Investigations of Modern Vent Sites and the Feedback Loops Between These Natural Laboratories and Terrestrial VHMS Deposits.

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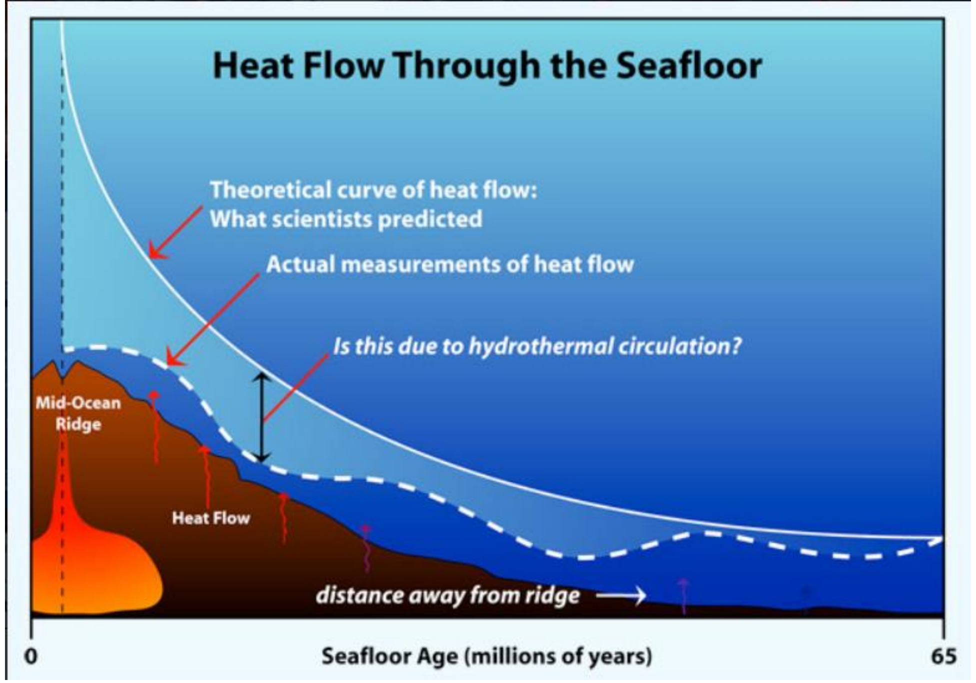
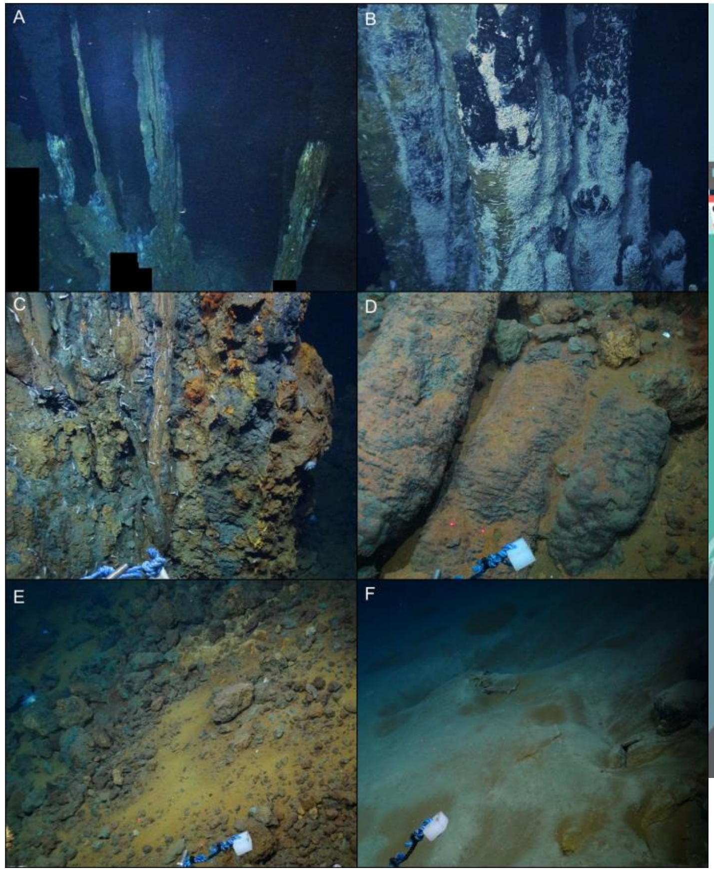
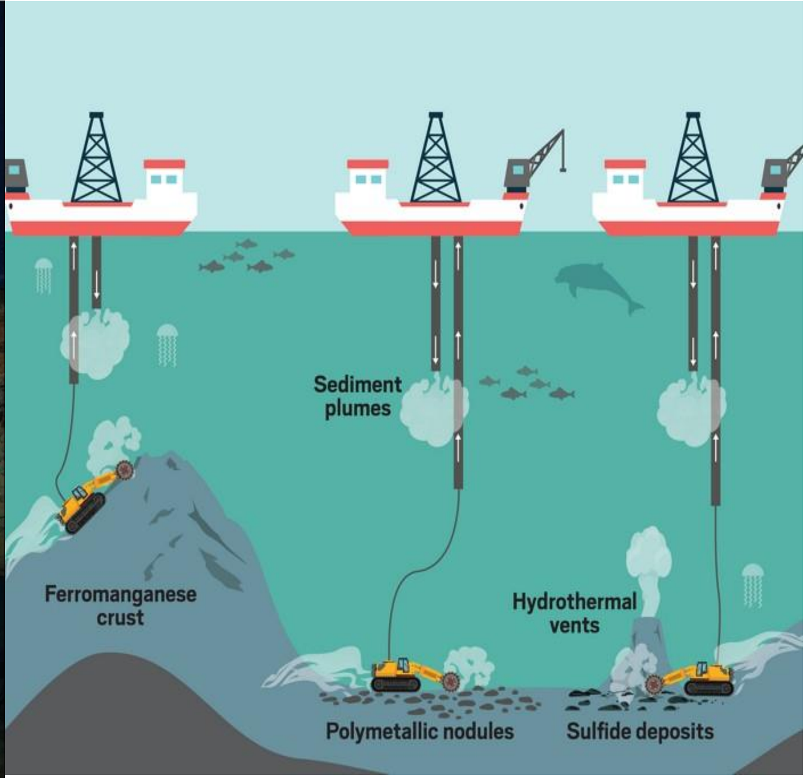
SEG 2025 Thayer Lindsley Visiting |Lecturer

Why Investigate metal precipitating sea-floor hydrothermal vent sites?

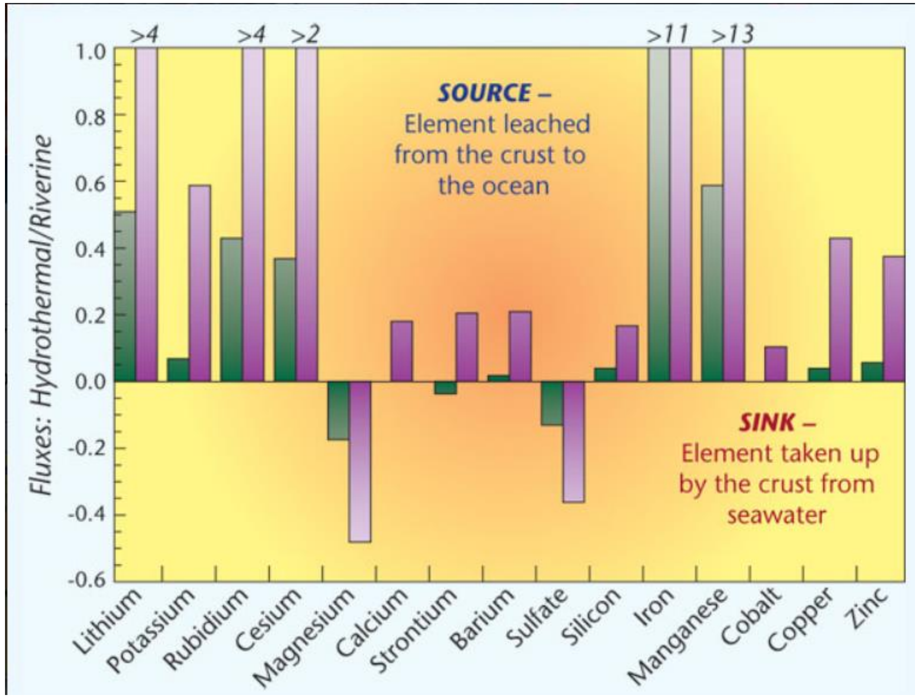
- Contribute to Ocean Chemistry
- Contribute Heat Loss From the Planet
- Provide a Natural laboratory for VHMS Formation
- Are Potential Sites of Future Resource Extraction (Cu)





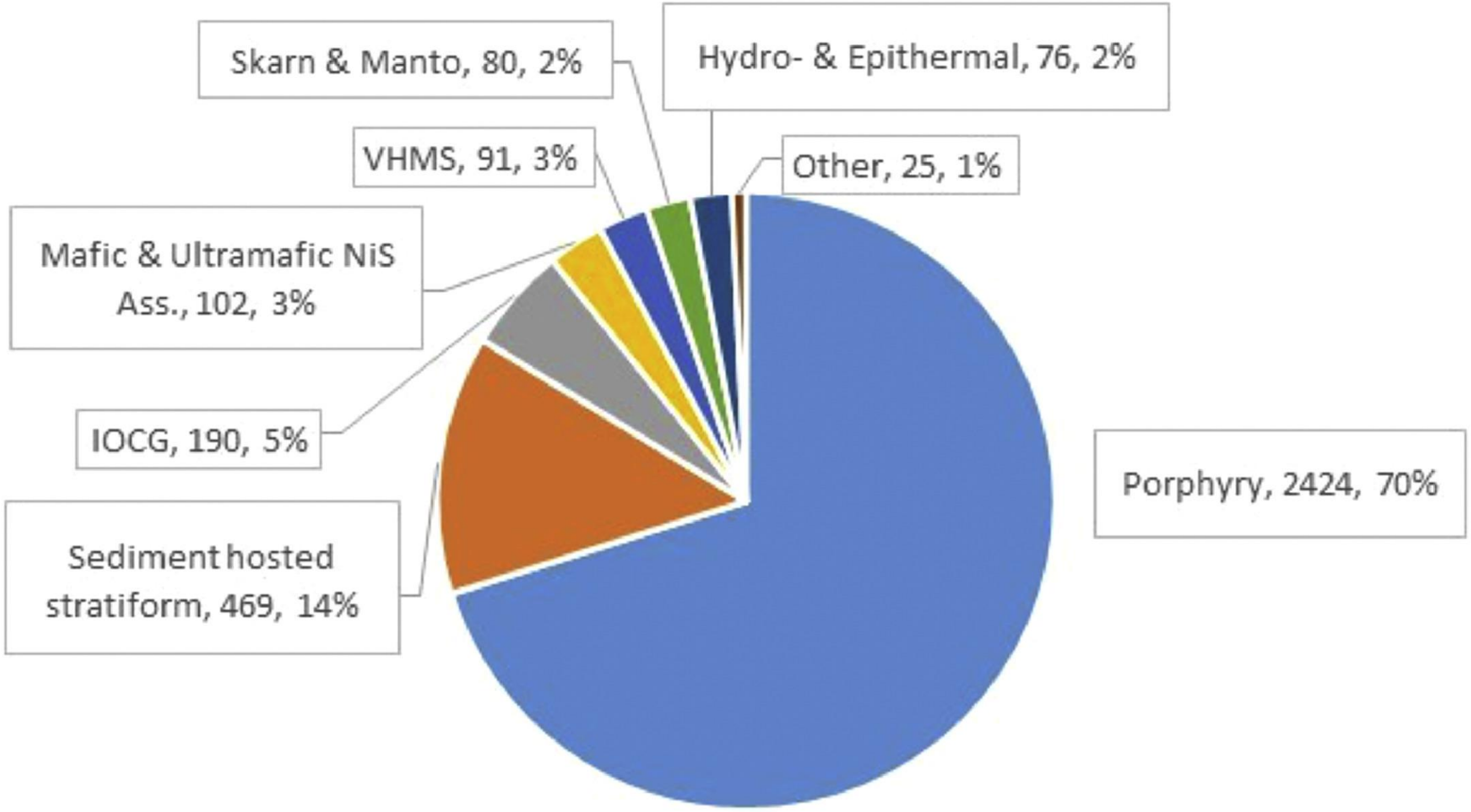


https://cen.acs.org/environment/water/deep-sea-mining-dilemma/101/i3



The Final Report, RIDGE/VENTS Workshop, 1994.)

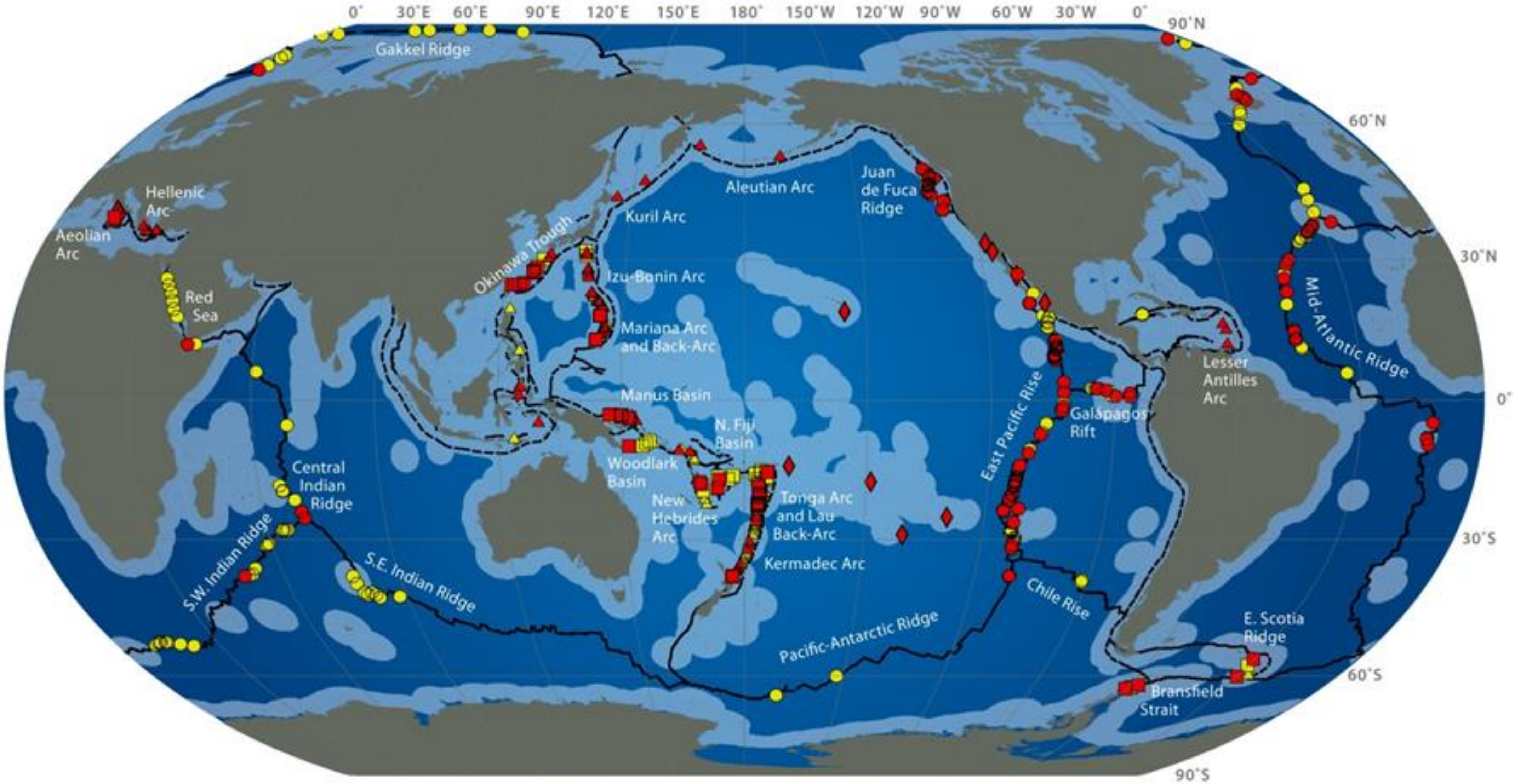
Resource Importance of Copper Deposit Types: Mt and %



Still approaching 100Mt per annum in 2022

Pietro Guj and Richard Schodde 2025 https://doi.org/10.1016/j.geogeo.2024.100320

Global Distribution of Hydrothermal Vent Fields



International Ocean Discovery Program

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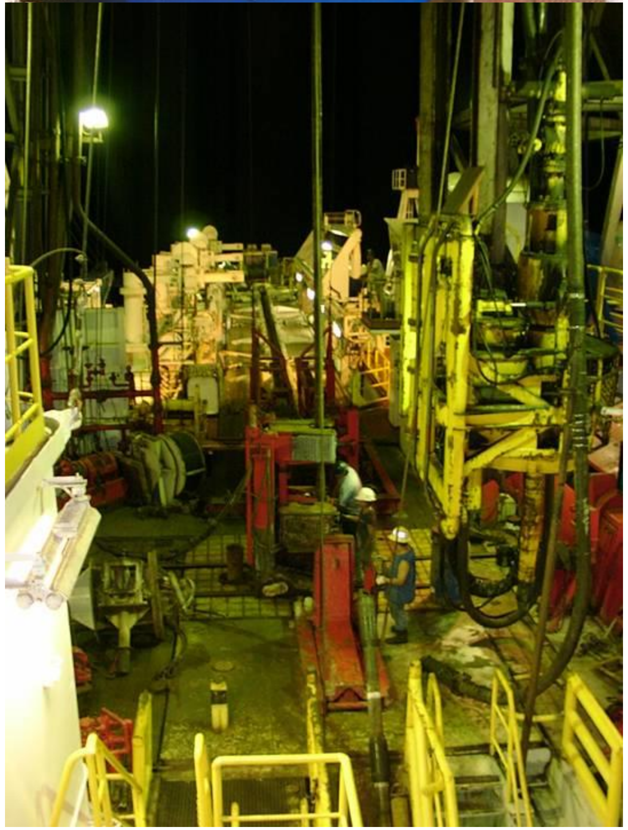

Location of Major ODP/IODP Drilling Campaigns on Sea Floor Massive Sulfide Deposits

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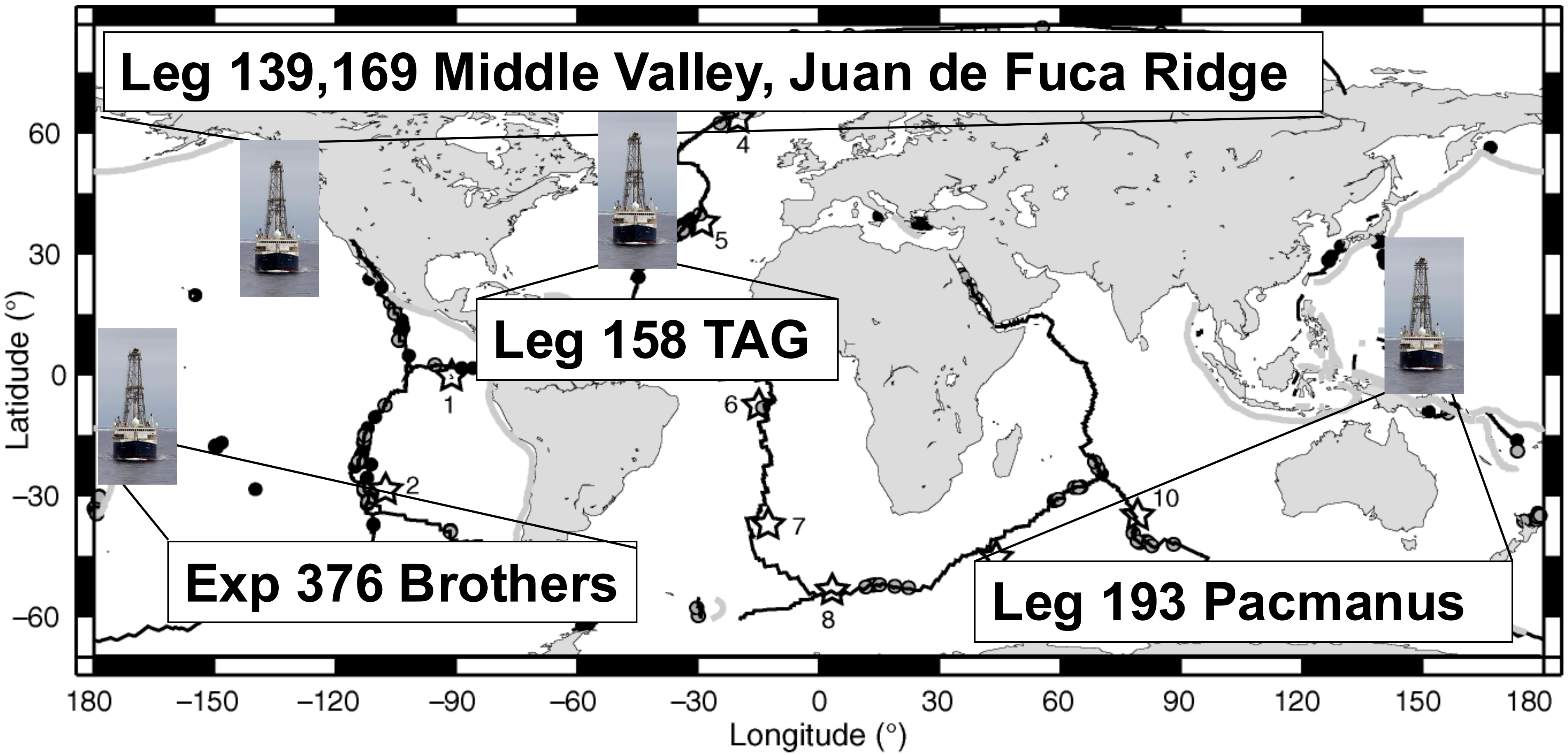
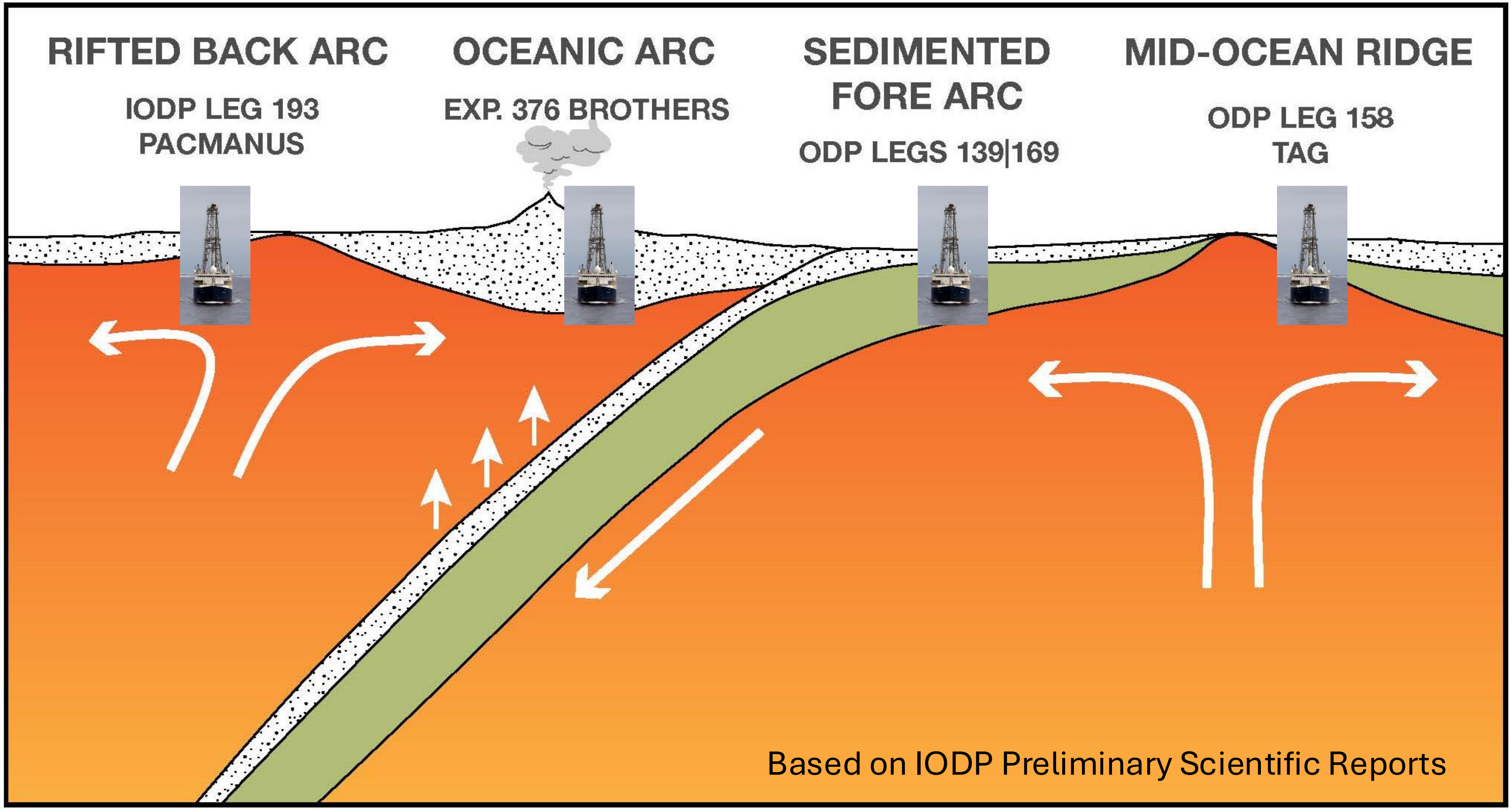
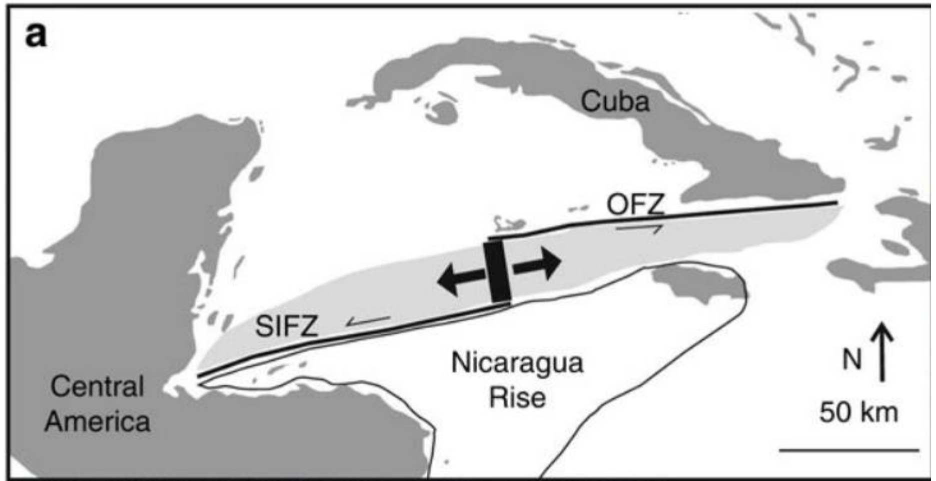


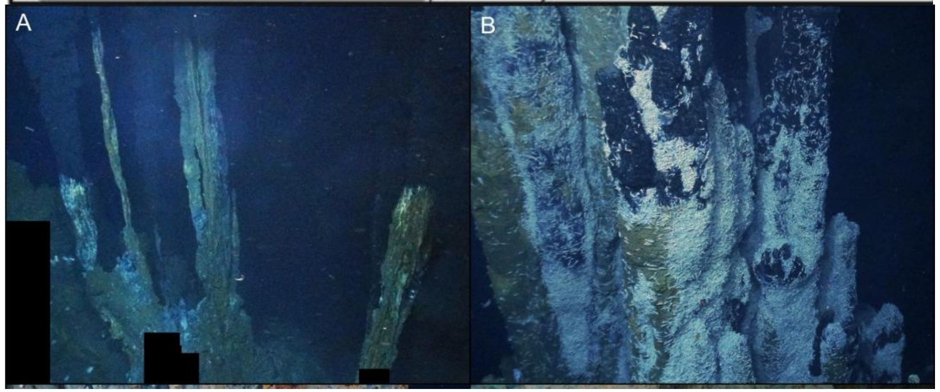
Modified After: Mid-Ocean Ridges: Hydrothermal Interactions Between the Lithosphere and Oceans, Geophysical Monograph Series 148, C.R. German, J. Lin, and L.M. Parson (eds.), 245–266 (2004)

Geotectonic Location of Ocean Drilling Vent Sites



Expedition to Worlds Deepest Known Vent Sites in the Cayman Trough





Seminar Outline

Complex vent site alteration patterns and varied hydrothermal alteration and fluid pathways often variable at the local scale.

Evidence that tectonics at active sites play a key role in vent location and fluid flow.

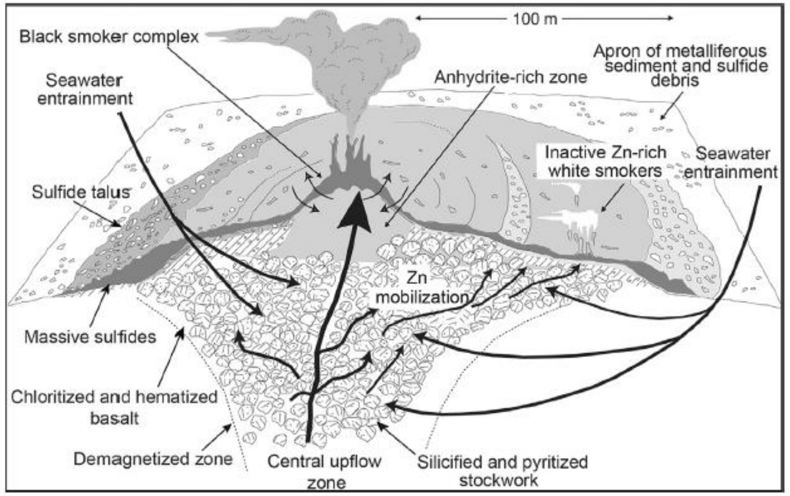
The development of gold-rich deposits may depend on a range of factors including :

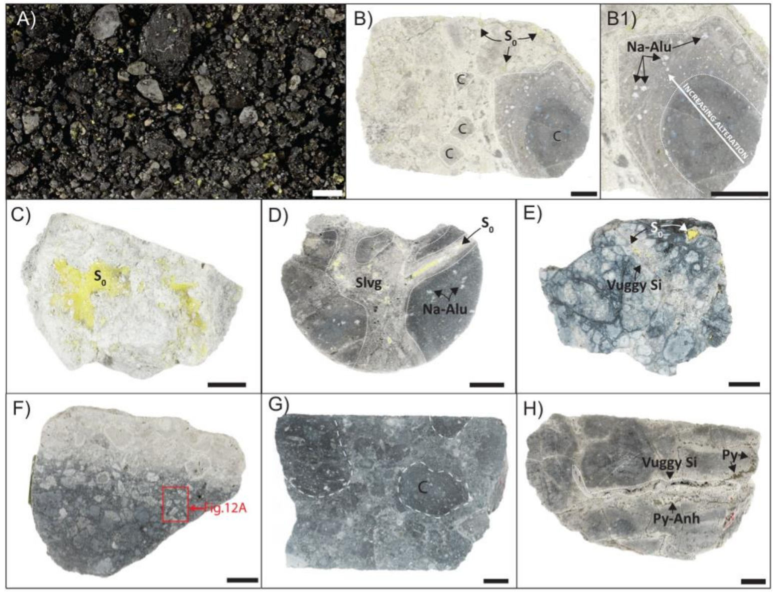
- Plume influenced host rocks
- Spreading rate of initial oceanic crust formation
- Modes of hydrothermal fluid discharge vents v beehive structures

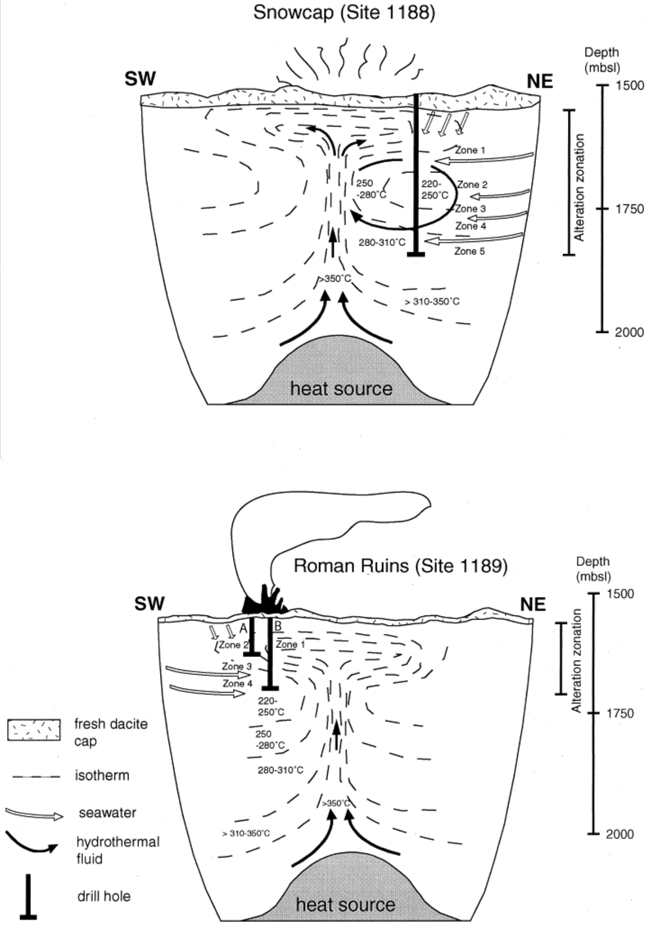
Investigations of the Beebe Vent Field amplify understanding of key elements of mineralization including the potential roll of topography.

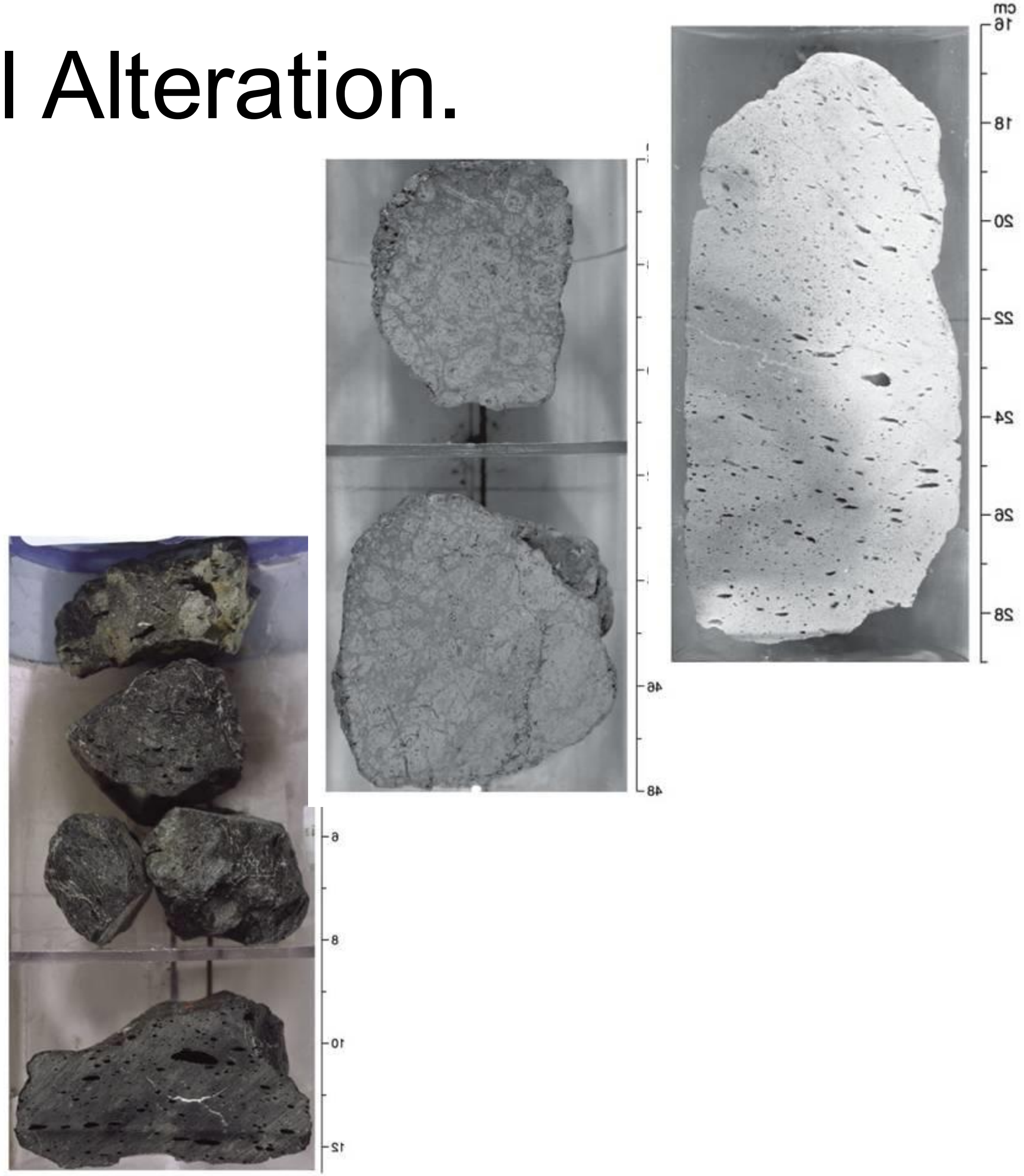
Seawater sulfide experiments highlight potential role of oxide formation in preserving hydrothermal vent sites into the geological record.

Fluid Pathways and Hydrothermal Alteration.

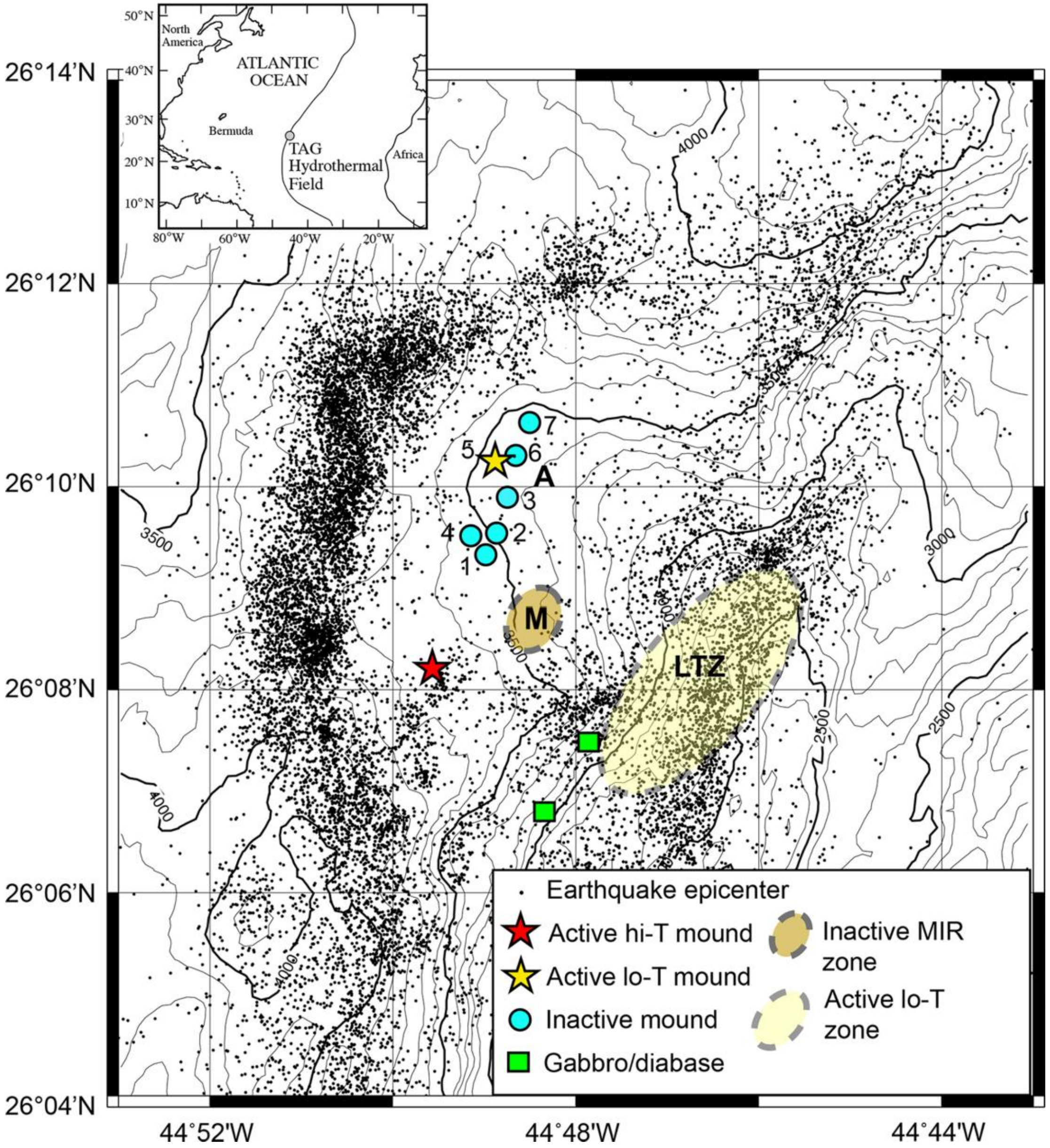


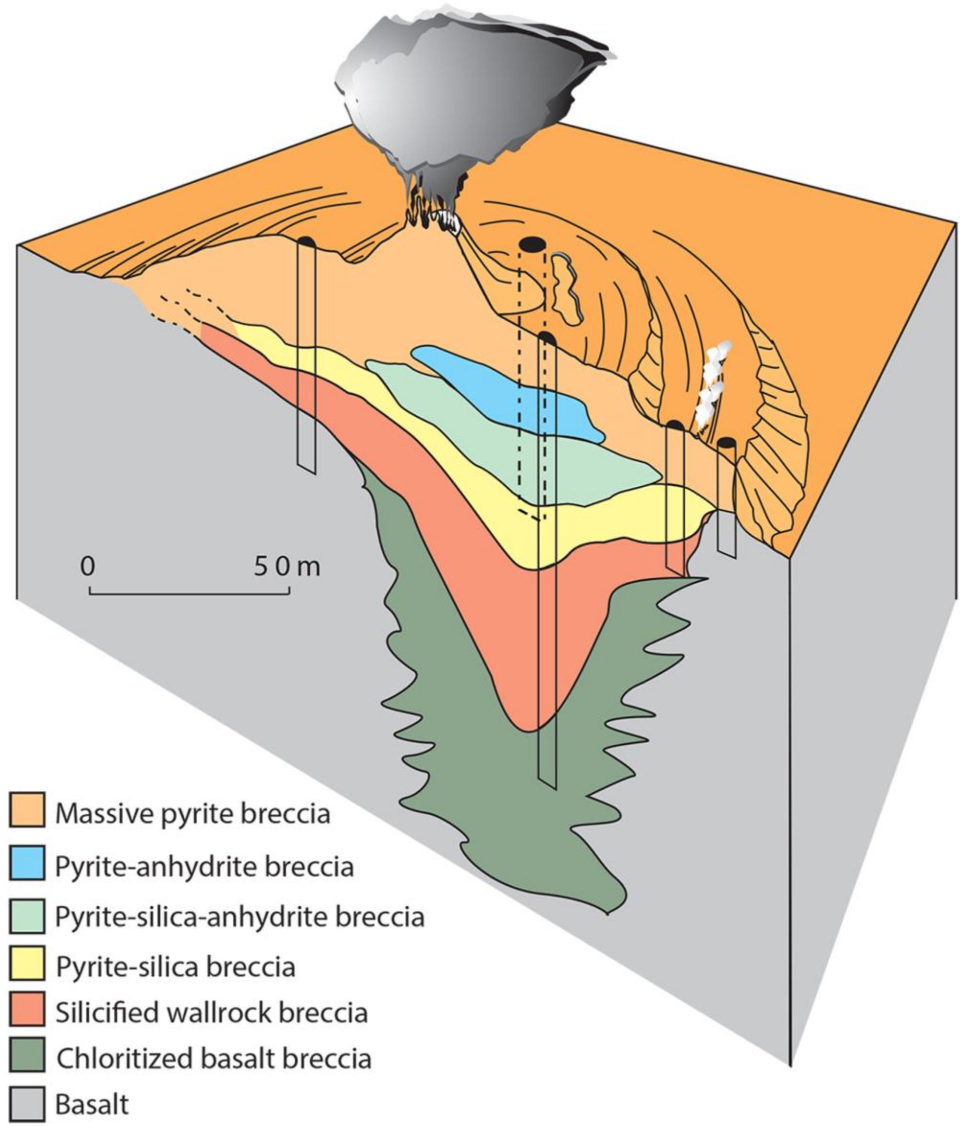






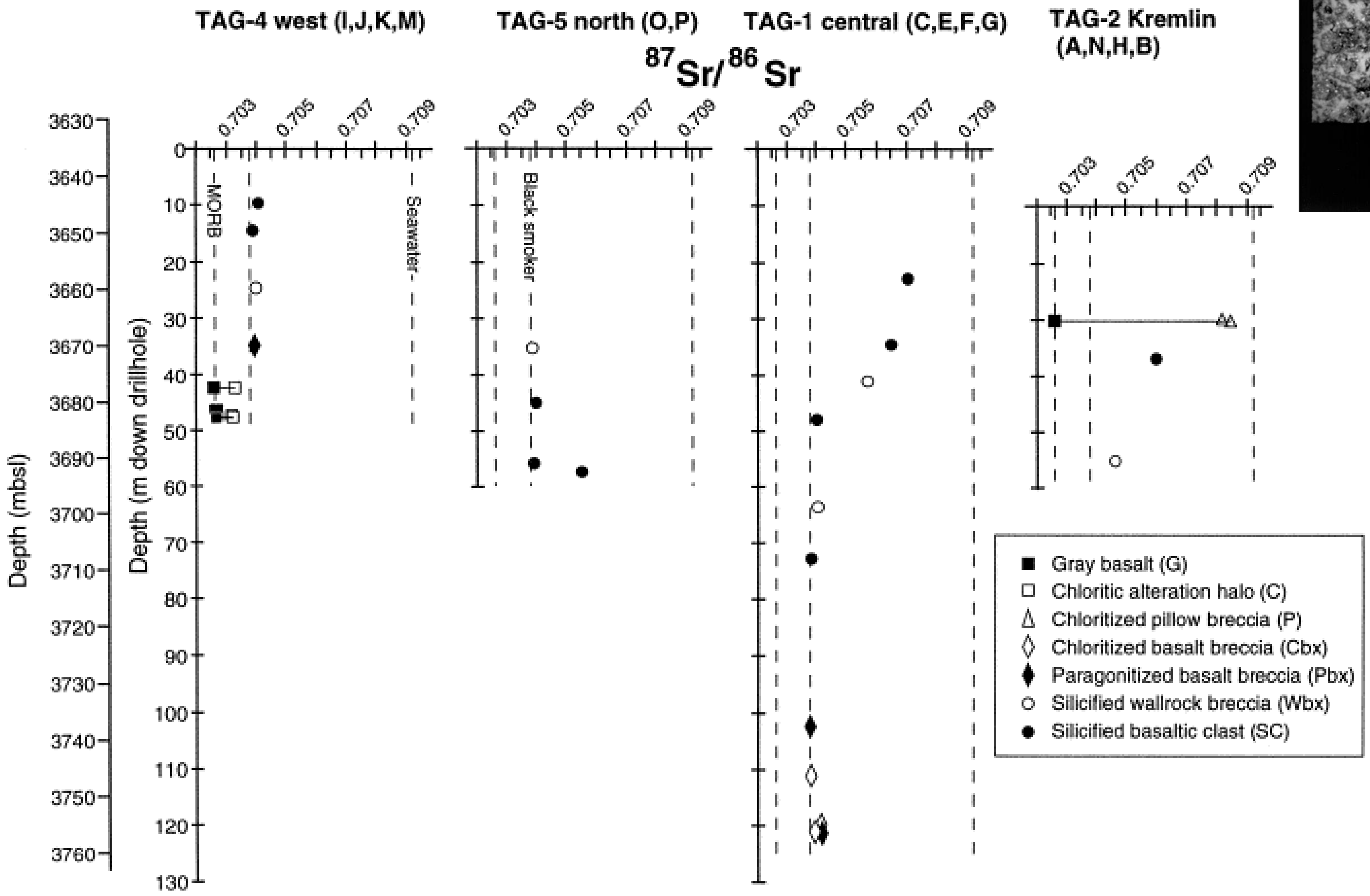
ODP Leg 158 "Classic Alteration" of TAG Mound.

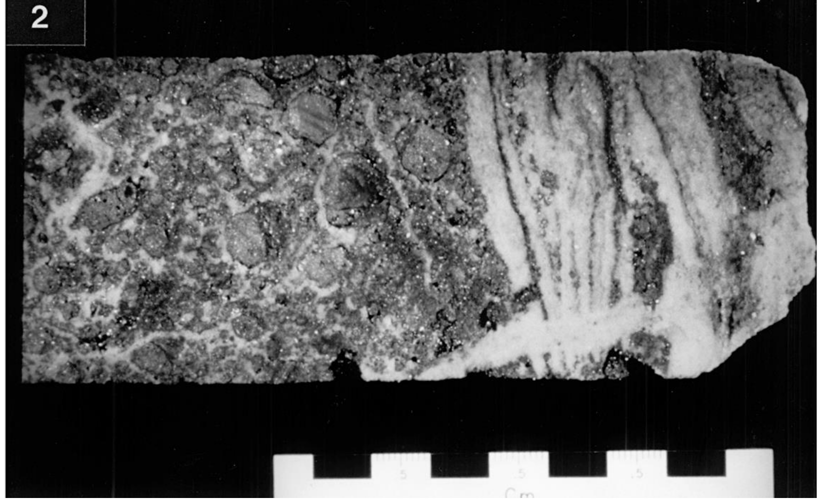




Humphris et al. Deep Sea Research Part II: Topical Studies in Oceanography: Volume 121, November 2015, Pages 8-16

Fluid mixing from anhydrite 87/86 Sr isotope studies.





Abundance of anhydrite. Estimate, based on the drilling results, that the TAG mound currently contains about 165,000 metric tons of anhydrite.

Through stable and radiogenic isotope analyses of anhydrite insights into circulation of seawater within the deposit.

Teagle et al. 1998

ODP Leg 158 Classic Alteration and Fluid Flow of TAG Mound.

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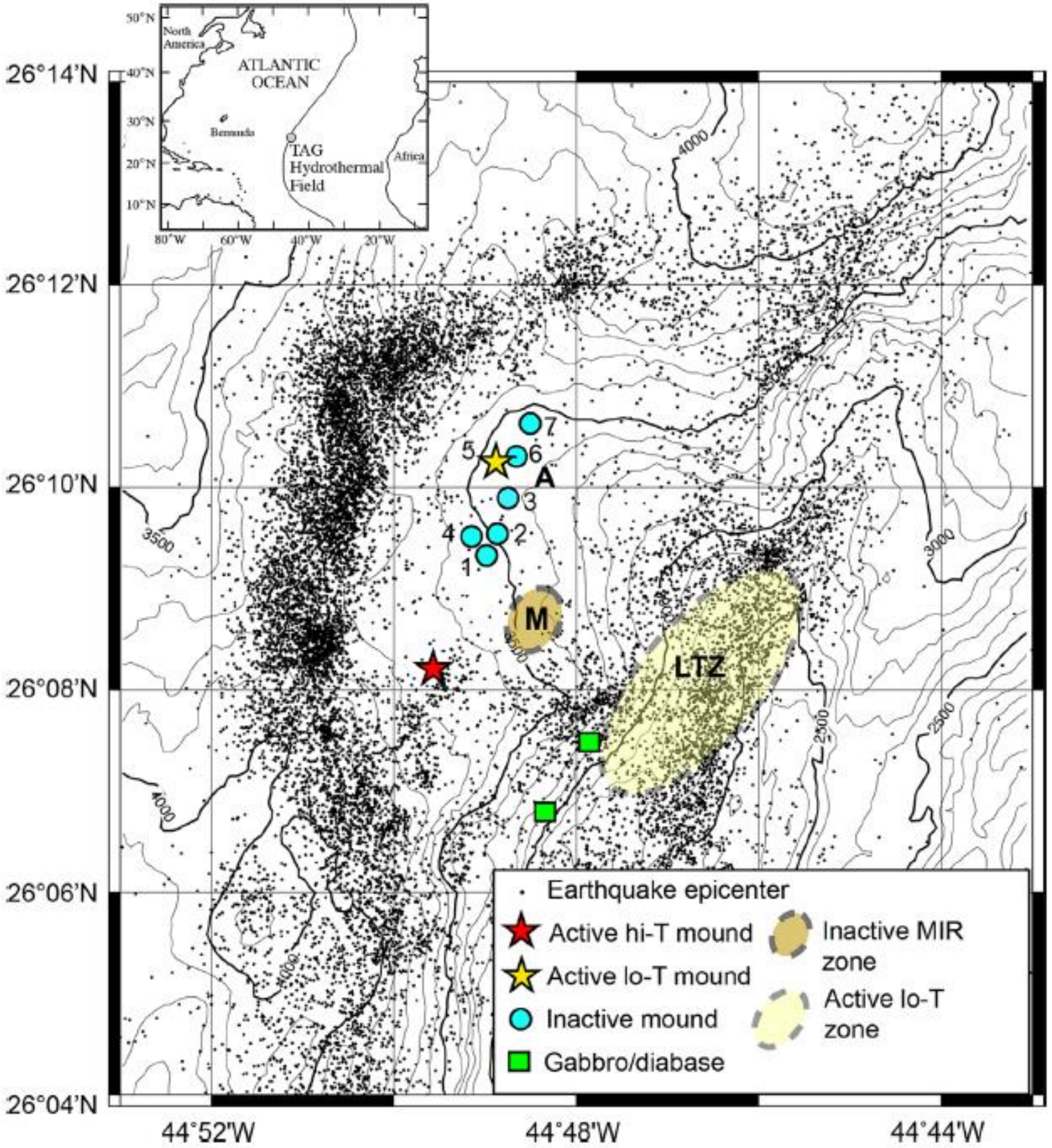
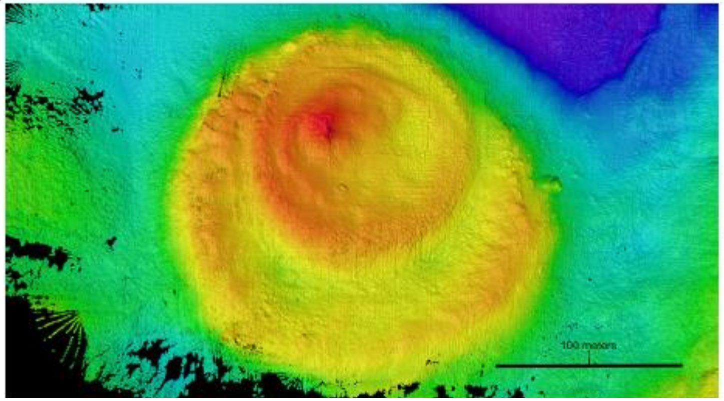
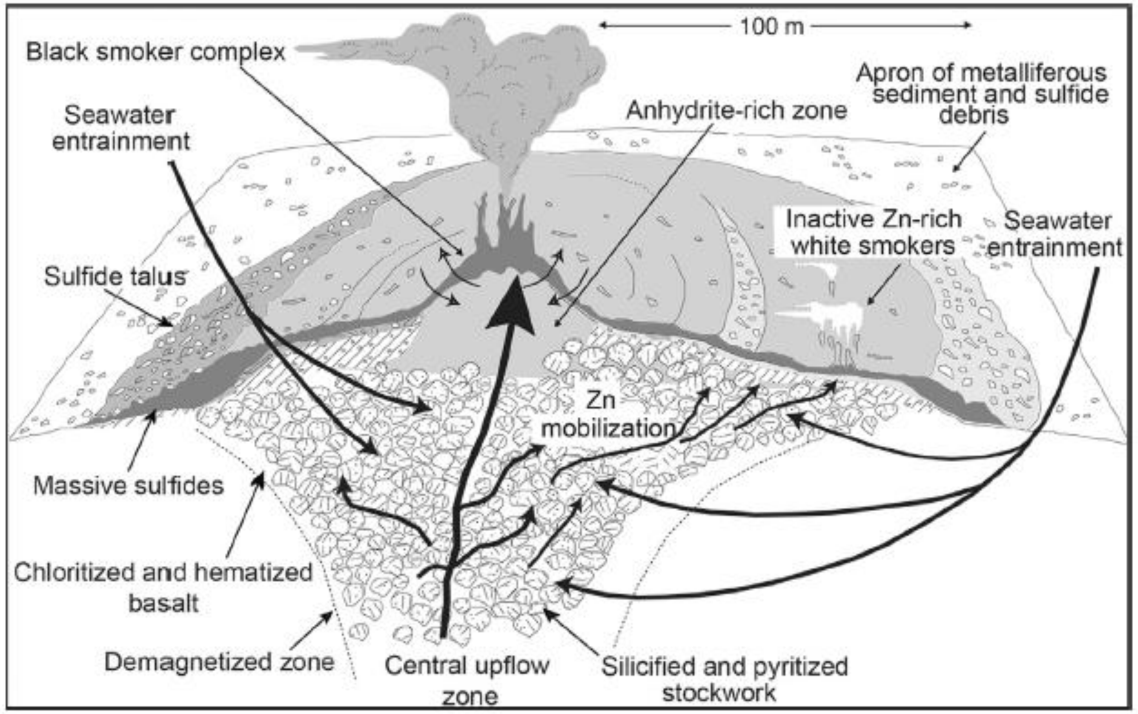
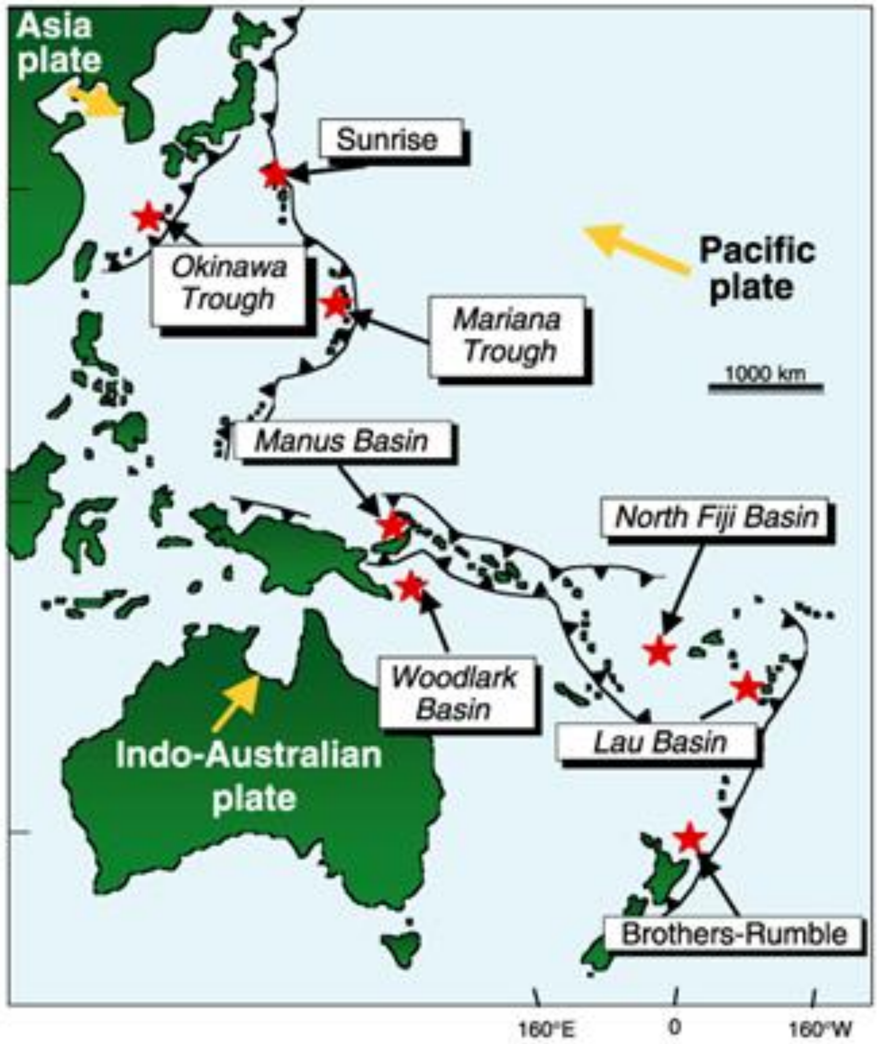






Source Humphris et al. 2015



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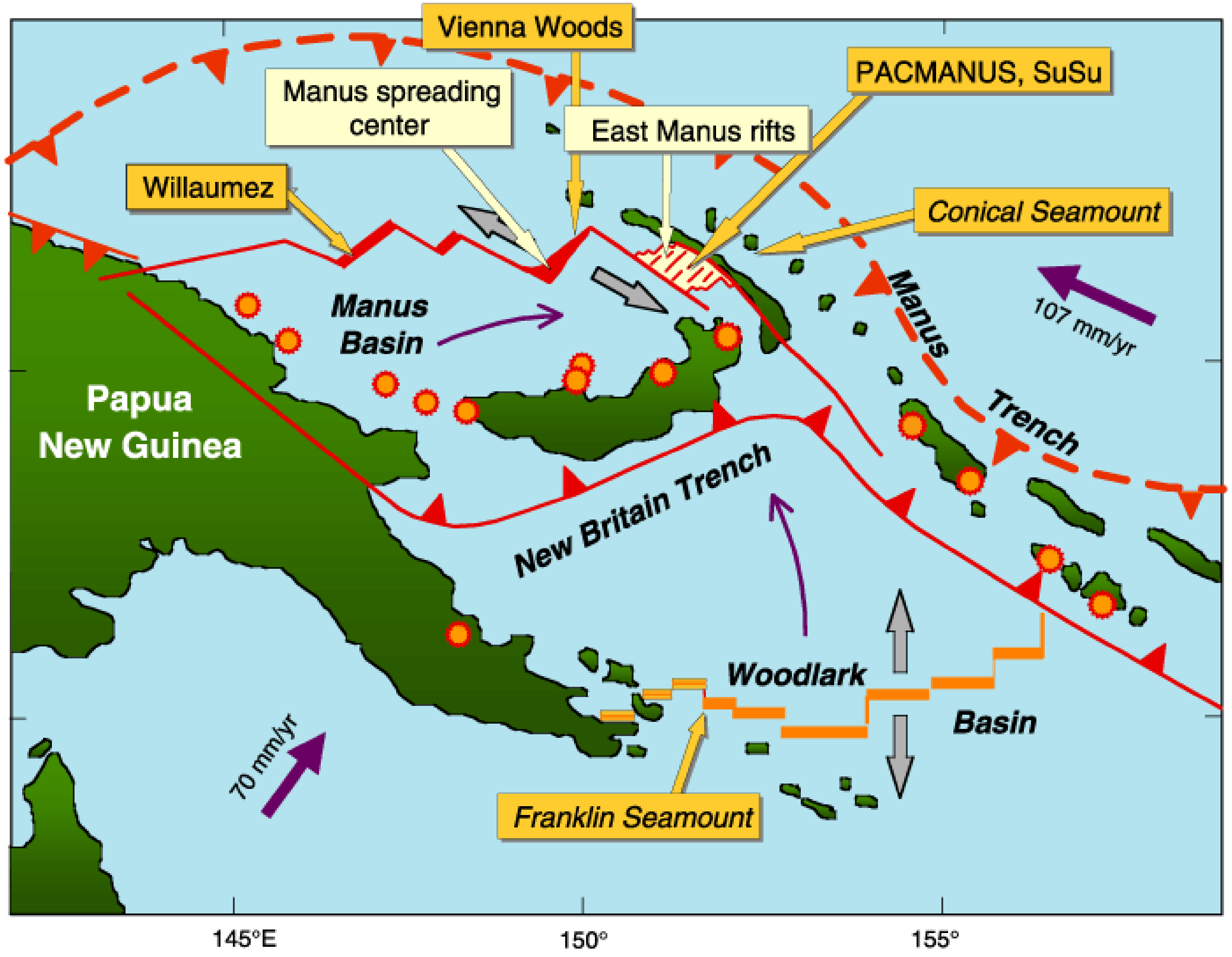
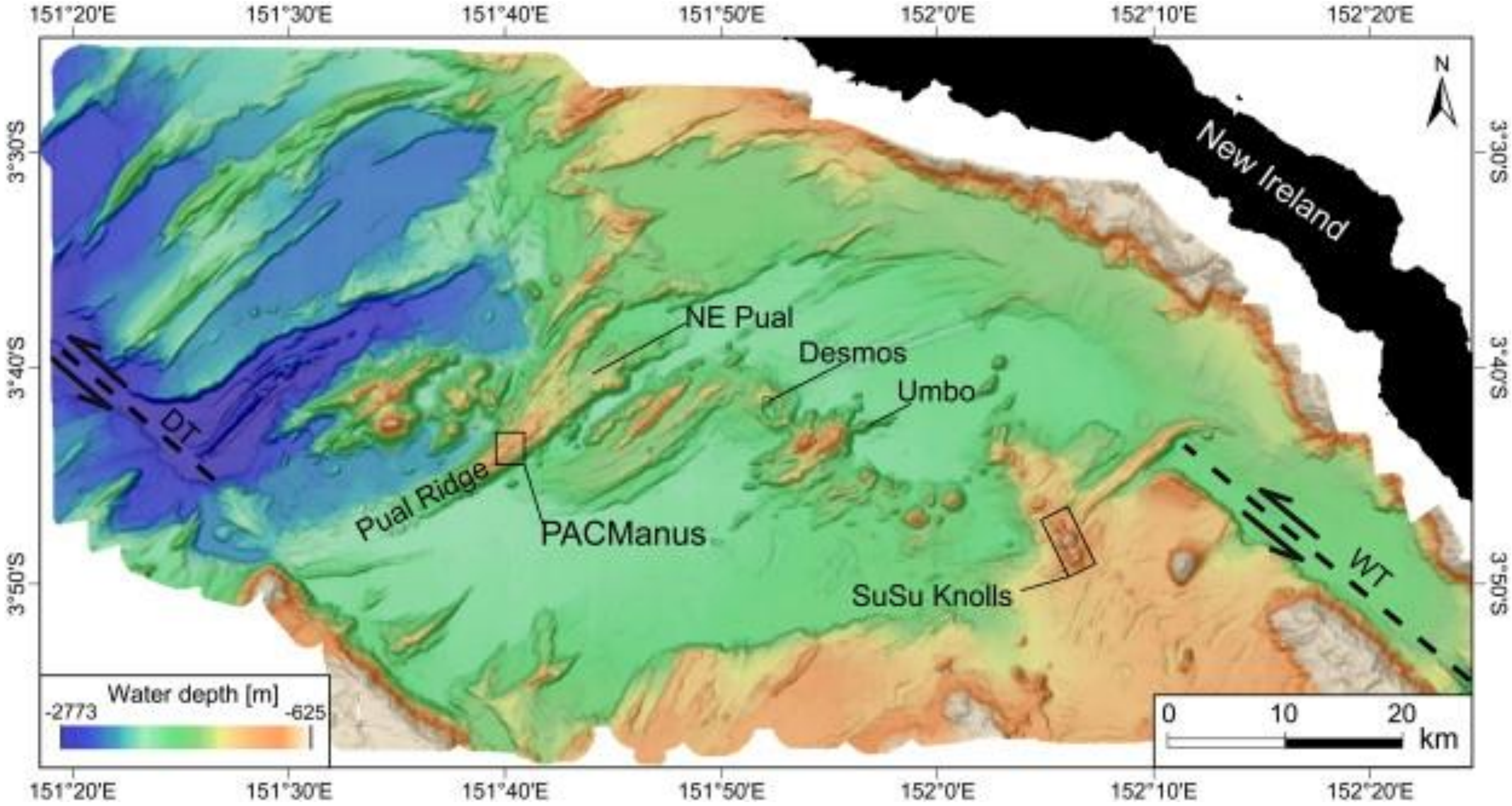


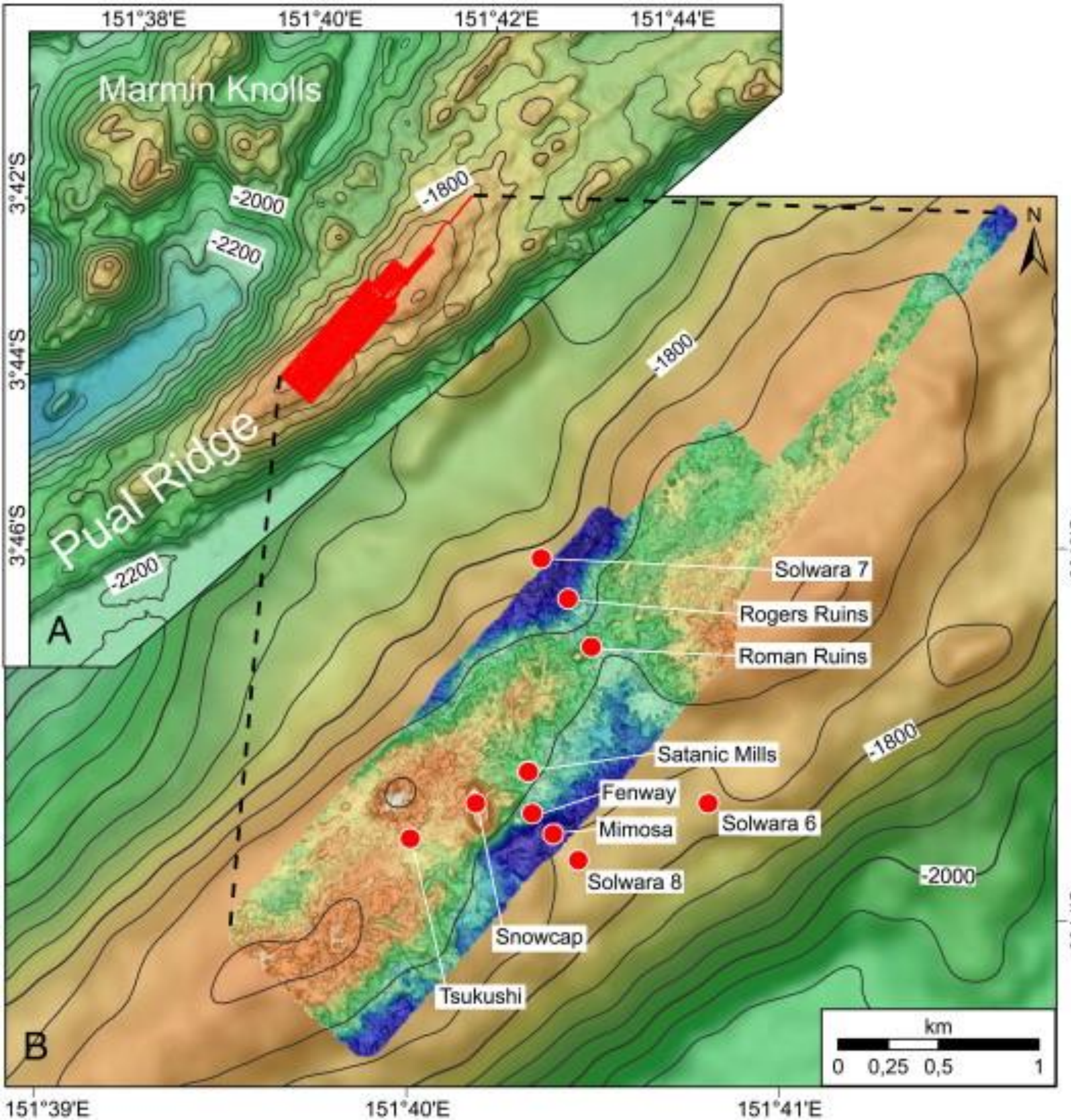
Location of PACMANUS Hydrothermal Field ODP Leg 193

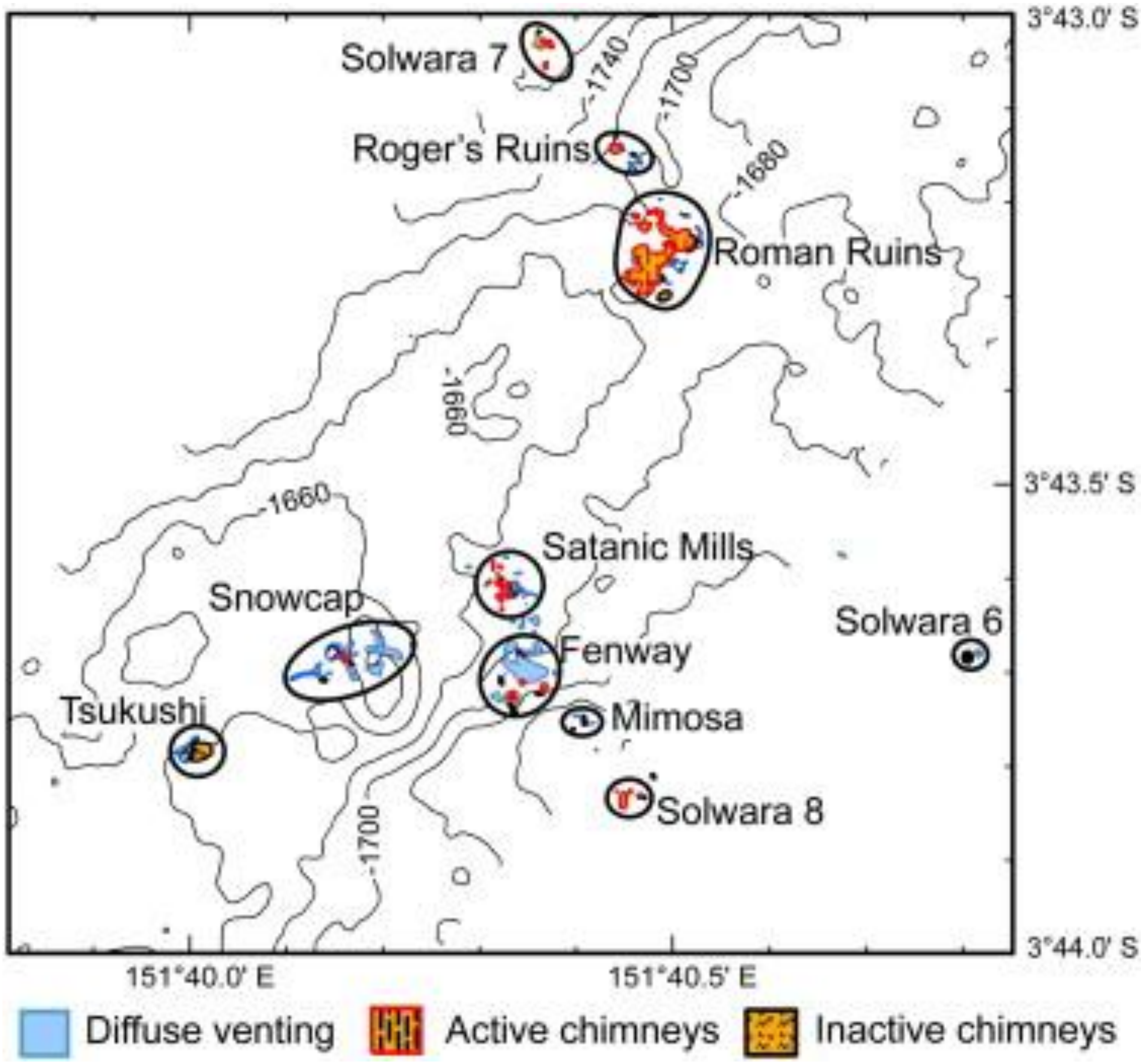
Location and Bathymetry of the Pual Ridge



Thal et al. 2014

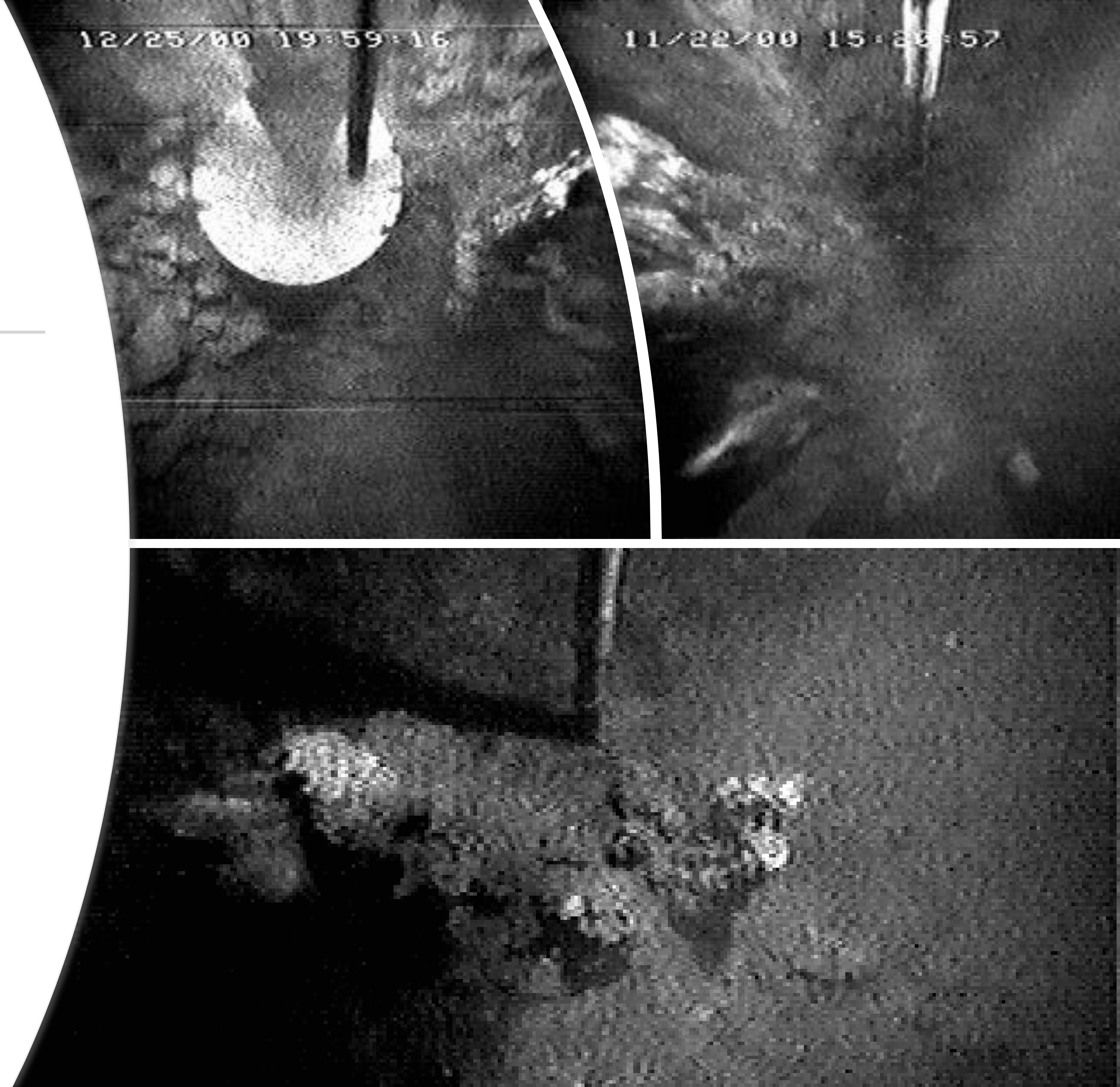
Location of Hydrothermal Vents on the Pual Ridge



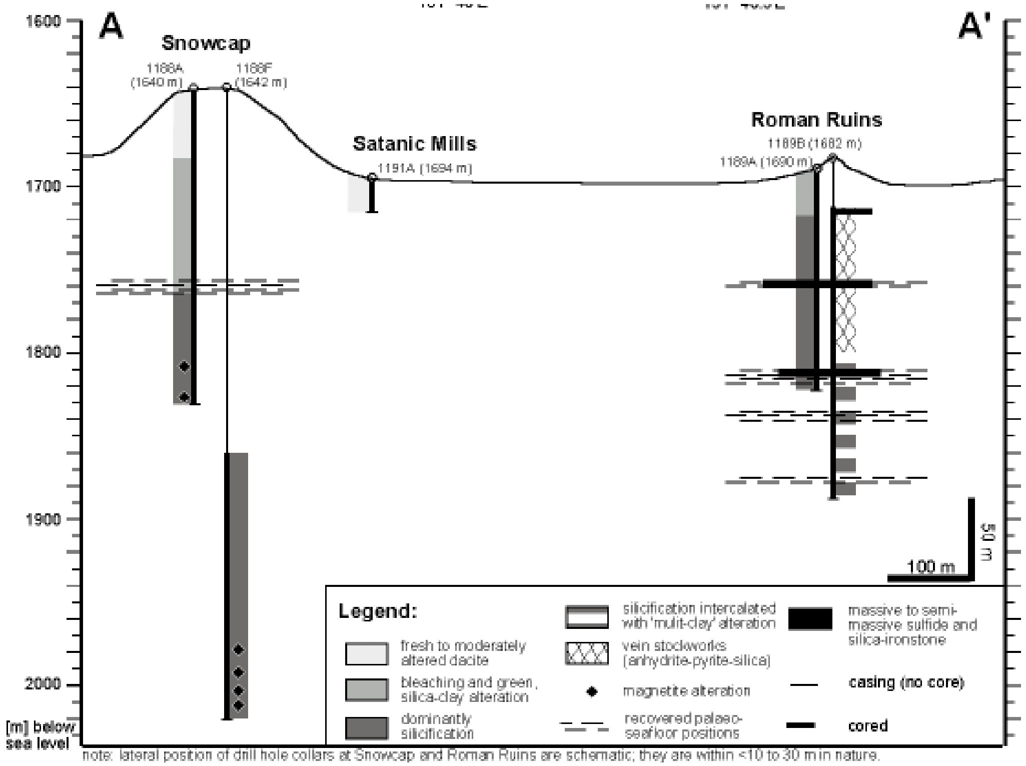


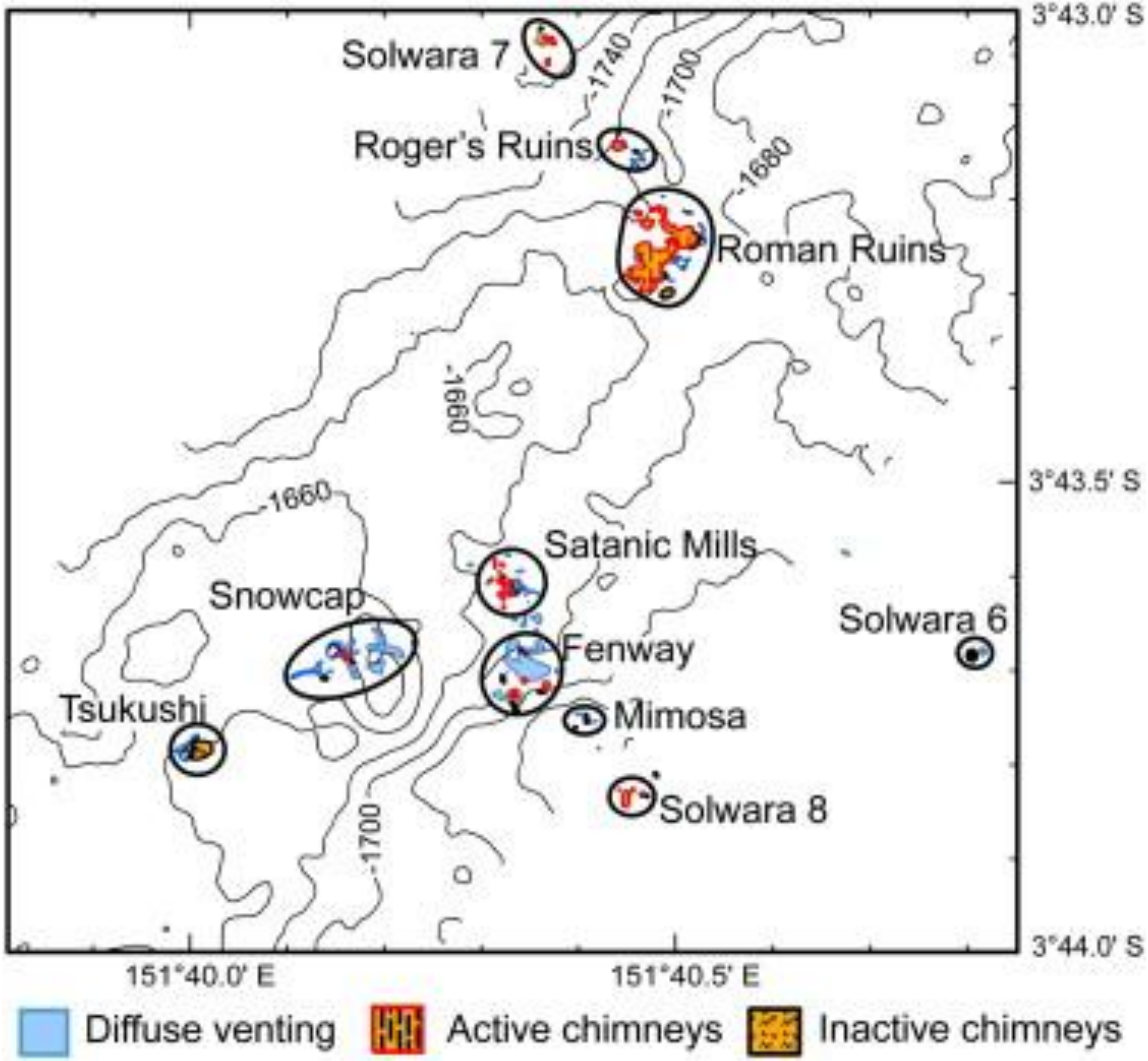
Thal et al 2014

- Shots from ODP Leg 193 Drill Camera

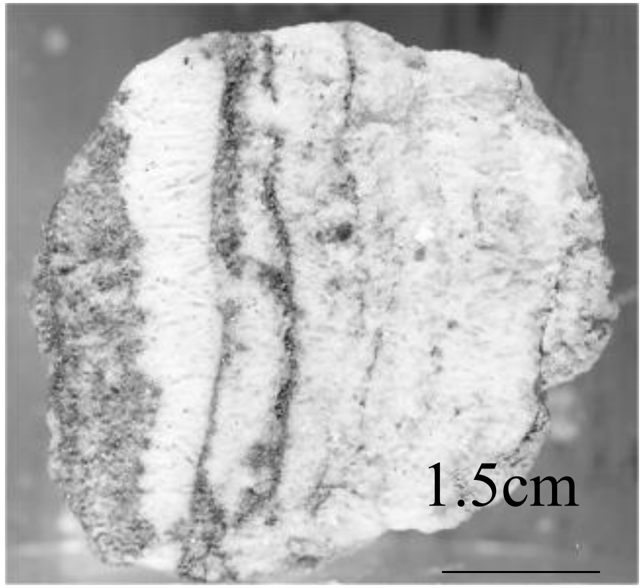


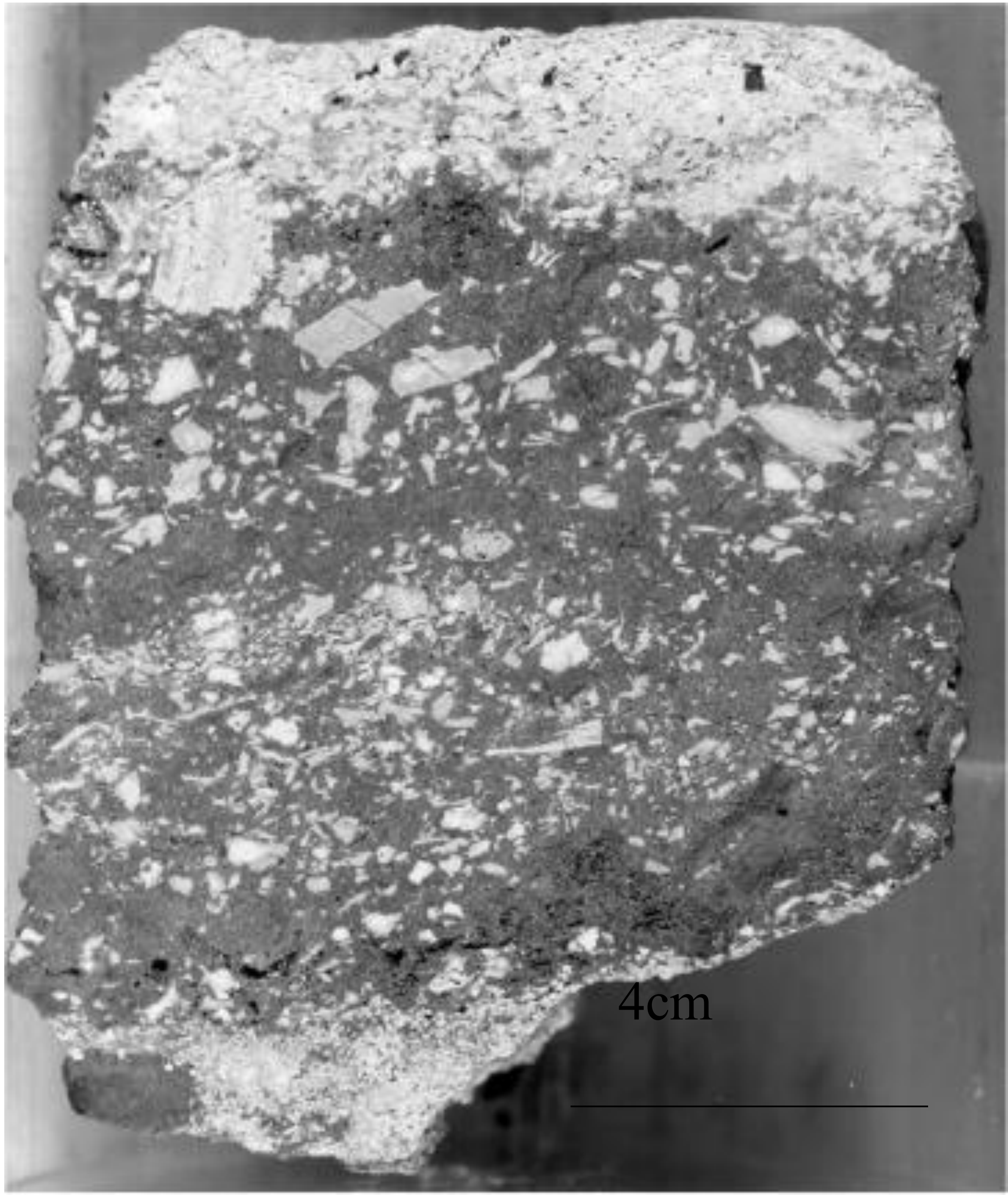
Focus of ODP Leg 193 drilling campaign on Snowcap and Roman Ruins

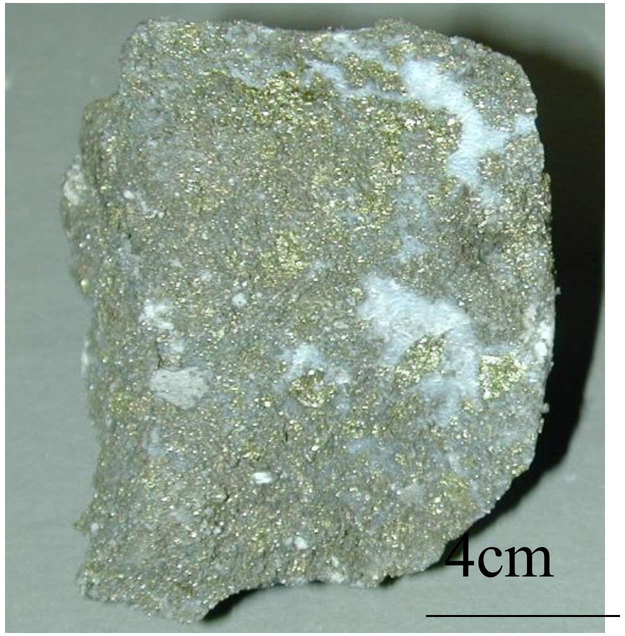




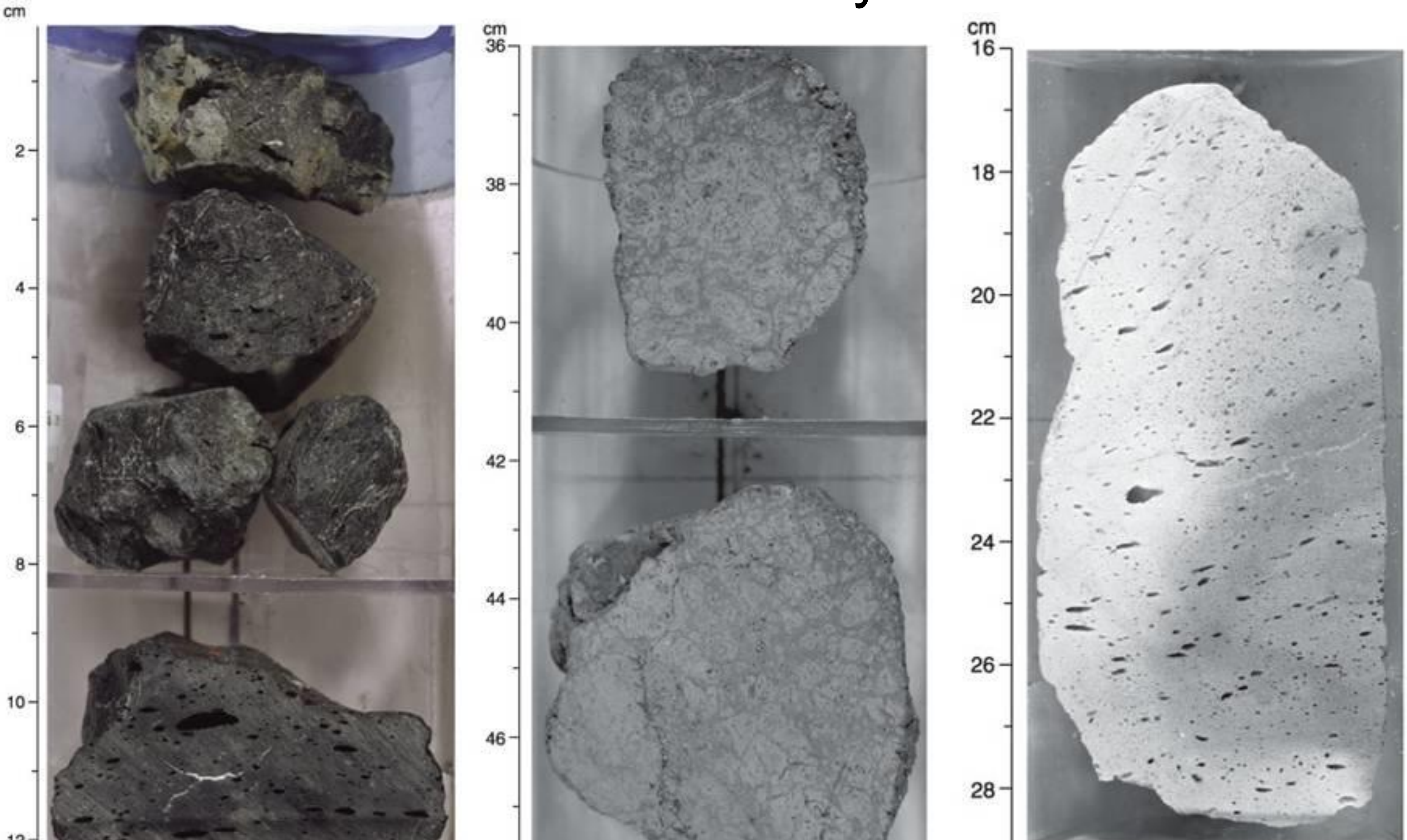
Sulfides & Anhydrite



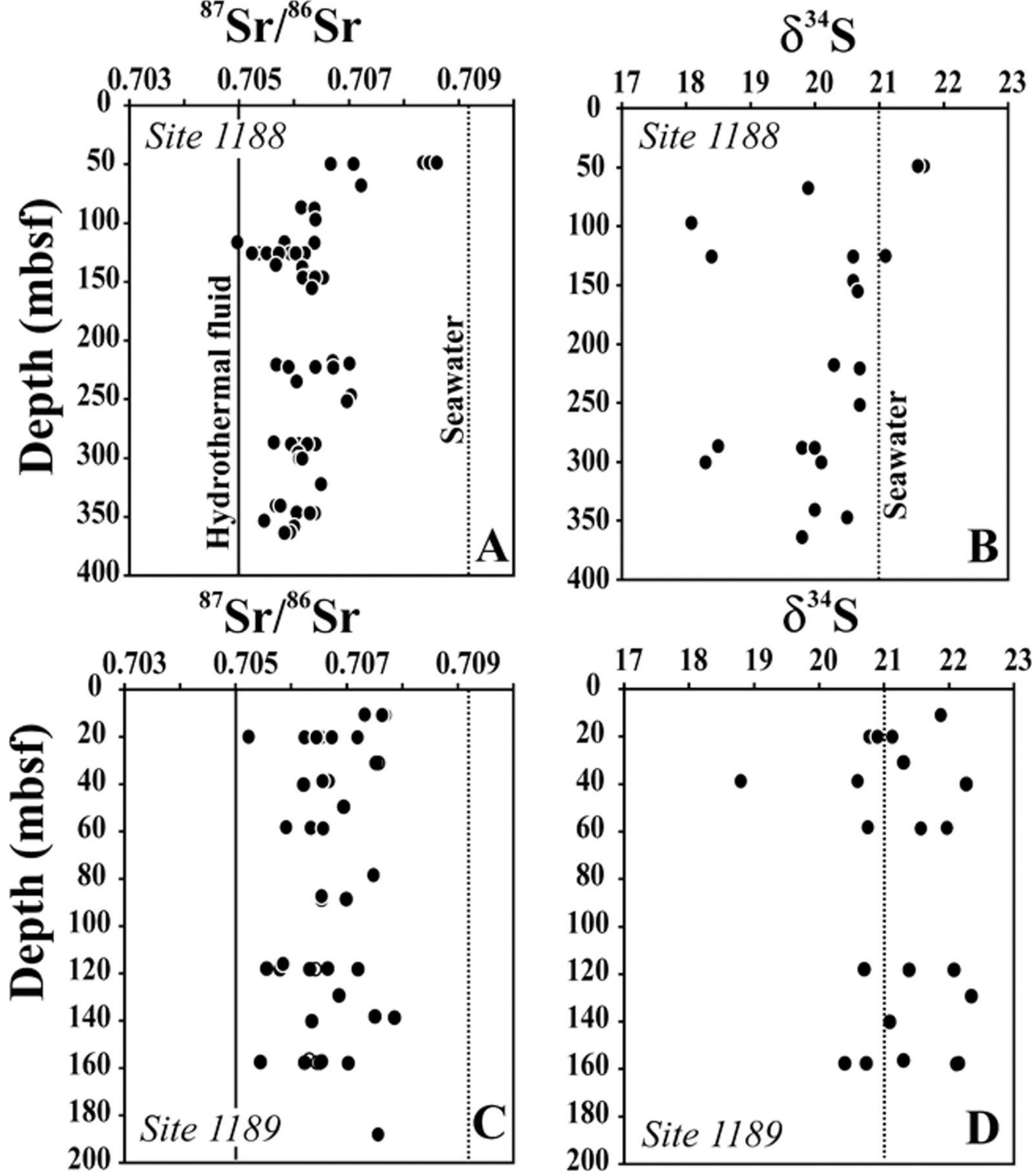


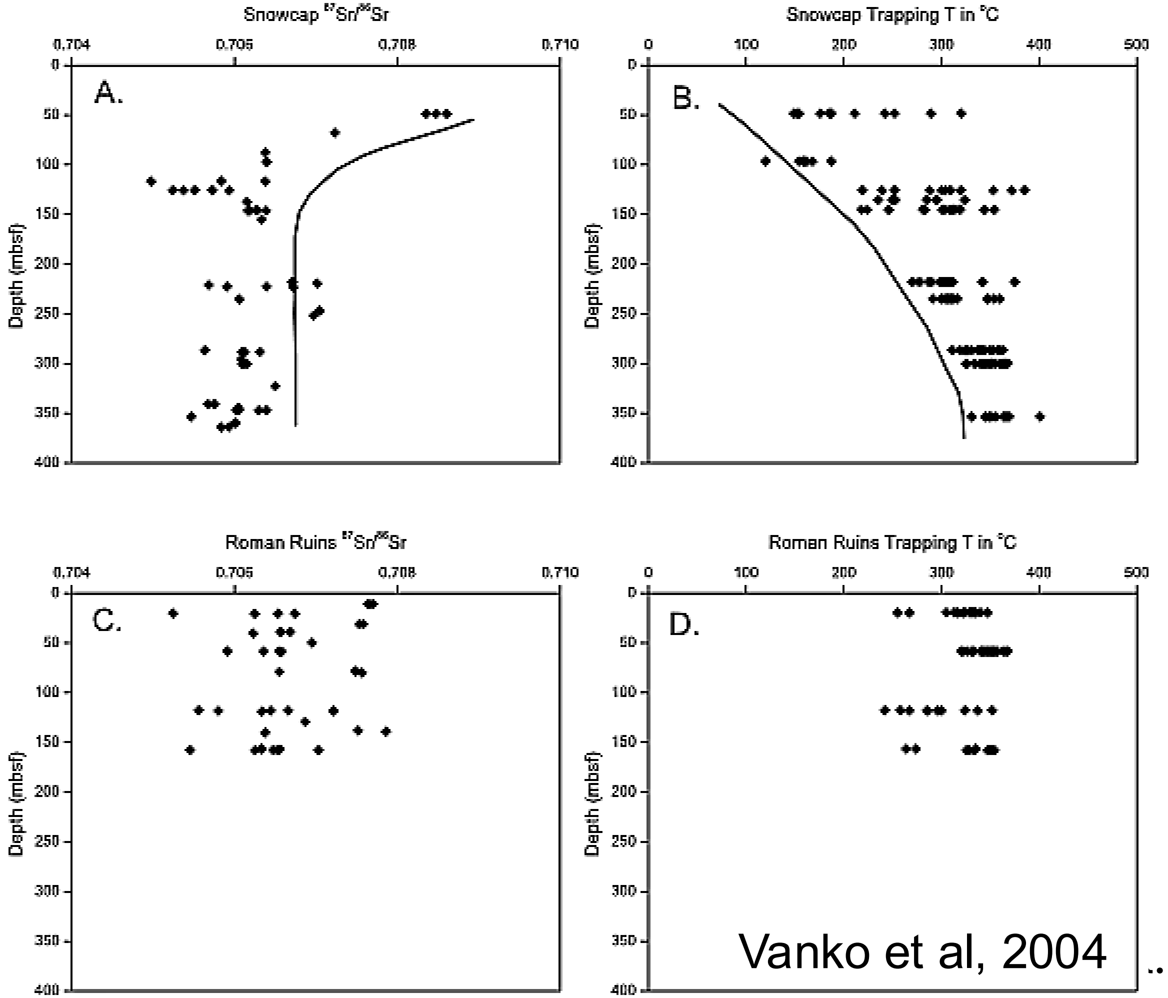


Variably Altered Volcanics



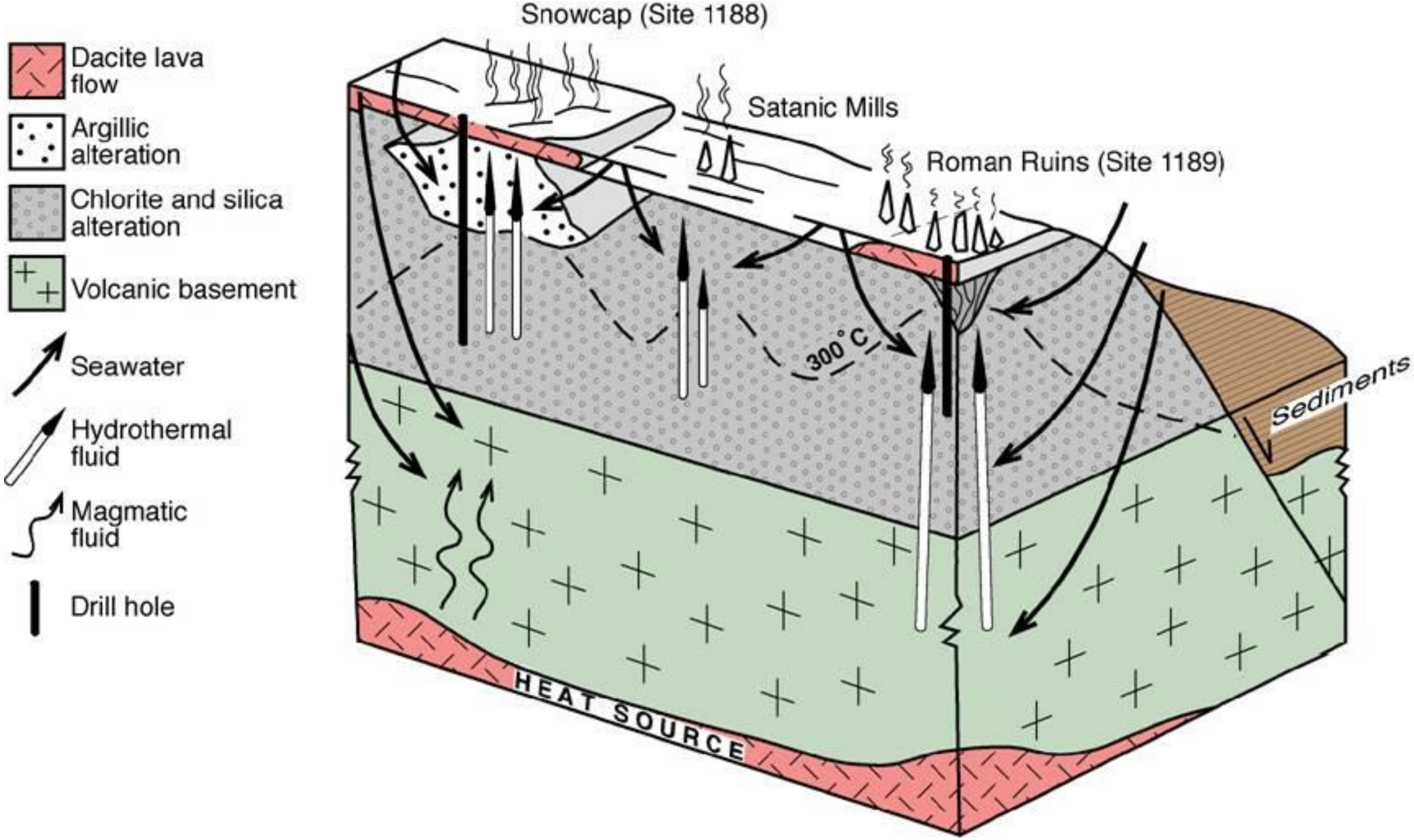
Fluid Mixing Contrasting Vent Site Characteristics only meters apart



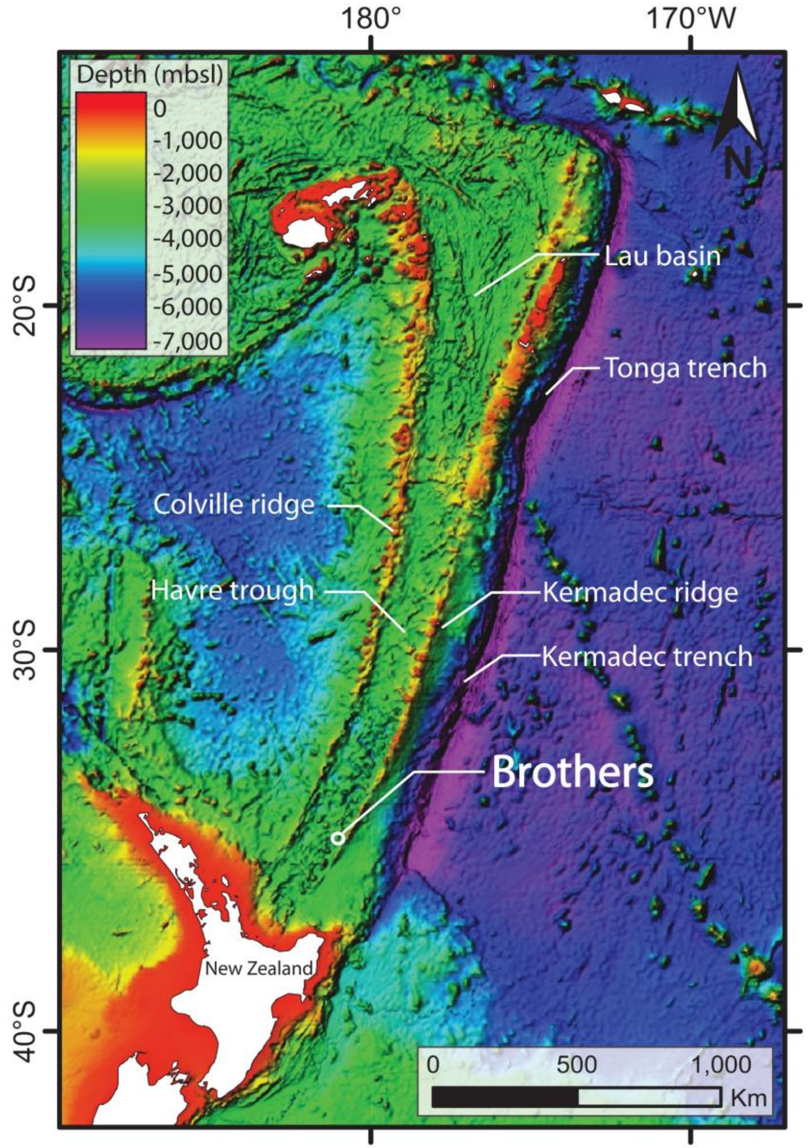


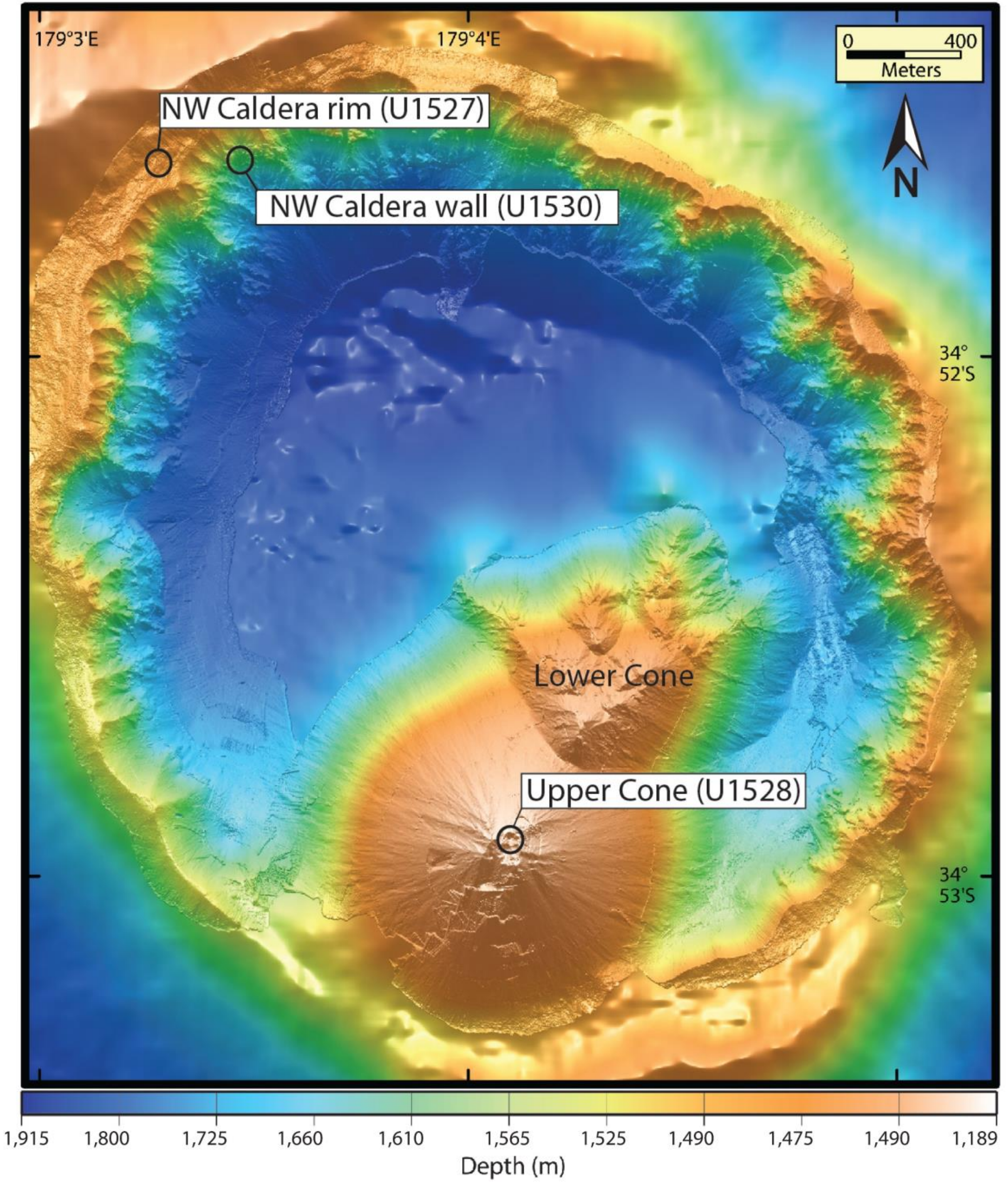
Vanko et al, 2004

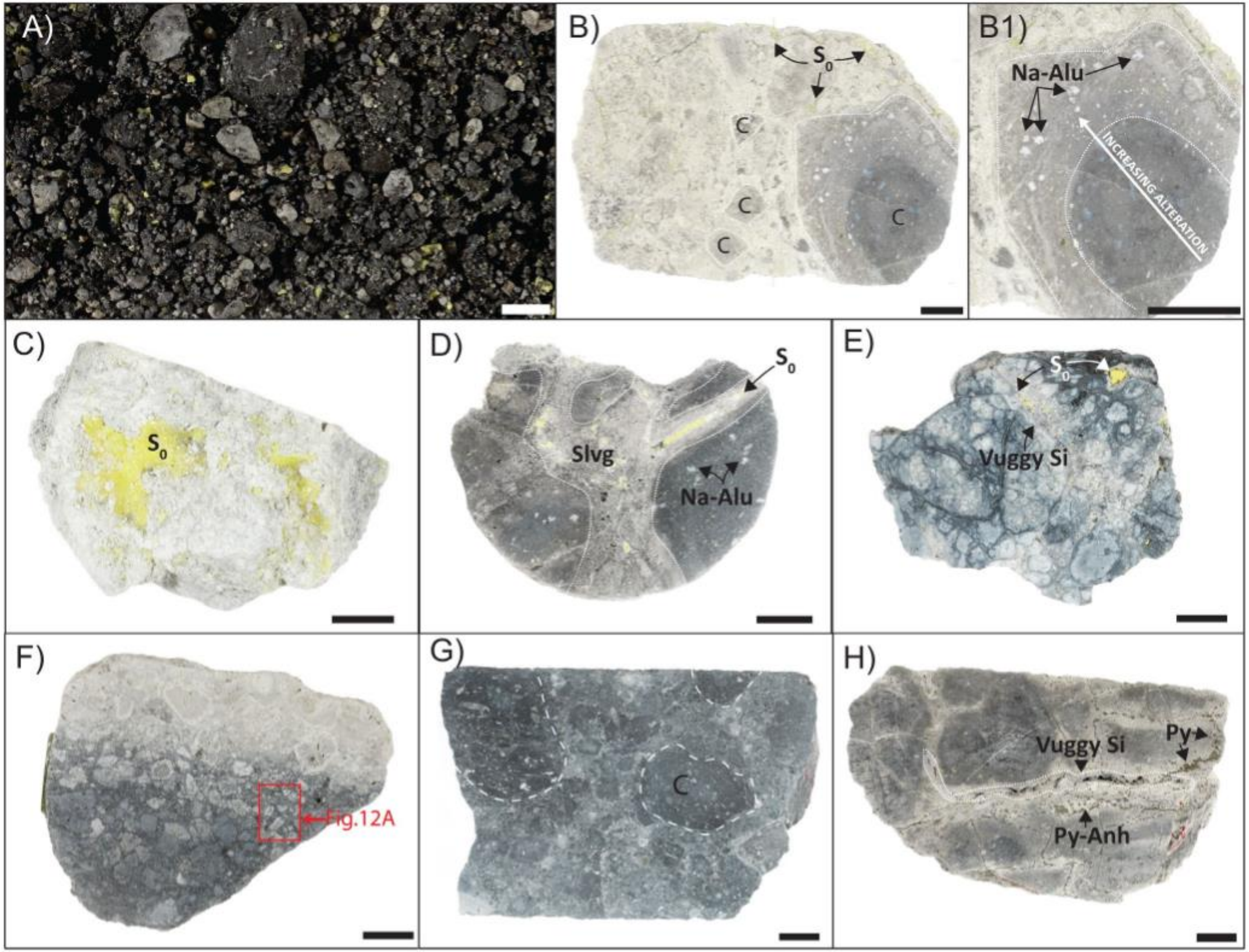
Schematic Model of Fluid Flow and Mineralization of The Pual Ridge



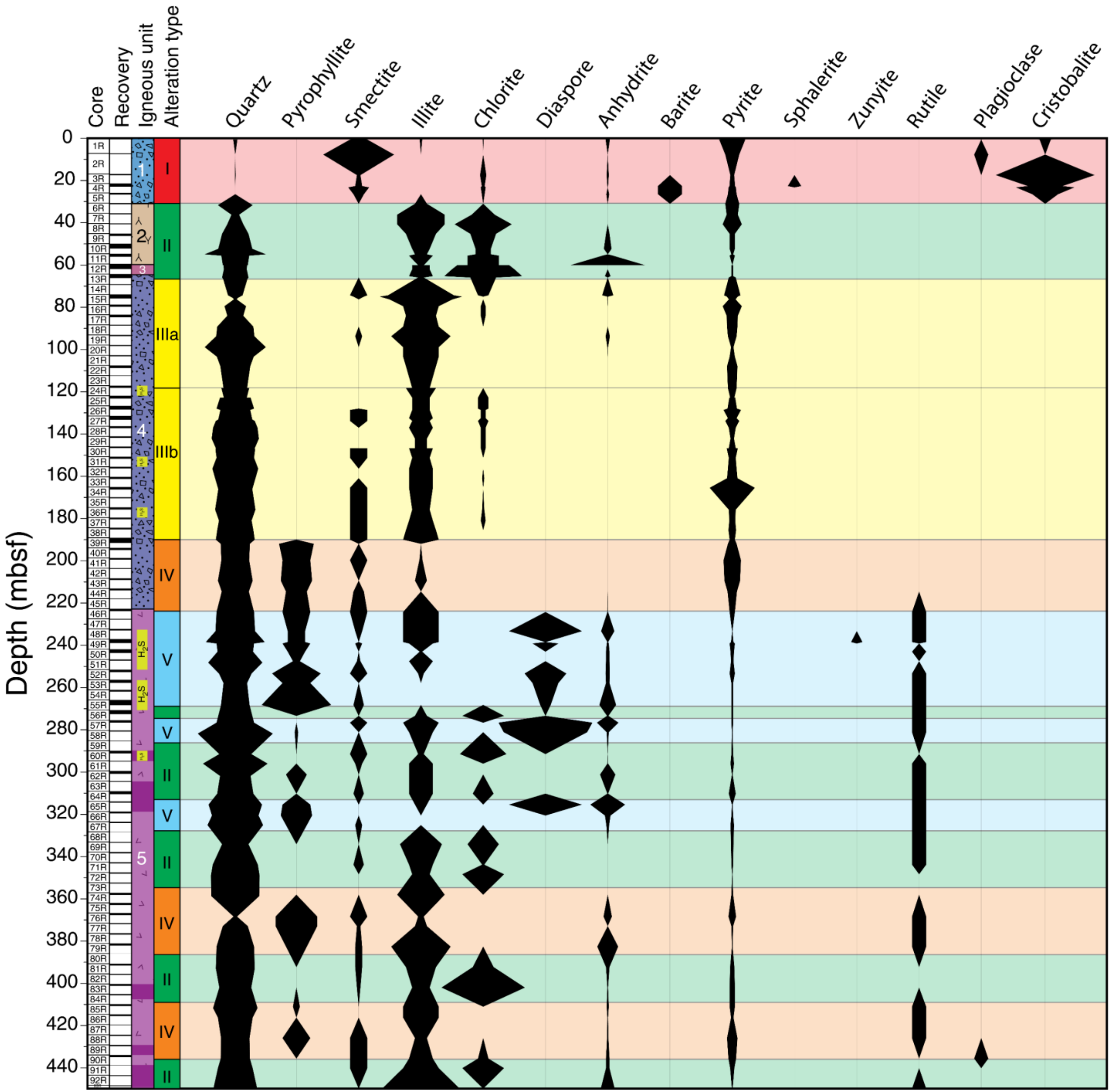
IODP Expedition 376






A)
B)
S_0
C
C
C
C
B1)
Na-Alu
INCREASING ALTERATION
C)
S_0
D)
S_0
Slvg
Na-Alu
E)
S_0
Vuggy Si
F)
Fig.12A
G)
C
H)
Vuggy Si
Py
Py-Anh

Drill Site U1530 A North Caldera Wall



In the deepest parts of Hole U1530A, diaspore and/or pyrophyllite zones are intercalated with and locally overprinted by chlorite- and illite-bearing assemblages, indicative of reaction with a relatively high-temperature, seawater-dominated fluid.

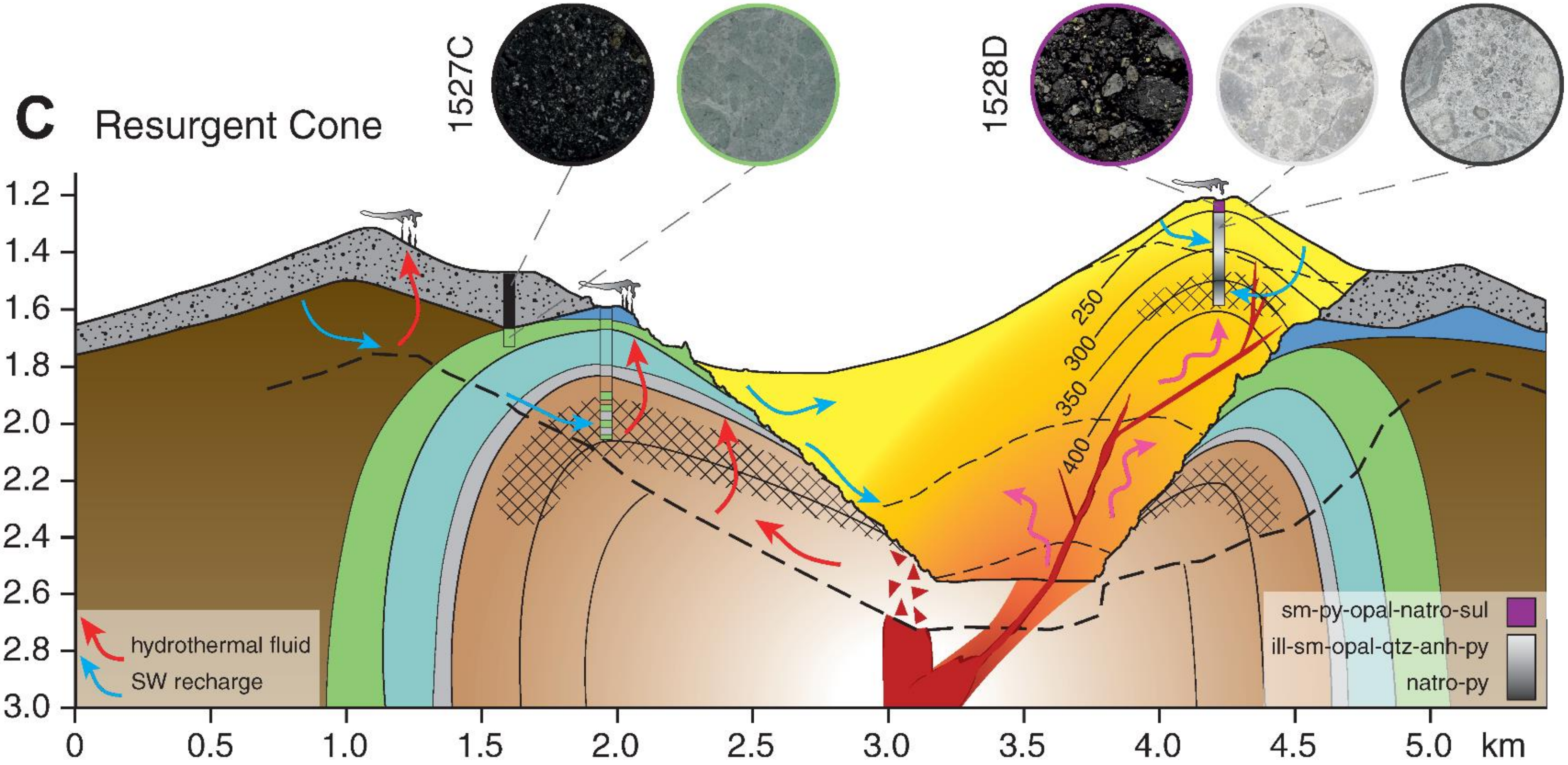
Table 3. Summary of Key Characteristics of Different Mineral Assemblages at Brothers Volcano

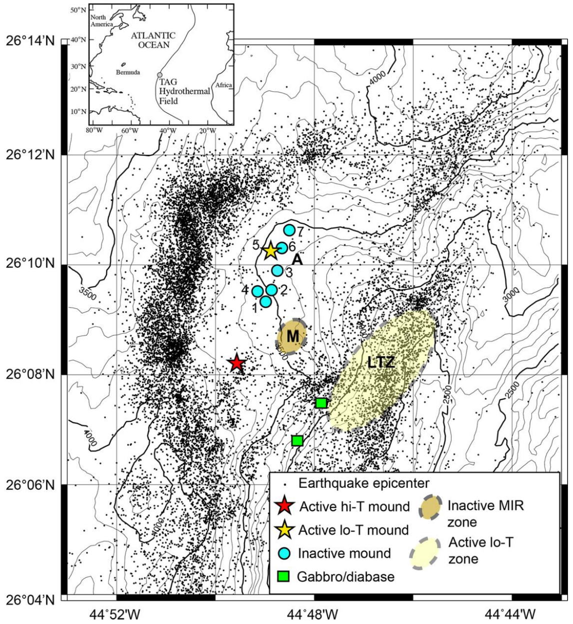
Assemblage	Distribution	Textural features	Formation conditions
Natroalunite and natroalunite + pyrophyllite	Upper Cone	Bleached selvages, brecciation, plagioclase pseudomorphs	Locally high fluid/rock ratios along selvages, temperatures ~250°–300°C, low pH 1–3
Pyrophyllite + illite + quartz	NW Caldera flank <189 mbsf	Coarse-grained equigranular texture, subhedral pyrite	Low fluid/rock ratios, pervasive fluid flow, high temperatures 200°–320°C, moderate to low pH 2–3
Mordenite + smectite + opal + geothite	NW Caldera rim <188 mbsf	Prominent brecciated appearance with quartz forming dominant matric phase	Near surface convection of seawater, high water-rock ratios, oxidized low-temperature fluids (50°–170°C)
Chlorite + quartz	NW Caldera flank and rim >188 mbsf	Variable, generally brecciated with anhydrite-pyrite veins	High-temperature >300°C seawater-derived fluid flow
Smectite + primary igneous plagioclase	Upper Cone – discrete intervals	Coherent intervals that lack a prominent brecciated texture	Highly variable fluid temperature, possibly ~180°C, higher pH fluids (>5)

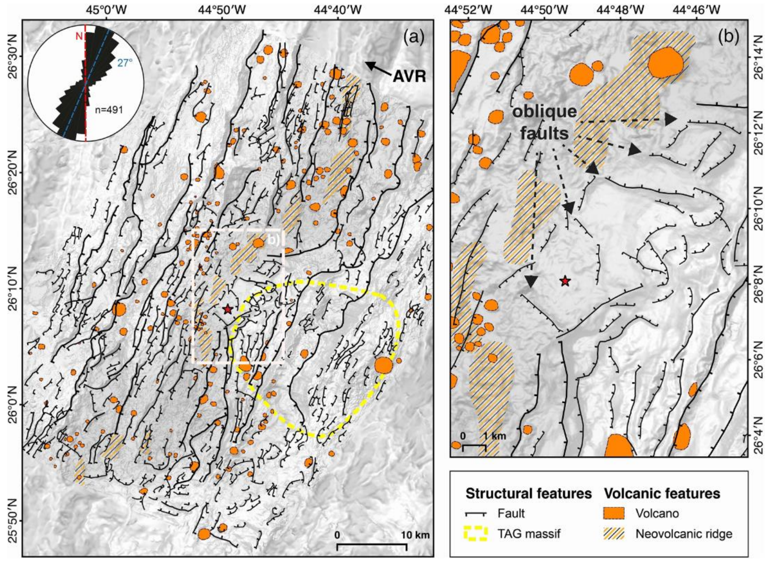
Note: The references used for the temperature ranges are Reyes (2003) and Seewald et al. (2019)

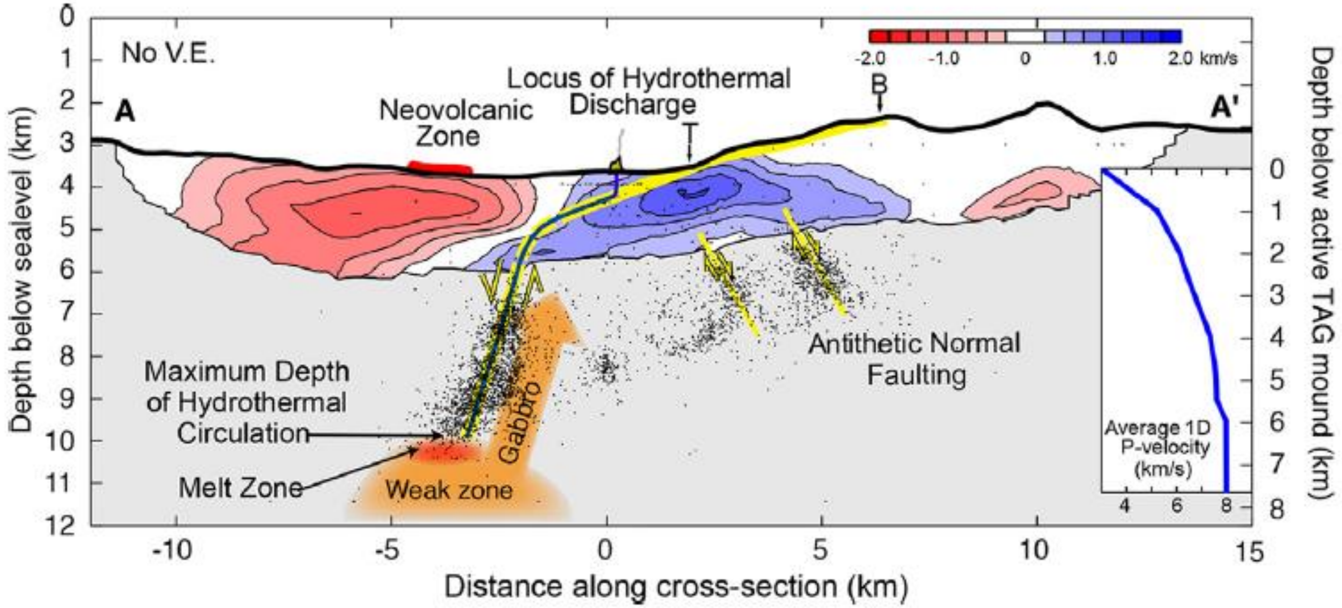
Martin et al. 2022

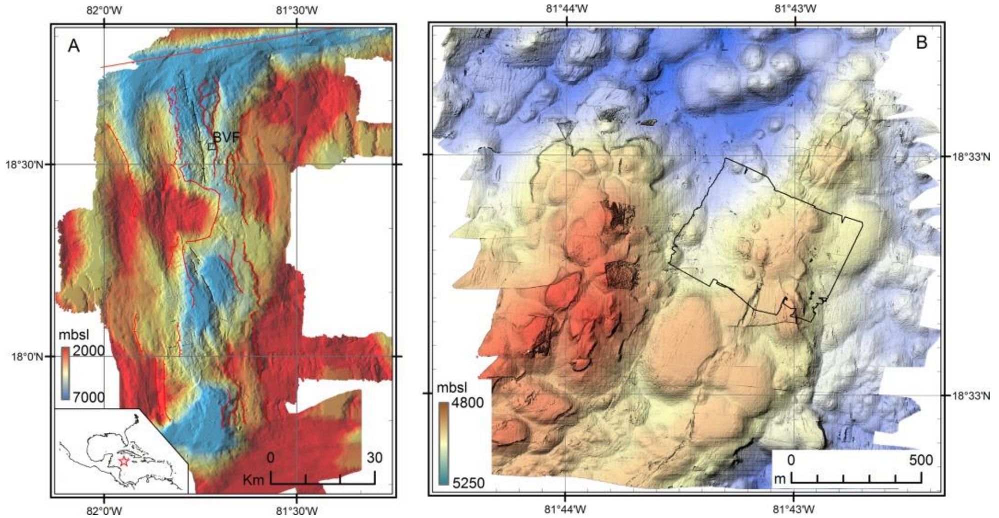
Schematic cross section of Brothers Vents and Alteration Assemblages



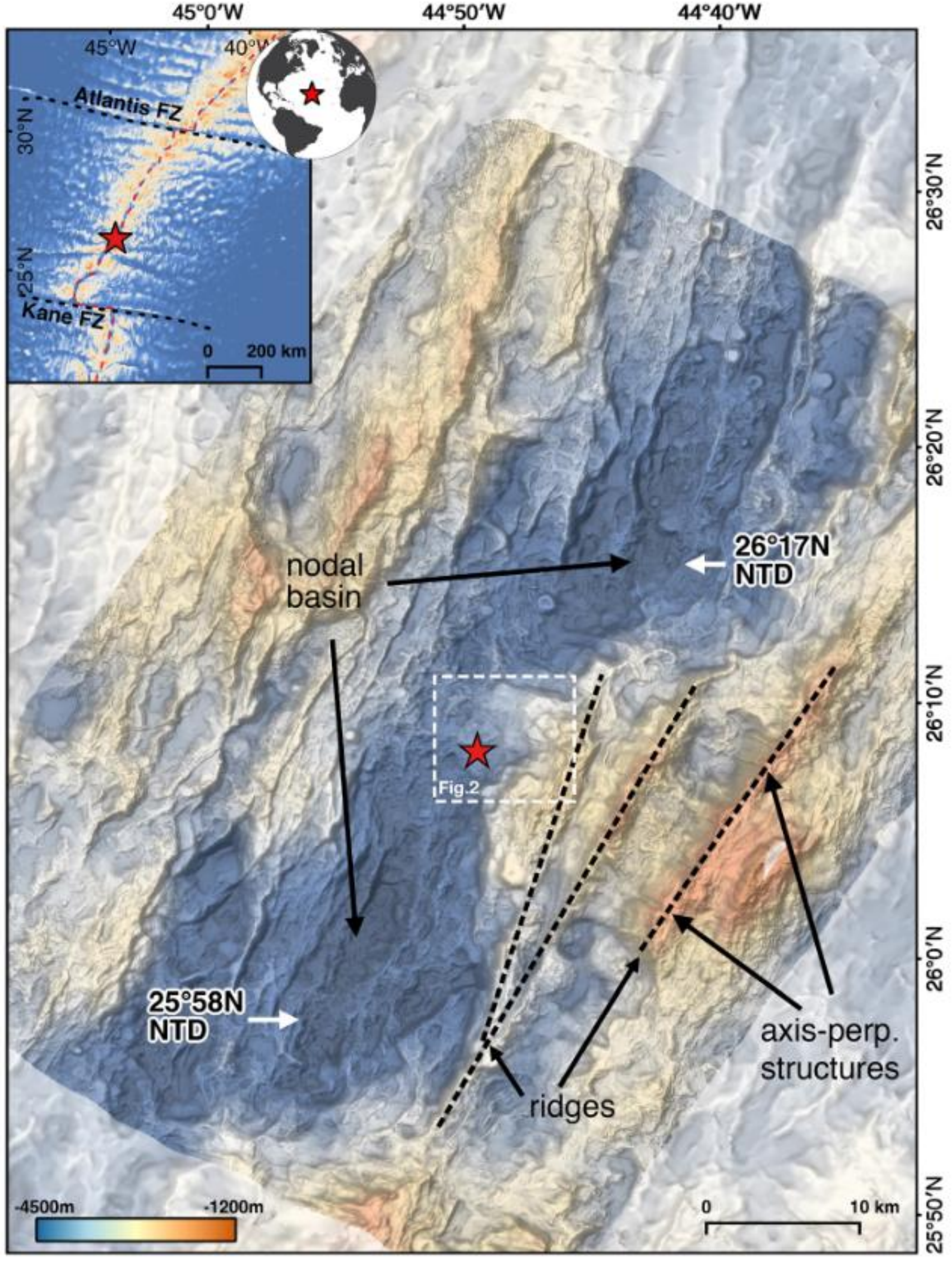








Role of Tectonics



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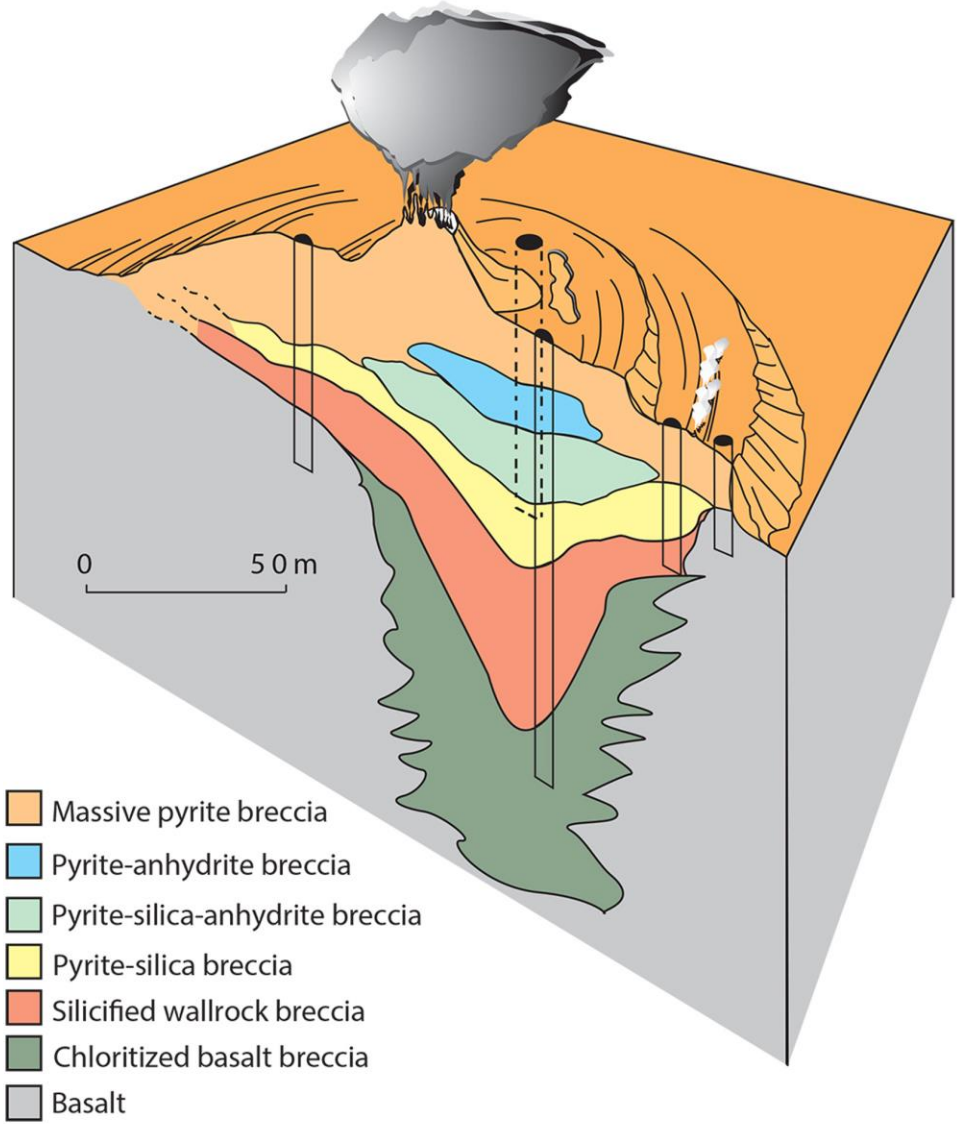
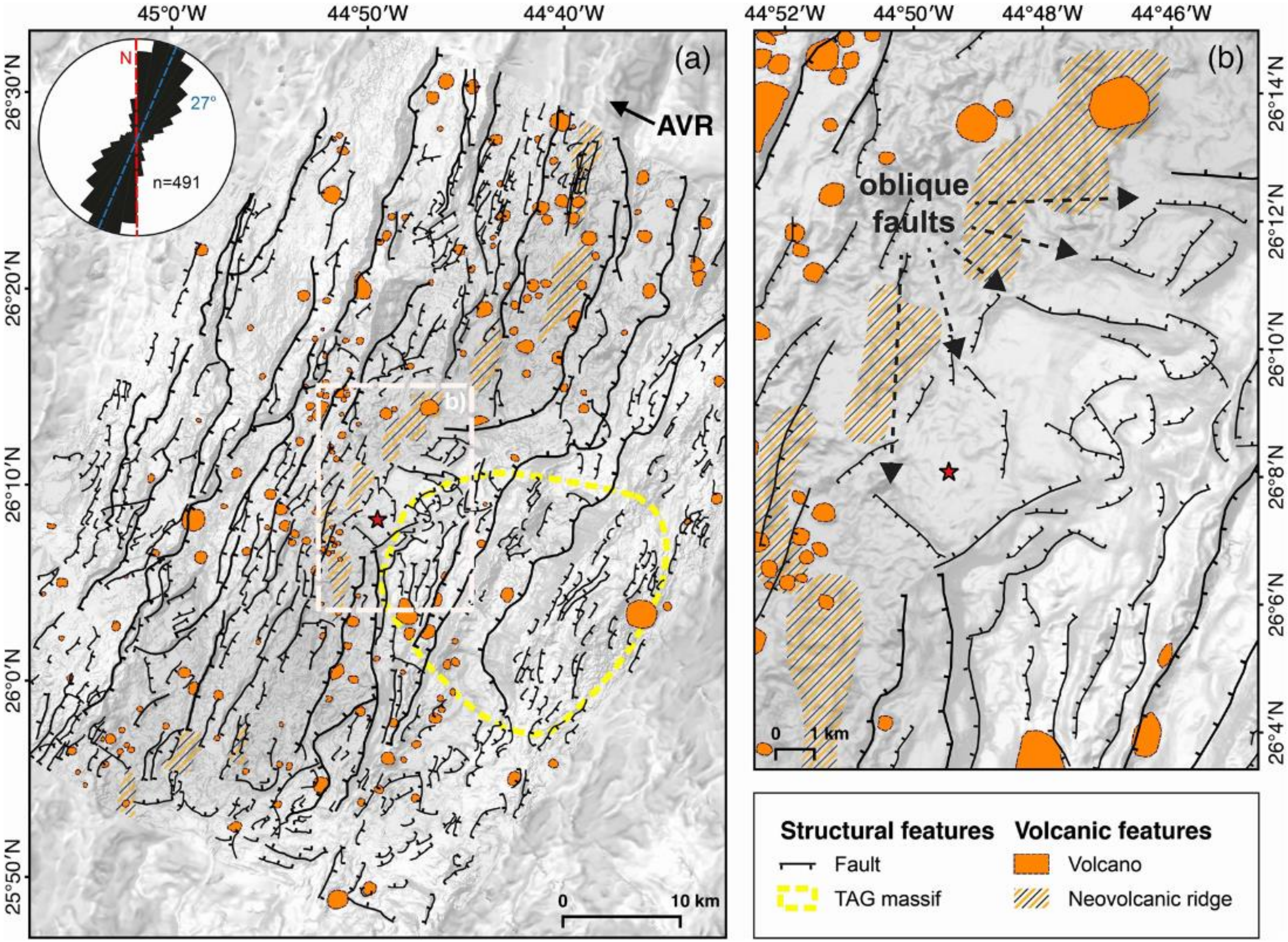
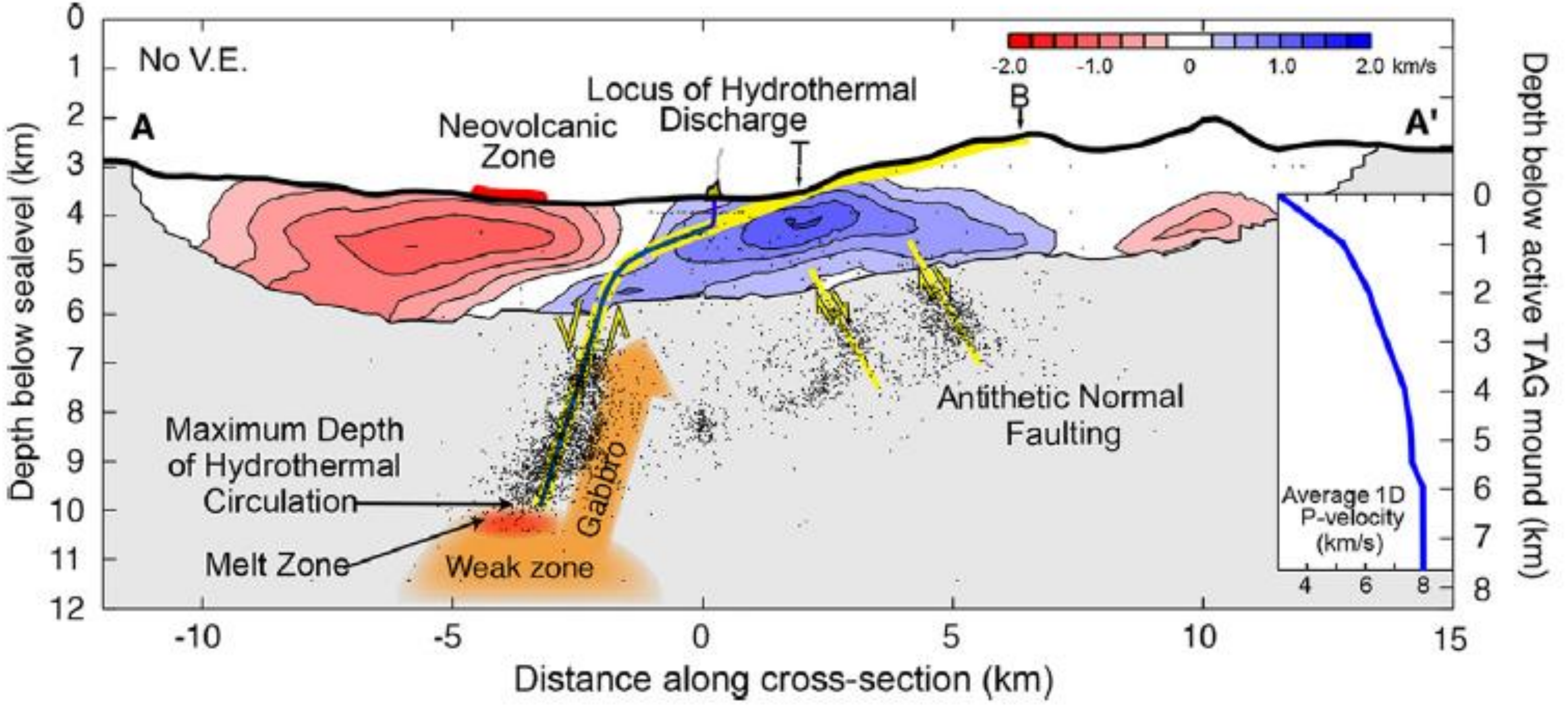


Tectonics in the vicinity of the TAG Mound



Graber et al. 2020

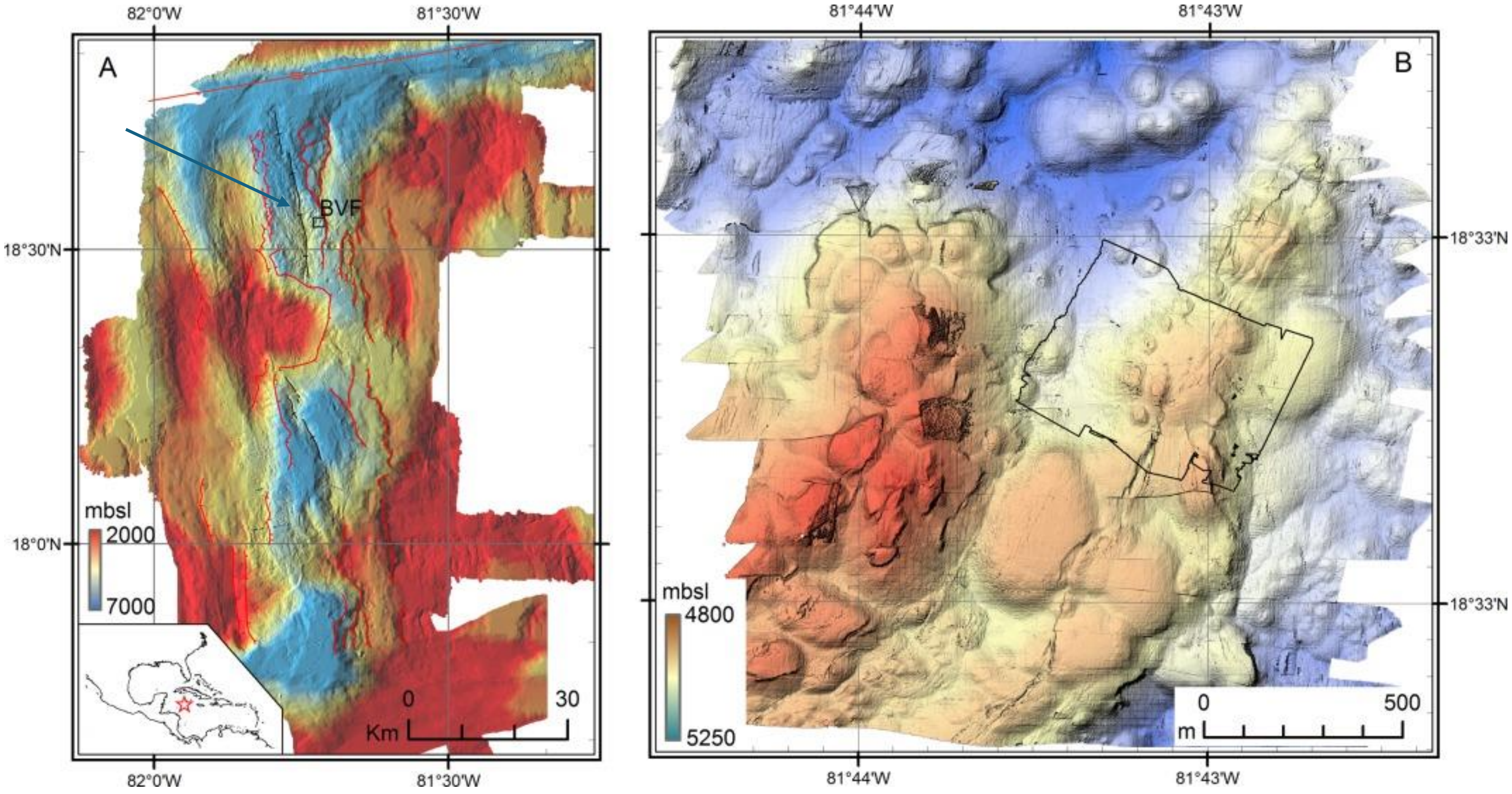
Interpretation of high resolution bathymetry.



Source Humphris et al. 2015

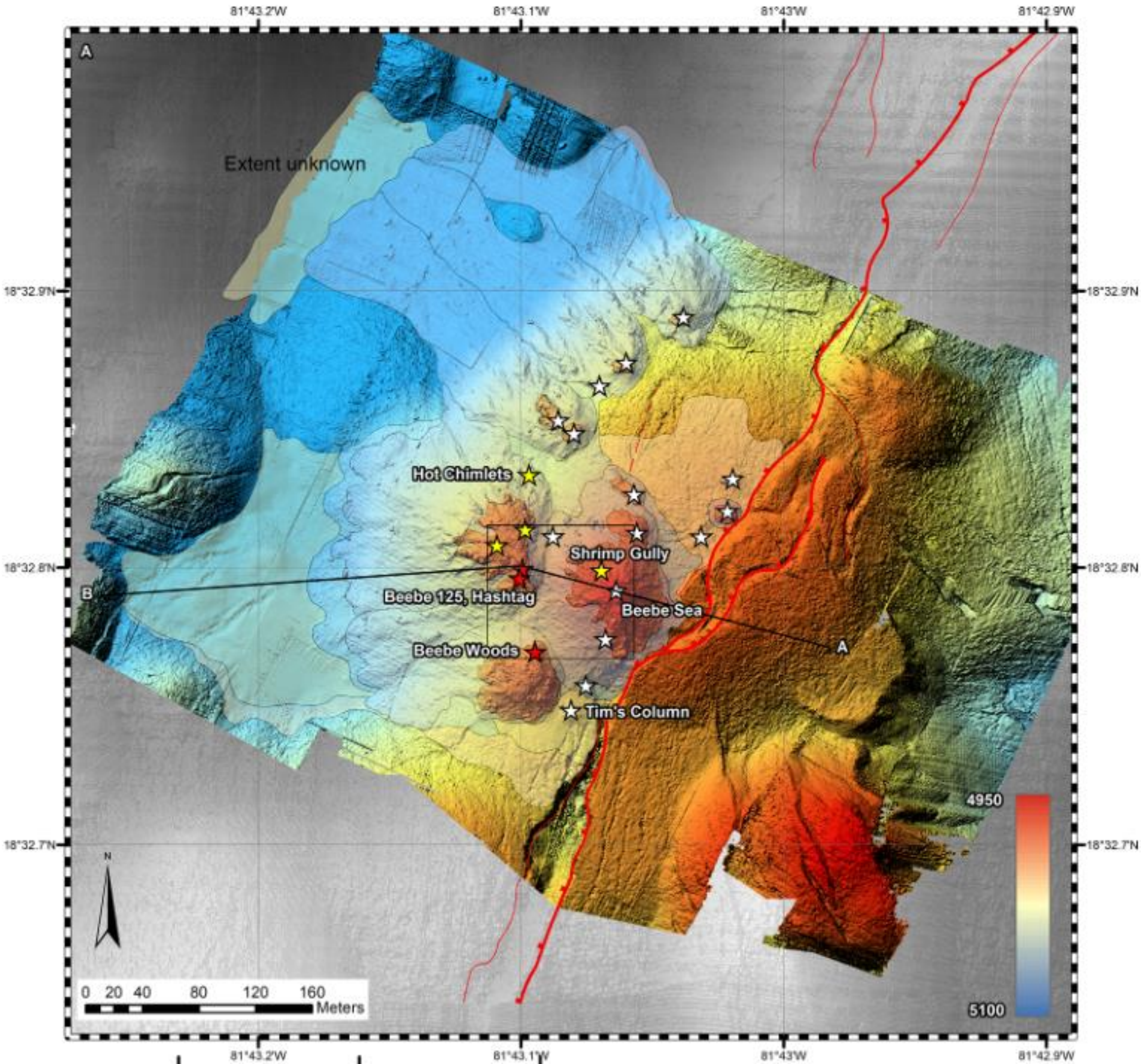
Schematic Section through detachment fault and location of the TAG Mound

Beebe Vent Field – Cayman Trough



Location of the Beebe Vent Field (BVF) in the Mid-Cayman Spreading Centre, Cayman Trough, and world location map (inset). Position of the BVF is given by the box, which shows the extent of (B). Major faults are displayed in red (b) The area immediately surrounding the BVF is composed of hummocky pillow basalt mounds.

Webber et al. 2015

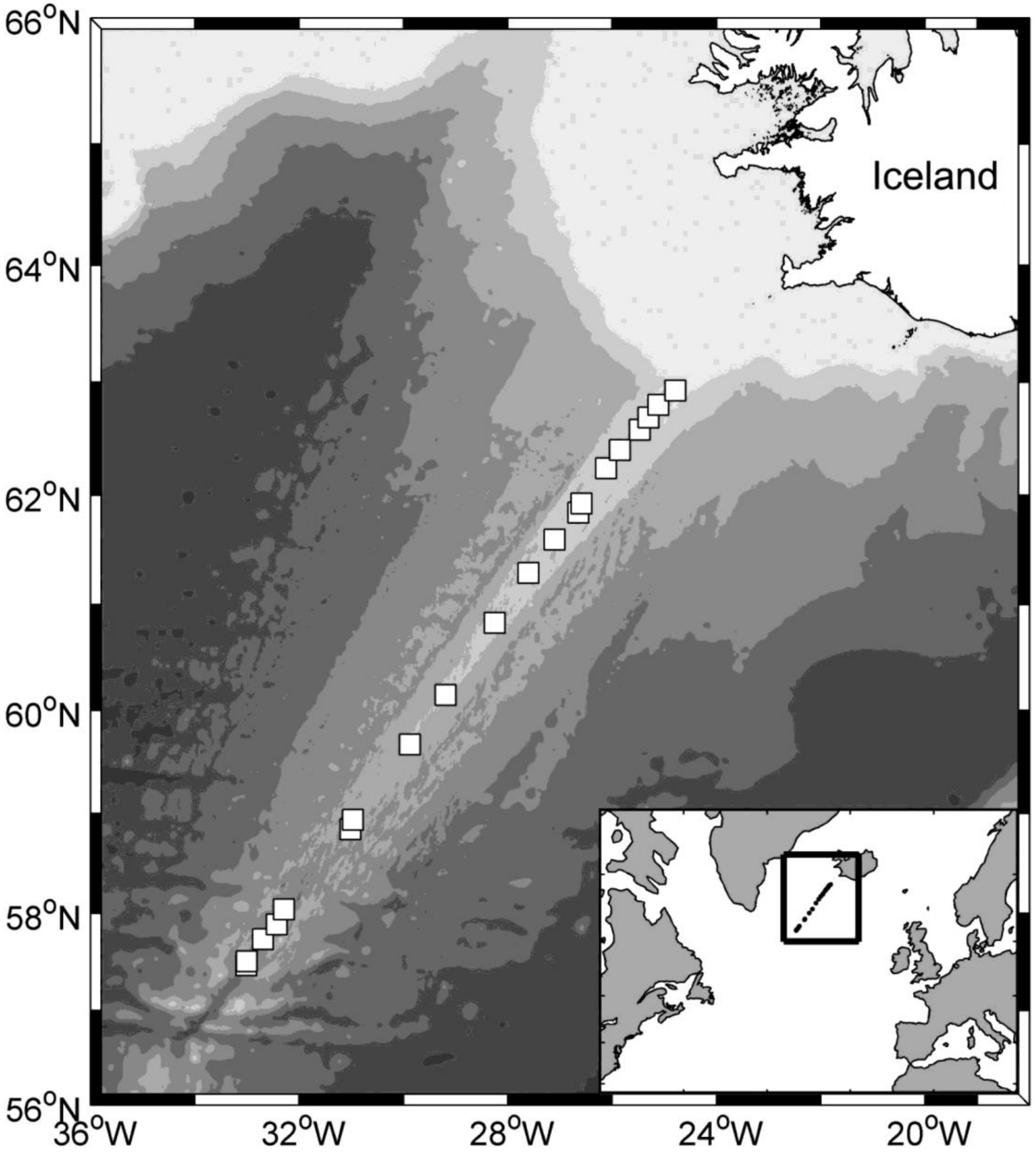


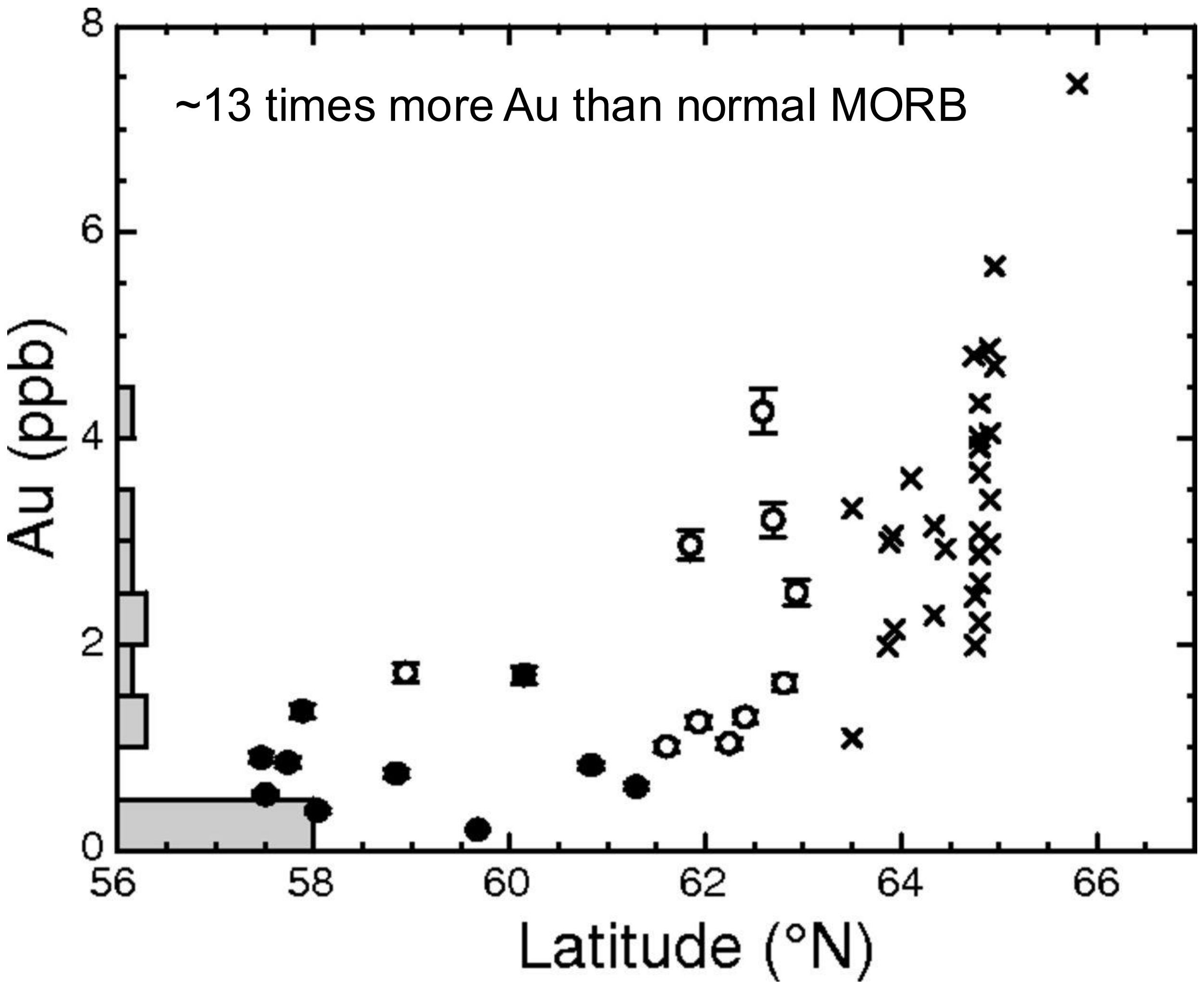
High resolution swath bathymetry, overlain with lithological boundaries and the main features of the Beebe hydrothermal vent field. Detailed positions of the main high temperature and several diffuse vent sites

Webber et al. 2015

Golden VHMS

Golden Plumes?

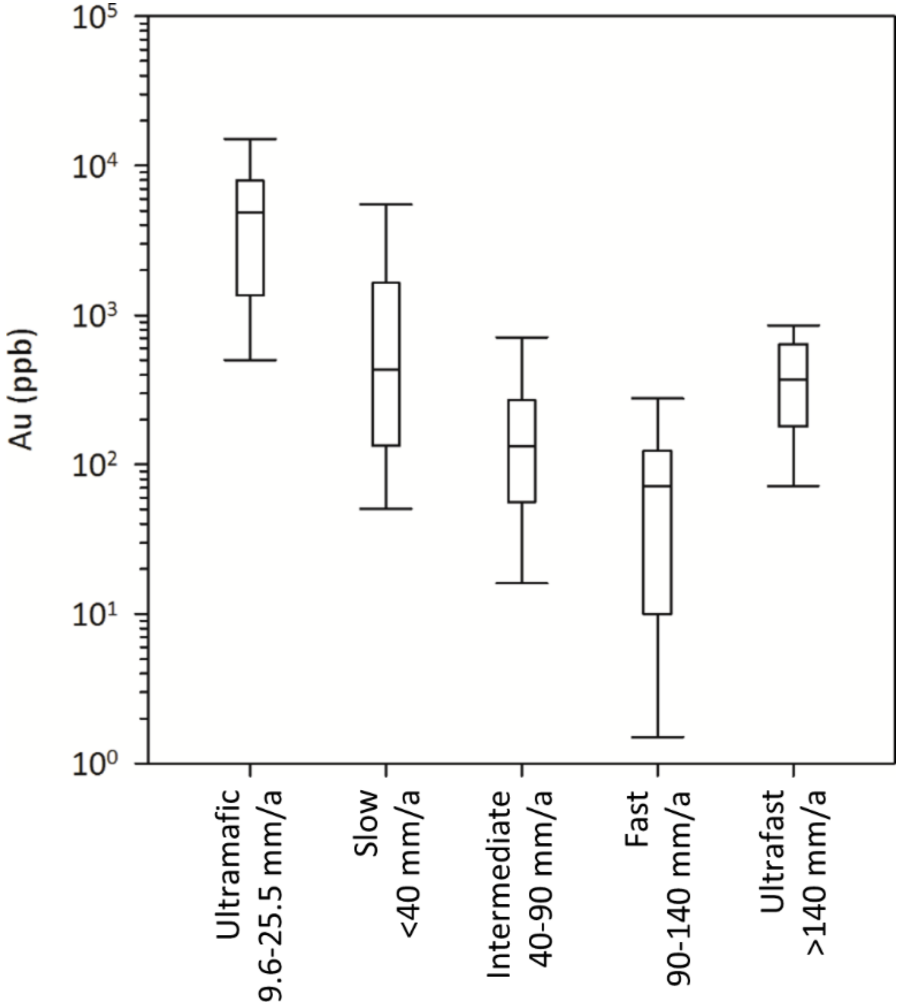


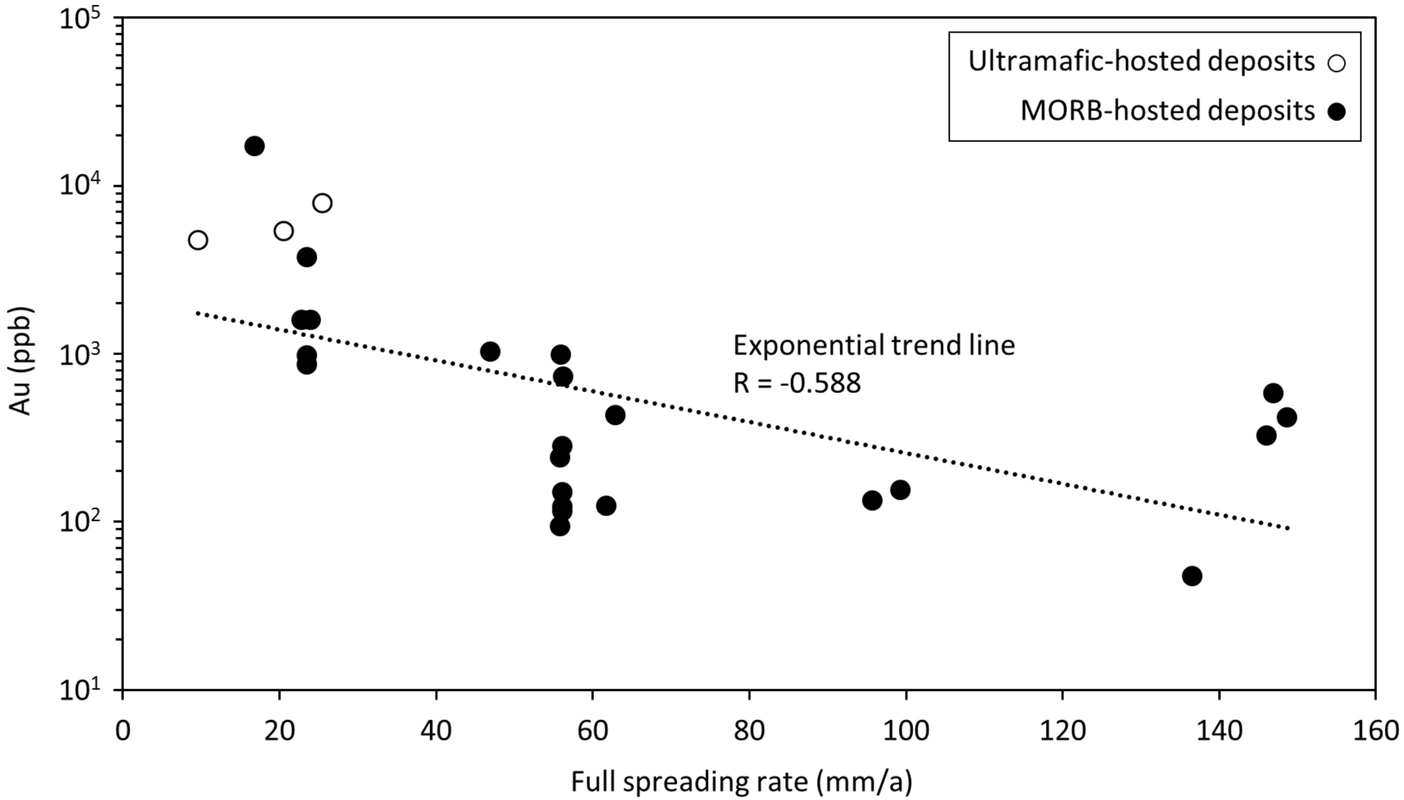


Metal-rich crusts on geothermal equipment, containing 589 ppm Au (Hardardottir et al., 2010).

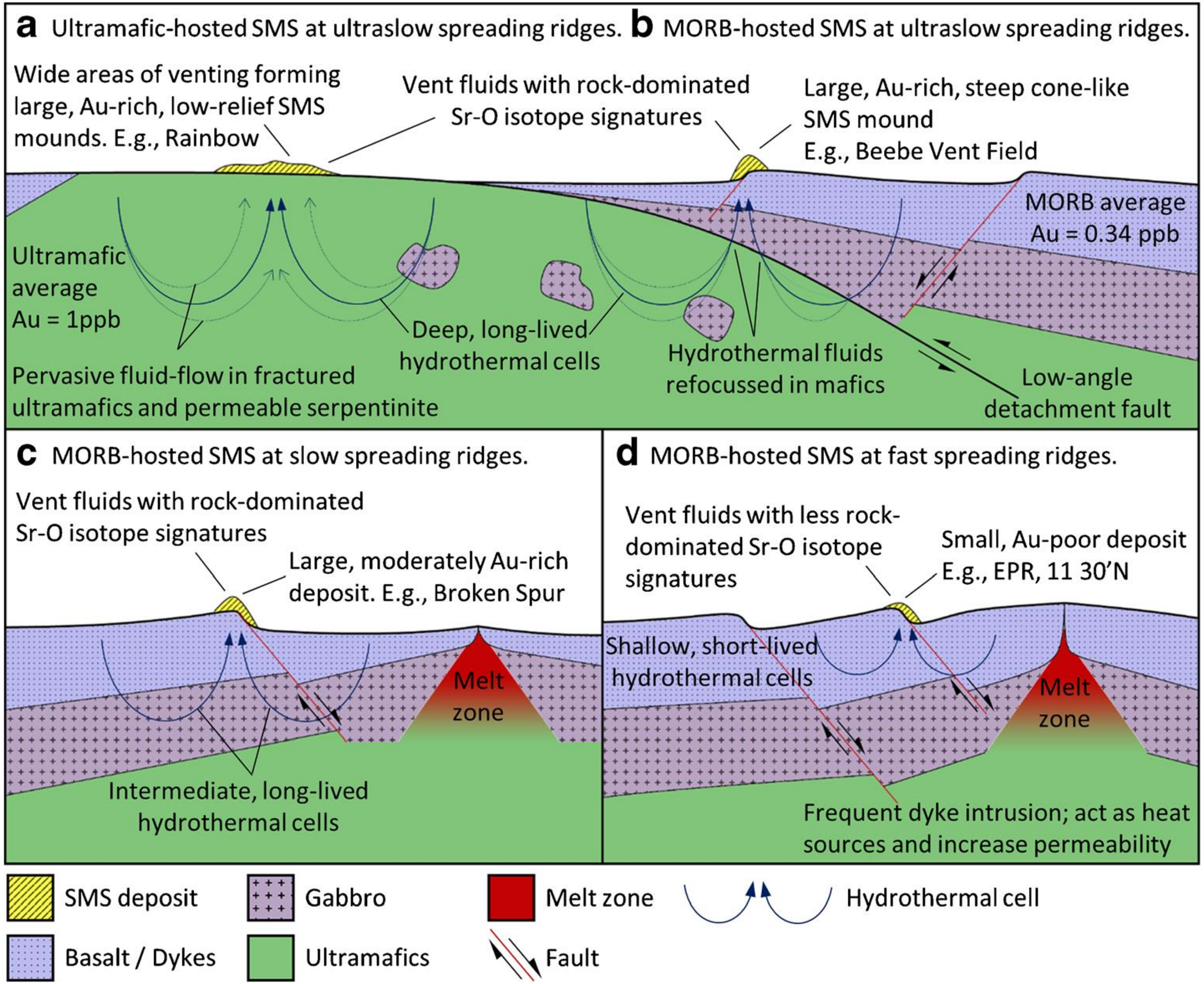
Webber et al.2013

Spreading Rate v Gold Content of Oceanic Crust

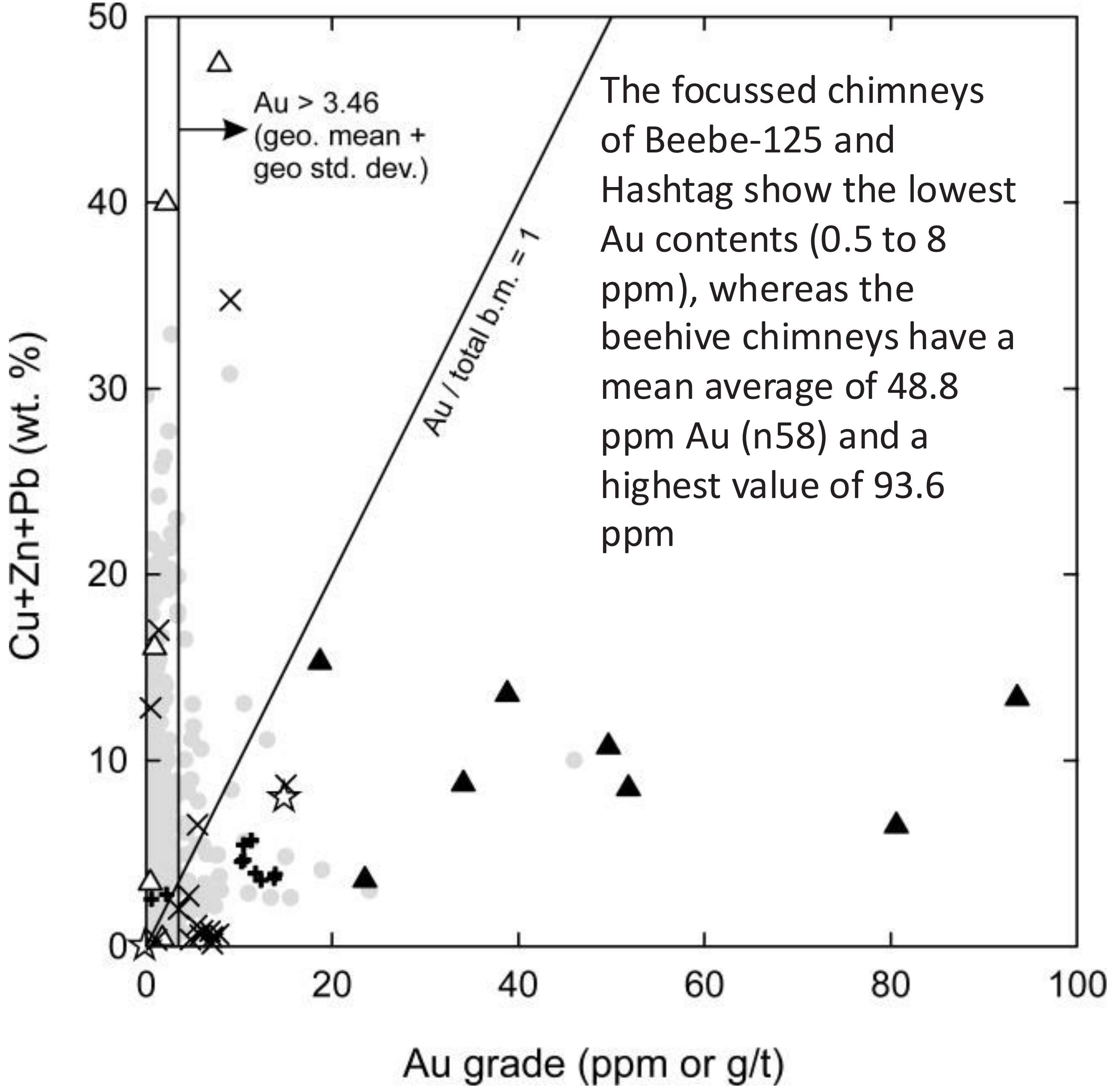




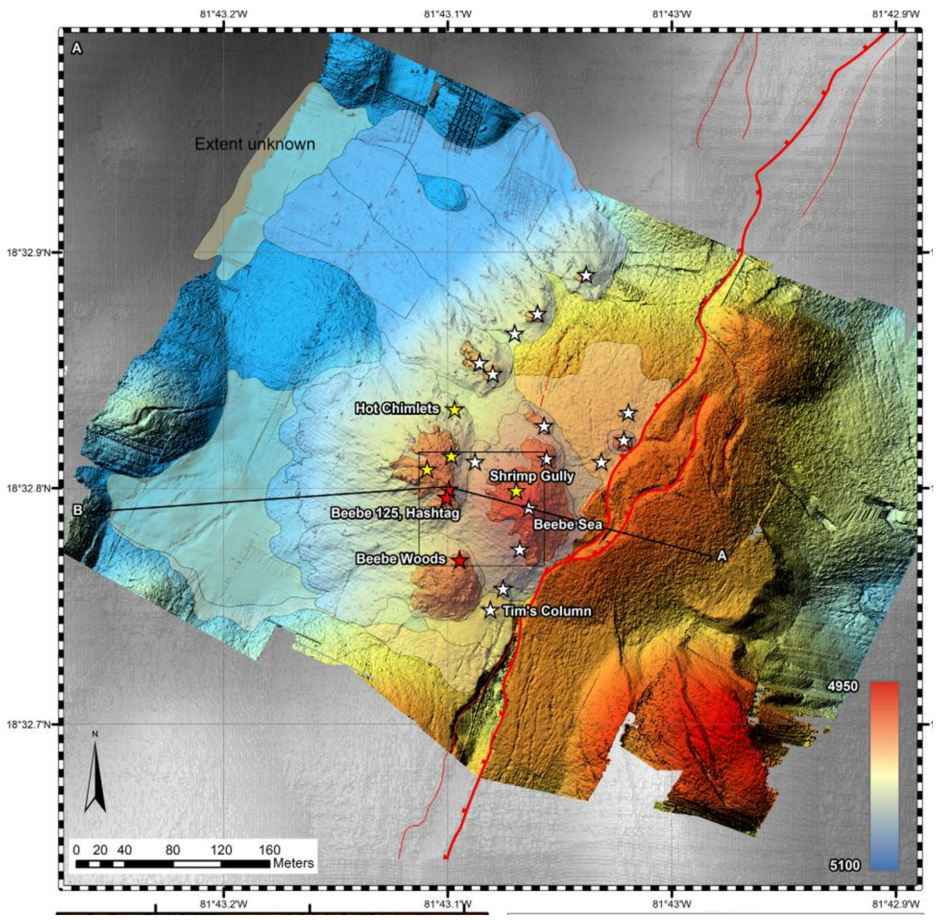
Knight et al. 2017

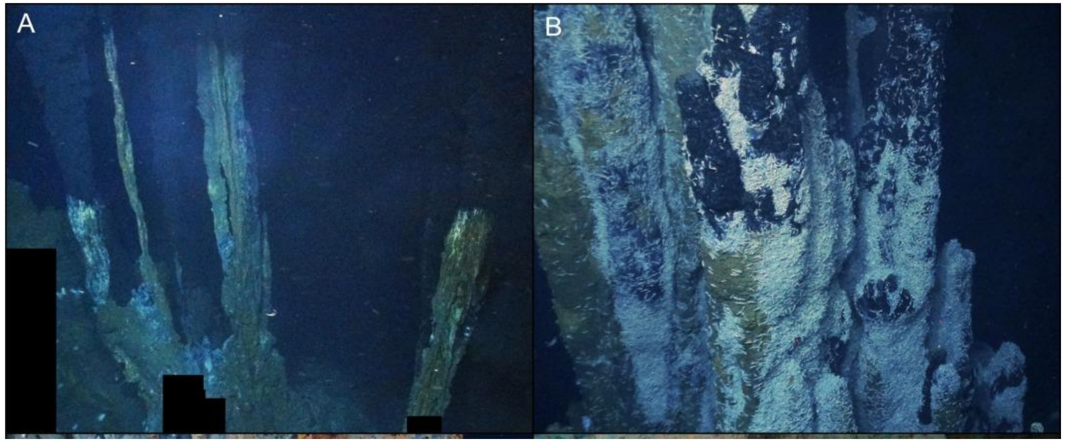


Knight et al. 2017



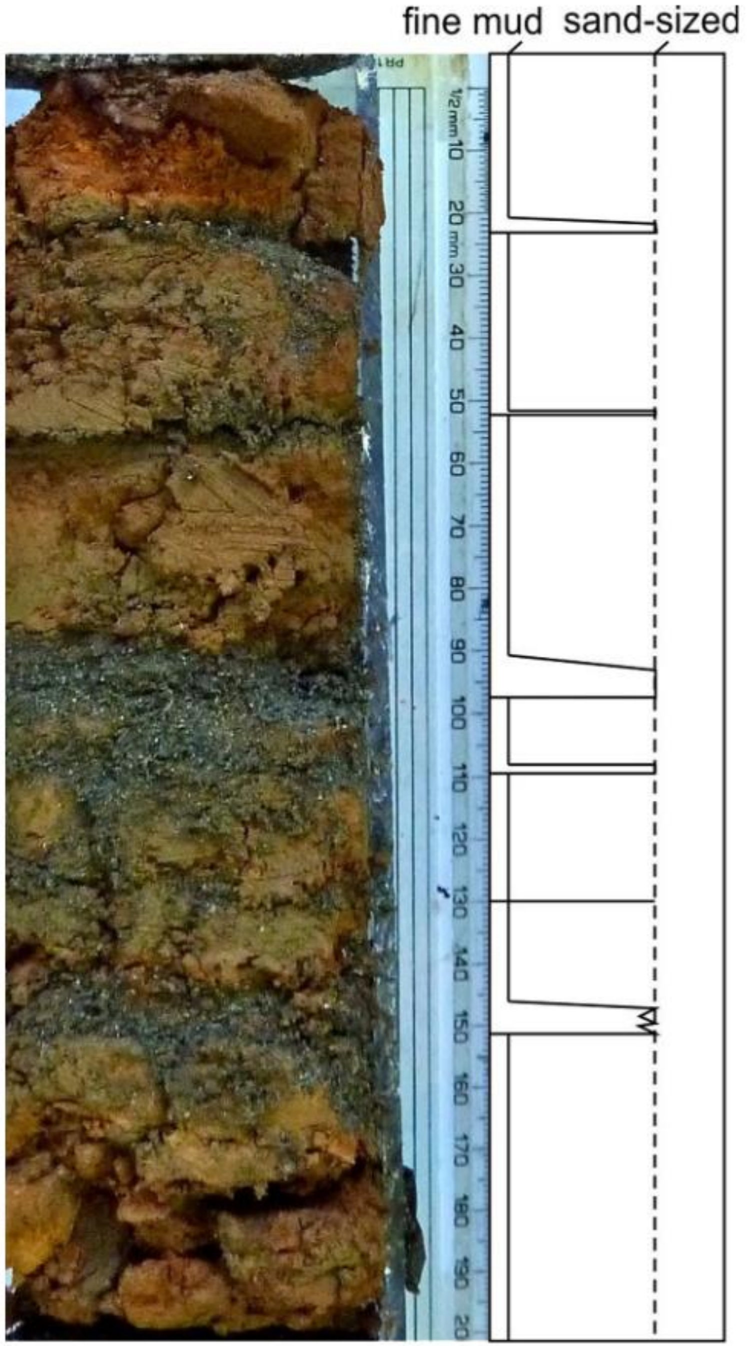
The focussed chimneys of Beebe-125 and Hashtag show the lowest Au contents (0.5 to 8 ppm), whereas the beehive chimneys have a mean average of 48.8 ppm Au (n58) and a highest value of 93.6 ppm

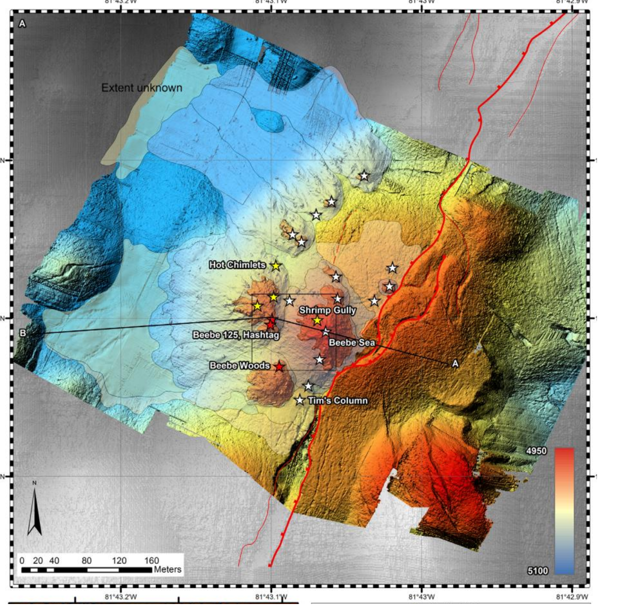


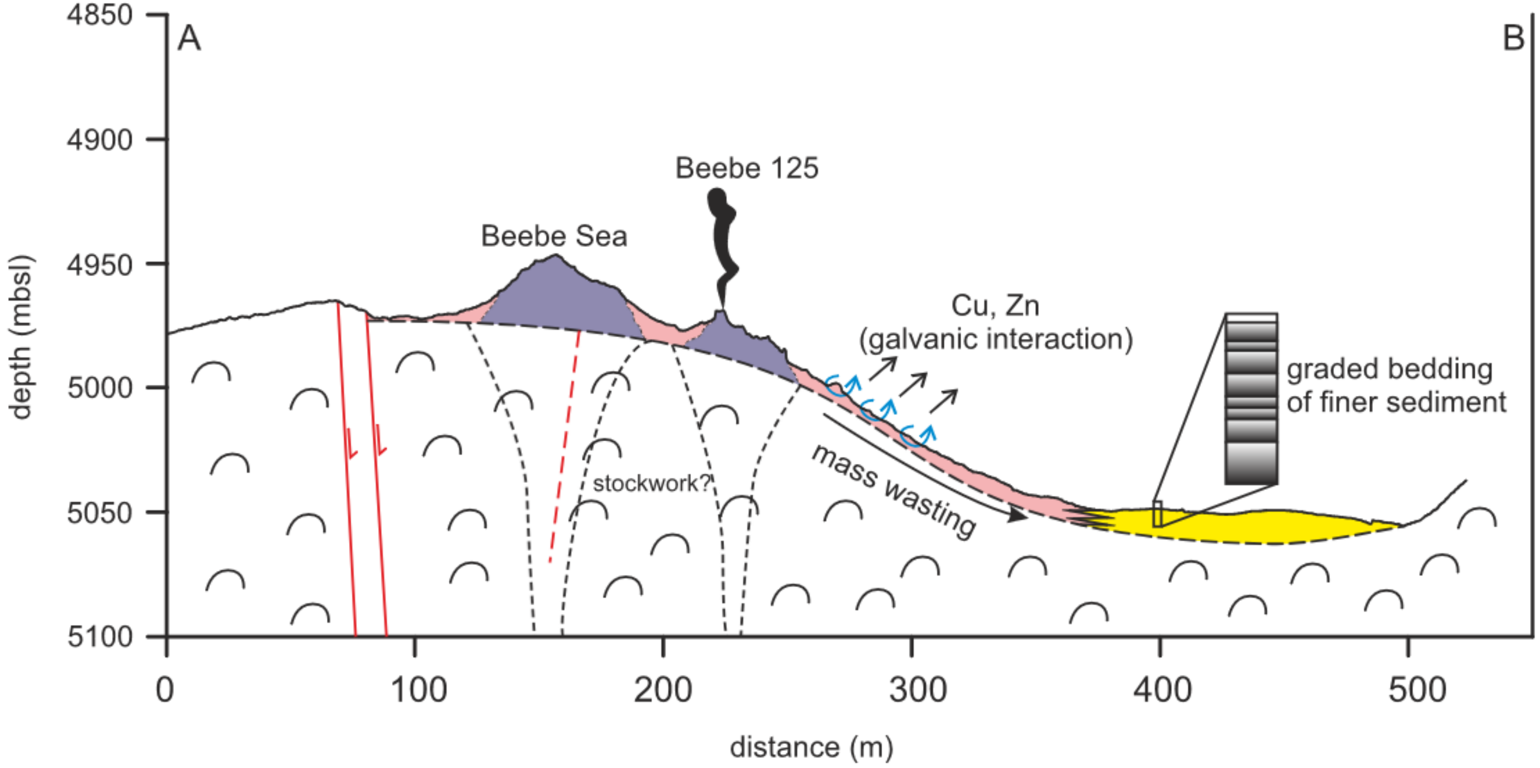


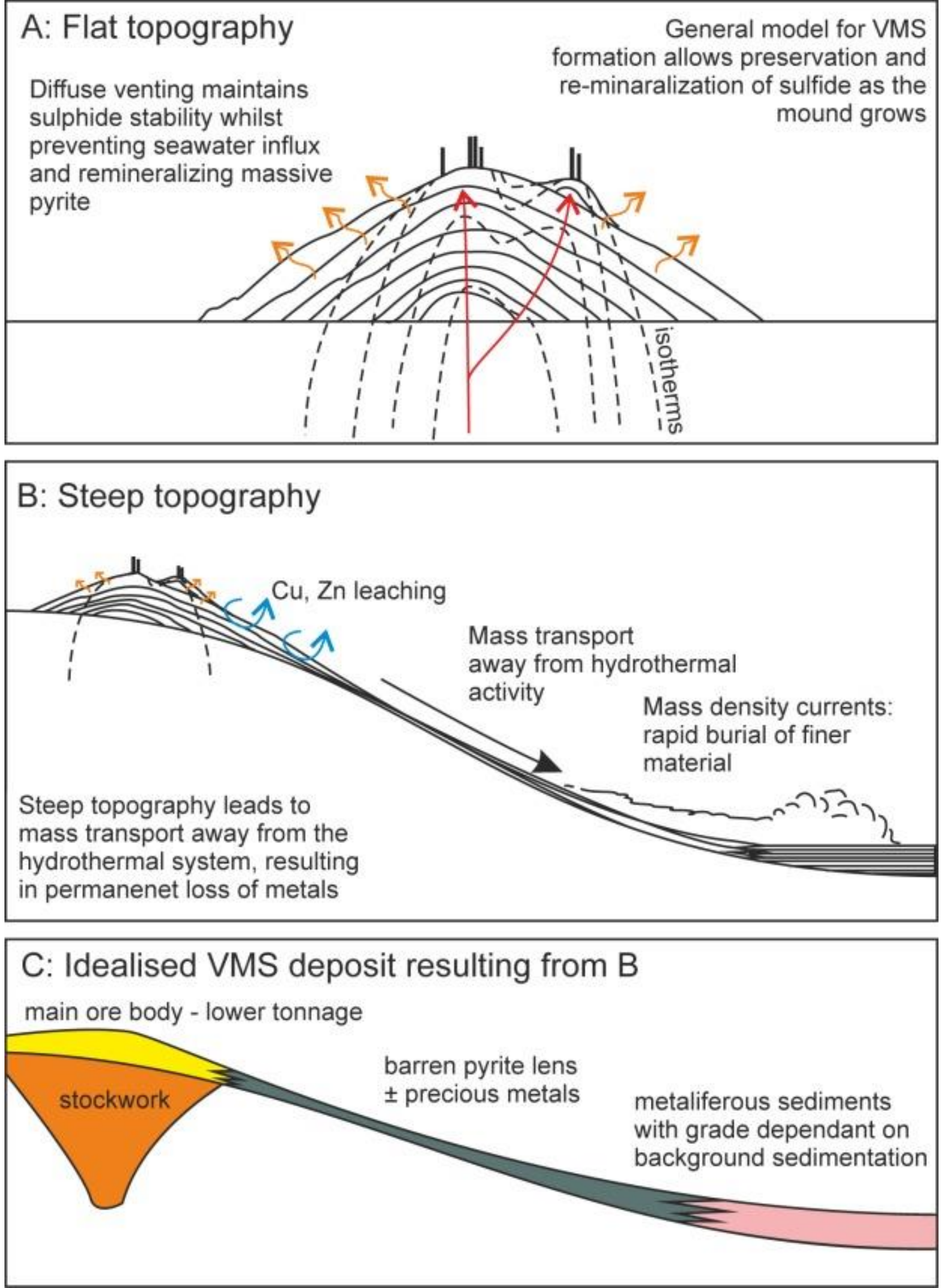
Webber et al. 2015

Evolution of a Vent Site







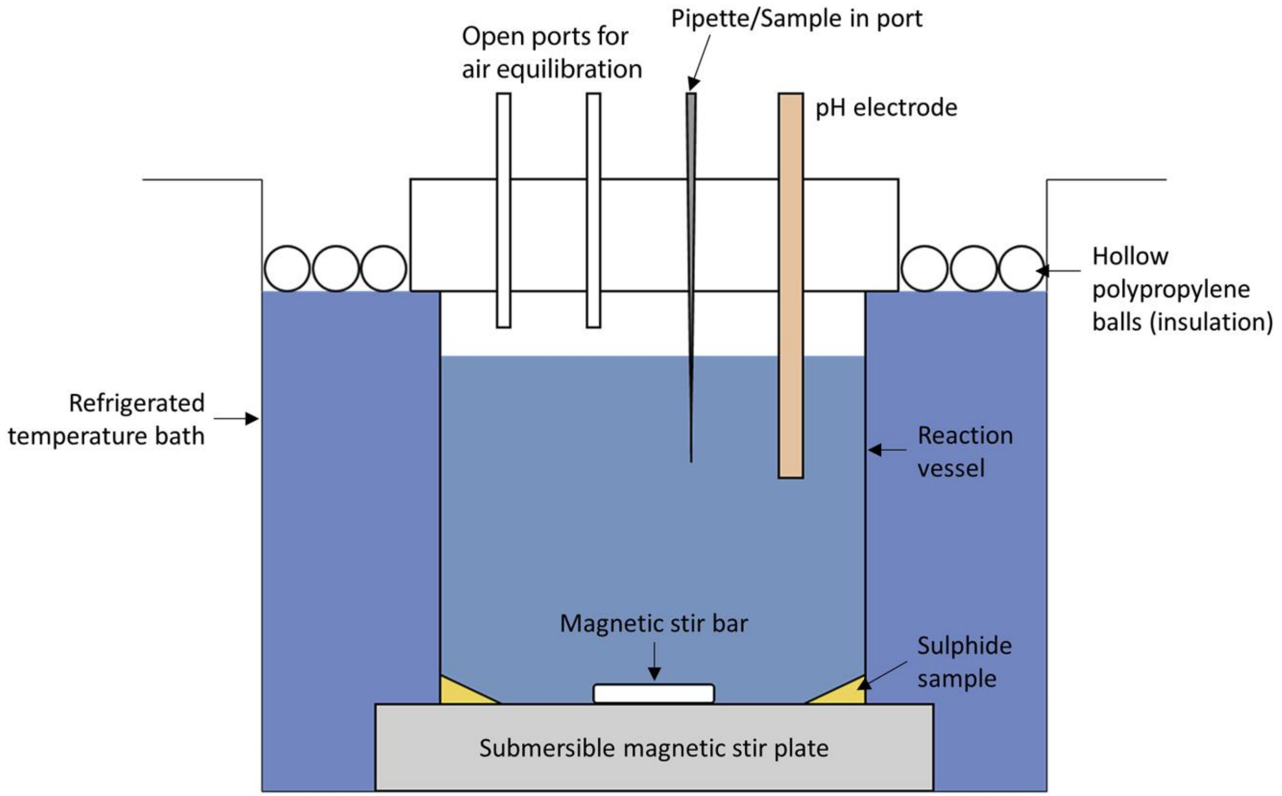


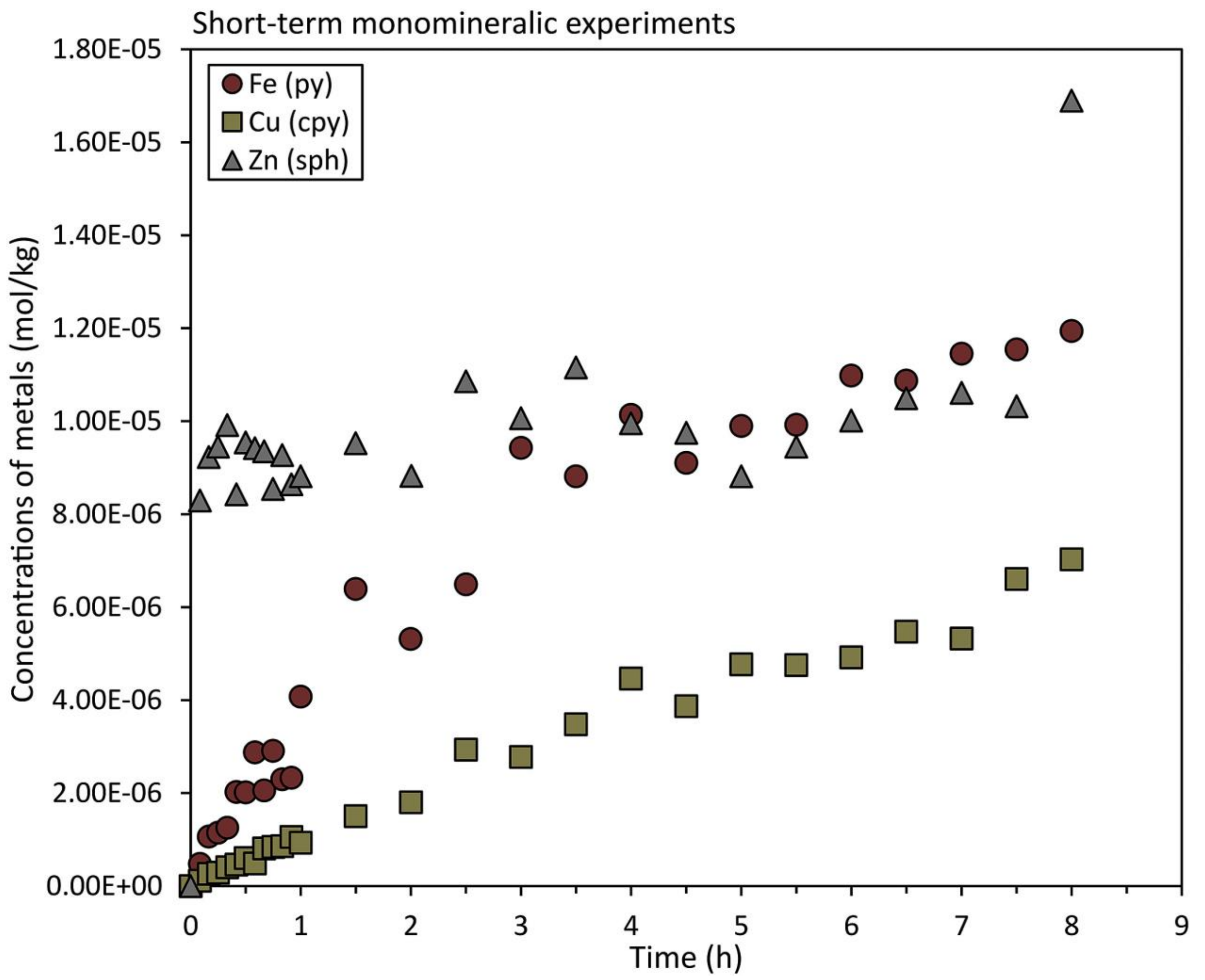
University of Southampton

Role of Topography and formation of an idealized VMS Deposit.

Webber et al. 2015

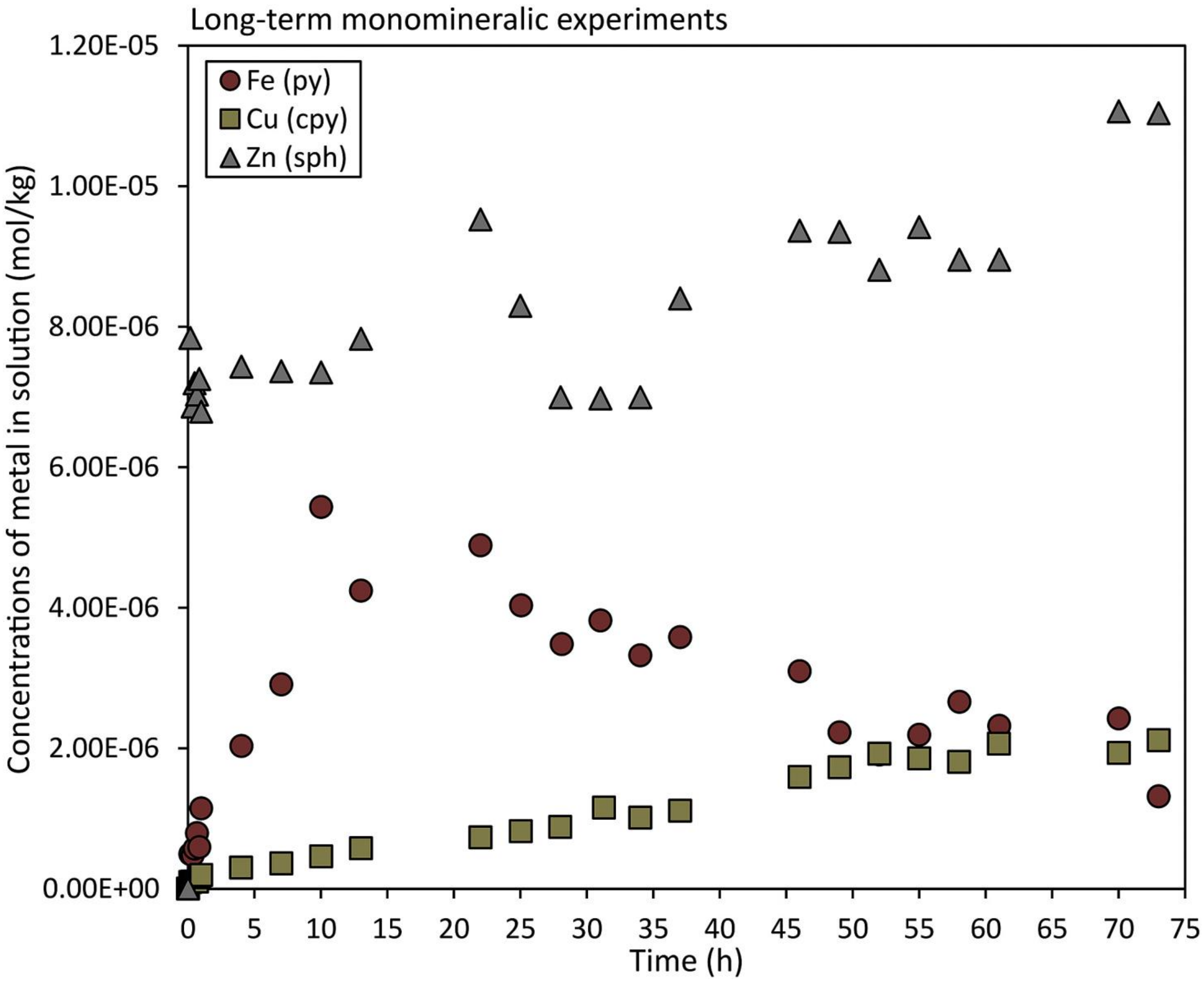
Seafloor Oxidation – Deposit Longevity & Sulfide Particles

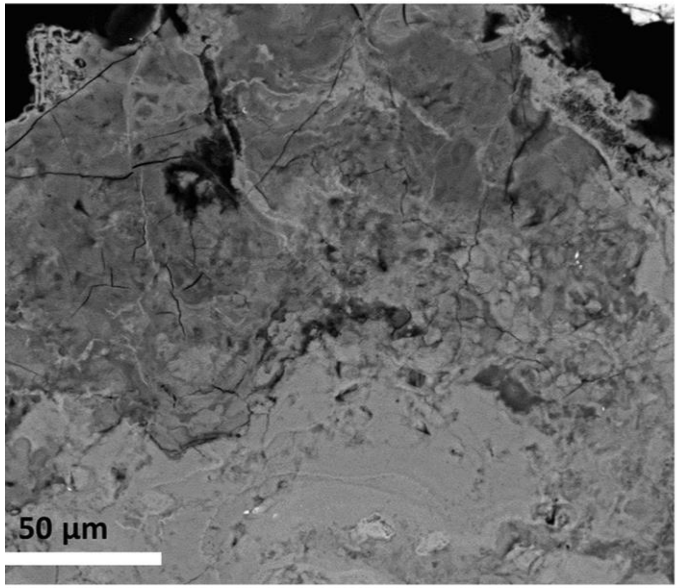


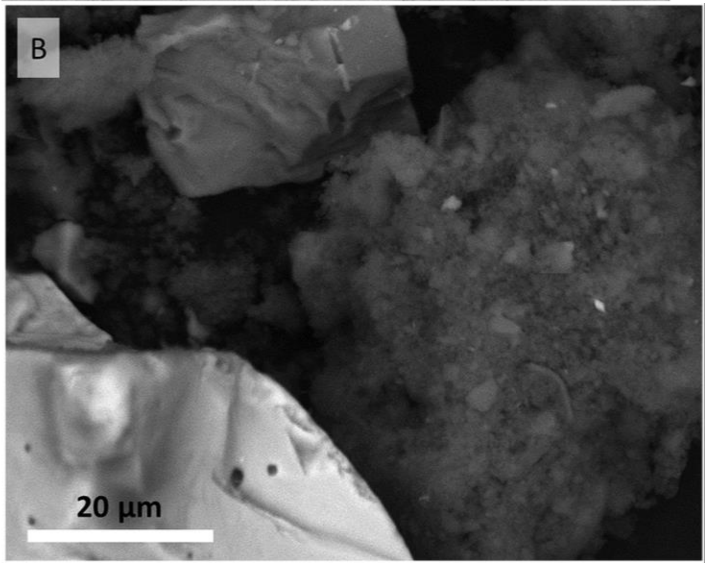


Knight et al. 2018

Longer Term Monomineralic Experiments







Summary - Conclusions

Complex vent site alteration patterns and varied hydrothermal alteration and fluid pathways often variable at the local scale.

Evidence that tectonics at active sites paly a key role in vent location and fluid flow.

The development of gold-rich deposits may depend on a range of factors including :

- Plume influenced host rocks
- Spreading rate of initial oceanic crust formation
- Modes of hydrothermal fluid discharge vents v beehive structures

Investigations of the Beebe Vent Field amplify understanding of key elements of mineralization including the potential roll of topography.

Seawater sulfide experiments highlight potential role of oxide formation in preserving hydrothermal vent sites into the geological record.

Try not to get stuck!