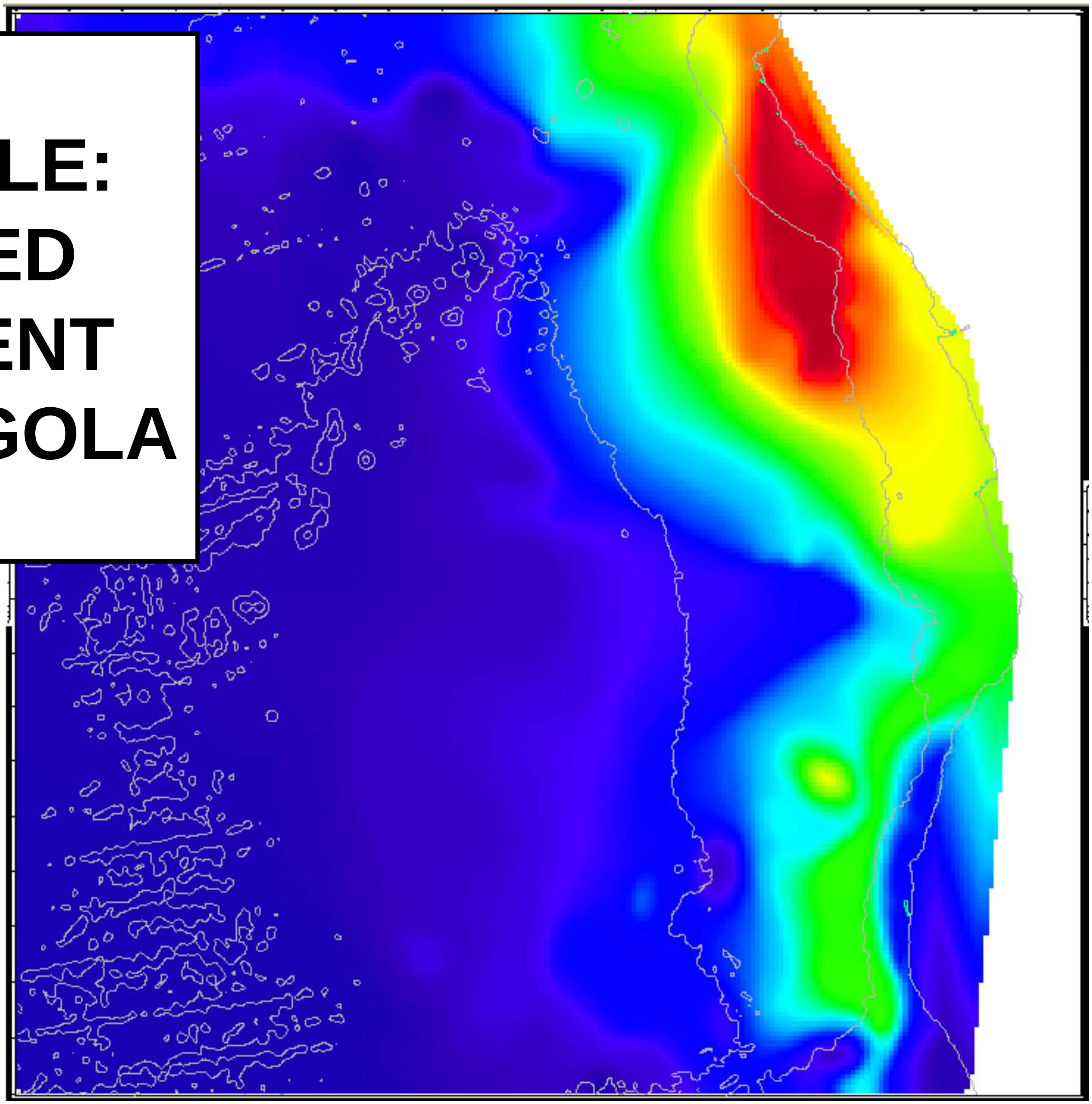
Upper figure: the principle.

Lower figure: the practice.

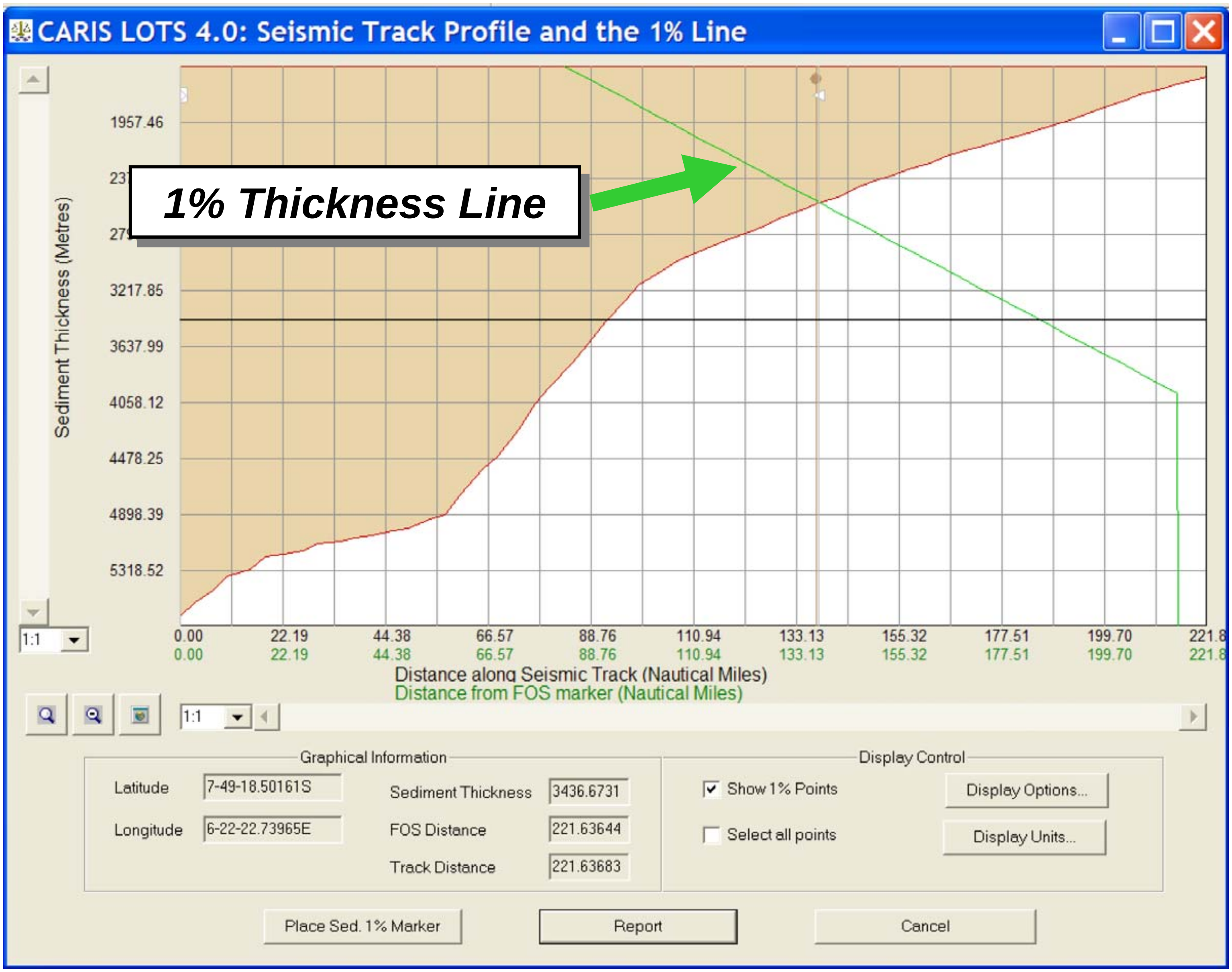




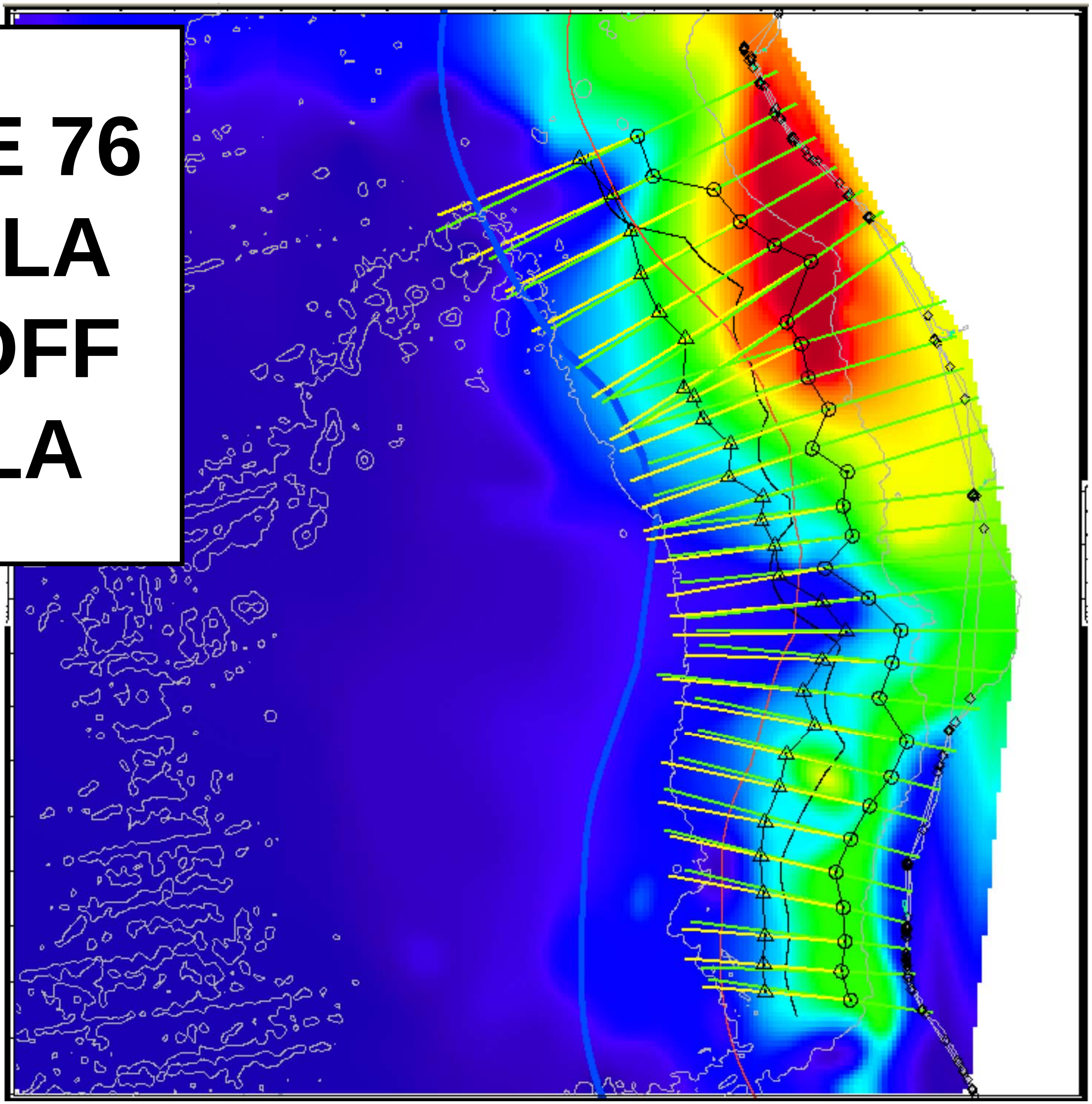
EXAMPLE: SEABED SEDIMENT OFF ANGOLA



A PROFILE ACROSS THE SEDIMENT OFF ANGOLA



ARTICLE 76 FORMULA LINES OFF ANGOLA



IN CONCLUSION…

- If making new measurements of bathymetry and sediment thickness, choose appropriate techniques.
- If using available databases, review their contents carefully to verify their suitability.
- Choose database and GIS tools that are adequate to the tasks.
- Document carefully all data sets and analytical procedures.
- Develop and maintain an awareness of how other States are developing their own OCS limits.

THANK YOU!