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Deep-Sea and Sub-Seafloor Resources: A Polymetallic Sulphide and Co-Mn Crust Perspective

by

Stephen Roberts

The LRET Research Collegium
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Deep-Sea and Sub-Seafloor Resources: A Polymetallic Sulphide and Co-Mn Crust Perspective.

Stephen Roberts
July 2012

Rationale

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- Ocean floor hydrothermal vent sites, with the associated formation of massive sulfide deposits:
  - play a fundamental role in the geochemical evolution of the Earth and Oceans,
  - are a key location of heat loss from the Earth's interior
  - provide insights into the formation of ancient volcanogenic massive sulfides.
- Furthermore, they are increasingly viewed as attractive sites for the commercial extraction of base metals and gold.
- In addition Mn-Co nodules and crusts are increasing recognised as potentially attractive environments for Mn and Cobalt extraction

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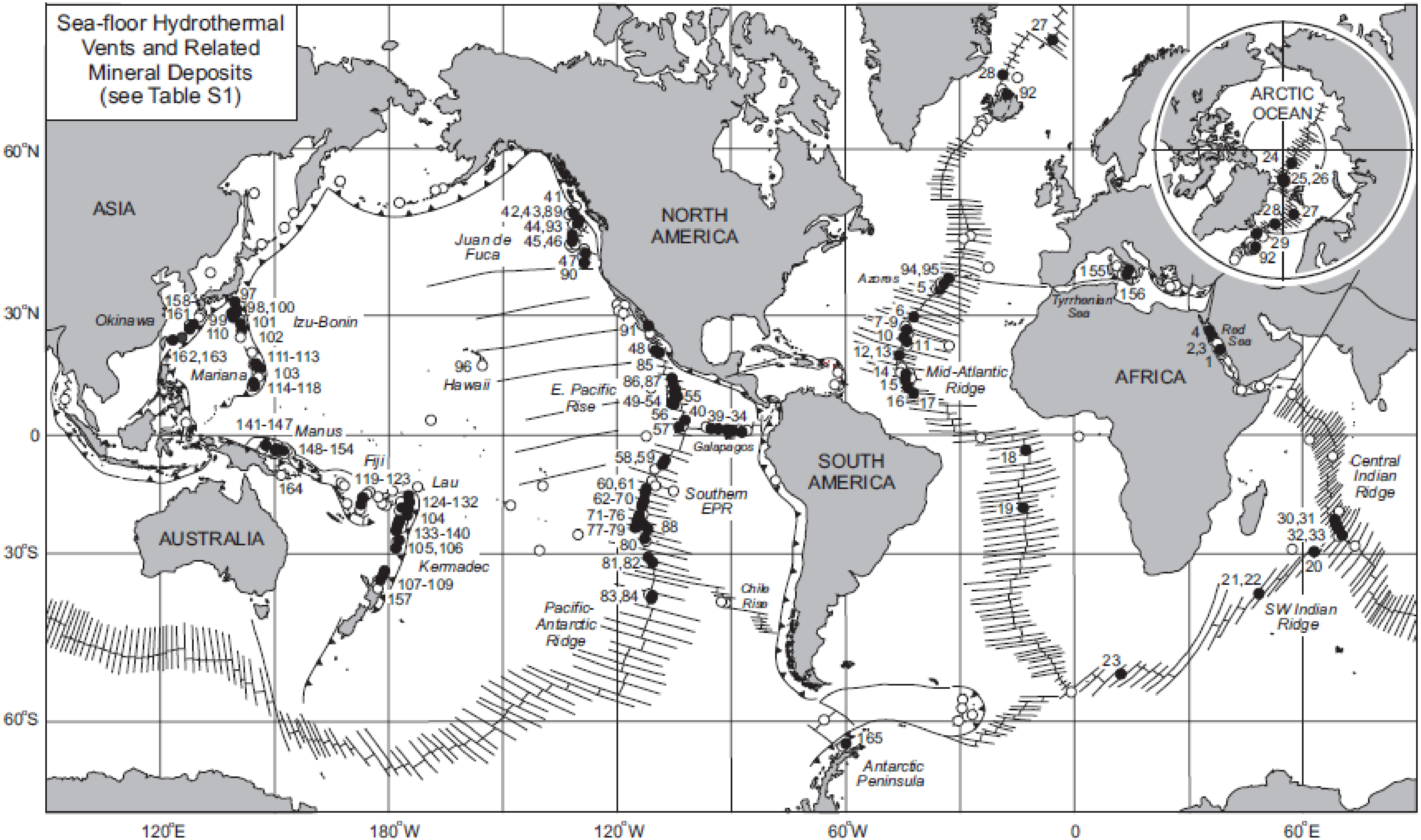
Recent Compilation of Sea-floor Hydrothermal Vents



Source: Hannington et al 2011

Location of Major ODP Drilling Campaigns on Massive Sulfides

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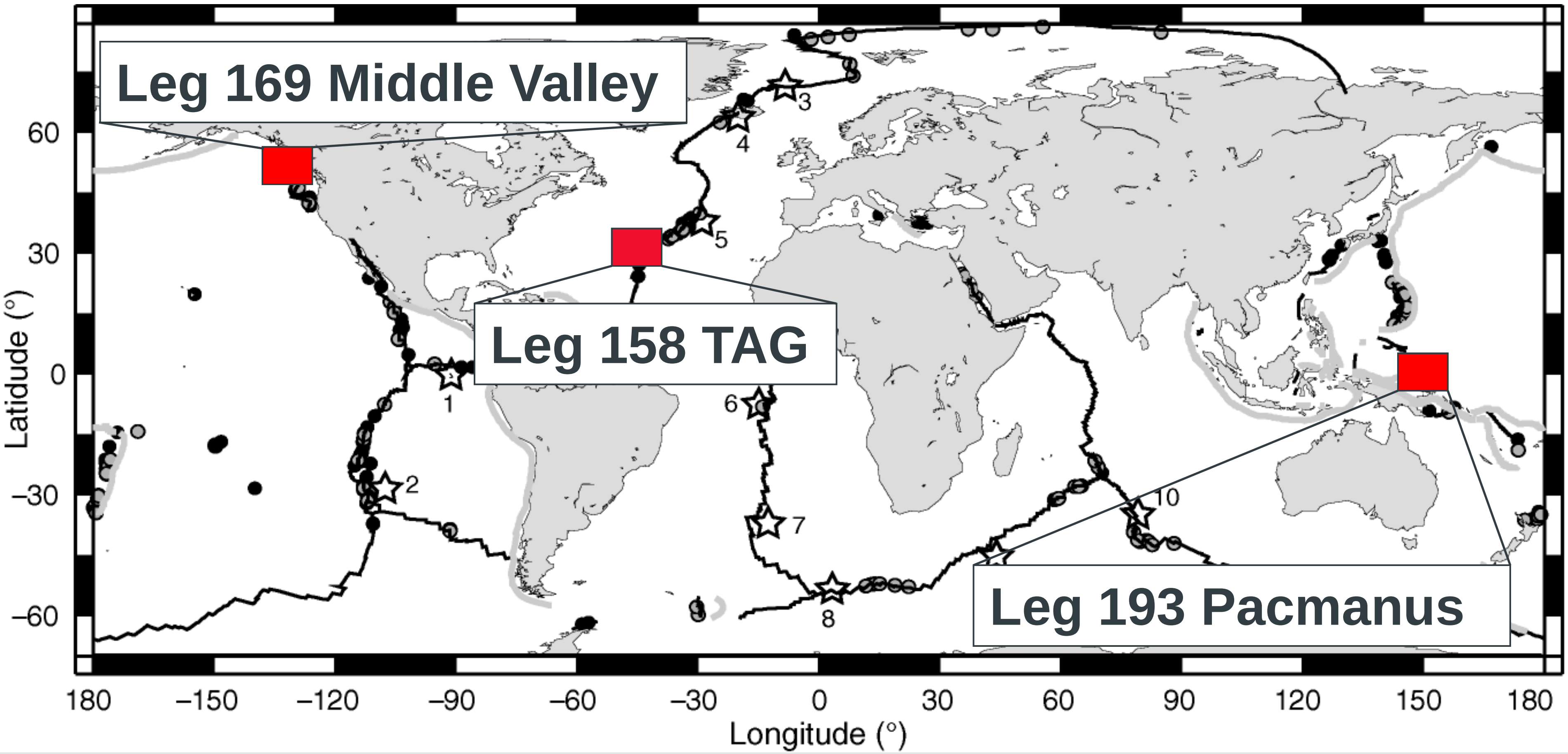
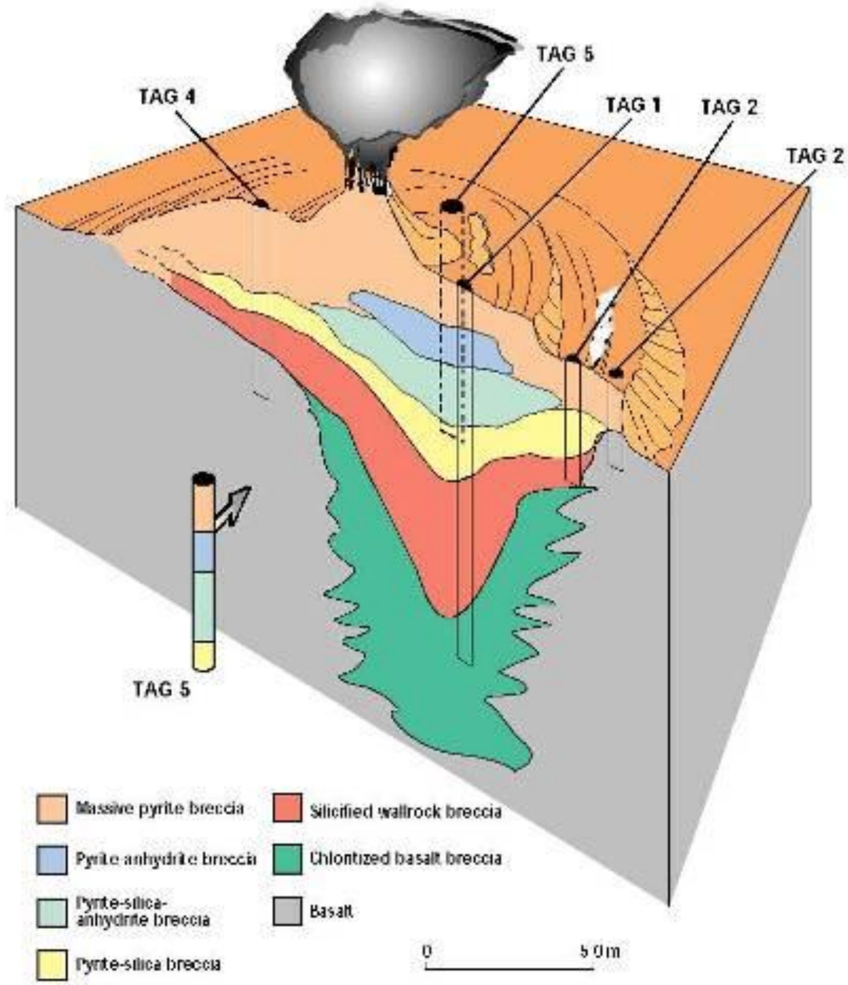
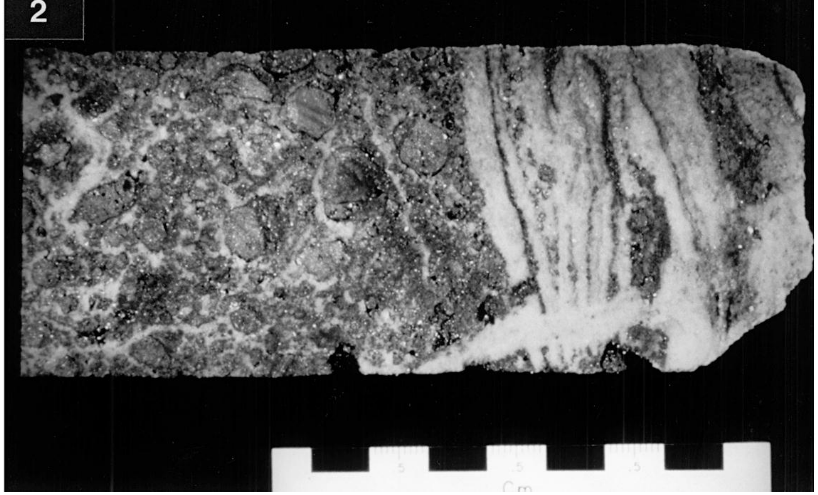


Source: Mid-Ocean Ridges: Hydrothermal Interactions Between the Lithosphere and Oceans, Geophysical Monograph Series 148, C.R. German, J. Lin, and L.M. Parson (eds.), 245–266 (2004)

Leg 158 TAG



Sketch of the active Trans-Atlantic Geotraverse (TAG) hydrothermal mound showing the generalized internal structure and mineralogic zones as revealed by drilling (modified from Humphris et al., [1995]).



Some Key Observations:

Circa 2.5-3 Million Tonnes of Massive Sulphide

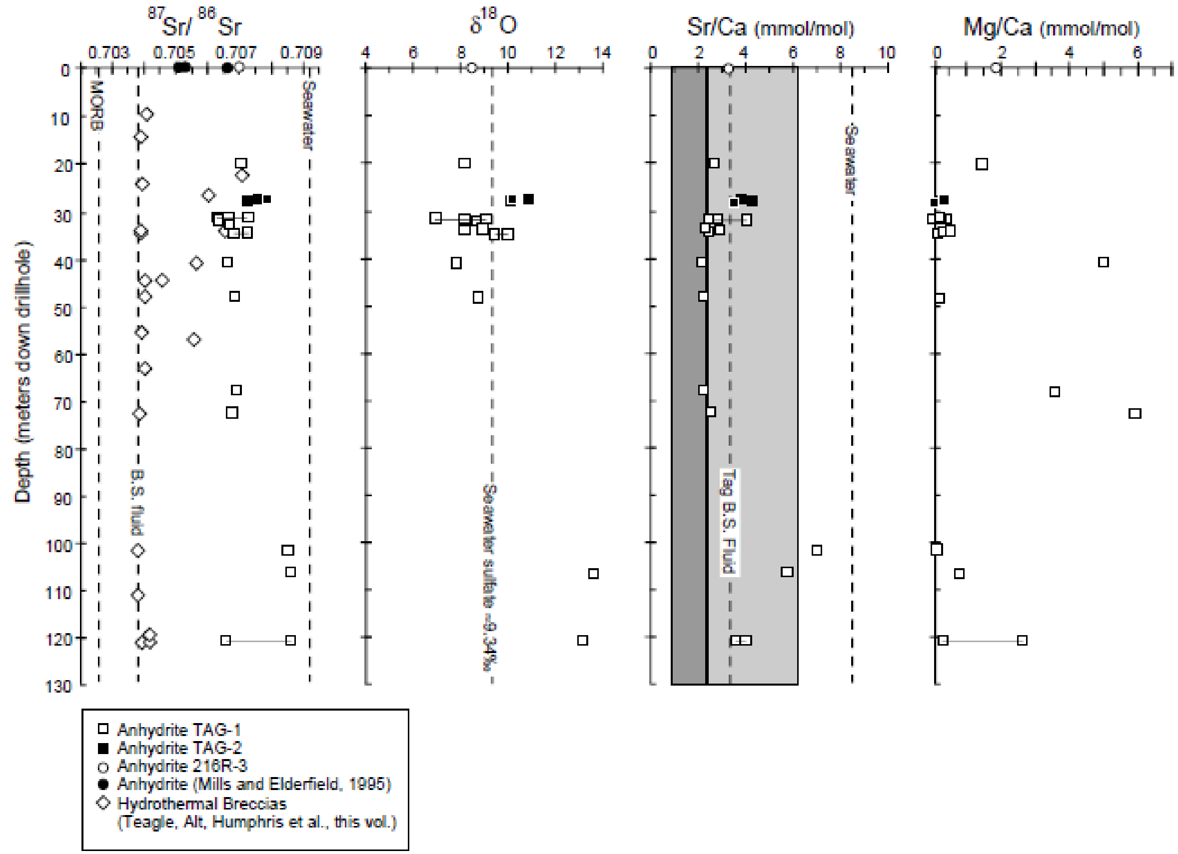
Abundance of anhydrite. Estimate, based on the drilling results, that the TAG mound currently contains about 165,000 metric tons of anhydrite.

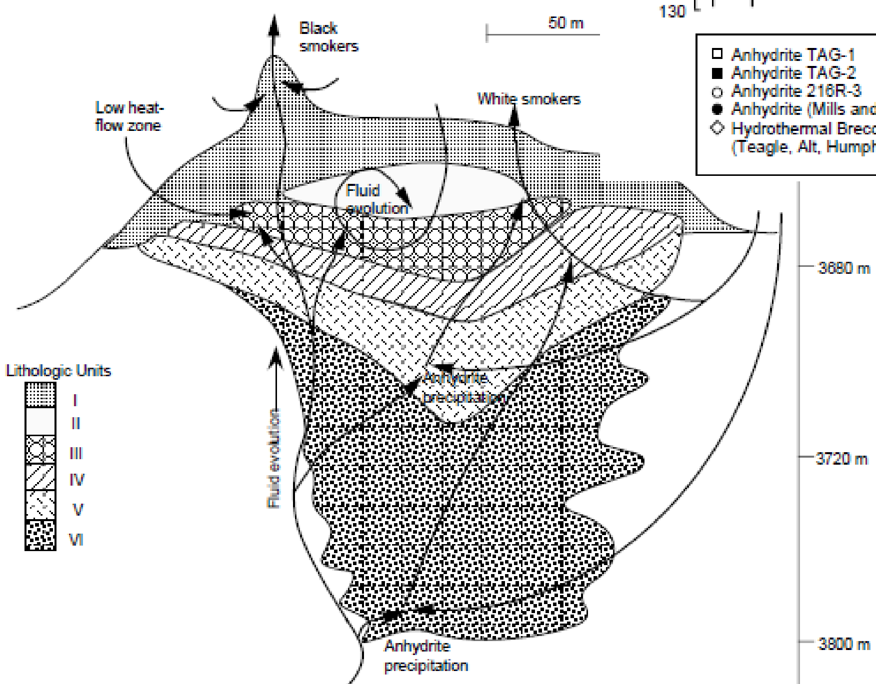
Through stable and radiogenic isotope analyses of anhydrite insights into circulation of seawater within the deposit.

This important mechanism for the formation of breccias provides a new explanation for the origin of similar breccia ores observed in ancient massive sulfide deposits.

Leg 158: TAG

$^{87}Sr/^{86}Sr$ isotope analyses of anhydrite provides evidence for seawater hydrothermal fluid mixing in the sulfide mound.



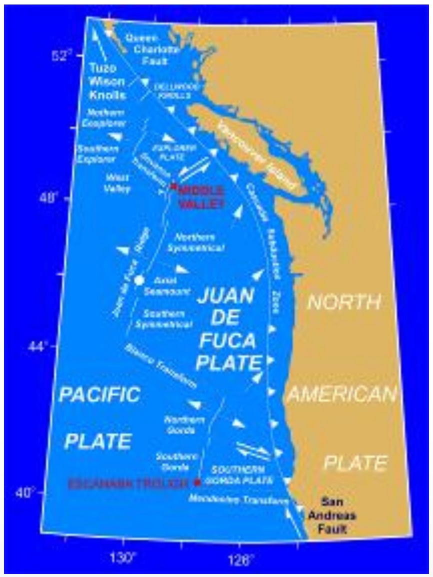


Source: Teagle & Mills 1996.

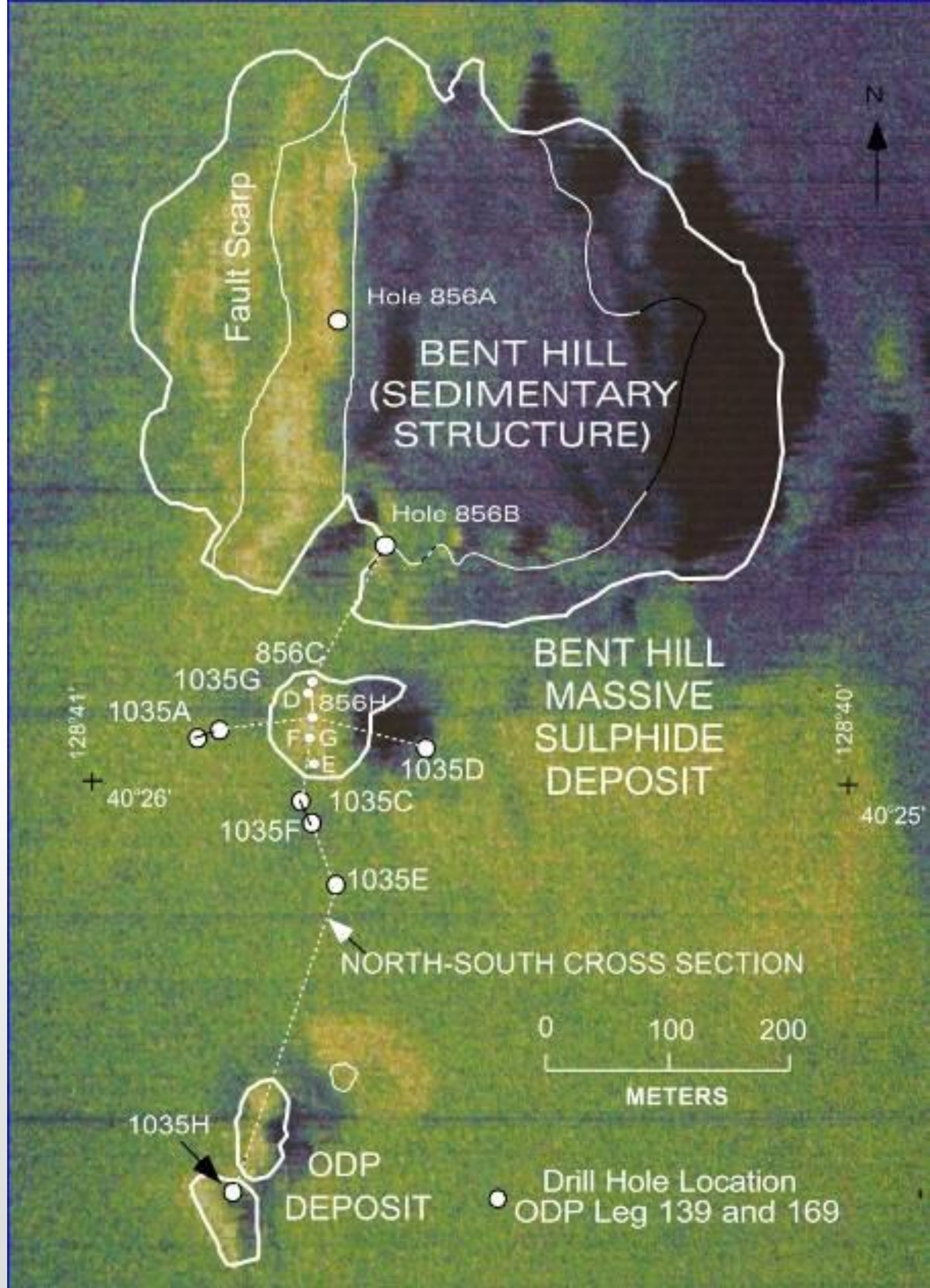
The construction of the TAG mound is interpreted to be substantially a process of hydrothermal replacement and mineralization in the upflow zone, coupled with mass wasting, brecciation and cementation of material that was precipitated on the sea-floor.

Humphris et al. Nature, 1995.

Leg 169 Bent Hill Middle Valley



Estimated 10 Million Tonnes Massive Sulphide in a Sedimented Ridge



Leg 169 Bent Hill Middle Valley

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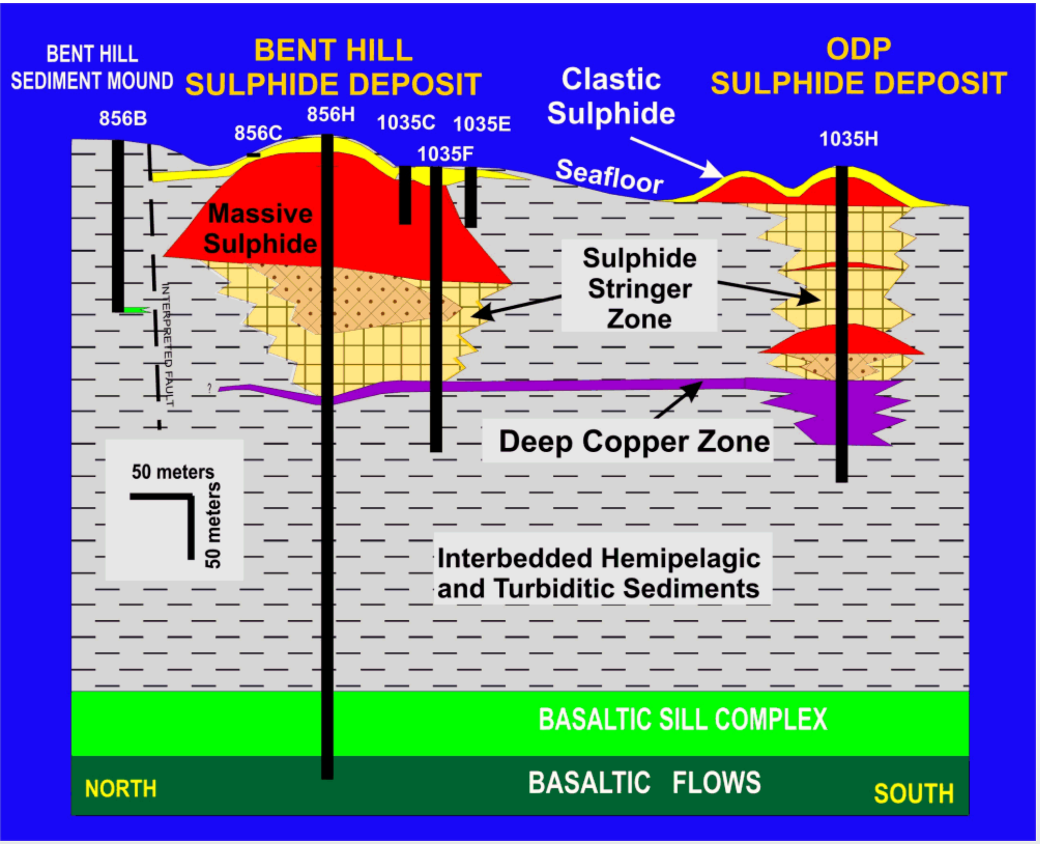


(From Goodfellow et al., 1999)

One of the main accomplishments of leg 169 was the first successful recovery of feeder zone mineralization underlying a sea-floor massive sulfide deposit.

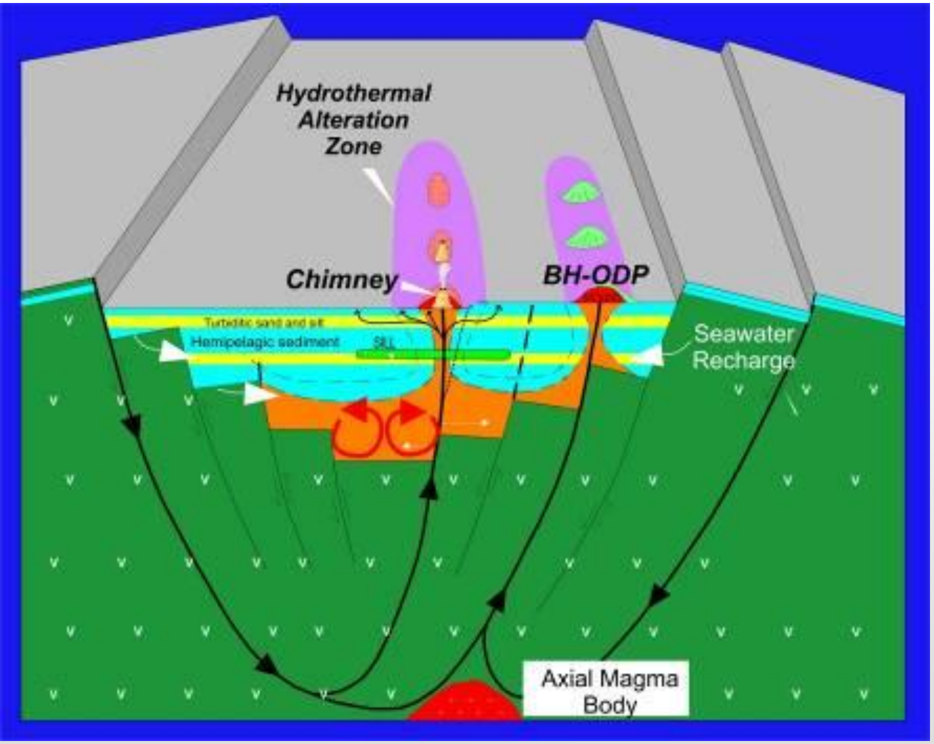
Source of hydrothermal fluids: Sulfide metal ratios, Pb and Sr data suggest that the high T hydrothermal fluid reacted extensively with basaltic crust.

Sr isotope ratios indicate Sr of sea-water origin was modified by mixing with radiogenic Sr, mostly from seawater.

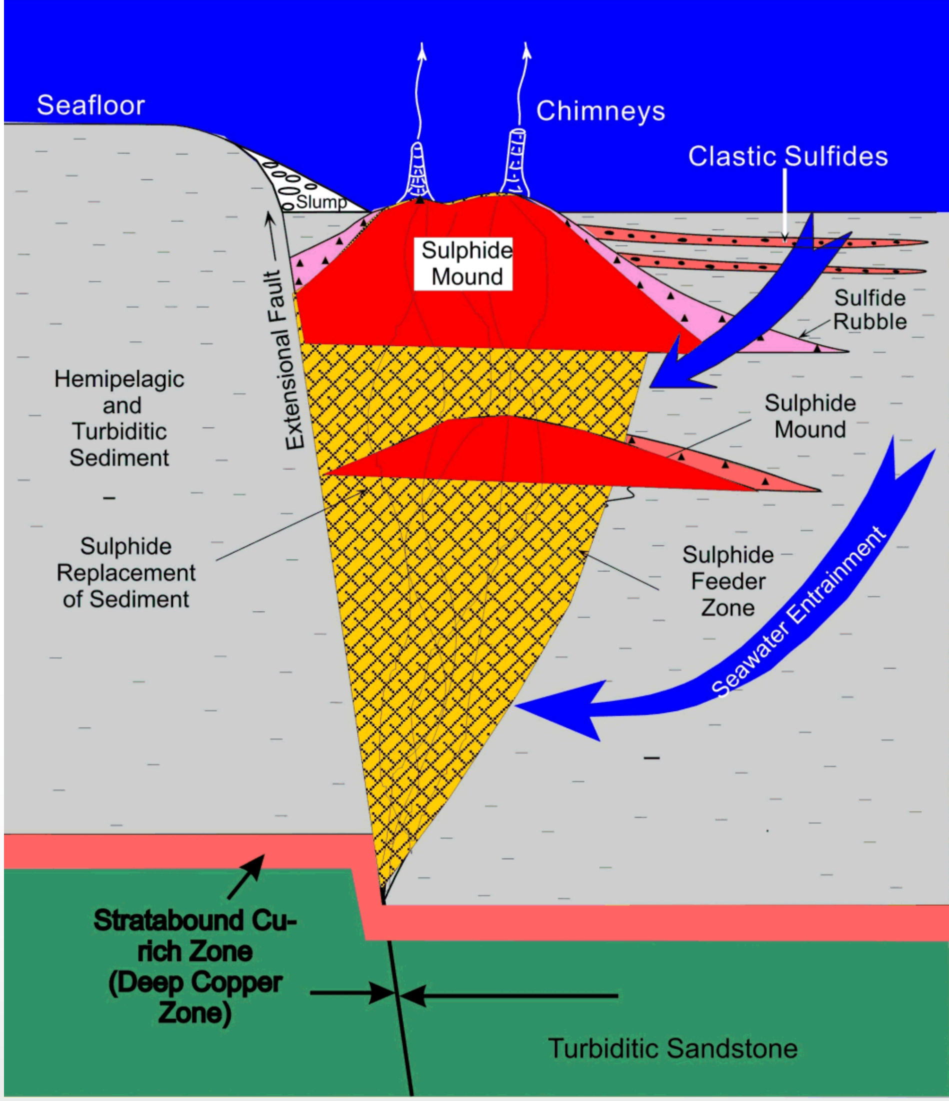
Zierenberg et al. Nature 1998

Leg 169 Bent Hill Middle Valley

Focusing of hydrothermal fluids along rift parallel extension faults.
Sulfide deposition, quenching of hydrothermal fluids in chimney structures.



(From Goodfellow et al., 1999)



A key element in creating massive sulfide deposits as large as those drilled in Middle Valley is the extended focusing of intense hydrothermal discharge

Leg 193 PACMANUS

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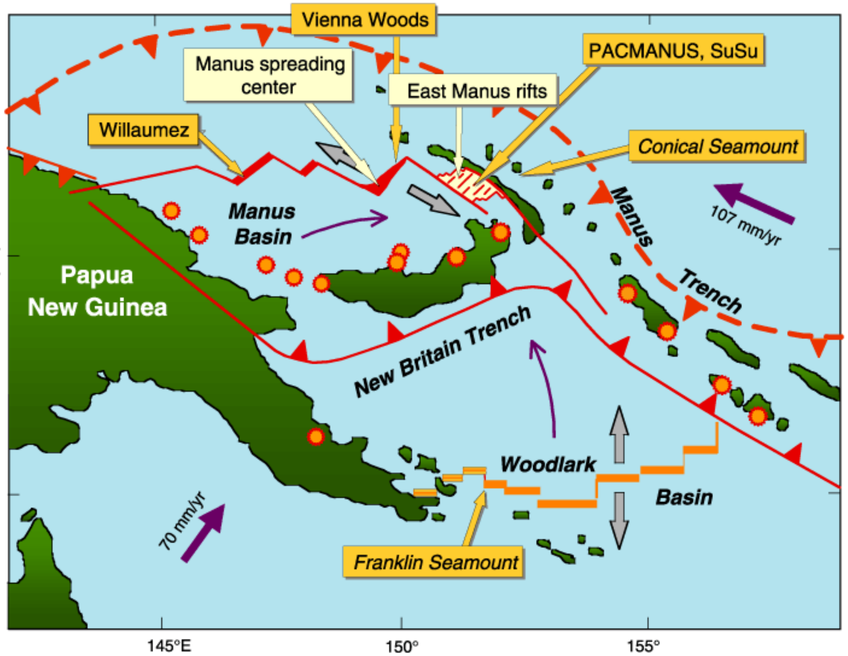
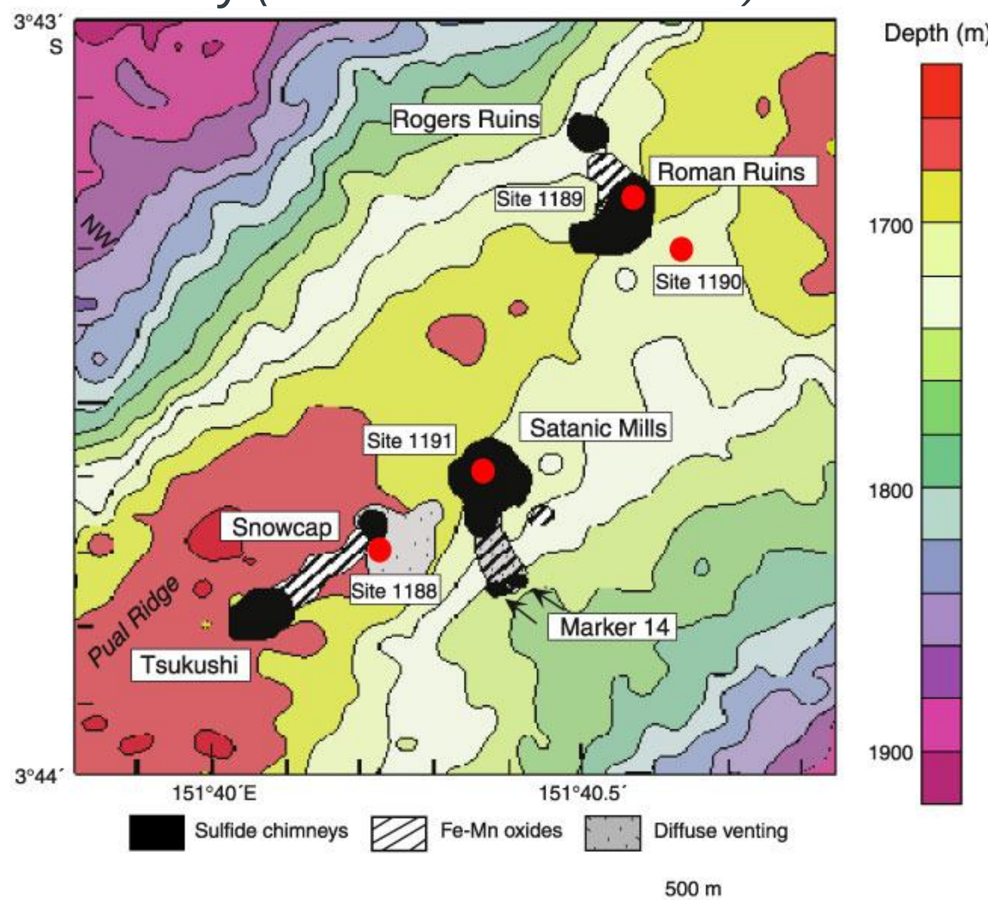


Hydrothermal sites located on rifted arc crust. Circa 1 Million Tonnes at 7% Cu and 5g/t gold – 860 Million Dollar Ore Body *(Source Nautilus Minerals)*

The cruise strategy was to drill as deeply as possible at sites of hydrothermal activity including two along the crest of the Paul Ridge representing outflow zones characterized by low-temperature diffuse venting (Site 1188a,f) and high-temperature focused venting, respectively (Site 1189a,b).



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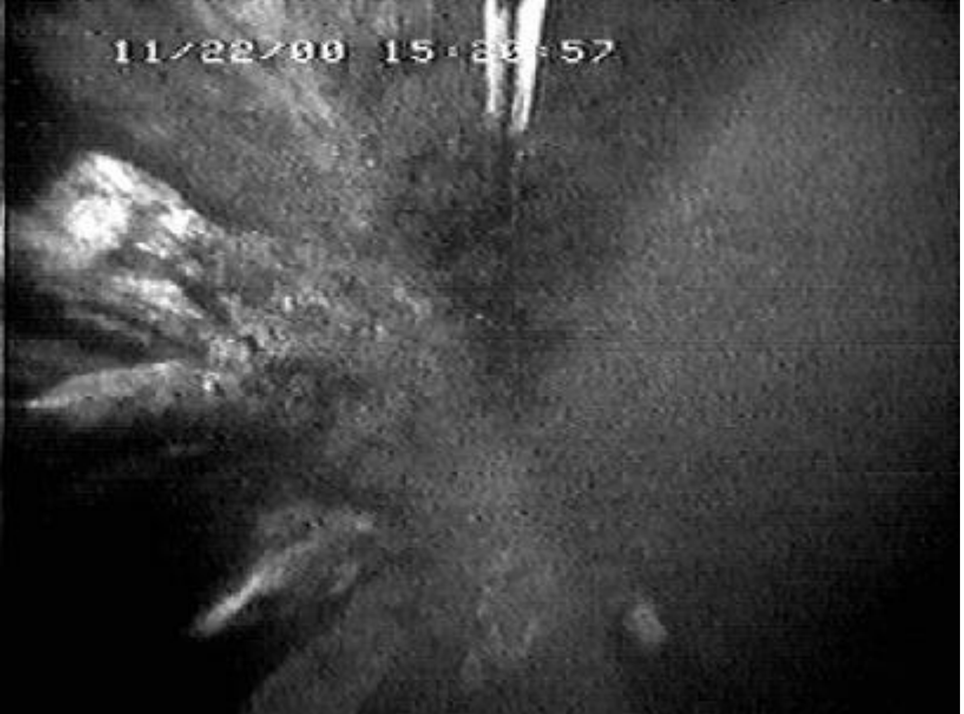
Shots from the Drill Camera



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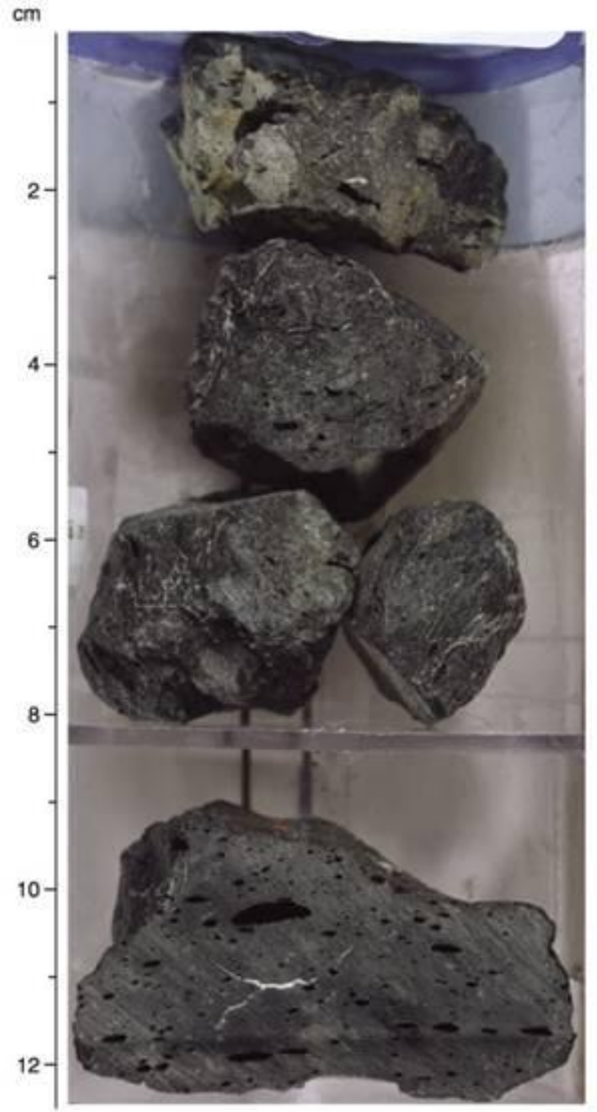
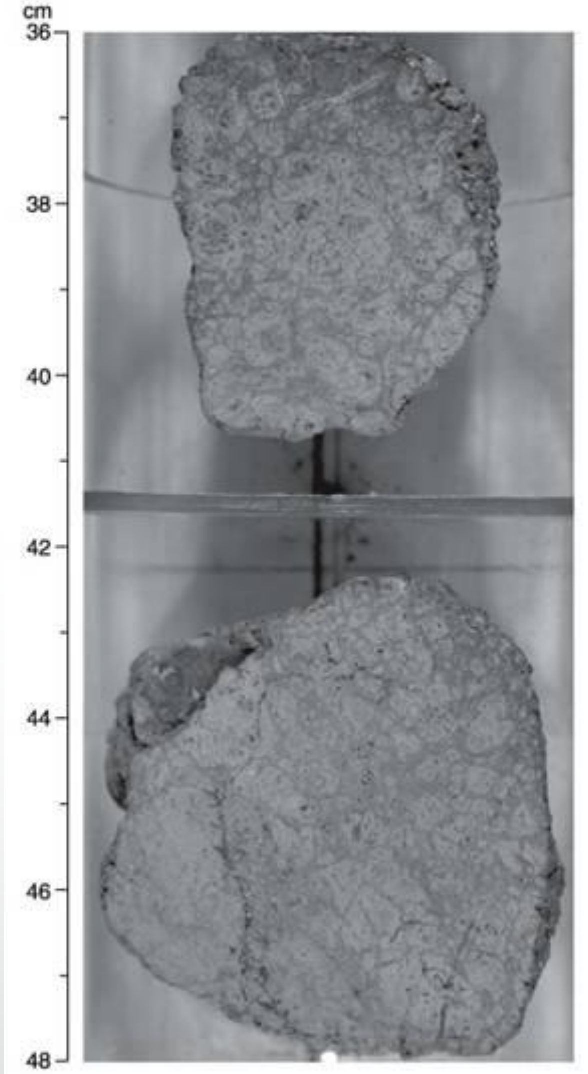
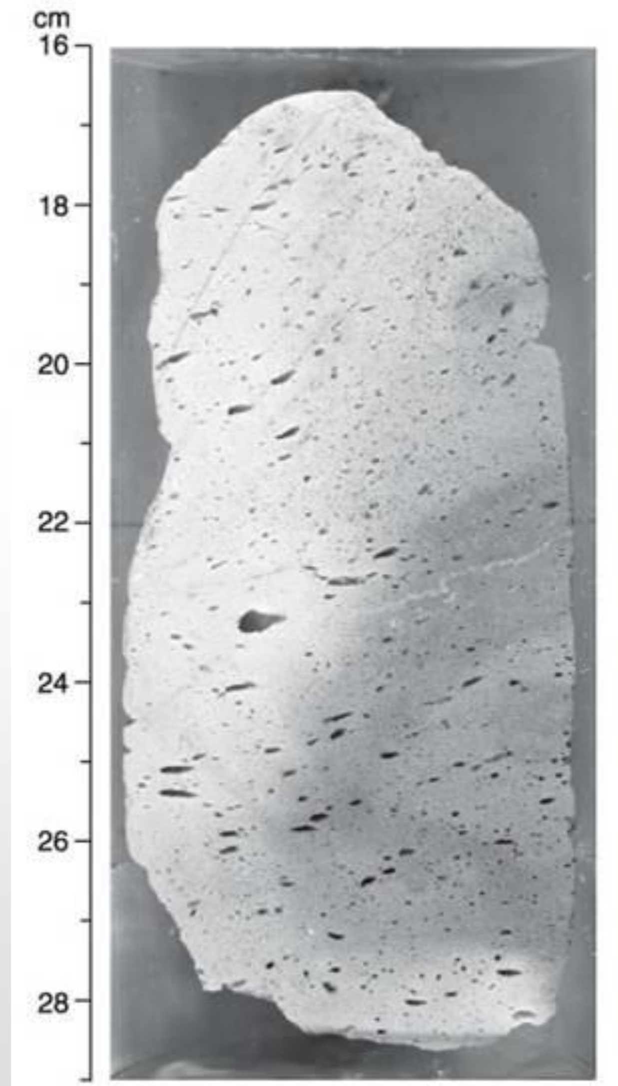


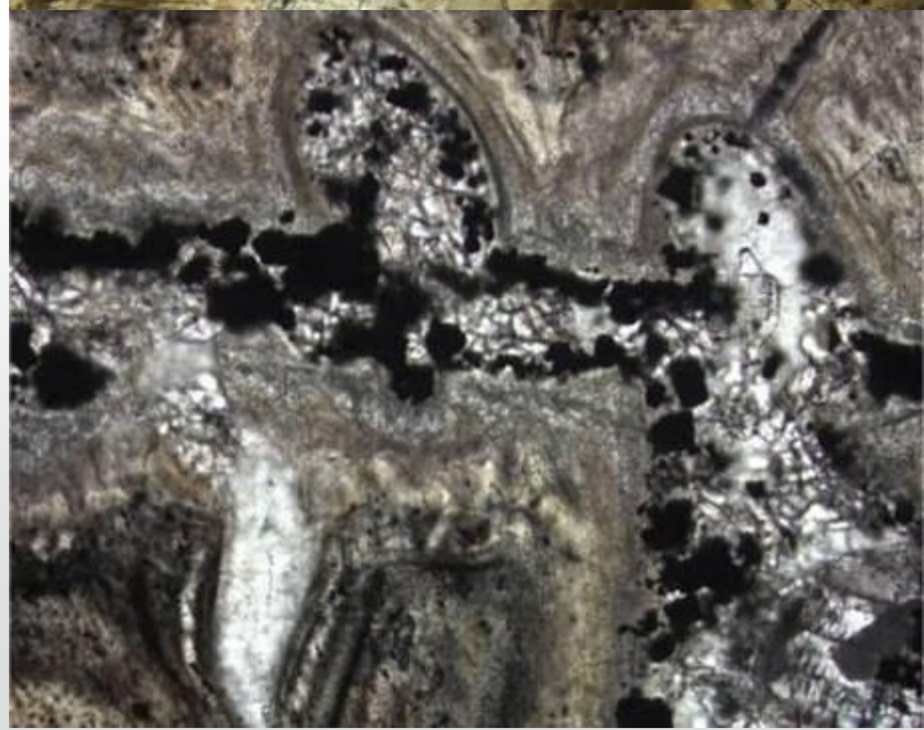




Variably Altered Volcanics


Leg 193
Hole 1188F
Core 1Z-2
CM 65-87


1188A_133



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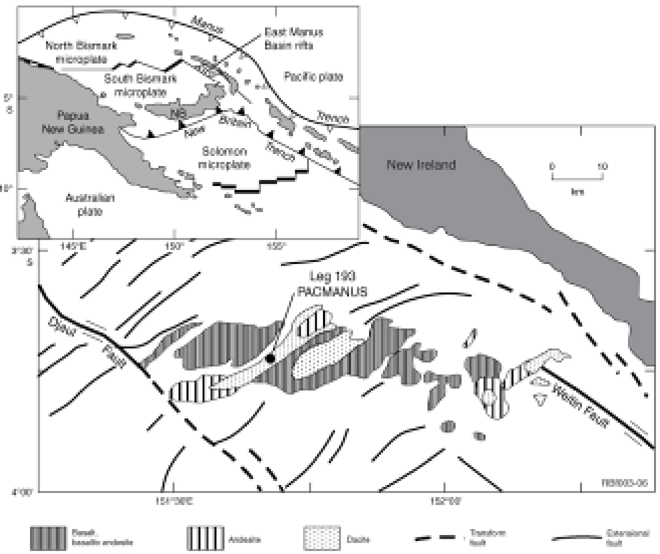
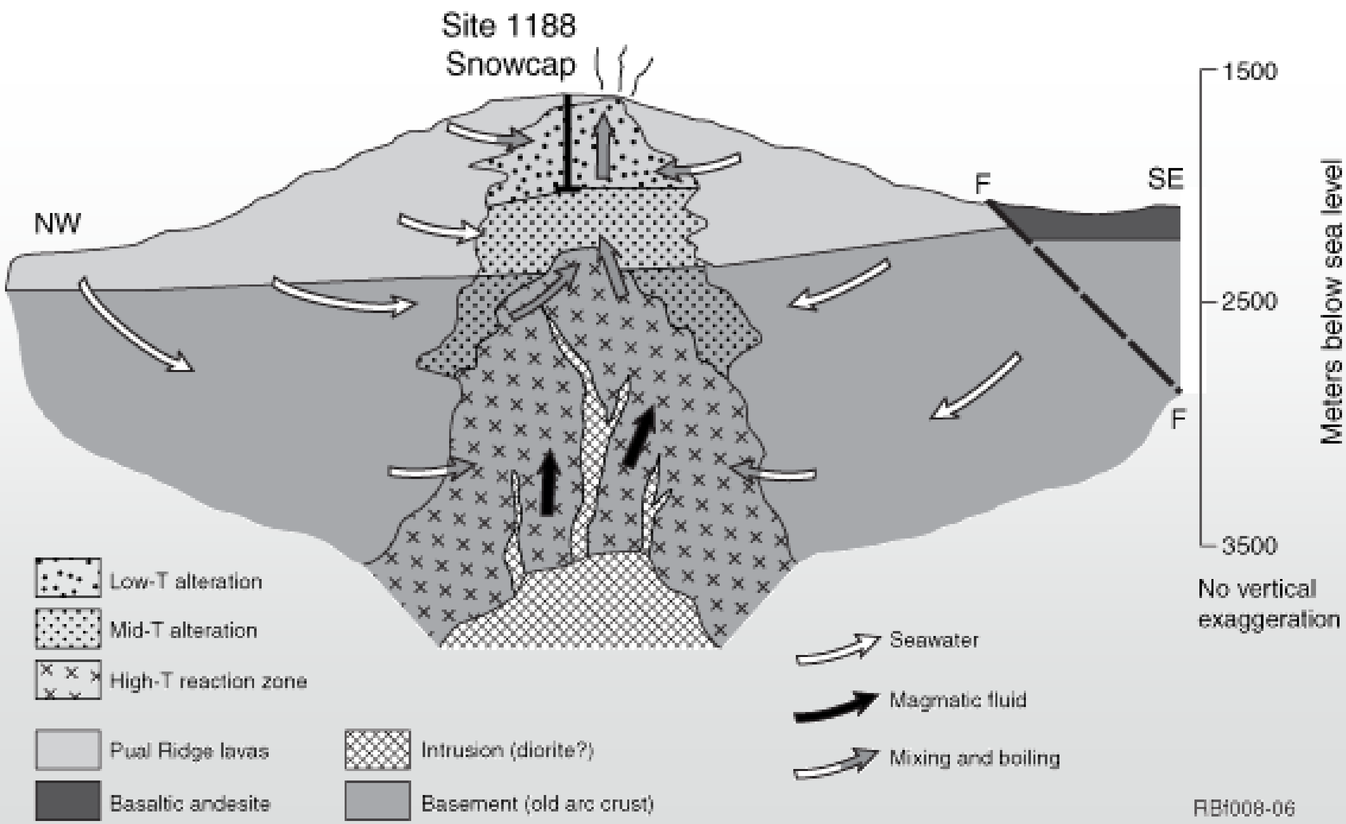


Leg 193 PACMANUS



Schematic Model of Fluid Flow and Mineralization of The Pual Ridge

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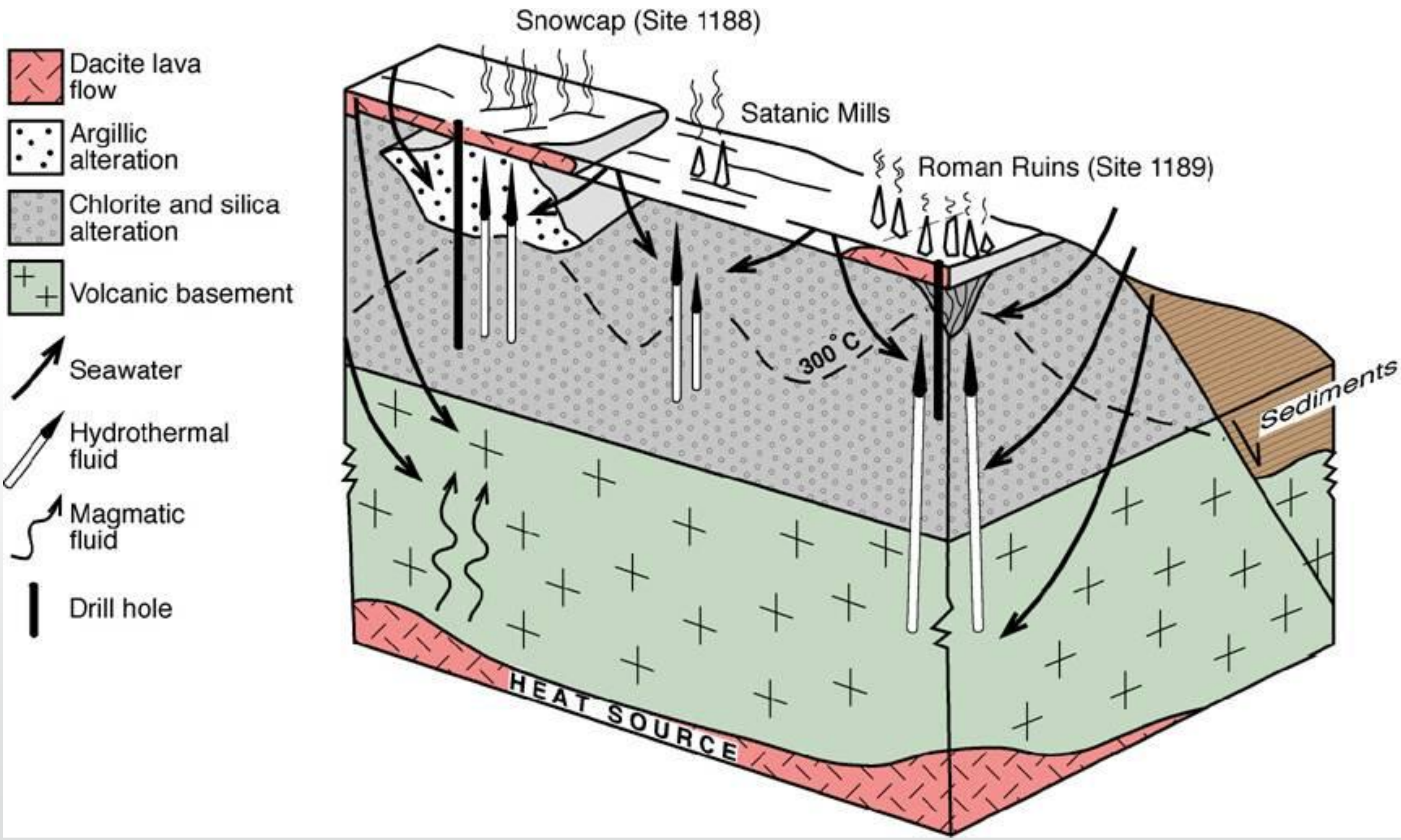

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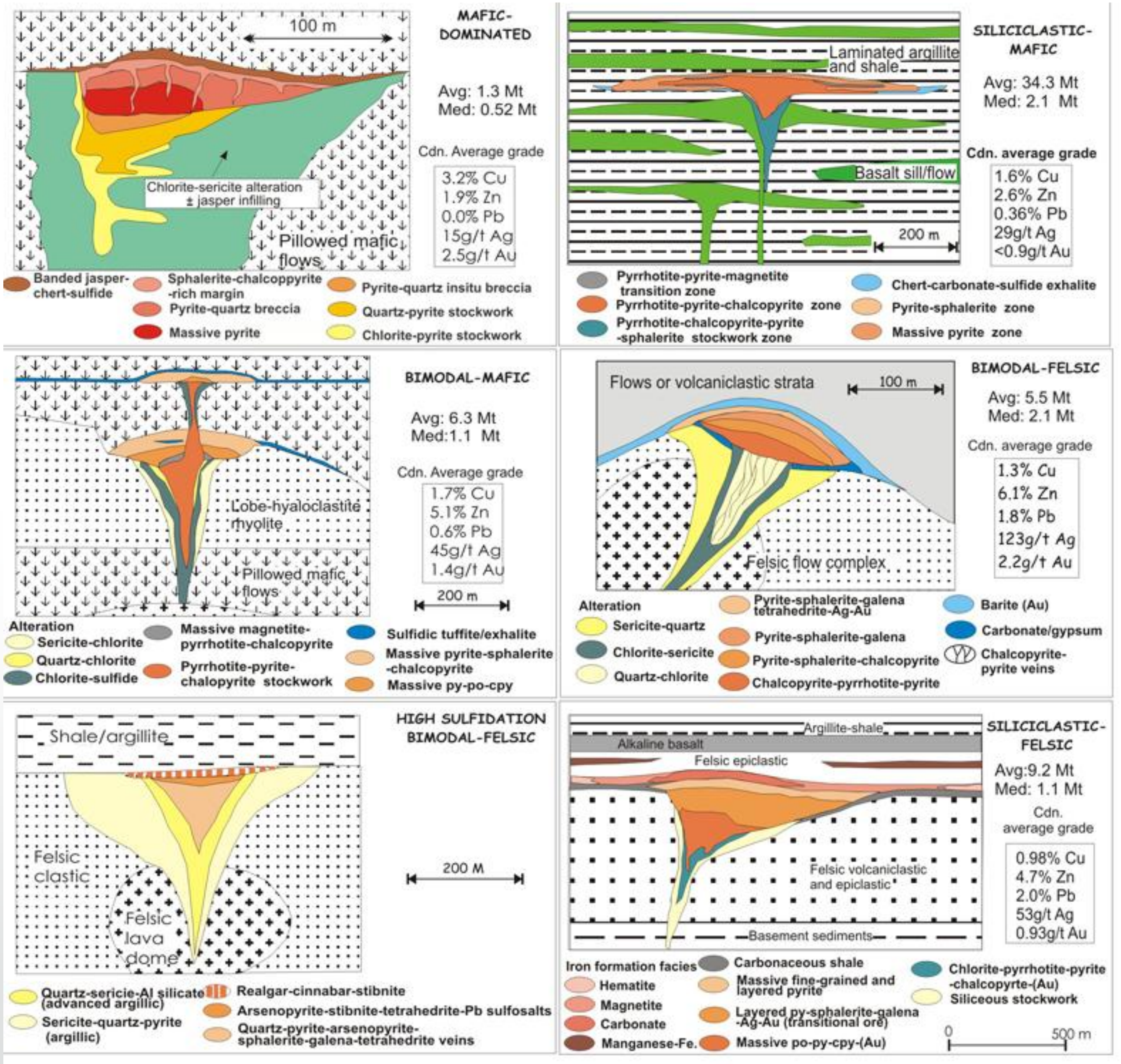

Basement controls metal tenor of the ores

http://gsc.nrcan.gc.ca/mindep/synth_dep/vms/index_e.php

Wetar Island, Indonesia

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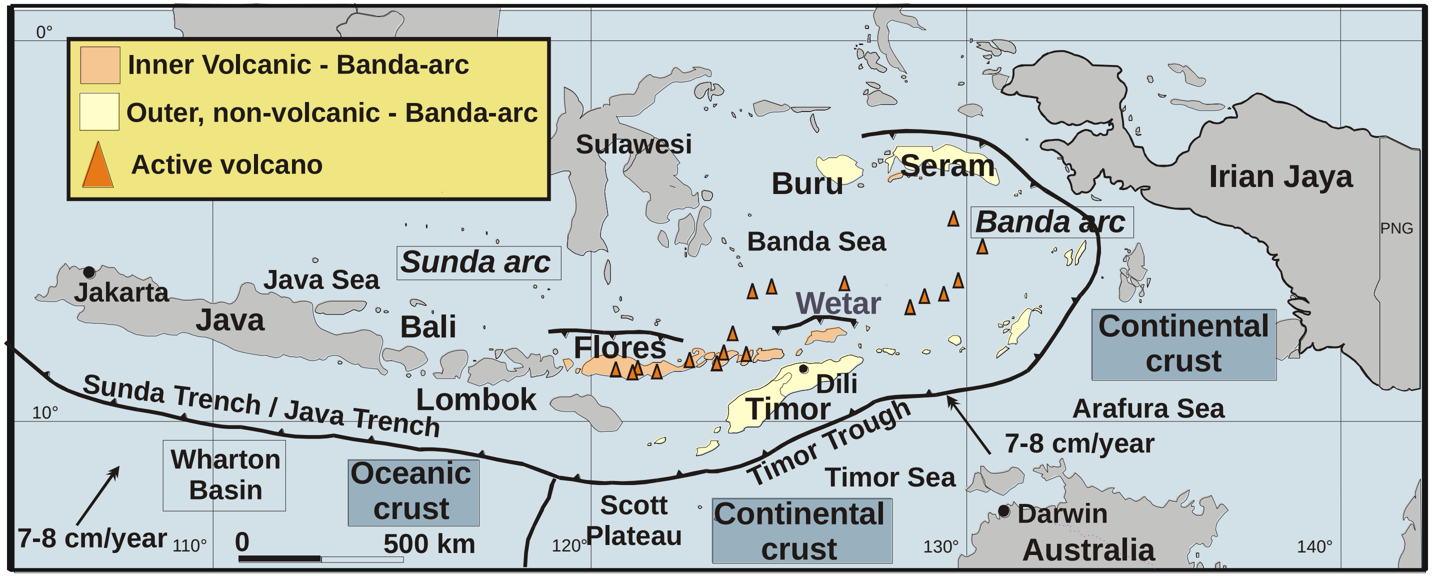

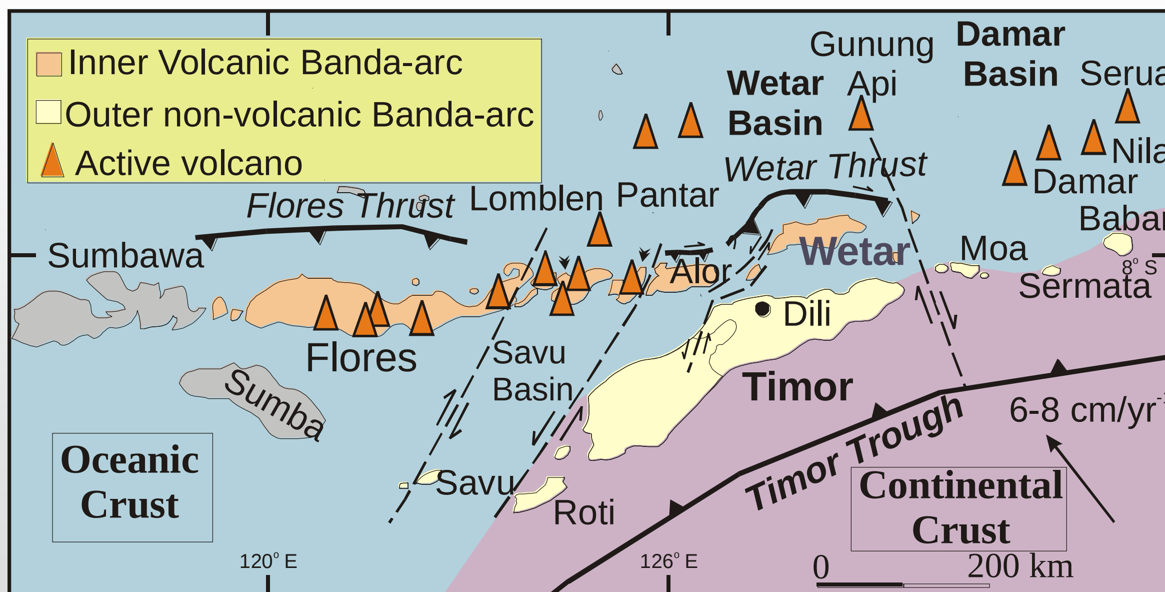

Wetar Island

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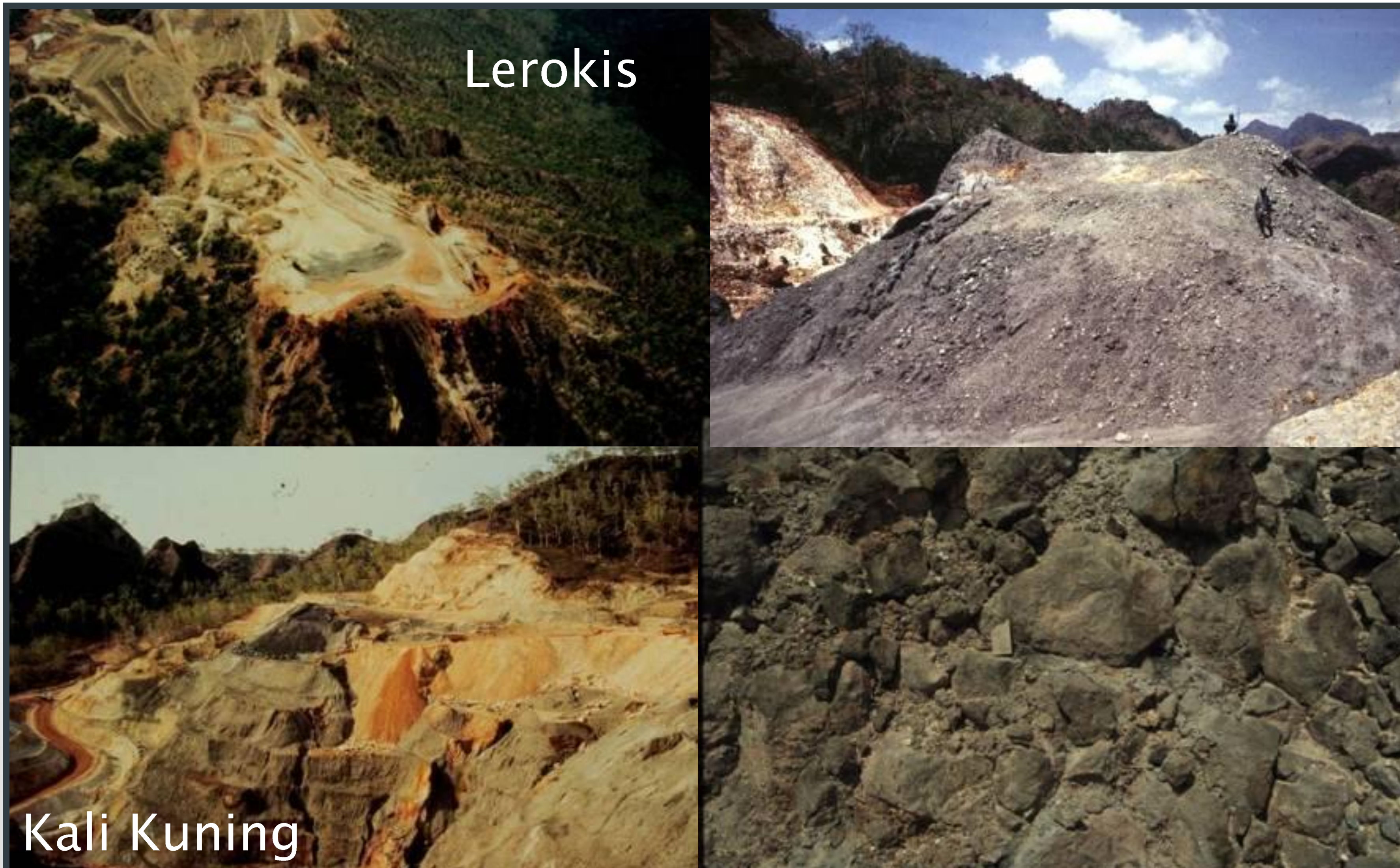

Open Pit - Alteration

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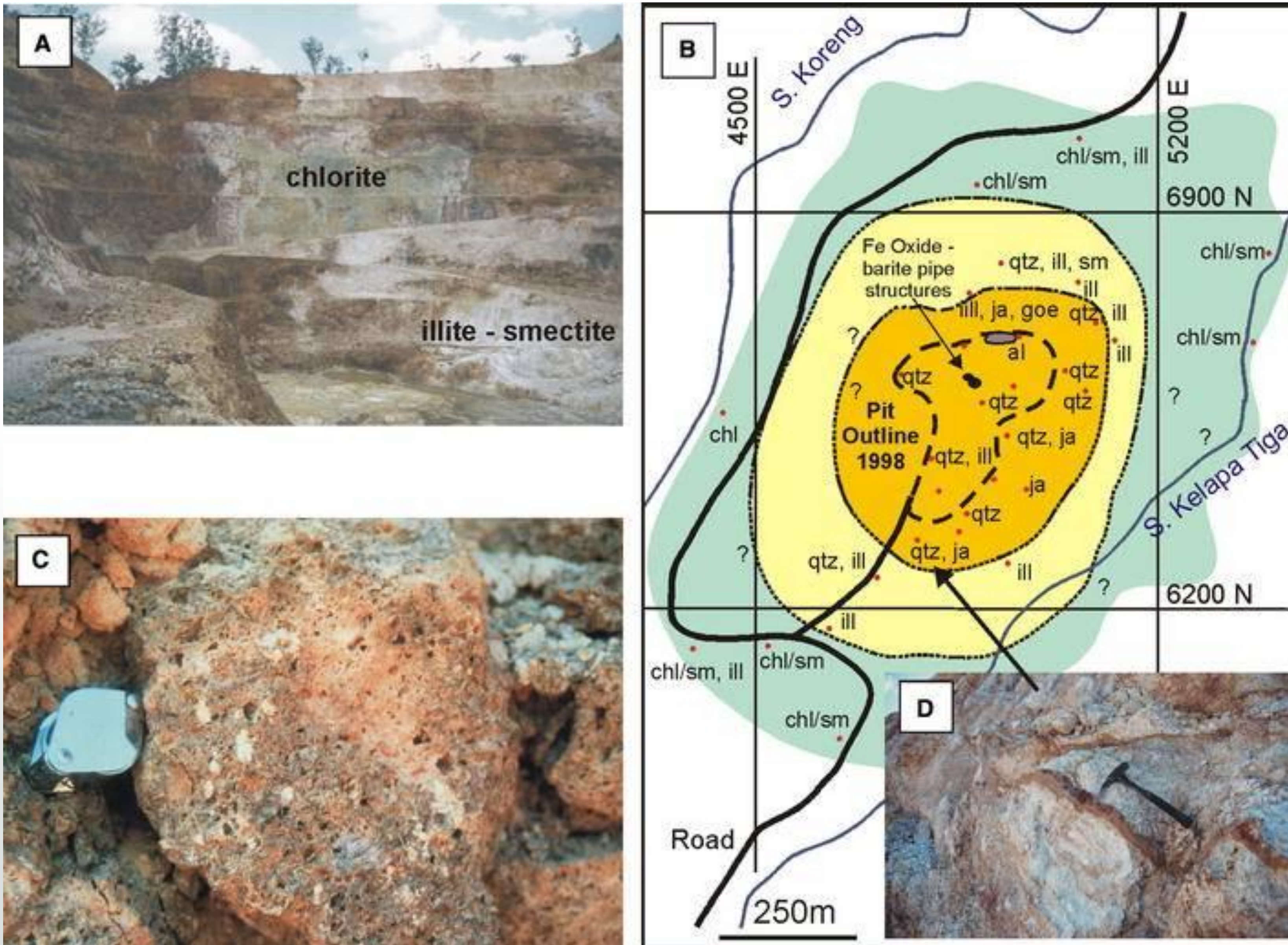

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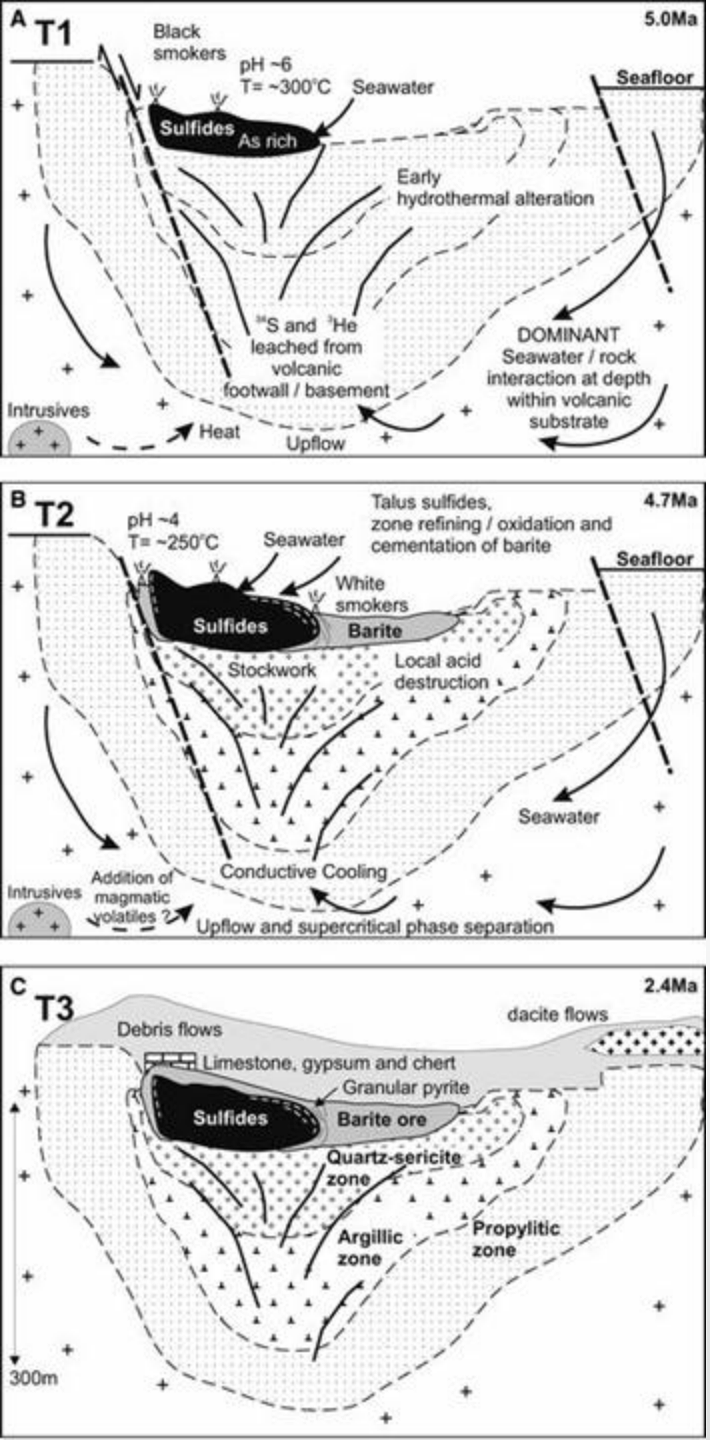
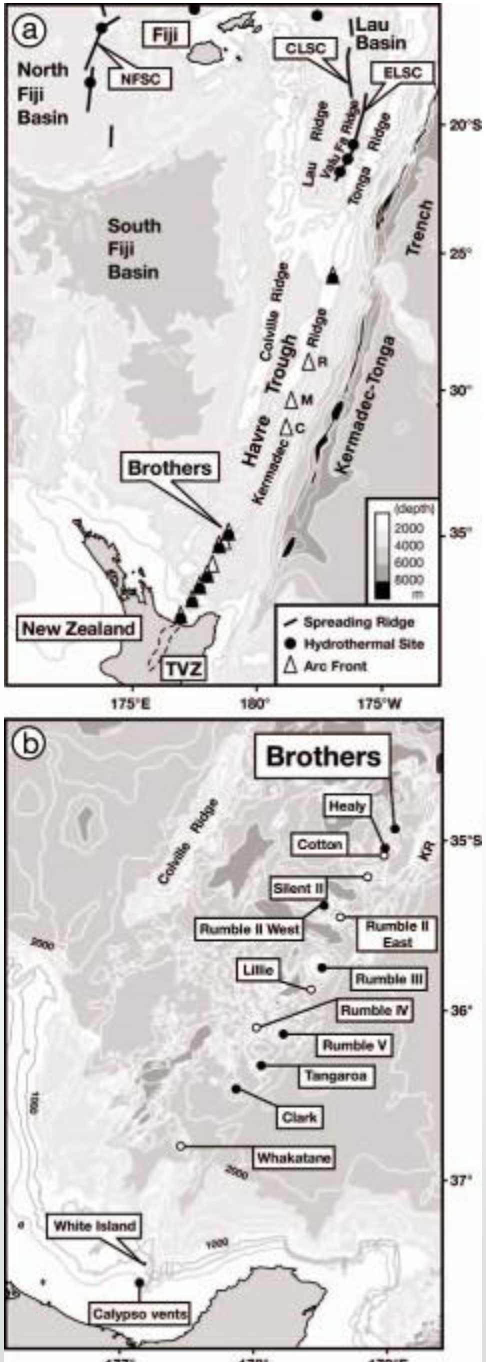


Wetar Island preserves massive sulfides (Py+Cpy) with a later fracture fill *“High Sulfidation Assemblage”* and associated barite sand deposits.

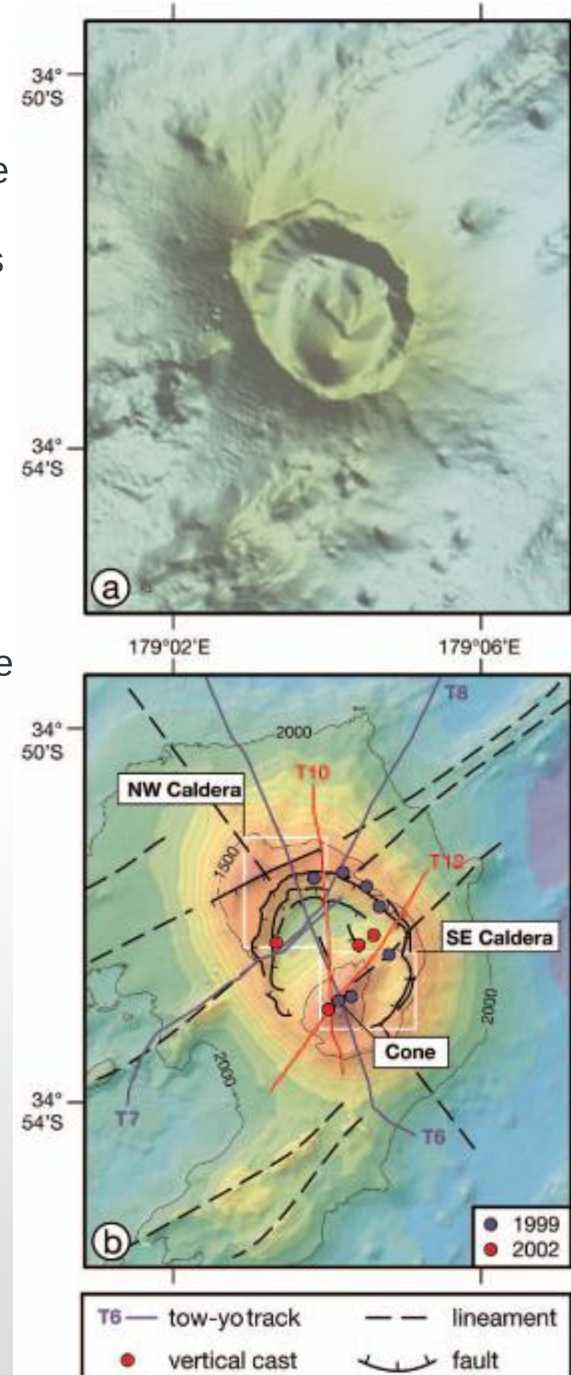
These systems formed at or near the sea-floor at around 2km water depth associated with extensional fault structures and miocene magmatism.

Mineralogical, fluid and isotopic data suggest a sea-water dominated hydrothermal fluid with the barite sands and gold linked to “white smoker” vents marginal to the main sulfide structures.

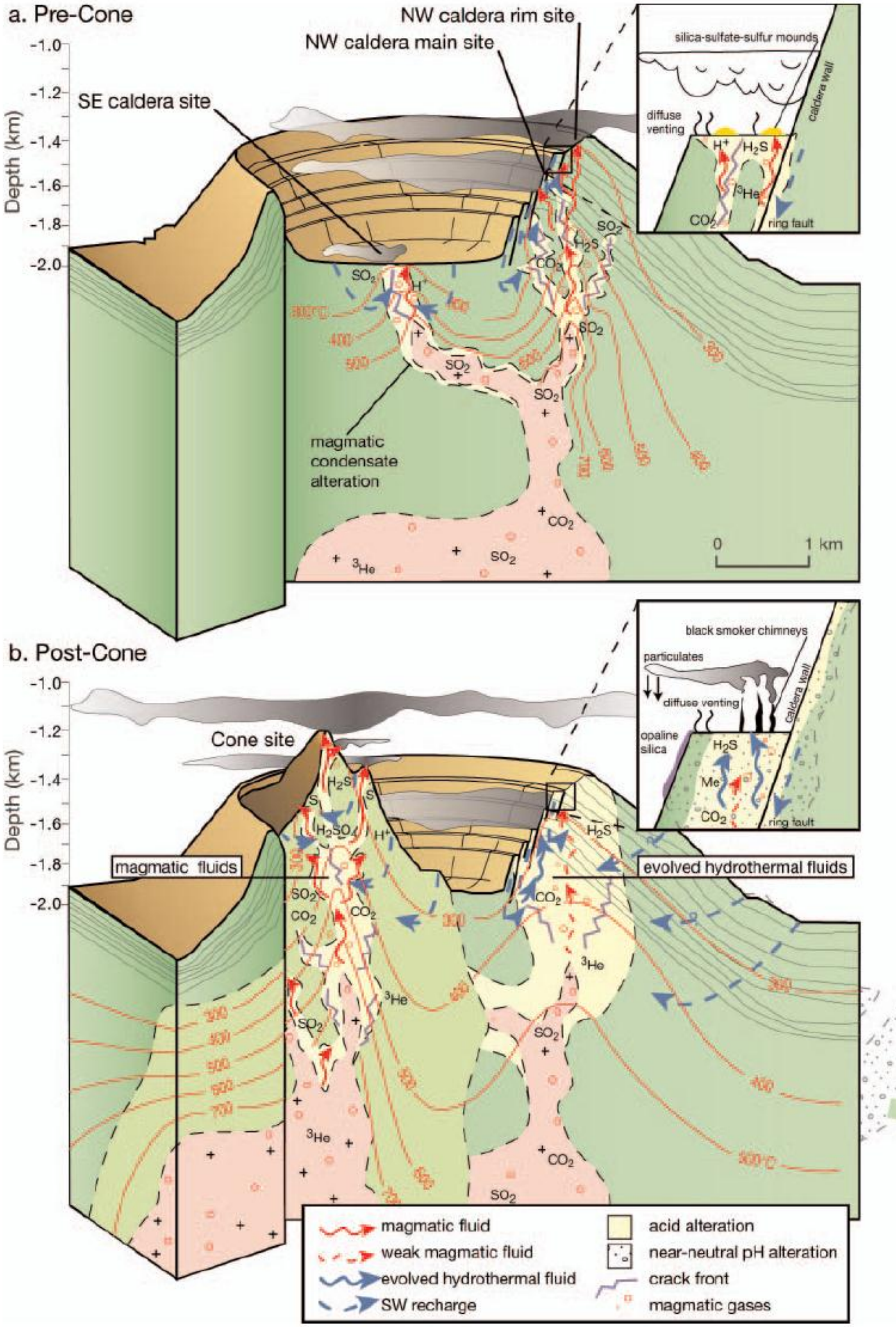


Towards the Arc

Furthermore, during the lifetime of ODP, the recognition of massive sulfides associated with submarine arc volcanoes e.g. Brothers Volcano, Conical Seamount, provide examples of massive sulfide formation where the “3rd dimension” remains untested, yet such sites are presently the focus of scientific research and potential exploitation as a mineral resource. Indeed, these locations may provide the key evidence to resolve the open question of the the role of magmatic contributions to the metal budgets of volcanogenic massive sulfide deposits.



Source. De Ronde et al. 2005, Wright Pers Com.



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Source. De Ronde et al. 2005, Wright Pers Com.

Sea-floor mining – a realistic prospect 2010/14

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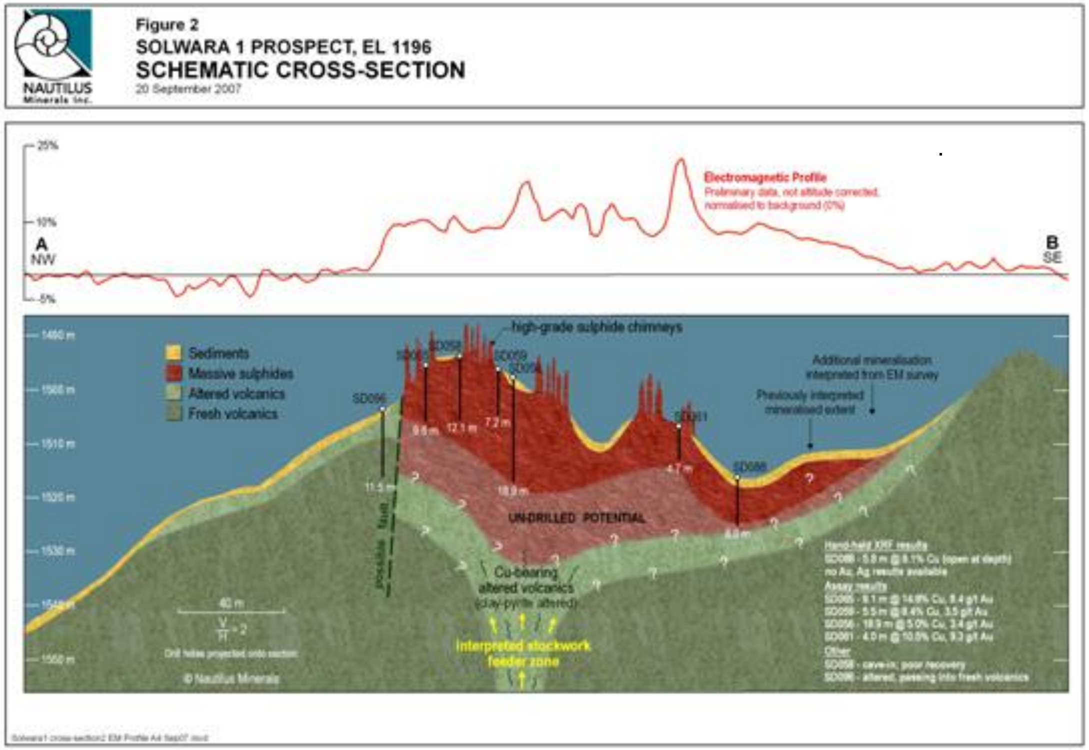
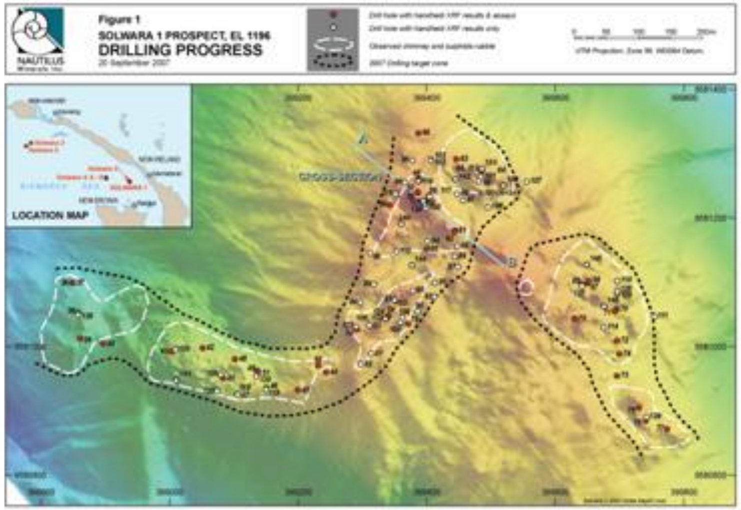
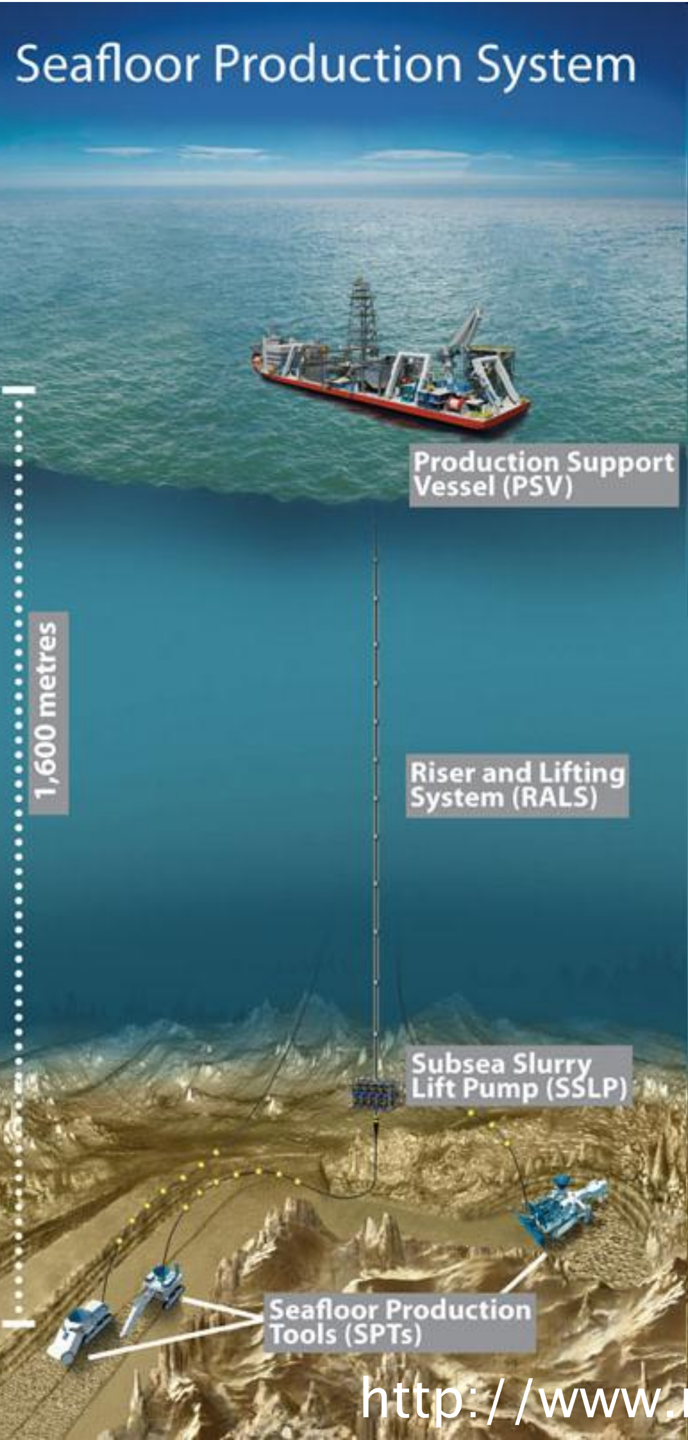
Aim listed companies Nautilus Minerals – backed by Anglo and (BHP Minerals), (Neptune Minerals - backed by Newmont – liquidated 2011).







(Source Nautilus Minerals)

http://www.nautilusminerals.com/s/resourceextraction.asp

Solwara Environmental

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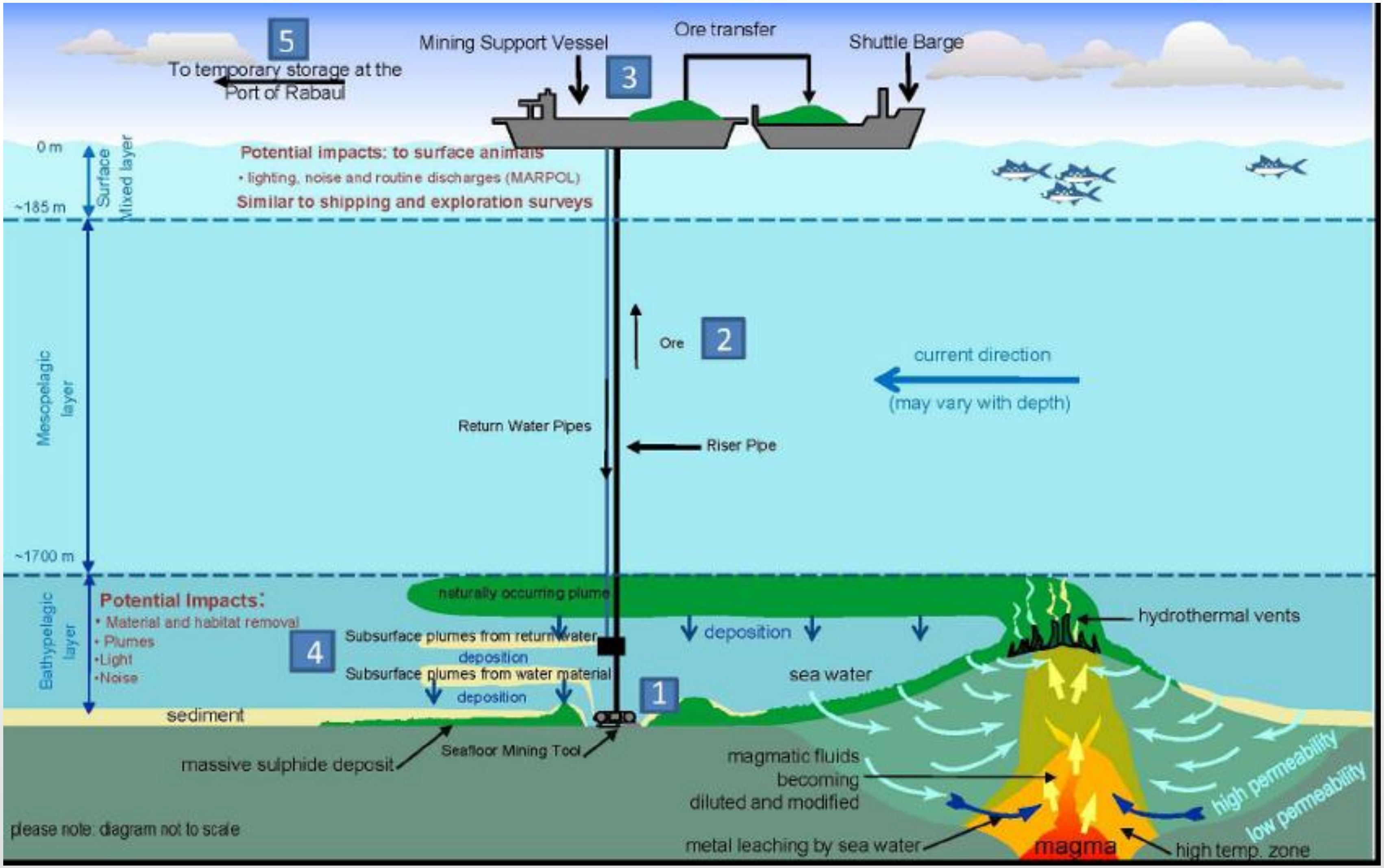

Source: Nautilus Minerals

Schematic Dewatering Process – Solwara

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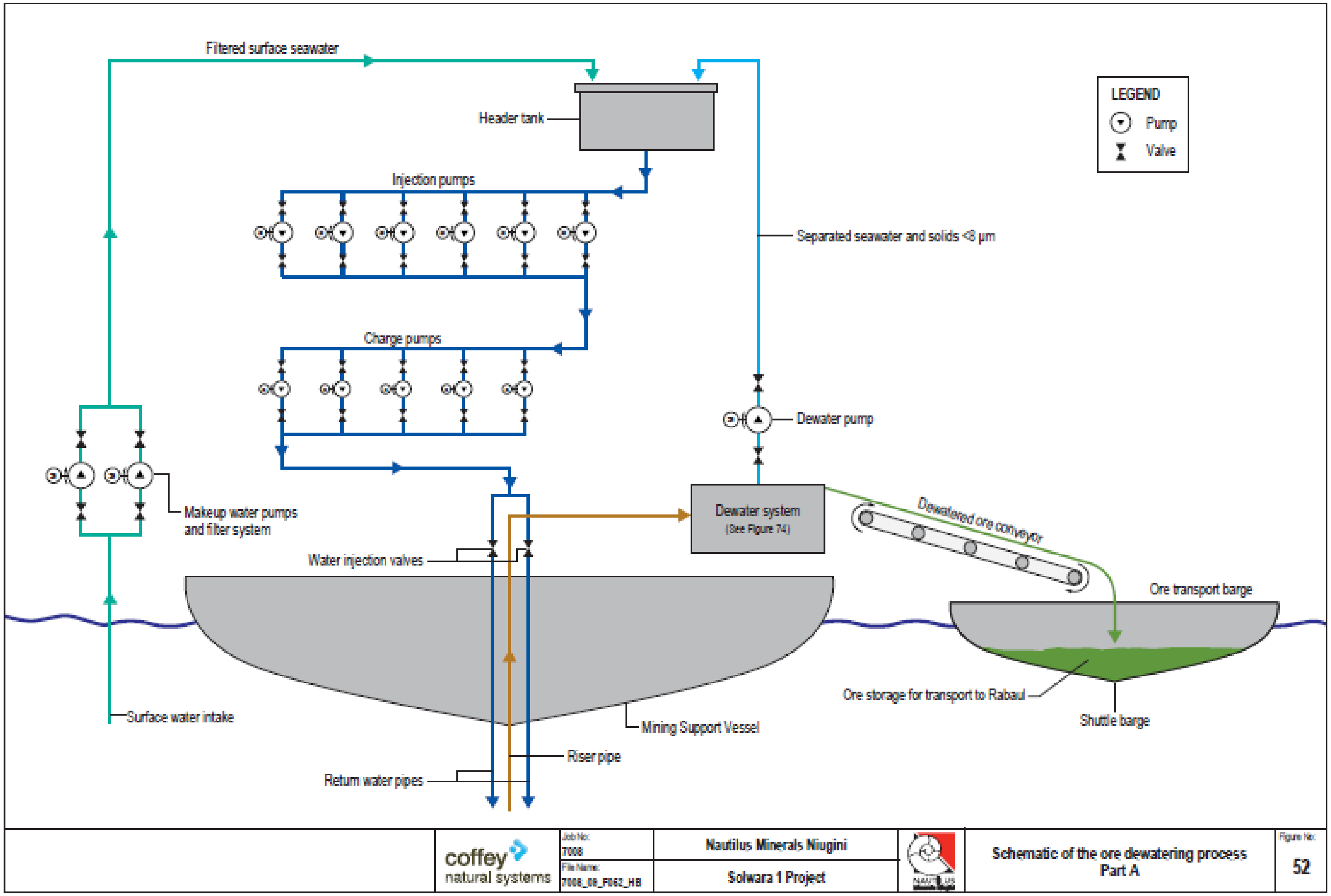

Source: Nautilus Minerals

“Nautius Impact Statement”

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Dewatering process on the Production Support Vessel ("PSV") will be achieved by:

1. Discharging at depths between 25 to 50 metres above the seafloor to confine all impacts to the bottom zones from where the water/sediment originated.

2. Filtering the water prior to release, which is expected to significantly reduce the quantities of sediment lost in the dewater discharge.

3. Limiting the exposure time of the return water to surface temperatures and oxygenation, thereby reducing potential for geochemical changes. The pipes used to transport the return water to the seafloor will allow for cooling of the return water.

The result of these strategies is that the Solwara 1 Project will cause no harm to fisheries, coral reefs, whales, turtles or other pelagic animals.

Deep-Sea and Sub-Seafloor Resources

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Some Thoughts:

1) Sea bed mining closer than ever to becoming a commercial reality.

2) The exploration and extraction of these resources was largely research led using a geological understanding developed through scientific investigations of these marine resources.

3) These scientific studies focussed on processes responsible for initial sulphide precipitation and habitat of vent fauna and flora.

4) Limited studies have investigated these sea floor hydrothermal mineral deposits within the context that they may soon become sites of mineral extraction.

Some Key Questions?

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The increased likelihood of extraction raises some important and fundamental questions, these include:

1) What are the controlling factors on minor metal associations within sea floor vent systems?

2) Given that current technologies suggest “in situ comminution” will constitute the initial phase of sulphide/oxide recovery, what will be the likely release of minor elements, into the prevailing ecosystems?

3) What are the fundamental grade tonnage controls on sea floor vent systems.

4) What are the spatial controls on hydrothermal activity and SMS deposition?

5) What are the timescales for the evolution of SMS deposits?

6) What are the changes in biological communities that occur during the evolution of an SMS deposit?

Manganese – Cobalt Crusts and Nodules

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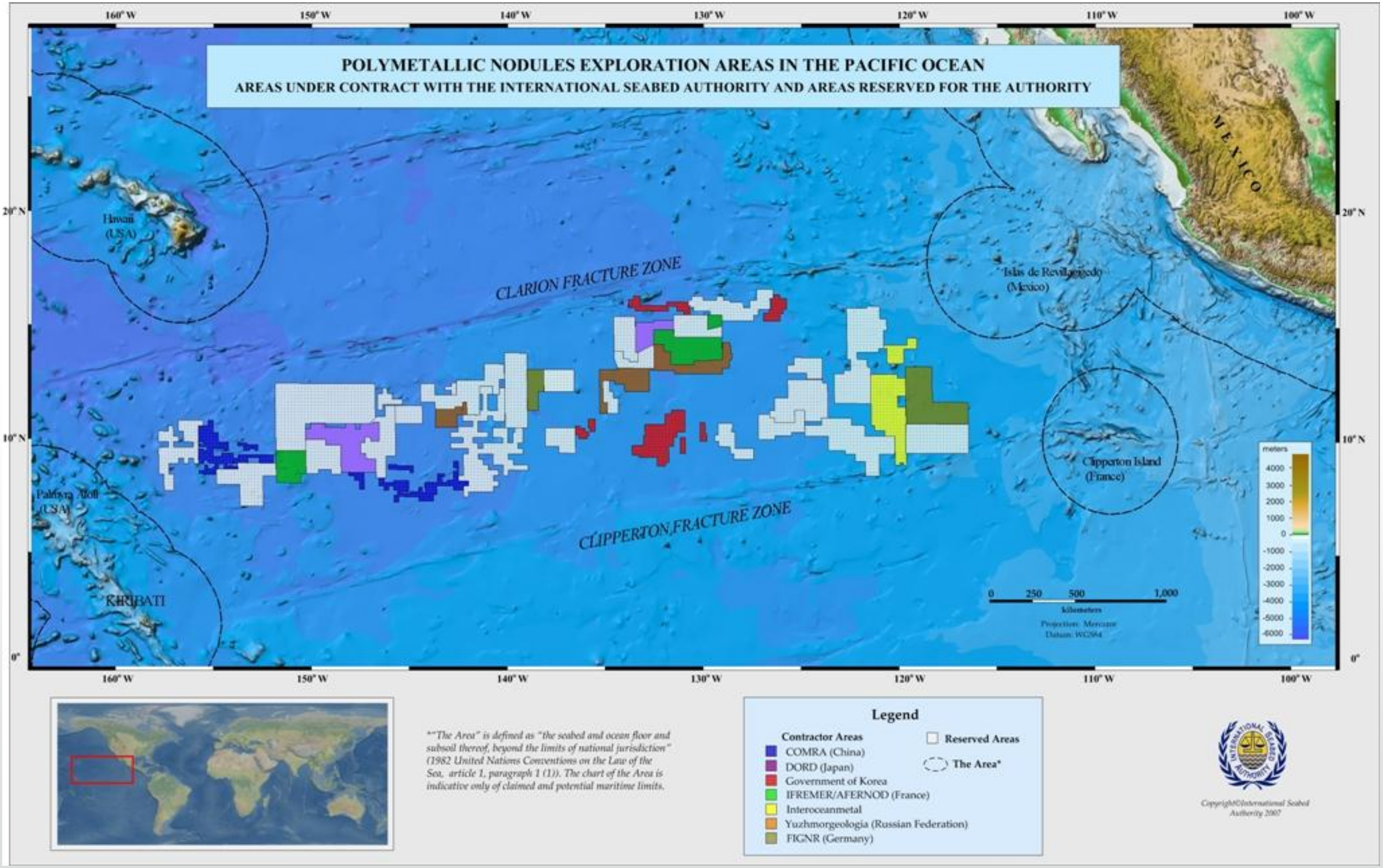

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Usui a & Okamoto 2010

Manganese – Cobalt Crusts and Nodules Metal Content

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Sample 35D193

Layers	Thick	Mineralogy	Mn	Fe	Ni	Cu	Co	P_2O_5
			Elemental composition (%)					
III	0-20 mm	Fe-vernadite, Mn-ferroxyhyte, quartz, buserite, goethite, haematite, feldspars	20.0	18.9	0.33	0.10	0.57	1.4
II	20-50 mm	Fe-vernadite, Mn-ferroxyhyte, goethite, clayey materials, feldspars, apatite, quartz, calcite, haematite	16.9	16.2	0.38	0.18	0.38	2.0
I-2	50-65 mm	Fe-vernadite, Mn-ferroxyhyte, apatite;	16.8	13.3	0.31	0.17	0.30	9.3
I-1	65-105 mm	Fe-vernadite, Mn-ferroxyhyte, goethite, apatite, asbolane, calcite, quartz, feldspars	14.6	11.9	0.33	0.09	0.25	8.2
R	105-165 mm	Asbolane, vernadite, todorokite, ferrihydrite, apatite, calcite, quartz	8.9	5.8	0.47	0.11	0.13	14.0

Hein et al. 2009

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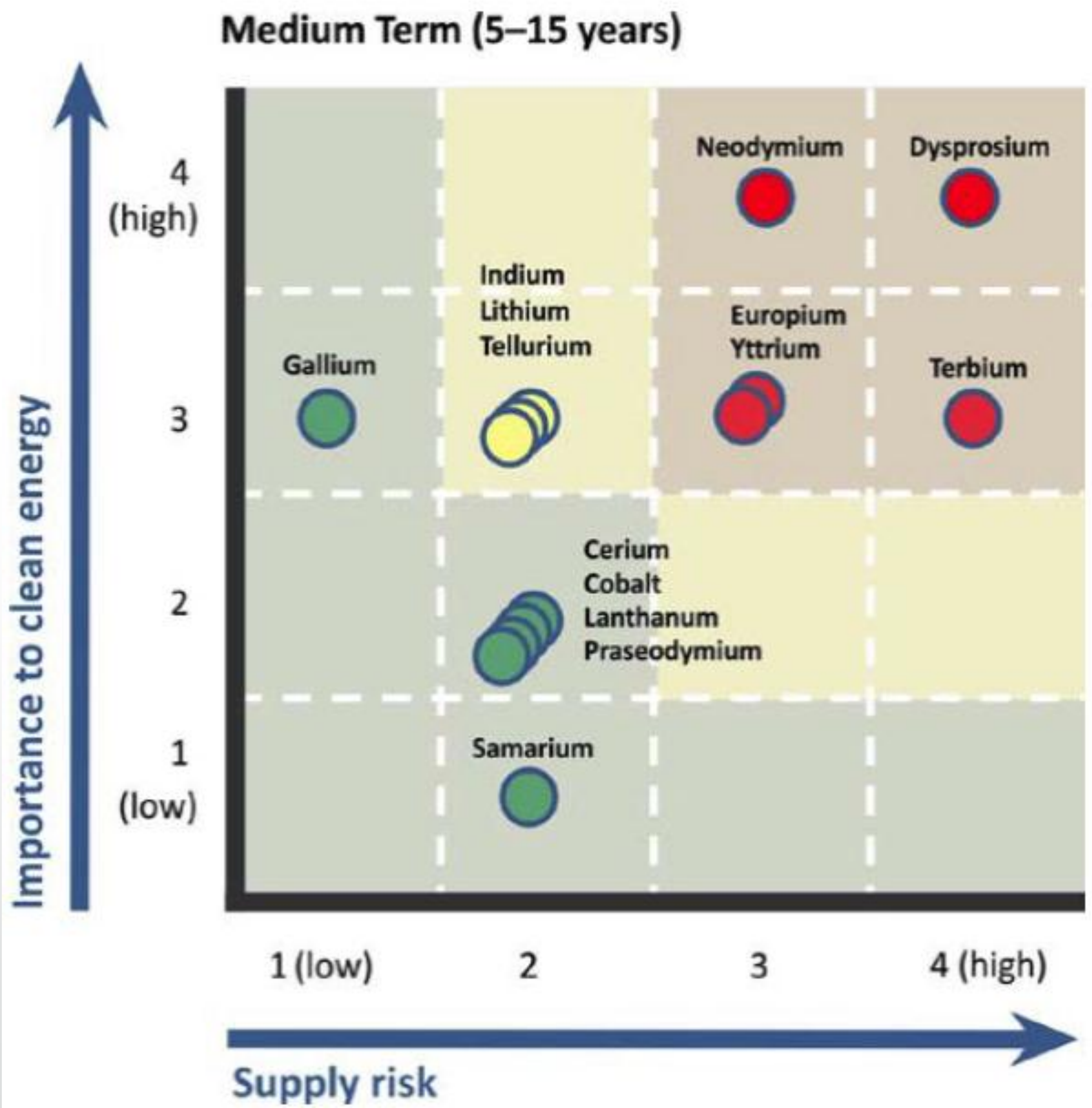

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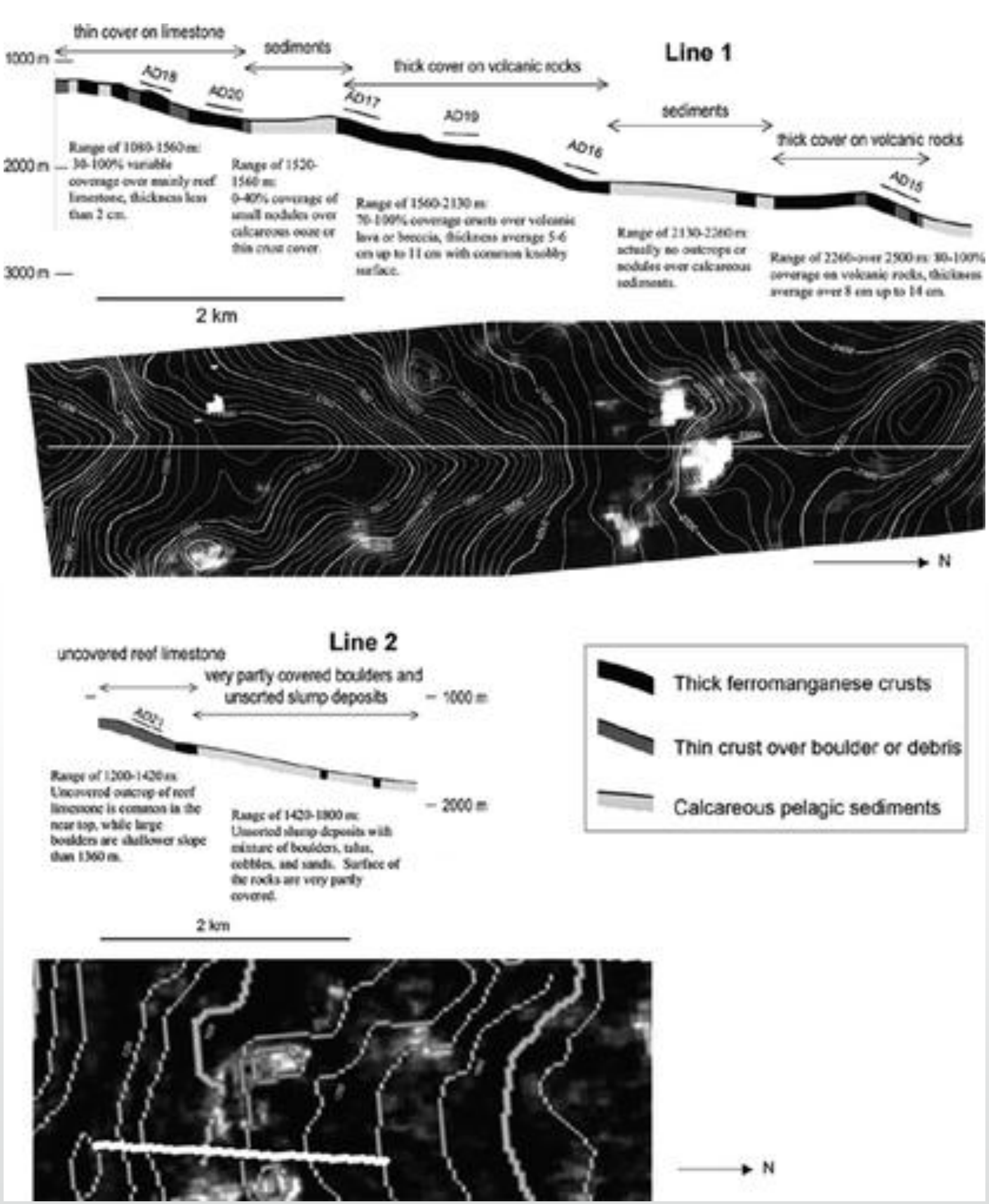

Usui a & Okamoto 2010

Some thoughts:

- “Renewed interest” in extraction of ocean floor sulfides and maganese-cobalt nodules.
- However significant technological and environmental challenges