Submarine Volcanism

Adam Soule, WHOI

Acknowledgement and thanks to: NSF, NOAA OER, WHOI, Meghan Jones, Dan Fornari, Rebecca Carey, Michael Manga, Ken Rubin, James Gardner, Helge Gonnermann, James White, Claire Pontbriand, Sam Mitchell, Kristen Fauria, Alison Fundis, Mike Perfit, Tushar Mittal, Anna Michel, Einat Lev, Hannah Dietterich, and many more.


Your face here!

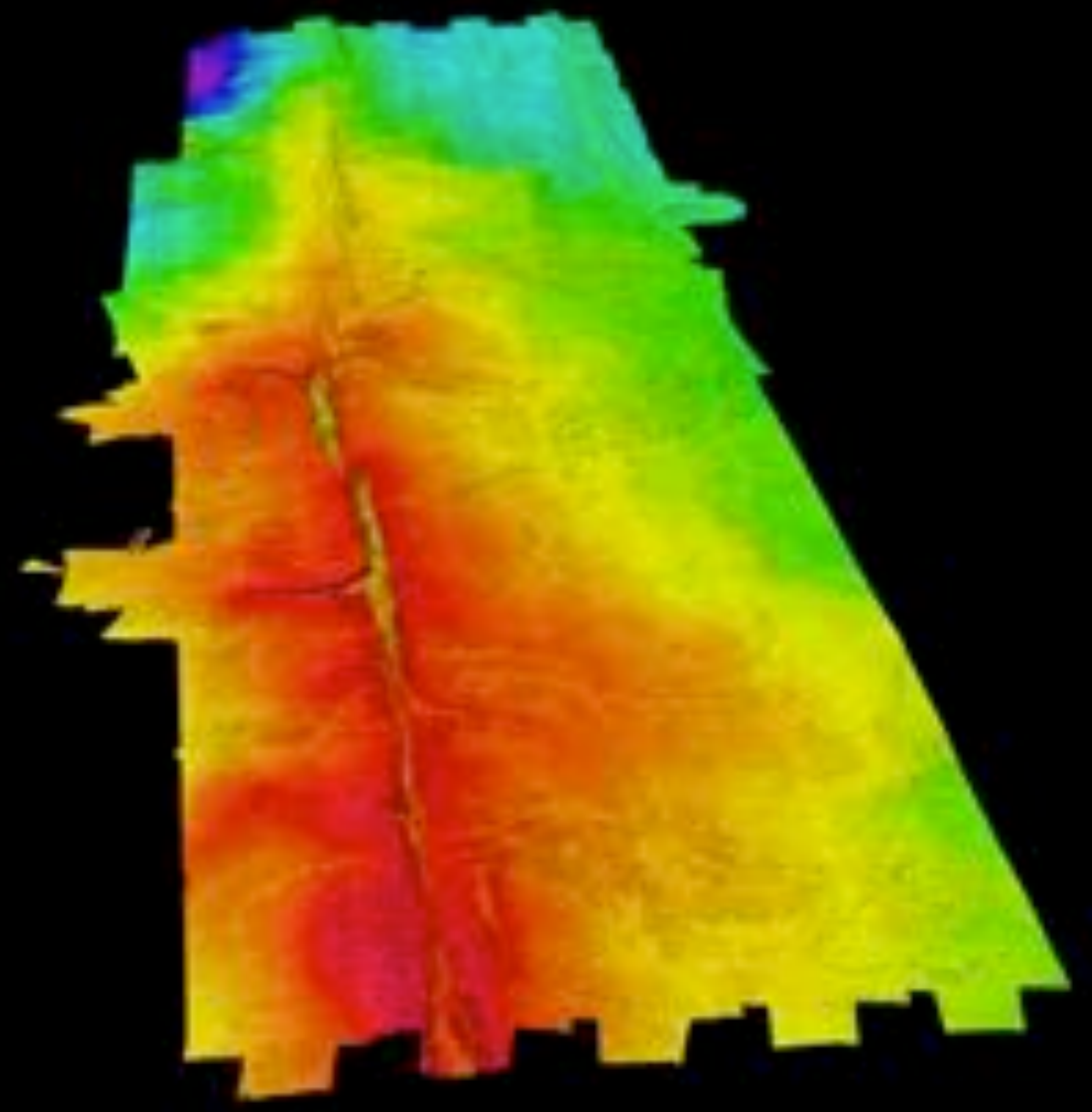
Outline

1. **Global submarine volcanism**
    - Significance
    - Relative volumes to subaerial
    - Accessing the deep ocean

2. **Mid-ocean ridges**
    - Magma supply
    - Eruption style/recurrence
    - Constraining dynamics

3. **Submarine Arcs**
    - Explosive? processes
    - Dispersal and deposition

East Pacific Rise Axis, 2500 mbsl



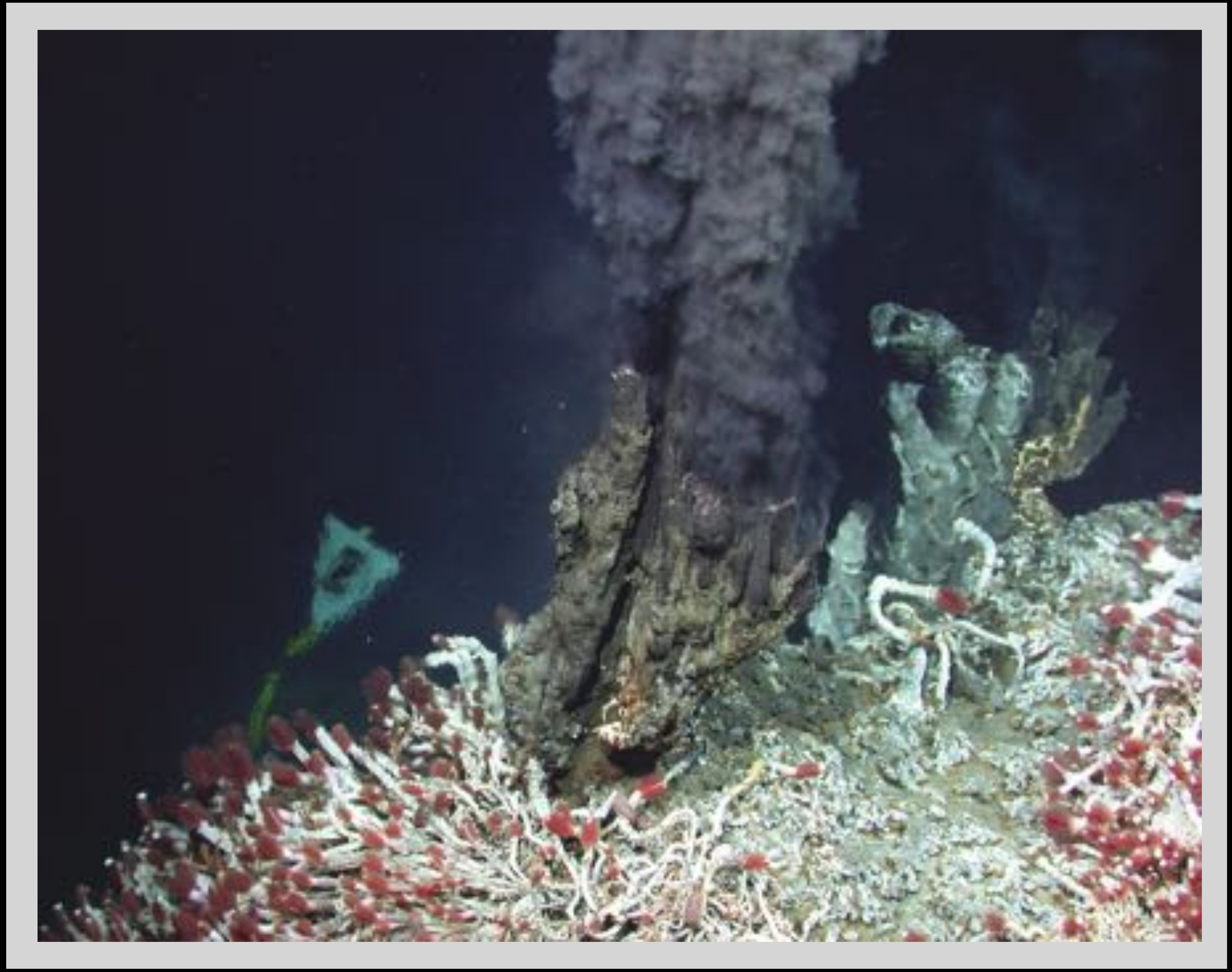
Significance of Submarine Volcanism (associated processes):

- Biological diversity, origins of life, extra-terrestrial life, pharmaceuticals.

- Mineral resources - VHMS, Cobalt crusts

- Global-scale chemical cycling and biogeochemical processes: fertilization of photic zone, flux from hydrothermal systems

- Model systems that can reveal how volcanoes work - a) in some cases simpler, b) can isolate behavior under unique conditions (e.g., thin crust, hydrostatic pressure, eruption into water).



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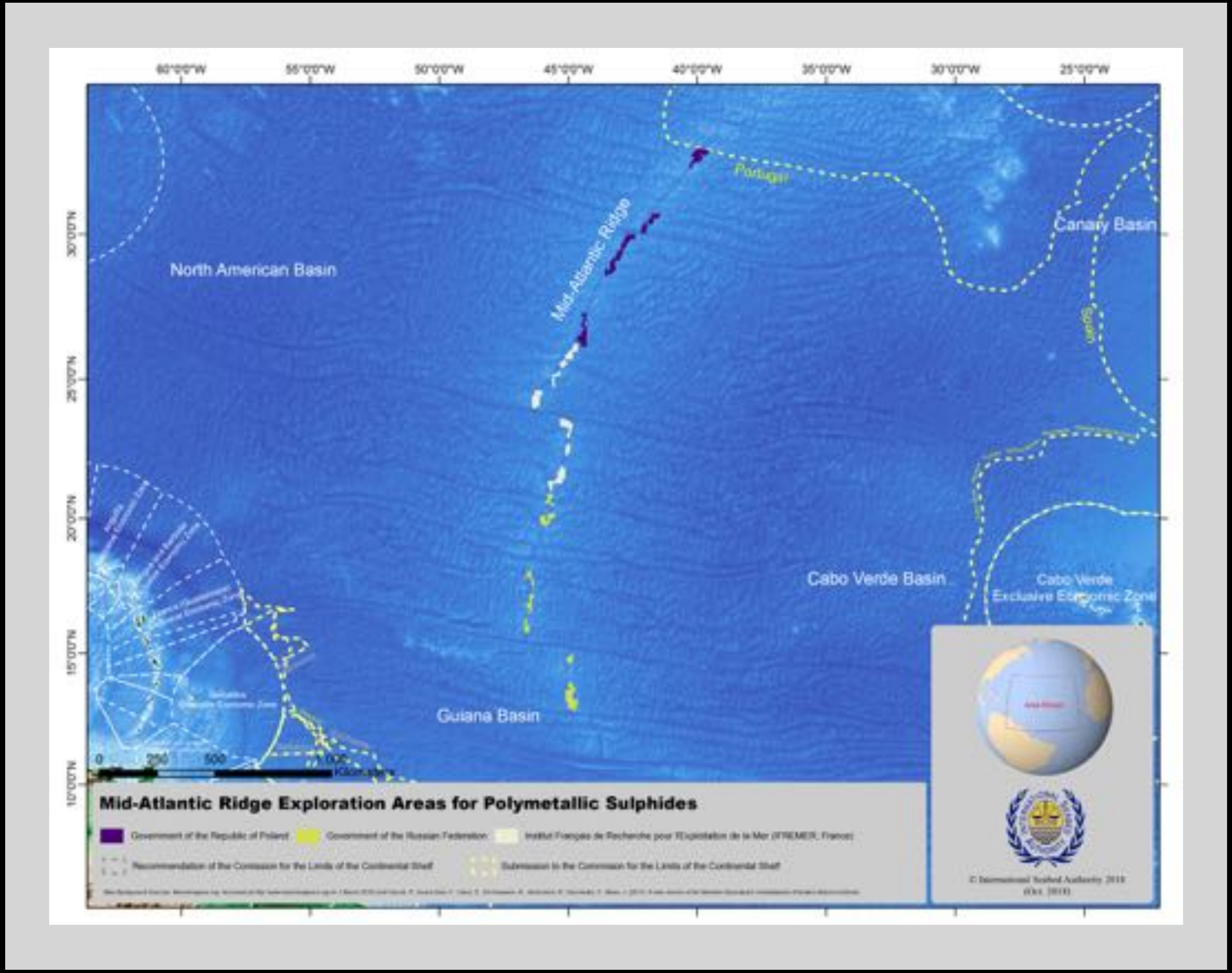

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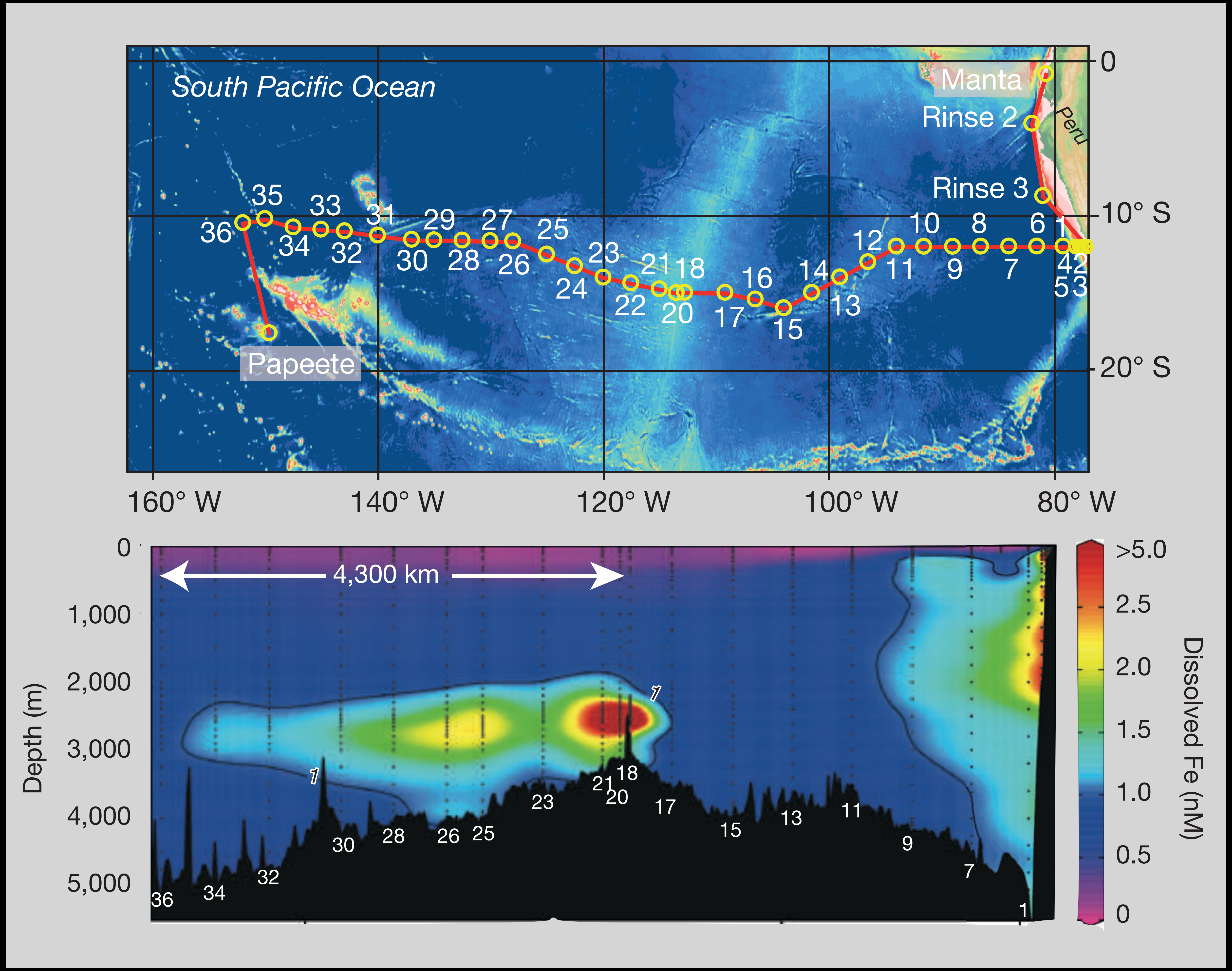
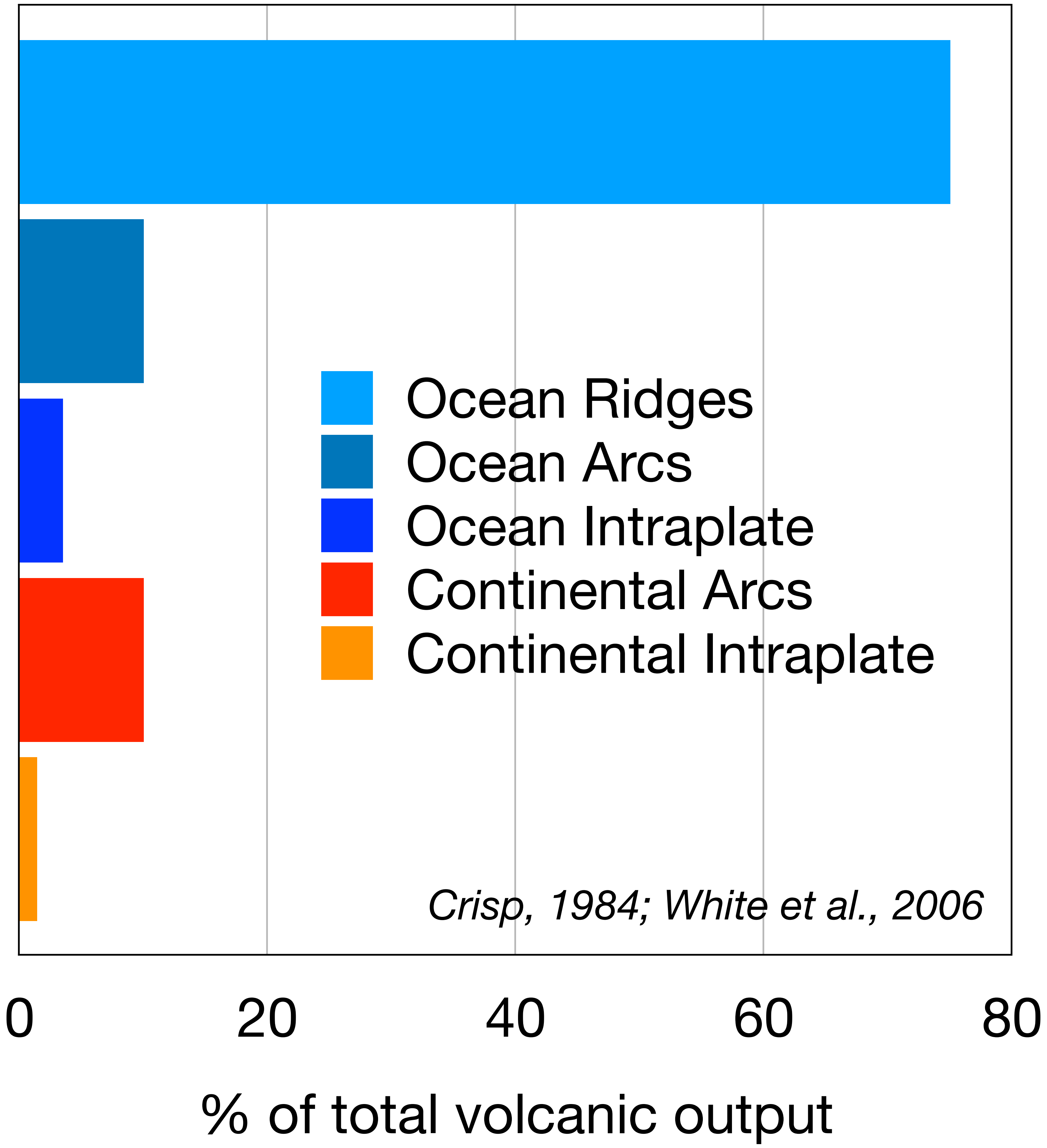
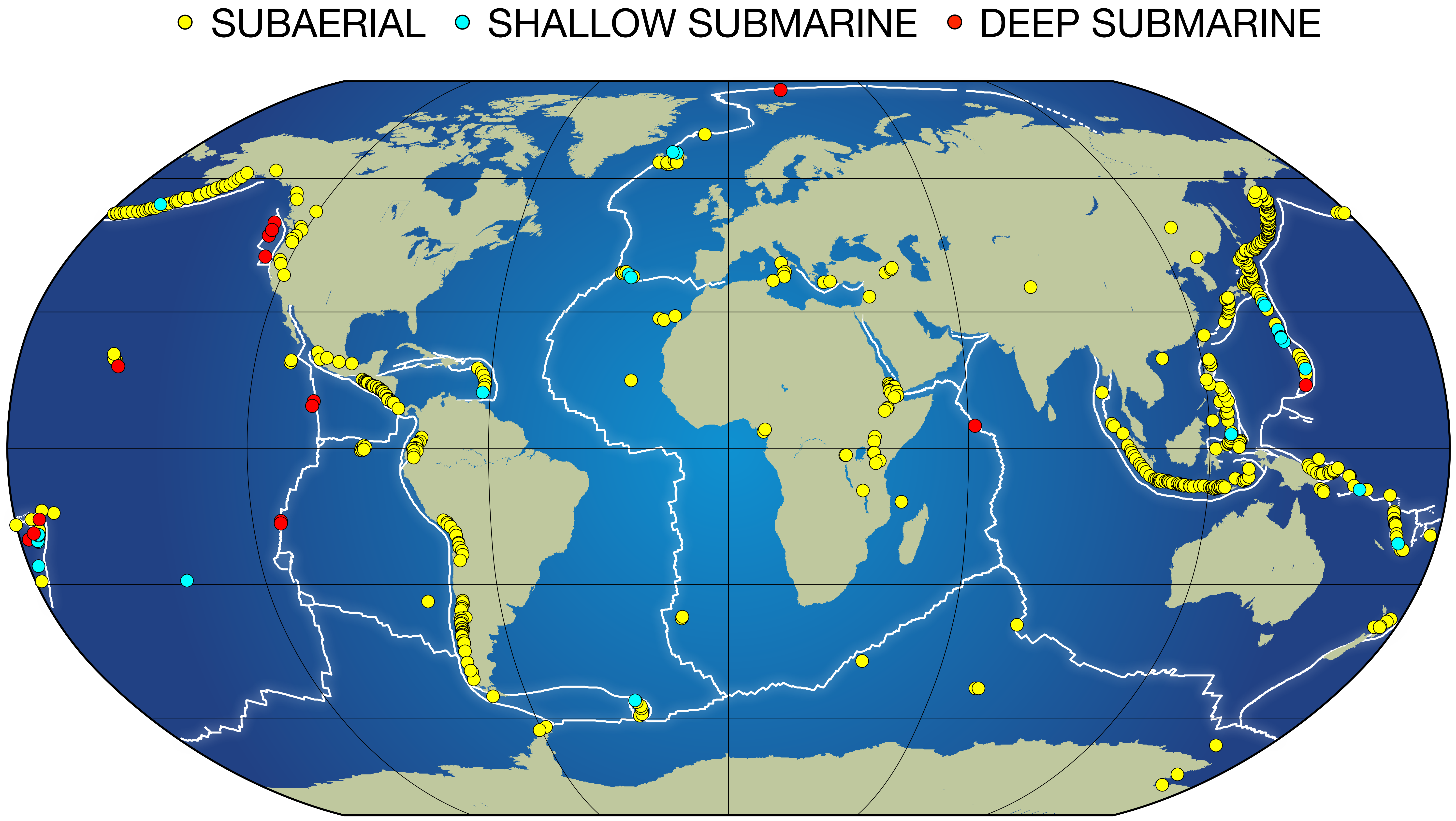


Resing et al., 2015

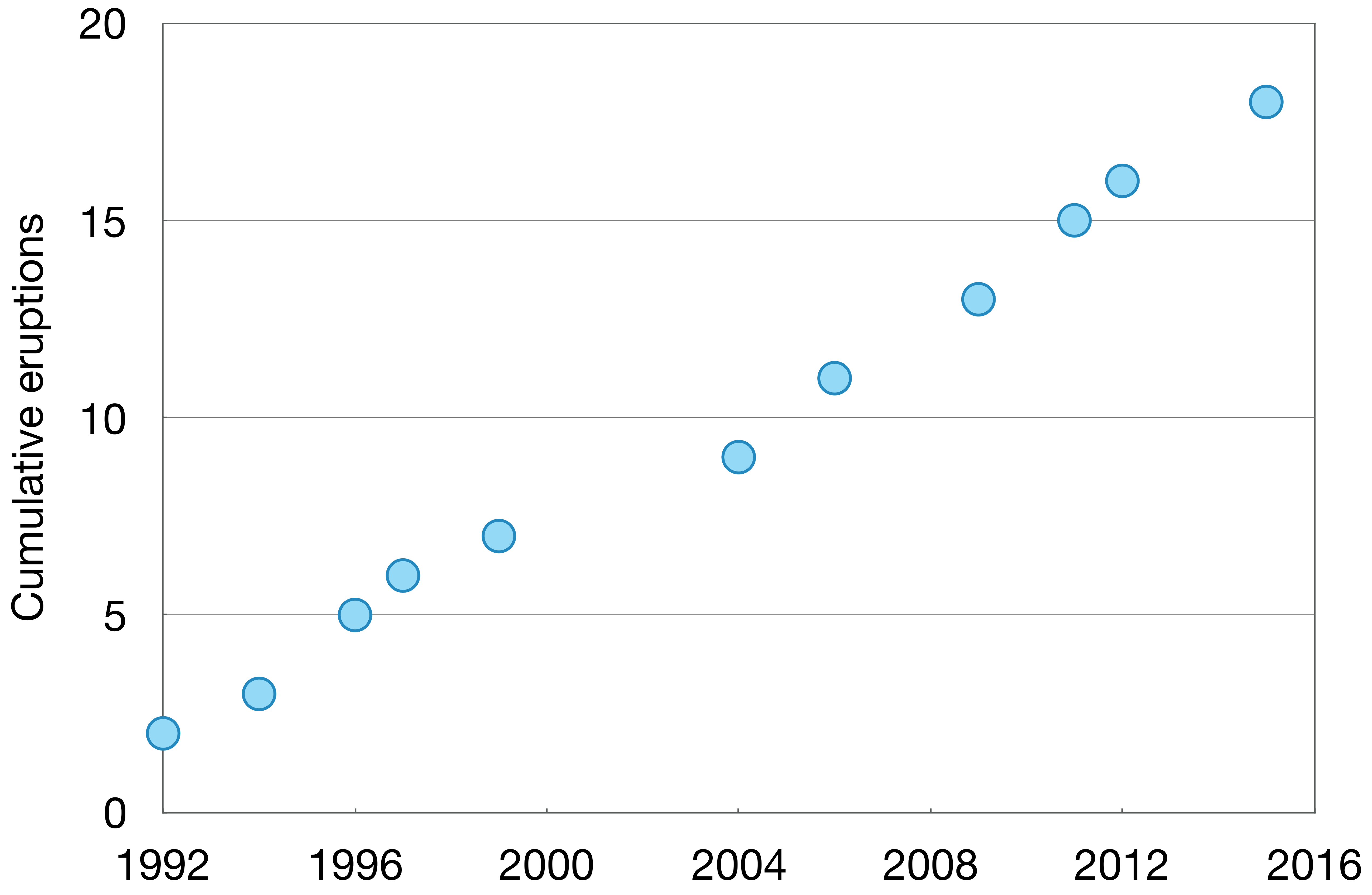
Oceanic vs. Continental Magmatism





Over 75% of the Earth's volcanism occurs within the oceans, but only 0.2% of the confirmed eruptions of the last 50 (N = 1776) years are submarine.

Number of confirmed eruptions



West Mata Eruption (1100 mbsl)

Resing et al., 2011

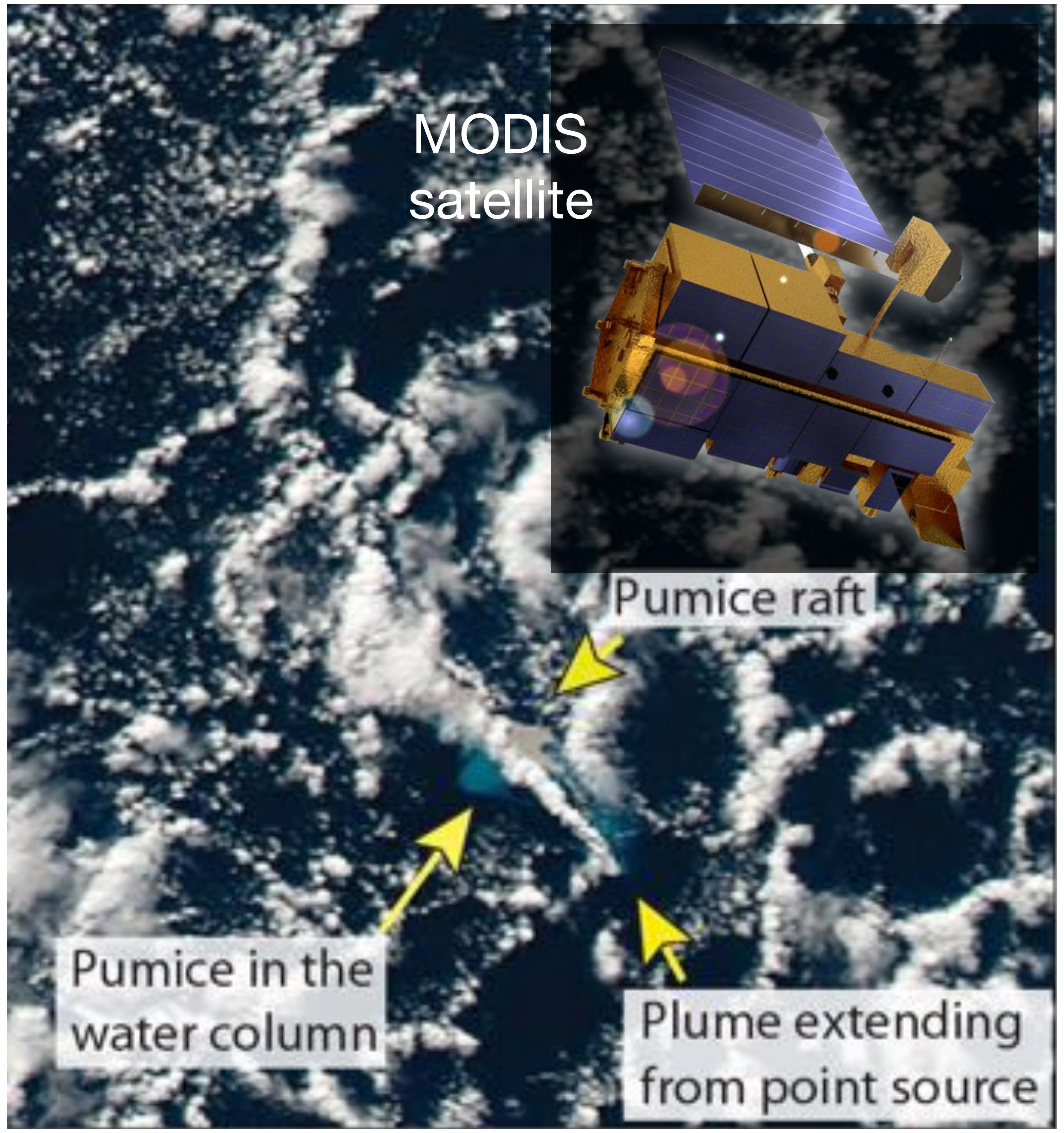
Despite tremendous advances in technology, *most* detected seafloor eruptions are discovered by serendipity rather than via monitoring.

Deep thought #1

Is our assessment of the relative proportions of subaerial and submarine volcanism correct, and can we better monitor the oceans at a global scale to identify the location, timing, and size of submarine eruptions.

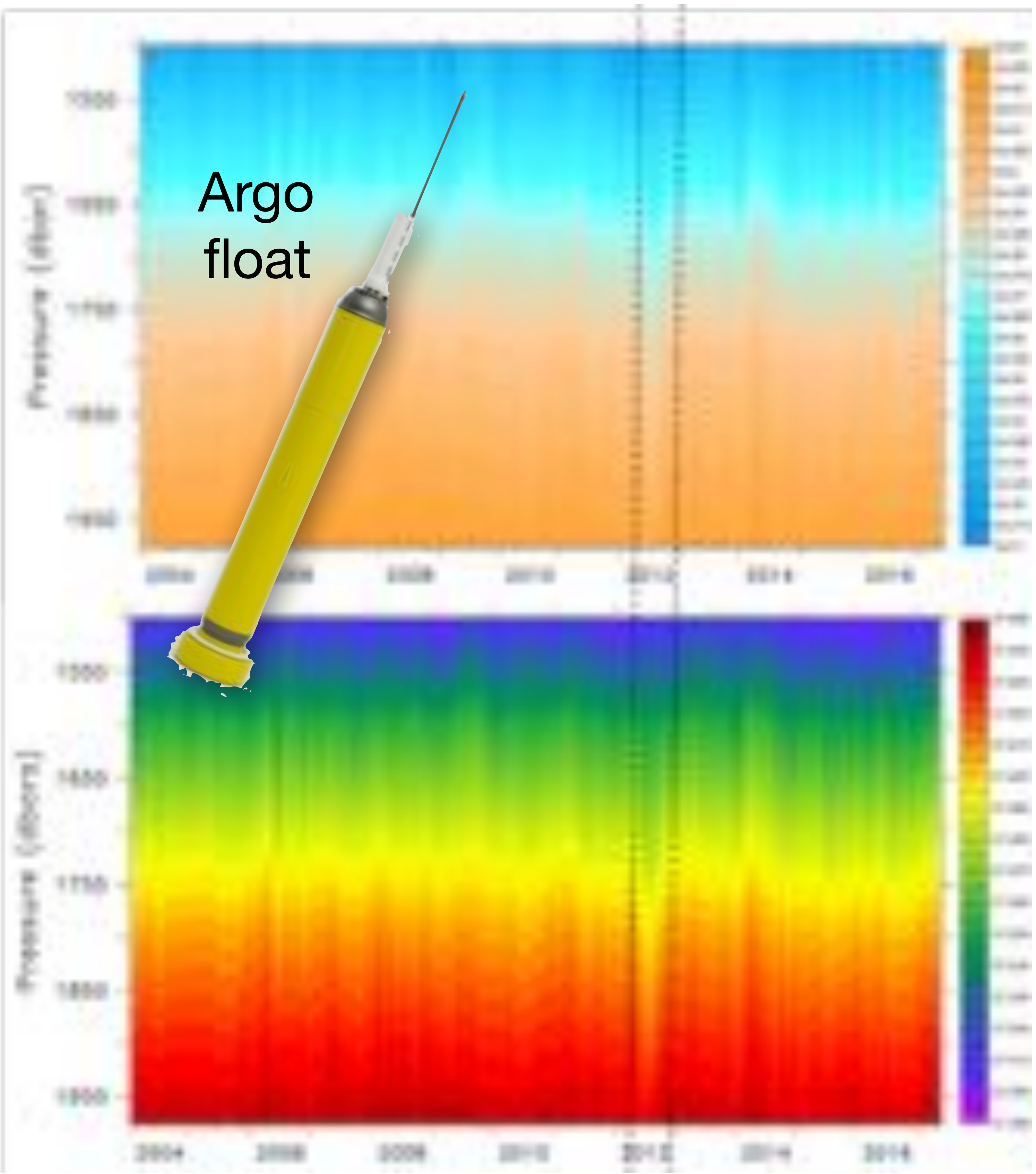
Can we monitor the ocean's volcanoes?

Sea surface signals
(e.g., pumice rafts, plankton blumes)



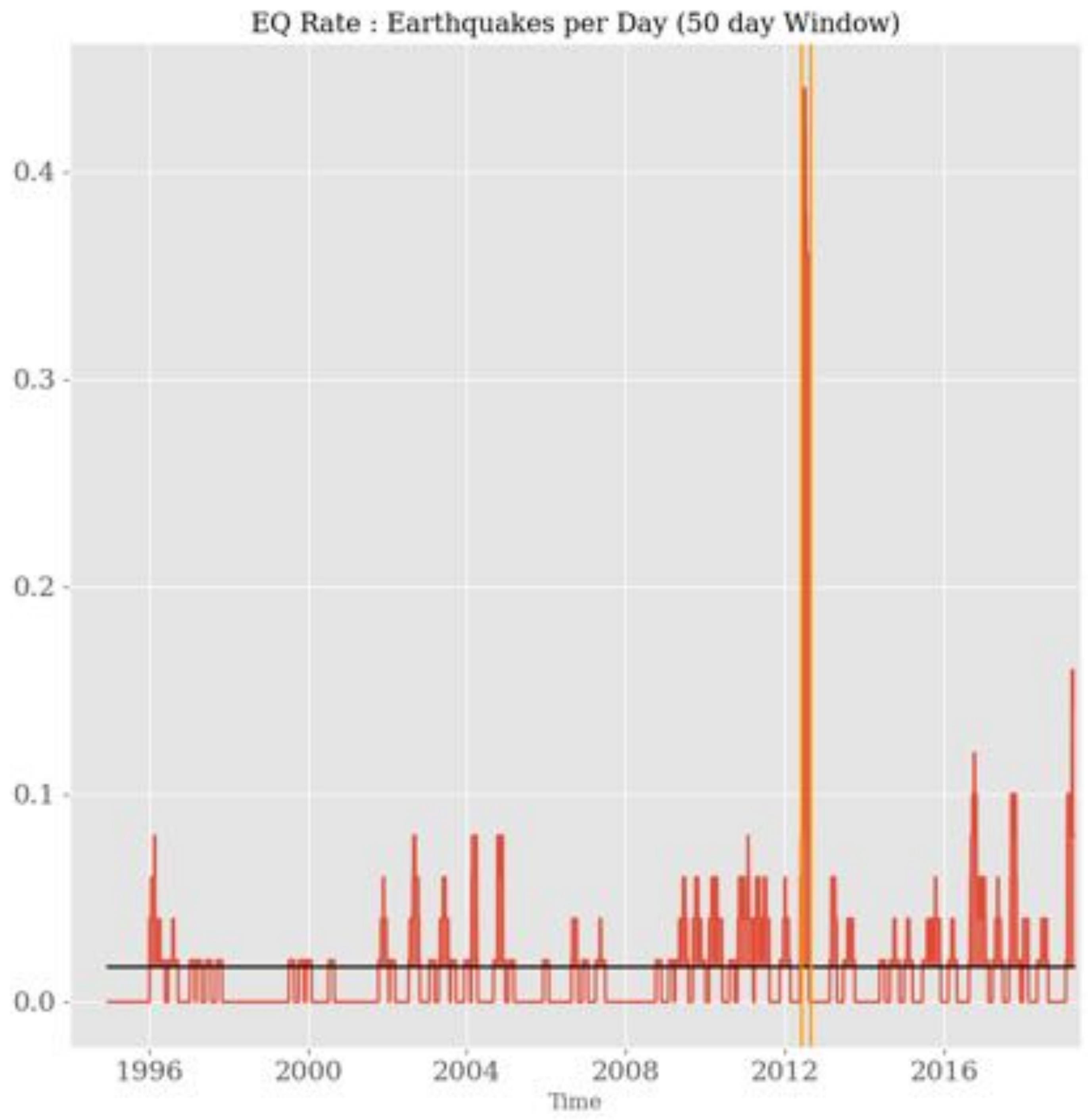
Jutzeler et al., 2014

Water column signals
(e.g., hydrothermal discharge)



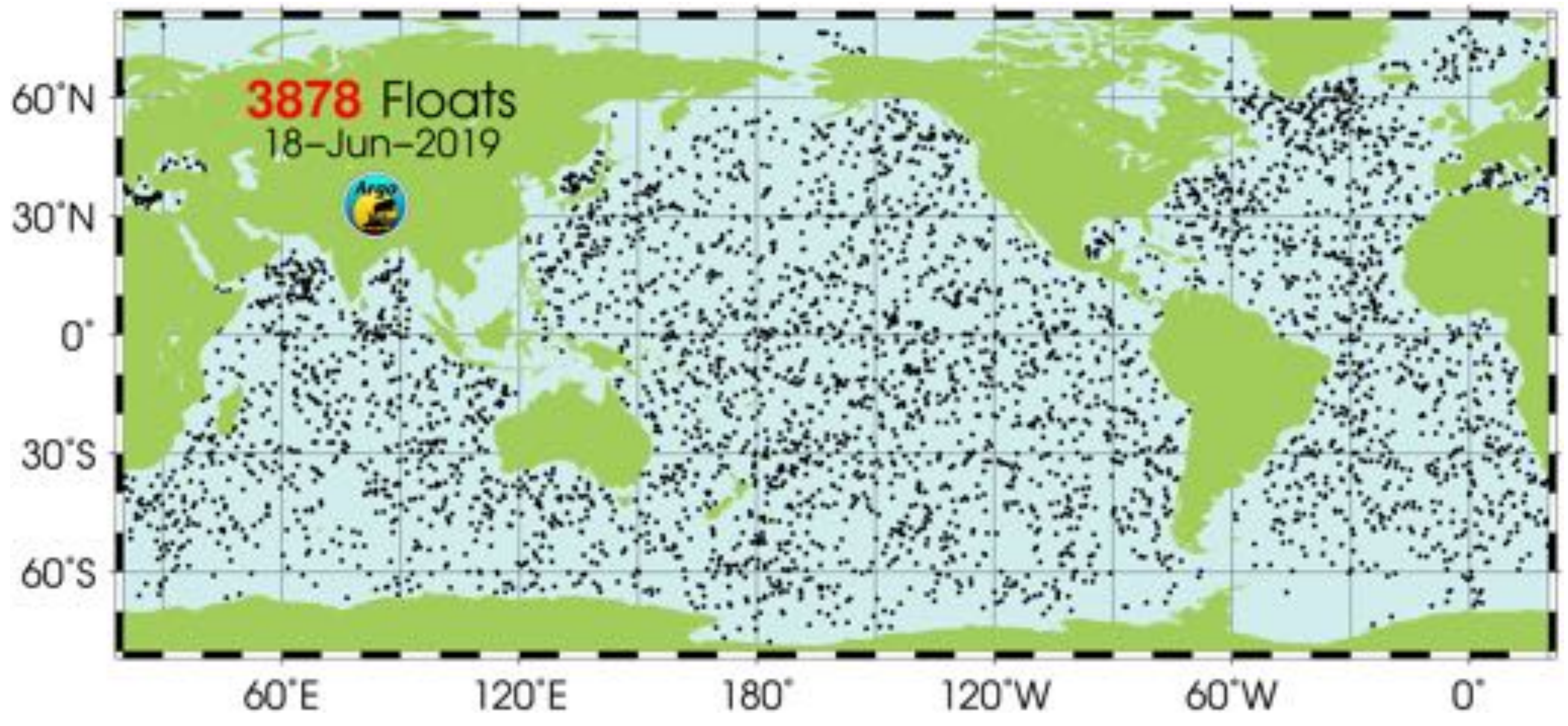
Mittal & Delbridge, 2019 - EPSL

Ocean crust signals
(e.g., volcano seismicity)



Mittal & Delbridge, 2019 - EPSL

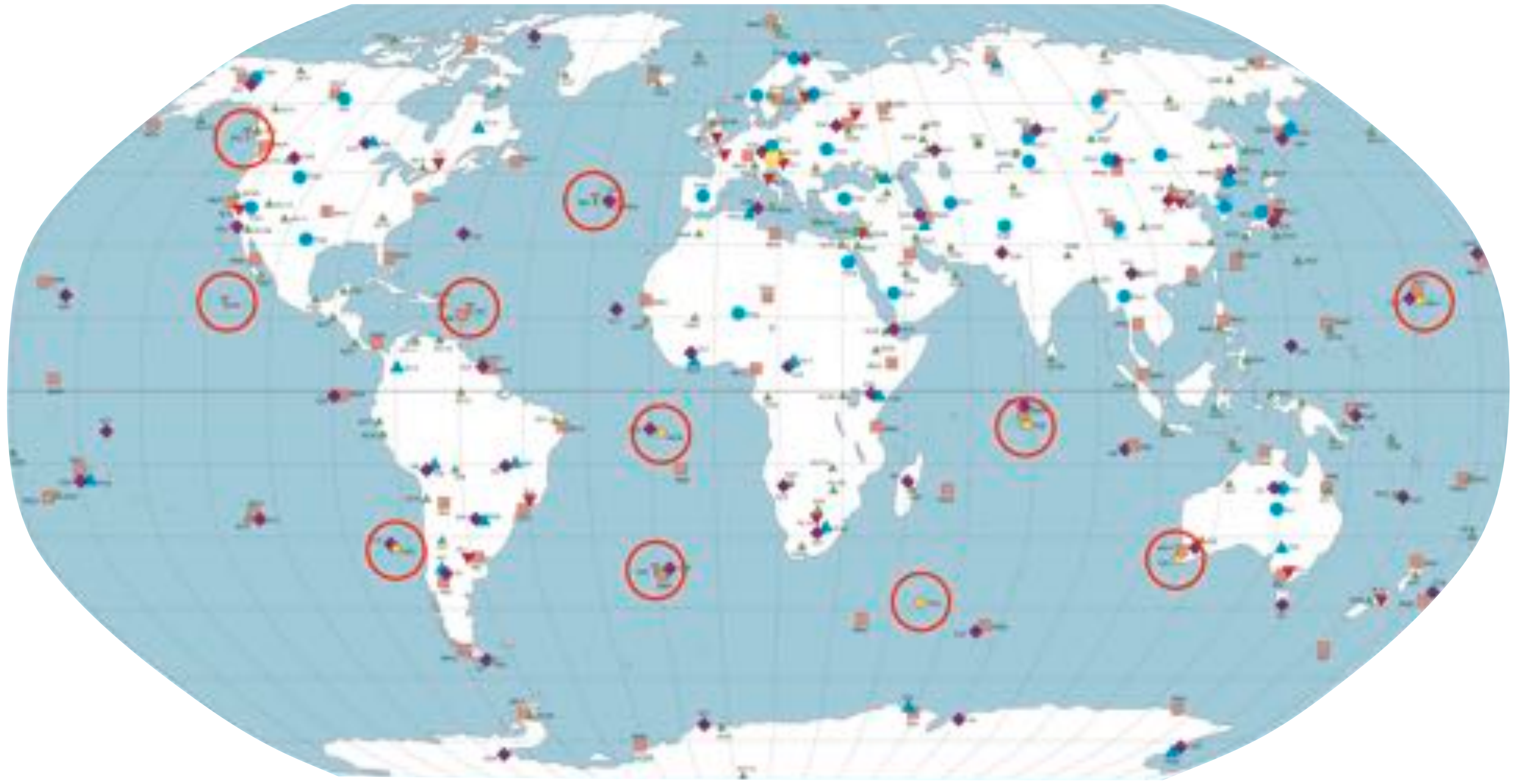
ARGO Network



Global Seismic Network

Global Satellite Coverage

Global Hydrophone Array (CTBT)



Data/Sample Repositories

http://marine-geo.org (Marine Geological & Geophysical Data)

http://www-udc.ig.utexas.edu/sdc/ (Academic Seismic Portal)

https://www.earthchem.org/petdb (Petrological Database)

https://www2.whoi.edu/site/seafloorsampleslab/ (WHOI physical samples)

https://www.ldeo.columbia.edu/core-repository (LDEO physical samples)

http://osu-mgr.org (Oregon State Physical Samples)

https://www.bco-dmo.org (Biological & Chemical Oceanography Data)

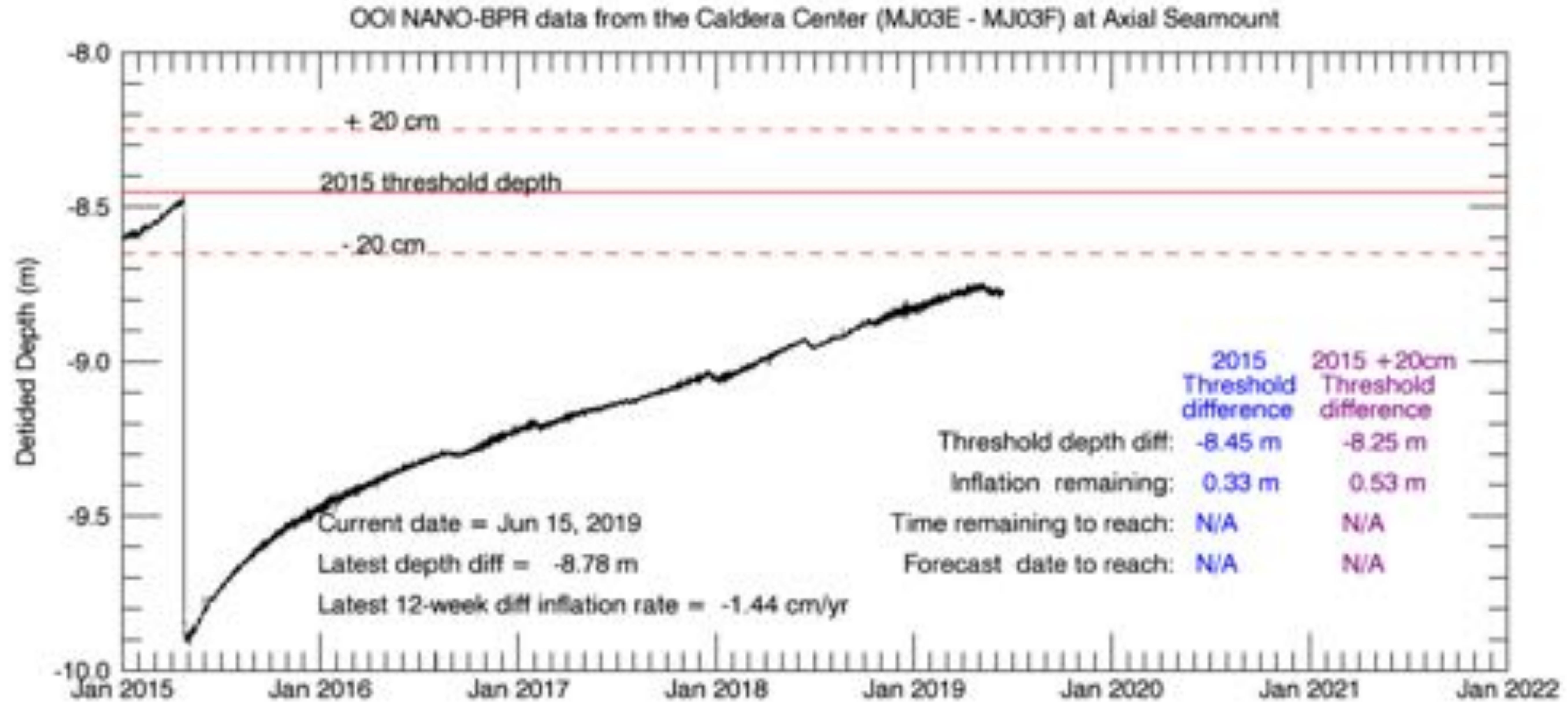
http://4dgeo.whoi.edu/alvin or /jason (Alvin & Jason seafloor imagery)

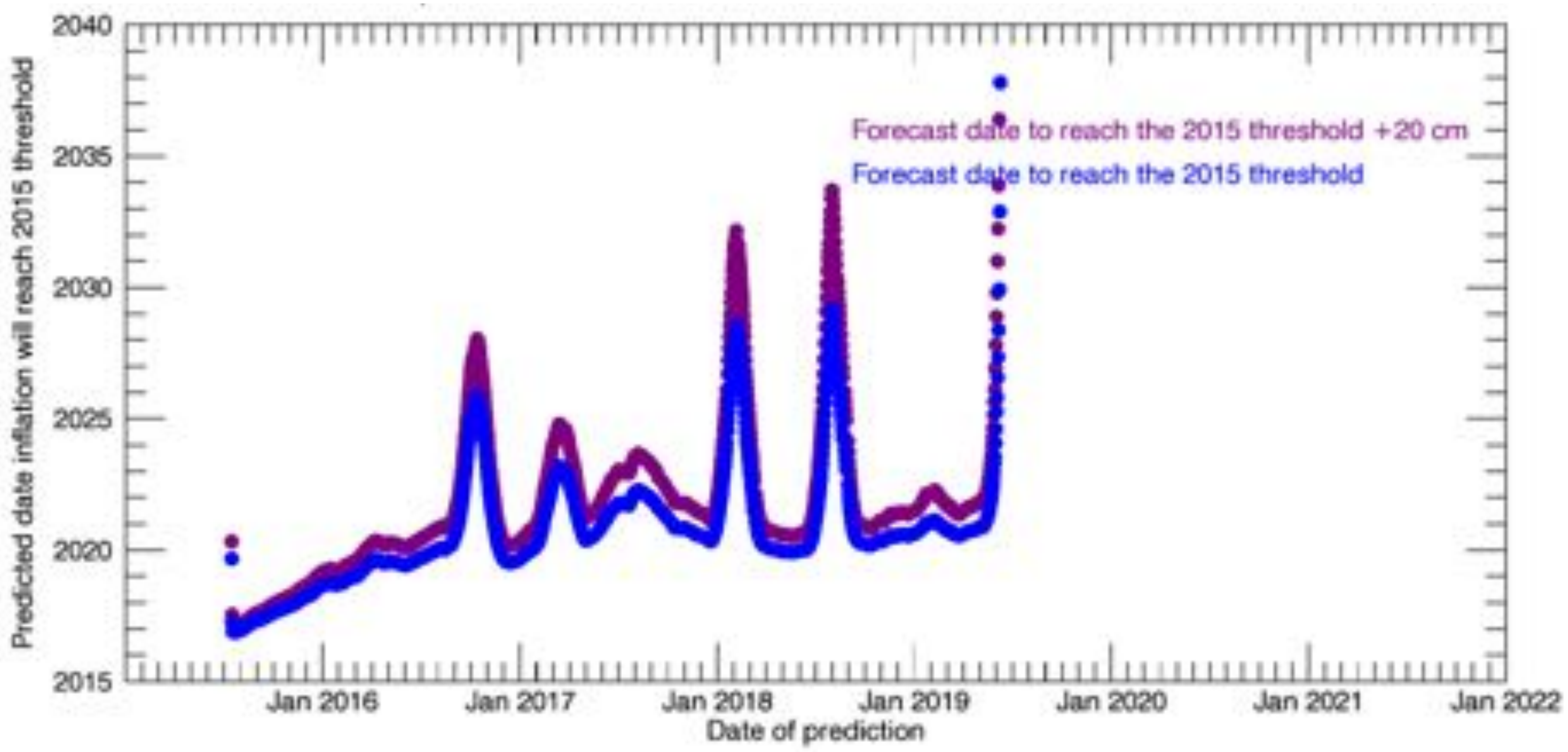
http://app.iedadata.org/ndsf/dives/ (NDSF dive metadata)

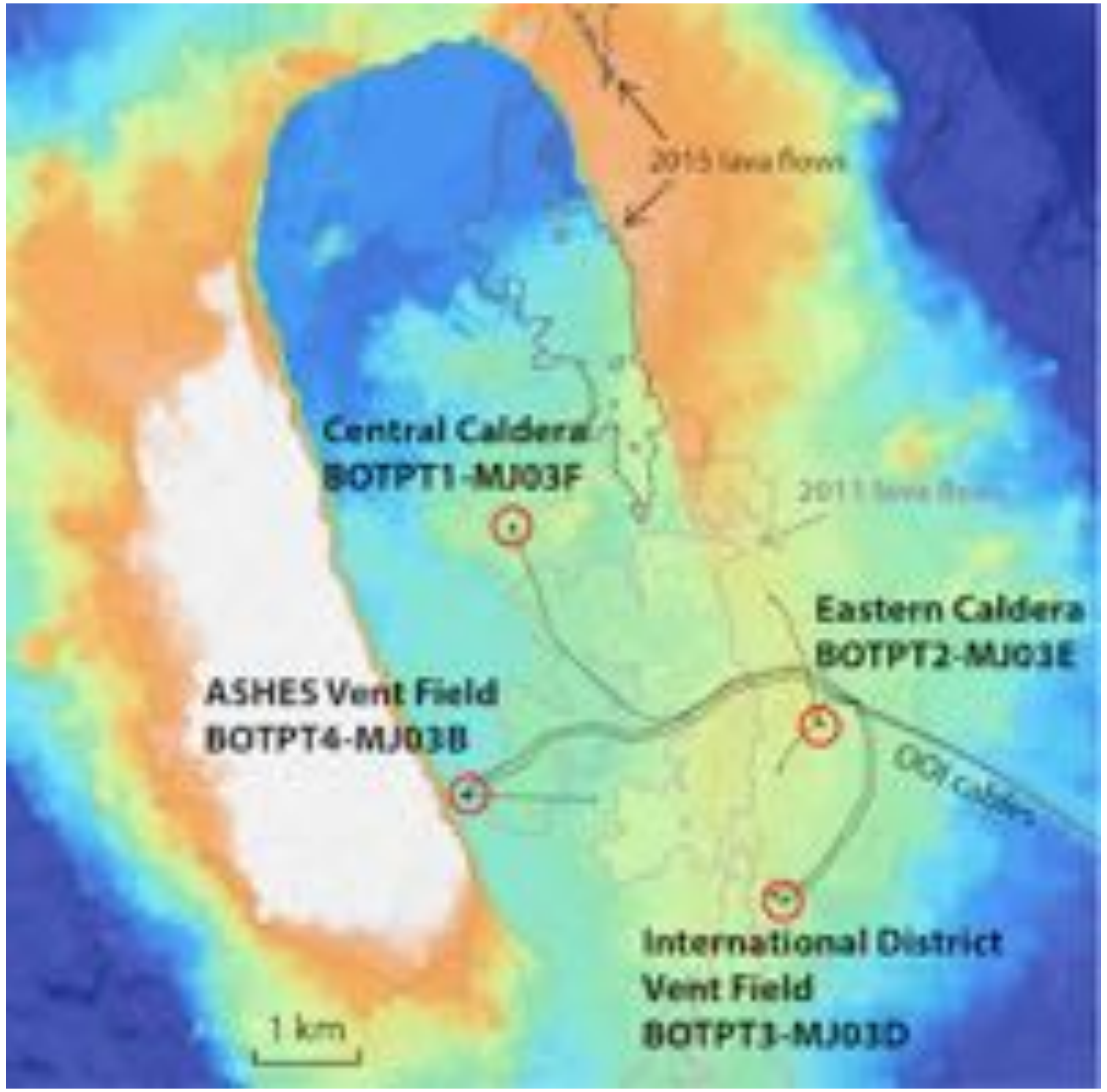
Smith and Sandwell (1997)


Cabled Axial Seamount PN3B
Central Caldera (RS03CCAL)
Medium-Power JBox (MJ03F)
Bottom Pressure and Tilt
Broadband Seismometer
Low Frequency Acoustic Receiver (Hydrophone)
Short-Period Ocean Bottom Seismometer
Eastern Caldera (RS03ECAL)
Medium-Power JBox (MJ03E)
Bottom Pressure and Tilt
Broadband Seismometer
Low Frequency Acoustic Receiver (Hydrophone)
Nodes and J-Boxes
Primary Node
Medium Power J-Box
Cable Types
RSN Primary
Medium Power Electro-Optical
Electrical Extension
Short-Period Ocean Bottom Seismometer
ASHES (RS03ASHS)
Medium-Power JBox (MJ03B)
Osmosis-Based Water Sampler
Diffuse Vent Fluid 3-D Temperature Array
Central Caldera
MJ03F
4683 m
1262 m
PN3B
MJ03E
Eastern Caldera
250m
4356 m
4229 m
MJ03B
ASHES
1286 m
Short-Period Ocean Bottom Seismometer
2238 m
2300 m
MJ03C
MJ03D
INTERNATIONAL DISTRICT
HD Digital Video Camera
Short-Period Ocean Bottom Seismometer
International District 1 (RS03INT1)
Medium-Power JBox (MJ03C)
Digital Still Camera
Mass Spectrometer
Hydrothermal Vent Fluid Interactive Sampler
Particulate DNA Sampler
Hydrothermal Vent Fluid In-situ Chemistry
Hydrothermal Vent Fluid Temperature and Resistivity
International District 2 (RS03INT2)
Medium-Power JBox (MJ03D)
Bottom Pressure and Tilt
Short-Period Ocean Bottom Seismometer
3-D Single Point Velocity Meter
1300
2700

Axial Volcano Monitoring

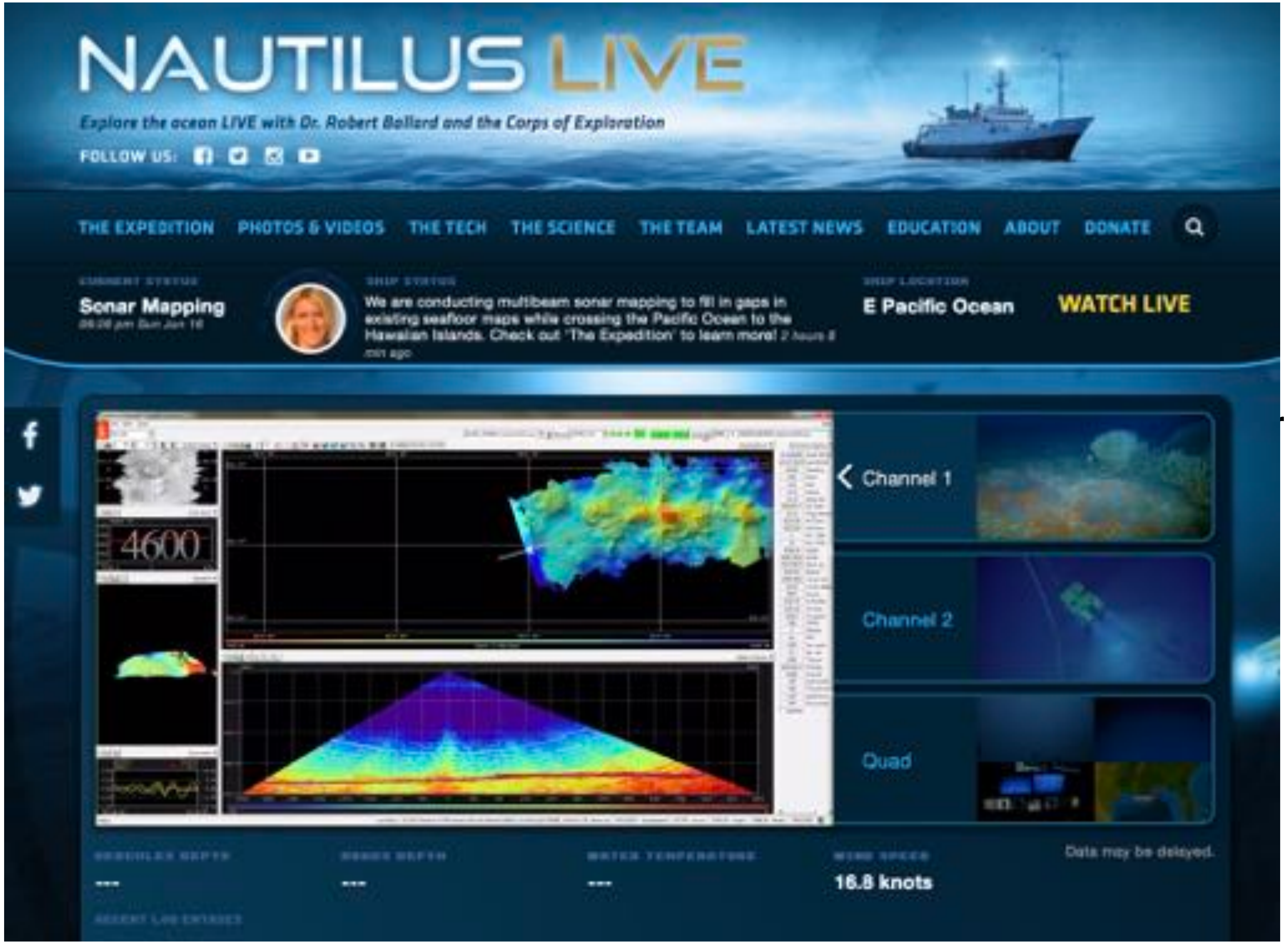






https://www.pmel.noaa.gov/eoi/axial_blog.html

Participate Remotely



www.nautiluslive.org/

schmidtocean.org

SCHMIDT OCEAN INSTITUTE

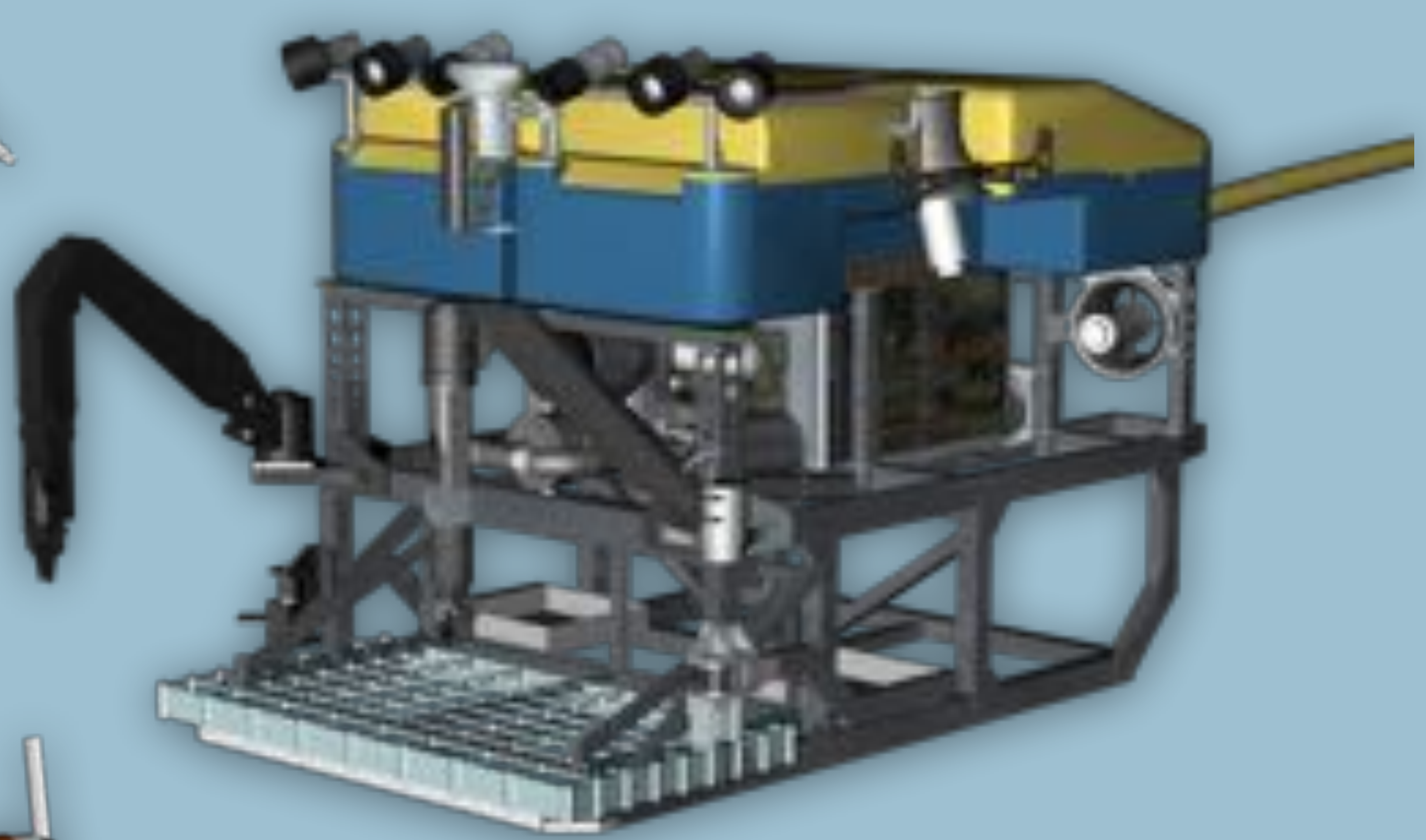
oceanexplorer.noaa.gov/livestreams/

NOAA Ocean Exploration and Research

NDSF NATIONAL DEEP SUBMERGENCE FACILITY

HOV Alvin

ROV Jason



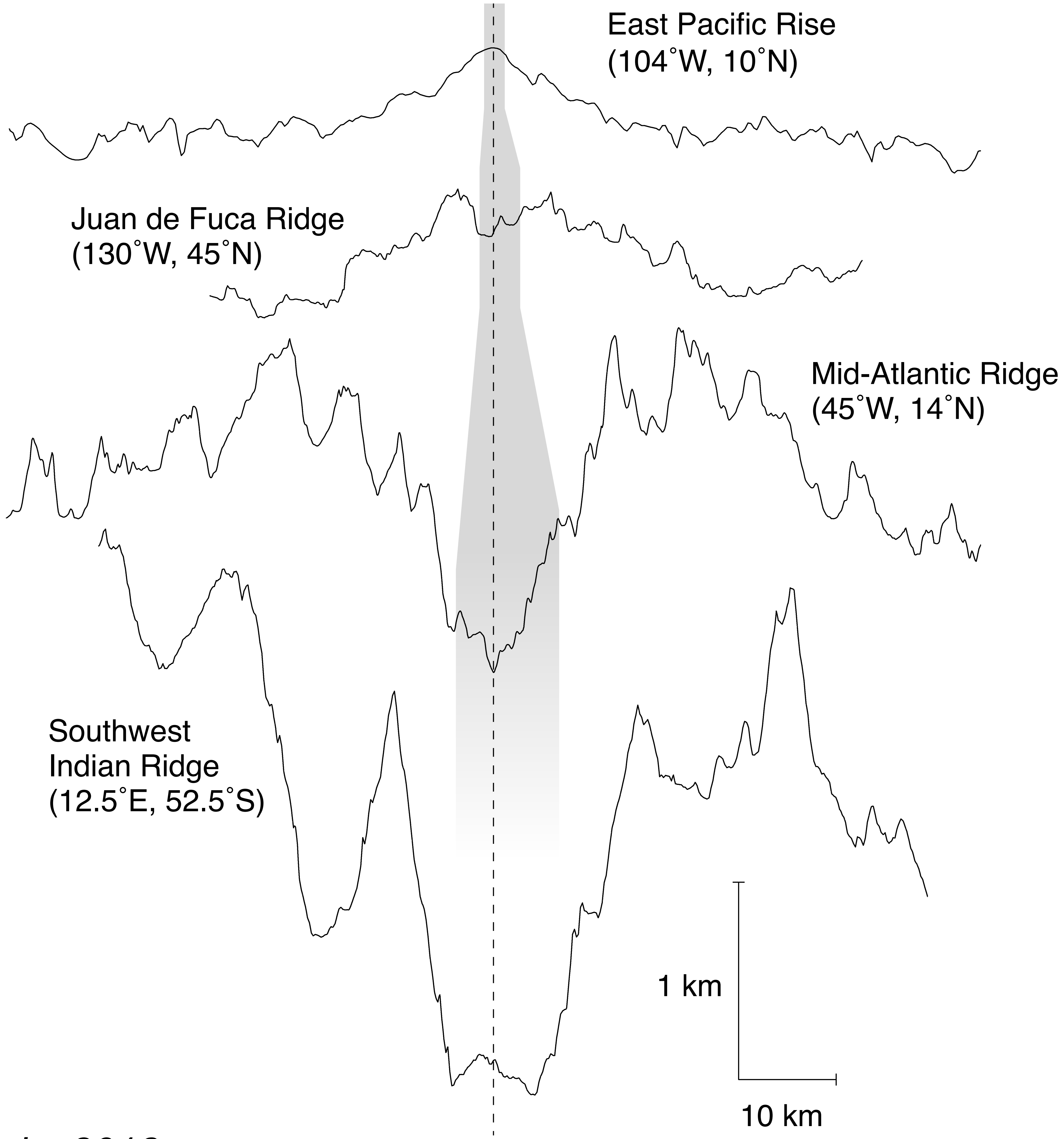
AUV Sentry

The National Deep Submergence Facility provides access to vehicles that take scientists beneath the ocean's surface to observe, sample, and conduct experiments.

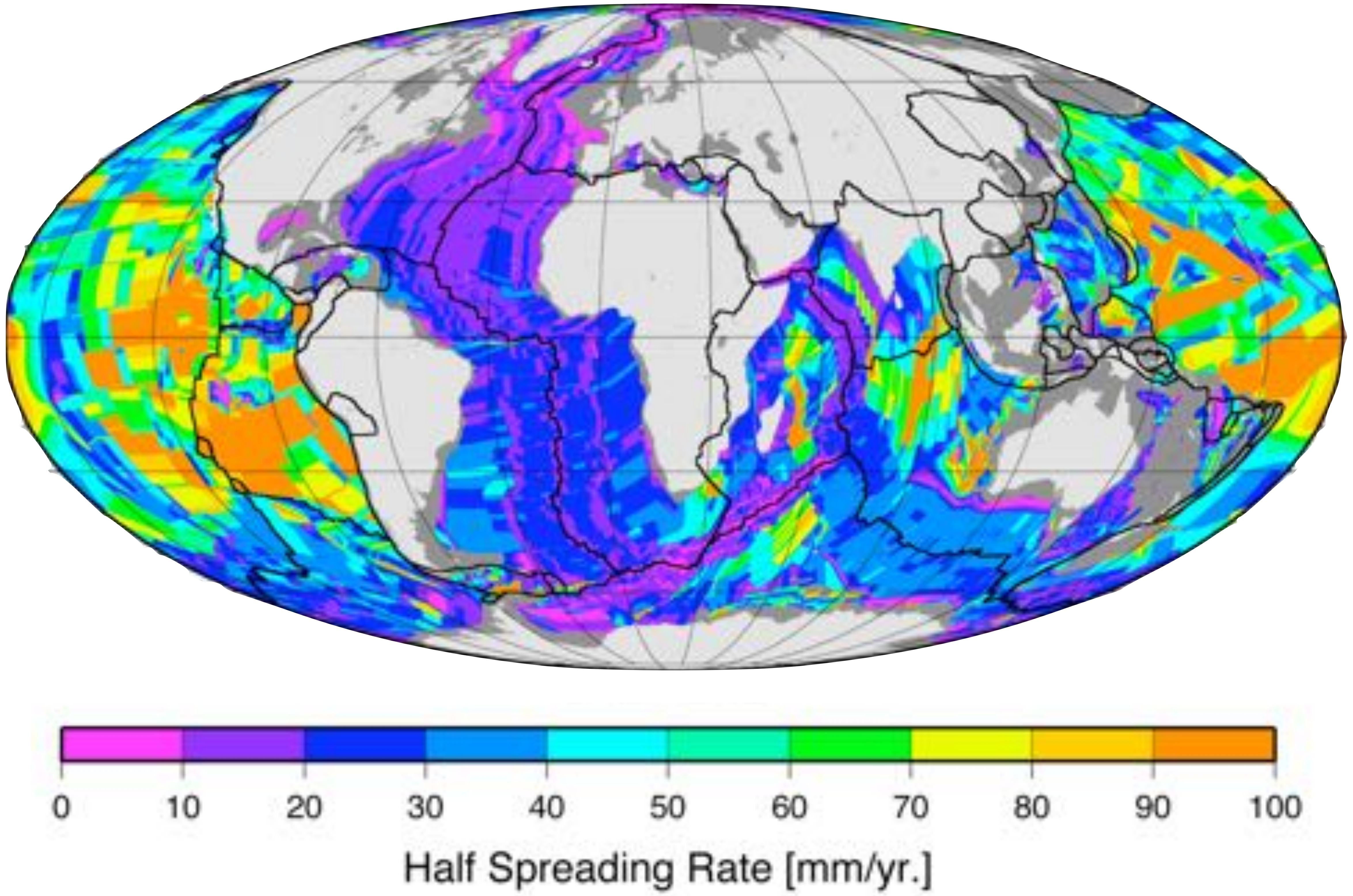
UNOLS and DeSSC runs a pre-AGU workshop every year to introduce new users to these and other deep submergence vehicles. Go to www.unols.org for more info.

Mid-Ocean Ridges

Mid-Ocean Ridge Volcanism

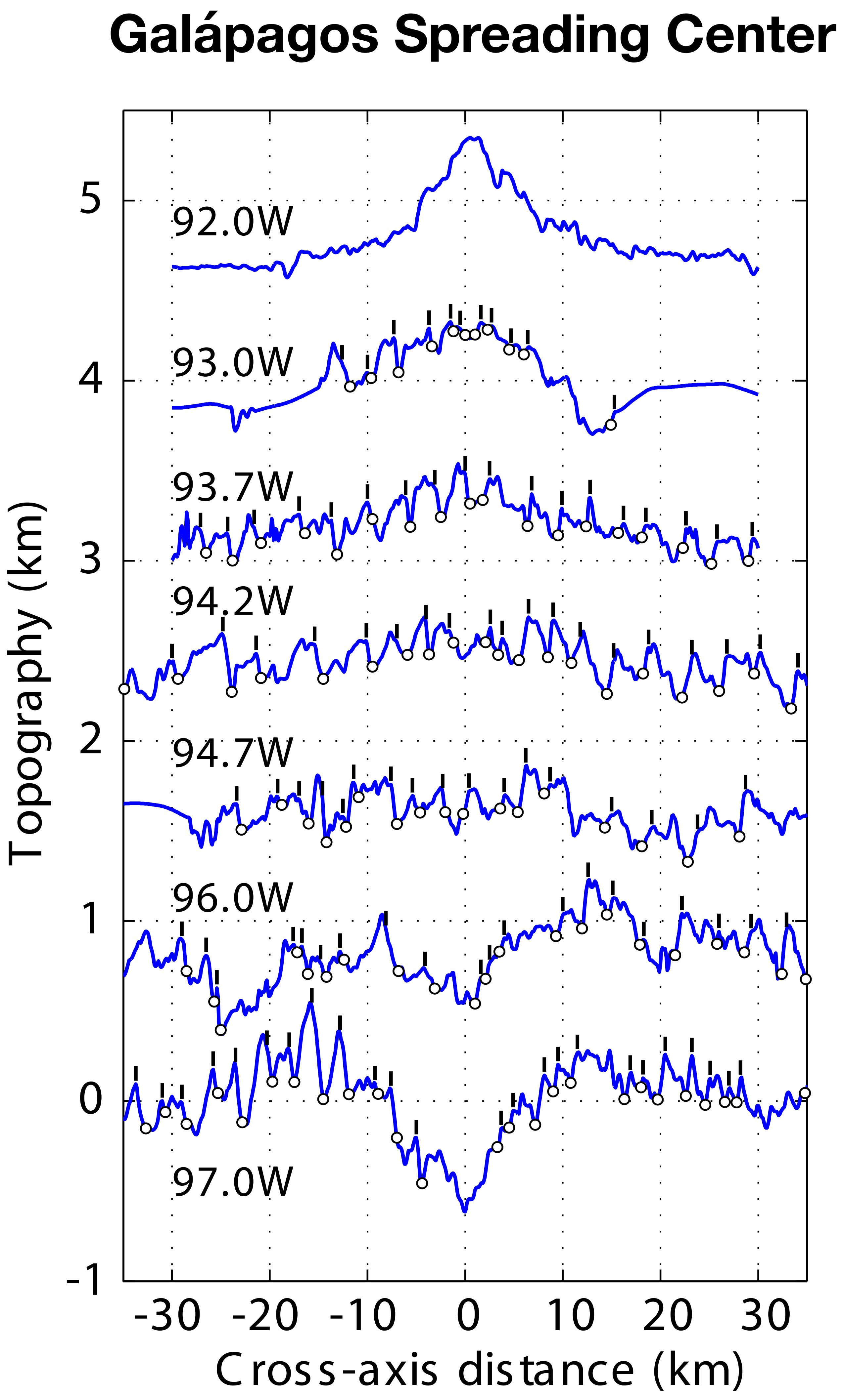


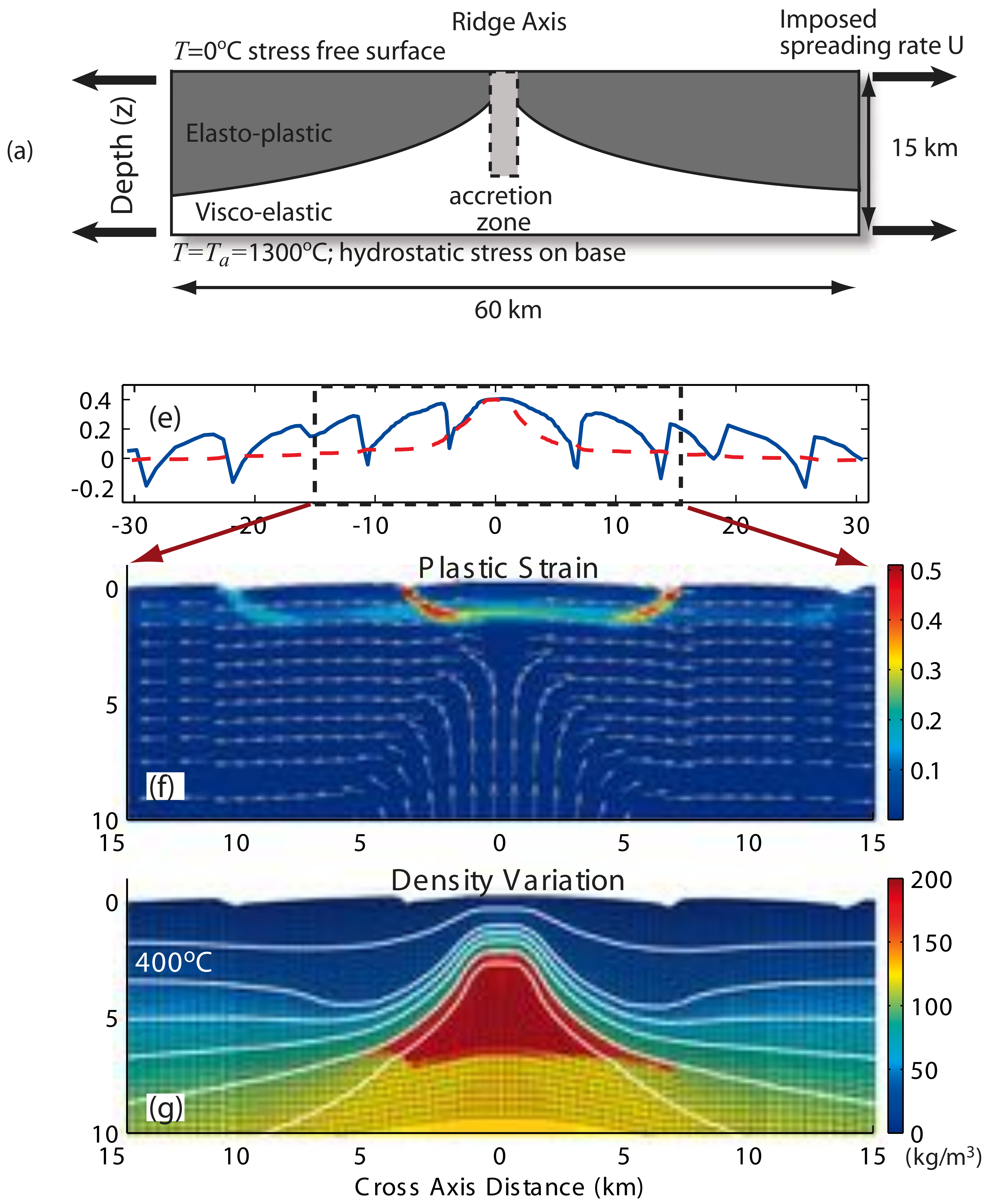
Soule, 2016



The global mid-ocean ridge can be categorized by spreading rate, which loosely predicts a number of ridge characteristics: morphology, magma lens depth, hydx plume incidence.

Magmatic and Tectonic Extension: M

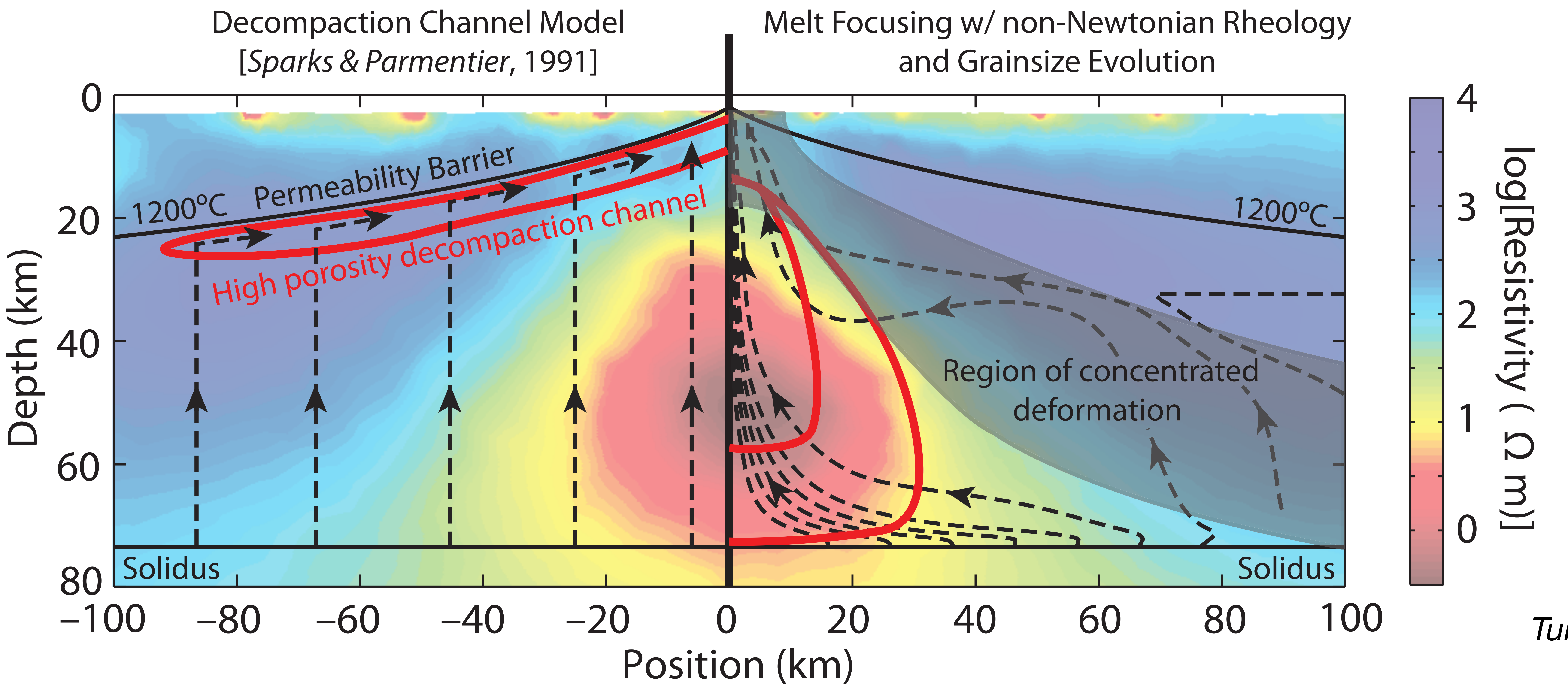




Ito & Behn, Behn & Ito, 2008

- Differences in ridge morphology can be attributed to the fraction of spreading accommodated by magmatic intrusion relative to tectonic extension (M).
- High magmatism (M>0.75) yields symmetric spreading with an axial high.
- Moderate magmatism (0.75>M>0.5) yields symmetric spreading and an axial valley.
- Low magmatism (M<0.5) yields asymmetric spreading - i.e., low-angle detachment faults.

MOR Magma Generation



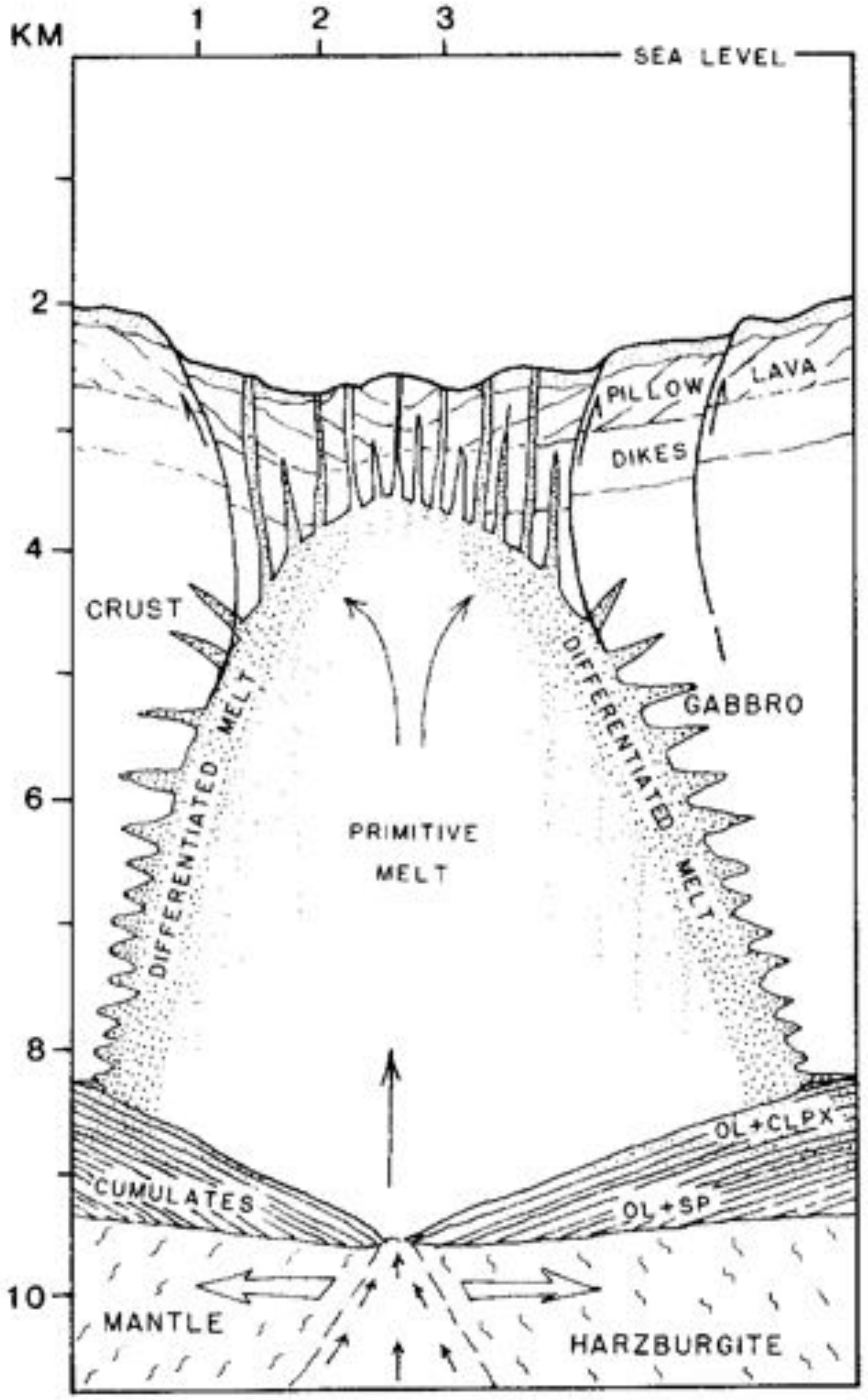
Turner et al., 2017

Magma supply is related to spreading rate, which sets the vertical flux through the melting region.

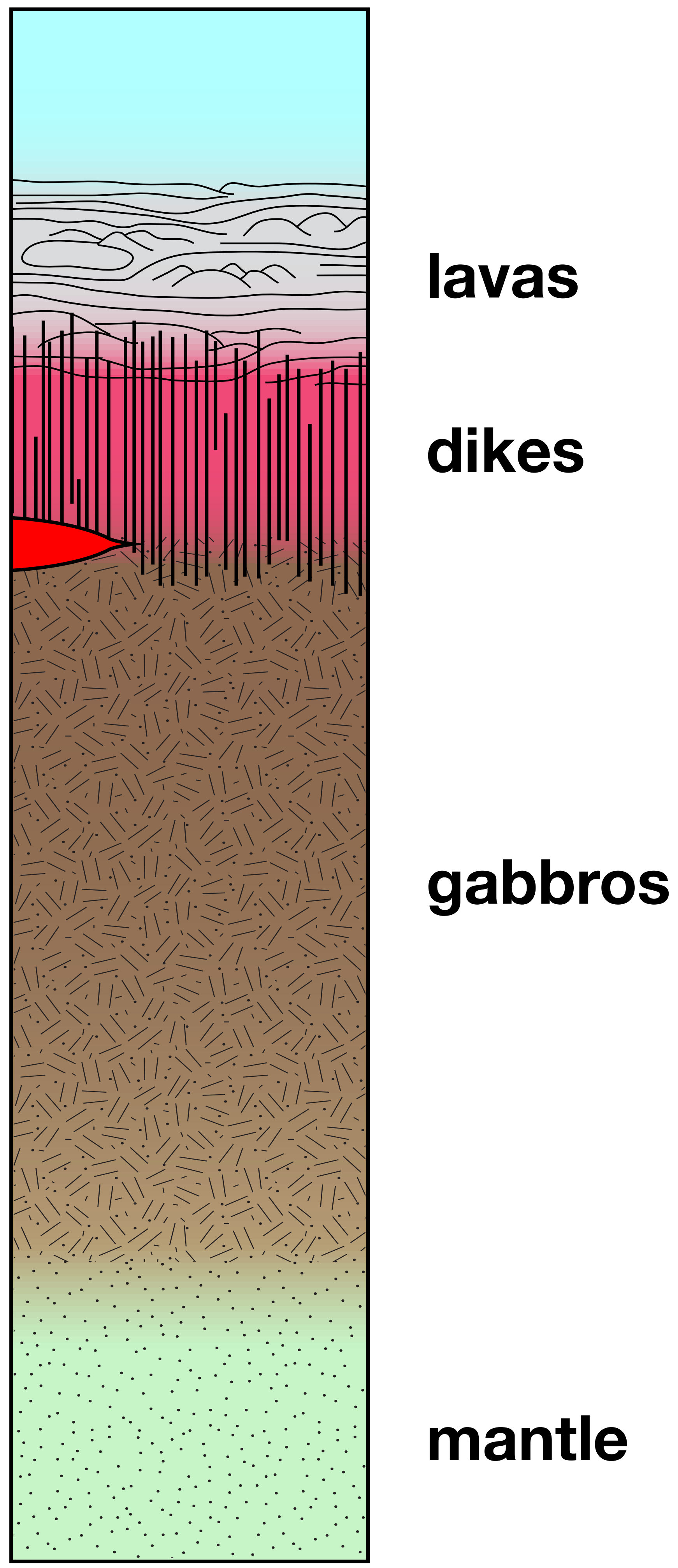
1. Fairly remarkable that a 100-200 km wide melting region is ultimately focused to a narrow (1-5 km wide) zone of volcanism.
2. Samples a large region of presumably well-mixed mantle that helps define length-scales of heterogeneity.

MOR magma chambers

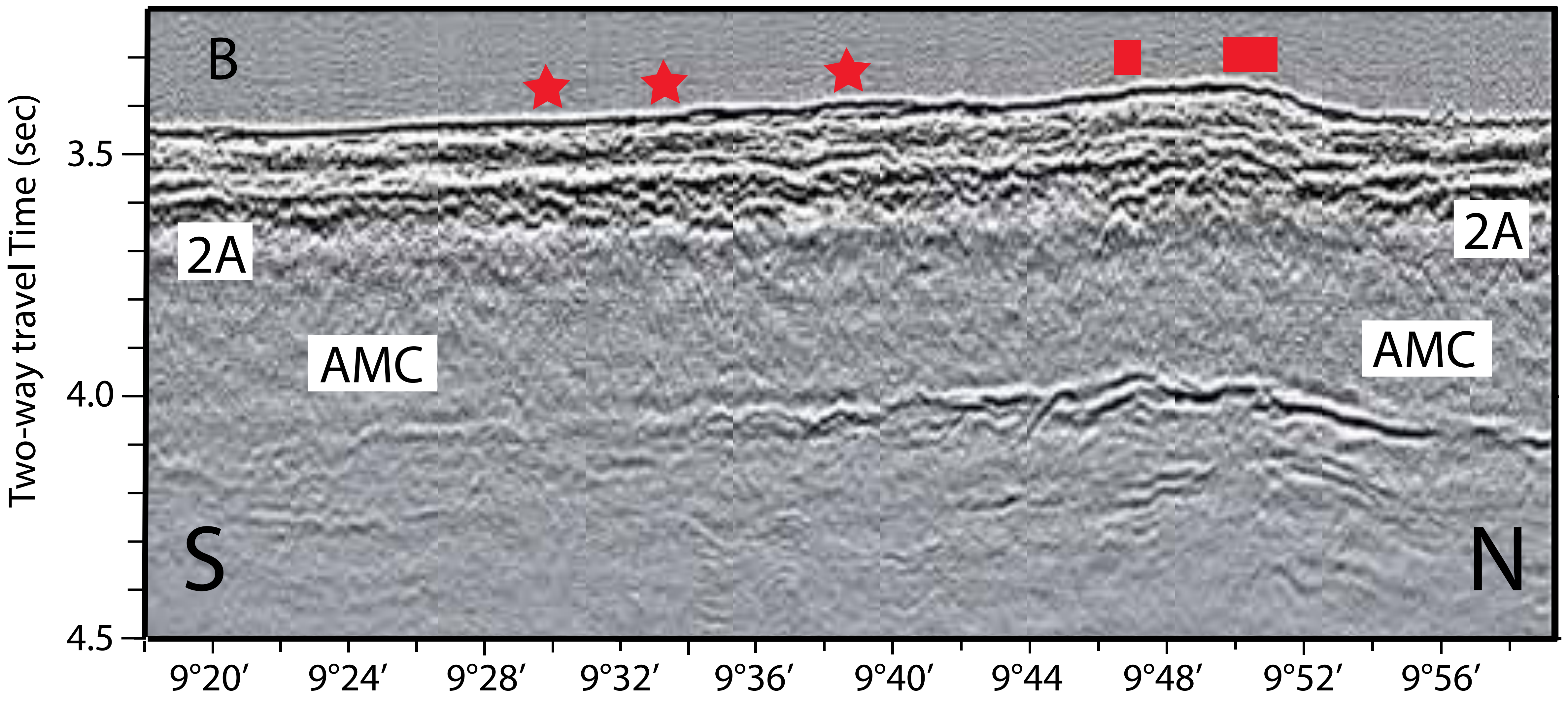
- Semi-permanent
- MORB magmas reflect homogenization of melts and fractional crystallization within the chamber.
- Periodic reinjection of fresh, primitive MORB
- Dikes upward through extending/faulting roof
- Crystallization at top and sides → successive layers of gabbro (layer 3) "infinite onion"
- Dense olivine and pyroxene crystals → ultramafic cumulates (layer 4)



Byran and Moore (1977)



Seismic Reflection Imaging at Mid-Ocean Ridges



Van Ark et al., 2007

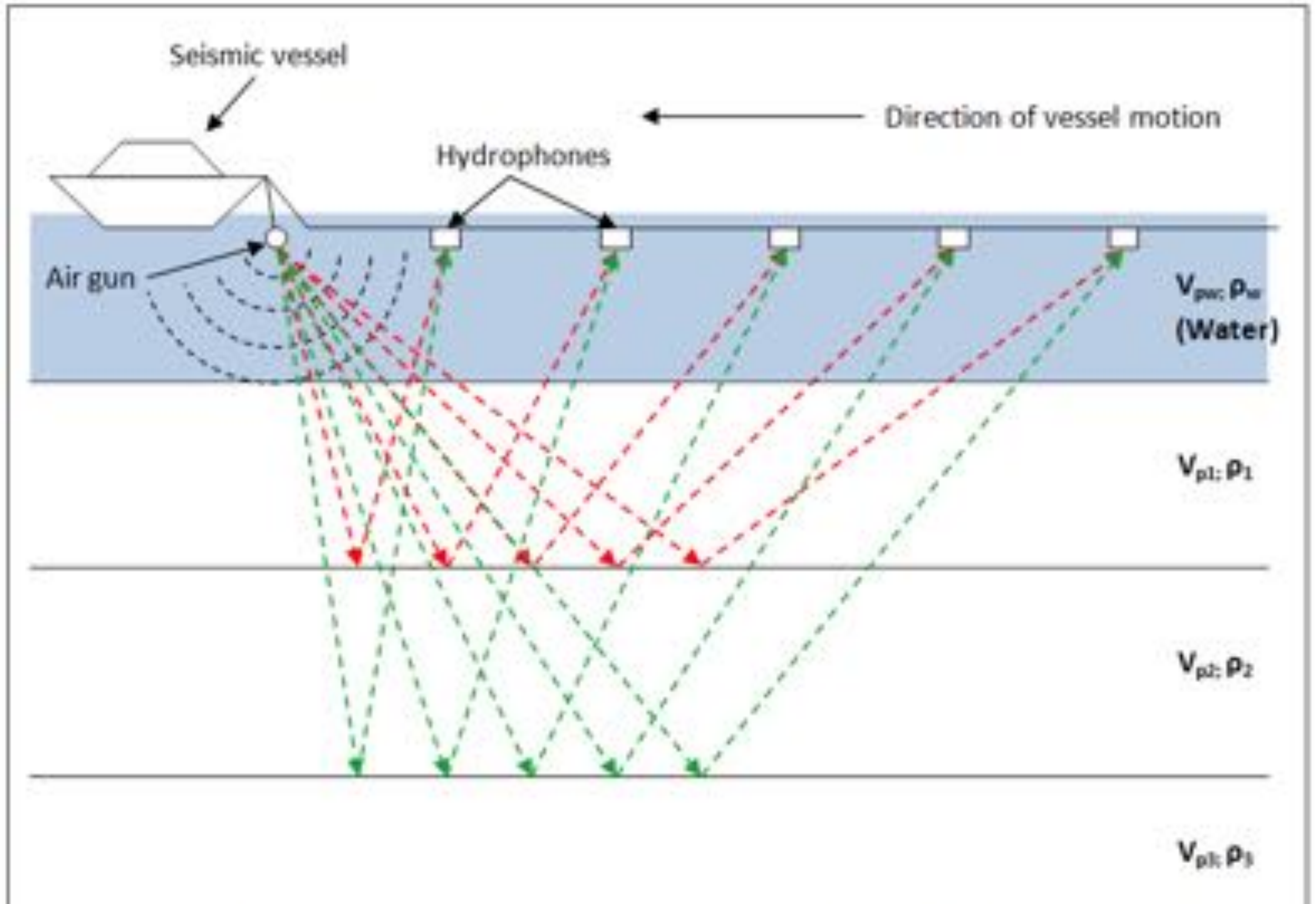
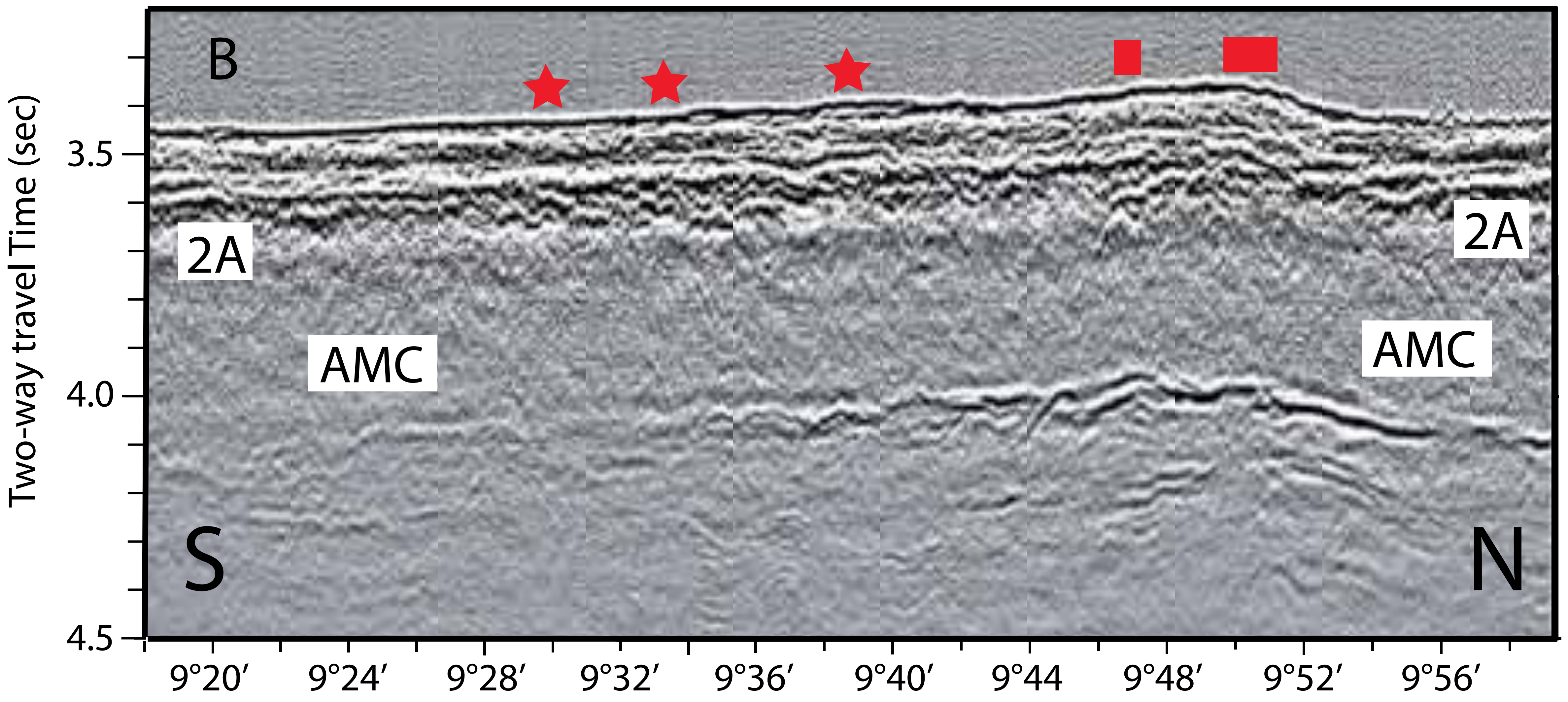


Diagram of a marine towed streamer seismic survey with the raypaths that result from a single shot by an airgun into a streamer containing 5 hydrophones.
--- = raypaths to first reflector; --- = raypaths to second reflector;

Wikipedia

Multi-channel seismic reflection have significantly improved our conception of the extent and complexity of mid-ocean ridge melt distribution and revealed connections to hydrothermal circulation and eruption processes.

Seismic Reflection Imaging at Mid-Ocean Ridges



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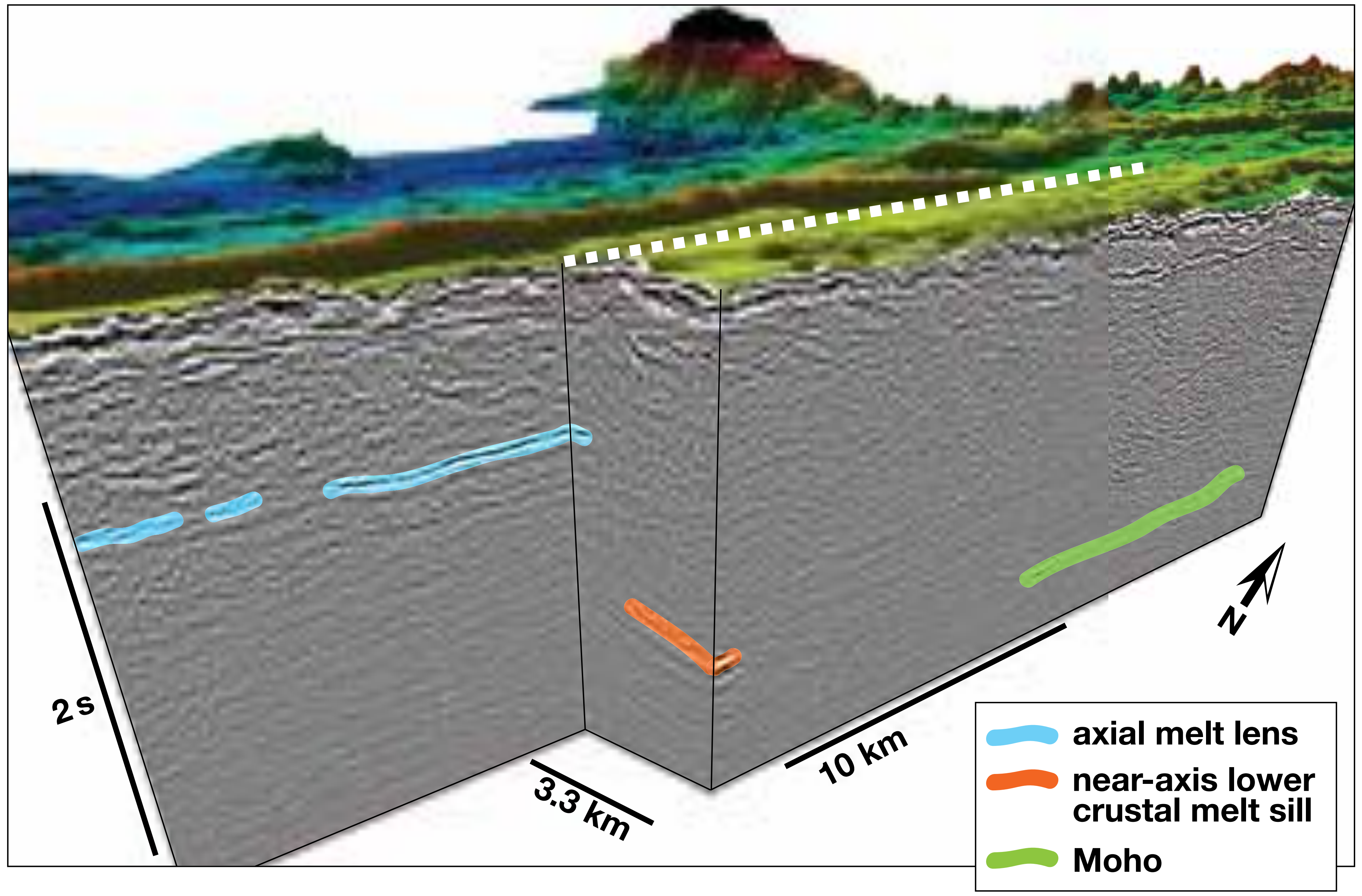
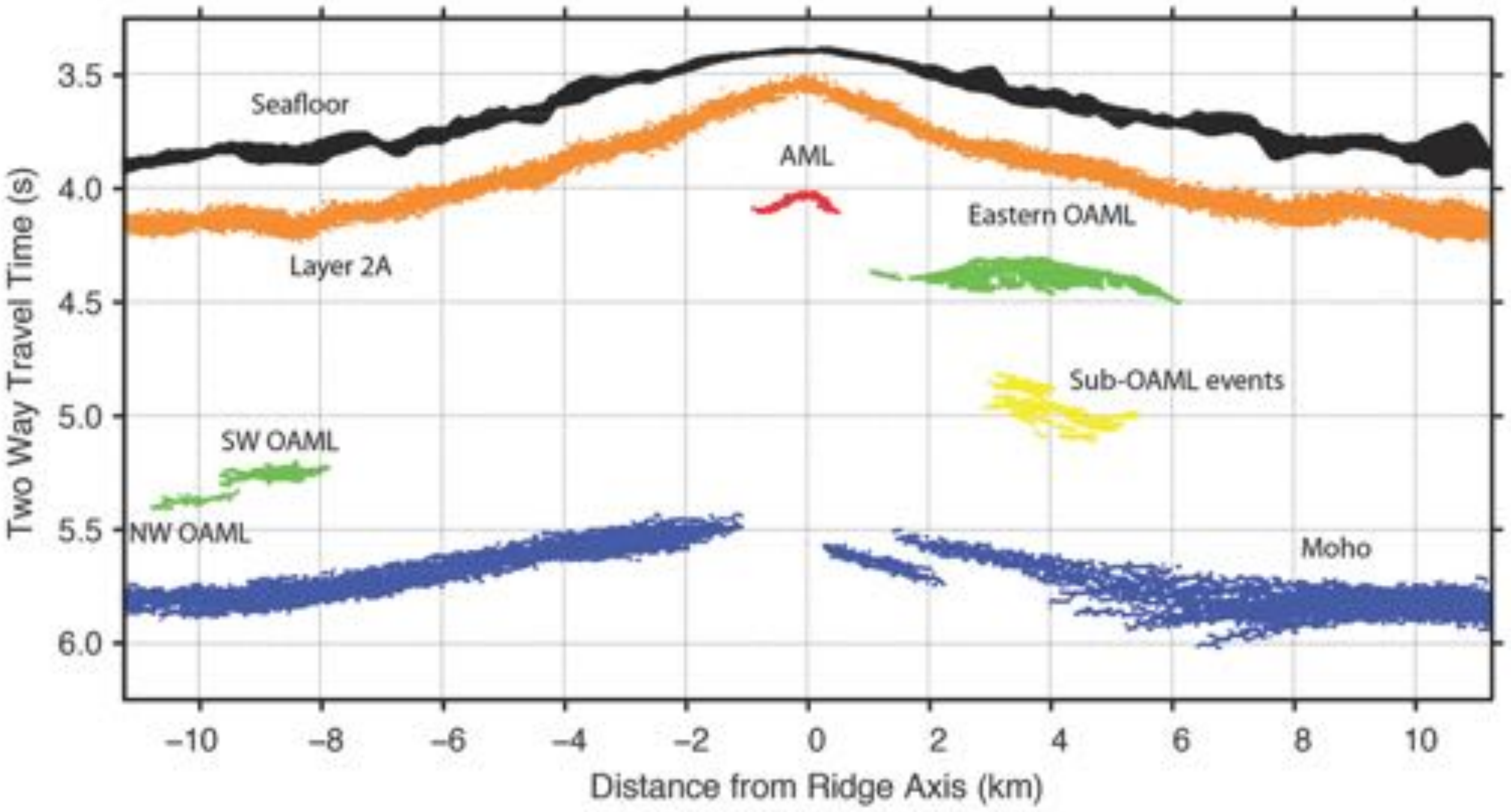


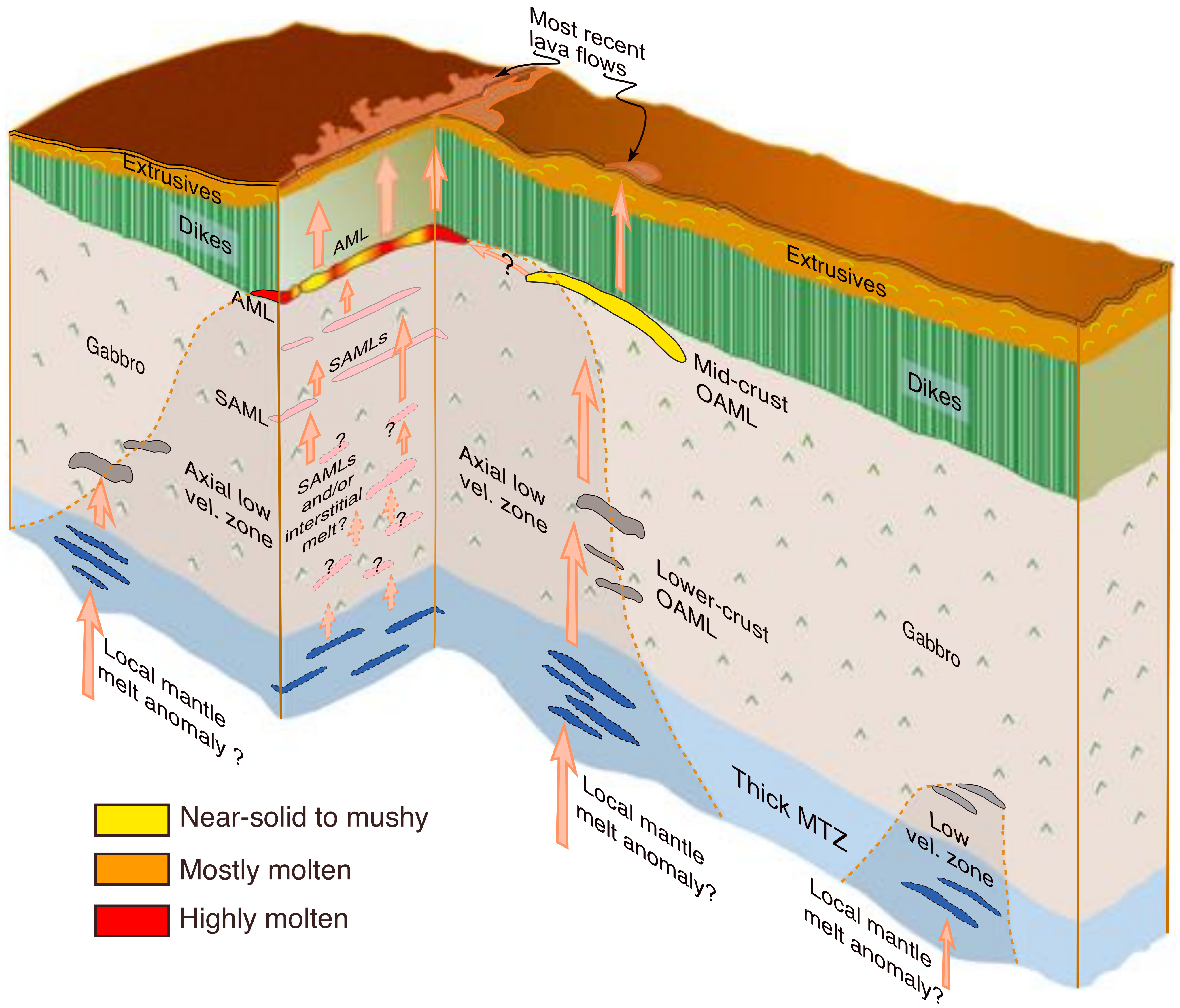
Canales et al., 2009

Multi-channel seismic reflection have significantly improved our conception of the extent and complexity of mid-ocean ridge melt distribution and revealed connections to hydrothermal circulation and eruption processes.

Seismic reflection imaging of ocean crust

Stacked across-axis MCS lines

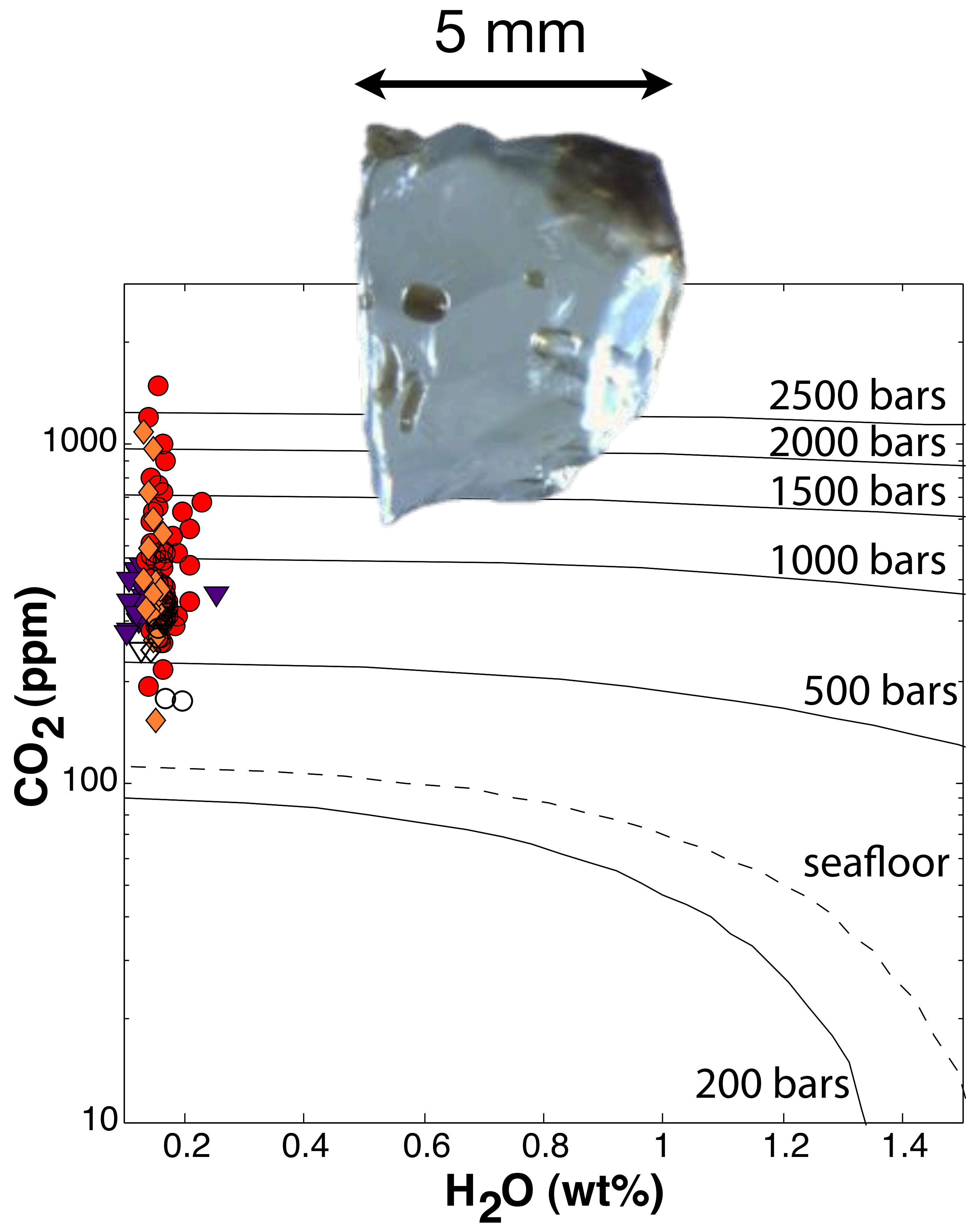


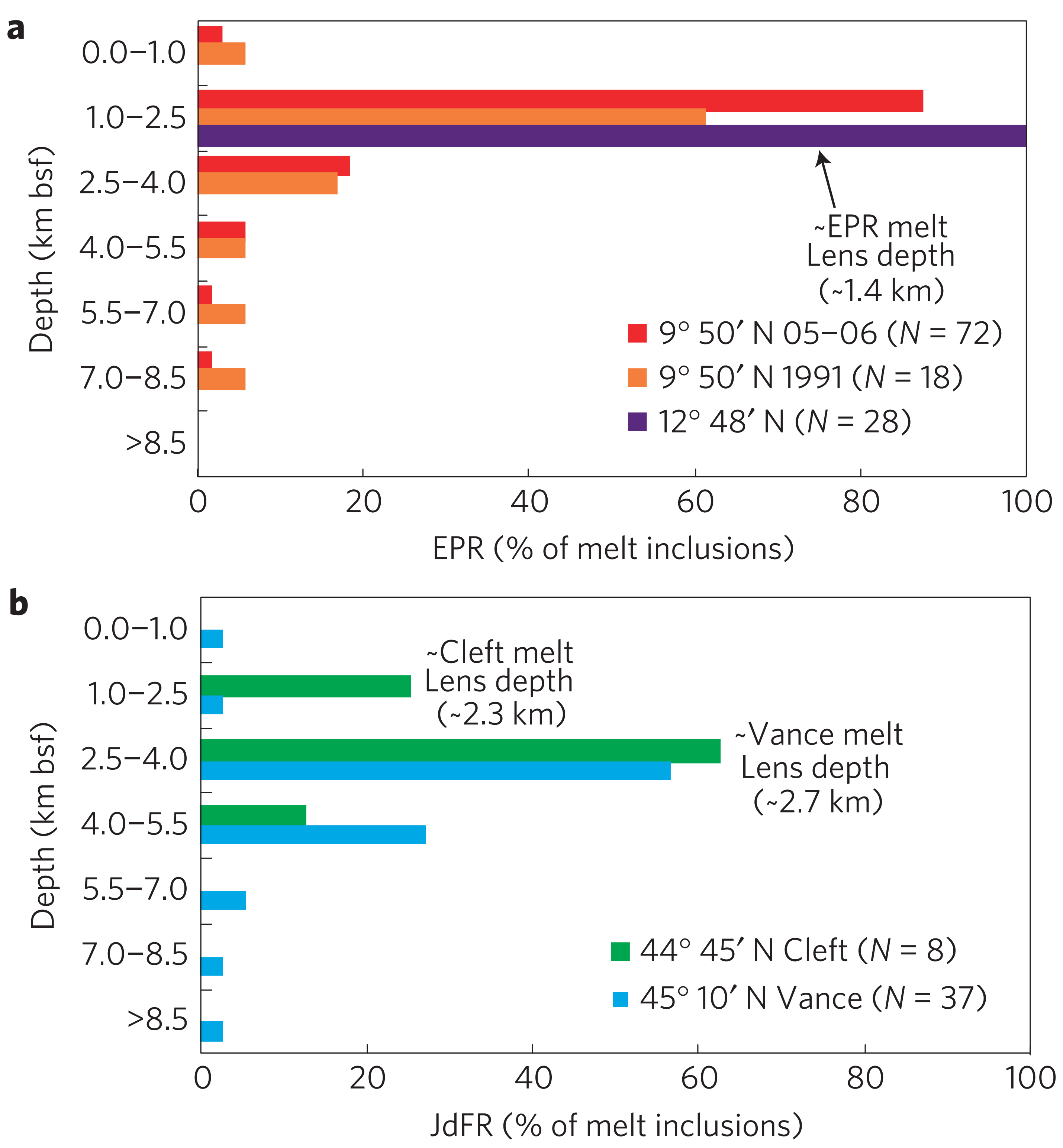


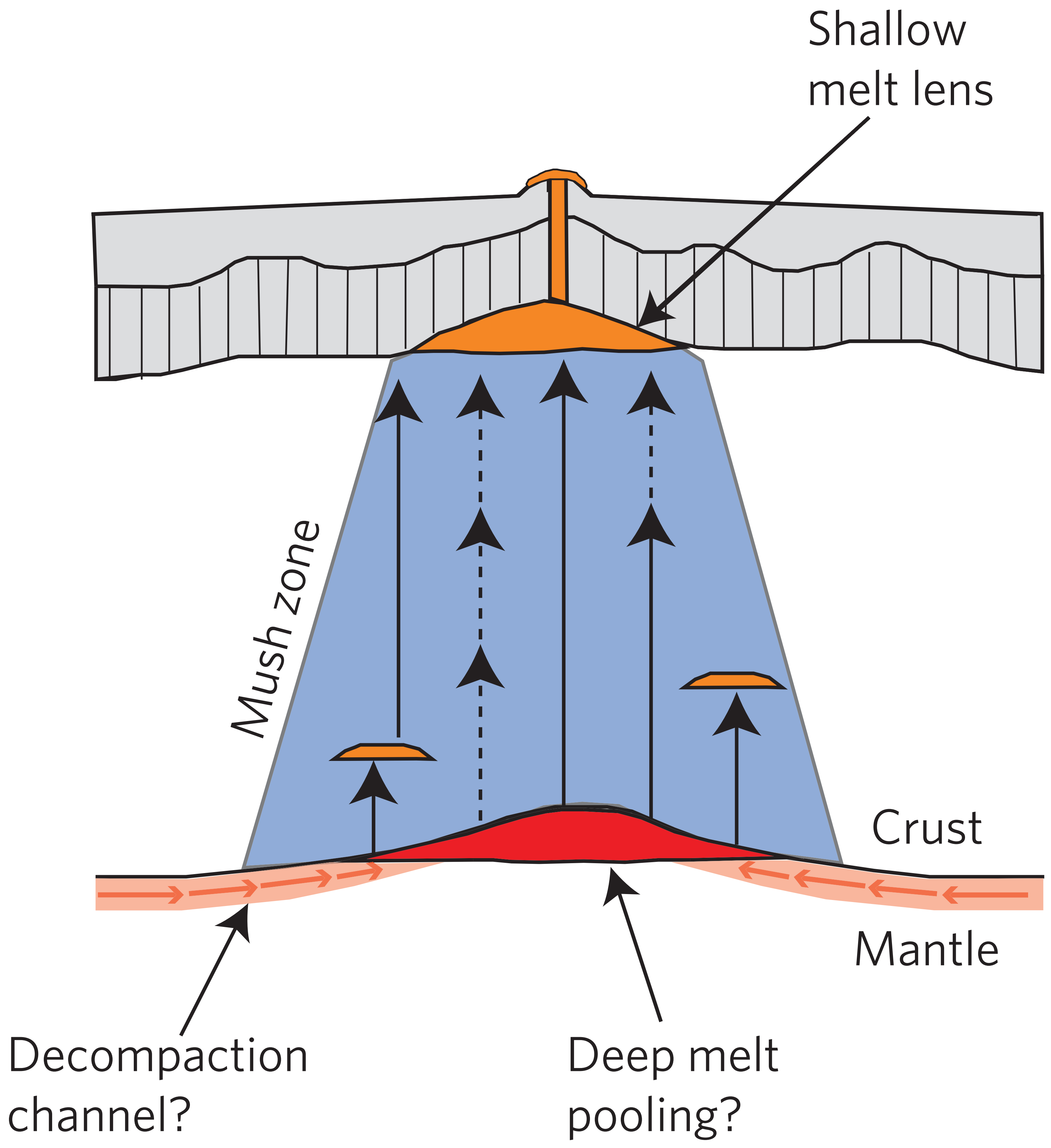
Aghaei et al., 2017

Current conception of fast and intermediate spreading rate magmatic systems look alot like the TCMS envisioned for terrestrial arcs, but compressed to 6-ish km.

Construction of the lower oceanic crust

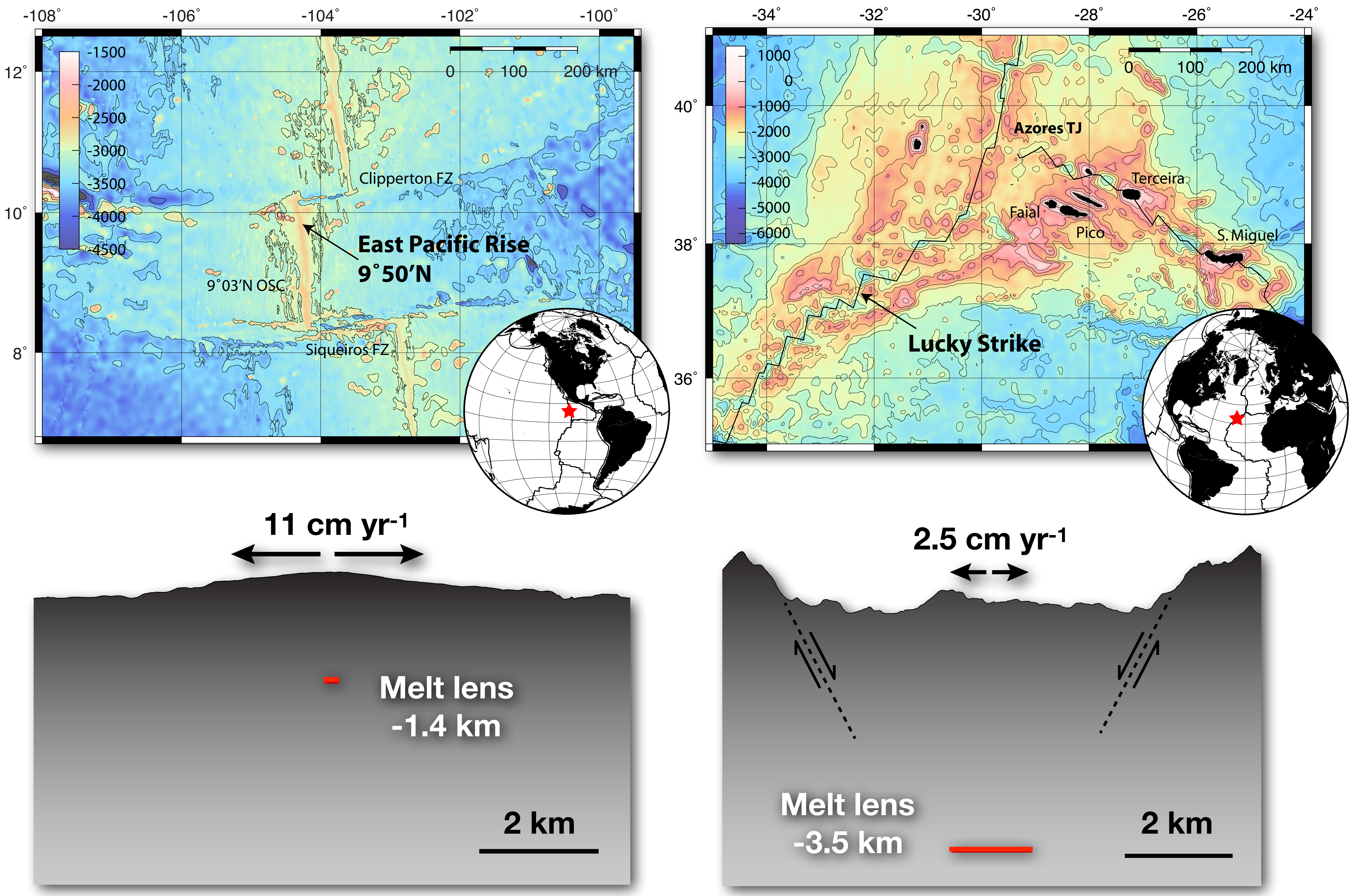




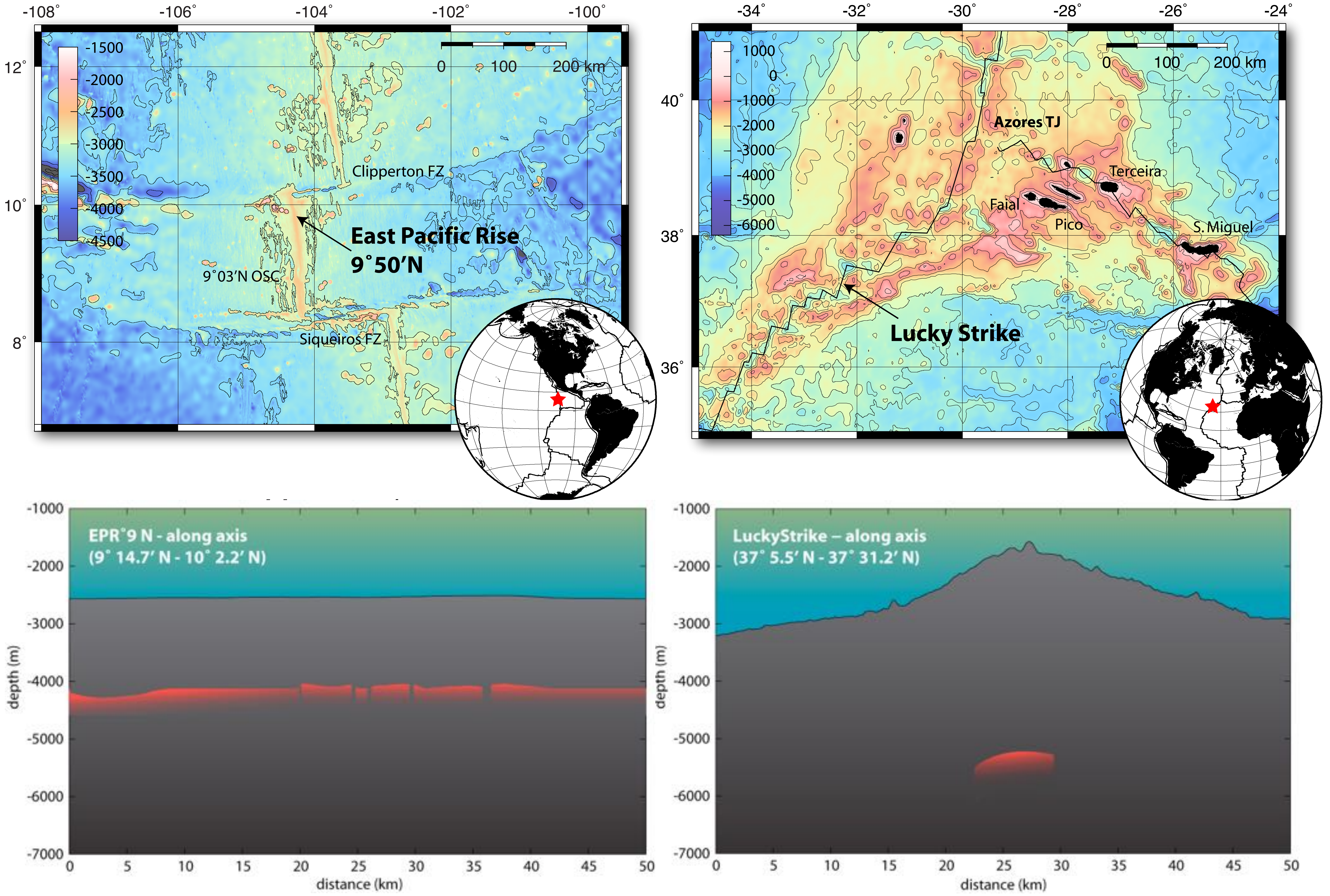


Wanless & Shaw, 2012

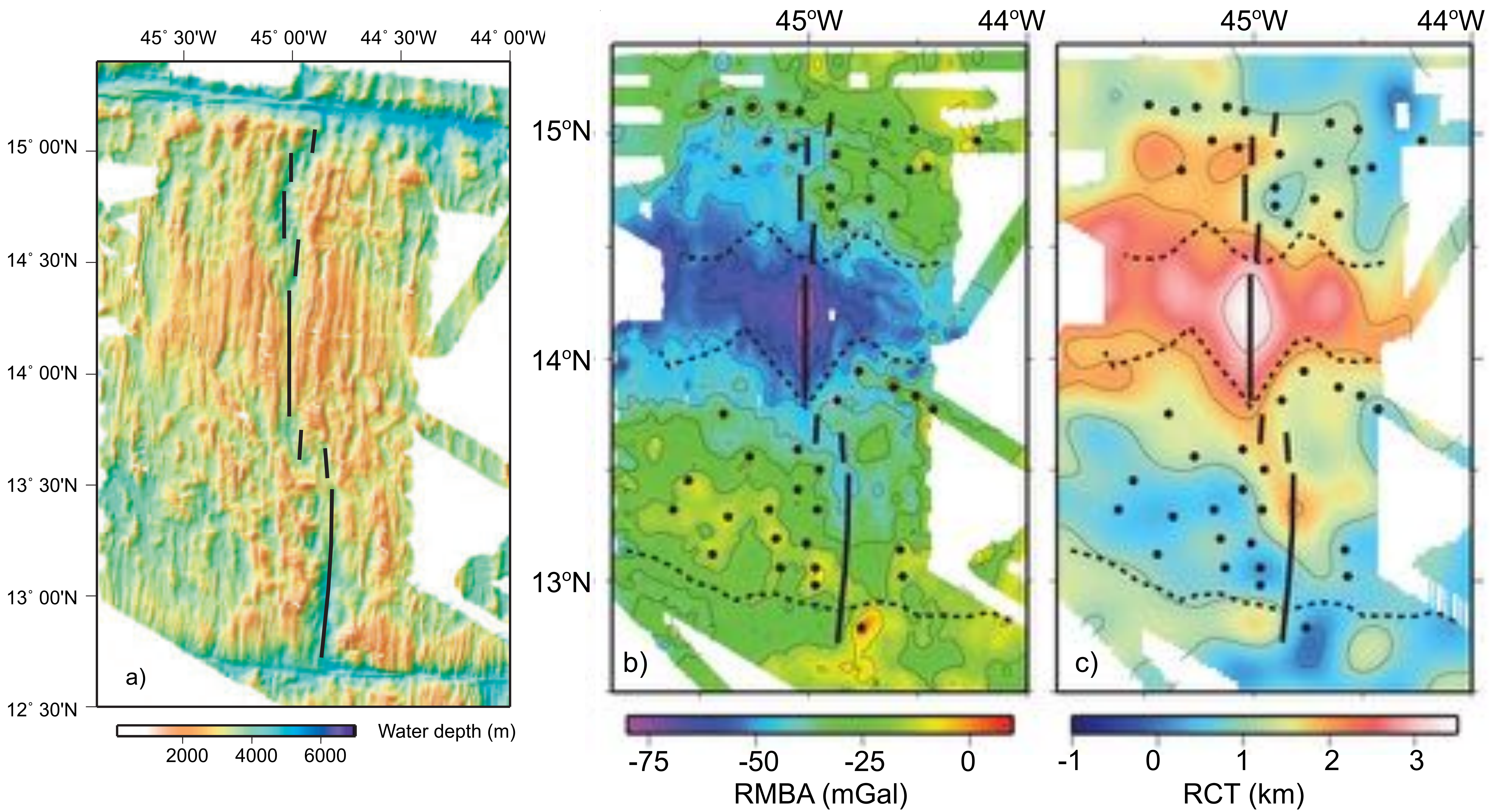
Olivine hosted melt inclusions indicate crystallization primarily in melt lens at depths consistent with seismic reflection, but also throughout the lower crust.



East Pacific Rise
9°50'N
Clipperton FZ
9°03'N OSC
Siqueiros FZ
0 100 200 km
-1500
-2000
-2500
-3000
-3500
-4000
-4500
Lucky Strike
Azores TJ
Terceira
Faial
Pico
S. Miguel
1000
0
-1000
-2000
-3000
-4000
-5000
-6000
11 cm yr-1
Melt lens
-1.4 km
2 km
2.5 cm yr-1
Melt lens
-3.5 km
2 km


-108˚
-106˚
-104˚
-102˚
-100˚
12˚
10˚
8˚
-1500
-2000
-2500
-3000
-3500
-4000
-4500
0
100
200 km
Clipperton FZ
East Pacific Rise
9˚50′N
9˚03′N OSC
Siqueiros FZ
-34˚
-32˚
-30˚
-28˚
-26˚
-24˚
40˚
38˚
36˚
1000
0
-1000
-2000
-3000
-4000
-5000
-6000
Azores TJ
Terceira
Faial
Pico
S. Miguel
Lucky Strike
EPR˚9 N - along axis
(9˚ 14.7′ N - 10˚ 2.2′ N)
LuckyStrike – along axis
(37˚ 5.5′ N - 37˚ 31.2′ N)
depth (m)
-1000
-2000
-3000
-4000
-5000
-6000
-7000
distance (km)
0
5
10
15
20
25
30
35
40
45
50

Example: MAR 13-16N



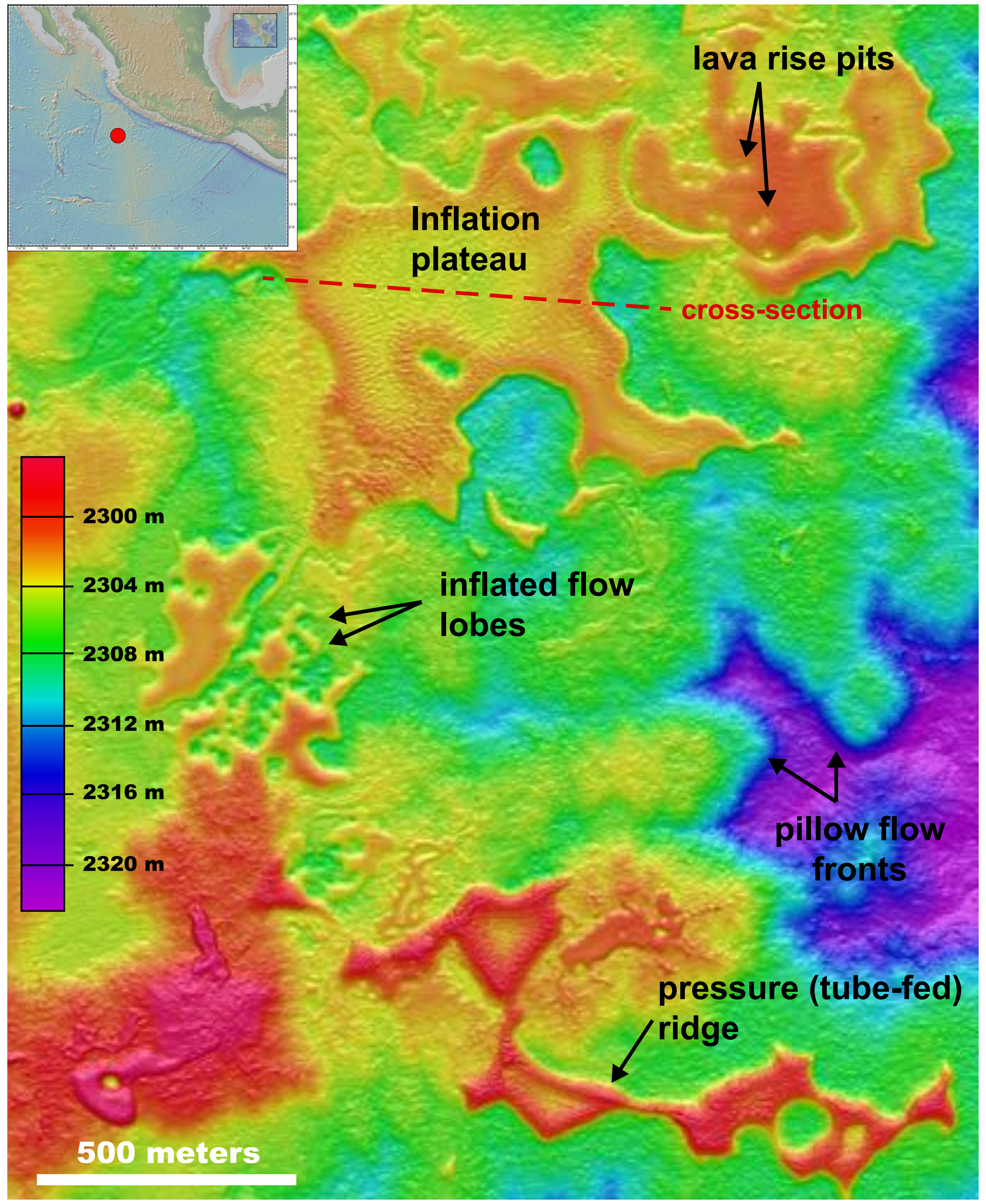
Increased magma supply at the segment center is reflected in reduced gravity due to warmer (less dense) crust as well as in the seafloor fabric.

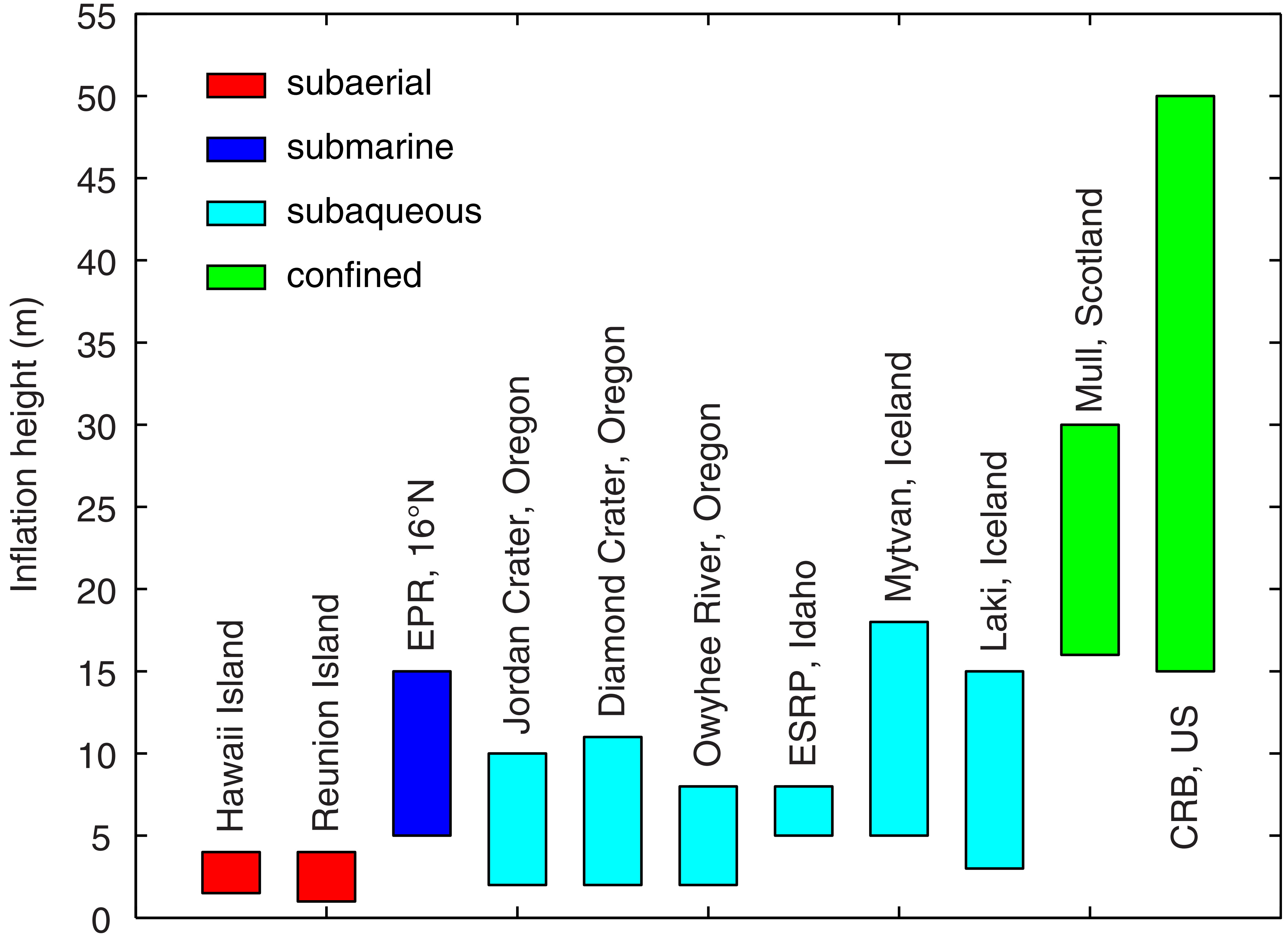
MOR Lava Flows

Mid-Atlantic Ridge, 14°N, 4000 mbsl

Role of water in submarine basaltic eruptions

East Pacific Rise, 16°N





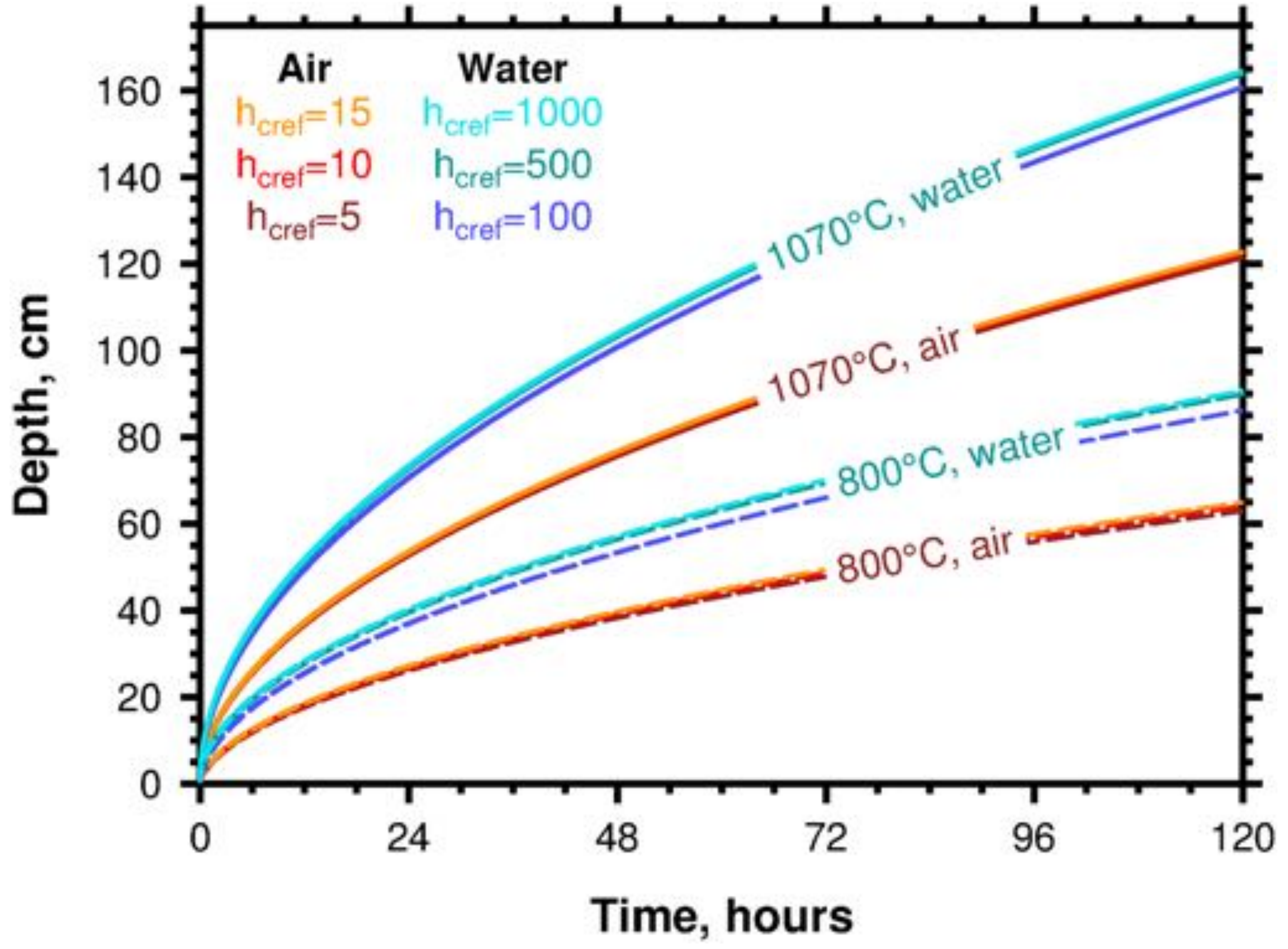
Deschamps et al., 2014

- **<u>Reduced gravity (increased flow thickness by 30% to 50%)</u>**
- **Cooling rates (empirically & theoretically higher in H2O)**
- **Potential for fragmentation (will return to this topic)**
- **Chemical influence (incorporation of sea-H_2O)**

$$g' = g\frac{(\rho_{lava} - \rho_{water})}{(\rho_{lava} - \rho_{air})}$$

Role of water in submarine basaltic eruptions

Predicted cooling



Deschamps et al., 2014

Radiative heat flux

$$Q_r = \sigma\varepsilon(T_l^4 - T_{amb}^4)$$

Boltzmann constant ~ 10^{-8}

Emissivity ~ 1 in air
~ 0 in water

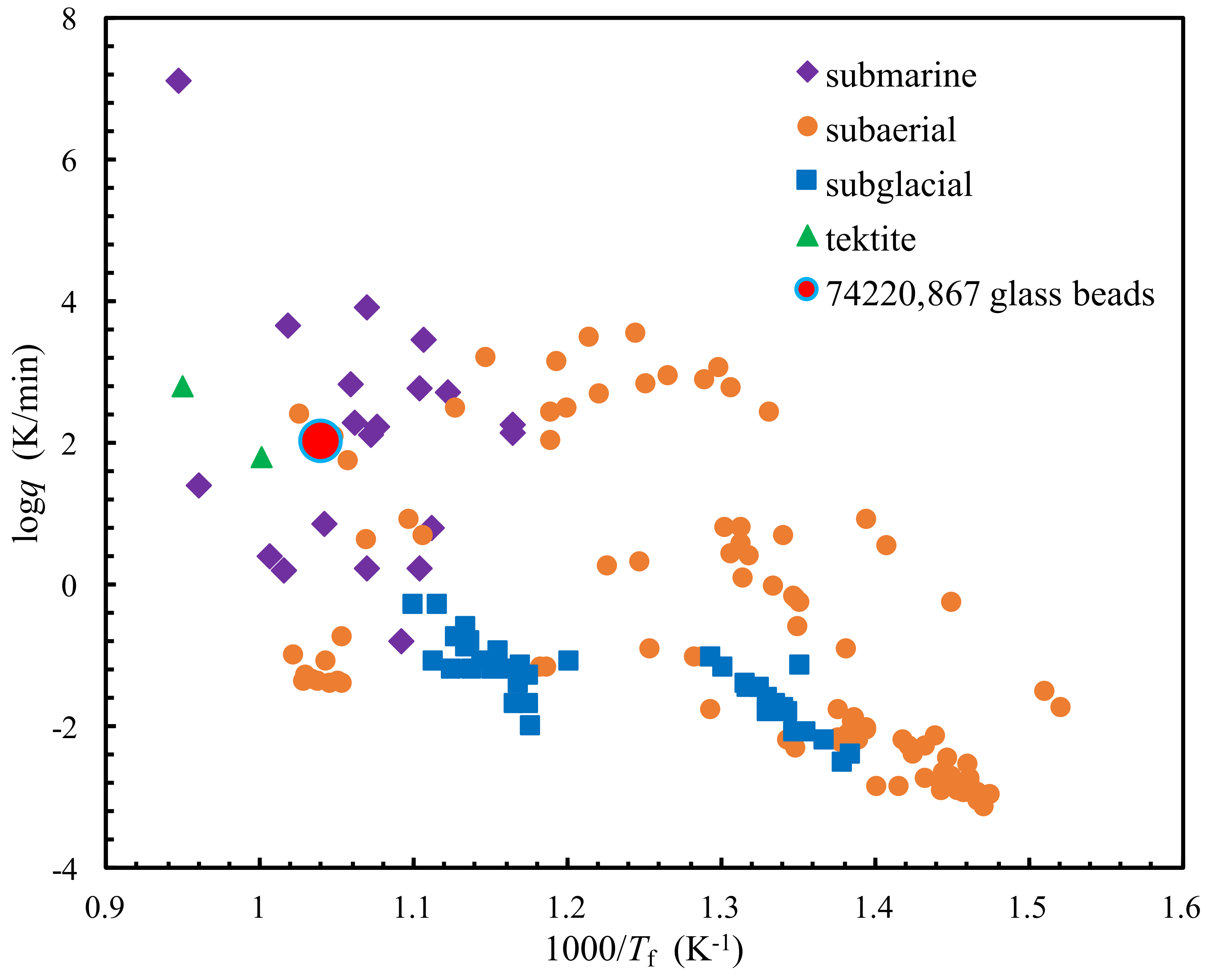
Convective heat flux

$$Q_c = h_c(T_l - T_{amb})$$

hcref (air) ~ 5-15 W m^{-2} K^{-1}

hcref (water) ~ 100-1000 W m^{-2} K^{-1}

Measured cooling rate



Potuzak et al., 20xx; Nichols et al, 20xx; Hui et al., 2018

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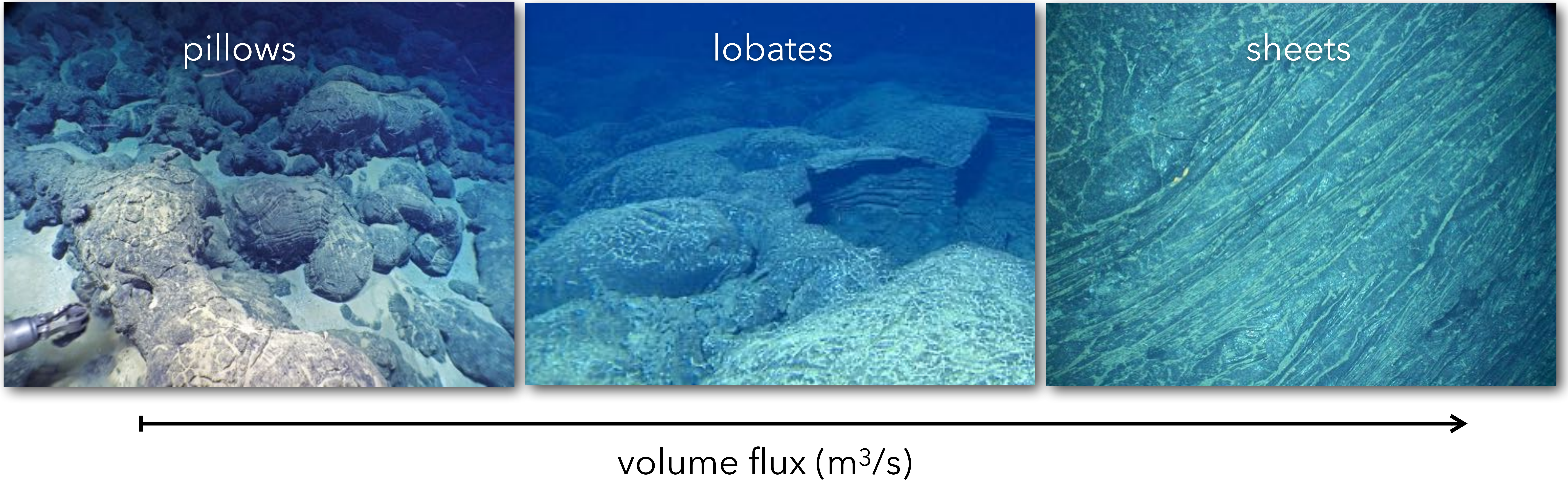
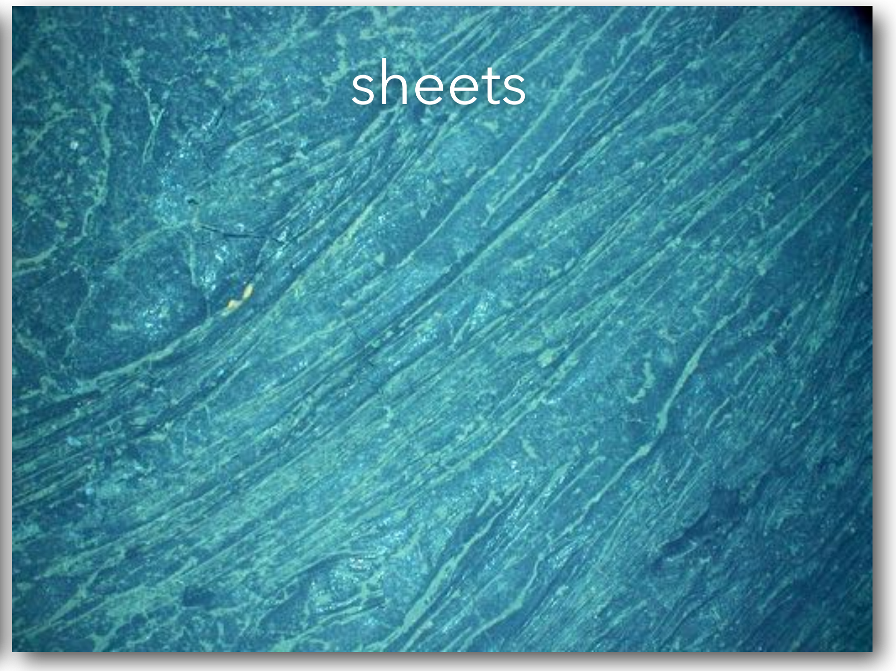
Volcanic Morphology

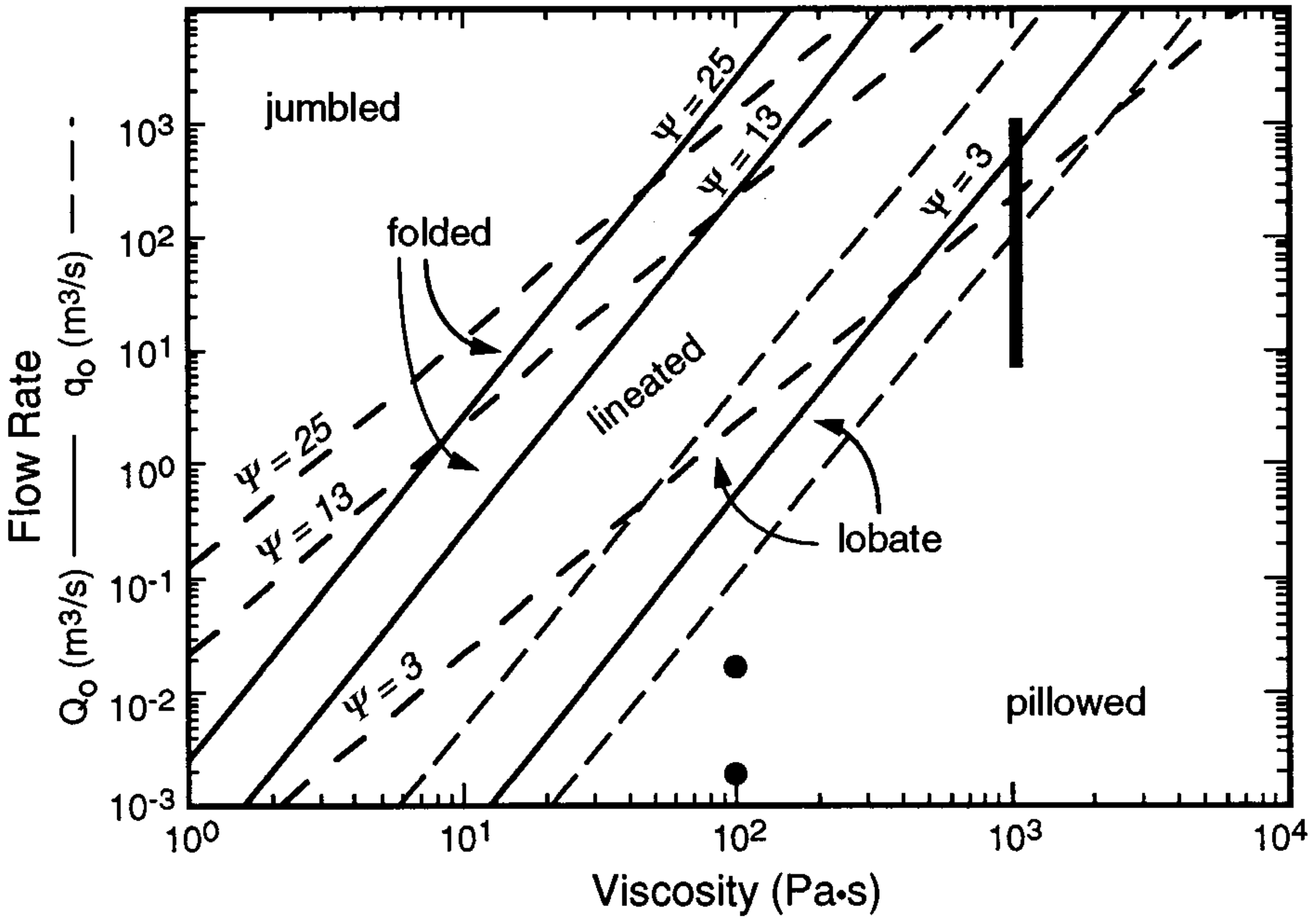


Mid-ocean ridge eruptions produce lava flows with a variety of morphologies. Pillows produce short, thick flows (i.e., mounds and hummocks), lobates produce broad, moderate relief flows, sheets produce flat, featureless flows. The differences are dictated largely by the effusion rate of the eruption.

Volcanic Morphology



volume flux (m^3/s)

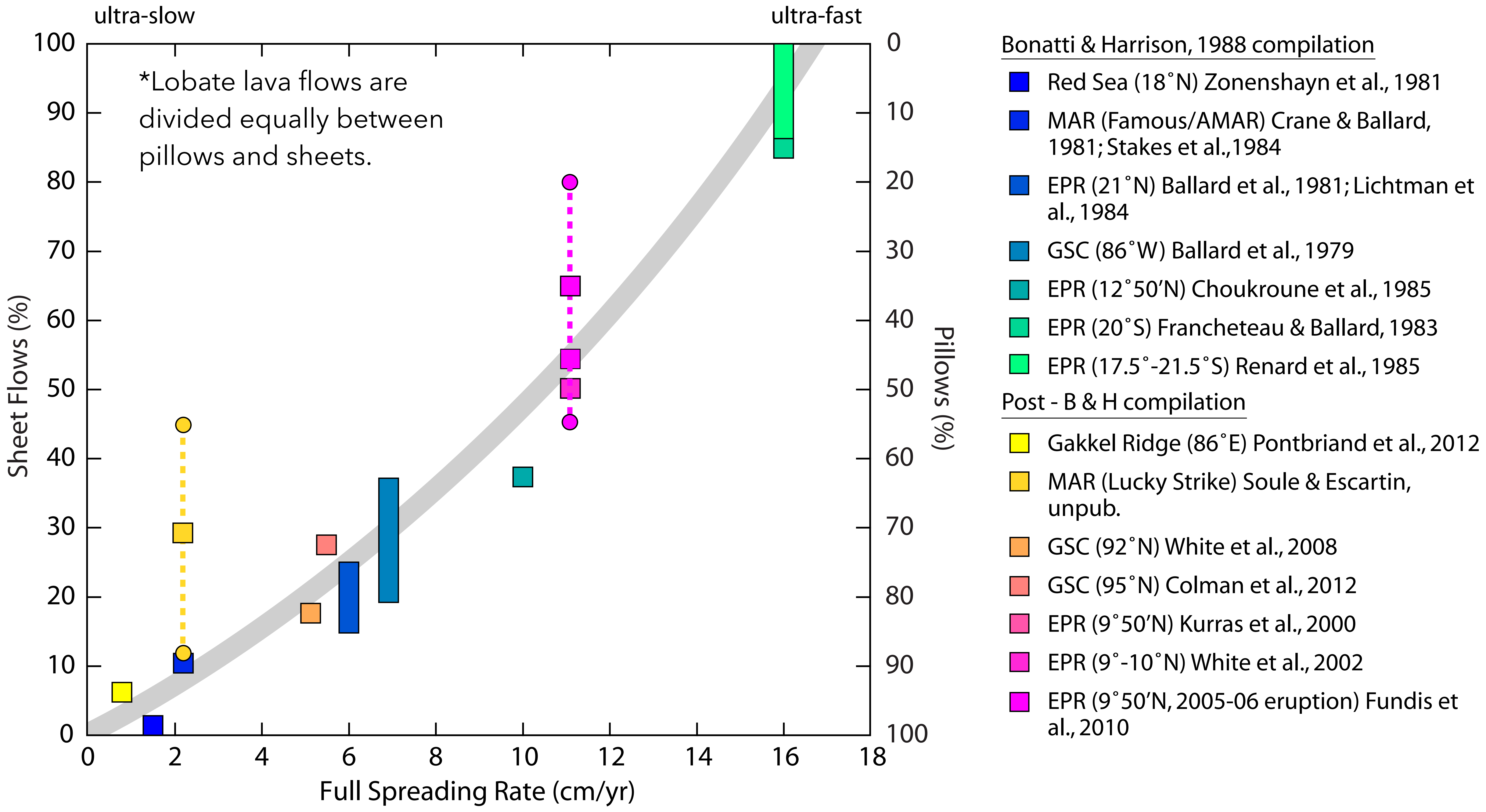


$$\Psi = \frac{\tau_{cooling}}{\tau_{advection}}$$

Gregg & Fink, 1990

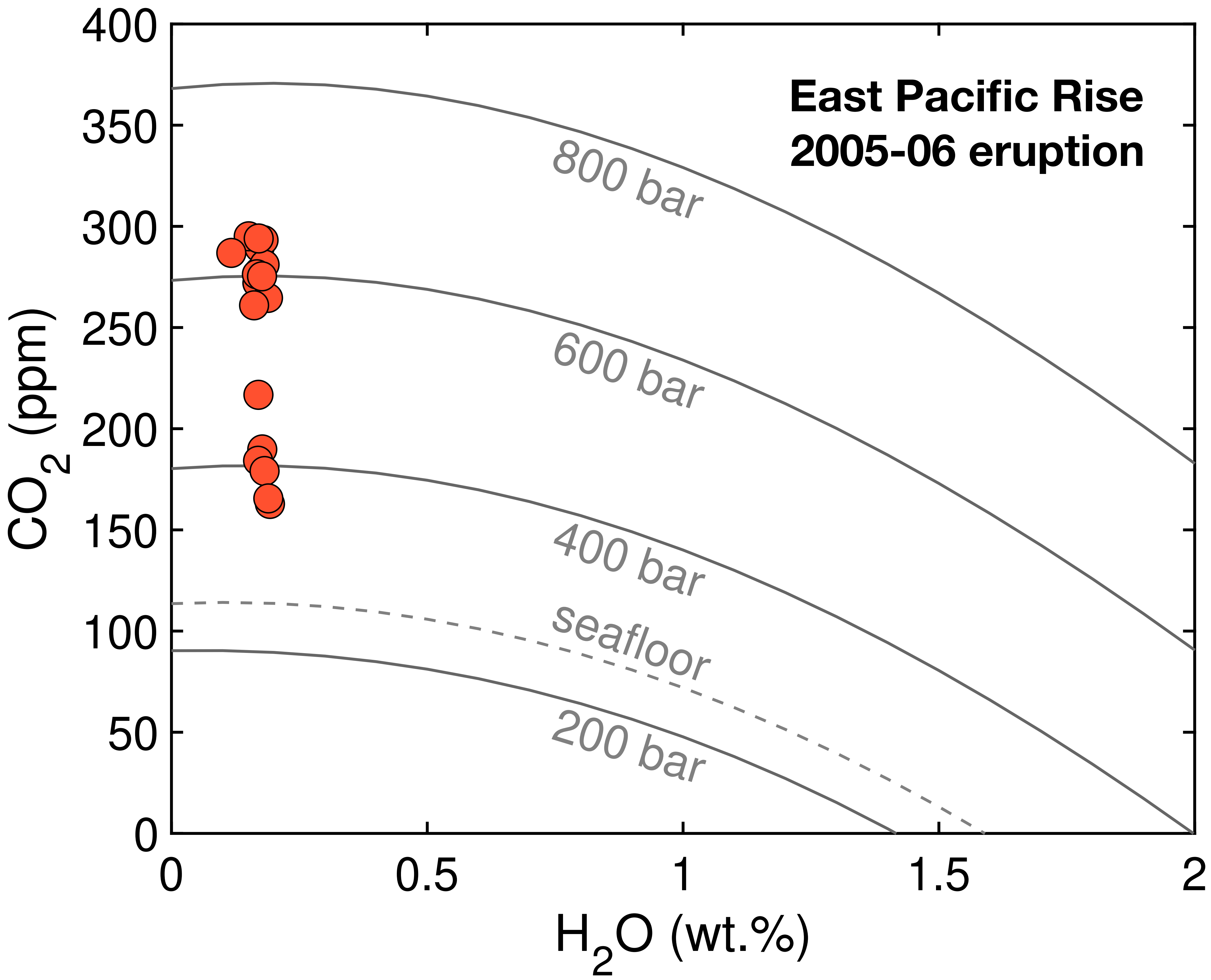

~75m
~675m
East Pacific Rise, 9°N
120 mm/yr
Mid-Atlantic Ridge, 14°N
22 mm/yr

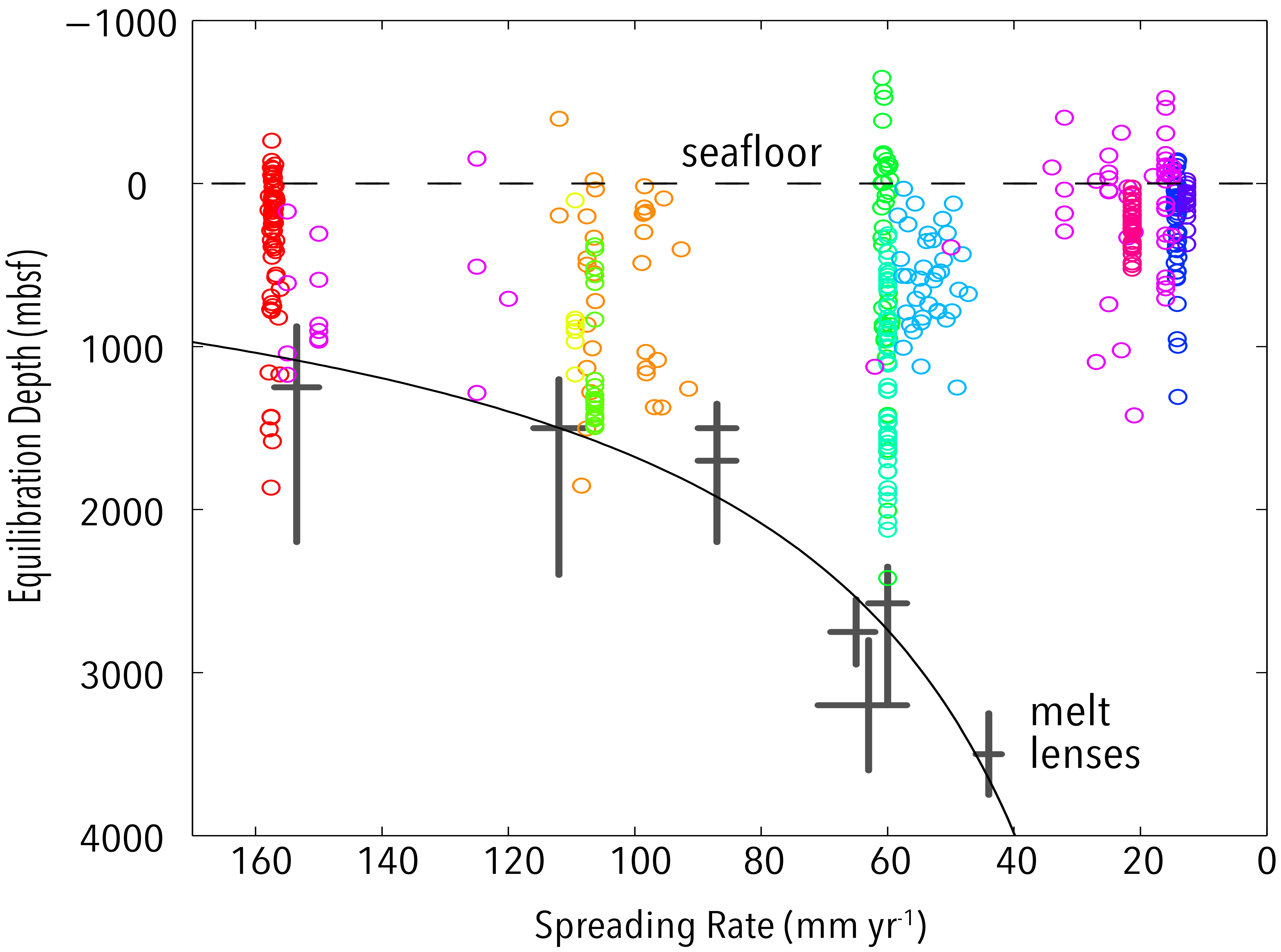
Morphology and spreading rate



Eruption properties (generally) scale with spreading rate. Lower spreading rates produce more pillows, greater spreading rates produce more sheet flows.

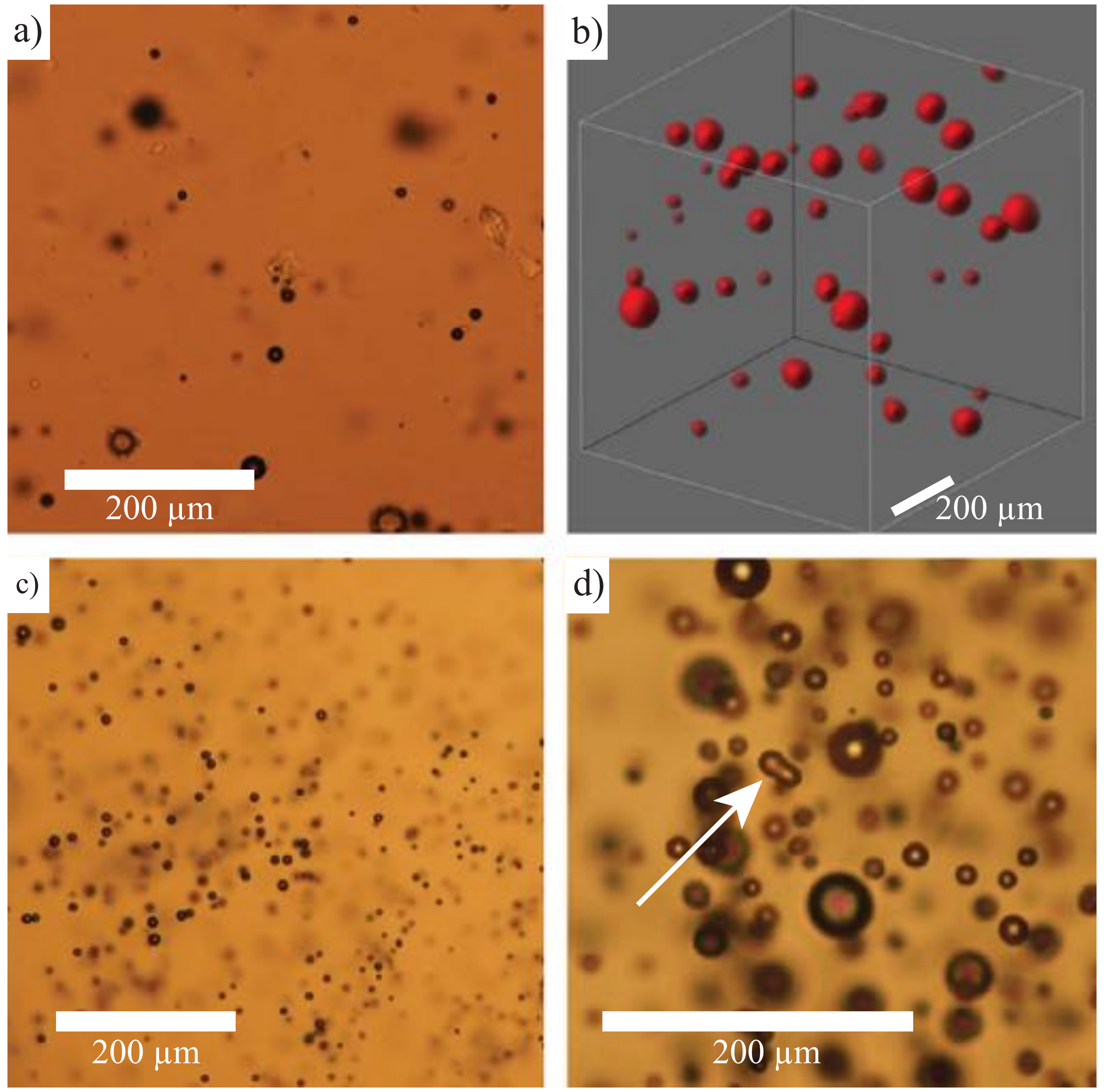
Quantifying MOR eruption rates

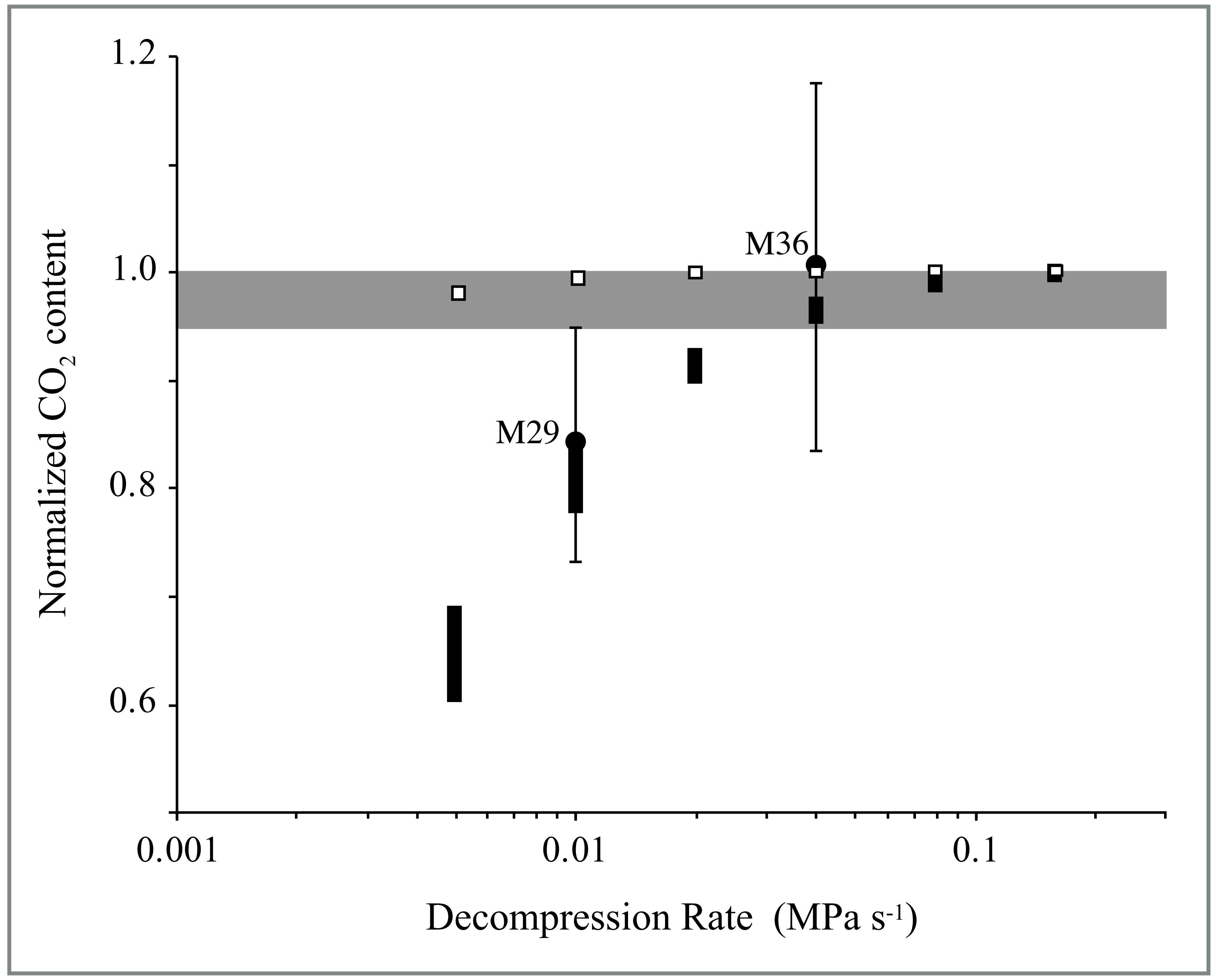


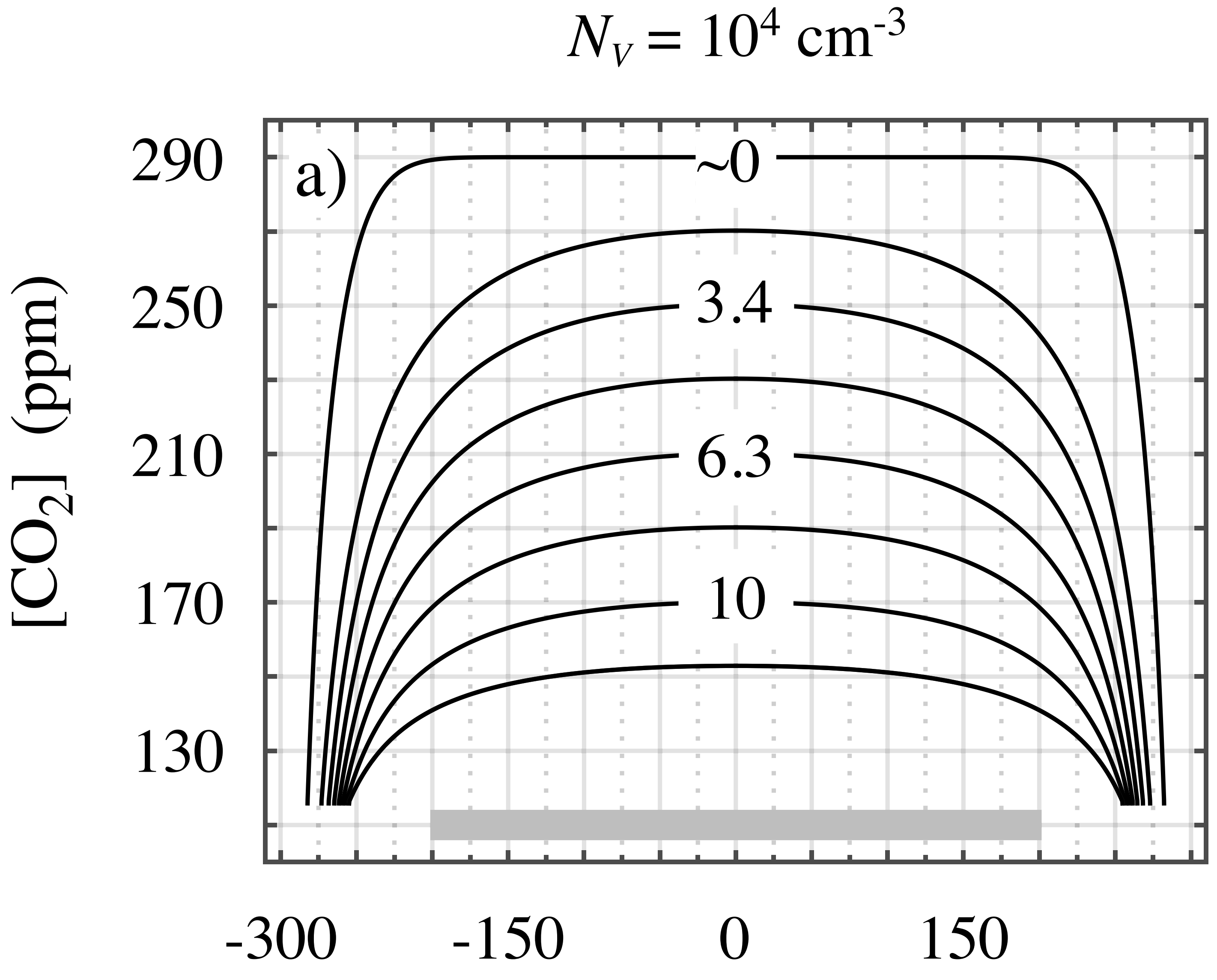


At fast to intermediate spreading rates, maximum dissolved CO_2 & H_2O are in equilibrium with observed (and predicted) melt storage depths and span a range approaching equilibrium with seafloor depths.

Rates of Decompression and Degassing



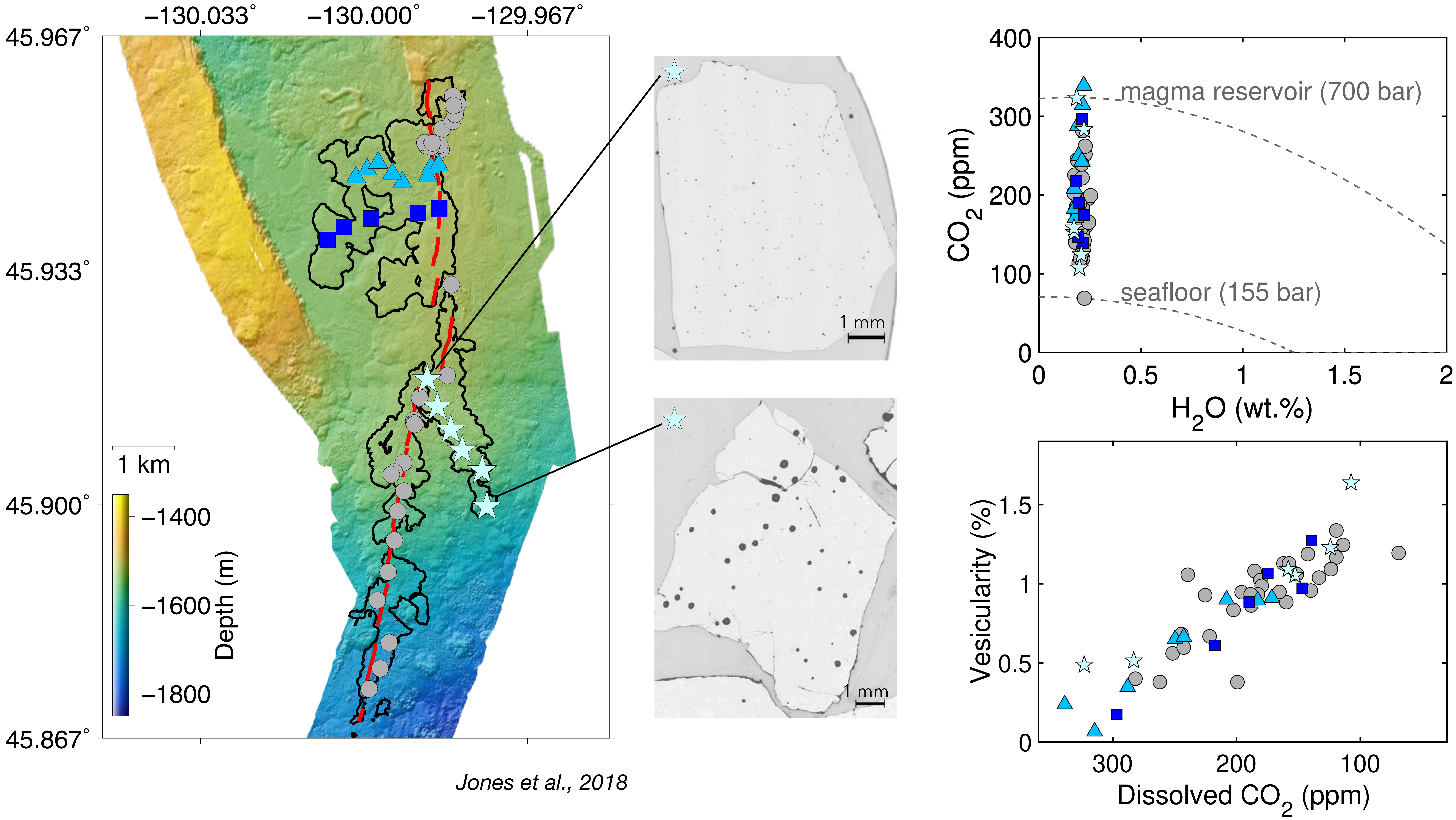




Gardner et al., 2017

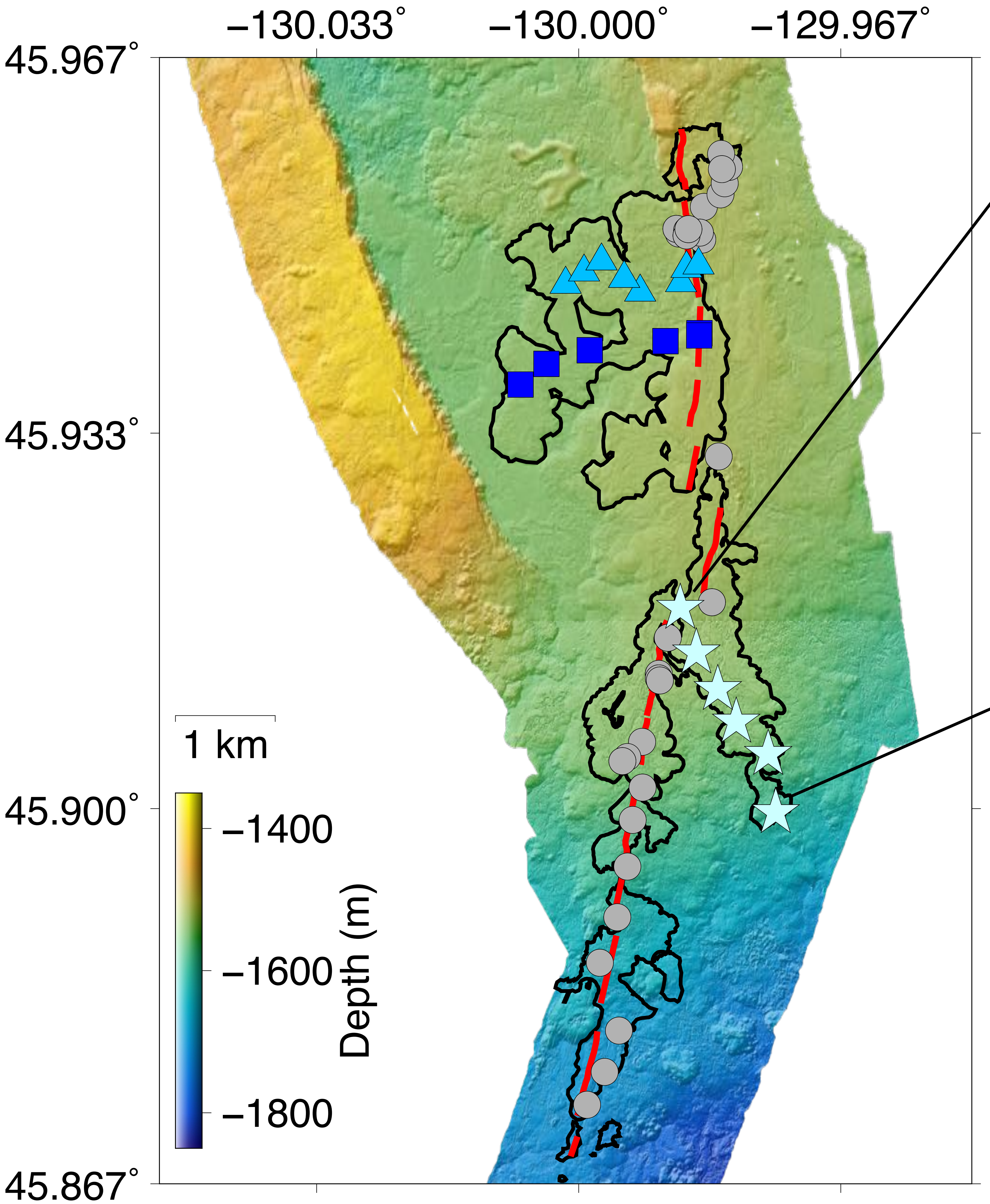
Decompression experiments on natural samples from the 2006-07 East Pacific Rise eruption determined an ascent rate of >0.2m/s and volumetric flow rates of $10^{3\text{-}4}$ m^3/s explain the observed CO_2 supersaturation. Experiments and modeling also demonstrated a strong dependence on degassing rate with number density (i.e., number/cm^3) of vesicles.

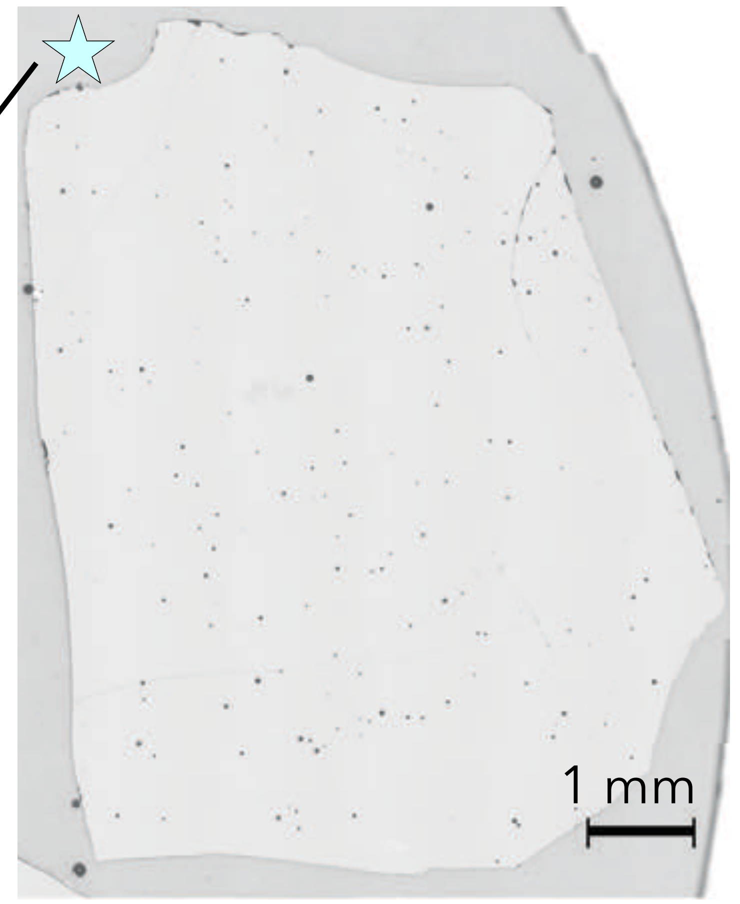
Application of CO_2 geospeedometry

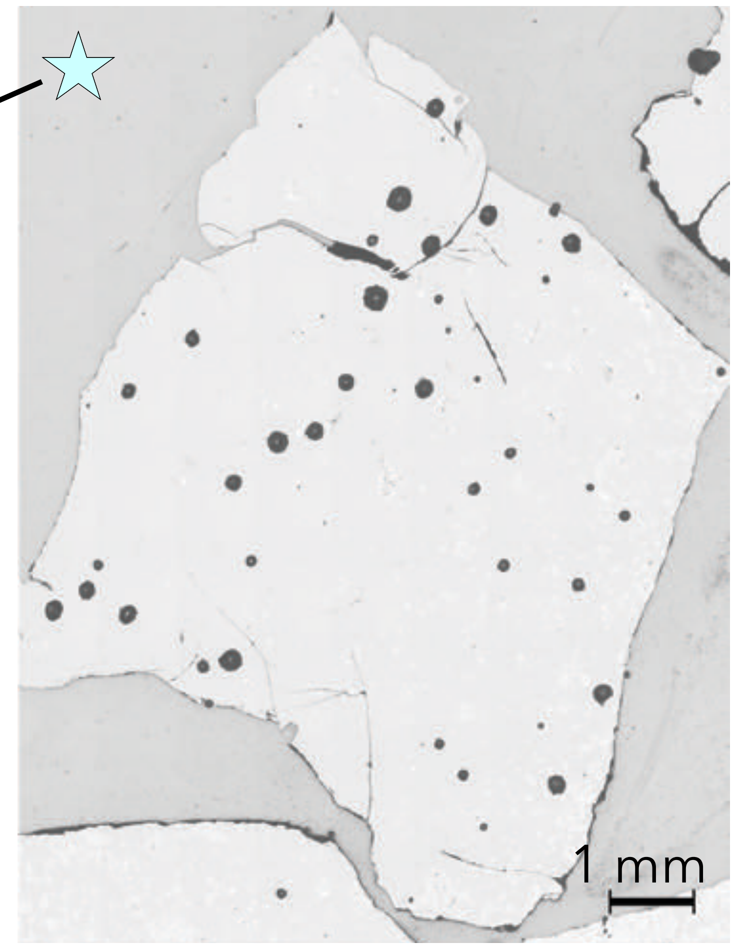


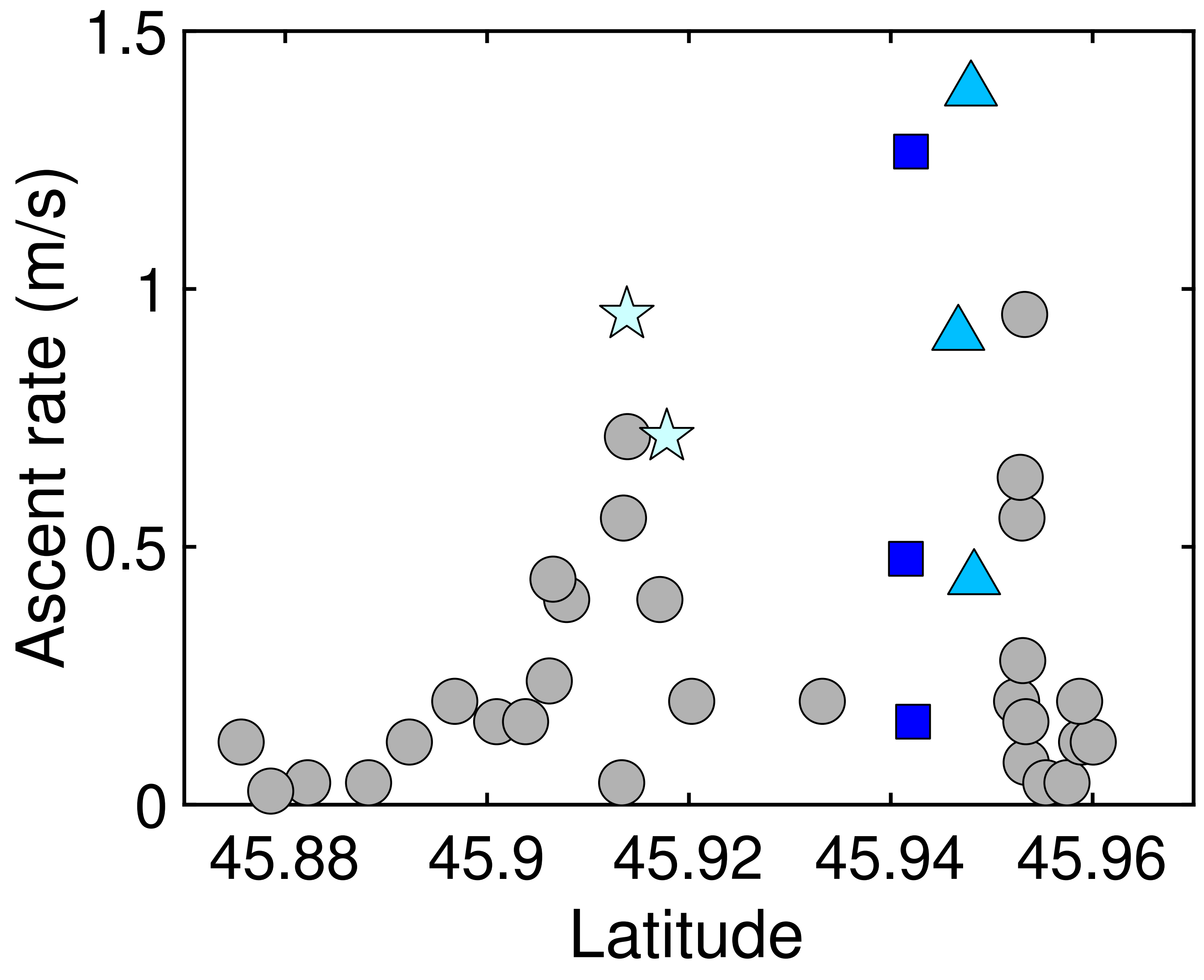
Jones et al., 2018

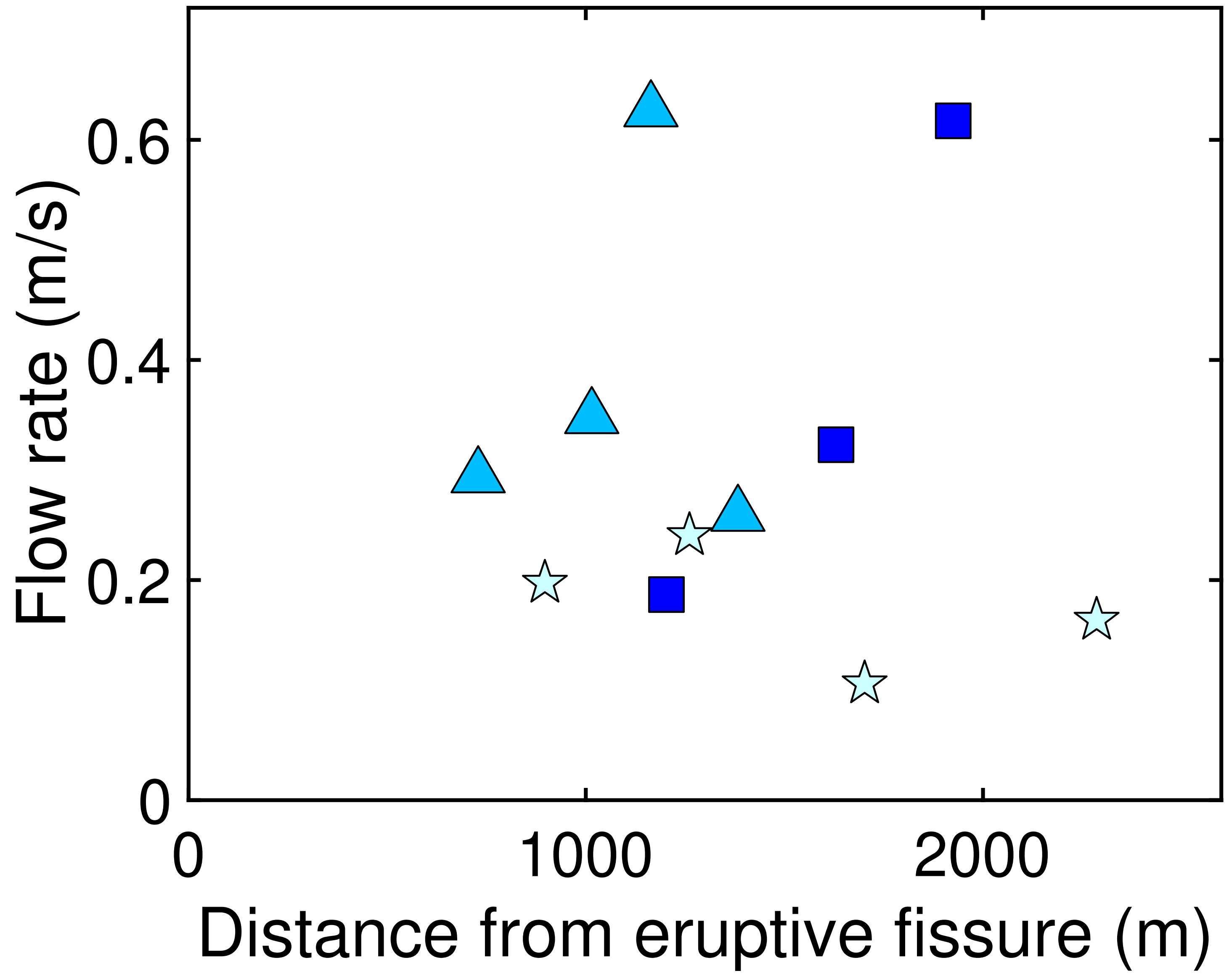
Application of CO_2 geospeedometry



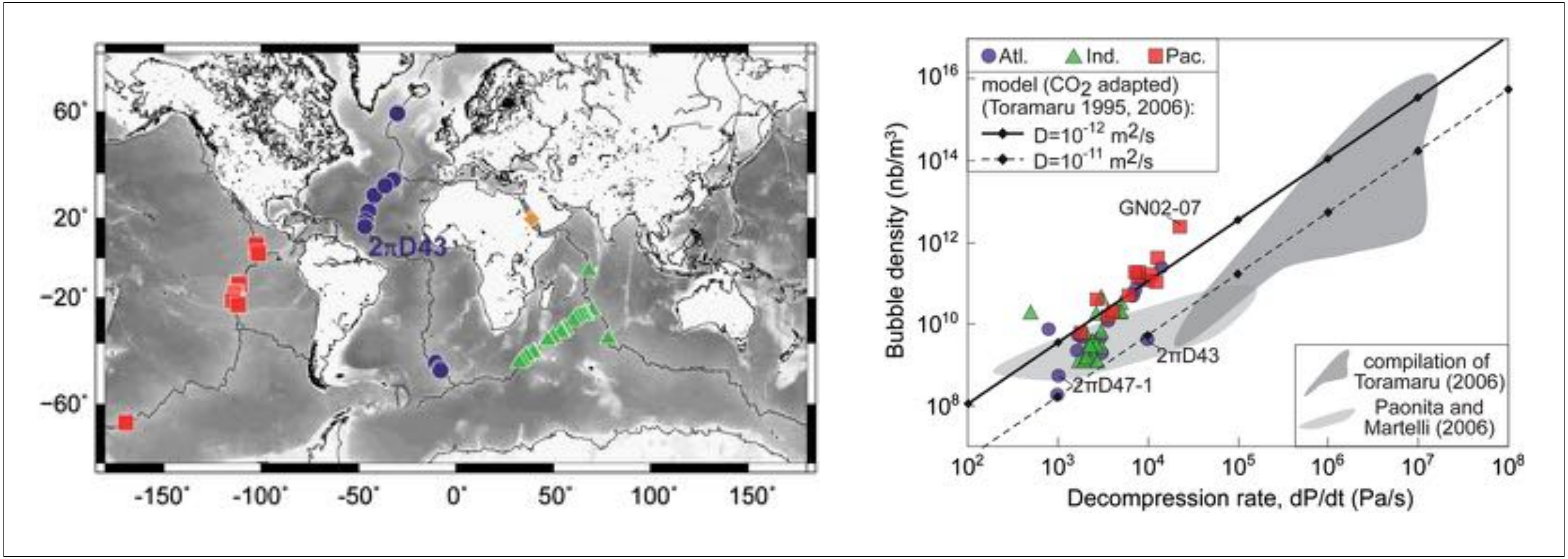








Jones et al., 2018

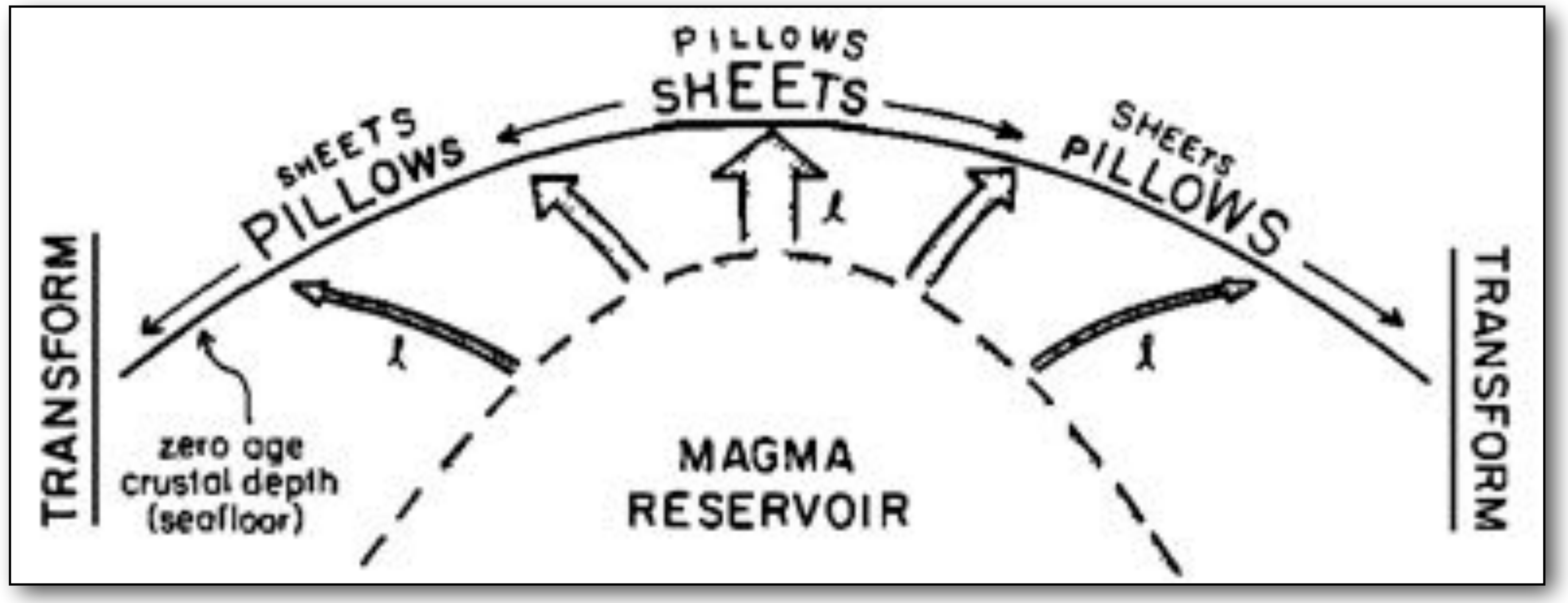


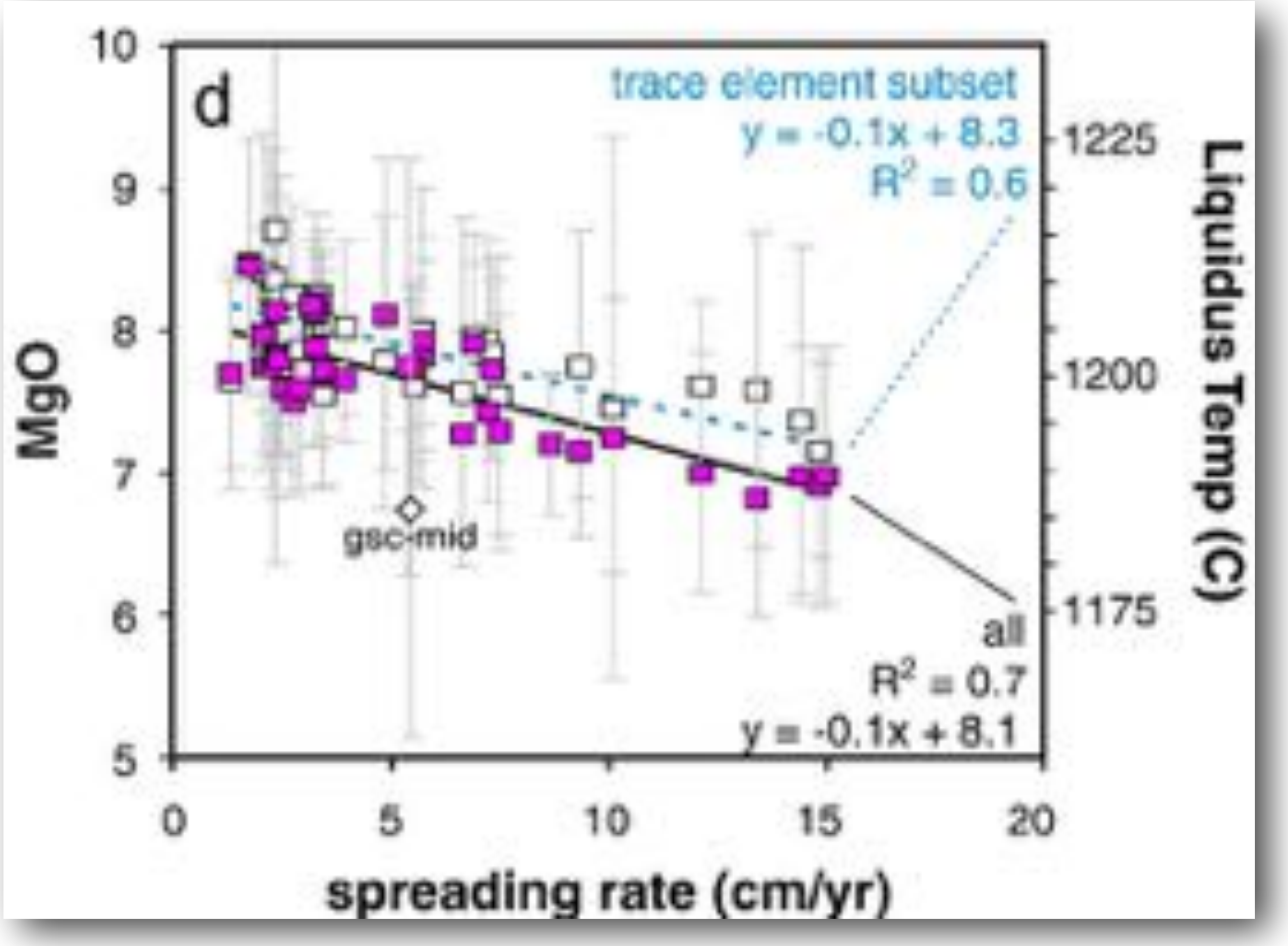
Chavrit et al. [2012] used a global dataset to demonstrate variations in decompression rate that broadly correlate with spreading rate.

What Controls eruption dynamics?

Cooling/viscosity

Bonatti & Harrison [1988] suggest that longer dike paths lead to greater cooling and increased viscosity.

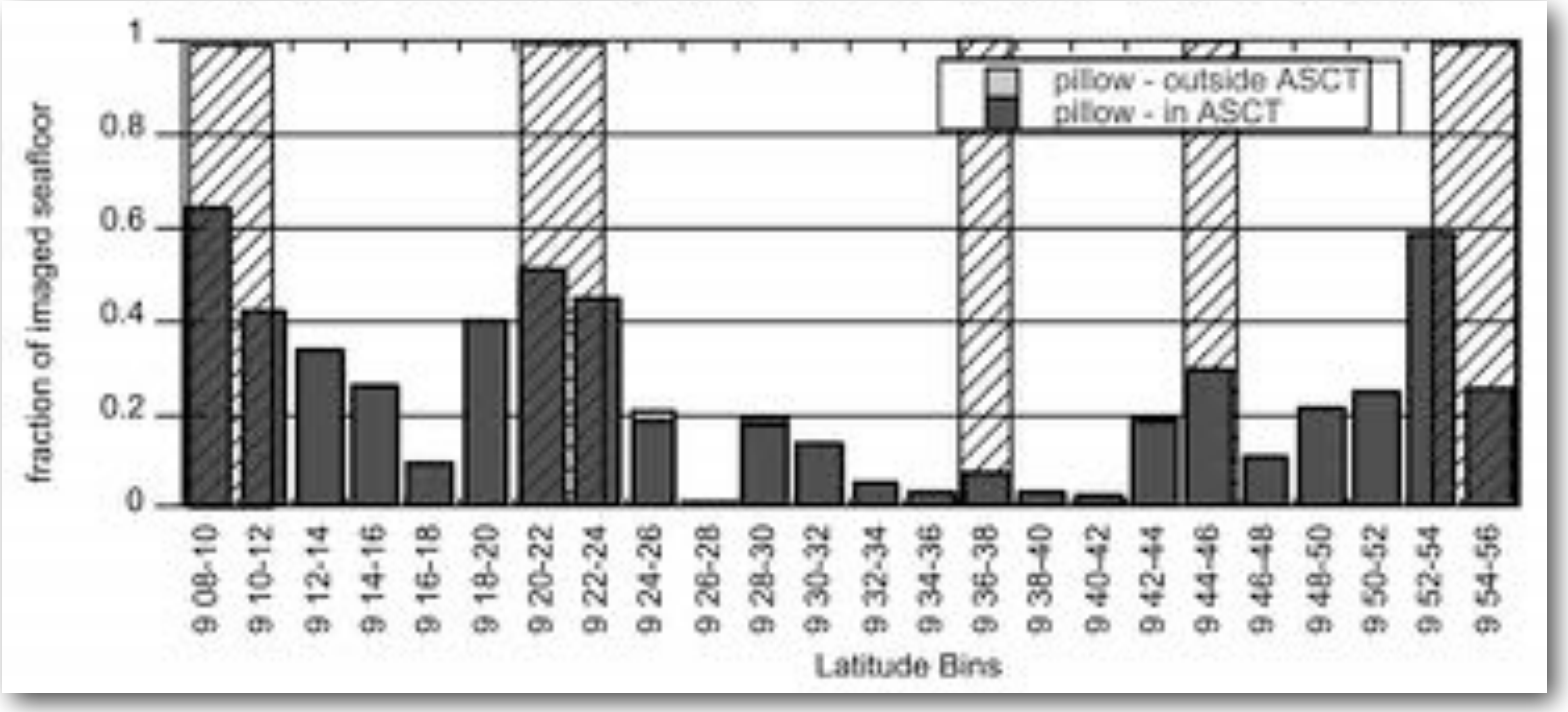




A compilation by Rubin & Sinton [2007] indicates that eruption temperatures are higher at slow-spreading ridges.

Variations in tectonic stress

Perfit & Chadwick [1998] suggest that increased tectonic stress at slow-spreading ridges (due to less frequent earthquakes) lead to lower overpressure in magma reservoirs and lower eruption rate.



Observations [e.g., White et al., 2004] suggest changes in eruption rate over length scales that are inconsistent with differences in tectonic stress.

Deep thought #2

Are there frequency/size/eruption rate relationships with spreading rate (i.e., magma supply) and what controls them?

What controls MOR eruption dynamics?

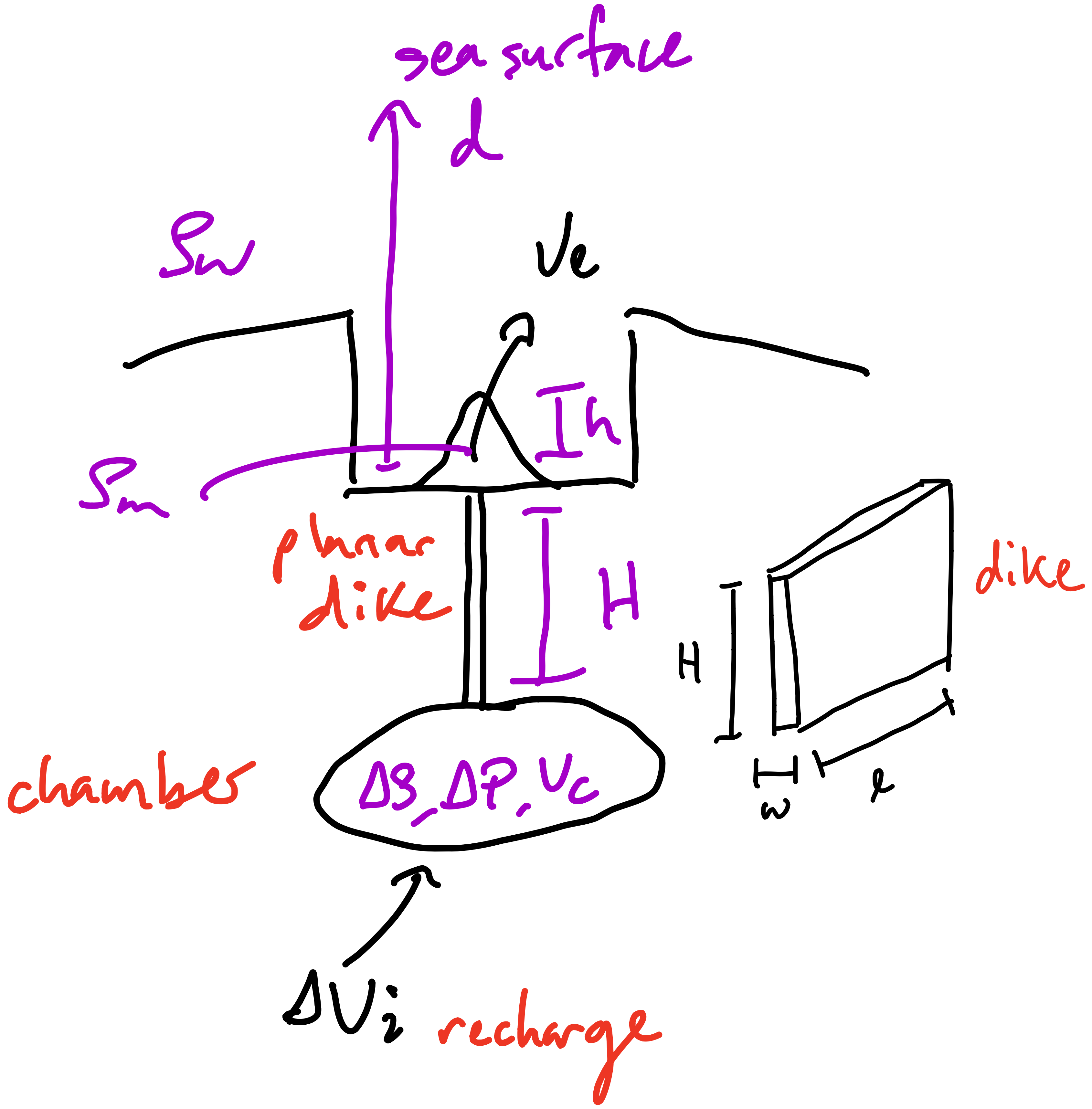
Karlstrom, Gonnermann

$$V_c = \frac{\Delta P(t)}{K} = \Delta V_i - V_e(t)$$

Mass balance in magma reservoir

$$Q = \frac{w^3 l}{12\mu}\left(\frac{\Delta\rho g H + \Delta P - (\rho_m - \rho_w) g h - \rho w g (d - h)}{H + h}\right)$$

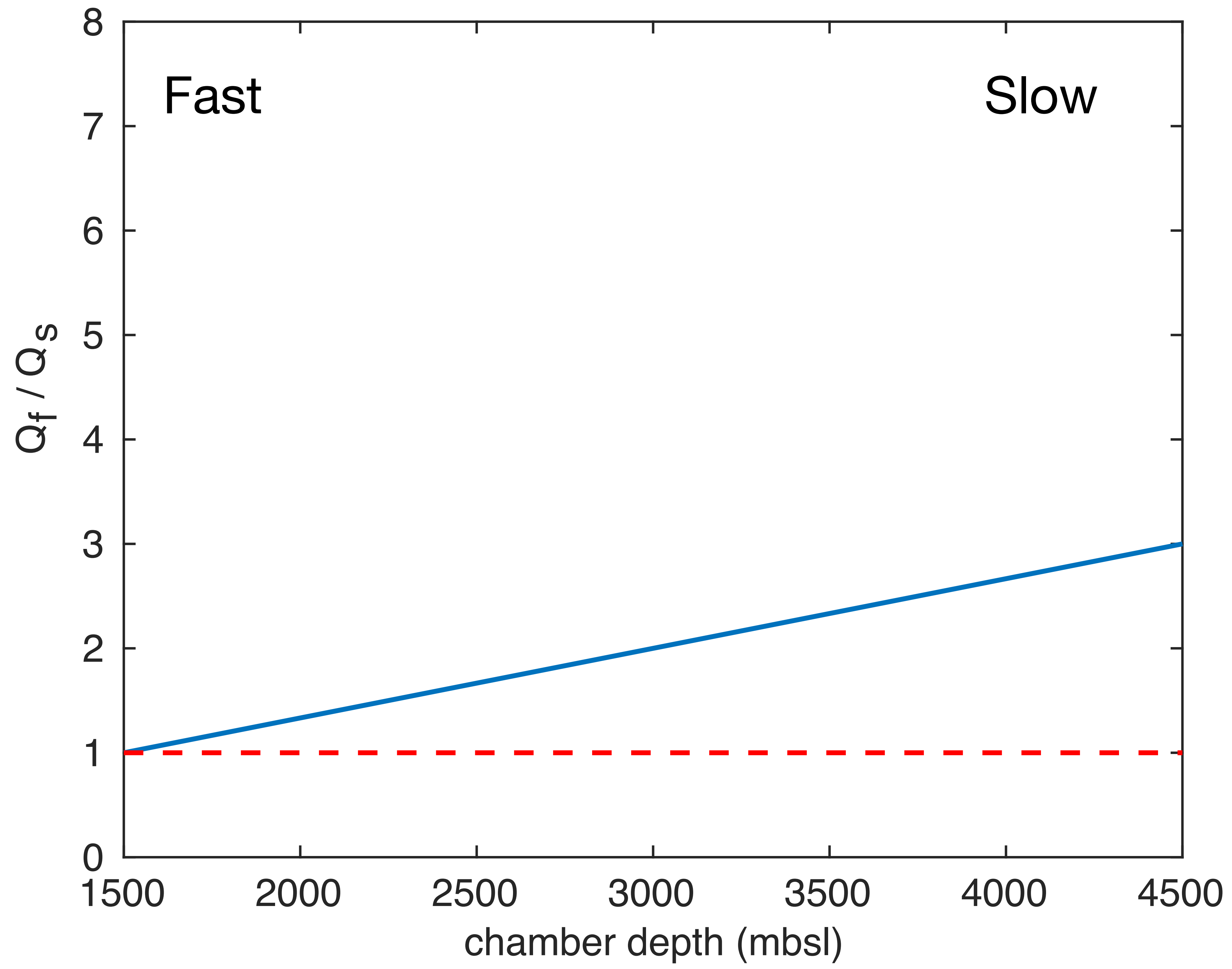
Flow through a dike (Castruccio et al., 2017)

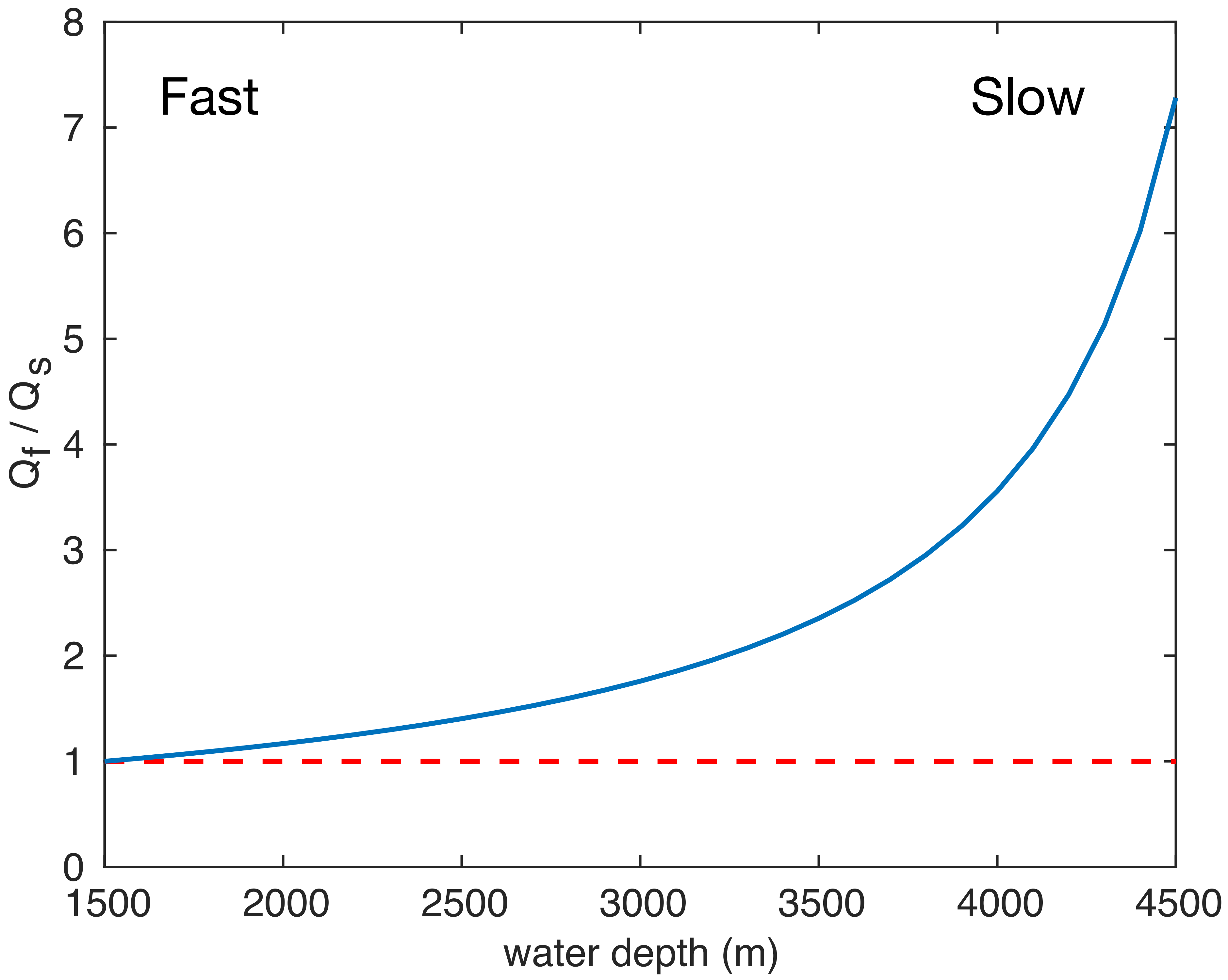


$$Q \equiv \frac{dV_e}{dt} = b\left(\frac{\Delta\rho g H - (\rho_m - \rho_w) g h - \rho_w g (d - h)}{H + h} + \frac{K}{V_c (H + h)}(\Delta V_i - V_e(t))\right)$$

What controls MOR eruption dynamics?

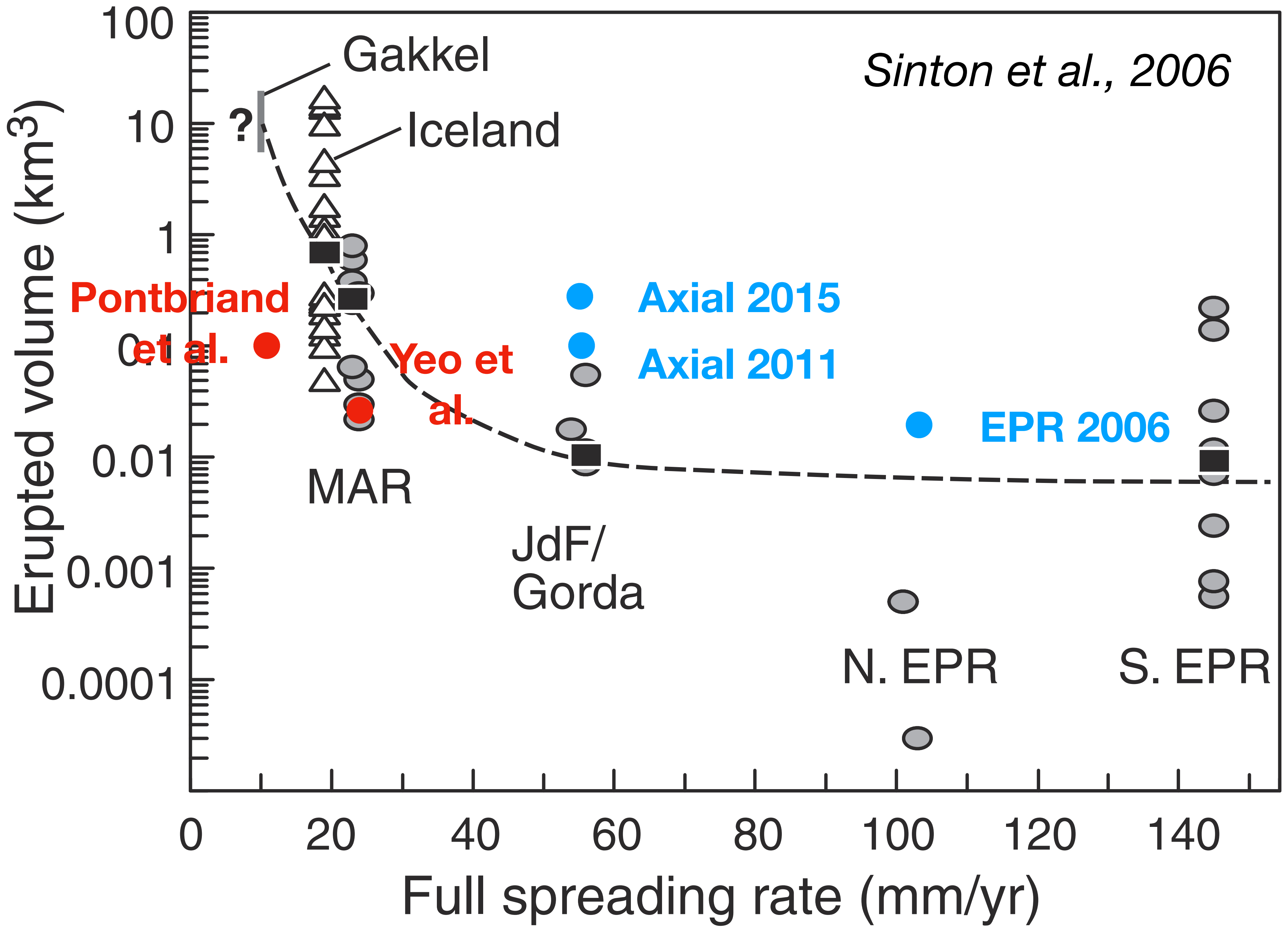
for equivalent initial overpressure, buoyancy, and chamber size…
the relative eruption rate for deeper ridges and magma chambers significantly decreases.



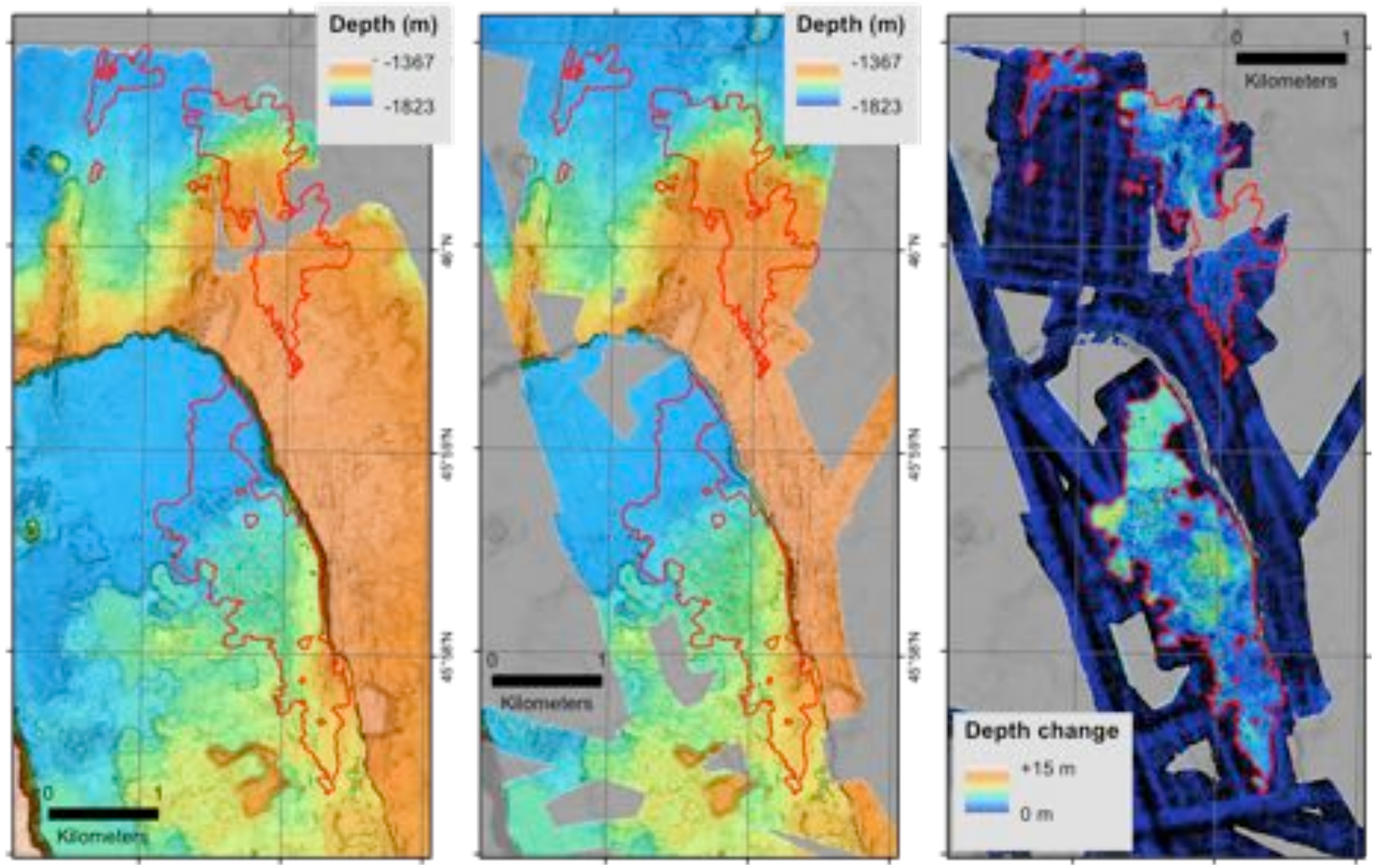


Perhaps the fundamental characteristics of ridges, largely controlled by spreading rate (sic. thermal structure) determine the global variations in eruption rate?

Eruption Size



courtesy of D. Clague

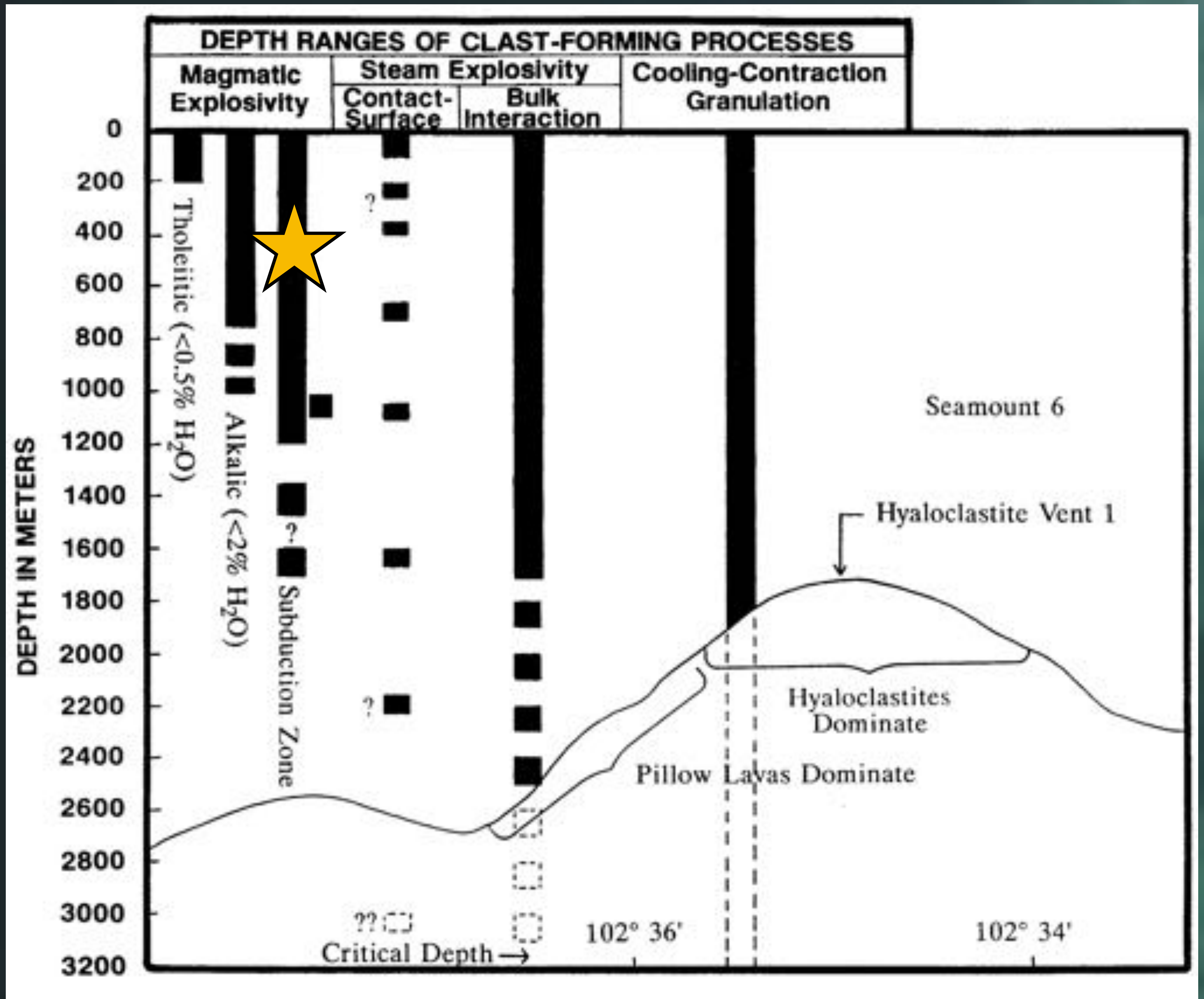


Pre 2015 bathymetry Post 2015 bathymetry Bathymetric difference

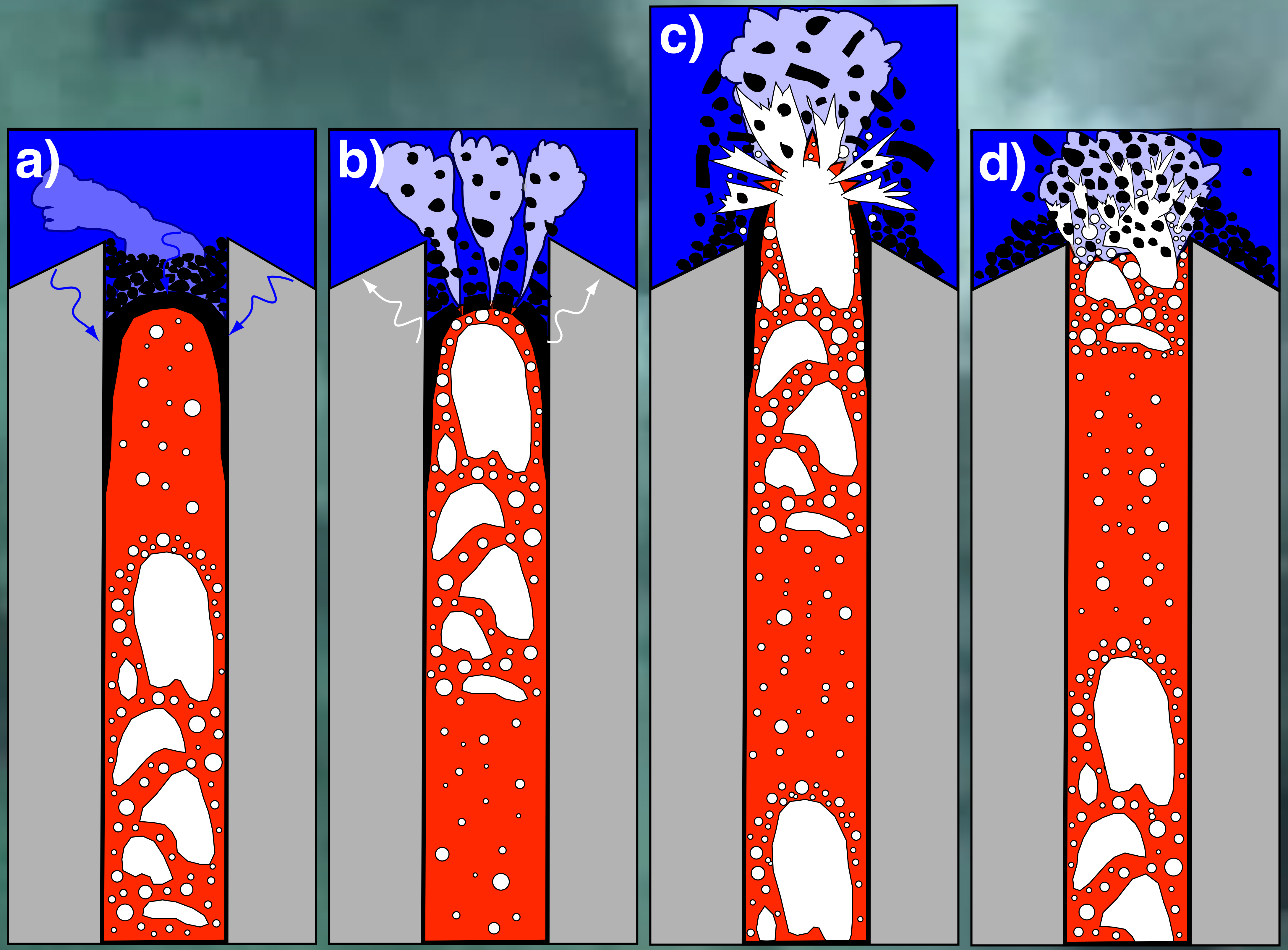
The previous model predicts greater eruption size at fast-spreading ridges, contrary to the current view, which is highly underdetermined.

Submarine Arc Volcanism

Perspective view to SE across Havre Caldera



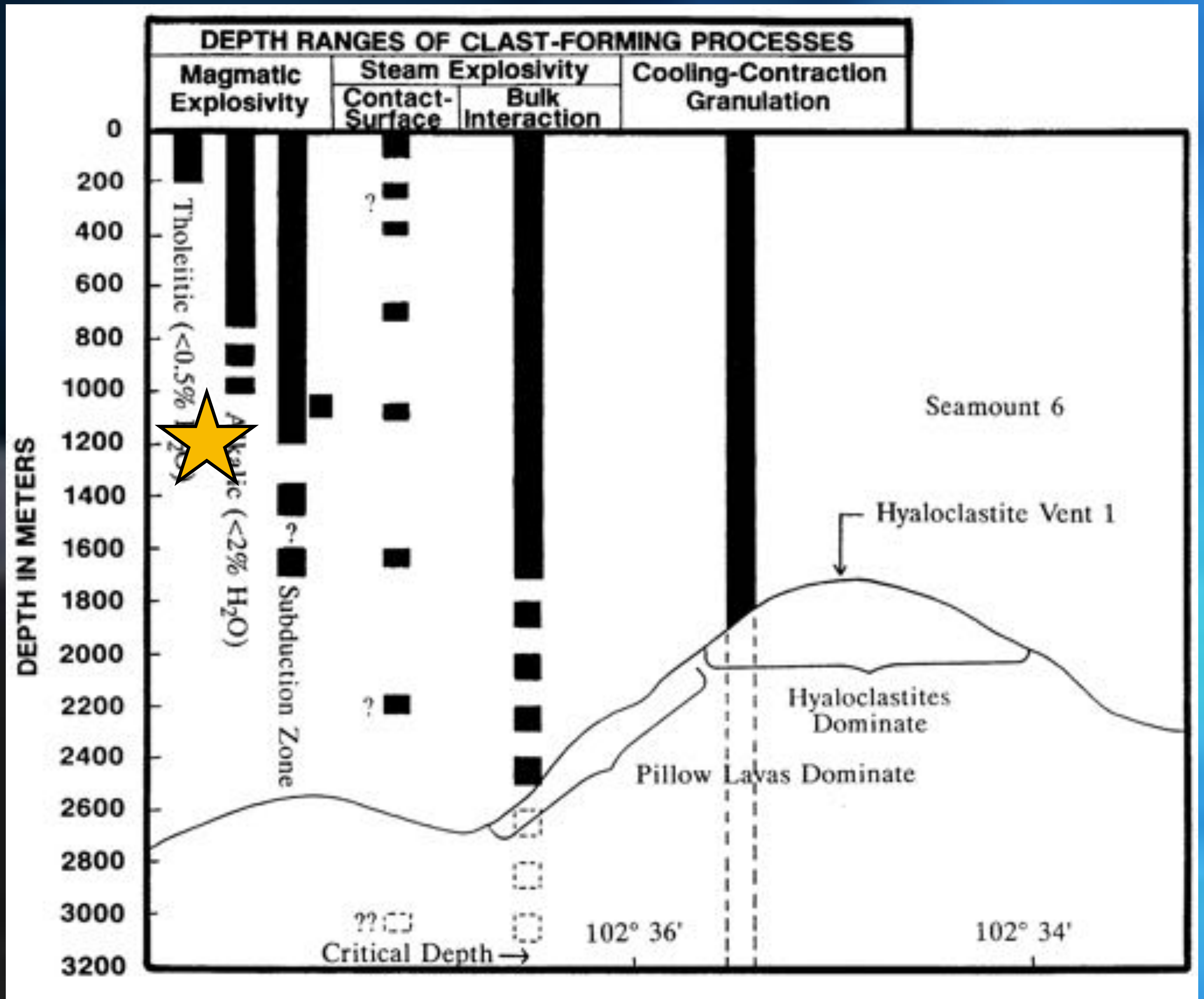
Head & Wilson, 2003



Chadwick et al., 2008

NW Rota, Mariana Arc, Brimstone Vent

video from NOAA/WHOI

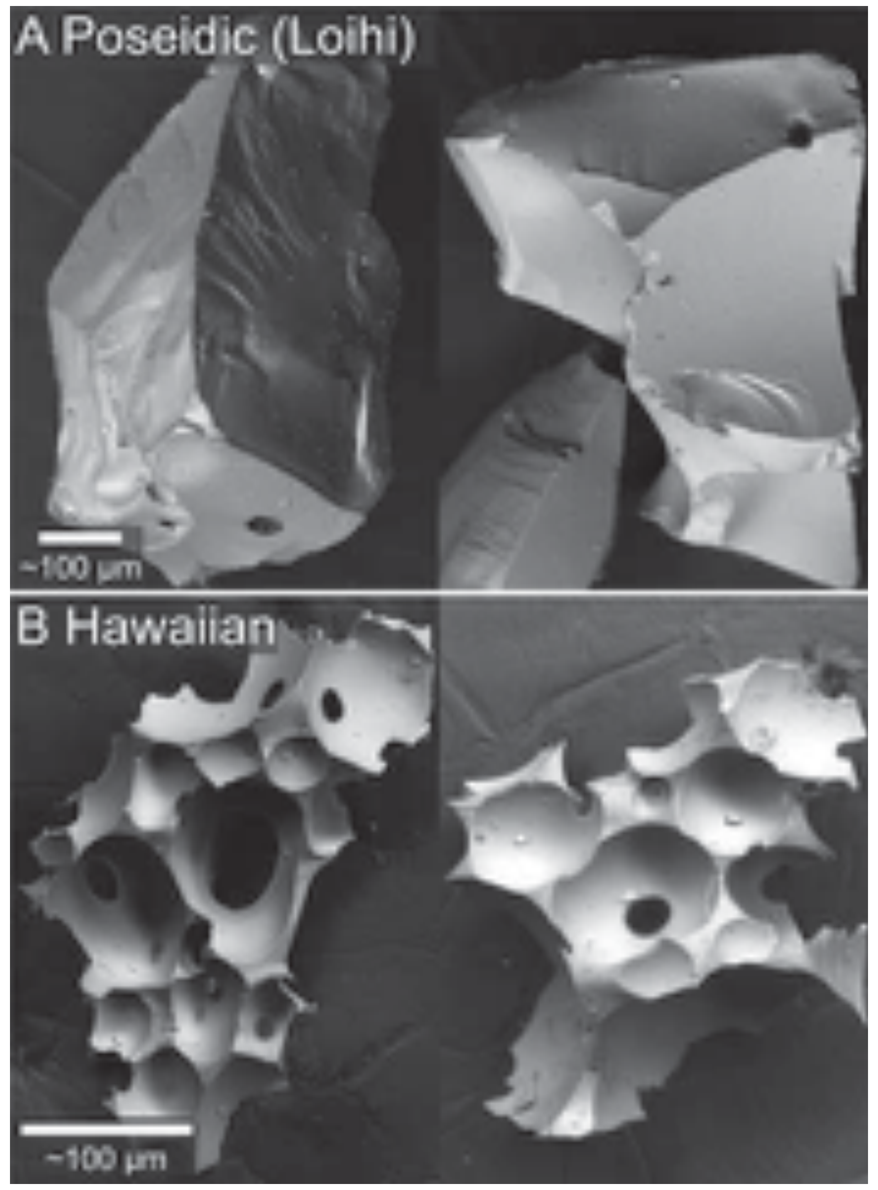


Head & Wilson, 2003

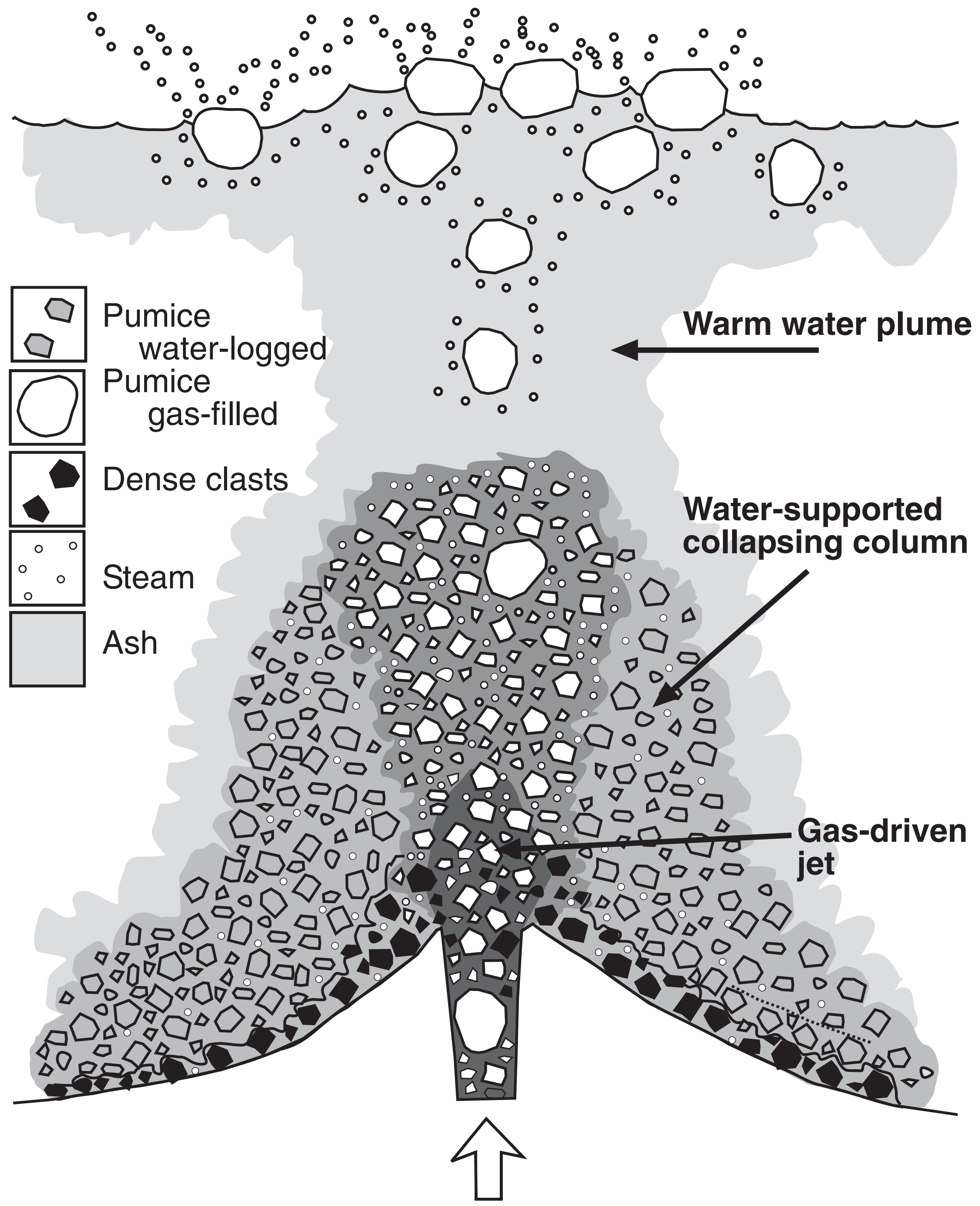
W Mata, NE Lau Basin

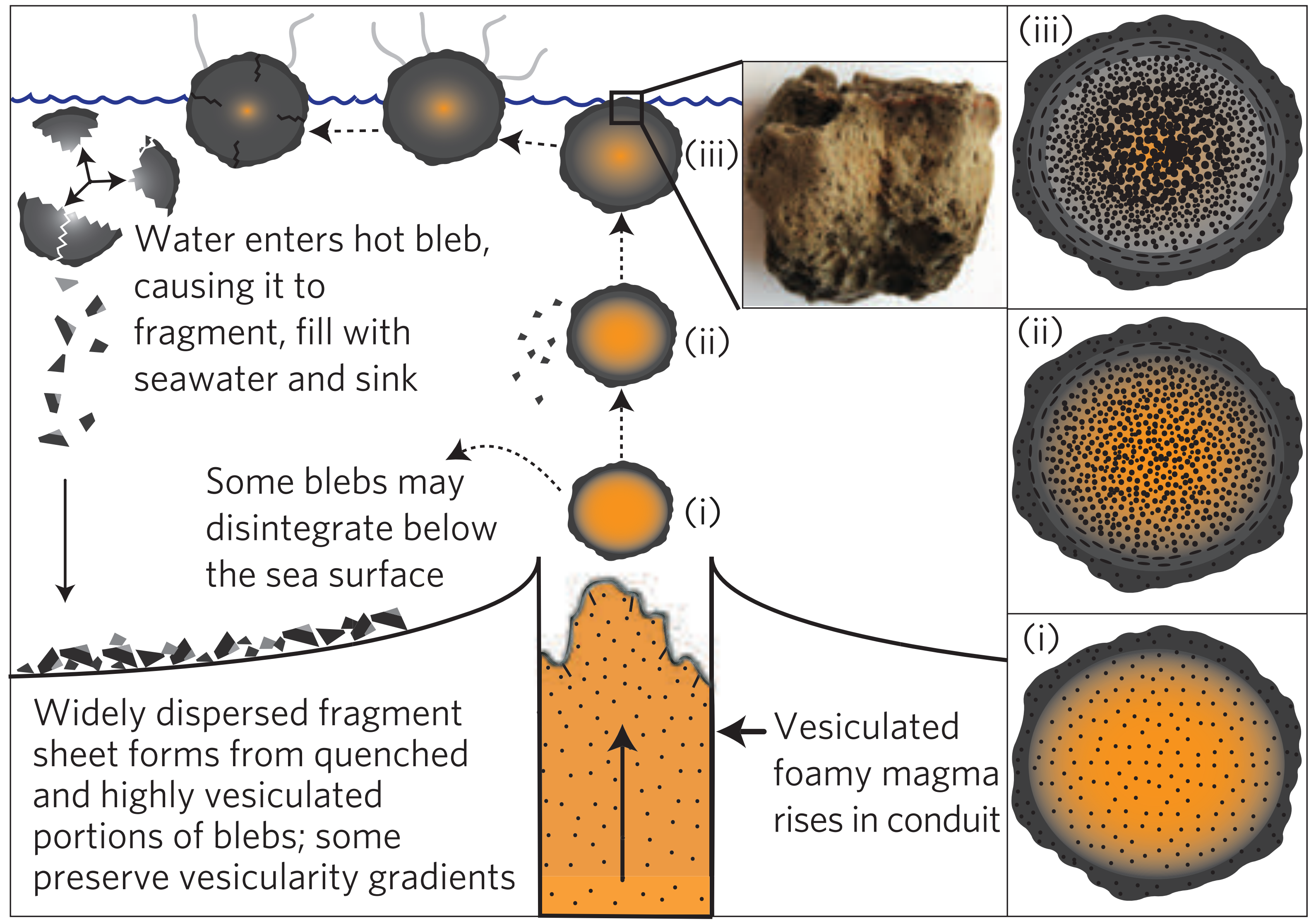
video from NSF/NOAA/WHOI

Poseidic - Schipper et al., 2010

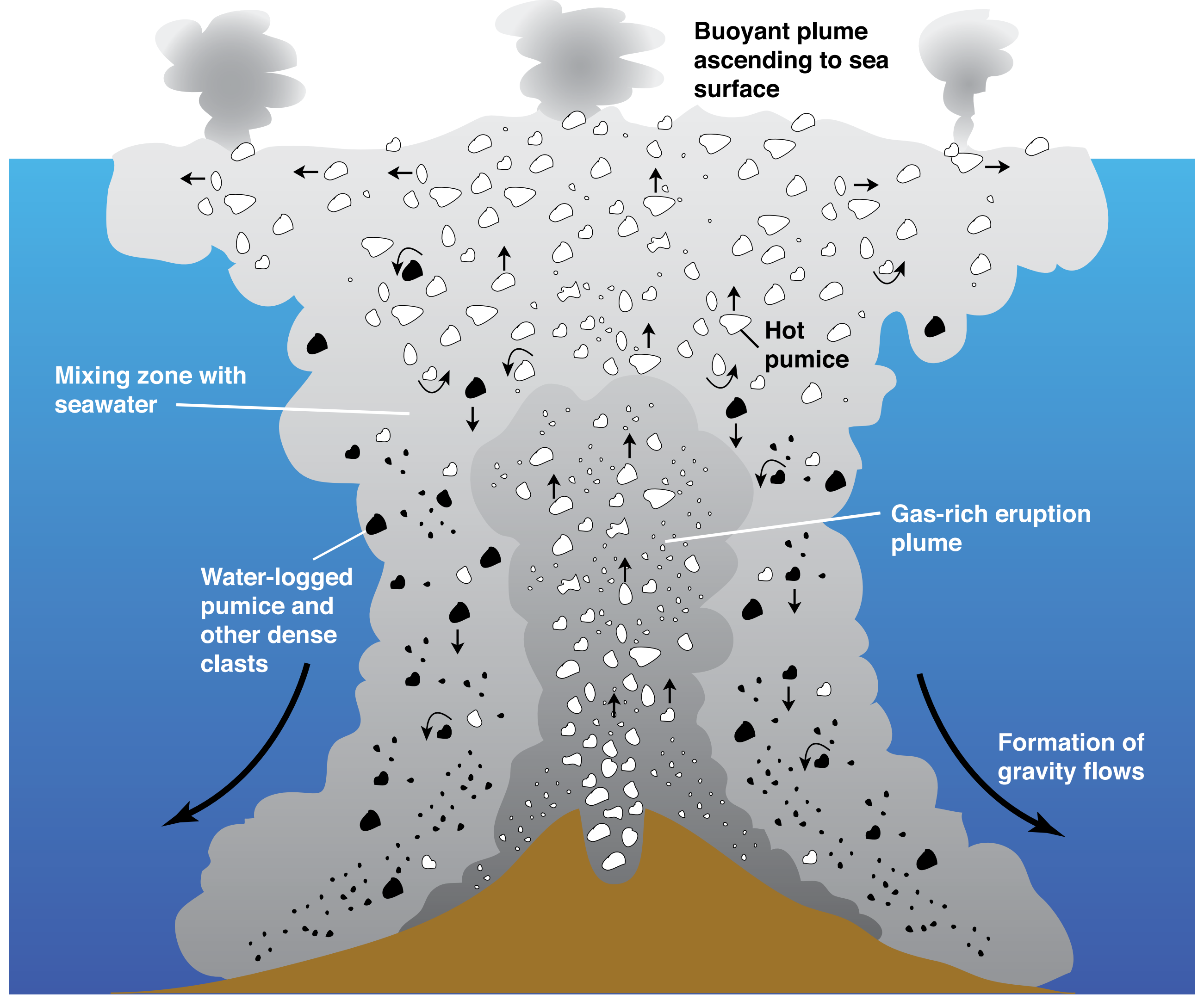


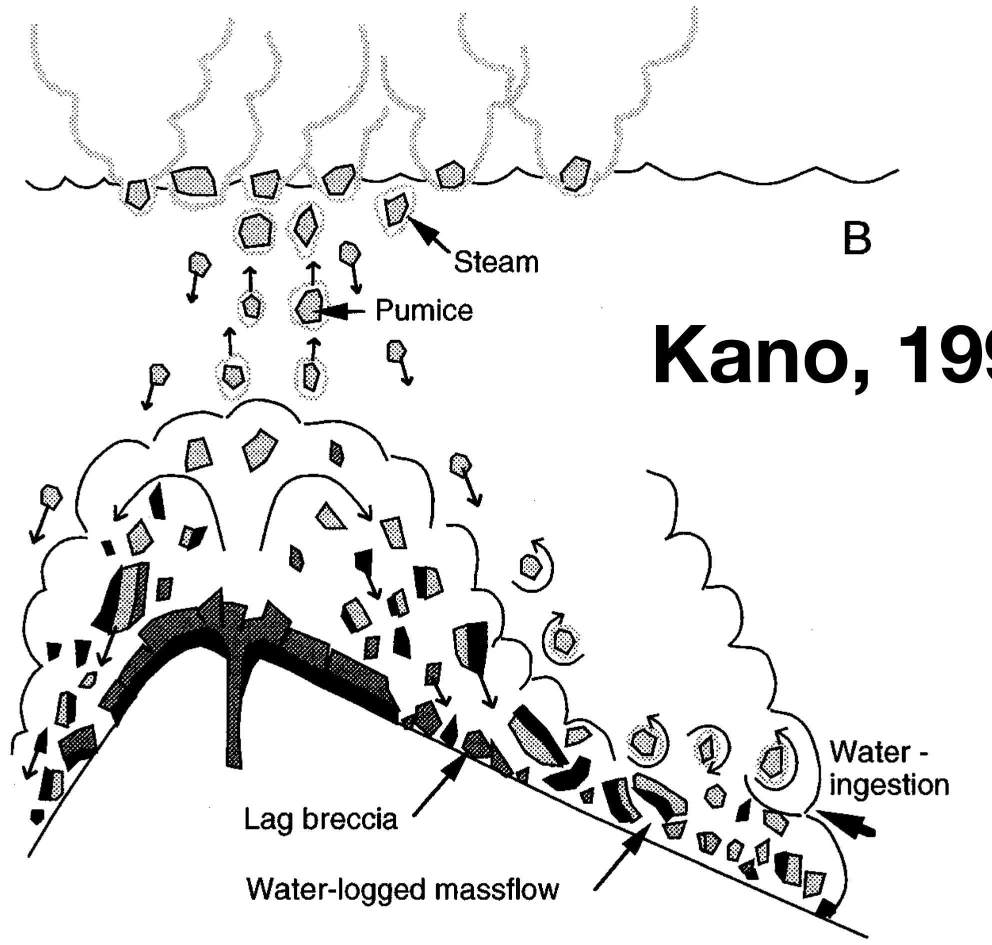
Neptunian - Allen & McPhie, 2009



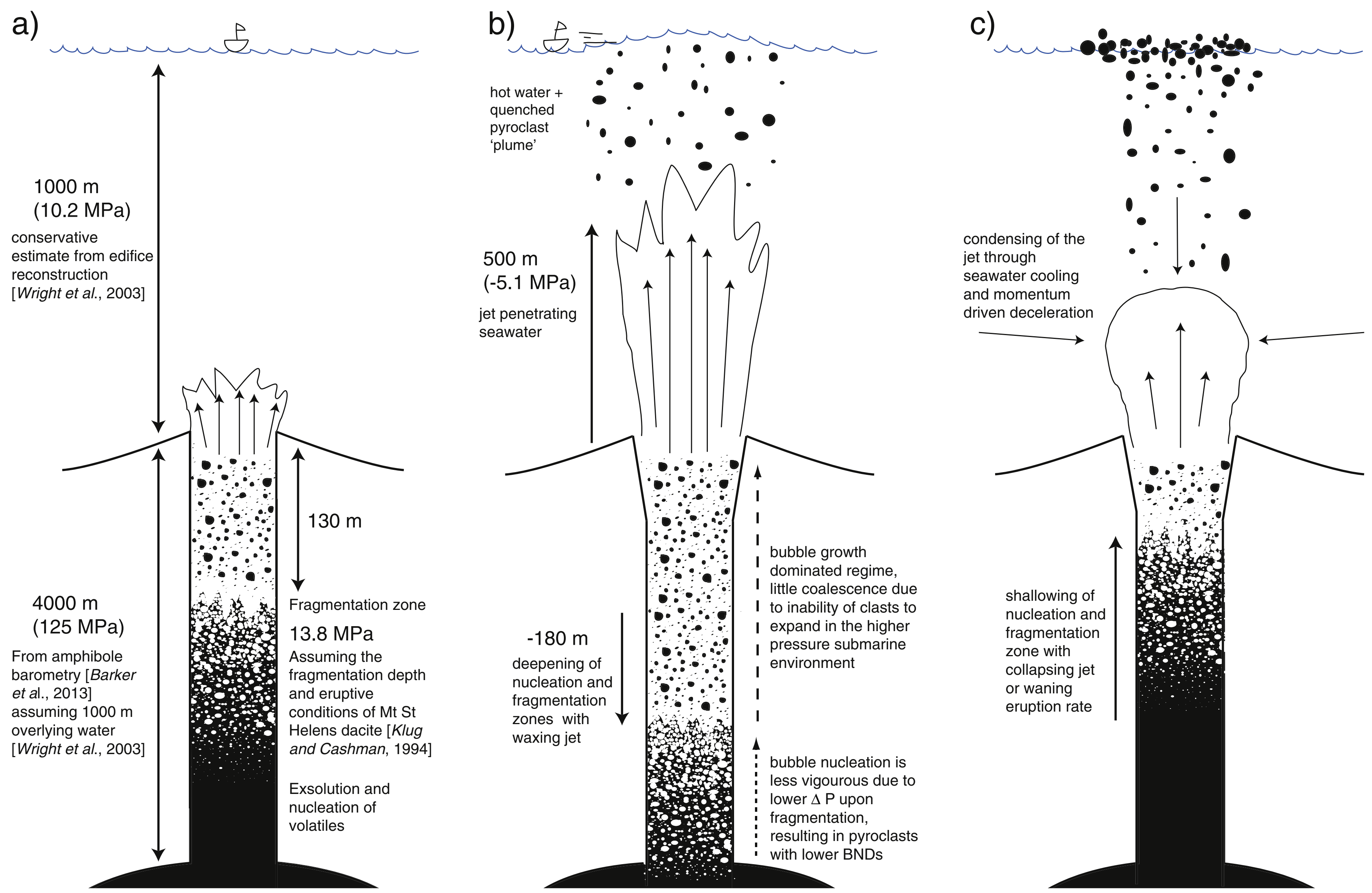


Tangaroan - Rotella et al., 2013





Kano, 1996



after Kano et al., 1996

Rotella et al., 2015

Deep thought #3

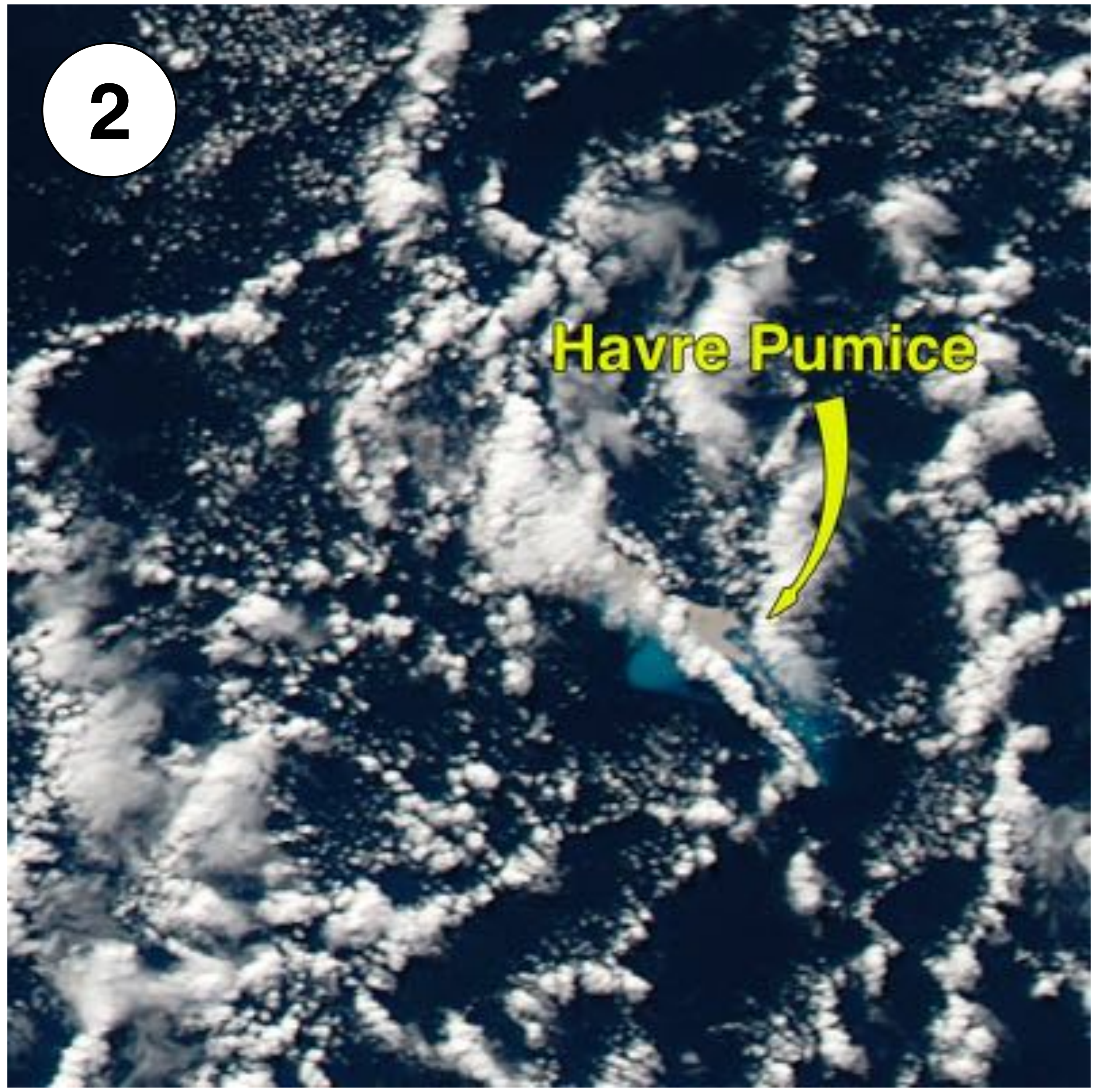
What influence does seawater have on fragmentation and dispersal in submarine arc eruptions i.e., can magmatically-driven pyroclastic eruptions occur in the deep ocean (>1000m)?

How can deposit characteristics be inverted to constrain eruption processes?

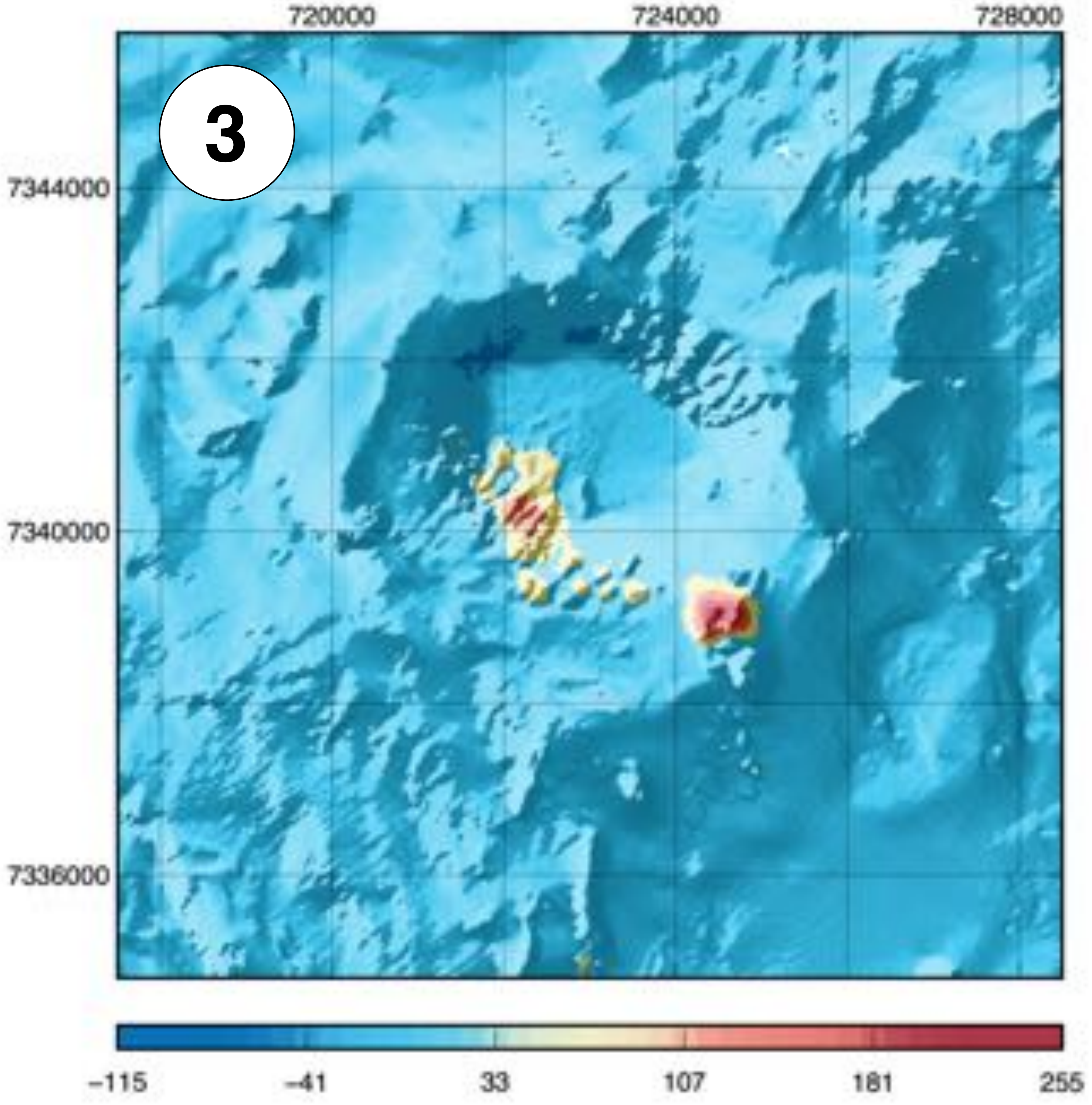
Discovery of the Havre 2012 Eruption

HMS Canterbury discovered pumice raft

MODIS satellite image, 19 July 2012



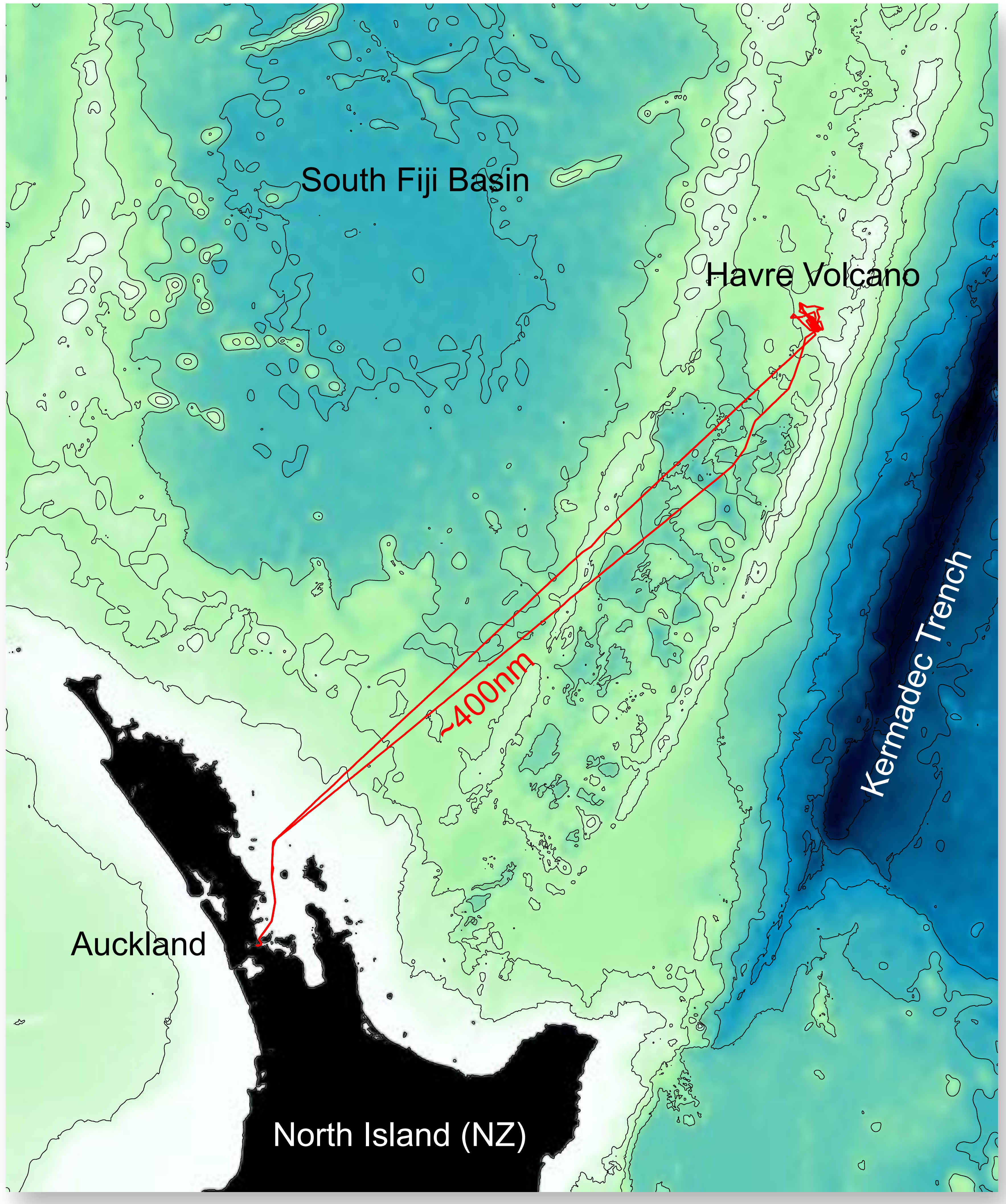
Jutzeler et al., 2014



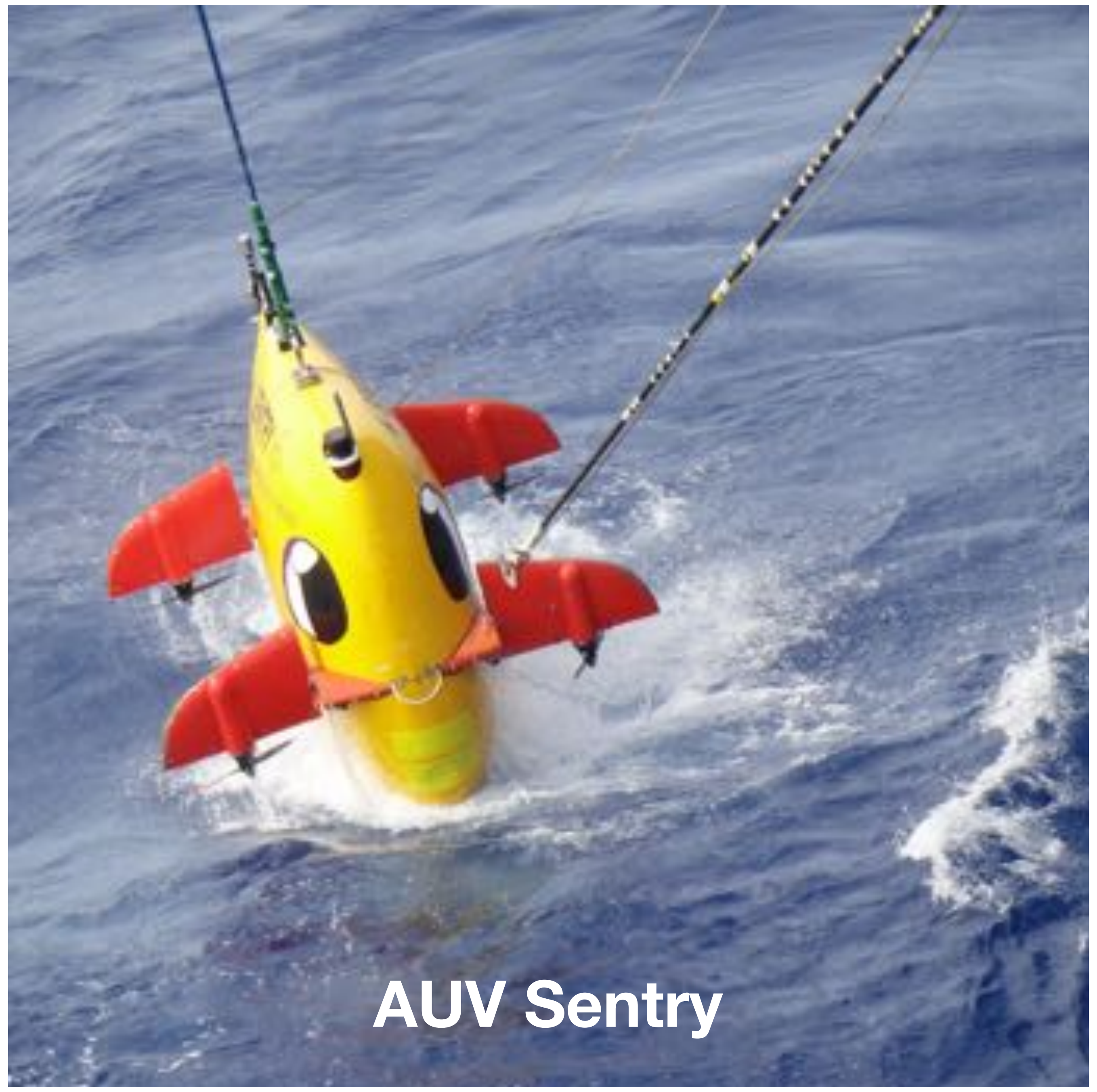
Carey et al., 2014

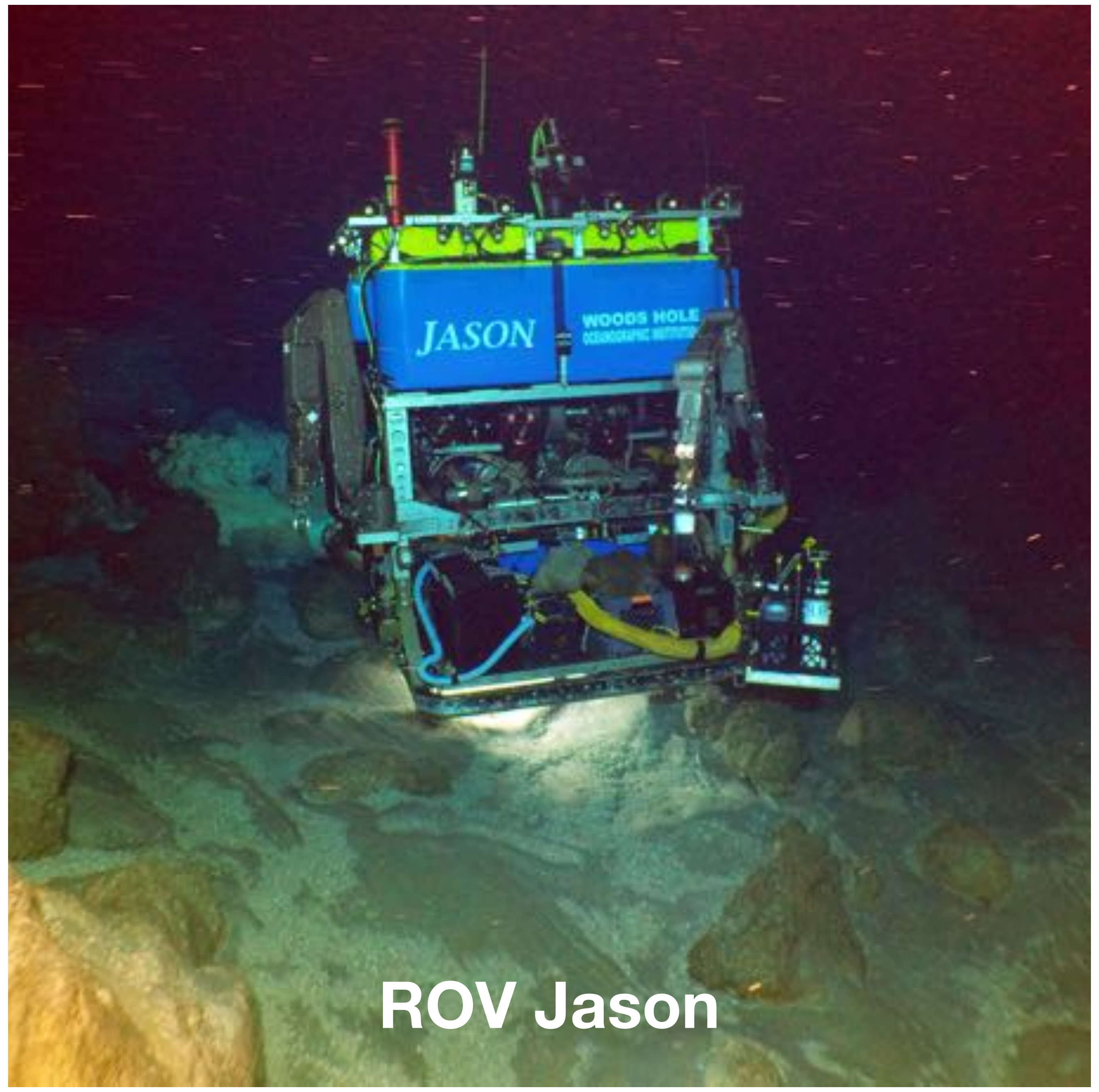
First viewed by a passenger on an airpline, the pumice raft was intersected by the NZ Navy and subsequently tracked to its source using satellite imagery. The pumice raft area was ~40 km^2 and its volume is estimated ~1 km^3

Mapping, Exploration, and Sampling at Havre (MESH)



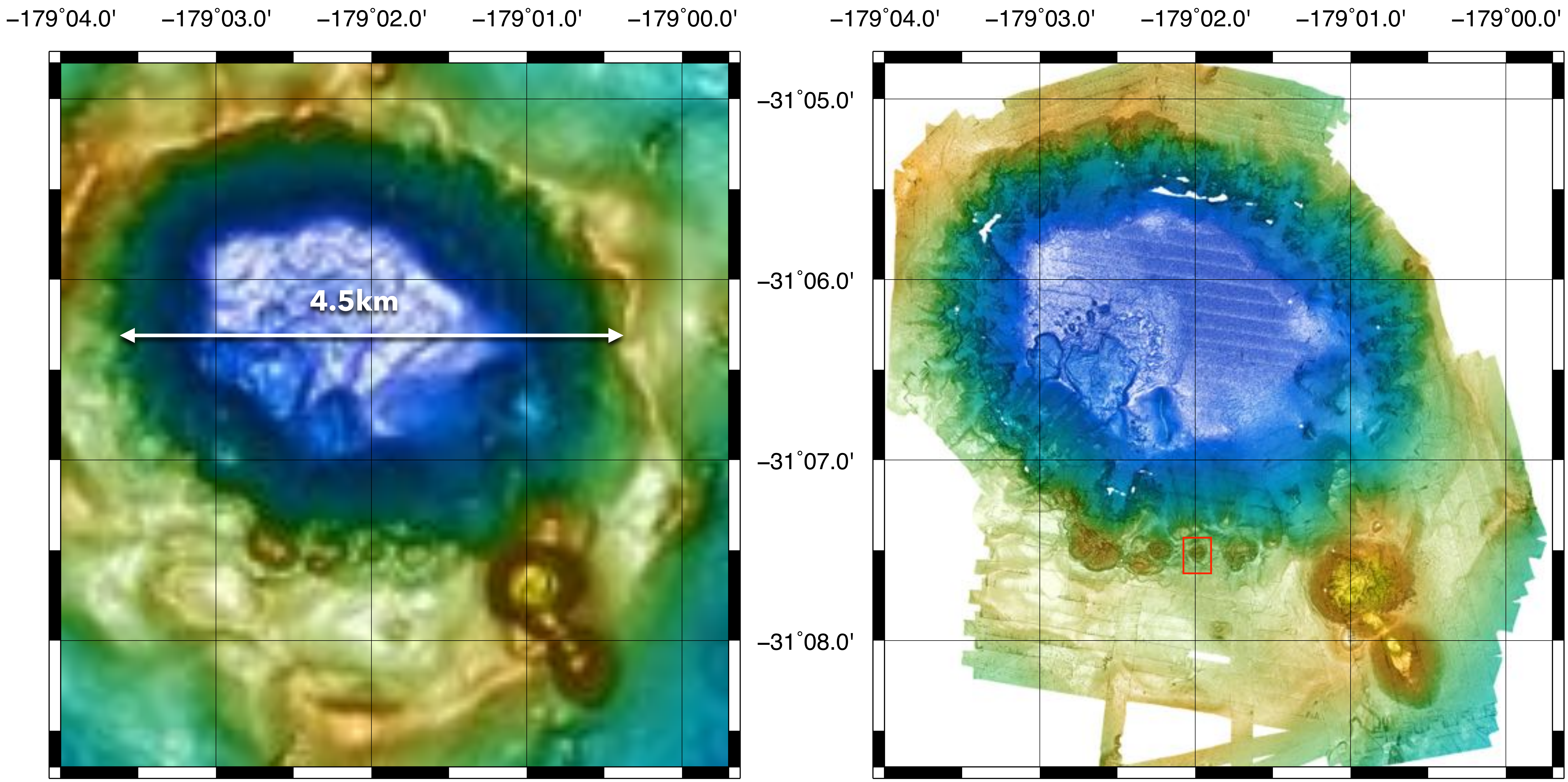
Carey et al., 2018





- **AUV Sentry**
  - (12 dives, 56km^2 survey area)
- **ROV Jason**
  - (12 dives, 240h bottom time)
  - (290 samples of rock, sediment)
  - (heat flow measurements)
- **Coring & clamshell grabs**
  - (35 cores/grabs, ~20 successful)

AUV Mapping


–179˚04.0'
–179˚03.0'
–179˚02.0'
–179˚01.0'
–179˚00.0'
4.5km
–31˚05.0'
–31˚06.0'
–31˚07.0'
–31˚08.0'
–179˚04.0'
–179˚03.0'
–179˚02.0'
–179˚01.0'
–179˚00.0'


100m


~850 m

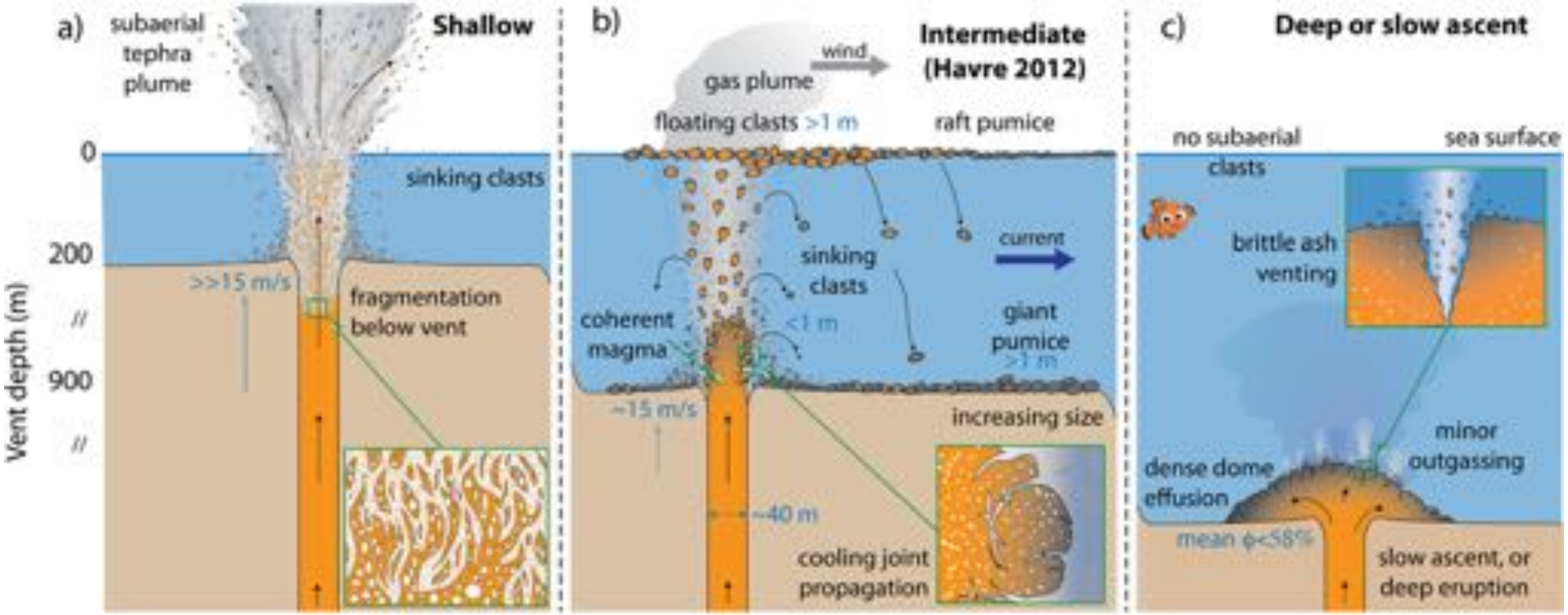

~850 m
Santiaguito, photovolcanica.com


Shastina Lava Flows, Miller, 1980


~850 m

~850 m
Pumice Raft
Lava & Domes
Seafloor Pyroclastic
0.8
0.6
0.4
0.2
0
Volume (km³)

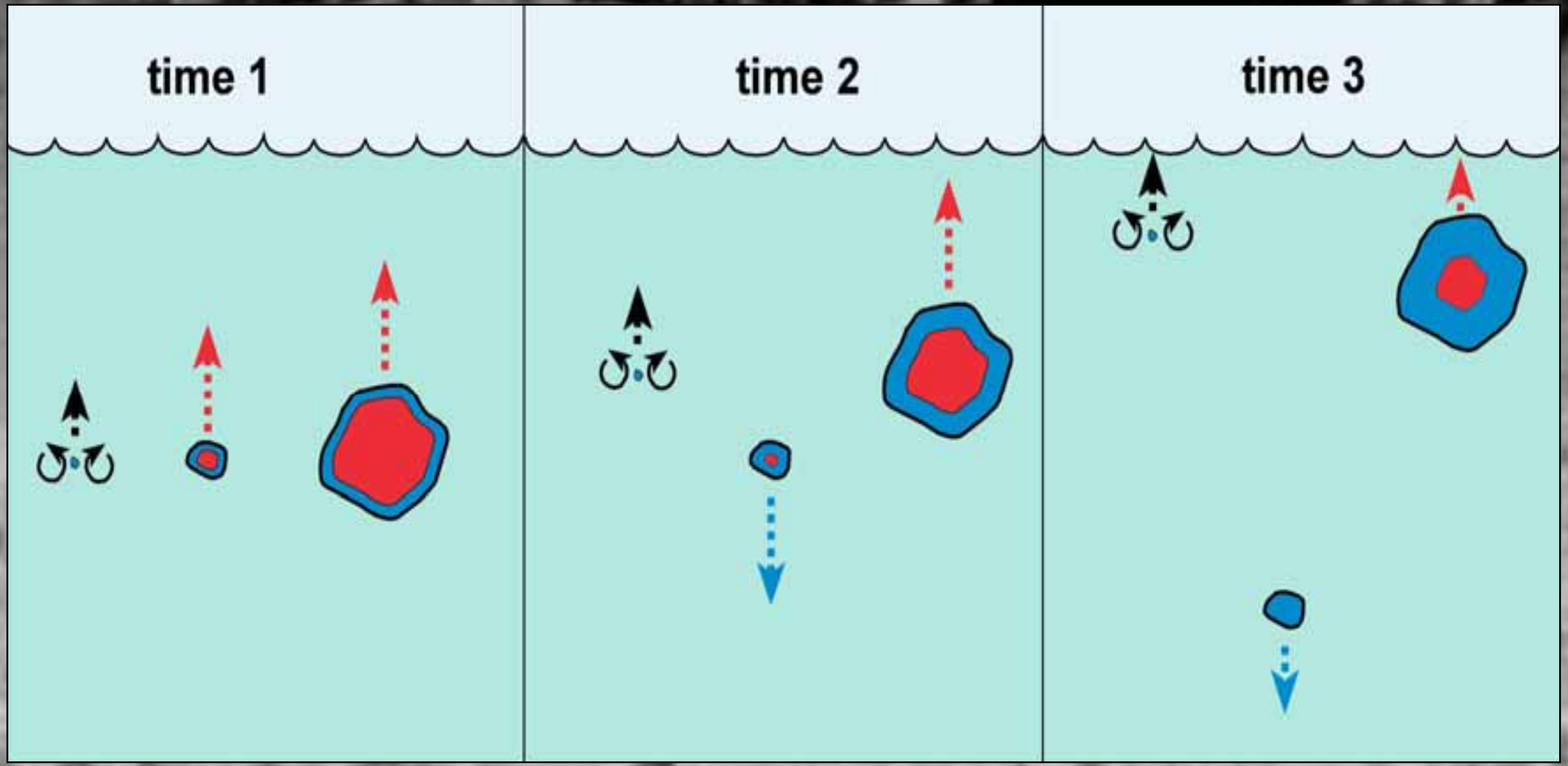

~850 m
Pumice Raft
Lava & Domes
Seafloor Pyroclastic
0.8
0.6
0.4
0.2
0
Volume (km³)
Murch et al., 2019
(a)
Subunit 4w
Subunit 2
Subunit 3
Subunit 4e
ALB unit
GP unit
Sampling method
Push core
Scoop
Slurper
Deposit
Boundary
Source
Subunit 4e
Subunit 4w
Subunit 3
Subunit 2
Subunit 1
GP Unit
ALB Unit
1 km
(b)
Lava and name
2012 Havre eruption stratigraphy
AL unit
15th Oct 2012 bathymetry survey
Unknown stratigraphic relationship between S1 and ALB unit
Stage 3
Stage 2
Stage1
Giant Pumice unit
ALB unit
Relative eruption timing of the pumice raft (18-19 July 2012)
Unsure what underlies the GP unit
Little constraint on eruption timing in stage 1
2002 bathymetry survey
Broken time scale

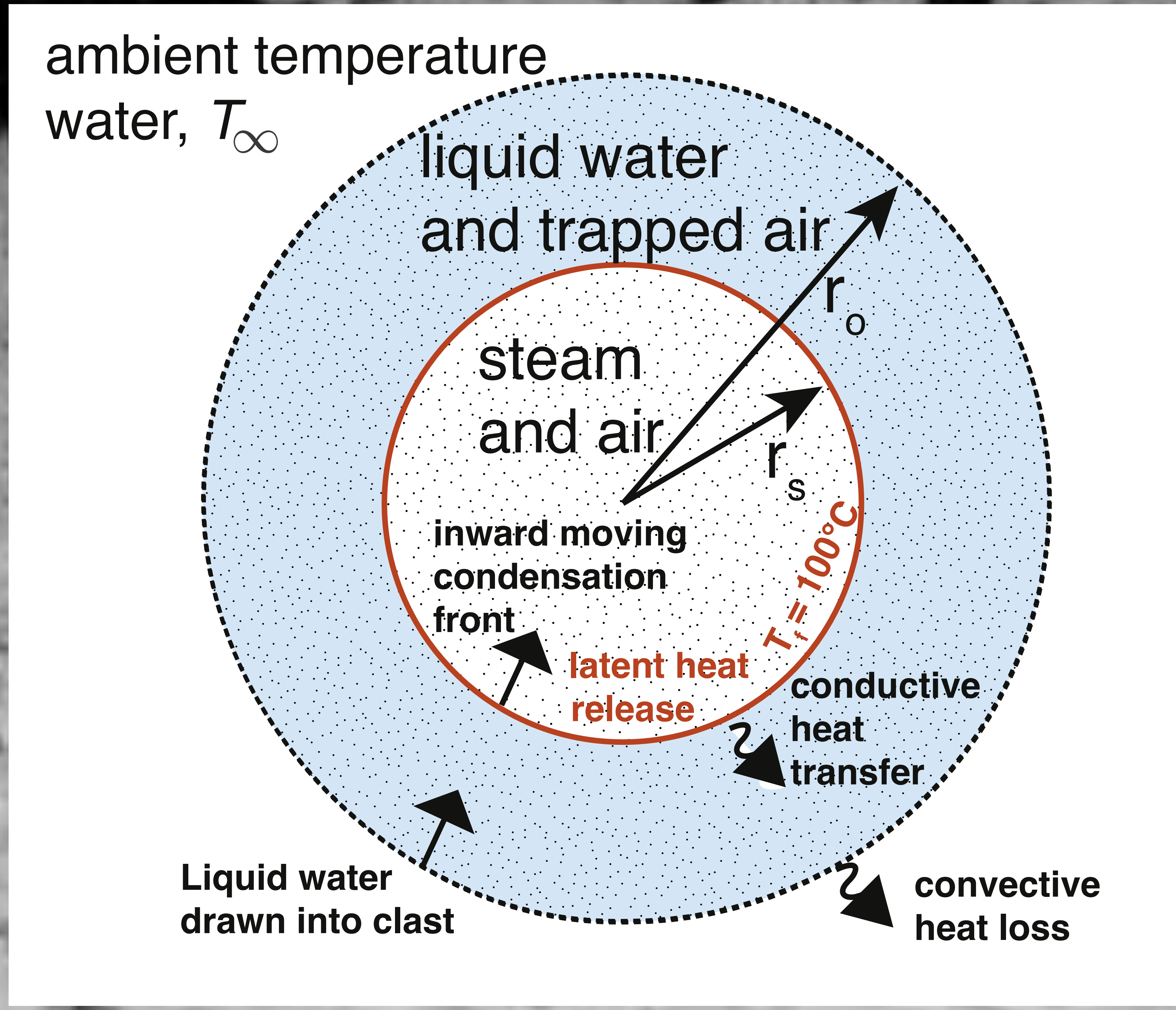


Manga et al., 2018 (see also Fauria et al., 2017; Fauria & Manga, 2018)

Conduit models suggest that the hydrostatic pressure at ~900m suppressed gas resolution enough to prevent strain rates required for fragmentation. Instead, the pumiceous magma extruded effusively and broke apart into pumice clasts which were bouyant relative to seawater.

This eruption occurred at a ‘goldilocks’ depth (>200m, <2800m). Deeper eruptions (with Havre magma) would produce dense flows and shallower eruptions would fragment in the conduit due to extensive degassing and accompanying viscosity increase.





Pumice are predicted to display a time-dependent buoyancy reflecting the rate of saturation such that larger pumice should travel further from the vent.

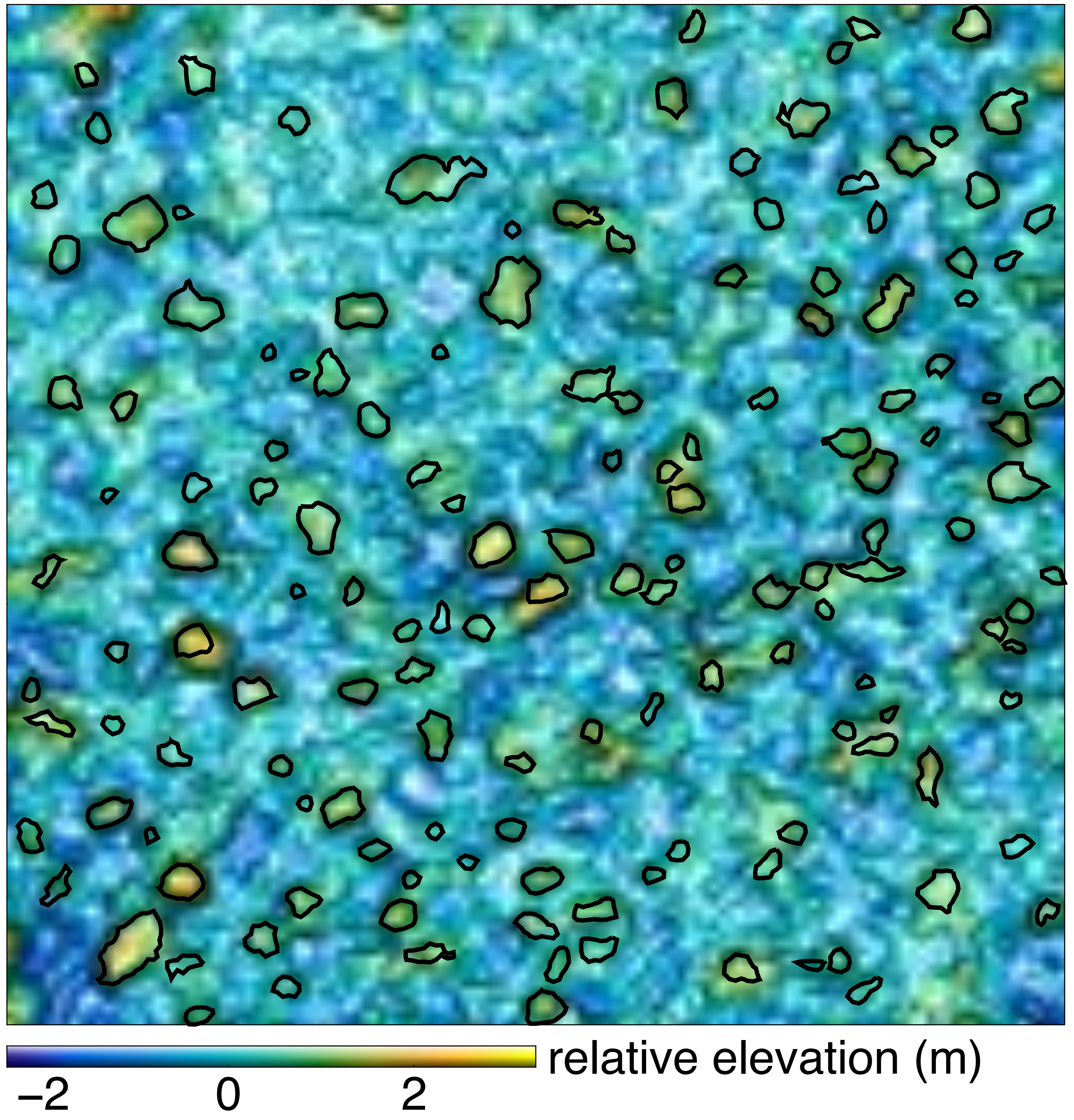
Fauria & Manga, 2018

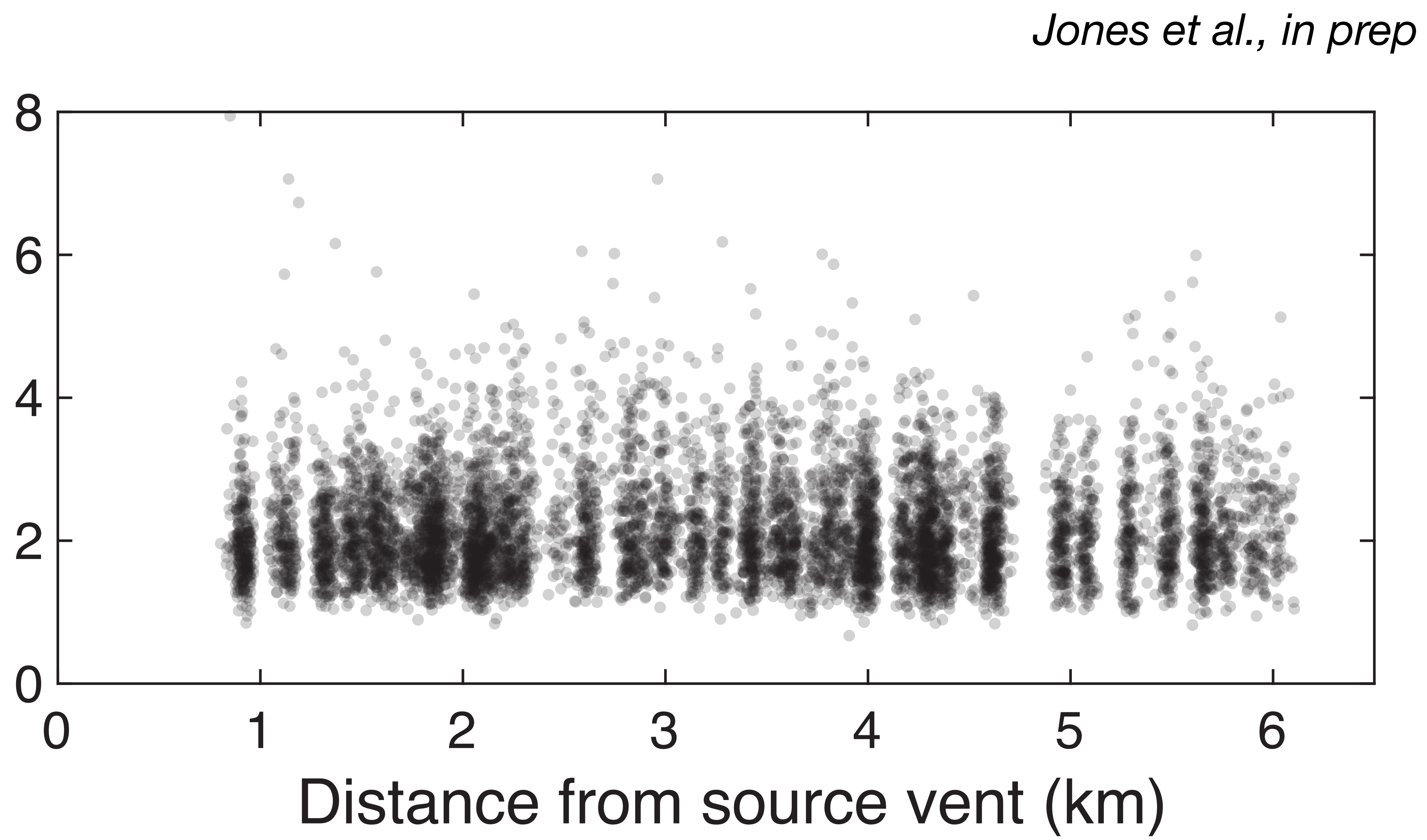
Giant pumice

Havre caldera floor, 1500m

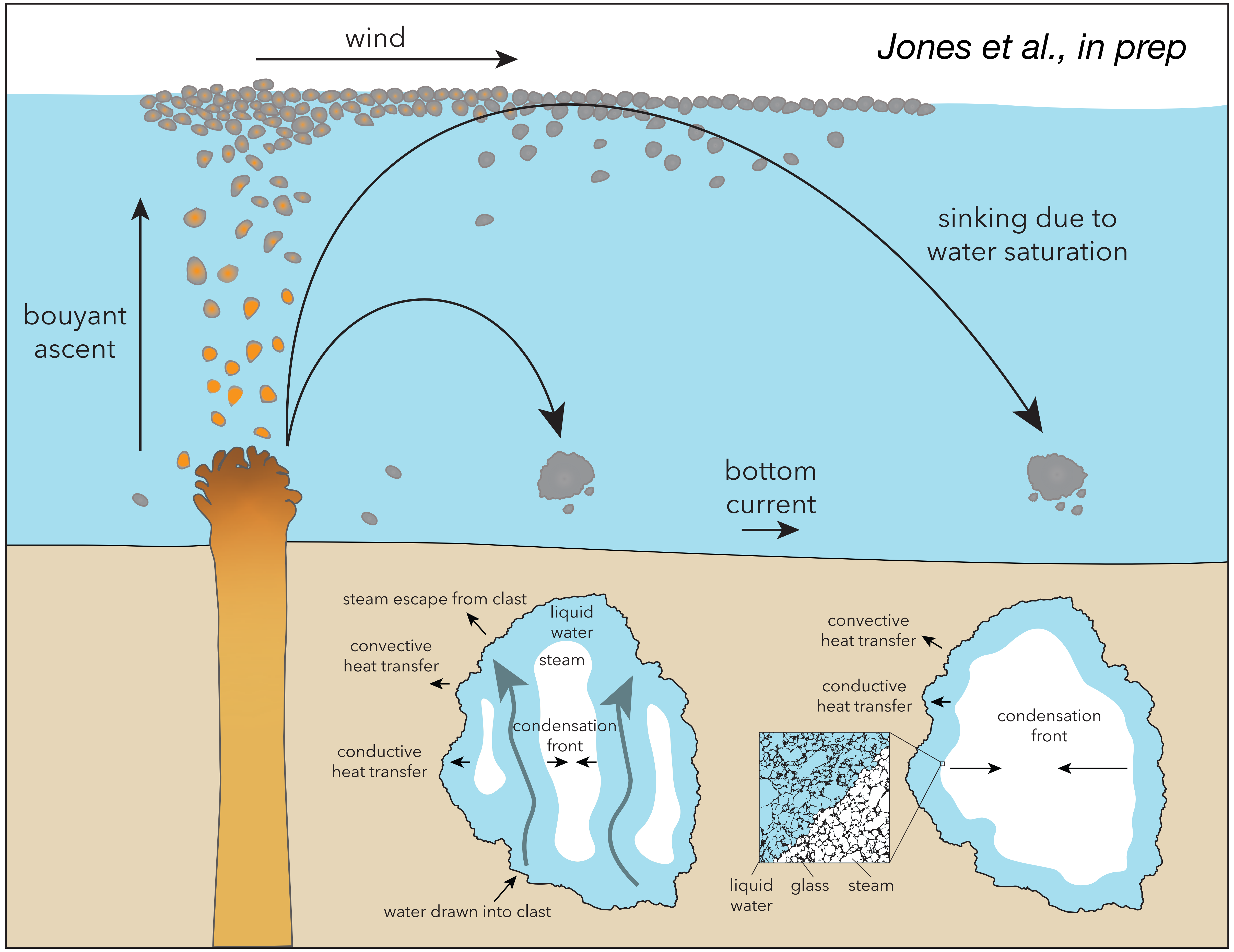
Giant Pumice Recovery

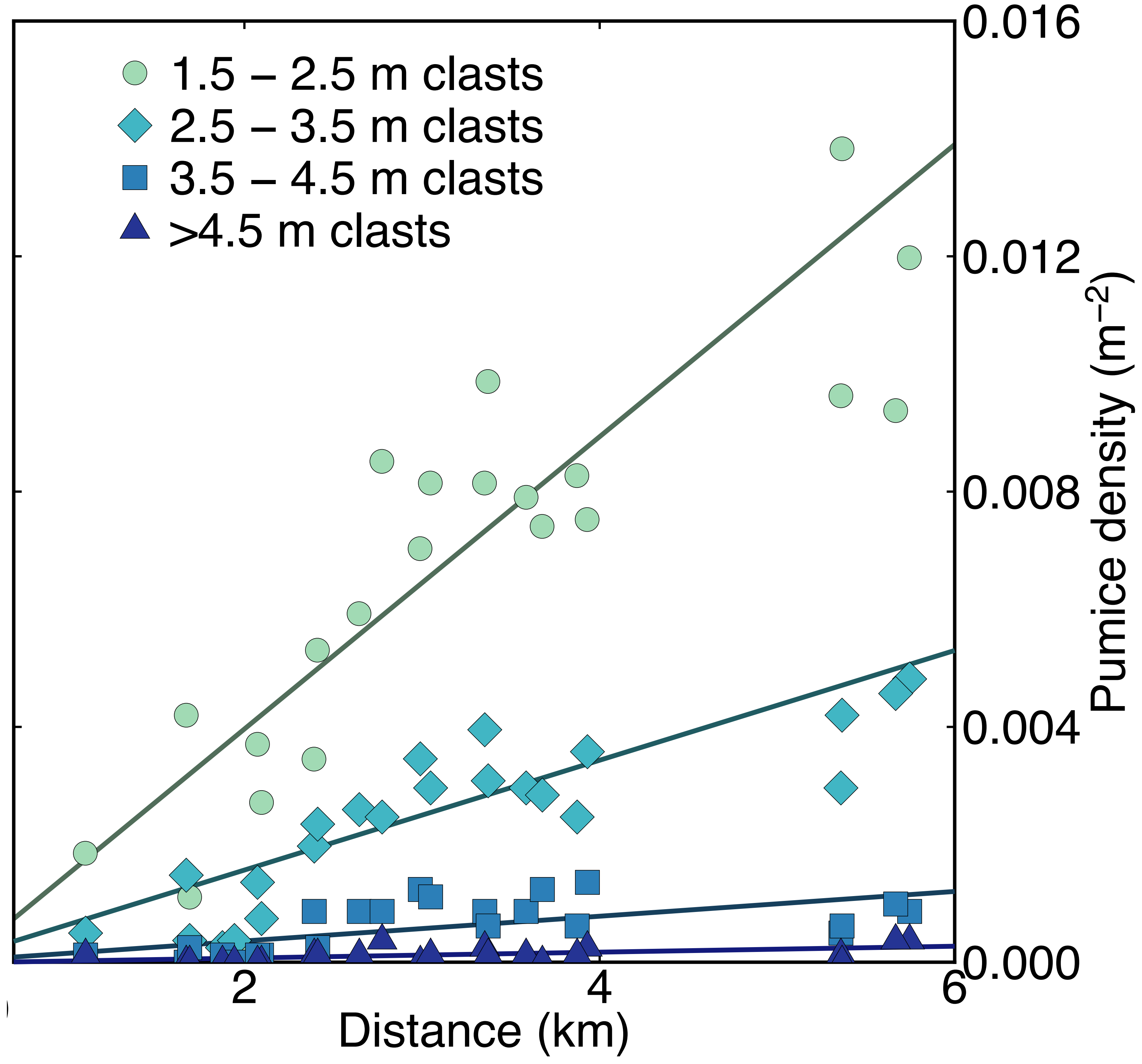
Giant Pumice Recovery





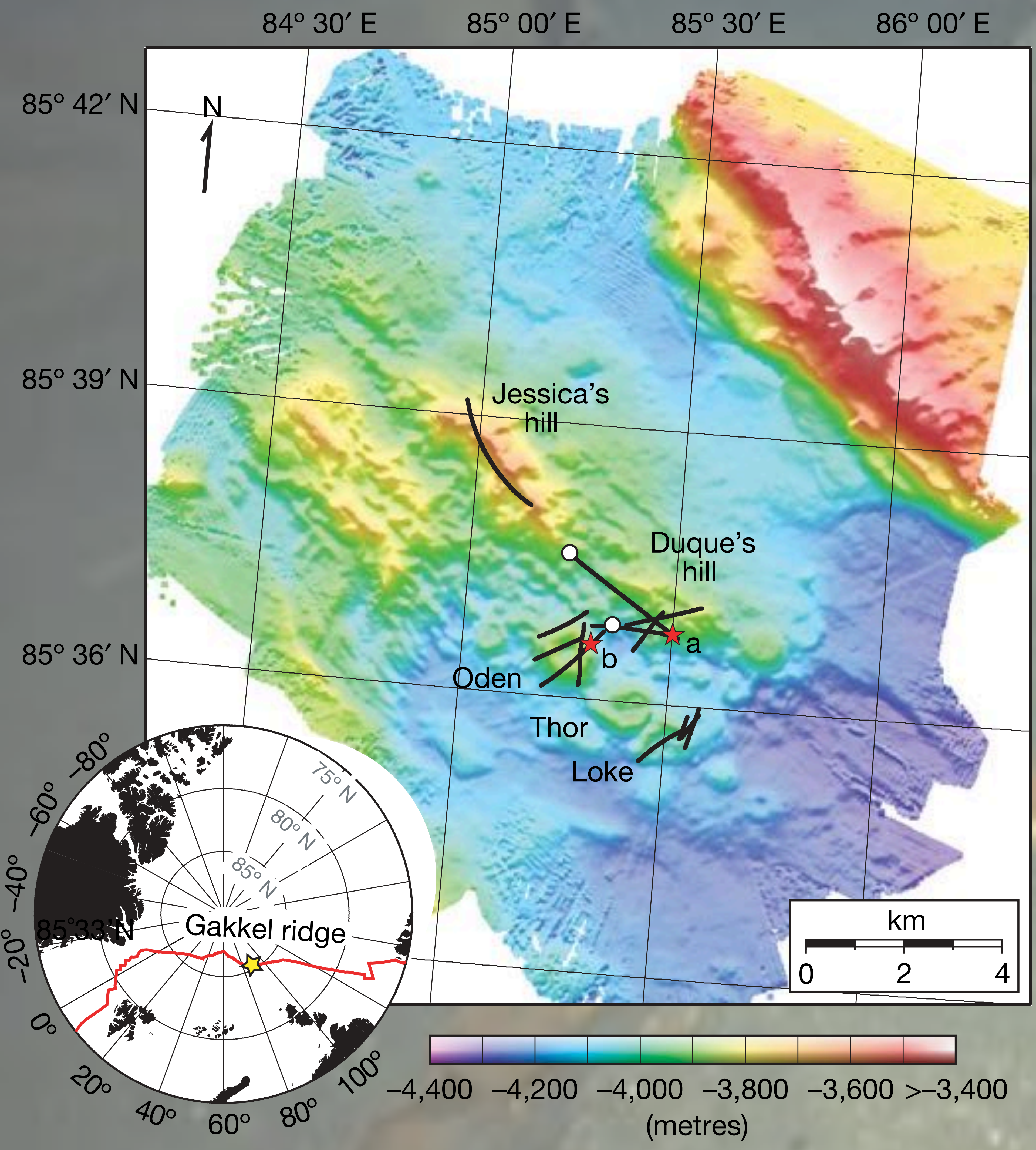
Giant pumice dispersal recorded in seafloor bathymetry shows much larger pumice closer to the vent than predicted and much smaller pumice farther from the vent than predicted.

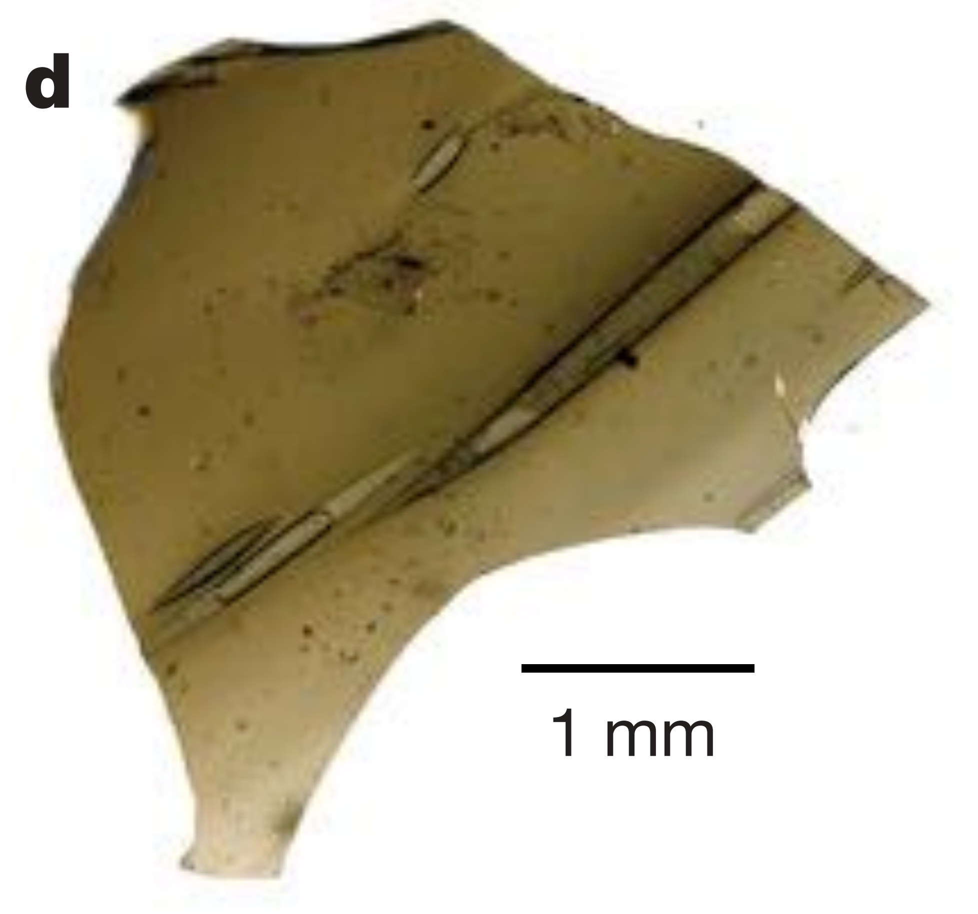




Although average size (as a function of distance) do not show any trends, pumice density (i.e., number per m^2) show distinct differences as a function of size and distance.

Cooling and saturation models appear to predict dispersal, but with significant second-order effects of pumice breakup and enhanced cooling via highly permeable bubble paths.

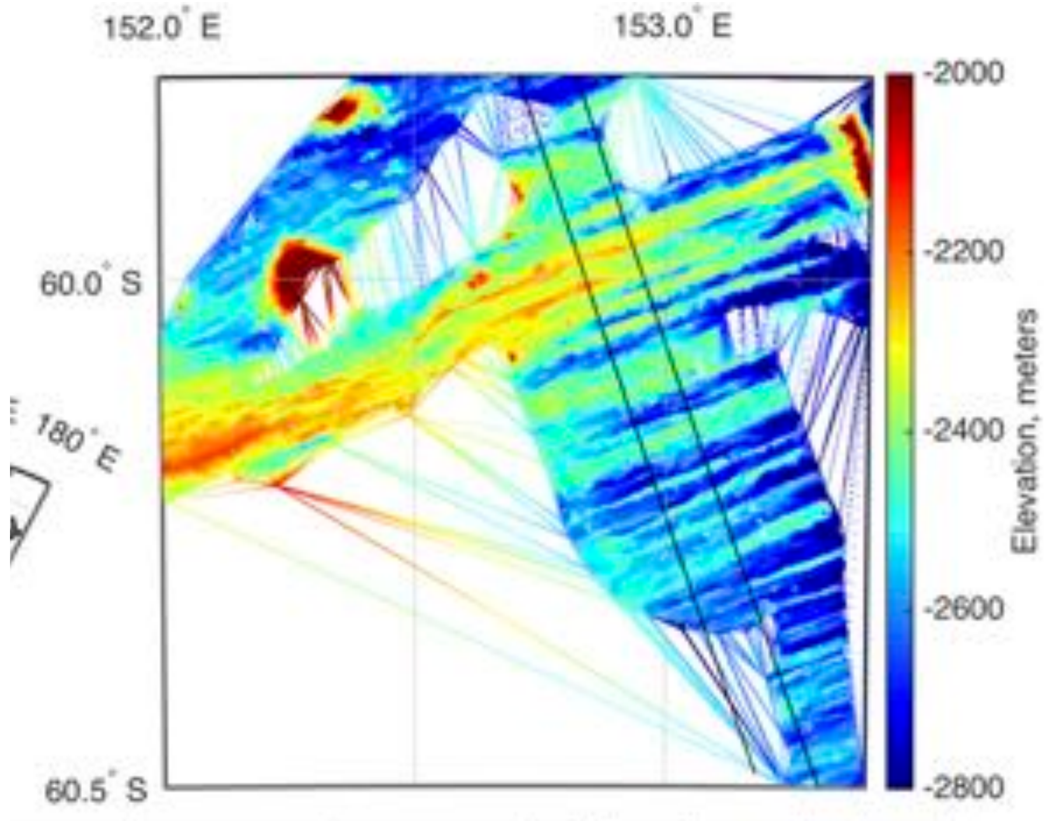




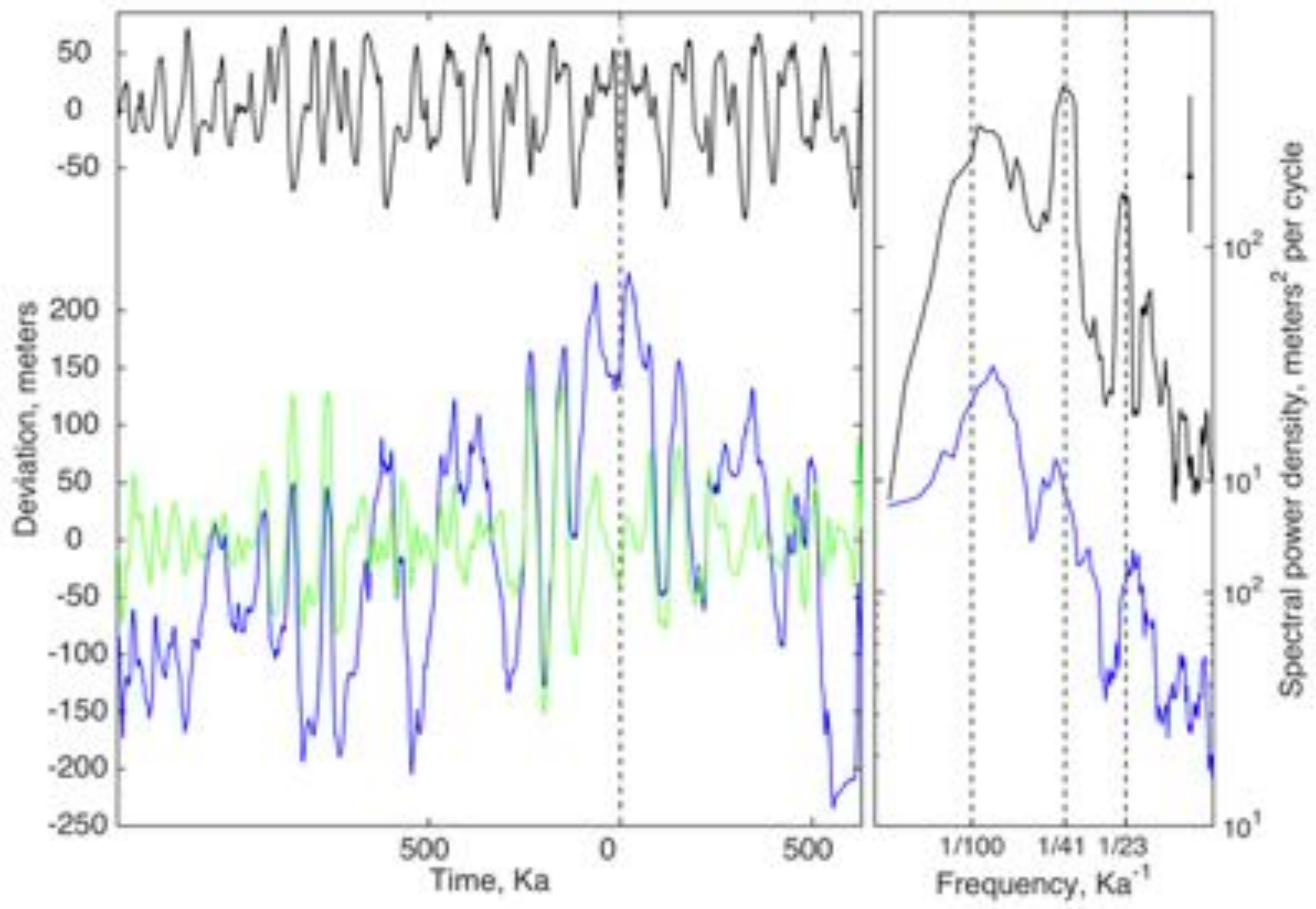
Sohn et al., 2008

Volcaniclastic sediment on recent lava flows at the **Gakkel Ridge, Arctic Ocean**
video courtesy of Rob Sohn & Susan Humphris

Climate Interaction with Mid-Ocean Ridges



Crowley et al. [2015] hypothesize, based on seafloor bathymetry, that glacial cycles (and consequent sea level rise/fall) cause variations in MOR magma production.



OCEANOGRAPHY

Glacial cycles drive variations in the production of oceanic crust

John W. Crowley,[1,2]* Richard F. Katz,[1]† Peter Huybers,[2]
Charles H. Langmuir,[2] Sung-Hyun Park[3]†

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Sensitivity of seafloor bathymetry to climate-driven fluctuations in mid-ocean ridge magma supply

J.-A. Olive,[1]* M. D. Behn,[2] G. Ito,[3] W. R. Buck,[1] J. Escartín,[4] S. Howell[3]

OCEANOGRAPHY

Comment on "Sensitivity of seafloor bathymetry to climate-driven fluctuations in mid-ocean ridge magma supply"

Peter Huybers,[1]* Charles Langmuir,[1] Richard F. Katz,[3] David Ferguson,[1]
Cristian Proistosescu,[1] Suzanne Carbotte[2]

Mid-ocean ridge eruptions as a climate valve

Maya Tolstoy[1]

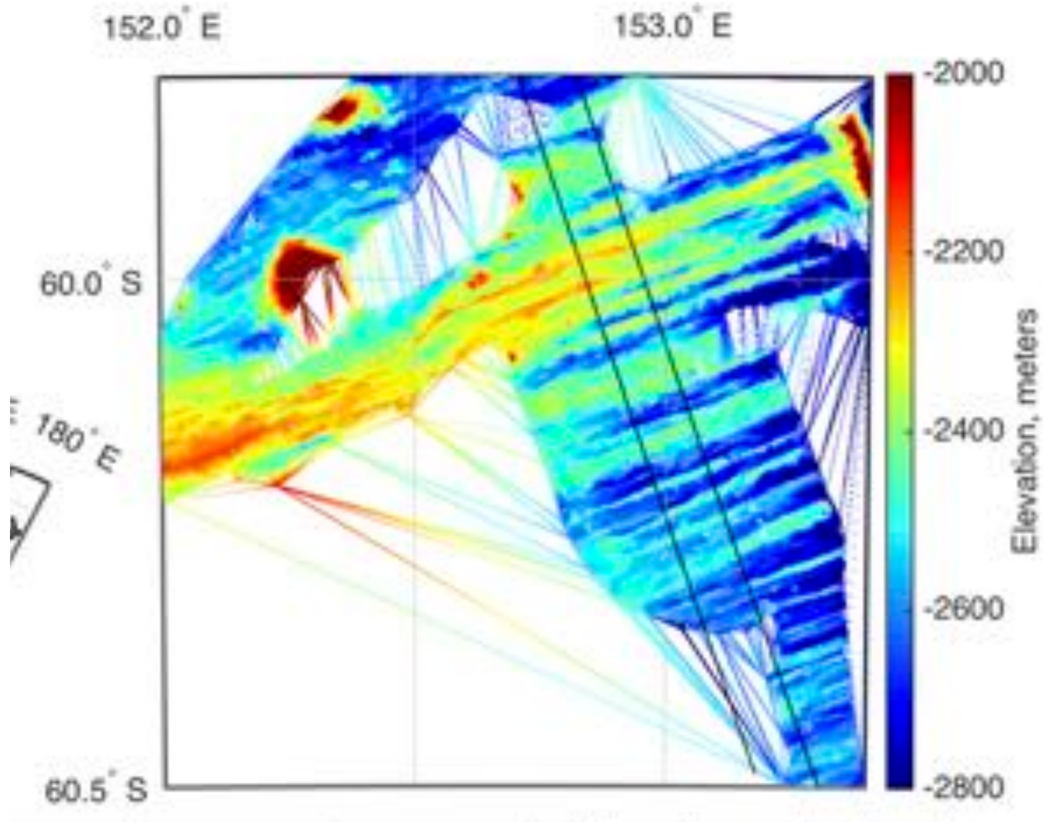
[1]Lamont-Doherty Earth Observatory, Columbia University, Palisades, New York, USA

No Evidence for Milankovitch Cycle Influence on Abyssal Hills at Intermediate, Fast, and Superfast Spreading Rates

John A. Goff[1], Sabin Zahirovic[2], and R. Dietmar Müller[2]

[1]Institute for Geophysics, Jackson School of Geosciences, University of Texas at Austin, Austin, TX, USA, [2]EarthByte Group, School of Geosciences, University of Sydney, Camperdown, New South Wales, Australia

Climate Interaction with Mid-Ocean Ridges



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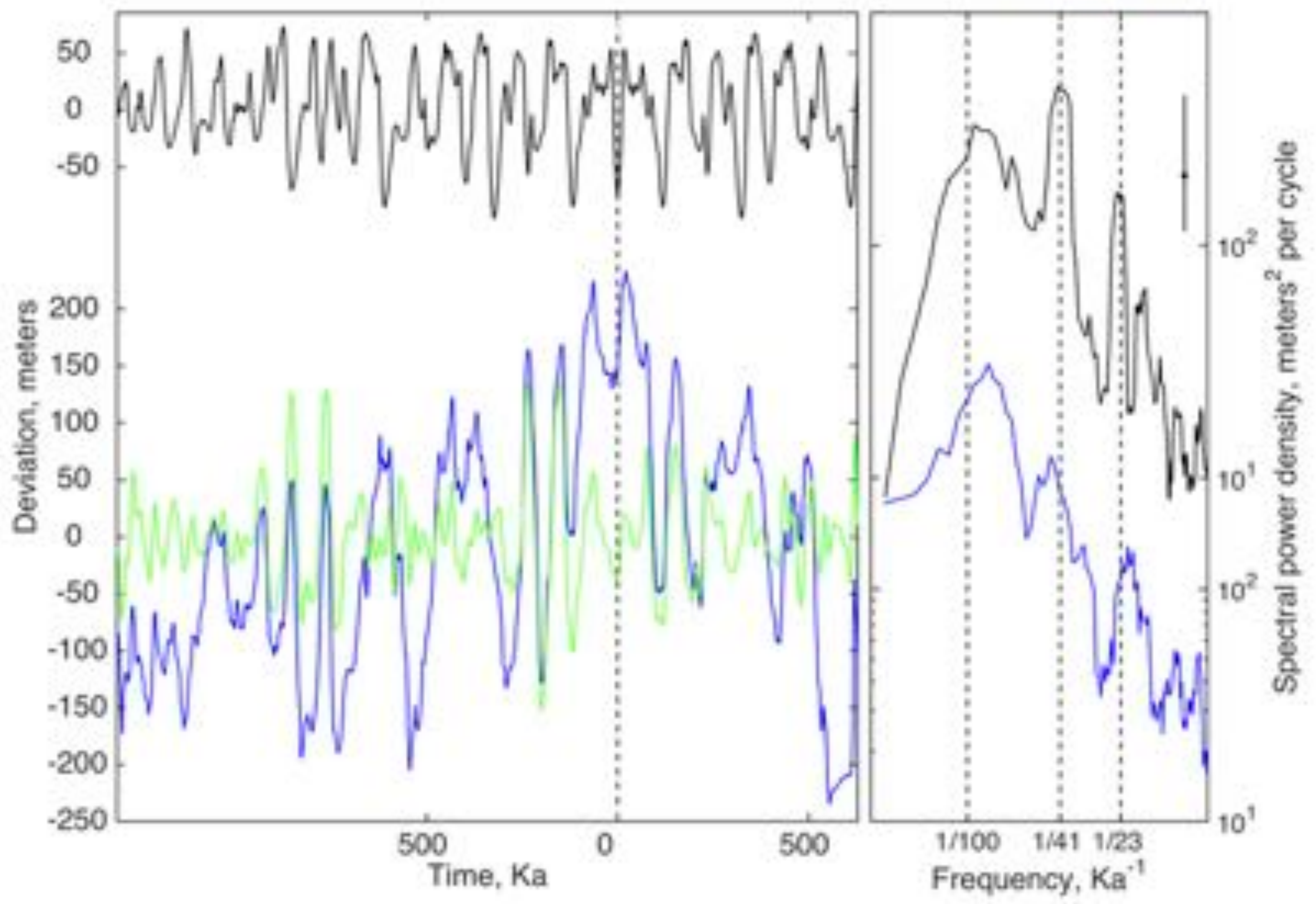
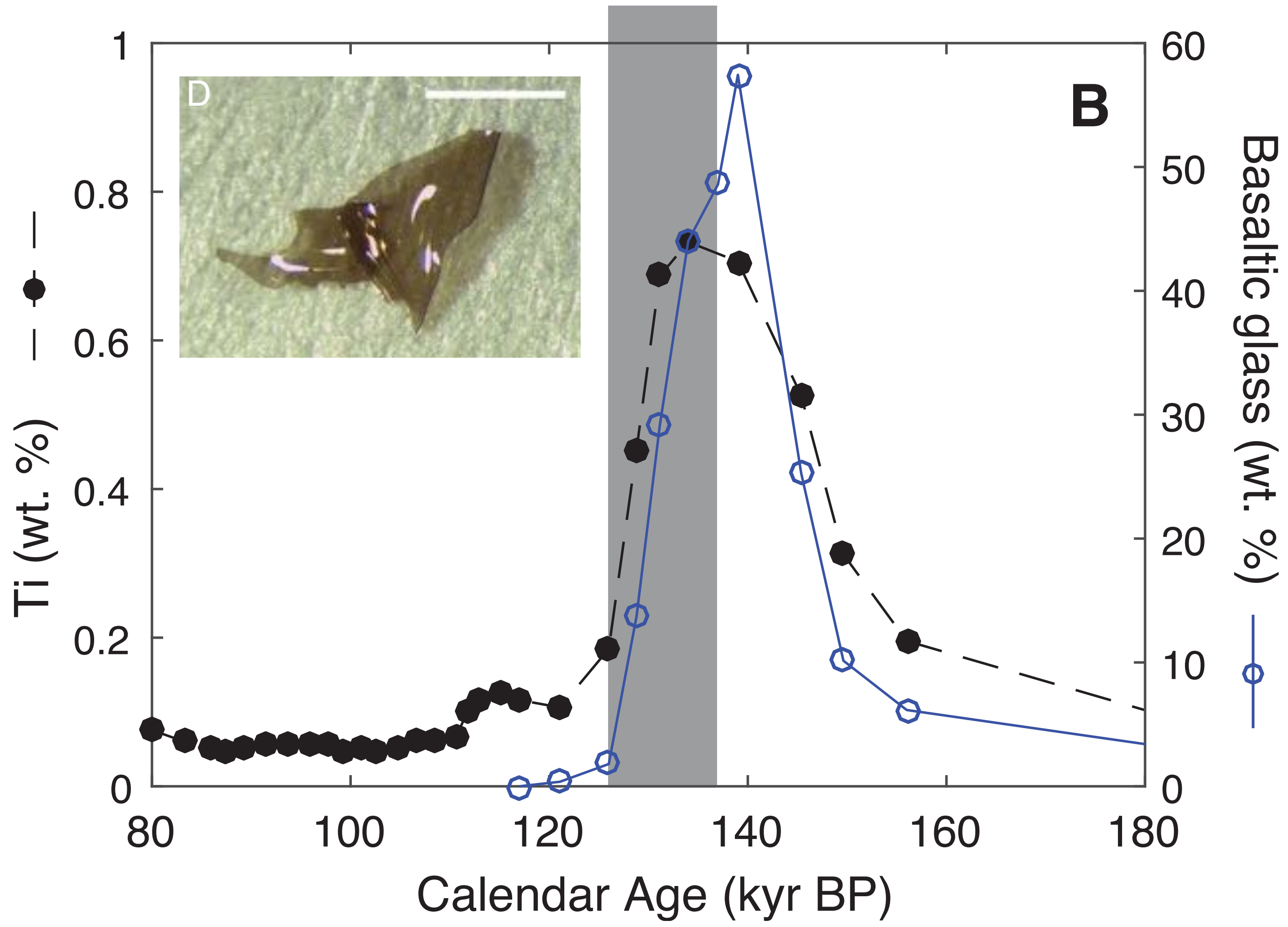
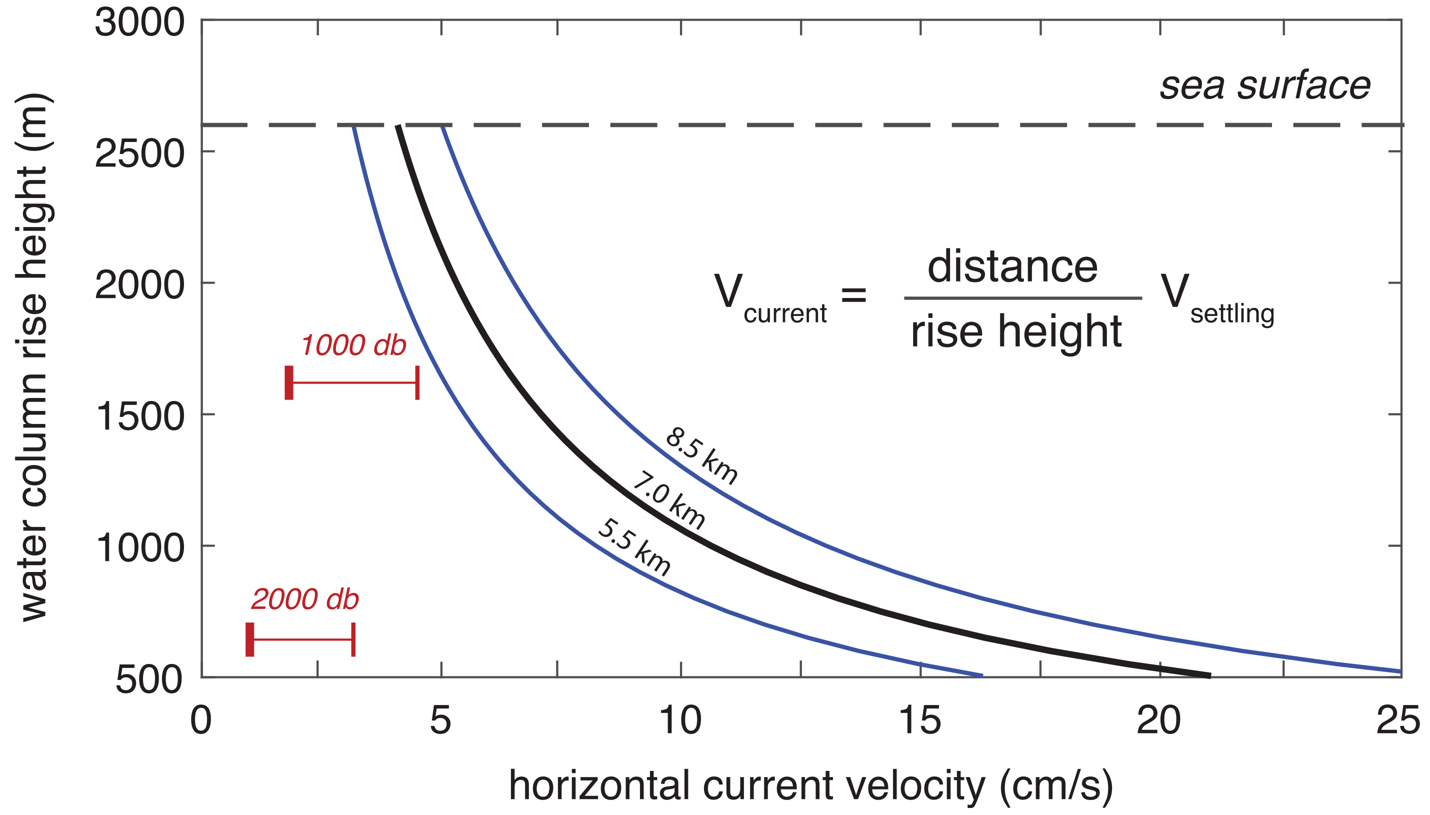
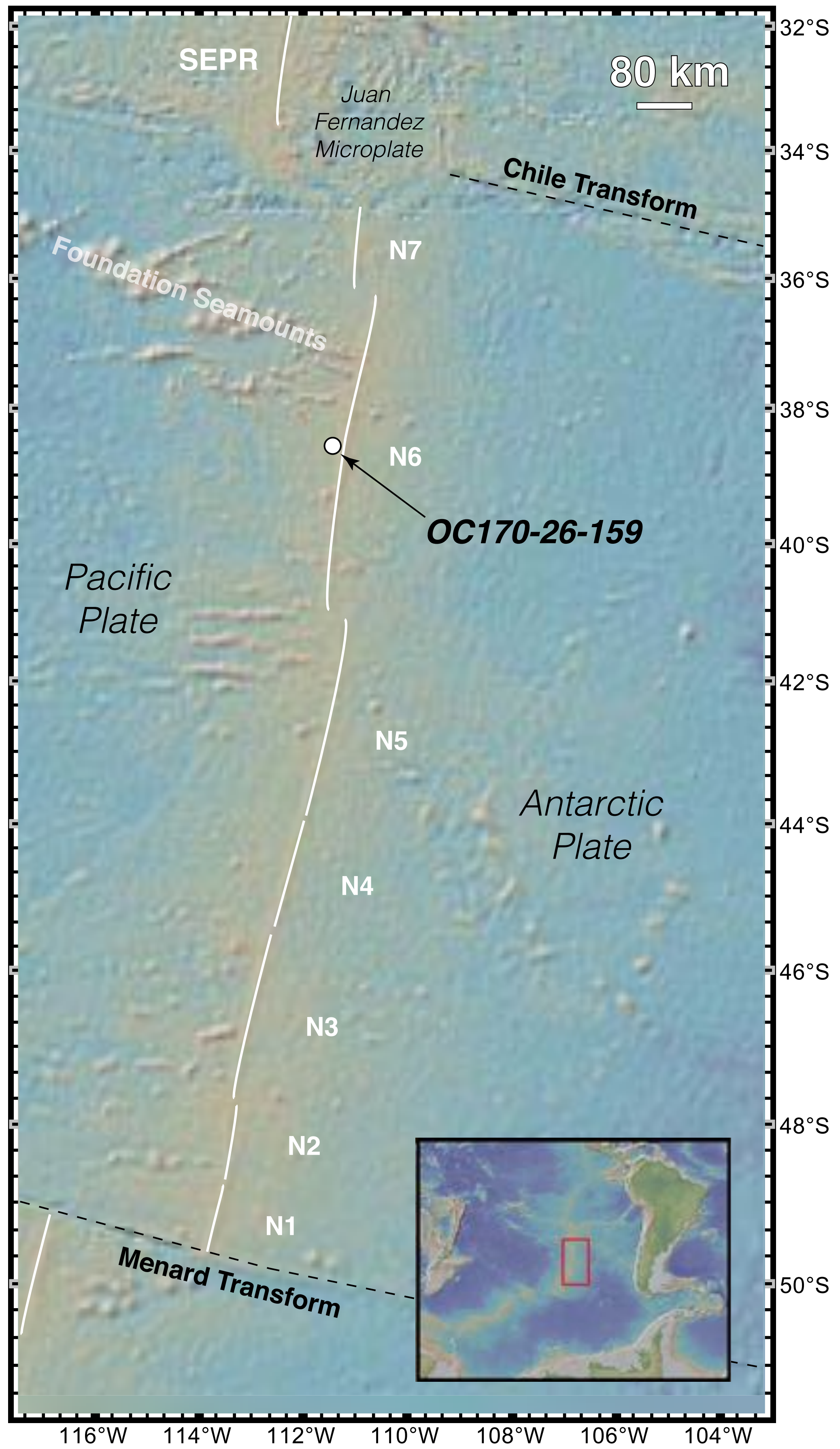


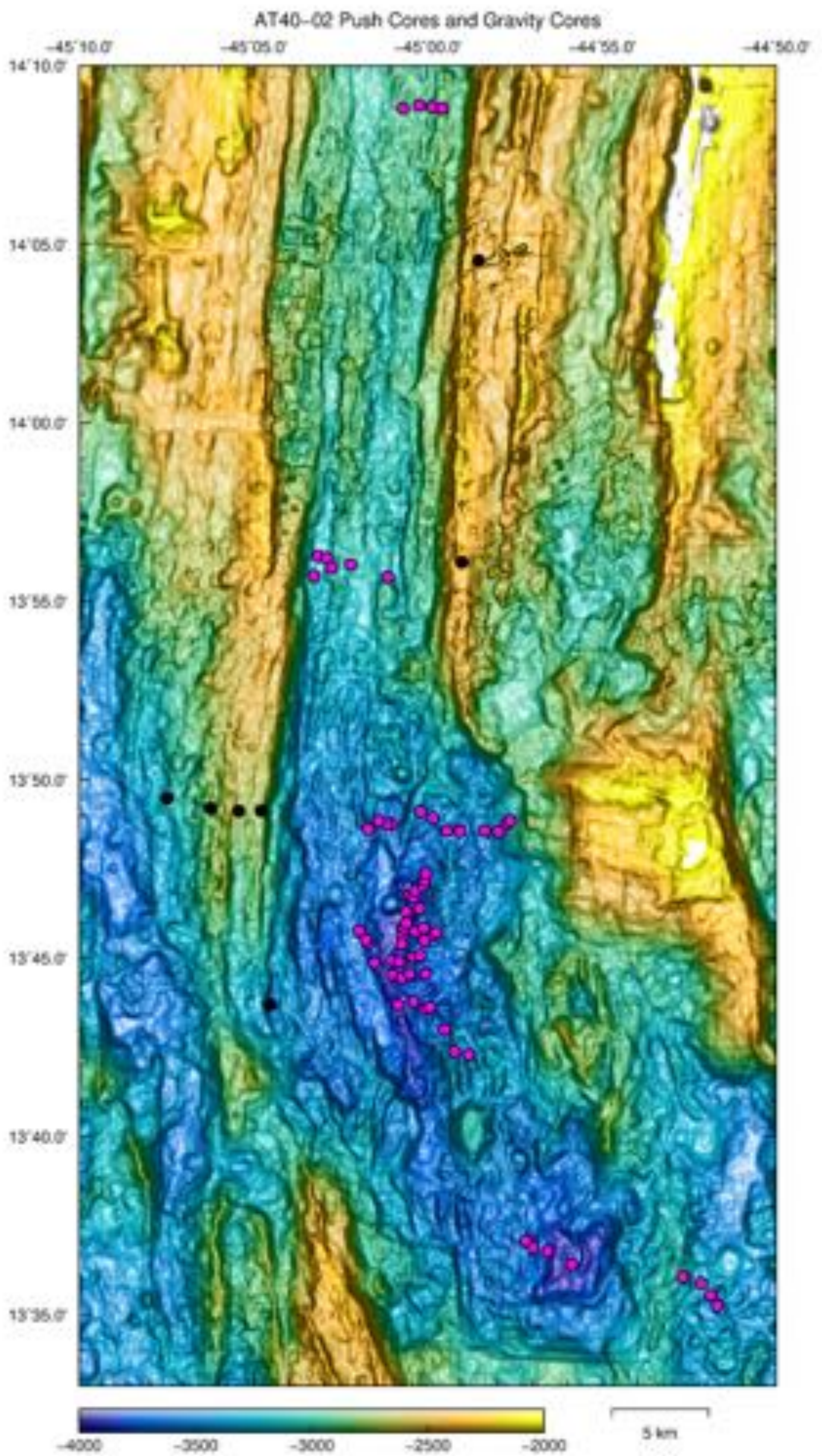


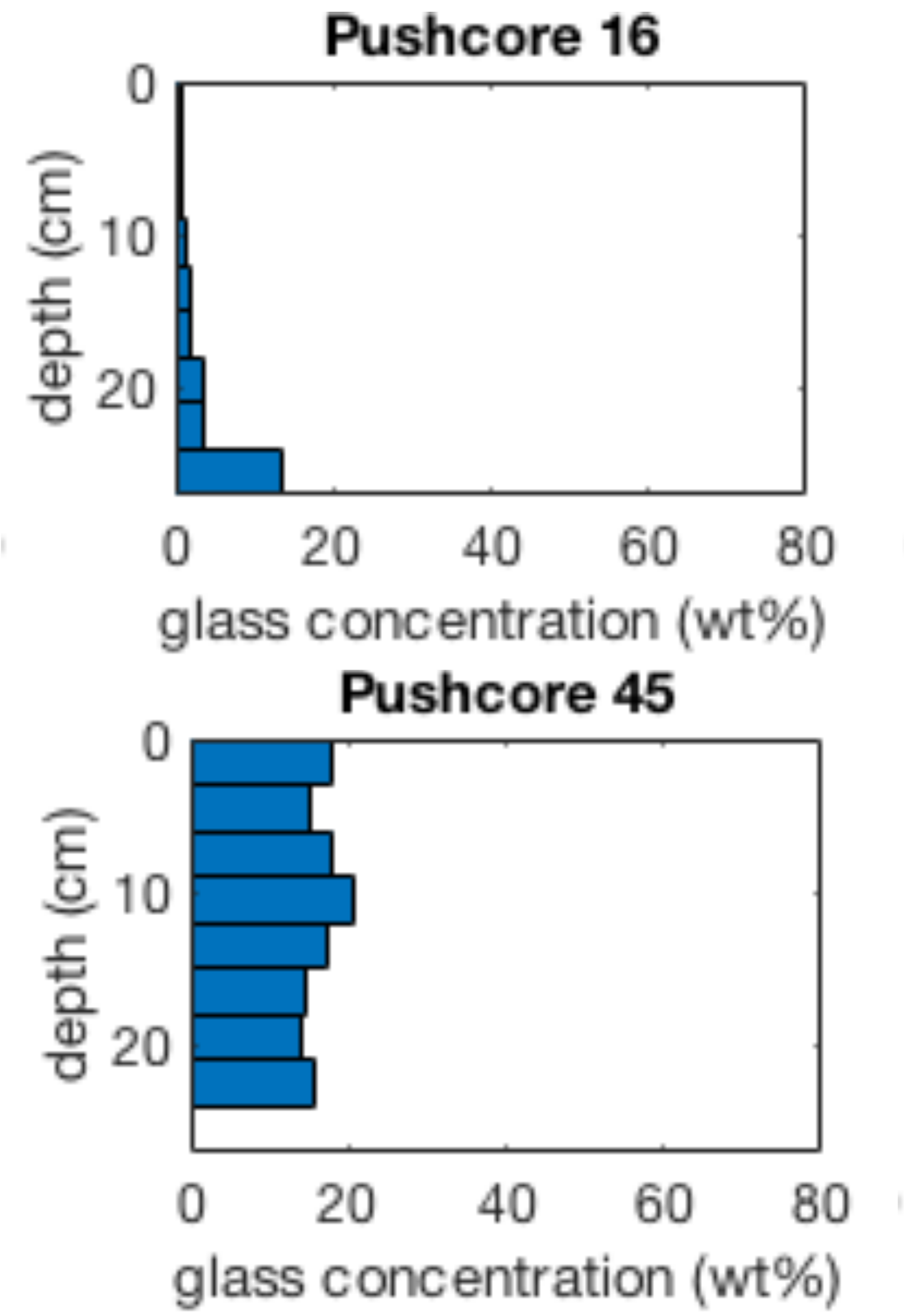


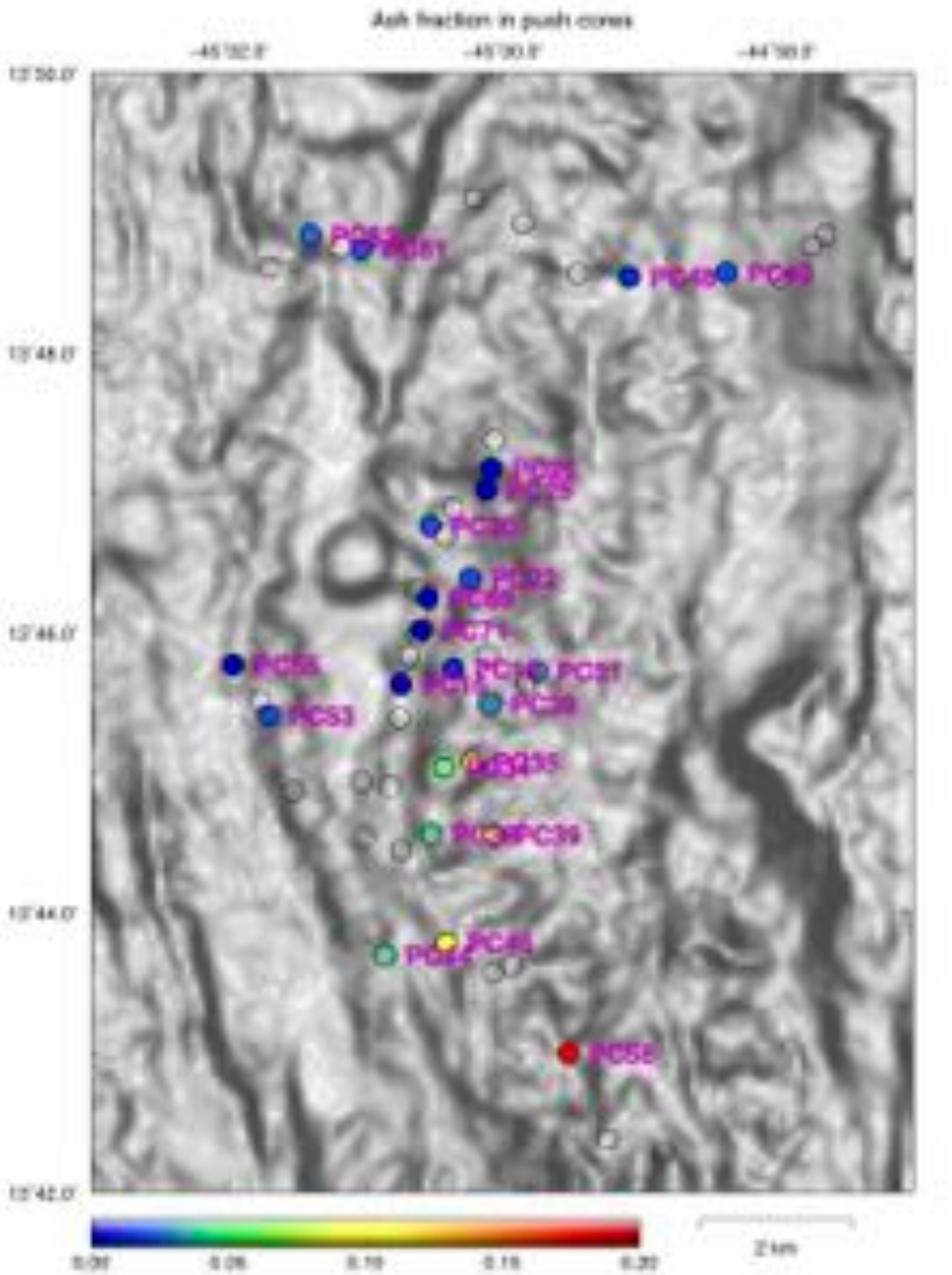


Lund et al. [2018] have used sediment core records to determine the timing of increased? volcanism.

Submarine volcanic contributions to marine sediments







Recent push/gravity core collection at the Mid-Atlantic Ridge will provide an opportunity to evaluate models of MOR ash generation and transport…

…talk to Kristen Fauria when she arrives!

1. Is our assessment of the relative proportions of subaerial and submarine volcanism correct, and can we better monitor the oceans at a global scale to identify the location, timing, and size of submarine eruptions. [*Tushar*]

2. Are there frequency/size/eruption rate relationships with spreading rate (i.e., magma supply) and what controls them? [*Leif, Helge*]

3. What influence does seawater have on fragmentation and dispersal in submarine arc eruptions i.e., can magmatically-driven pyroclastic eruptions occur in the deep ocean (>1000m)? How can deposit characteristics be inverted to constrain eruption processes? [*Michael, Rebecca, Kristen, et al.*]