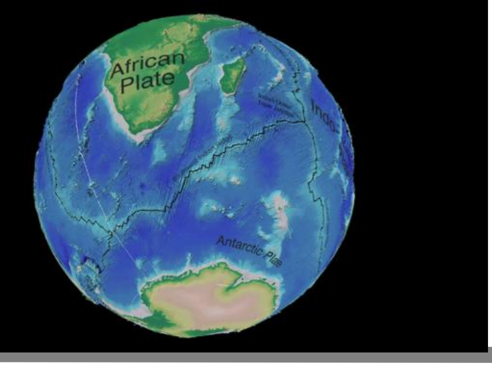
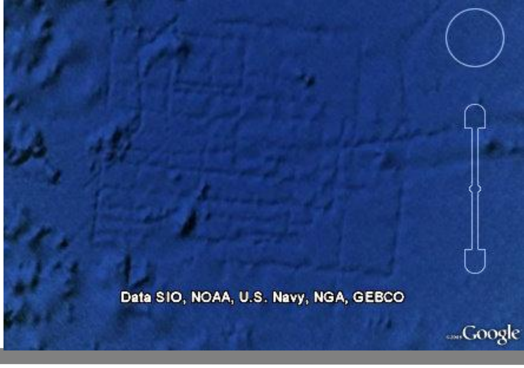


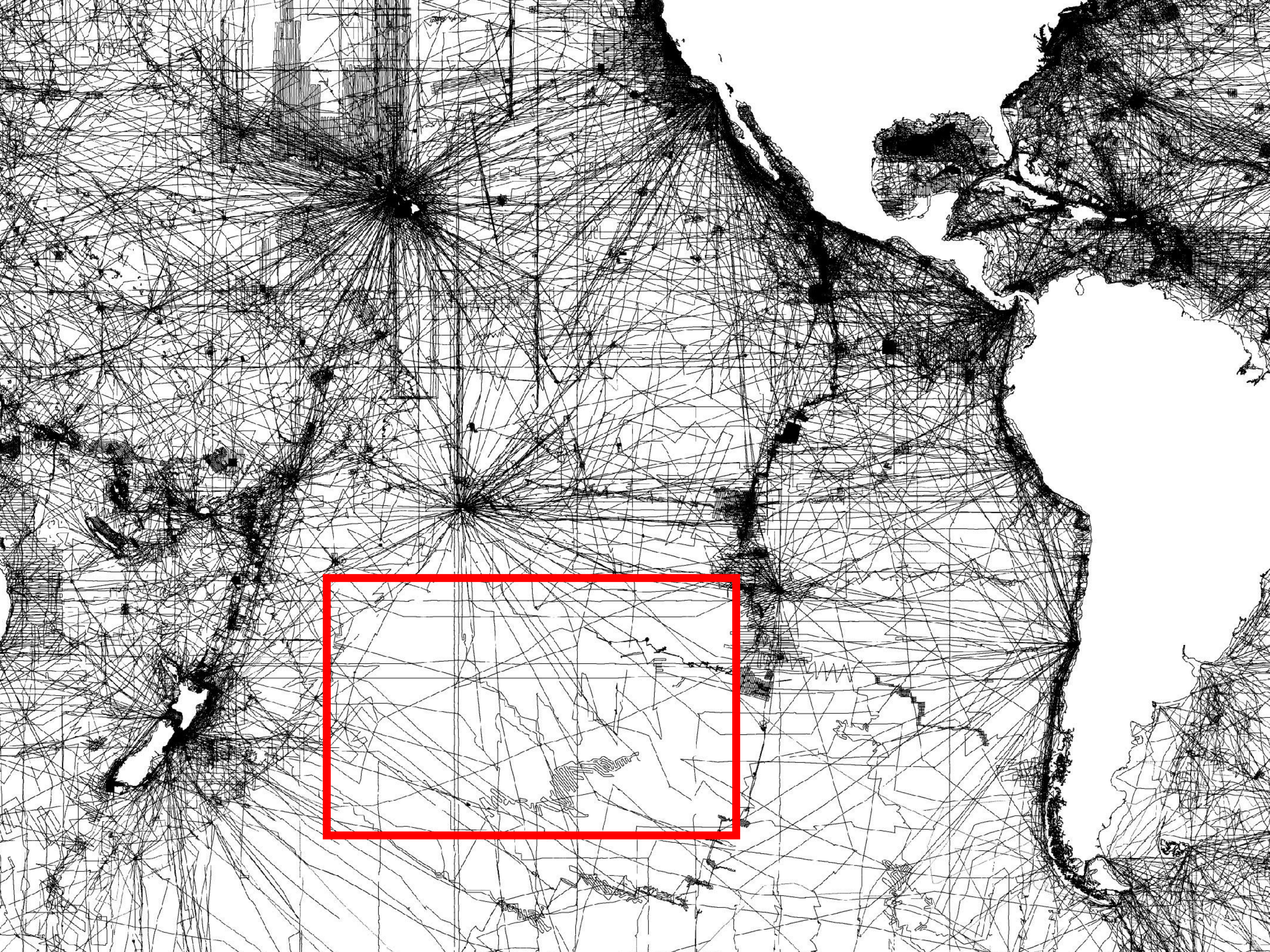

# Atlantis Discovered on the Abyssal Plain?

David T. Sandwell

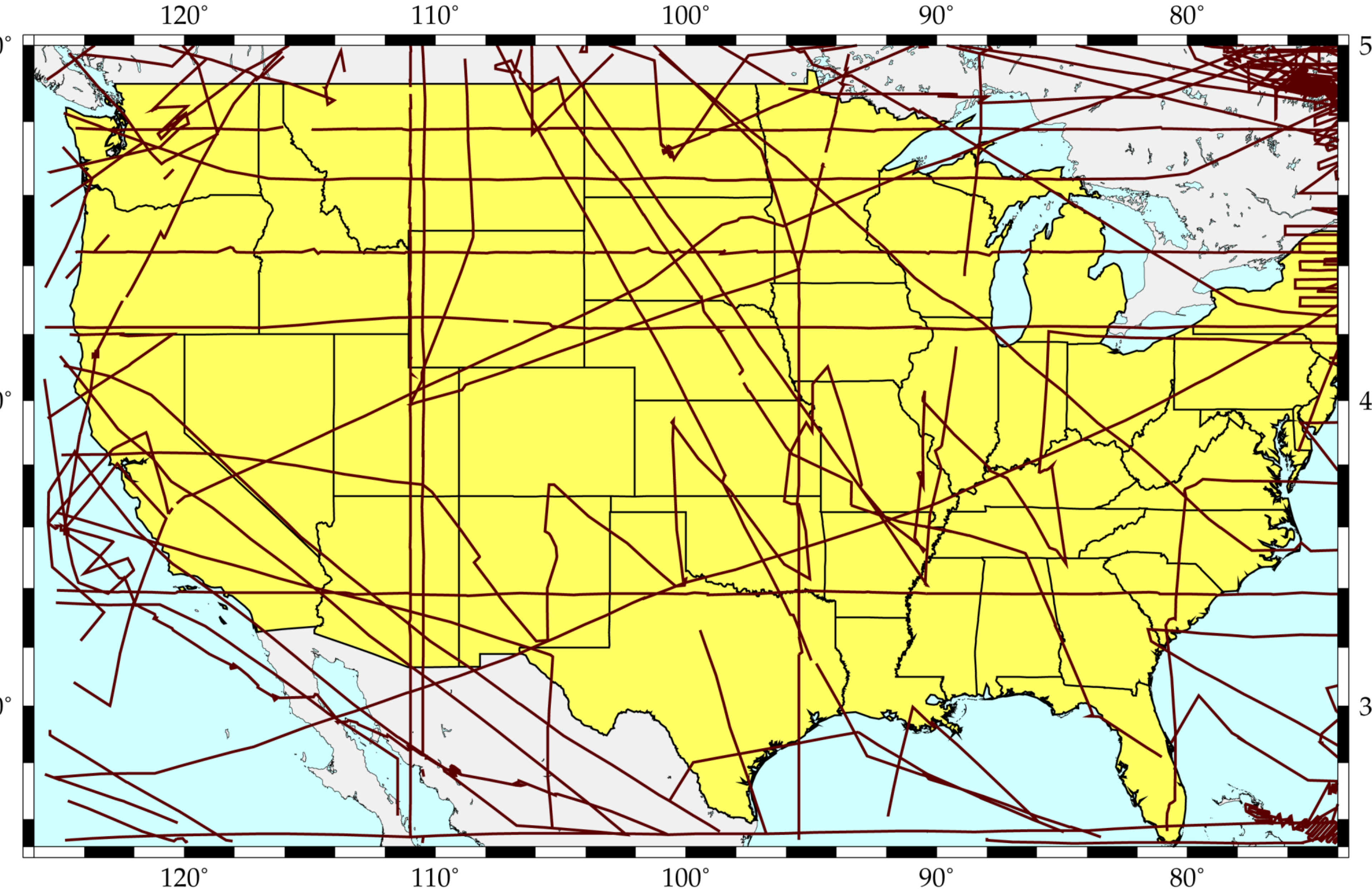
SWSU March 5, 2010



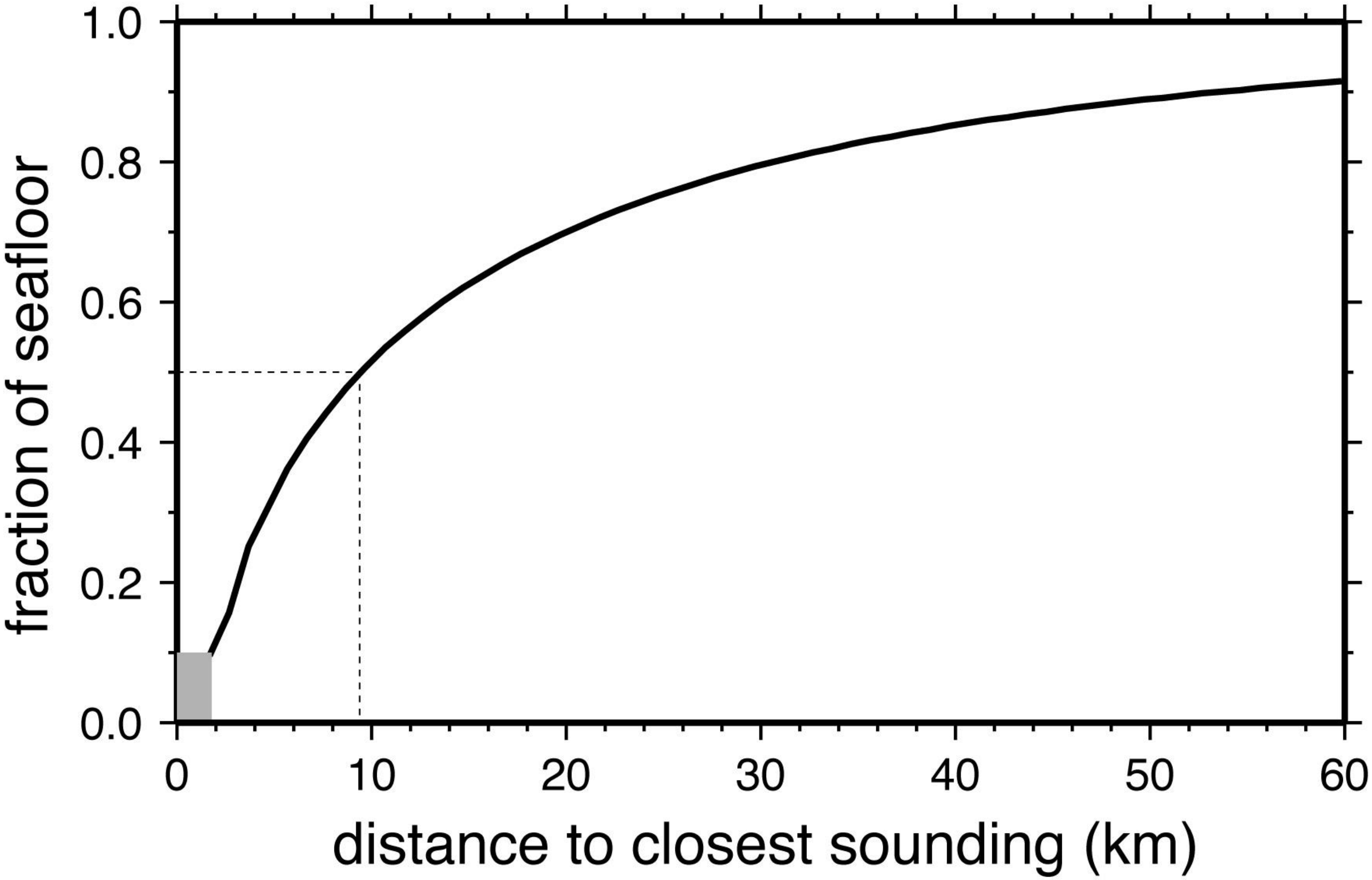

- Current bathymetry resolution worse than 10 km
- Atlantis discovered?
- Global gravity and bathymetry
- Discoveries from non-repeat altimeters (Geosat and ERS-1)
- Seafloor roughness and deep ocean mixing
- CryoSat - 2



# Depth Soundings - South Pacific

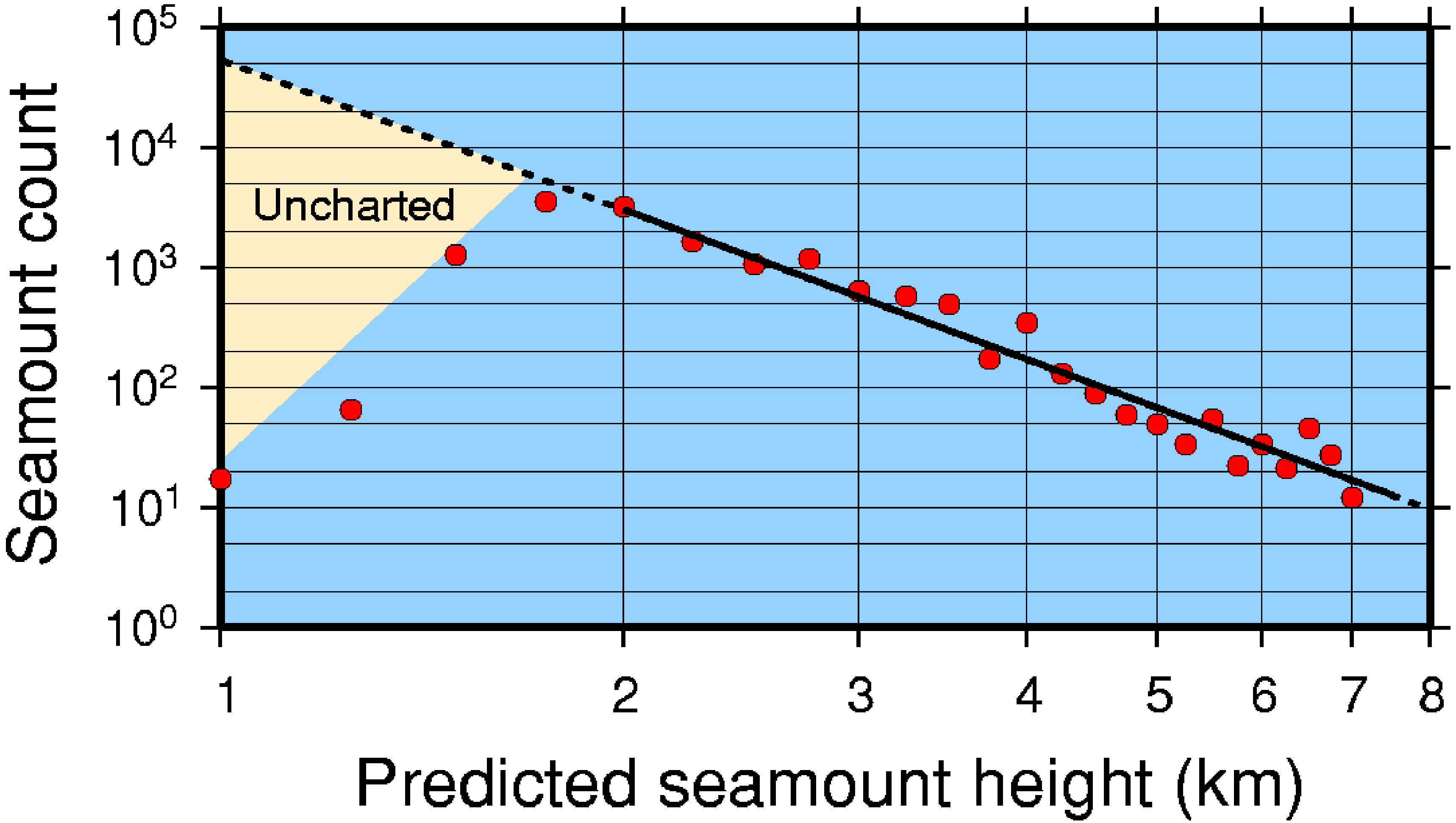


# 1/2 of global seafloor bathymetry not resolved at 10 km resolution



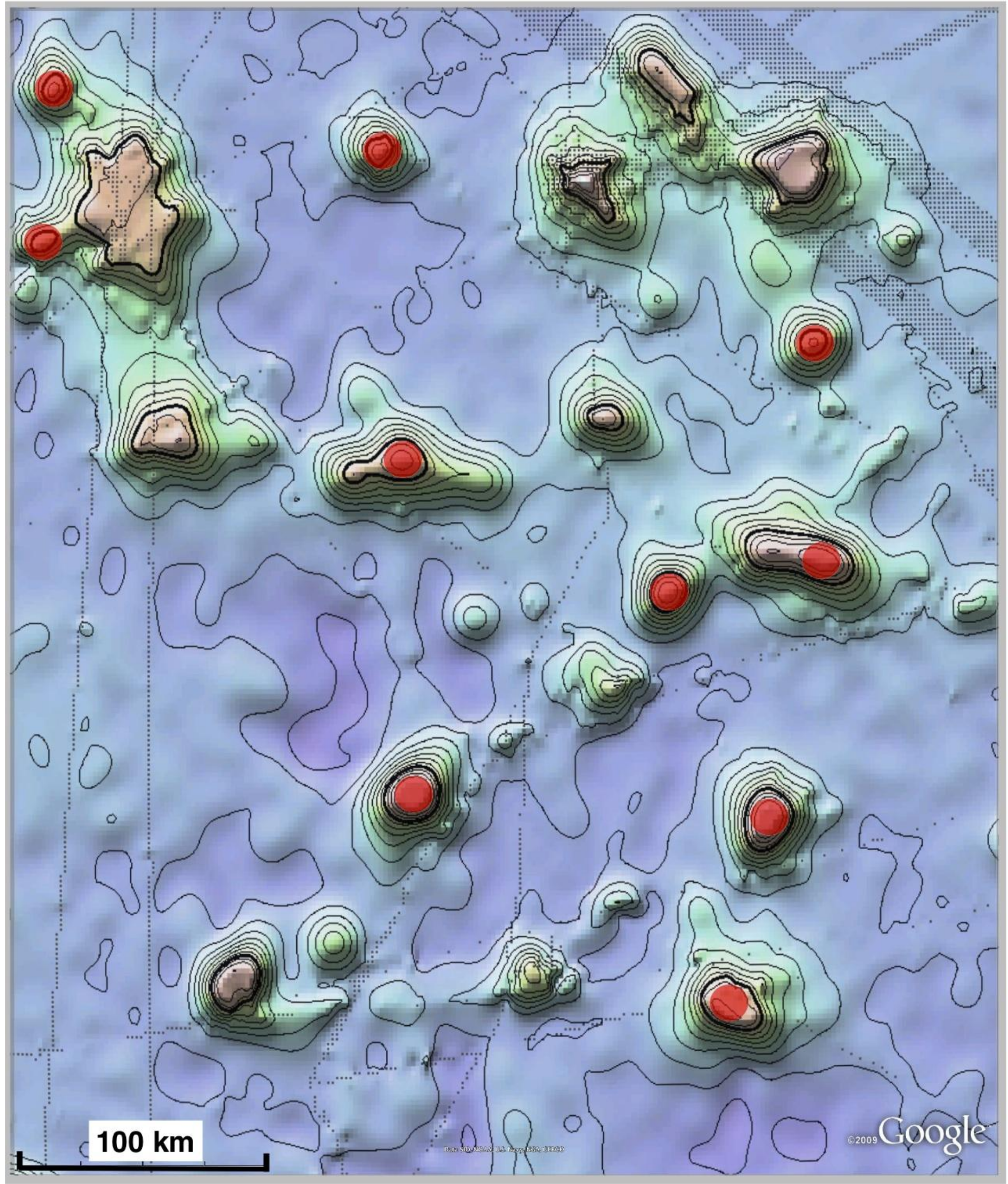

[Smith and Marks, 2009]

# seamounts




[Wessel, 2001]

# uncharted seamounts > 3 km tall



# USS San Francisco crashed into 2-km tall uncharted seamount

- Los Angeles class nuclear submarine ran aground in route from Guam to Brisbane, Australia - 8 January, 2005
- One sailor killed, 115 injured
- Crash depth ~160 m, speed 33 kn, Sonar measured a depth of 2000 m  4 minutes before crash
- 30-hour trip back to Guam, crew managed to keep the sub from sinking



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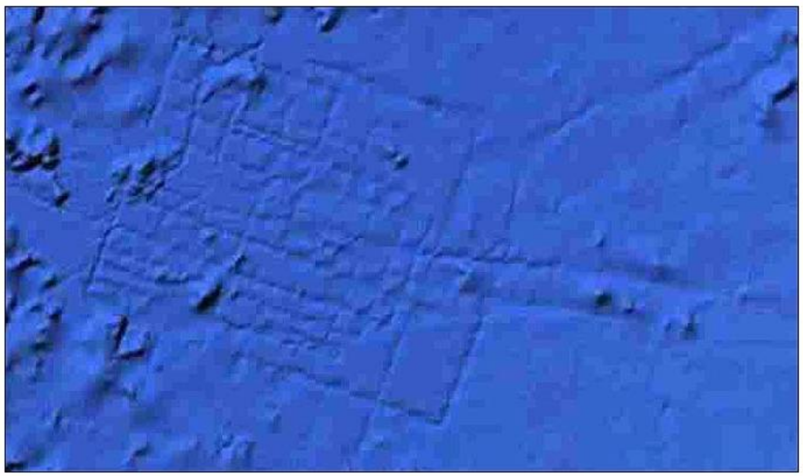
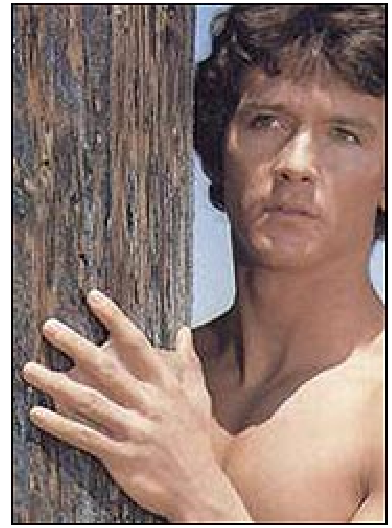
EXCLUSIVE

# Is this Atlantis?





Hero ... Patrick Duffy in TV show

The site lies 620 miles off the west coast of Africa near the Canary Islands - a location for Atlantis seemingly suggested by the ancient philosopher Plato.

He believed it was an island civilisation sunk by an earthquake and floods around 9,700BC - nearly 12,000 years ago.

The "grid" showed up on Google Ocean, a Google Earth extension that uses a combination of satellite images and marine surveys.

Last night Dr Charles Orser, curator of historical archaeology at New York State University - and one of the world's leading authorities on Atlantis - called it "fascinating".

He said: "The site is one of the most prominent places for the proposed location of Atlantis, as described by Plato. Even if it turns out to be geographical, this definitely deserves a closer look."

The legend of Atlantis has captured the imagination of scholars for centuries.

And in the 1970s it spawned a hit TV series, Man From A[t]
webbed hero who could live underwater.

The New York Times

**Bits**

**Business ▪ Innovation ▪ Technology ▪ Society**

FEBRUARY 20, 2009, 7:46 PM

## Fabled City of Atlantis Spotted on Google Earth?

*By JENNA WORTHAM*

**Update | 9:22 a.m.** *In a followup post, Google explains what caused the grid pattern.*

Screen shot of the mysterious grid of undersea lines in Google Earth's underwater search tool.

Ever since Google introduced its virtual globetrotting software, Google Earth, a treasure trove of odd findings have been unearthed by browsers, including images of anthropomorphic landmasses and giant pink bunnies.

Can the mythical city of Atlantis, described by Greek philosopher Plato, be added to that list?

British aeronautical engineer Bernie Bamford sighted a mysterious grid of undersea lines while browsing through Google Earth's new underwater search tool. The strange pattern was spotted off the western coast of Africa, apparently near one of the possible sites of the legendary island.

According to CNet, Google waved off claims that the bizarre pattern could be linked to the fabled sunken city, saying the criss-cross pattern of lines were remnants of sonar-equipped boats collecting data from the ocean floor.

"It's true that many amazing discoveries have been made in Google Earth, including a pristine forest in Mozambique that is home to previously unknown species and the remains of an ancient Roman villa," a statement from Google read. "In this case, however, what users are seeing is an artifact of the data collection process. Bathymetric (or sea floor terrain) data is often collected from boats using sonar to take measurements of the sea floor. The lines reflect the path of the boat as it gathers the data."

Not everyone is buying Google's explanation: Debates are raging on sites such as Digg and Facebook over the true identity of the watery discovery.

# Atlantis Found on Google Earth? You Decide

Monday, February 23, 2009
**FOX NEWS**

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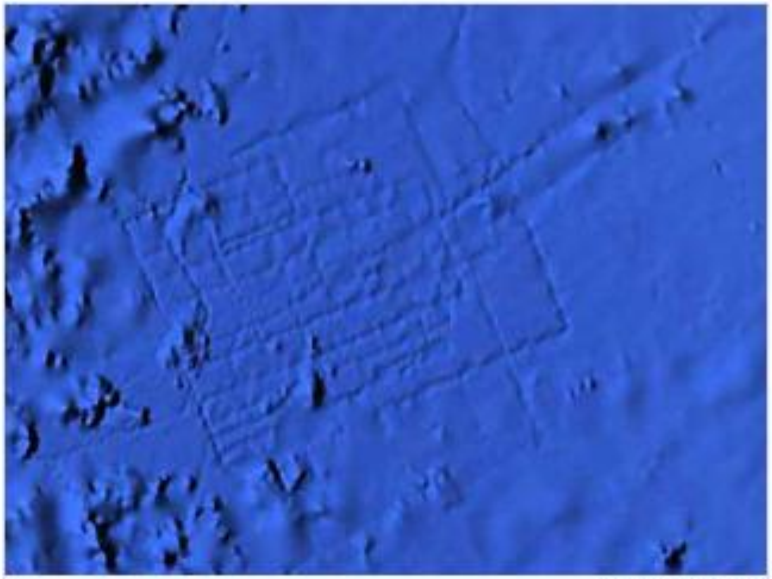


Google Earth

The purported grid of Atlantis beneath the waves off the west coast of Africa.

**Atlantis was found Friday — and then lost again to the ocean waves.**

London's Sun tabloid proclaimed Friday morning that an aeronautical engineer from Chester in northwestern England had discovered the fabled lost city using the armchair geographer's favorite tool — Google Earth.

A strange pattern in the ocean floor off the western coast of Africa looked a lot like an ancient city street grid, and the Sun even said it was in the location "seemingly suggested by the ancient philosopher Plato."

"Even if it turns out to be geographical, this definitely deserves a closer look," New York State Museum archaeologist Charles Orser told the Sun.

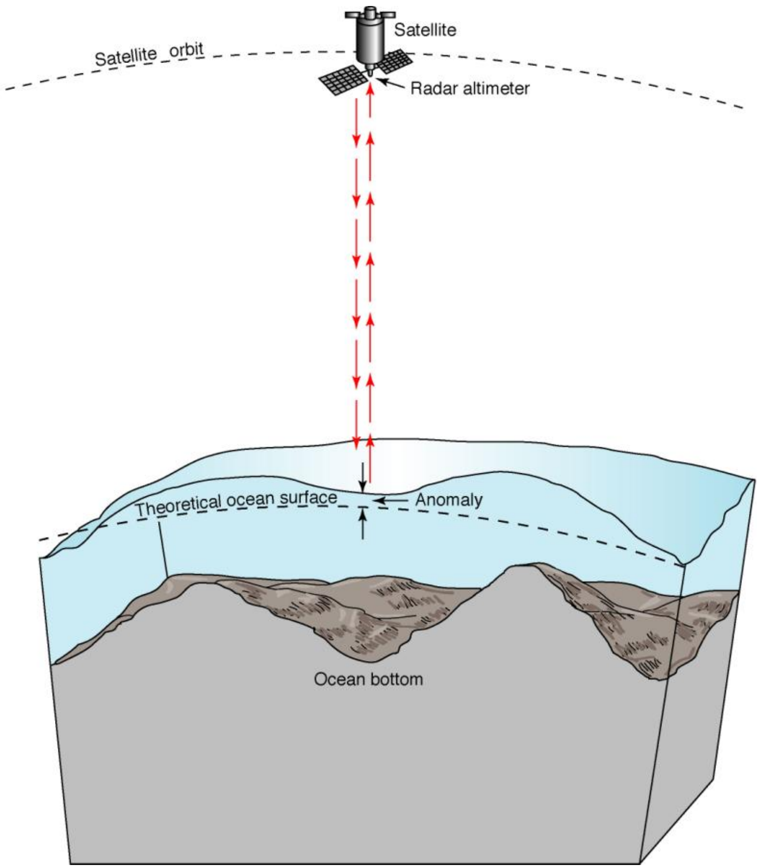
But the jubilation was to be short-lived.

Within hours, a Google spokeswoman told one of the Sun's rivals — it's not clear which one — that "what users are seeing is an artefact of the data-collection process."

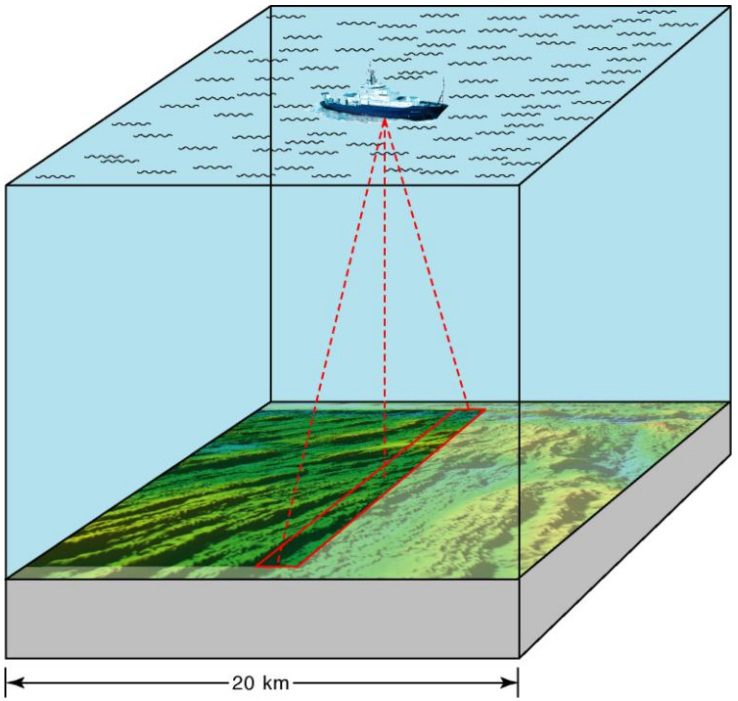
"Bathymetric (or sea floor terrain) data is often collected from boats using sonar to take measurements of the sea floor," the unnamed spokeswoman explained. "The lines reflect the path of the boat as it gathers the data. The fact that there are blank spots between each of these lines is a sign of how little we really know about the world's oceans."

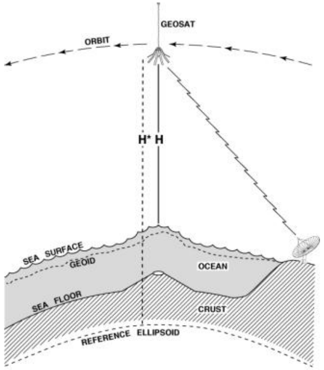
# modern mapping tools

satellite altimeter

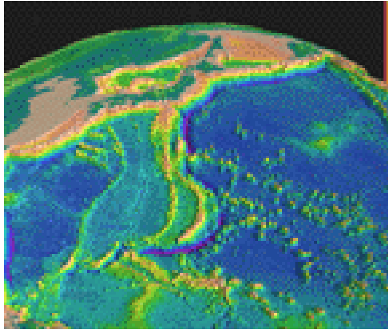



multibeam
echo sounder






# Radar Altimetry - Solid Earth

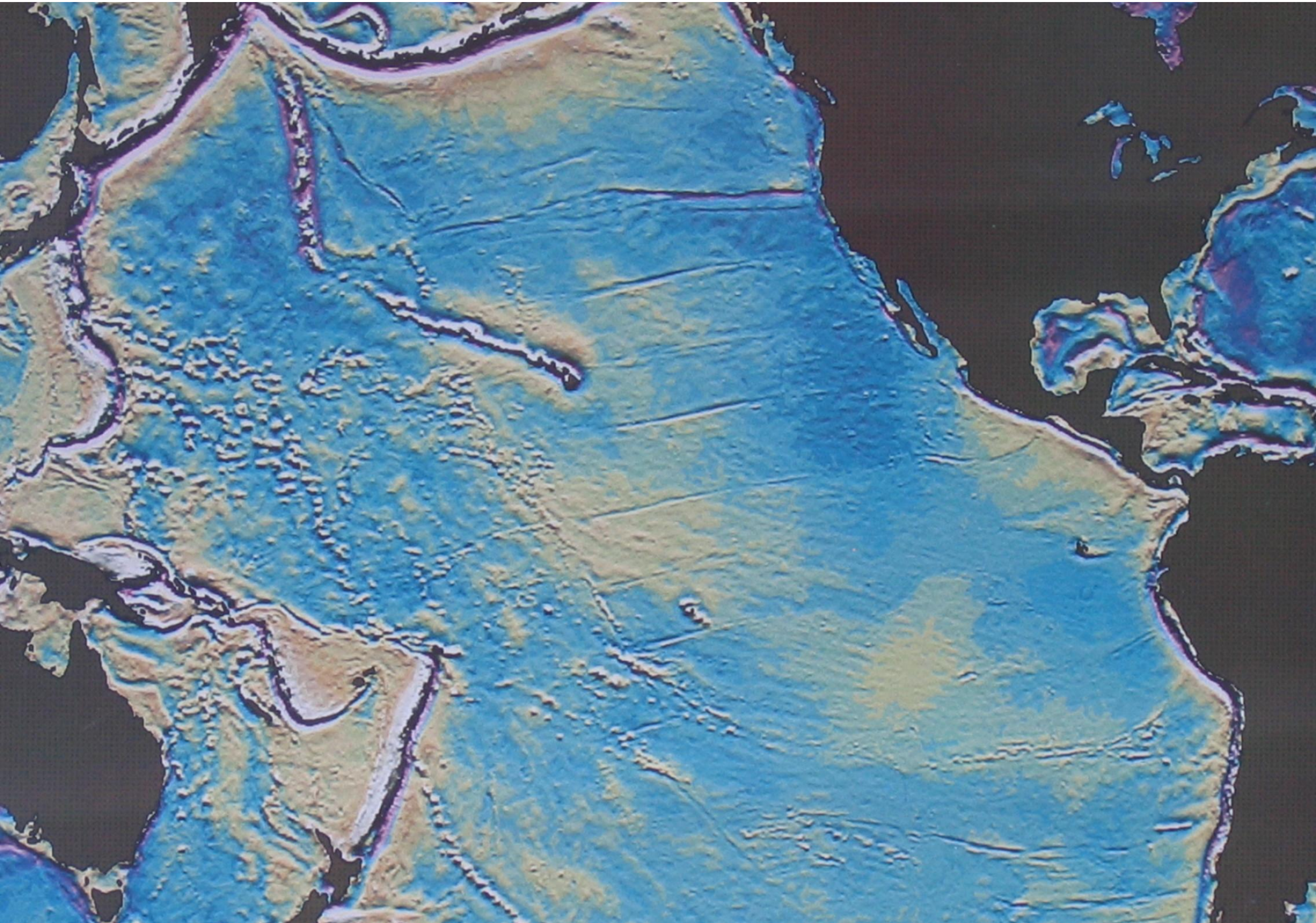


Bill Kaula

Keith Raney

Bill Haxby

Global Gravity from Seasat [ *Haxby*, 1987]

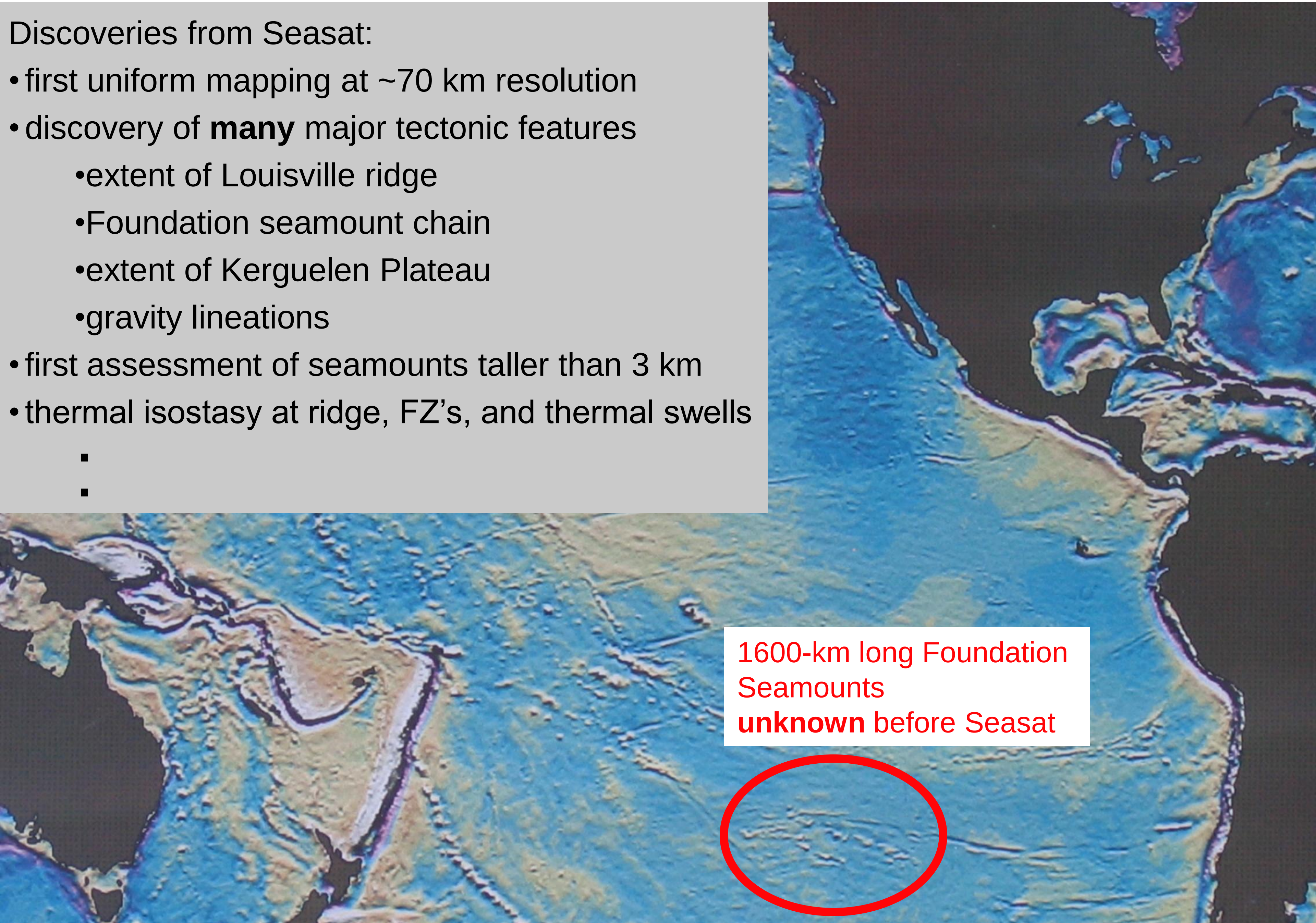


# Global Gravity from Seasat [ *Haxby*, 1987]

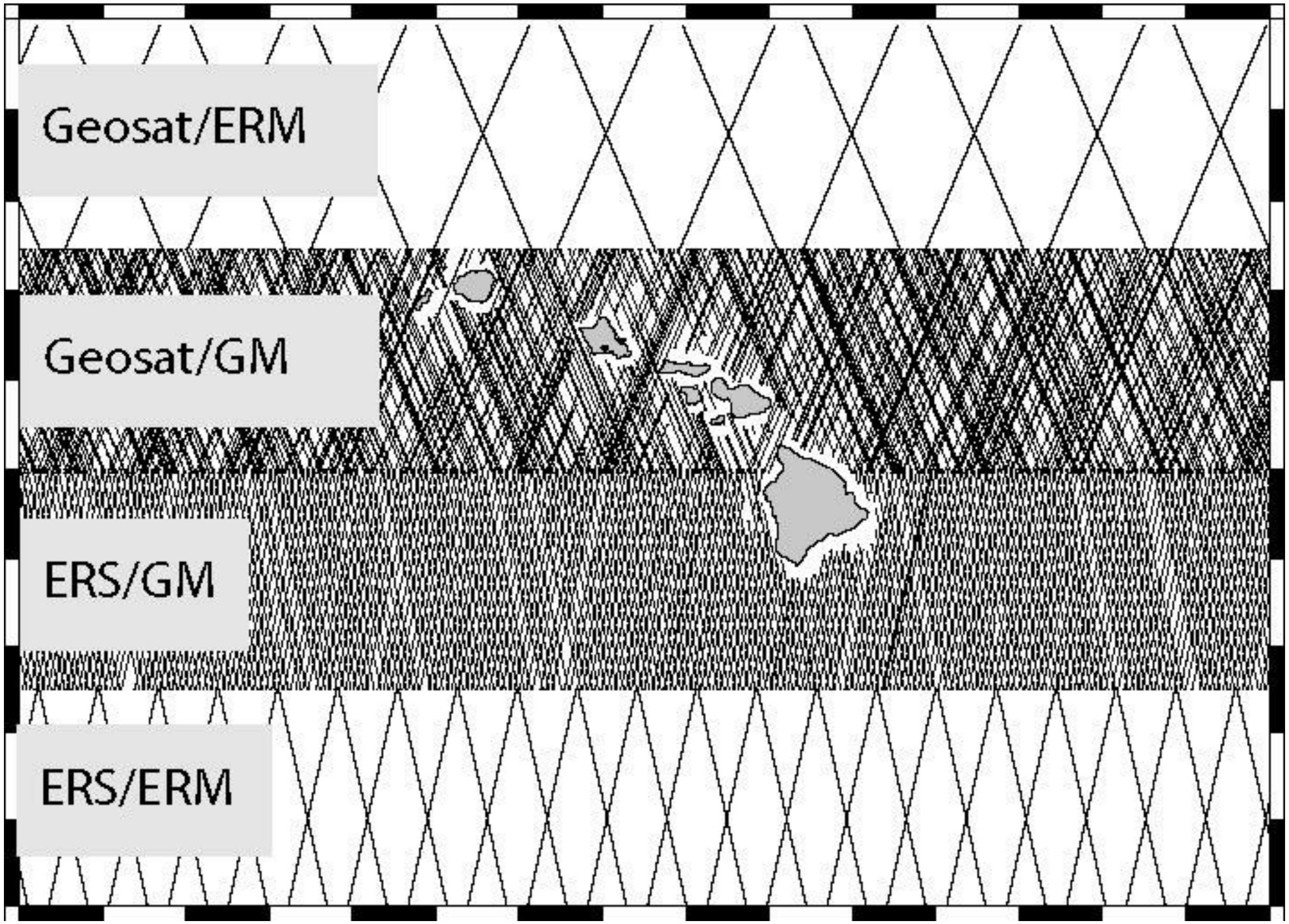
Discoveries from Seasat:

- first uniform mapping at ~70 km resolution
- discovery of **many** major tectonic features
    - extent of Louisville ridge
    - Foundation seamount chain
    - extent of Kerguelen Plateau
    - gravity lineations
- first assessment of seamounts taller than 3 km
- thermal isostasy at ridge, FZ’s, and thermal swells

    ⋮



# available altimeter data

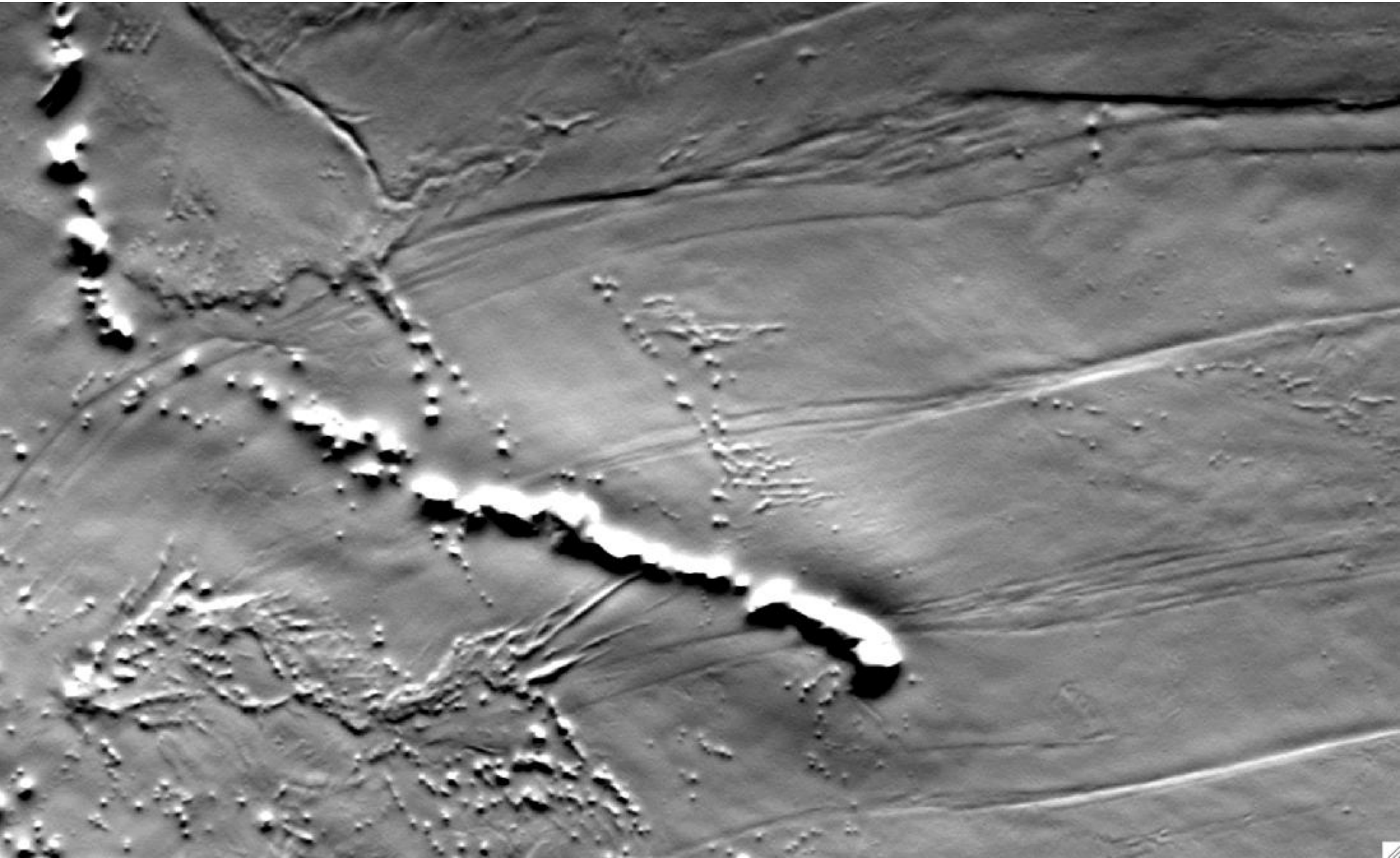



1985

1994

2.5 years non-repeat and 65 years of repeat

# bumps on the surface of the ocean



# construction of gravity anomaly from satellite altimeter data

1. Acquire a spherical harmonic model of the gravitational potential of the Earth and generate models of the relevant quantities (e.g., geoid height, gravity anomaly, deflection of the vertical, . . .) out to say harmonic 80. You may want to taper the harmonics between say 60 and 120 to avoid Gibb's phenomenon; this depends on the application.

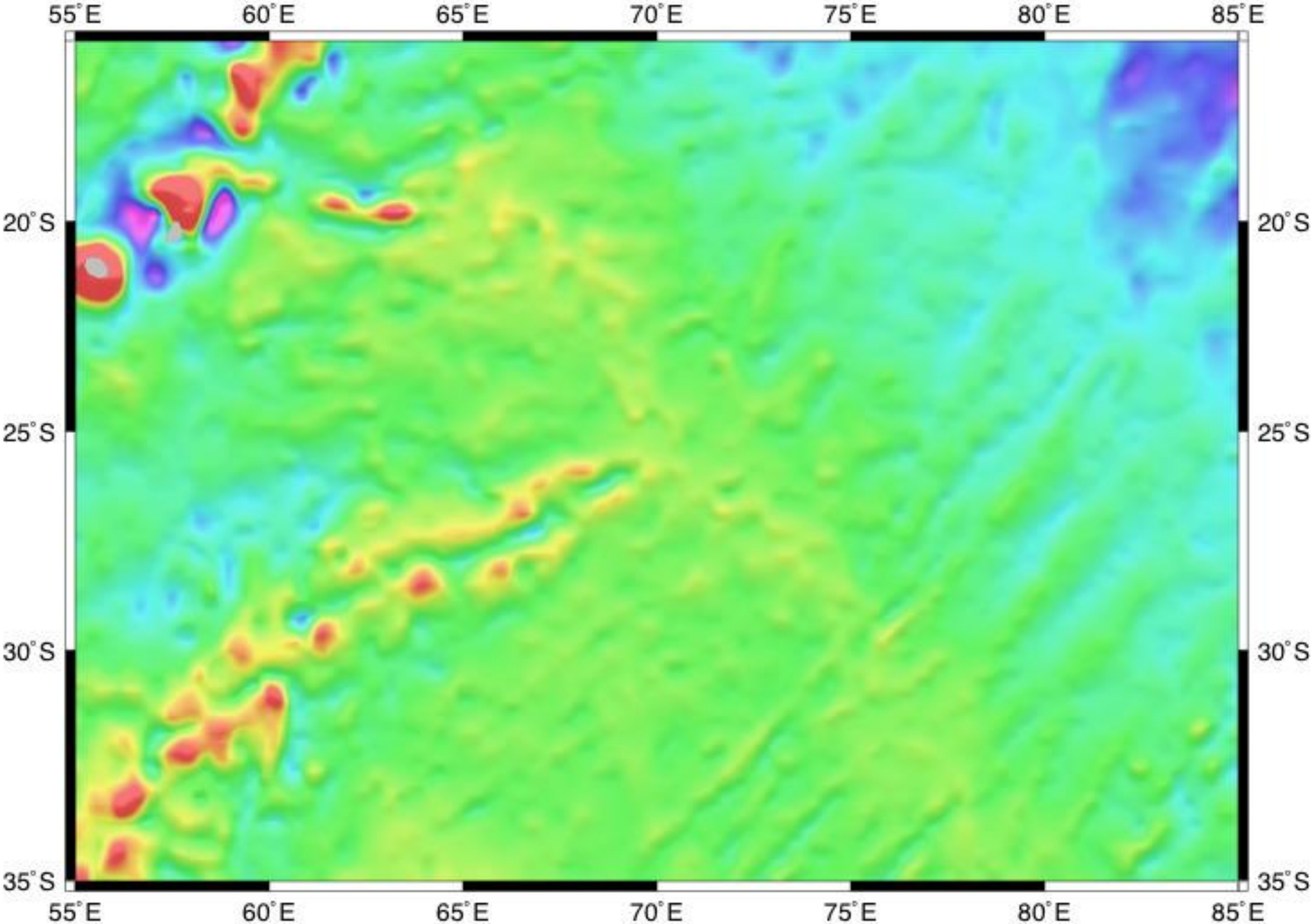
**2.** **Remove** that model from the satellite altimeter profiles.

3. Project the residual data onto a Mercator grid so the cells are approximately square and use the central latitude of the grid to establish the dimensions of the grid for Fourier analysis.

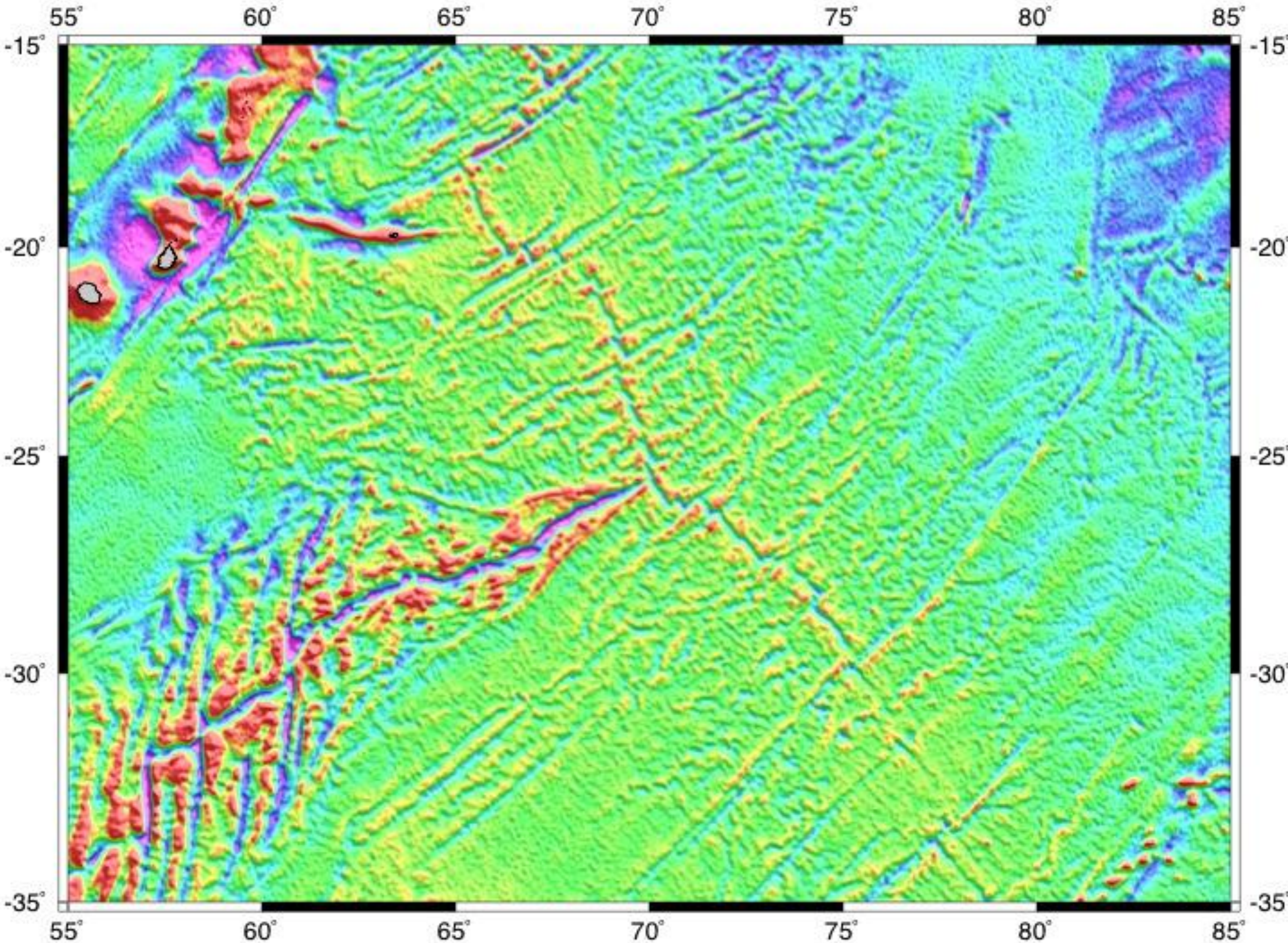
4. Perform the desired calculation (e.g., upward continuation, gravity/topography transfer function, . . .).

**5.** **Restore** the appropriate spherical harmonic quantity using the exact model that was removed originally.

# Seasat only (NASA - 1978)

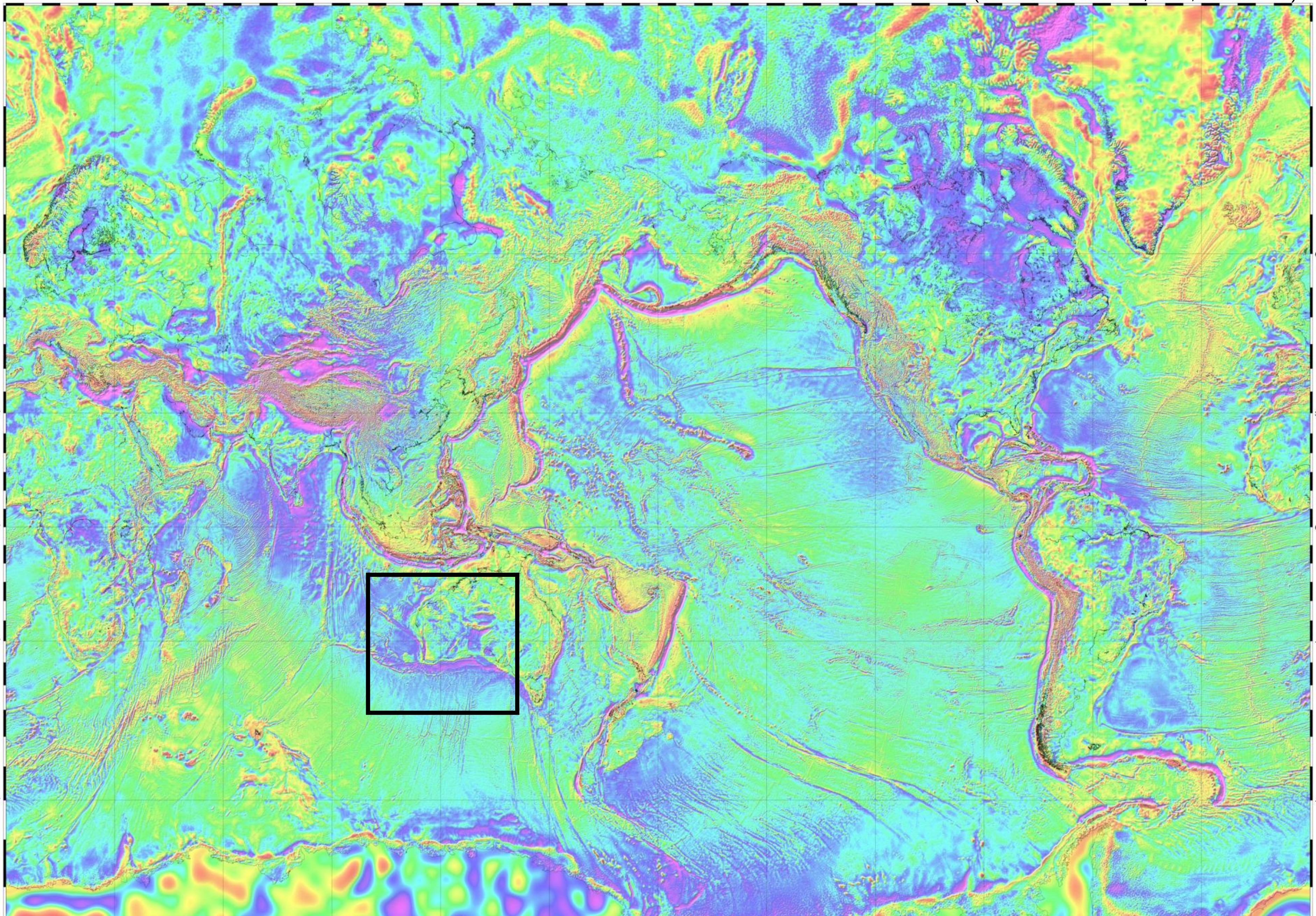


# retracked Geosat and ERS-1 (today)



# global marine gravity from satellite altimetry and EGM2008

(Sandwell and Smith, JGR, 2009 - V18)



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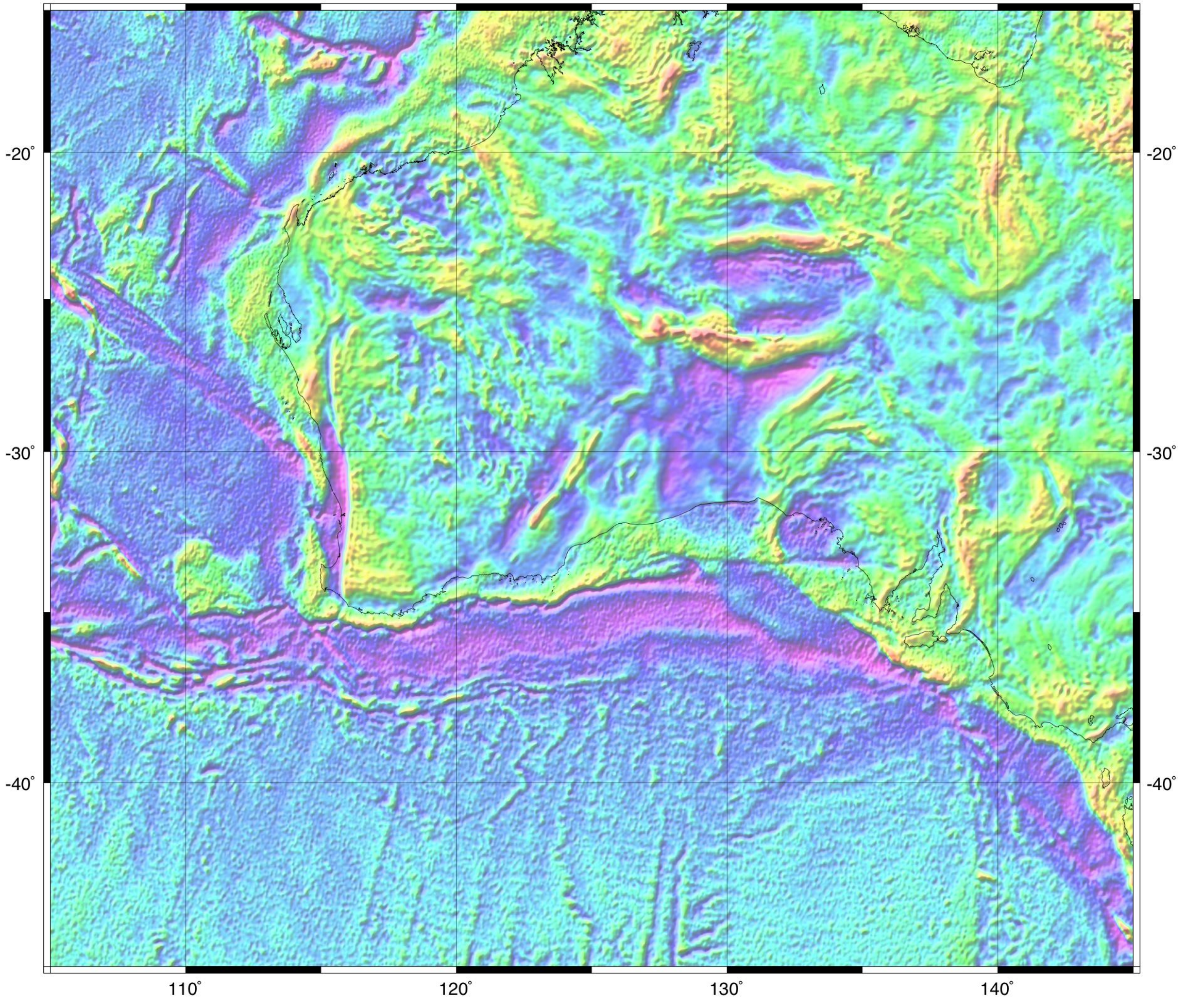



(Sandwell and Smith, JGR, 2009 - V18)

# applications of radar altimetry

**(non-repeat orbit)**

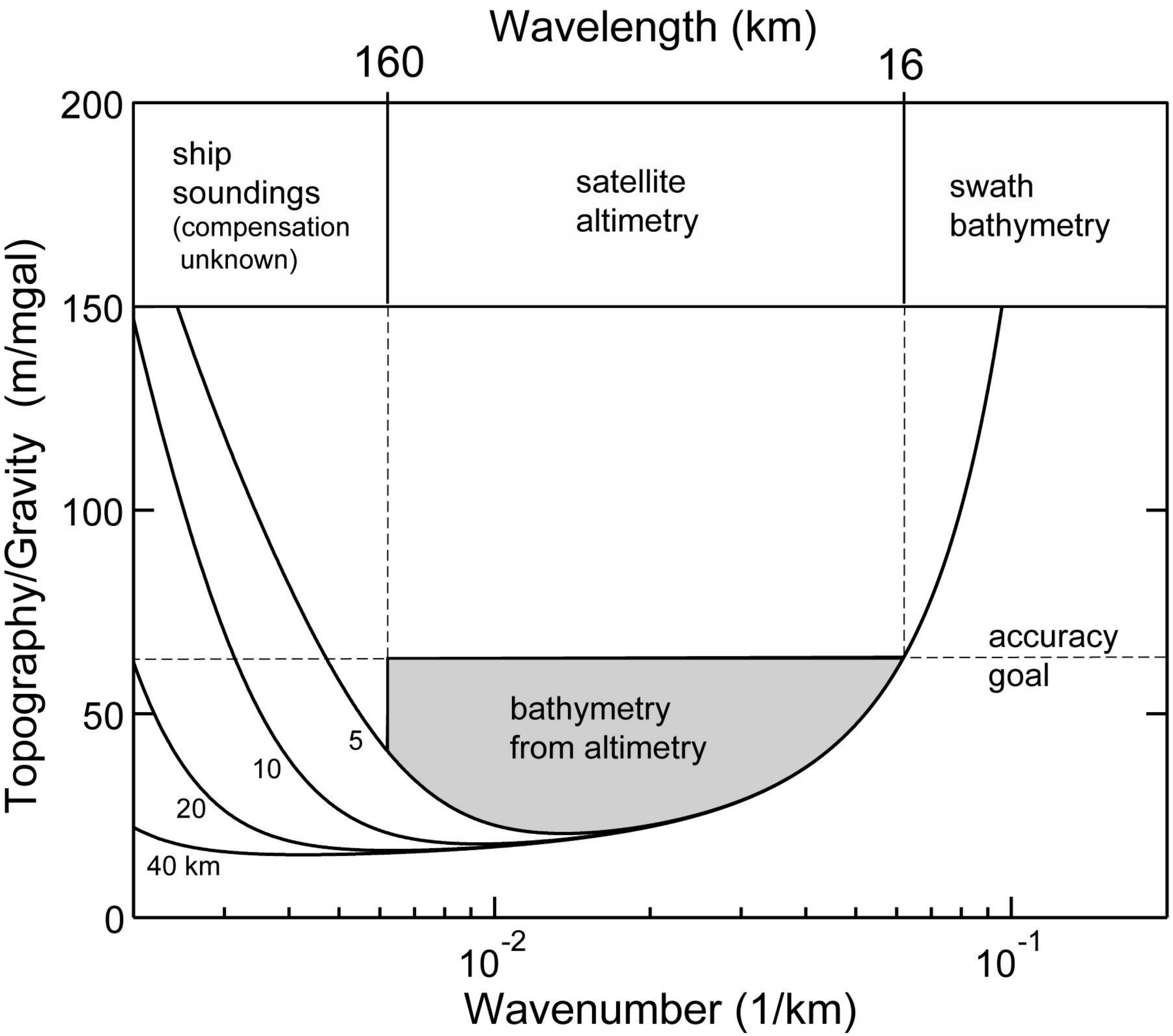
## Gravity:

- plate tectonics
- planning ship surveys
- inertial guidance (mostly military)
- petroleum exploration

## Topography:

- seafloor roughness
- linear volcanic chains
- tsunami models
- tide models, tidal friction, thermohaline circulation
- planning undersea cables
- law of the sea
- education and outreach

# predicting bathymetry from gravity




Walter H. F. Smith

# Bathymetry from Gravity and Ship Soundings: Inverse Nettleton Method

1. Grid available depth soundings.

1. Separate into low-pass and high-pass filtered components (~160 km).

1. High-pass filter gravity and downward continue to low-pass filtered depths.

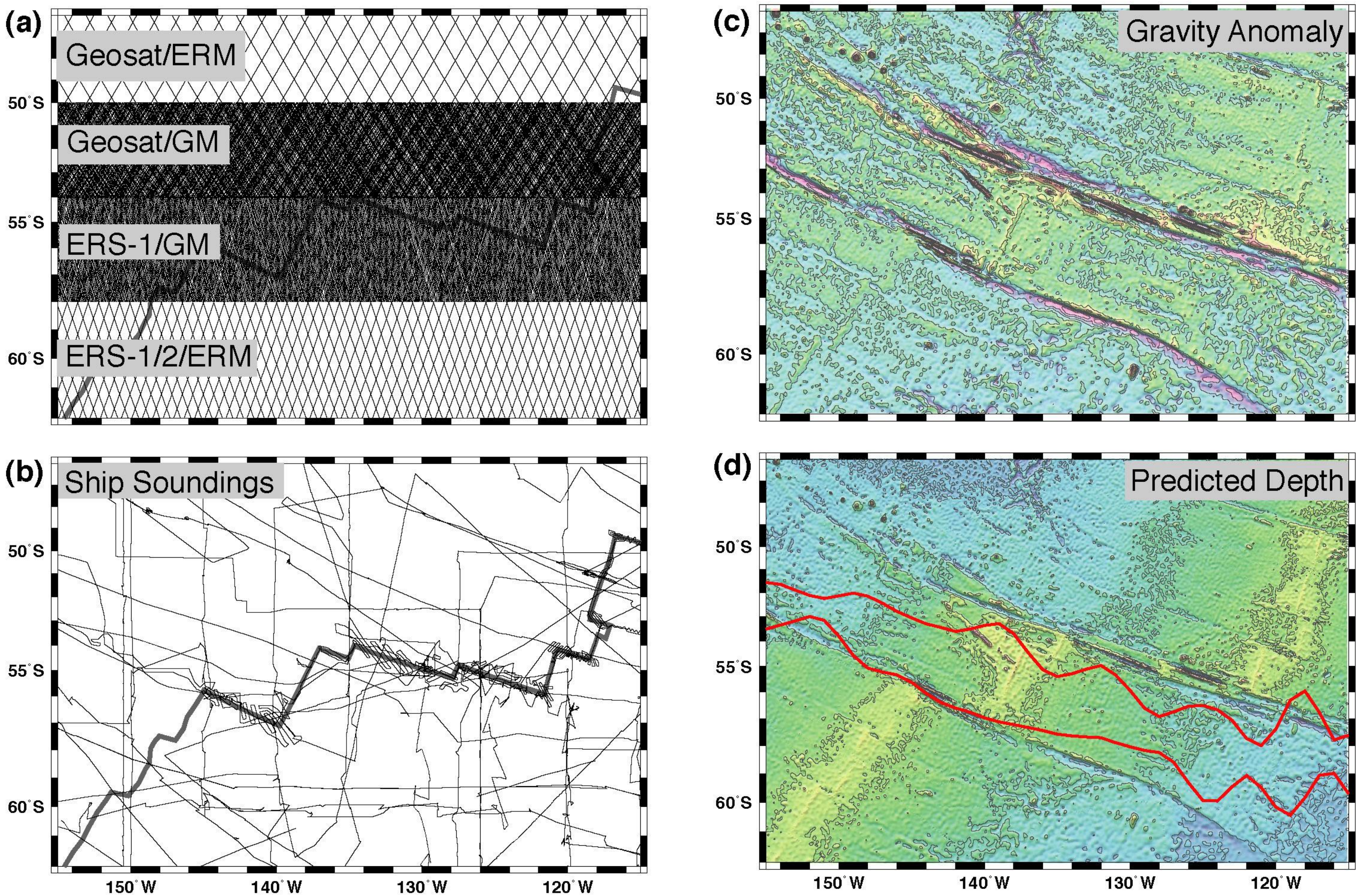
1. Perform a robust linear regression of high-pass topography and high-pass, downward-continued gravity in small regions.

1. Multiply gravity by topography/gravity slope to predict topography in pass band.

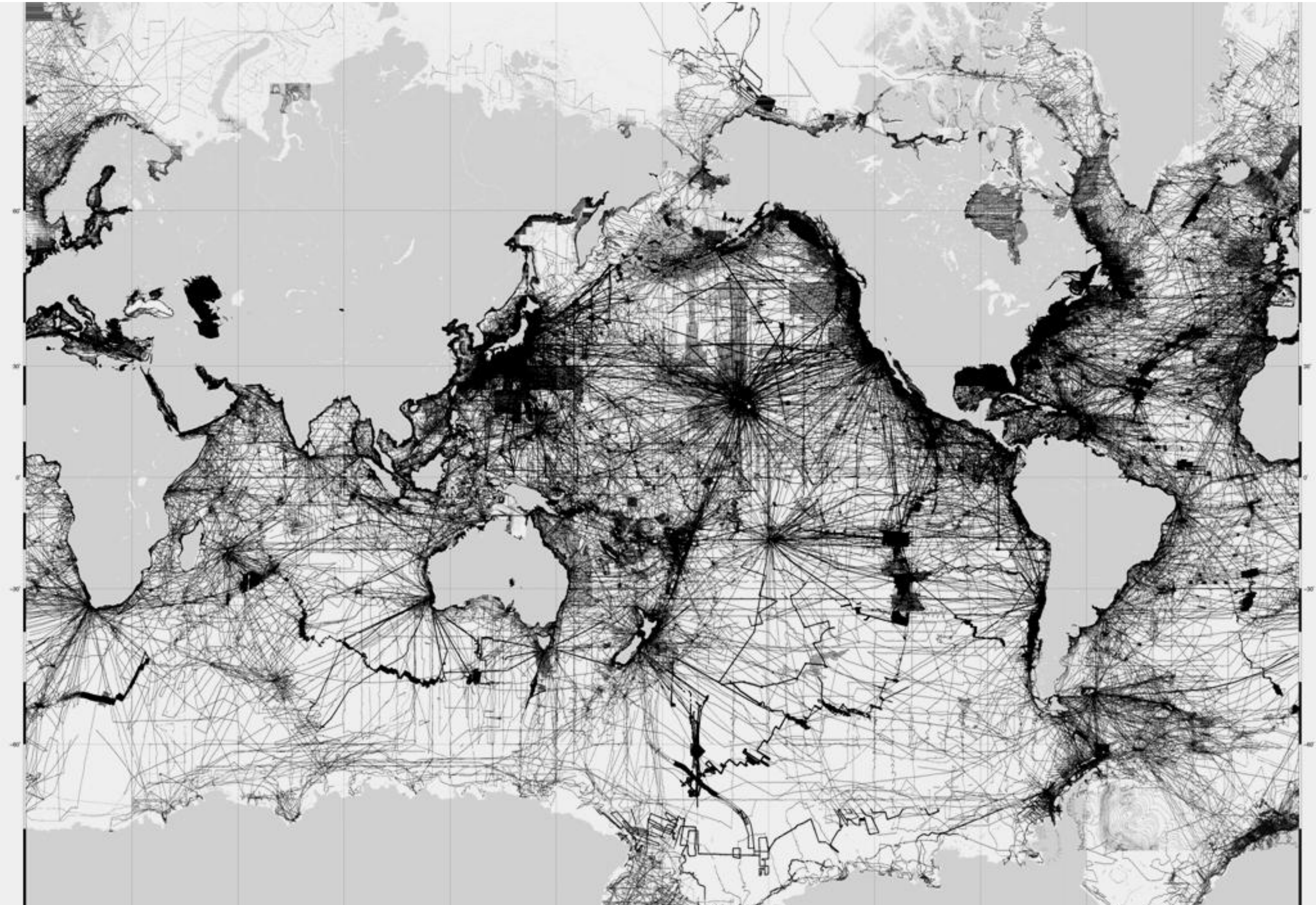
1. Add original low-pass filtered depth.

1. Force agreement with soundings.

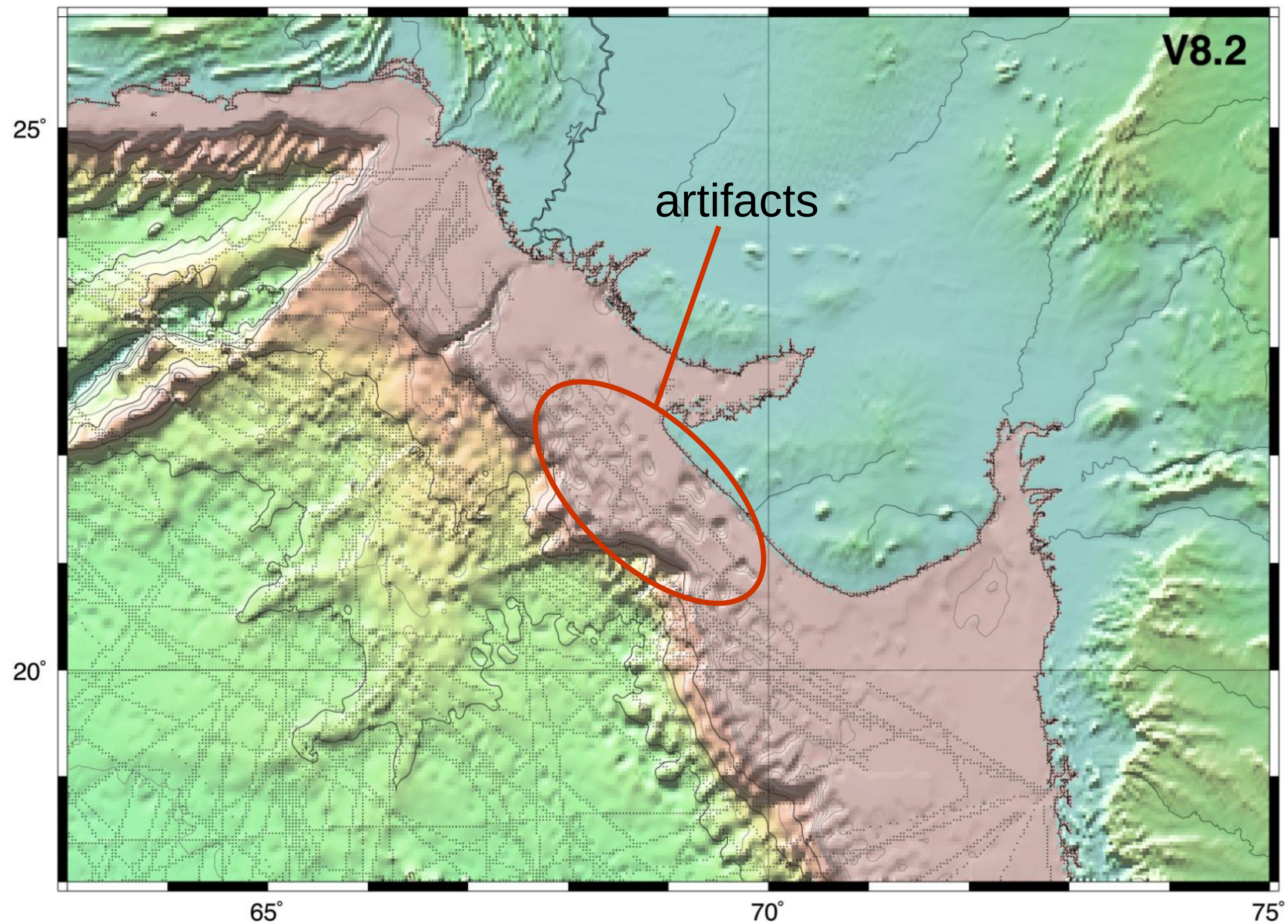
# sparse soundings + dense altimetry = global bathymetry



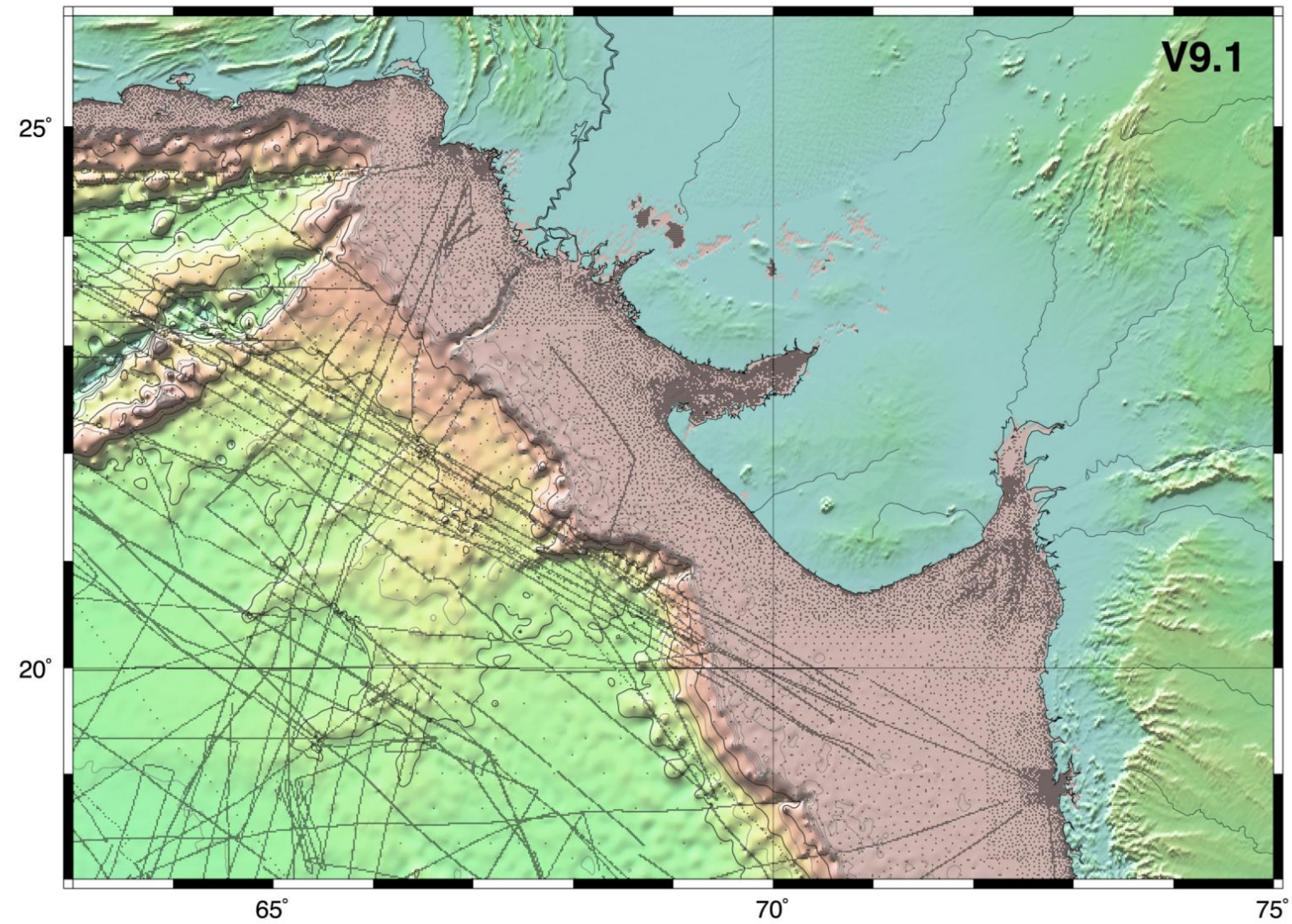
# archive of soundings @ SIO



# shallow water bathymetry before NGA contributions



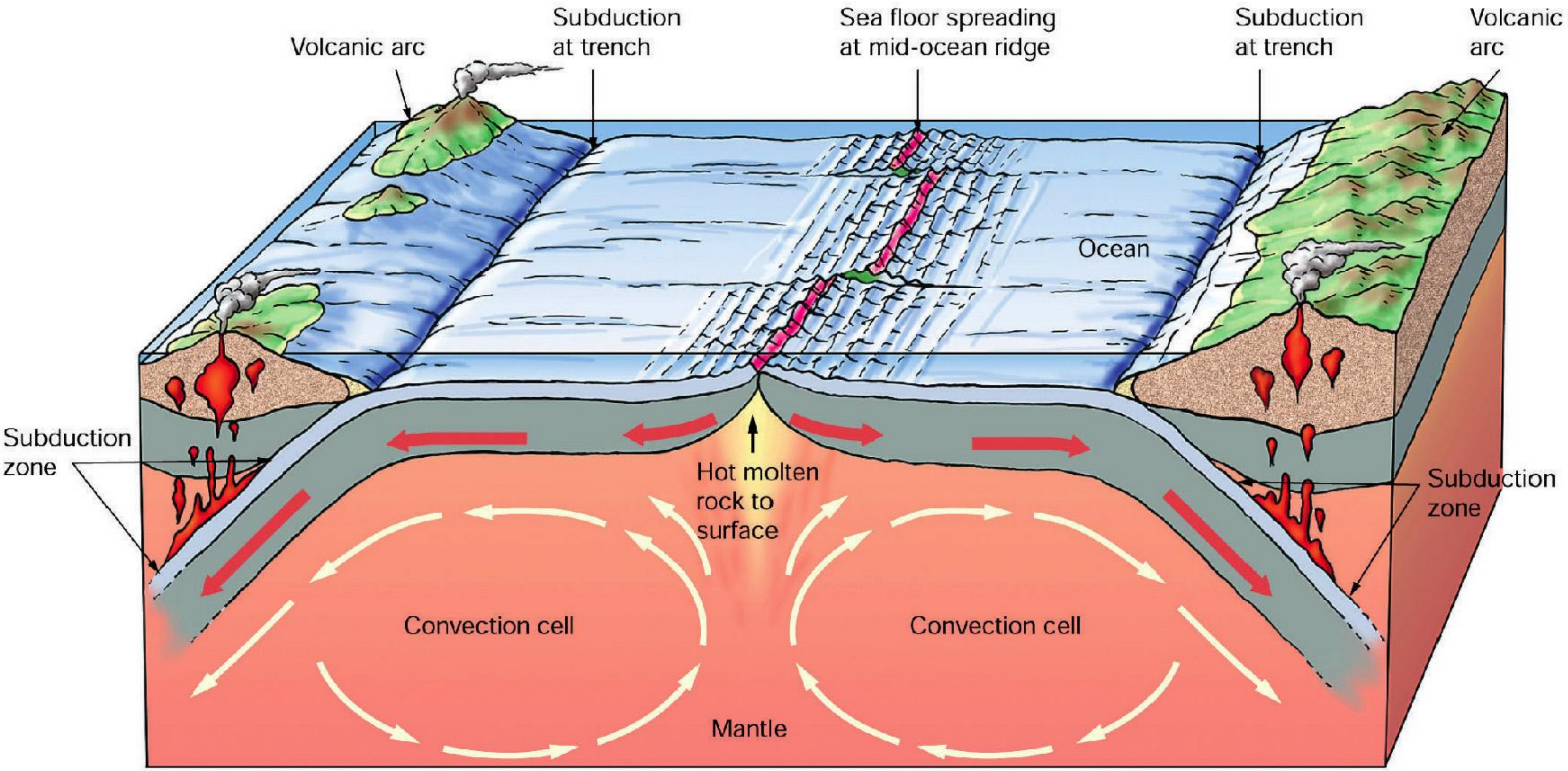
# shallow water bathymetry after NGA contributions



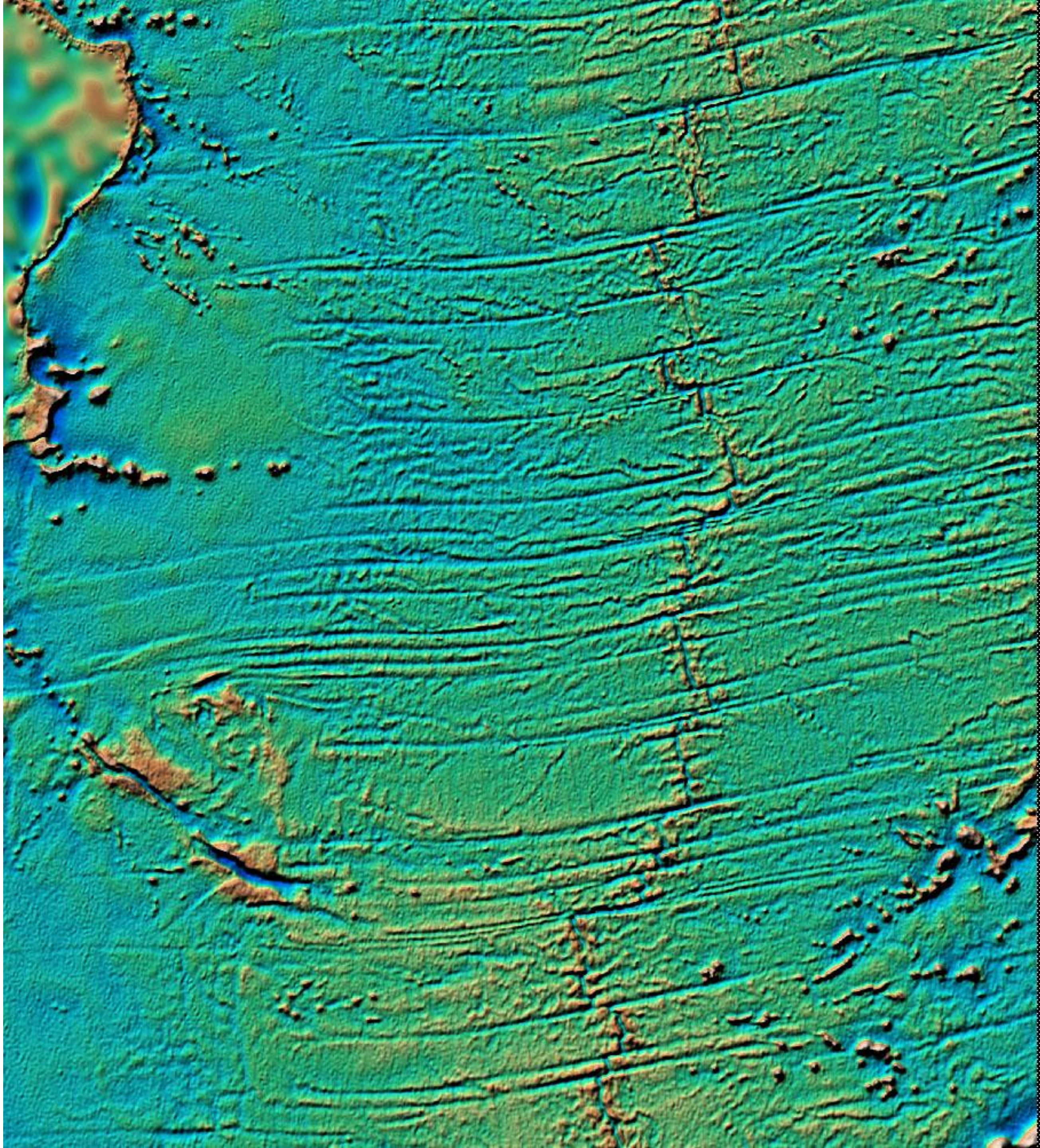
# discoveries from Geosat and ERS-1

- **confirming/refining plate tectonics**
- global seafloor age
- global bathymetry grids
- seamounts > 2 km tall
- seafloor roughness versus spreading rate
- deep ocean mixing
- links to surface currents/biology

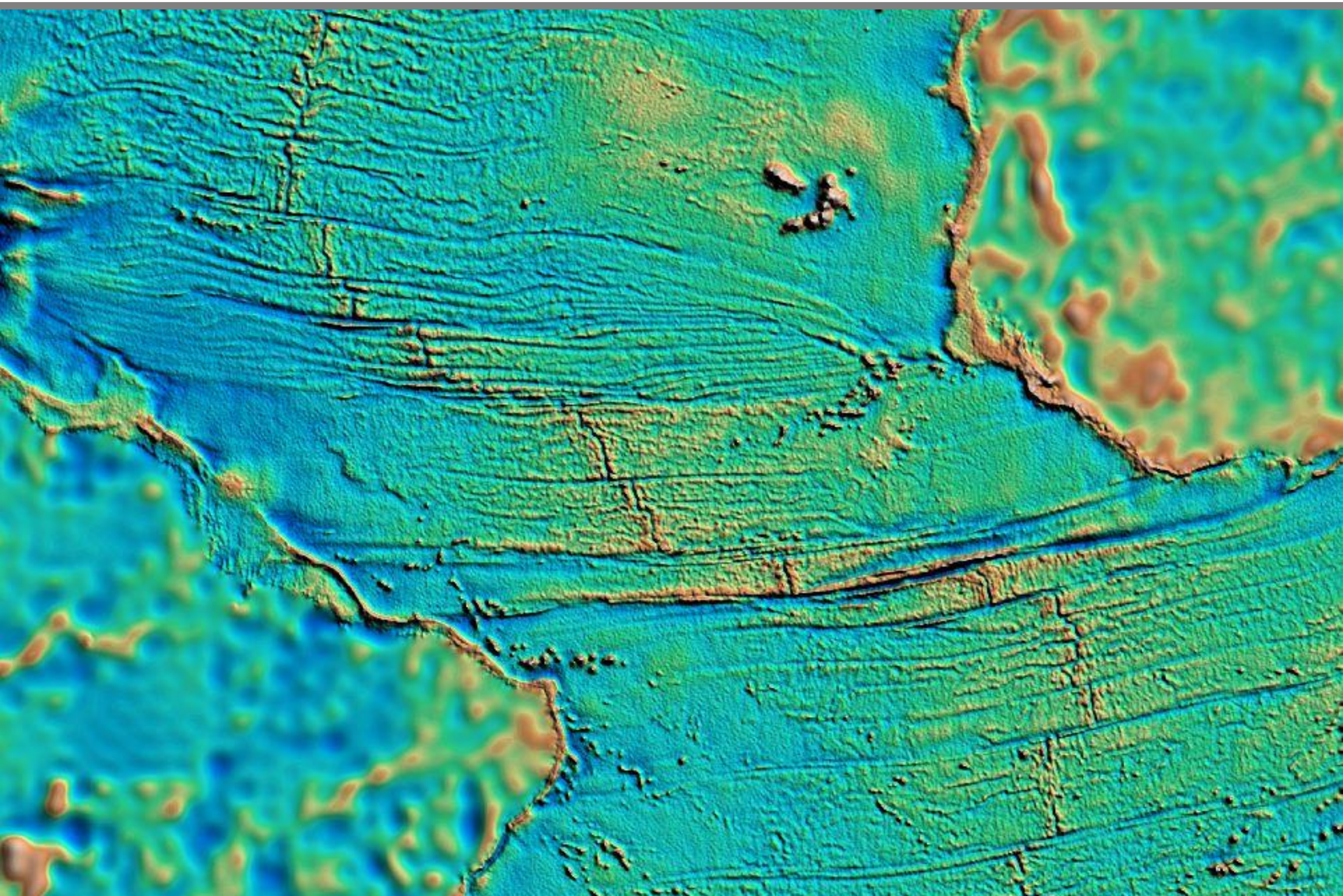
# what were they smoking in the 60's?



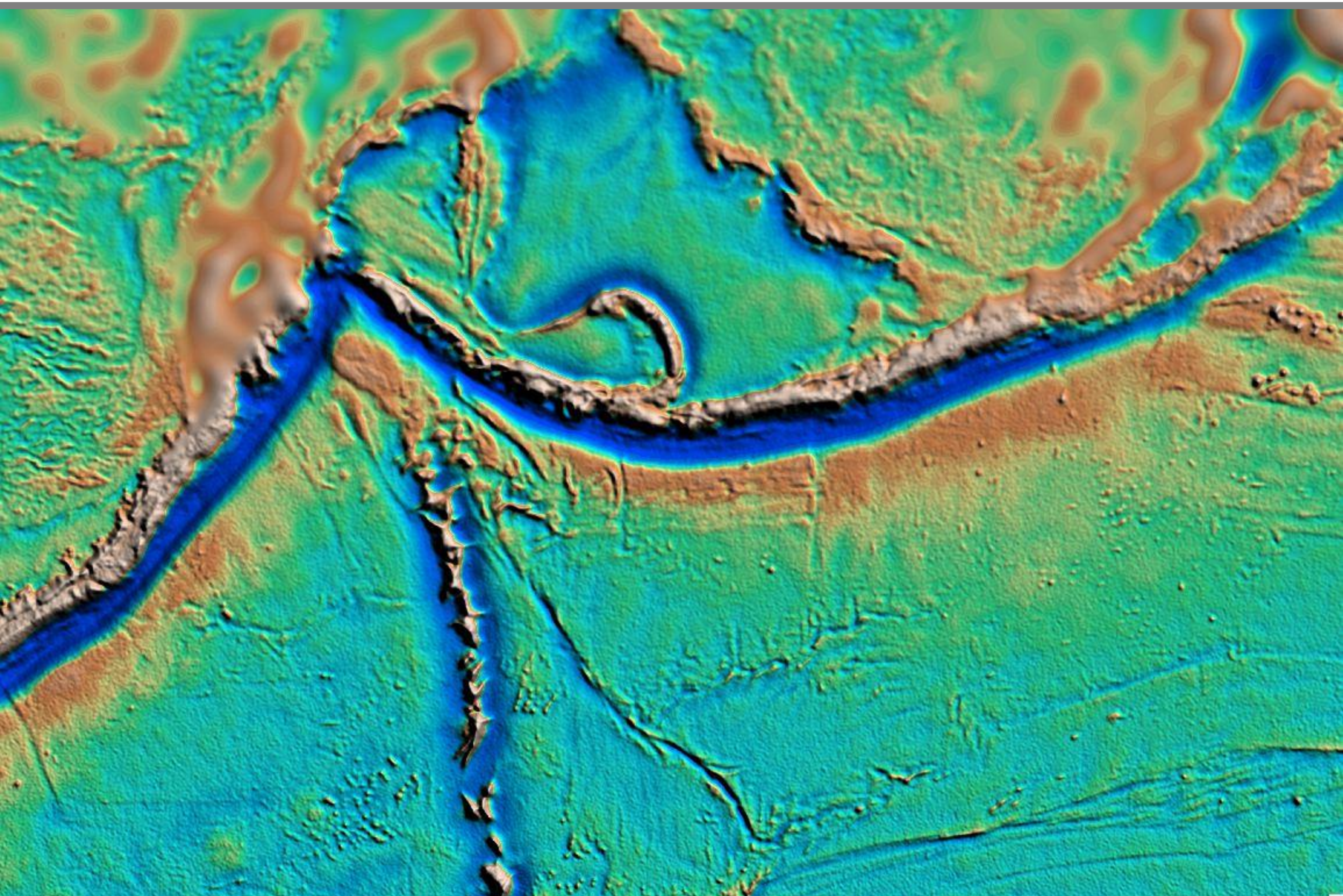
# ridges and transforms



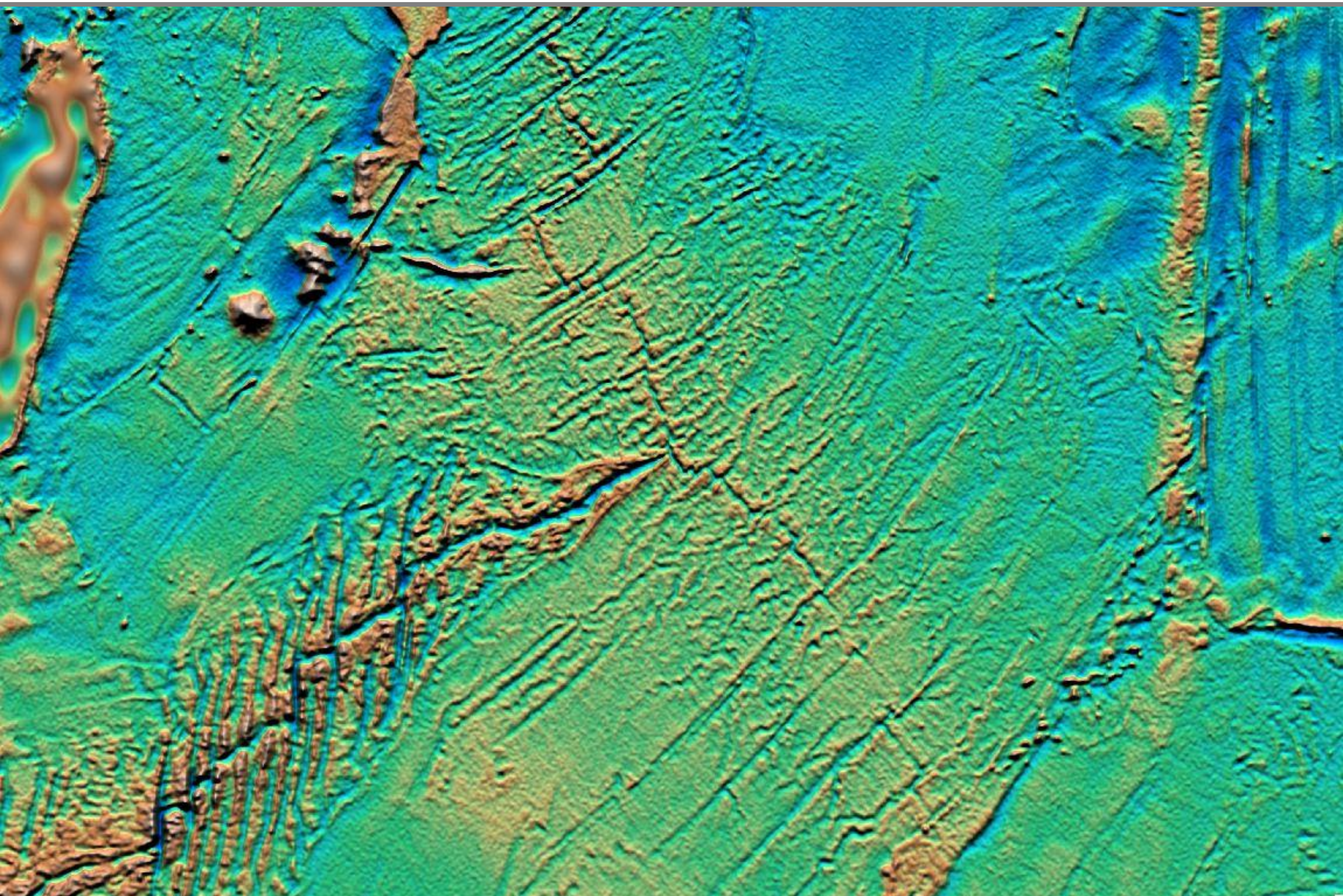
# fracture zones



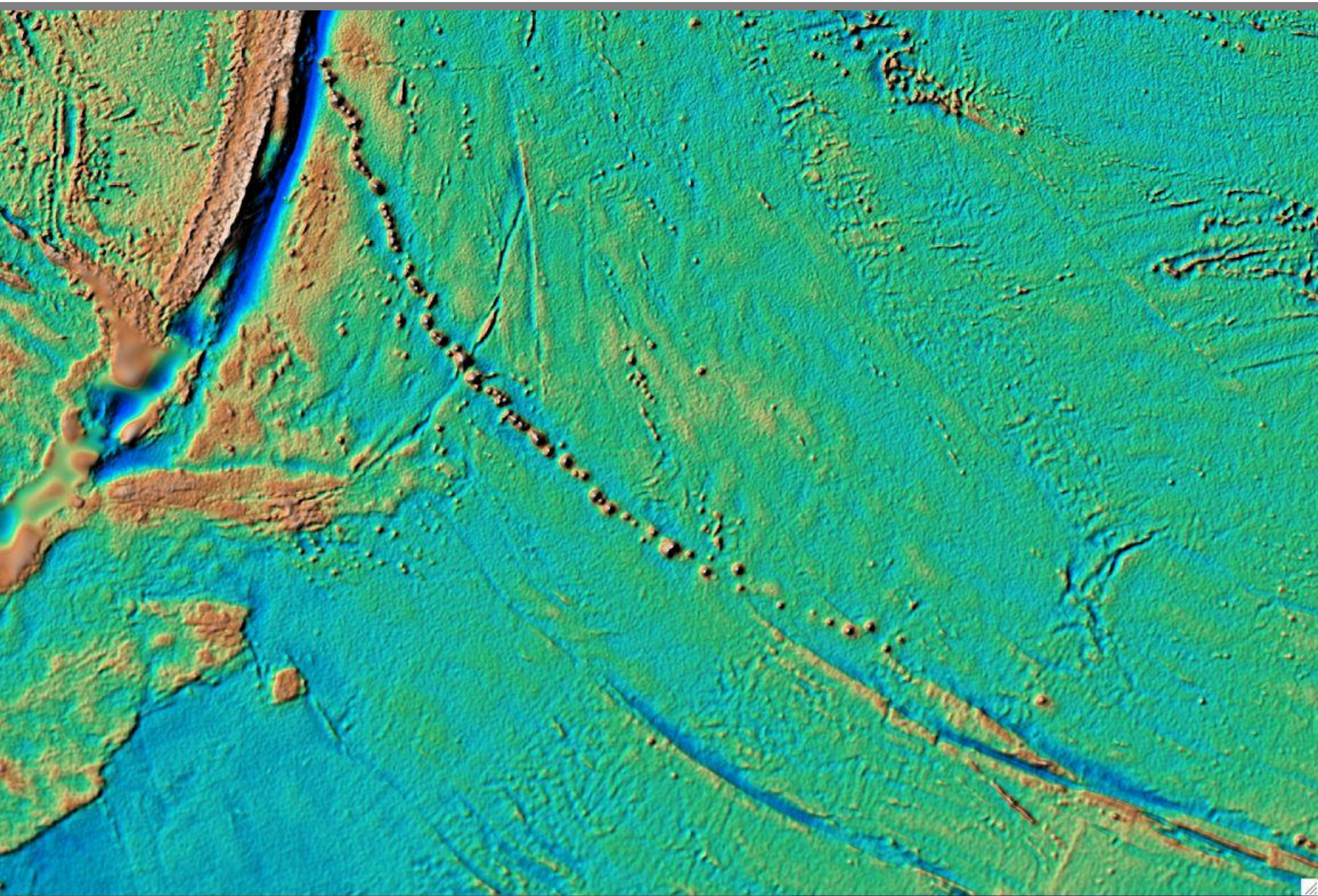
# subduction zones



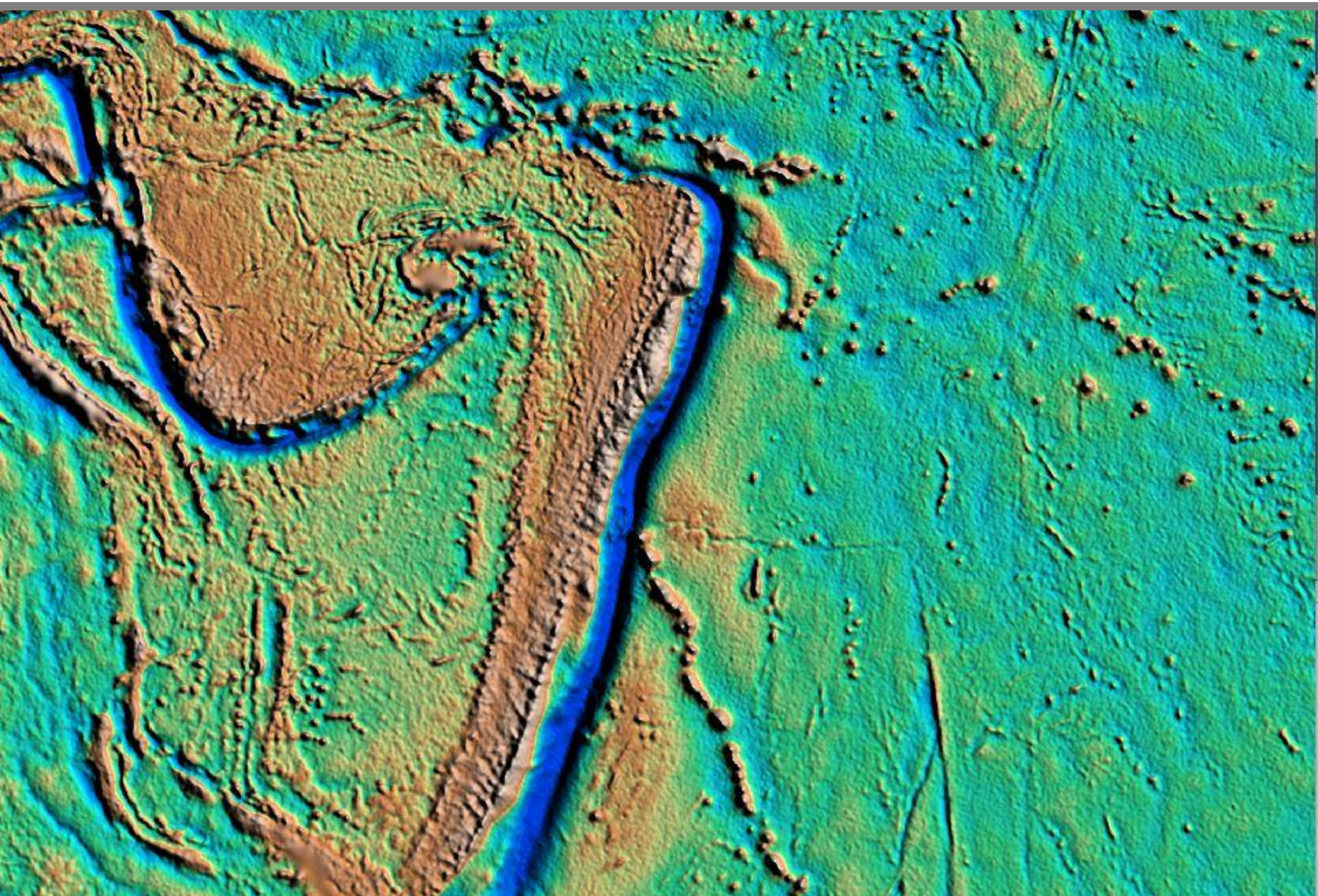
# triple junction



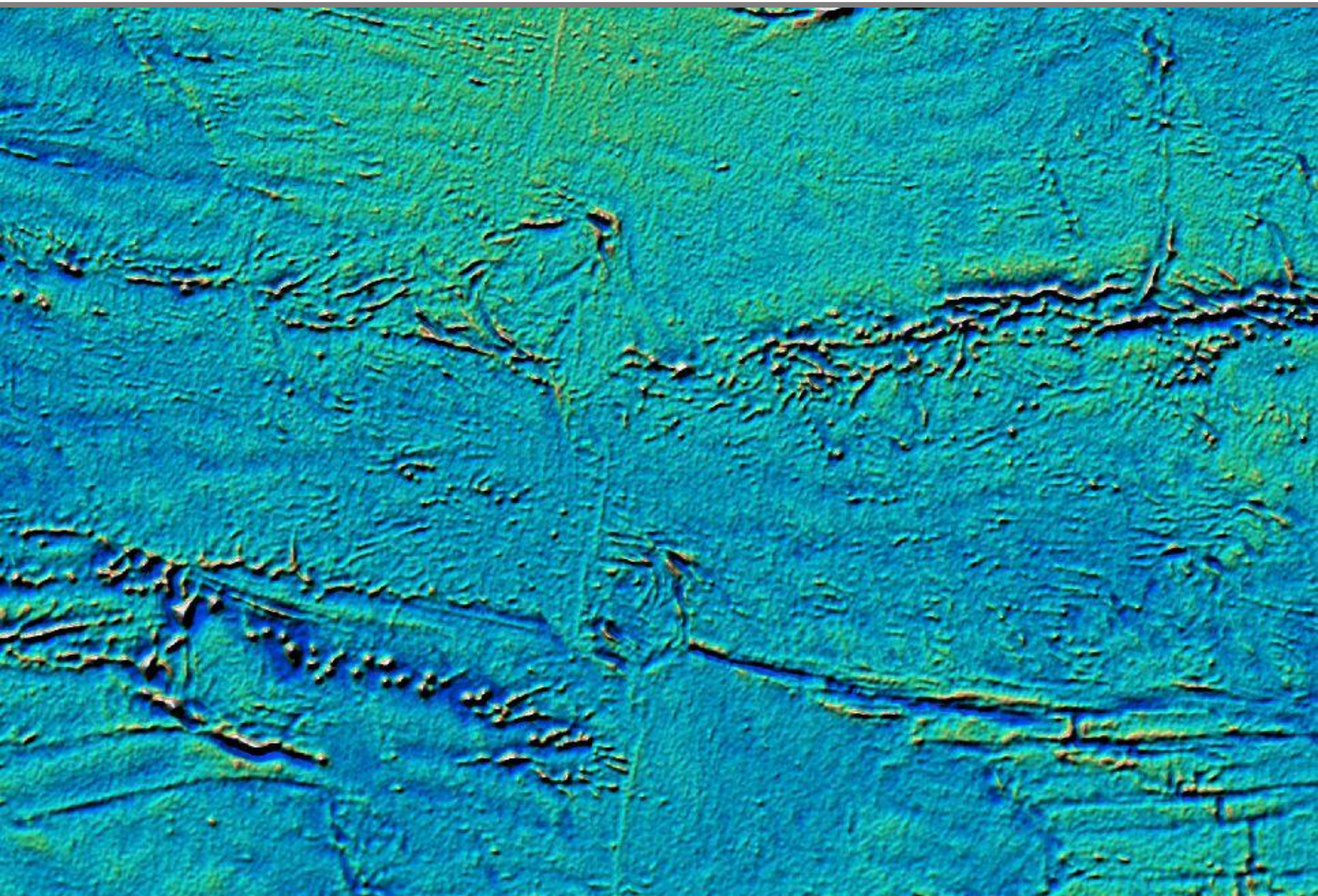
# hot spot



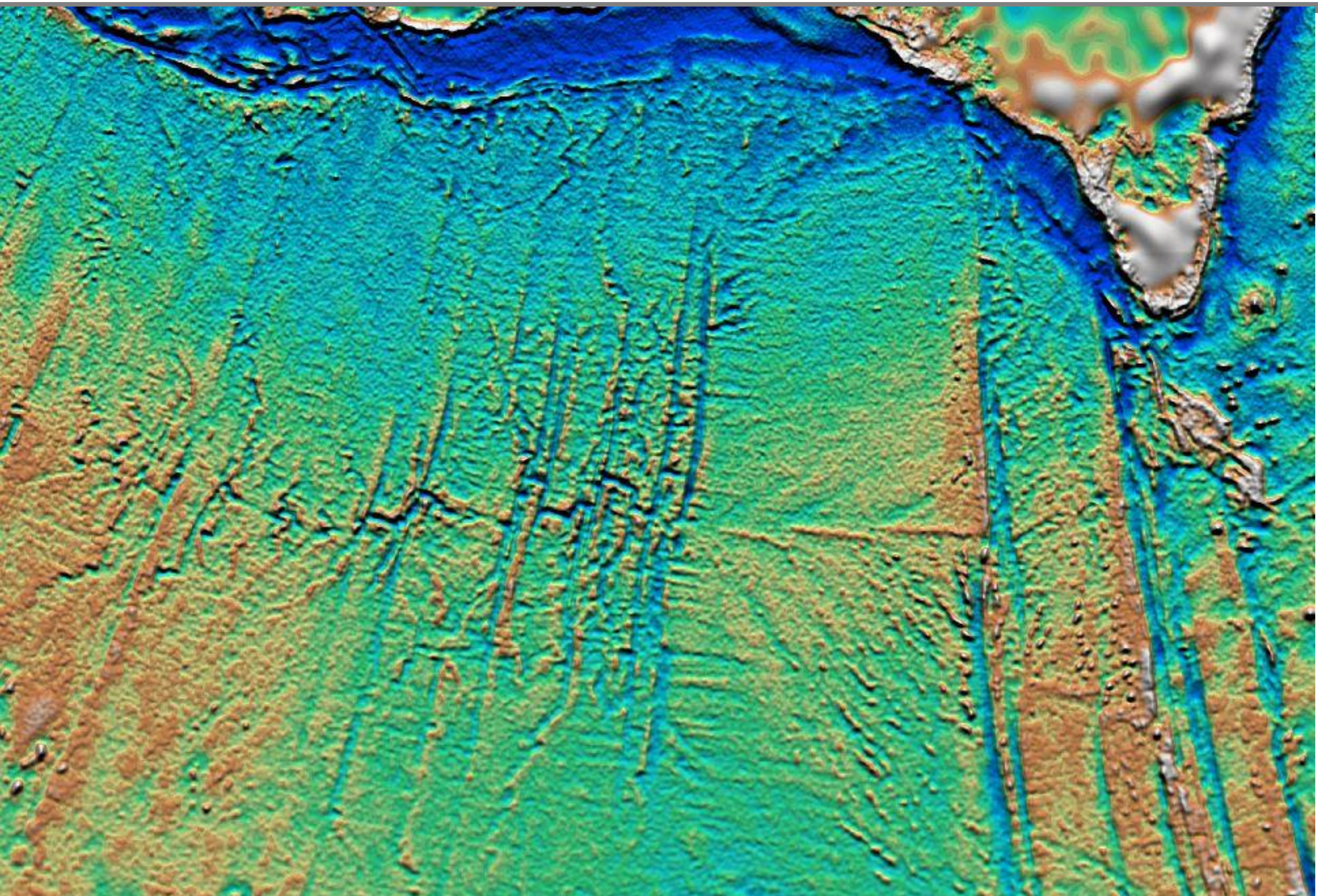
# back-arc spreading



# microplates



# propagating rifts



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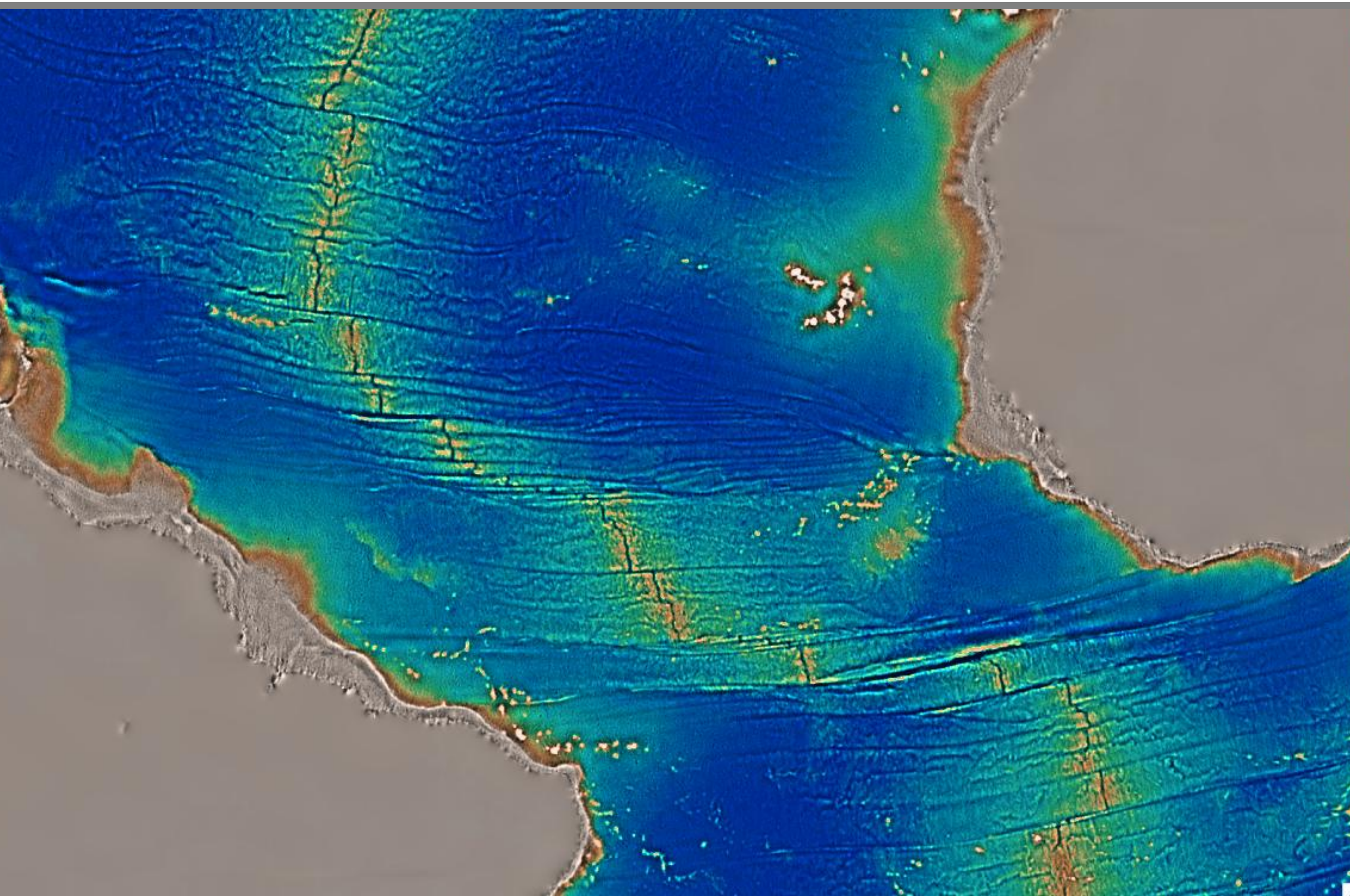
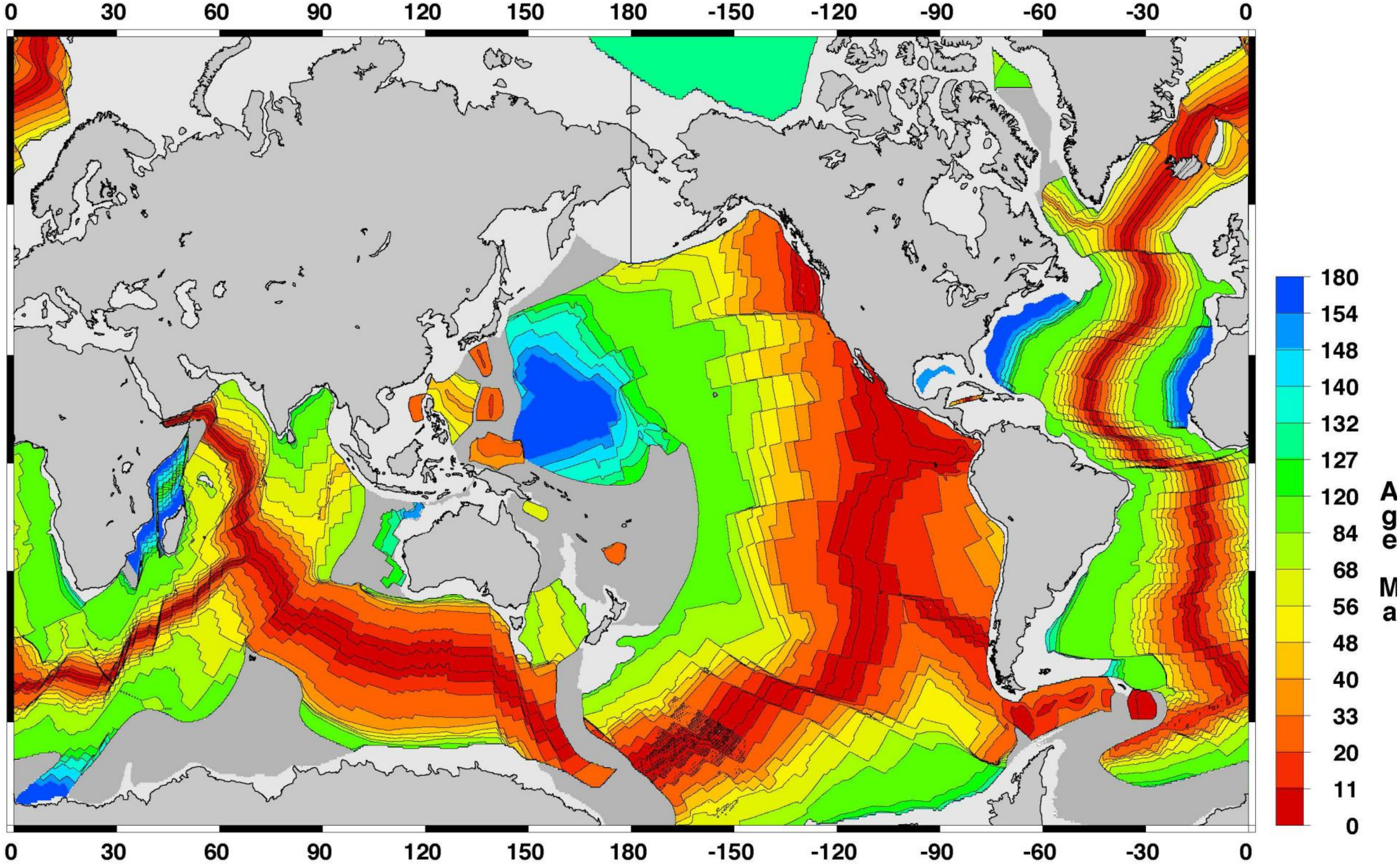
- deep ocean mixing
- links to surface currents/biology

# fracture zones = spreading direction



# FZ direction + magnetic anomalies = seafloor age

**[*Mueller et al.,* 1997]**



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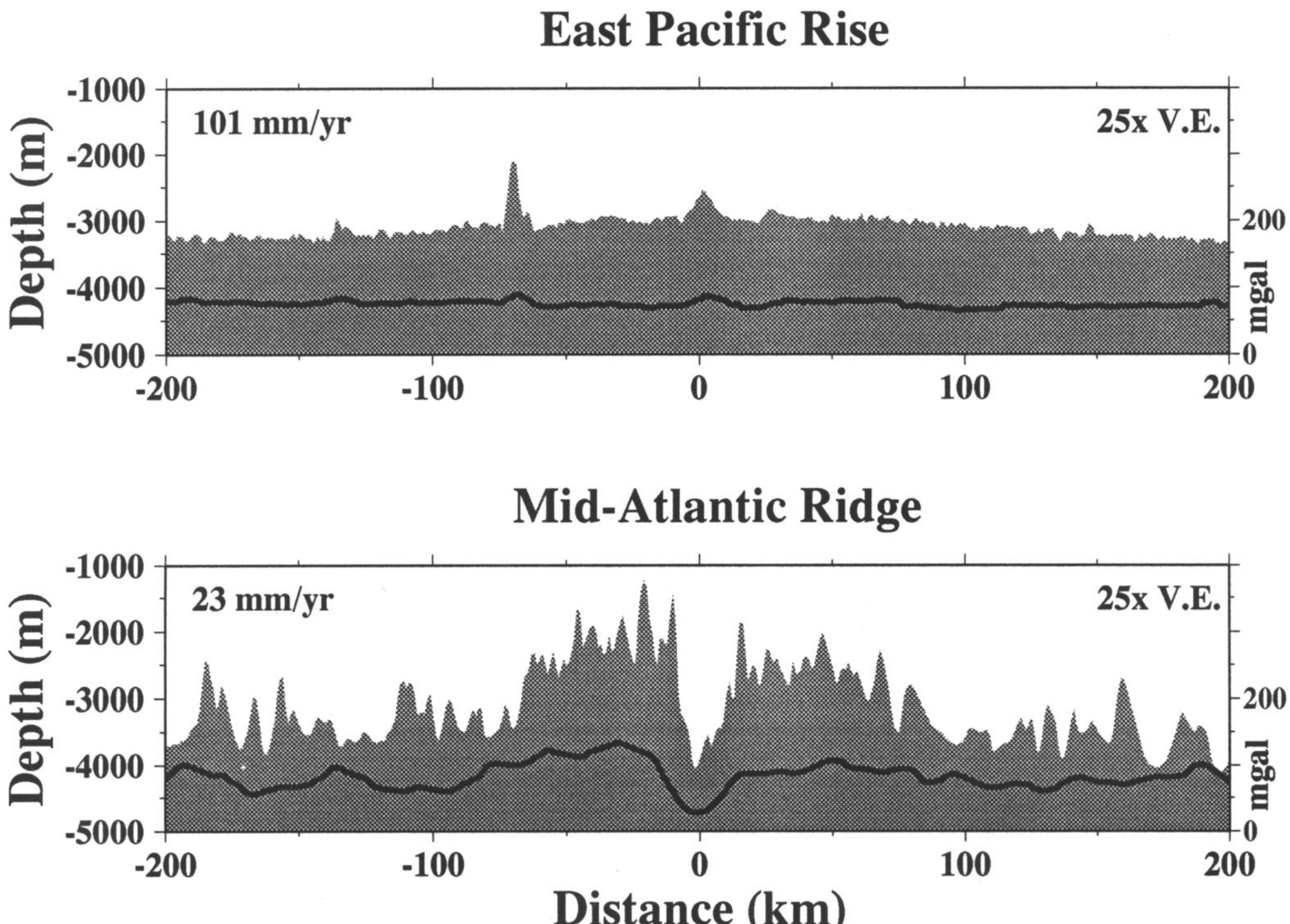
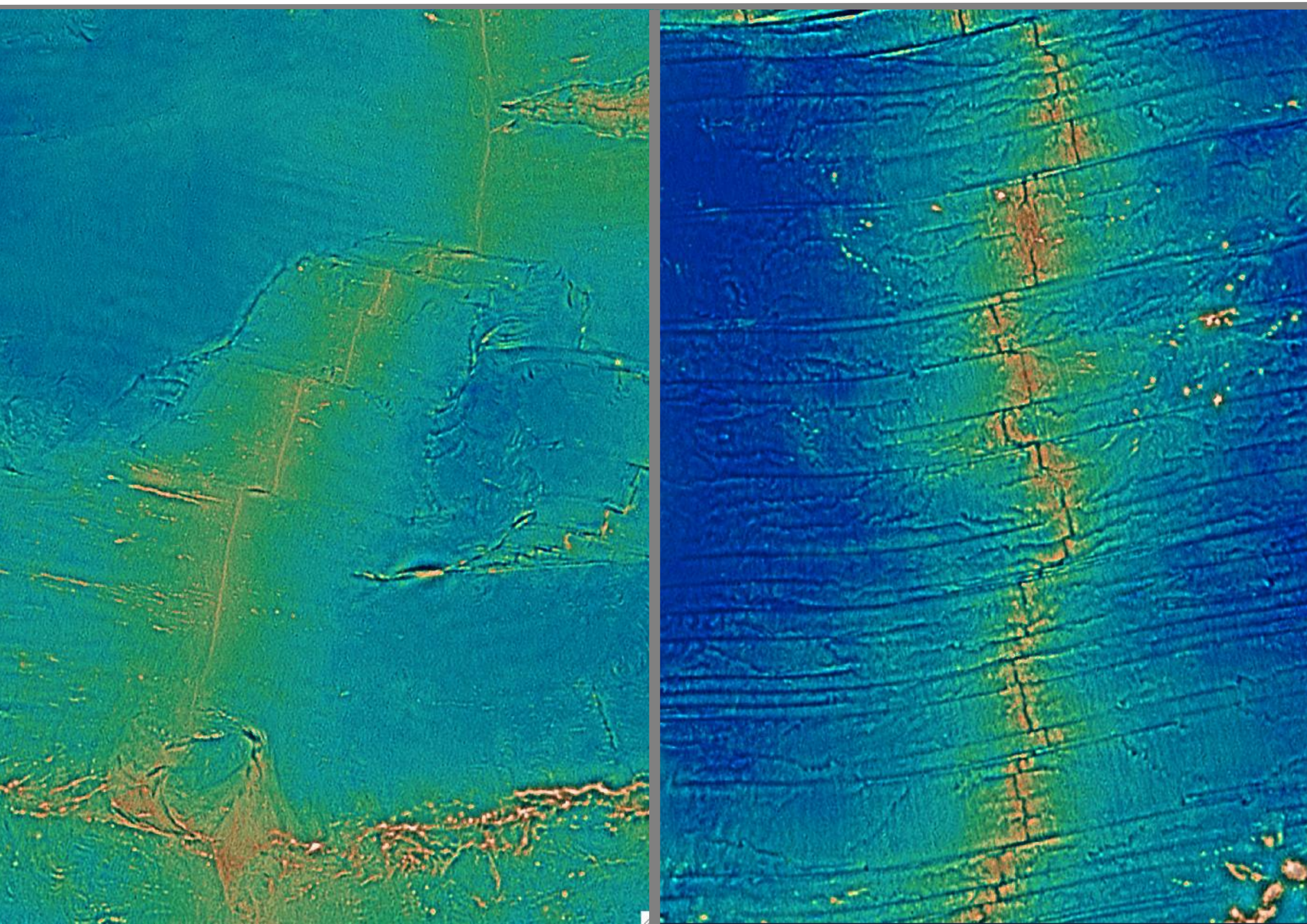
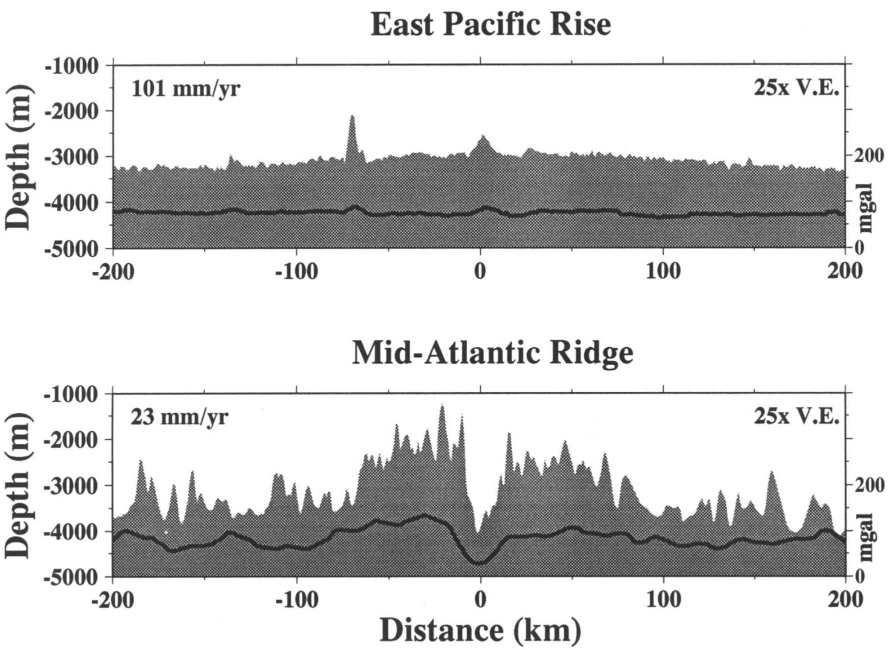
# fast vs. slow spreading

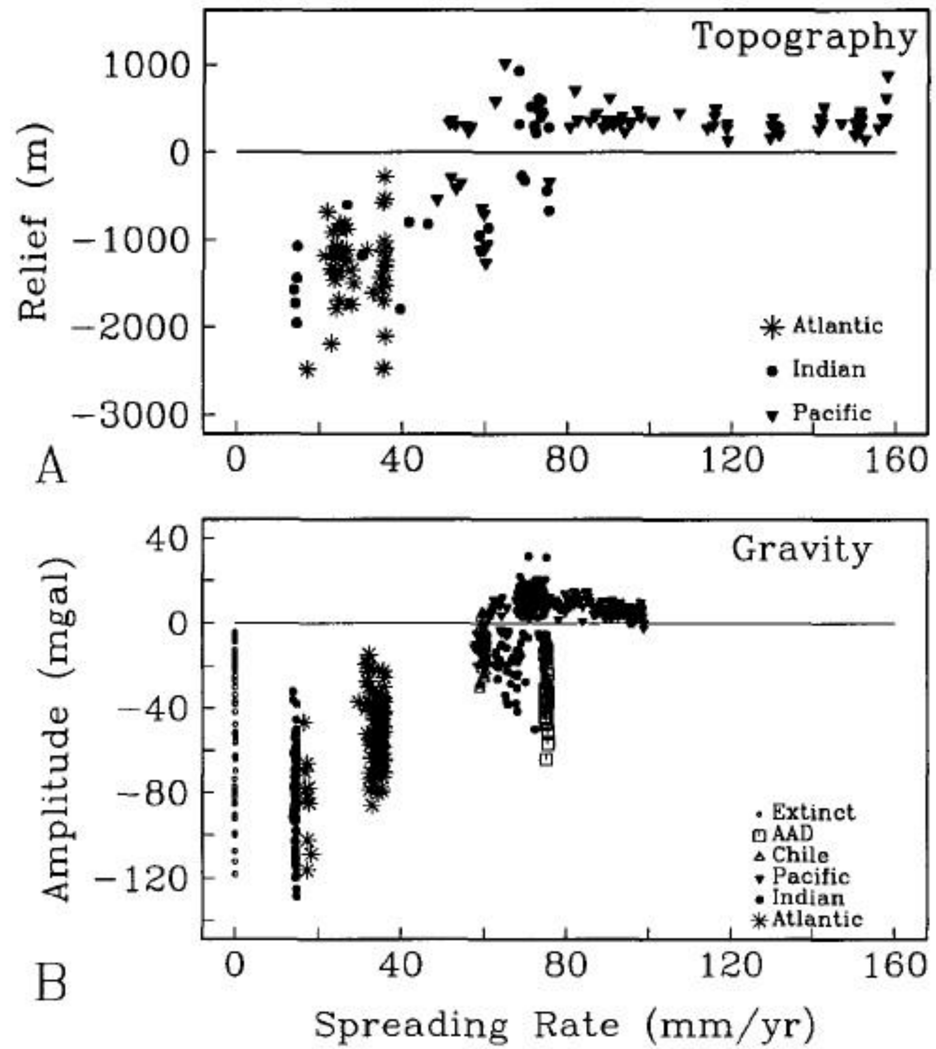


**fast spreading vs. slow spreading**



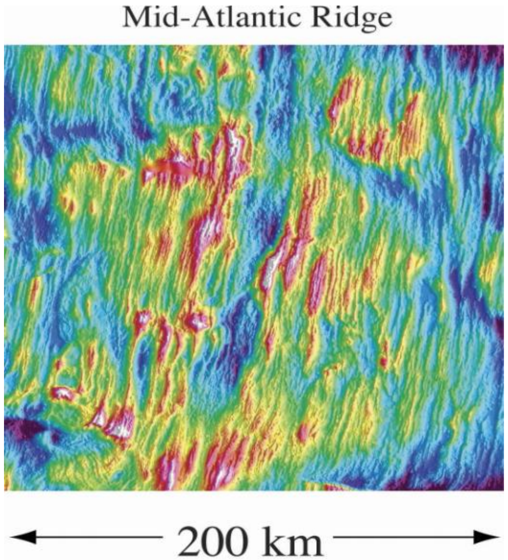
# fast vs. slow spreading

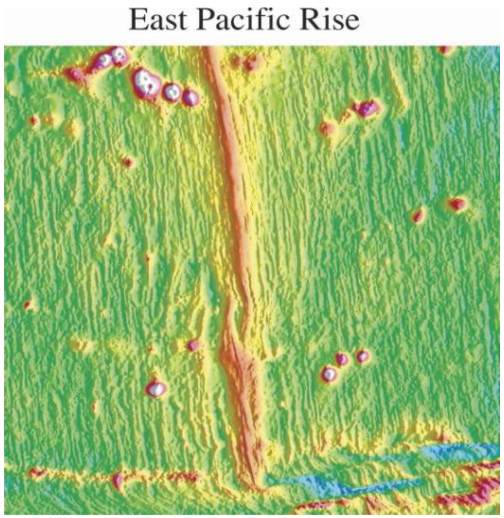


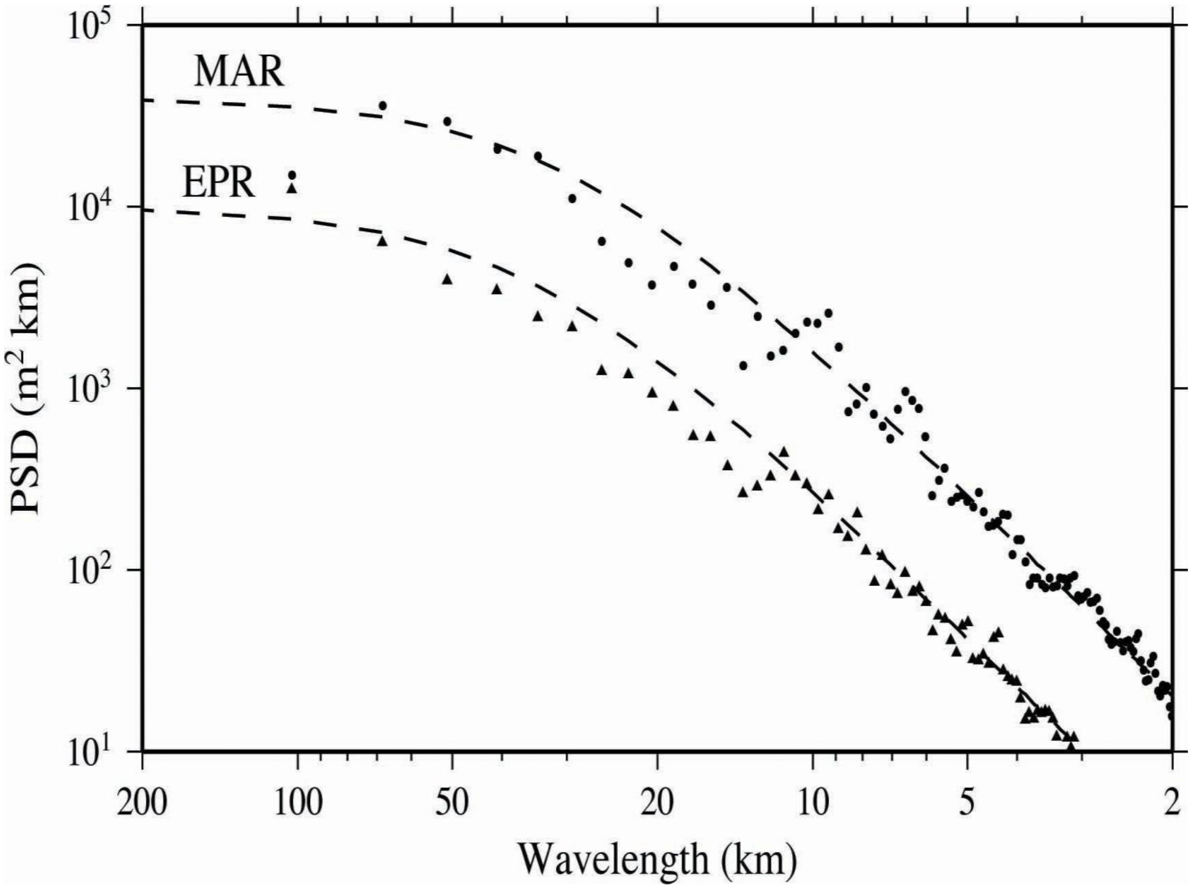




Small and Sandwell, Geology, 1994

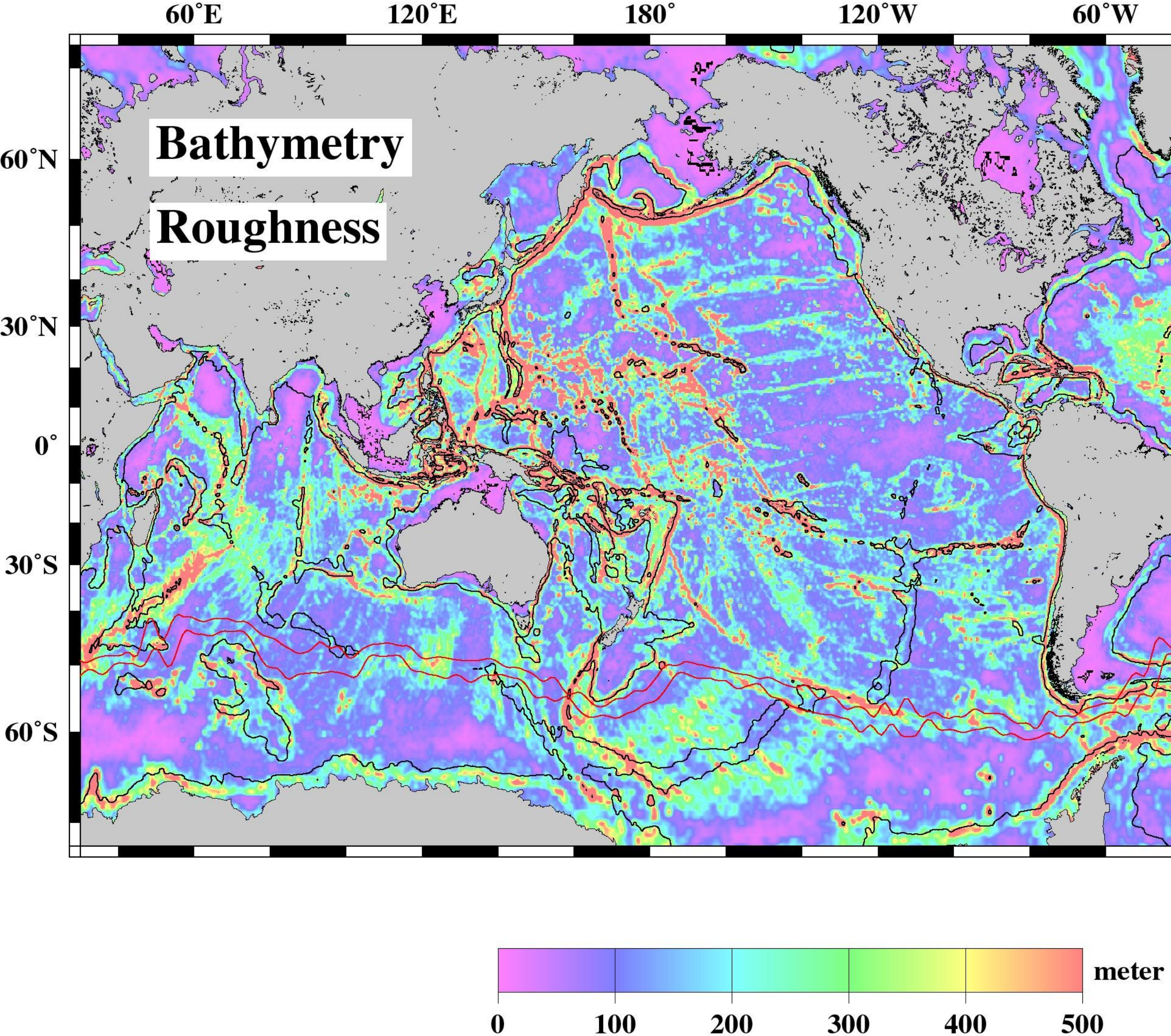
# Abyssal Hills: Fast v. Slow Spreading Rate




[Smith, W.H.F.: personal communication]




[Gille et al., 2000;
Becker et al., 2009]

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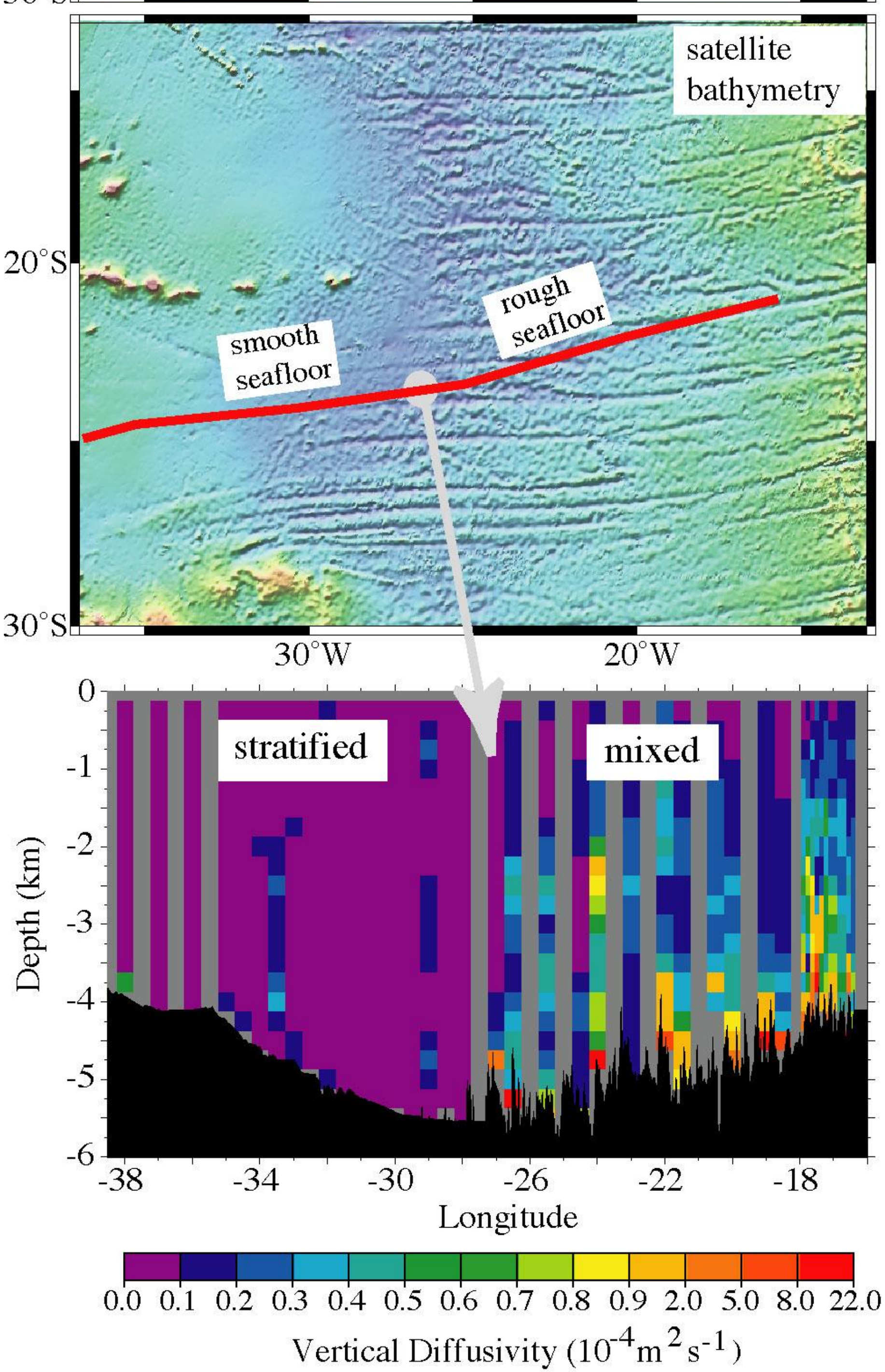
- seafloor roughness versus spreading rate
- **deep ocean mixing**
- links to surface currents/biology

# ocean mixing vs. seafloor roughness

[*Polzin et al.*, 1997]



QuickTime™ and a
decompressor
are needed to see this picture.

[Kunze and
Llewellyn-Smith
Oceanography
2004]

# Global Seafloor Slope Estimates From Single Beam Soundings

**Joseph J Becker & David T Sandwell**

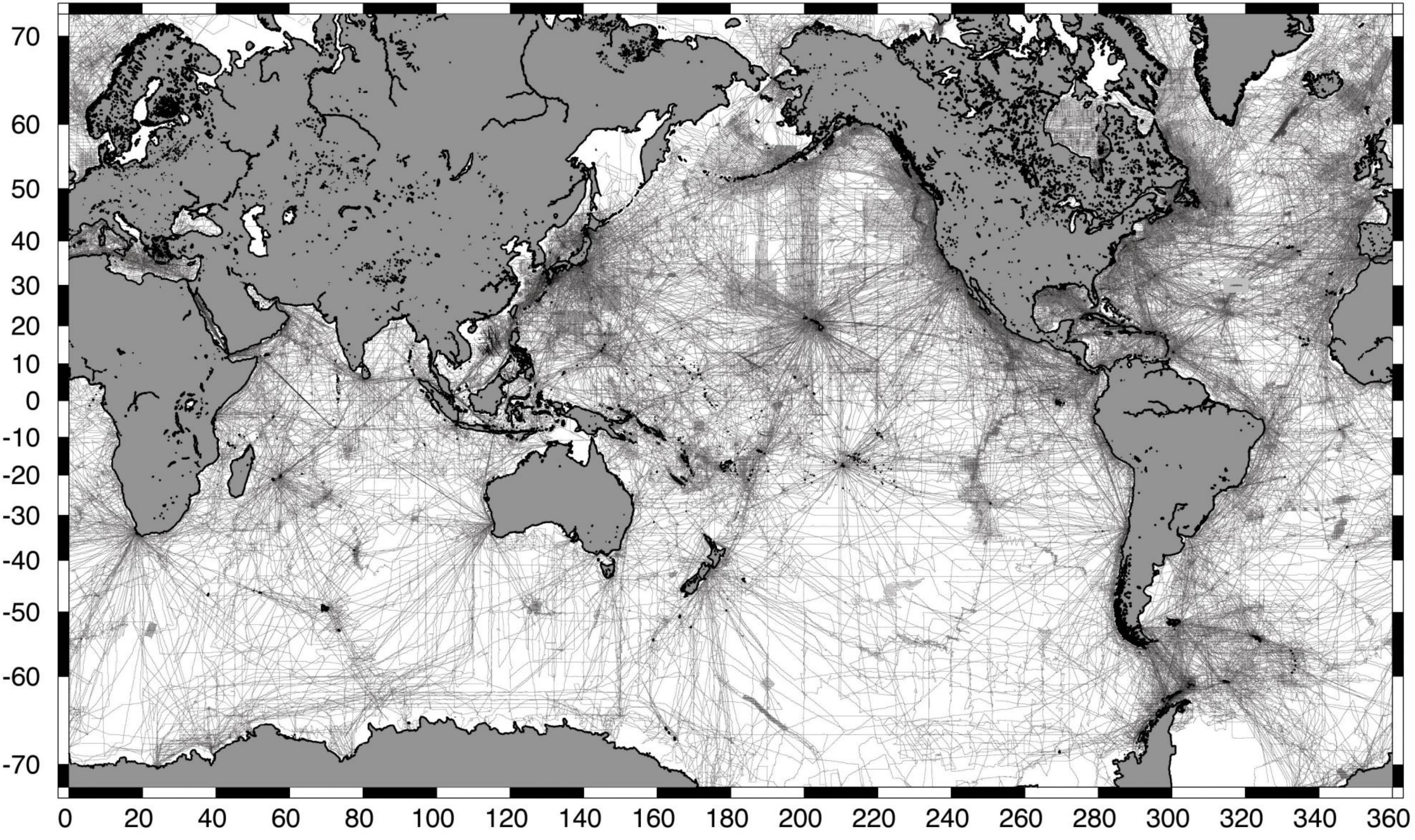
**[JGR, 2008]**

- **Smith & Sandwell (1997) “predicted” depth cannot measure slope**
- **Use 40 year archive of ship soundings**
- **Global maps of slope and roughness**
- **Fit of Levitus model extrapolated to bottom**
- **Large areas of Southern Ocean above critical slope??**

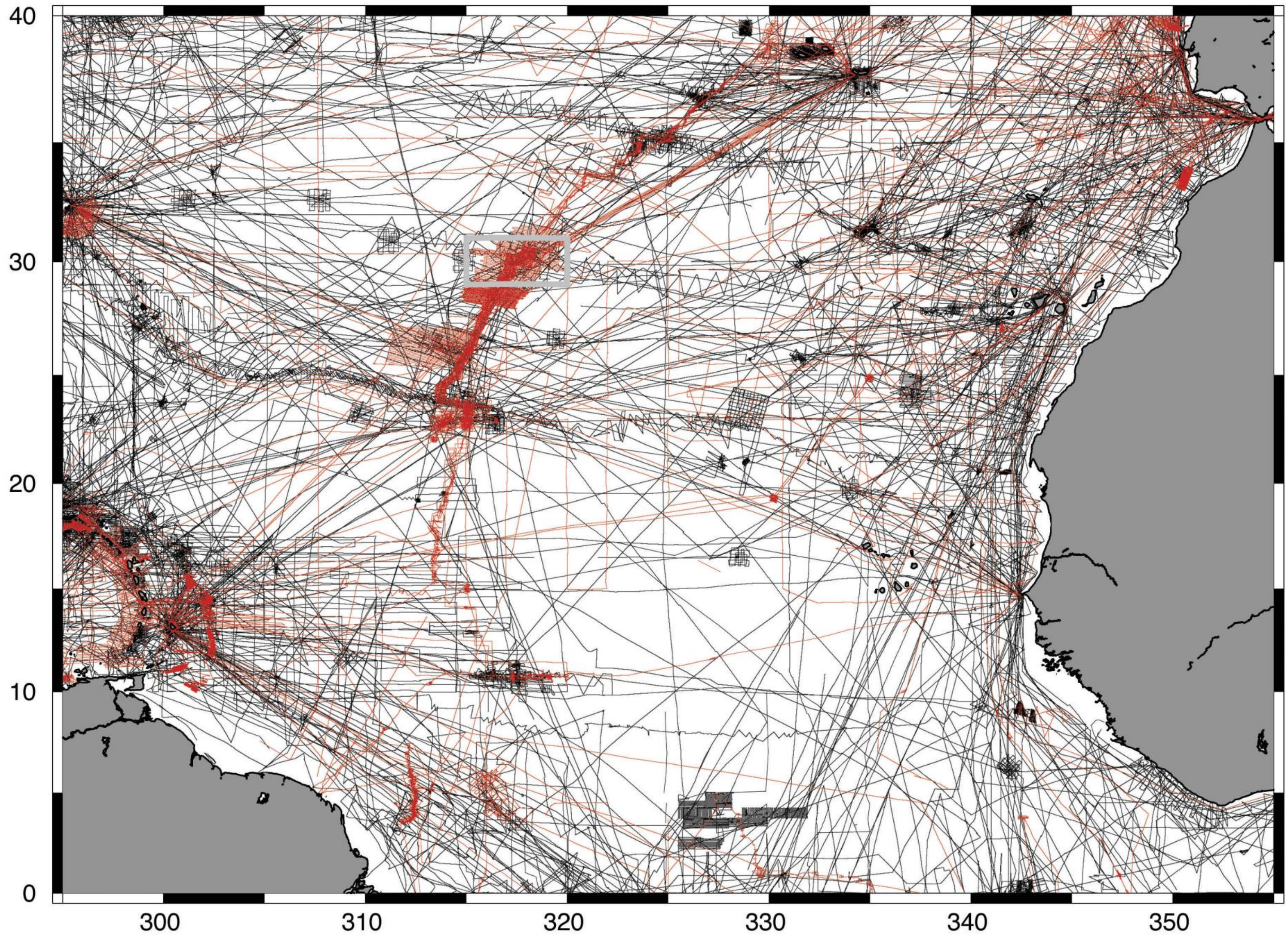
# Ship, Multibeam And Predicted Bathymetry

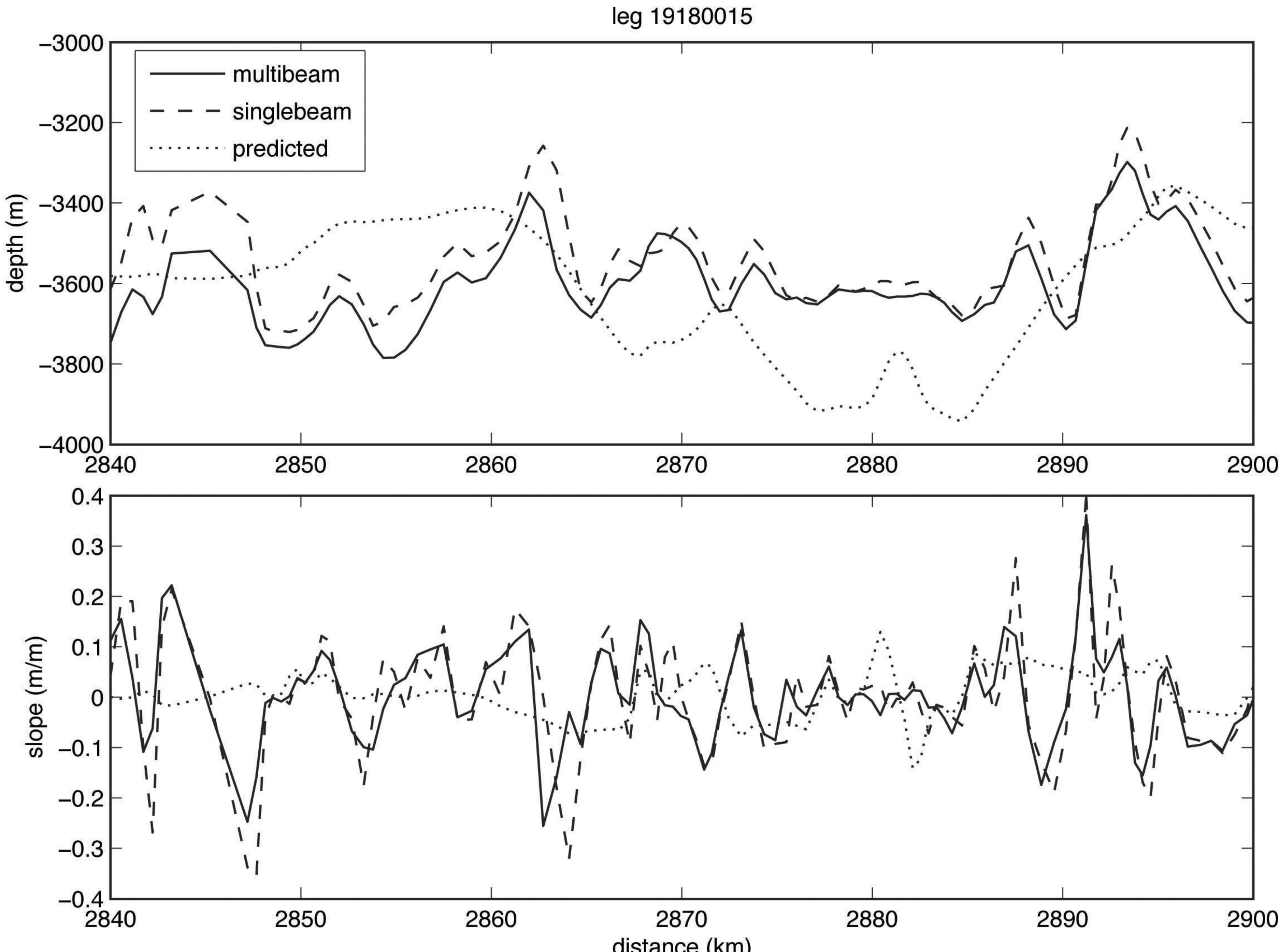
- Multibeam is “ground truth”
  – limited to a few interesting locations
- Predicted Bathymetry is global
  – low pass filtered around 20 km wavelength
- Ship data is global
  – tracks are not uniformly distributed
  – pings unequally spaced along track with a broad spectrum, (~1km/ping typical)

# Global Ship Track Distribution

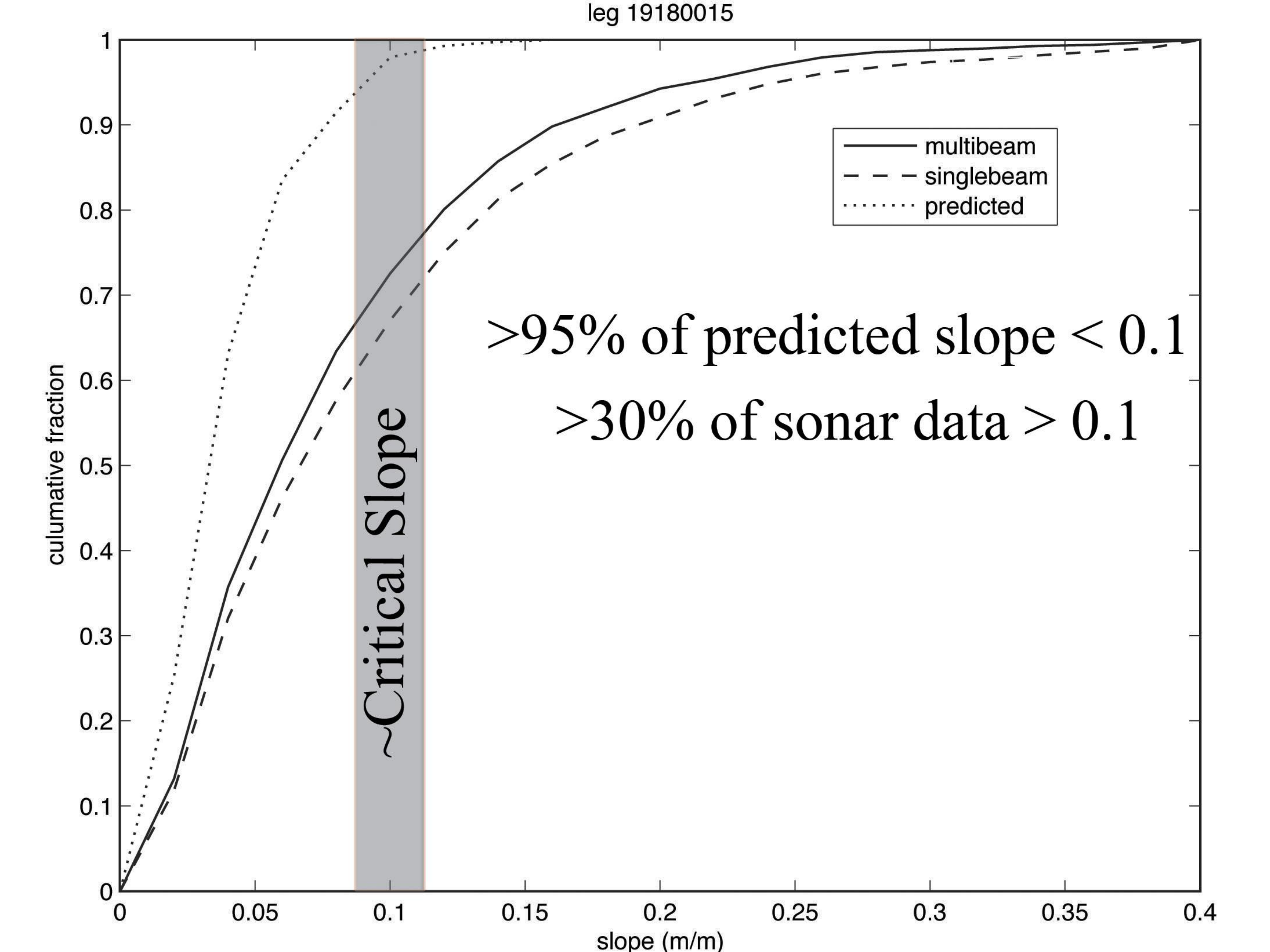


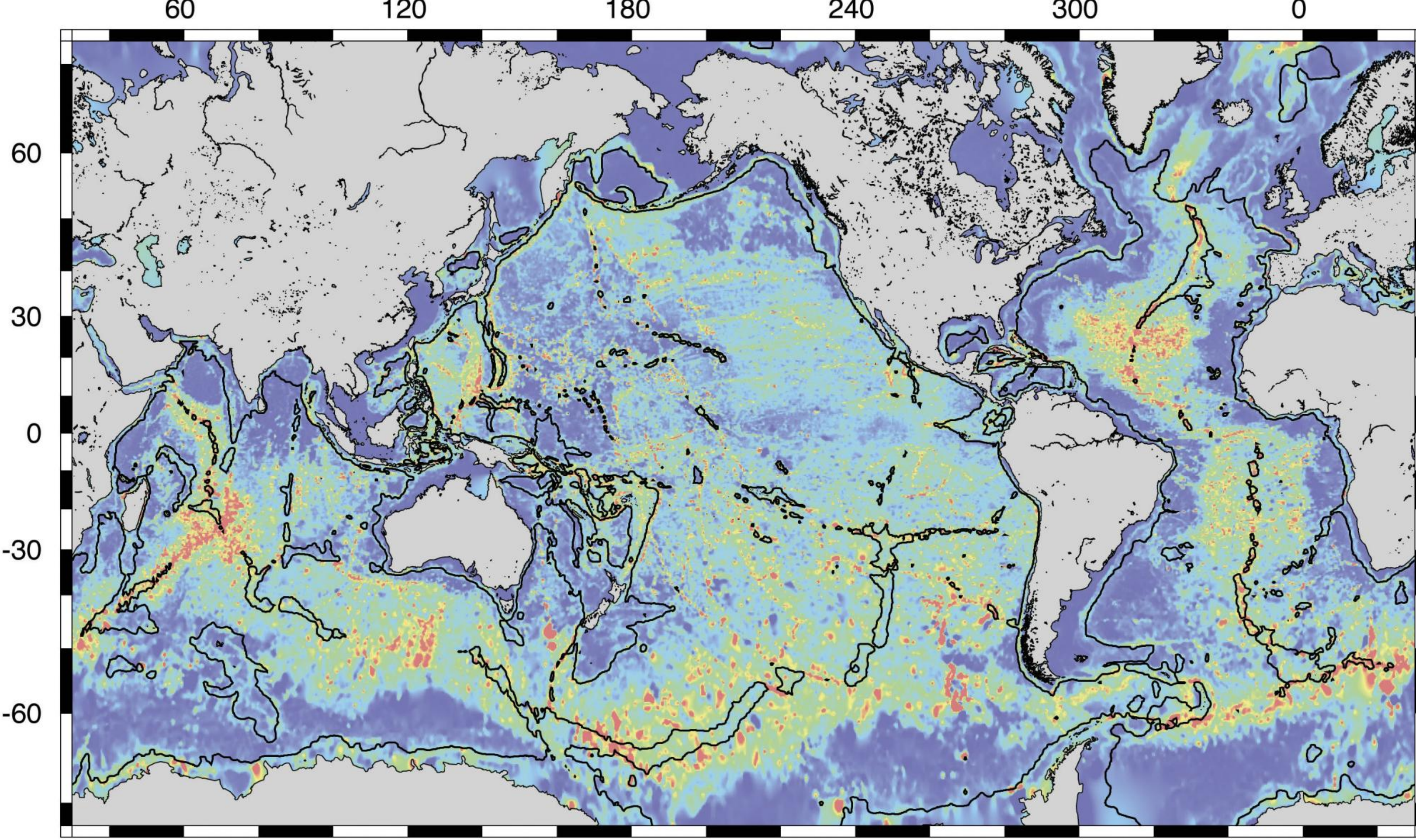
# Mid Atlantic Ridge Black - single beam Red- multibeam



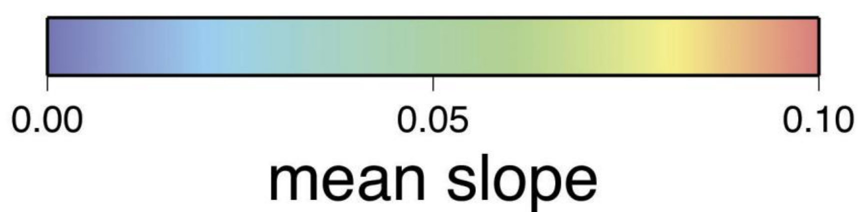


leg 19180015
multibeam
singlebeam
predicted
depth (m)
−3000
−3200
−3400
−3600
−3800
−4000
2840
2850
2860
2870
2880
2890
2900
slope (m/m)
0.4
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
−0.4
distance (km)


leg 19180015
multibeam
singlebeam
predicted
~Critical Slope
>95% of predicted slope < 0.1
>30% of sonar data > 0.1
culumative fraction
slope (m/m)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0.05
0.15
0.25
0.35




**Mean Slope From Ship Tracks**

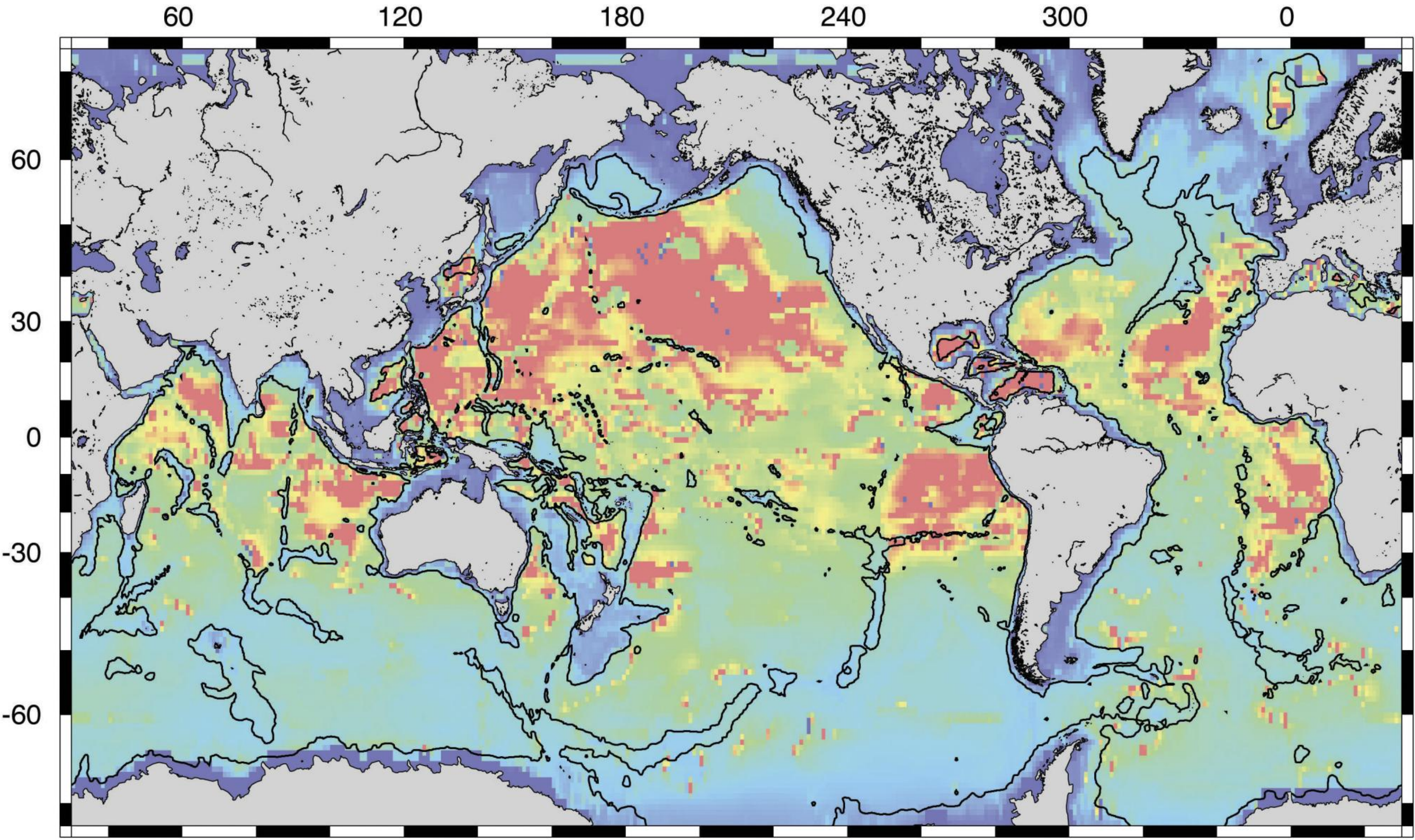


# Critical Slope Model

- Buoyancy frequency “N”
- $N^2$ = -g/❒ ⌧ d❒/dz
- Fit $N^2$ to exponential WOA2001 (“Levitus”) model nodes (CSIRO Matlab routines)
- Assume ◆ of $M_2$ tide (~12 hour period)

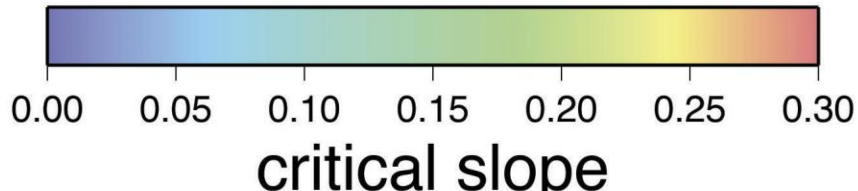
  ♋$^2$ = (◆$^2$ – $f^2$)/($N^2$ – ◆$^2$)

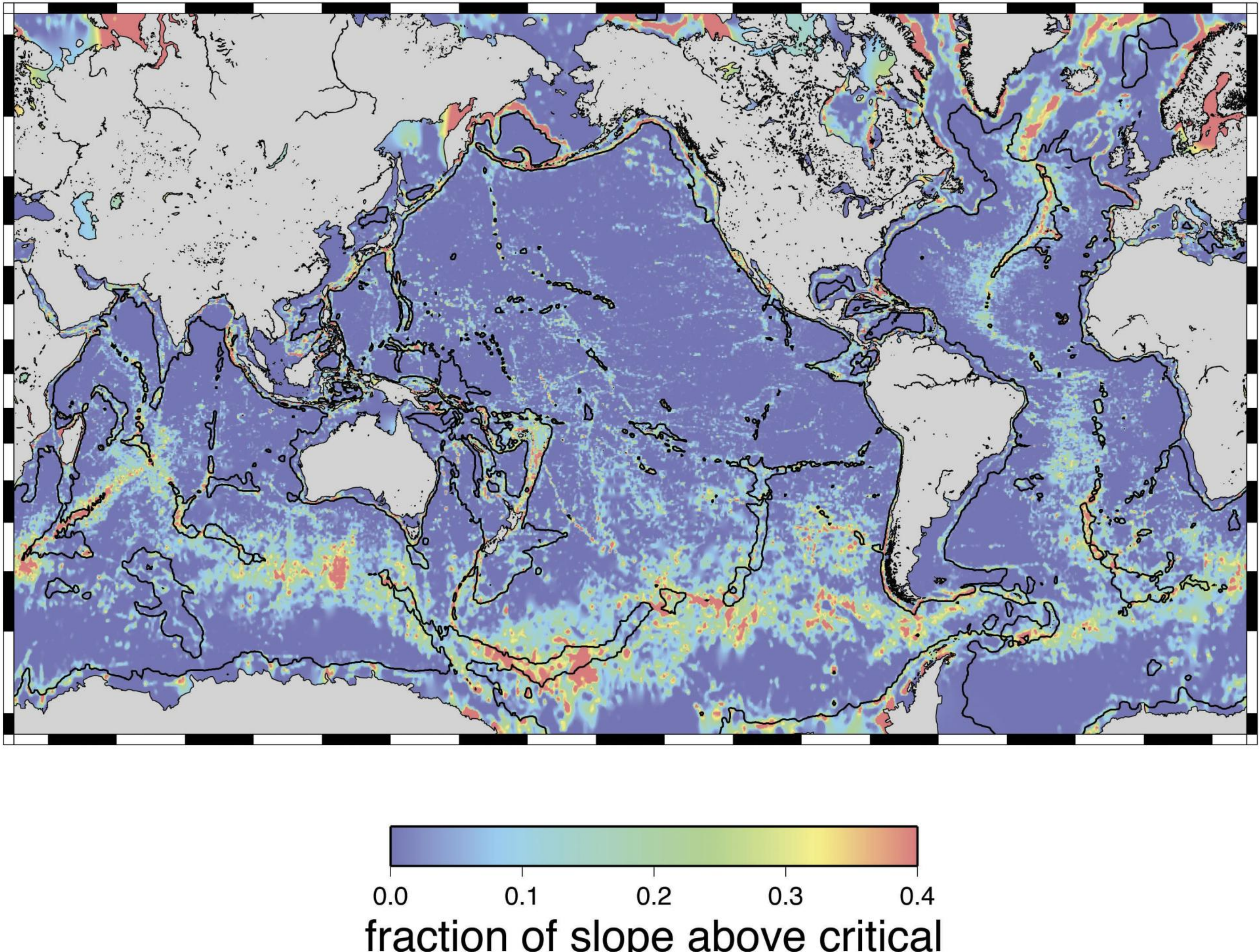
  ♋ ~ ◆ 📪 N ~ 0.1




**Fit Levitus and Extrapolate to Bottom**

- **Asymmetric at ridges**
- **Depth dependent**

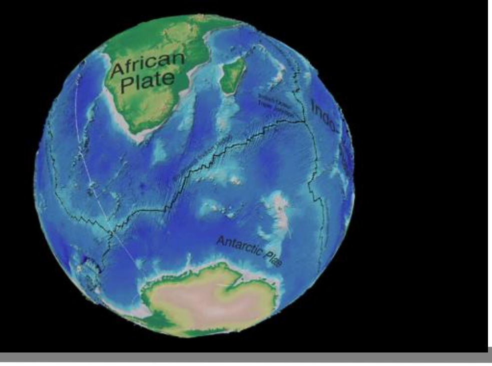




60
120
180
240
300
0
60
30
0
-30
-60
0.0
0.1
0.2
0.3
0.4
fraction of slope above critical

# Conclusions

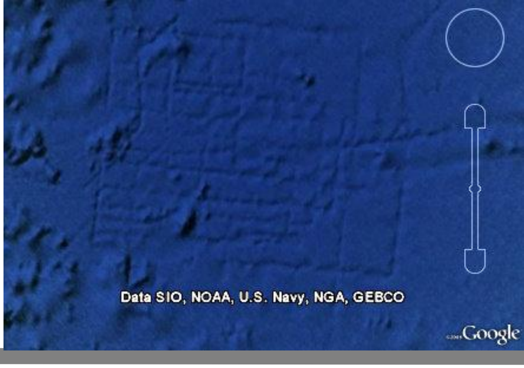
- **Bottom of ocean has large area of slope > 0.05**
- **Predicted depth poor measure of seafloor slope**
- **Global variability in seafloor slope depends on spreading rate, sediment thickness**
- **Significant tidal mixing in Southern Ocean given the critical slope distribution??**
- **1-D sampling of a 2-D surface underestimates slope by 50%**
- **Need to convolve slope models with tidal flow [e.g., Nycander, 2005]**




# Atlantis Discovered on the Abyssal Plain?

David T. Sandwell

SWSU March 5, 2010




- Current bathymetry resolution worse than 10 km
- Atlantis discovered?
- Global gravity and bathymetry
- Discoveries from non-repeat altimeters (Geosat and ERS-1)
- Seafloor roughness and deep ocean mixing
- **CryoSat - 2**

# New science from < 1 μrad mission

**Oceanography -** Determining the effects of bathymetry and seafloor roughness on ocean circulation, mixing, climate, and biological communities, habitats, and mobility.

**Marine Geology and Geophysics -** Understanding the geologic processes responsible for ocean floor features unexplained by simple plate tectonics, such as abyssal hills, seamounts, microplates, and propagating rifts.

**Hazard** - Improving tsunami hazard forecast accuracy by mapping the deep ocean topography that steers tsunami wave energy.

**Navigation -** Mapping the marine gravity field to improve inertial navigation and provide homogeneous coverage of continental margins.

**Applications -** Providing bathymetric maps for numerous other practical applications, including reconnaissance for submarine cable and pipeline routes, improving tide models, and assessing potential territorial claims to the seabed under the United Nations Convention on the Law of the Sea.

# Mission Requirements

- **Slope accuracy** - Better than 1 microradian over a 6 km horizontal distance.
- **Spatially uniform coverage and accuracy -** Complete spatial coverage (6 km resolution) with spatially uniform accuracy is required.
- **Moderate inclination** -- Current non-repeat-orbit altimeter data have high inclination and thus poor accuracy of the E-W slope at the equator. The new mission should have an inclination of ~60˚ or 120˚ to improve E-W slope recovery.
- **Near-shore tracking** -- For applications near coastlines, the ability to track the ocean surface close to shore is desirable.
- More information at http://topex.ucsd.edu/concept

**CryoSat-2**

*‘Rockot’ (SS19) Launch, Plesetsk*


*Launch scheduled - ~March 2010*

*CryoSat-2*

# *ESA's Ice Mission*

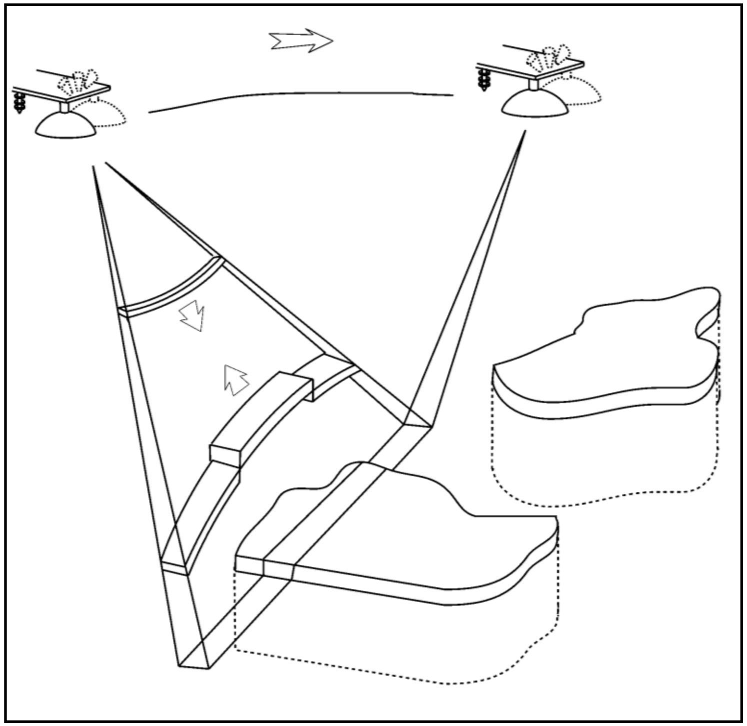
QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

**Mark Drinkwater**

**Mission Experts Division**

**www.esa.int/livingplanet/cryosat**

# SAR Mode

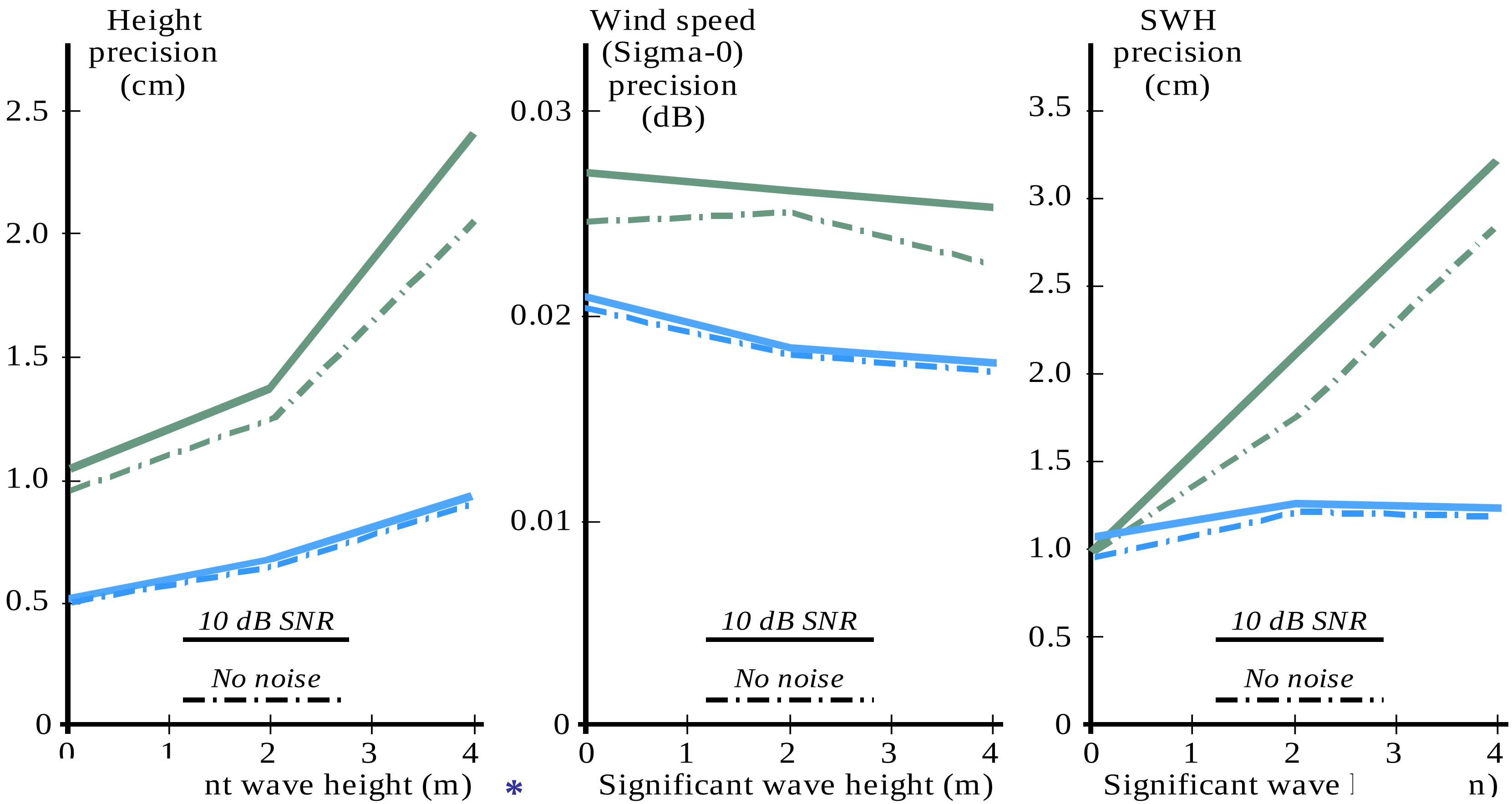


- Synthetic Aperture Radar (SAR) Mode
- Transmits bursts of 64 pulses: sequential echoes are correlated
- Aperture Synthesis technique: overlapping “Doppler beams” superimposed in a narrow 250 m strip - then waveforms coherently averaged
- Satellite moves 250 m between bursts

***Delay-Doppler Altimeter (DDA) vs Conventional:***

# Precision at 1 Hz Rate*♈

*Delay/Doppler ~ x2* ***better*** *than conventional*

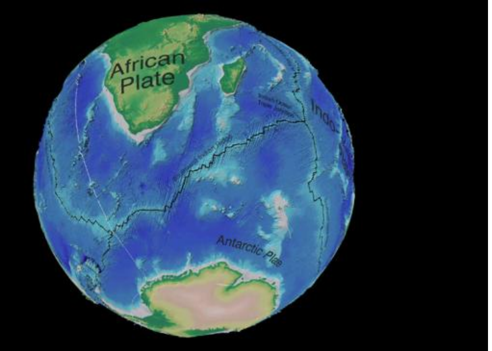



* ♈ *Based on computer simulations*

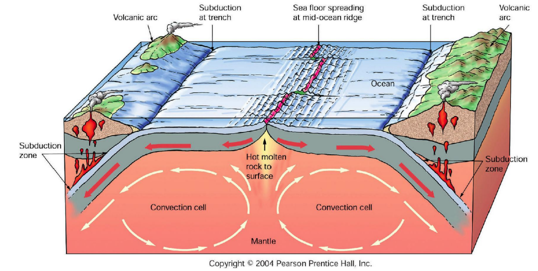
Initatvs\NASA\precisn.wpg

*rkraney*

*Courtesy: J. R. Jensen*




# Conclusions




- 1/2 of the seafloor bathymetry is not resolved at 10 km.
- Non-repeat orbit altimeters (Geosat and ERS-1) have revolutionized Marine Geology and Geophysics
- The topography of the land controls atmospheric circulation, climate and weather.
- The topography of the seafloor controls ocean circulation, tidal flow/vertical stratification, and eddies.
- We need a **complete coverage** altimeter mission to map the ocean basin.

(Google Earth overlays and gridded gravity/bathymetry available http://topex.ucsd.edu)