Making minerals from seawater

by

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The LRET Research Collegium
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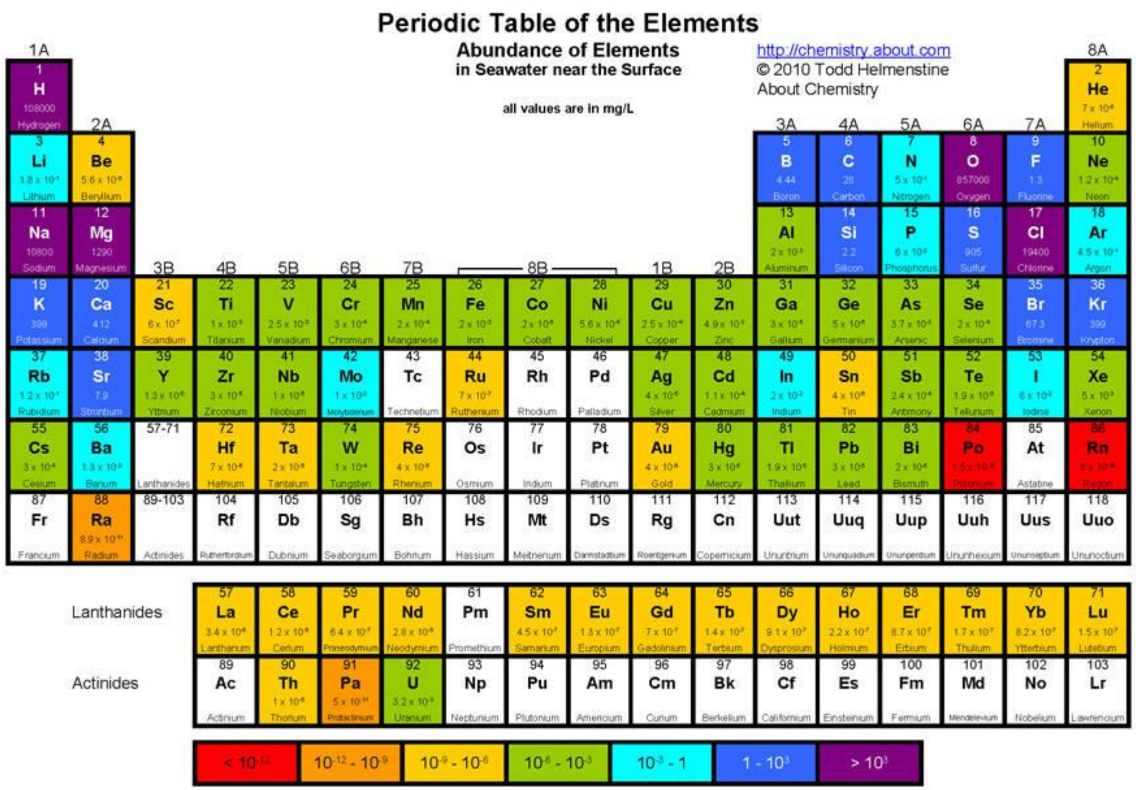
19 July 2012

Seawater Composition



http://chemistry.about.com

Trace metals in the oceans

- Trace metals are present in seawater at extremely low levels
- These metals are vital for cellular biological processes
- Our understanding of the sources, fluxes and timescales for removal of metals from seawater is still poor
- Metals are removed from seawater to form mineral deposits at the seafloor
- As the demand for metals increases, the feasibility of ocean mineral resources increases

How are minerals formed in the ocean?

1. Hydrothermal deposits and seafloor minerals
2. Hydrothermal plumes and metalliferous sediments
3. Manganese nodules and crusts

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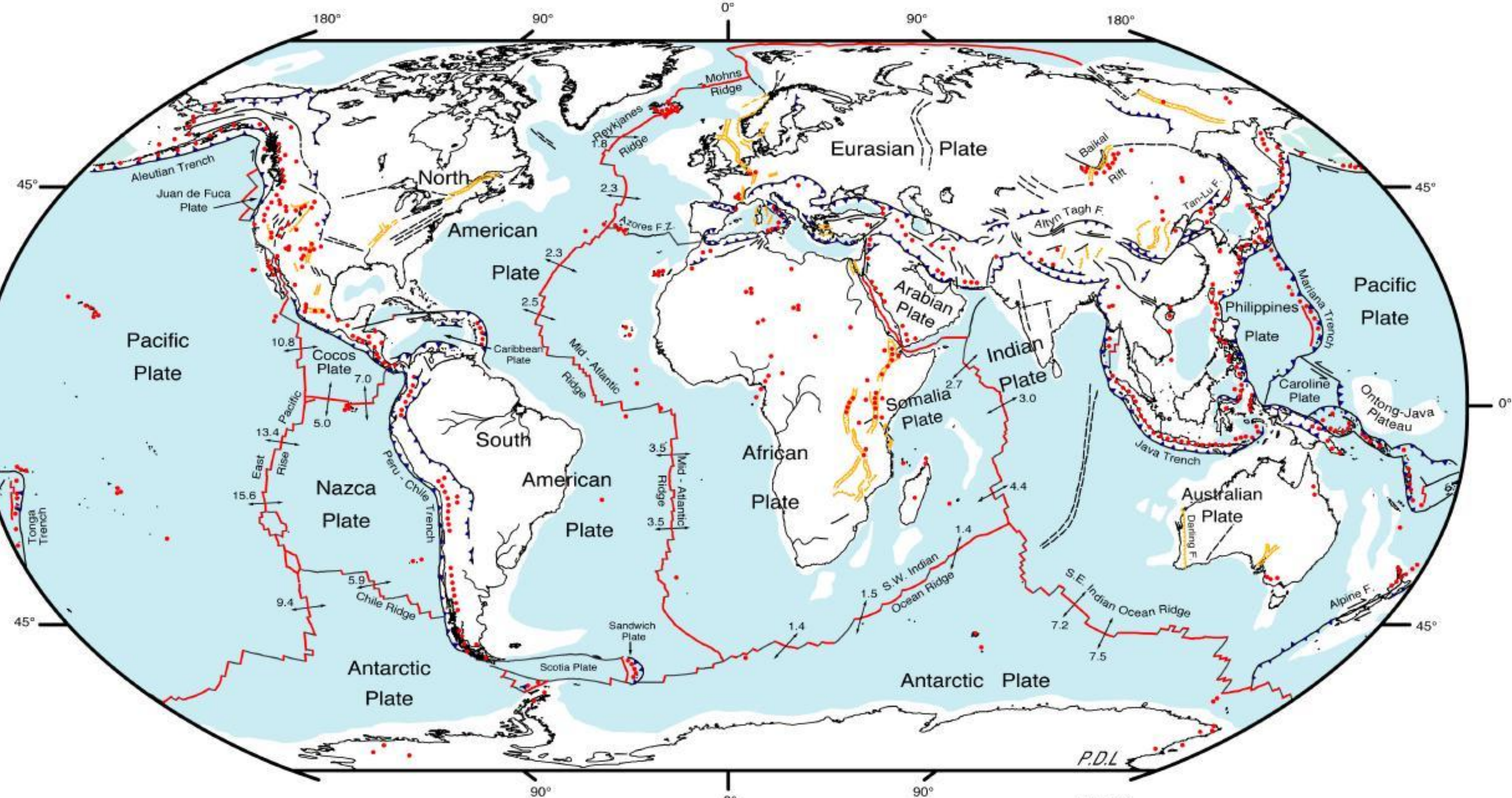

DIGITAL TECTONIC ACTIVITY MAP OF THE EARTH
Tectonism and Volcanism of the Last One Million Years

DTAM

NASA

NASA/Goddard Space Flight Center
Greenbelt, Maryland 20771

Robinson Projection
Mainly oceanic crust
October 1998

LEGEND
- Actively-spreading ridges and transform faults
- Total spreading rate, cm/year, NUVEL-1 model (DeMets et al., Geophys. J. International, 101, 425, 1990)
- Major active fault or fault zone; dashed where nature, location, or activity uncertain
- Normal fault or rift; hachures on downthrown side
- Reverse fault (overthrust, subduction zones); generalized; barbs on upthrown side
- Volcanic centers active within the last one million years; generalized. Minor basaltic centers and seamounts omitted.

G221.001

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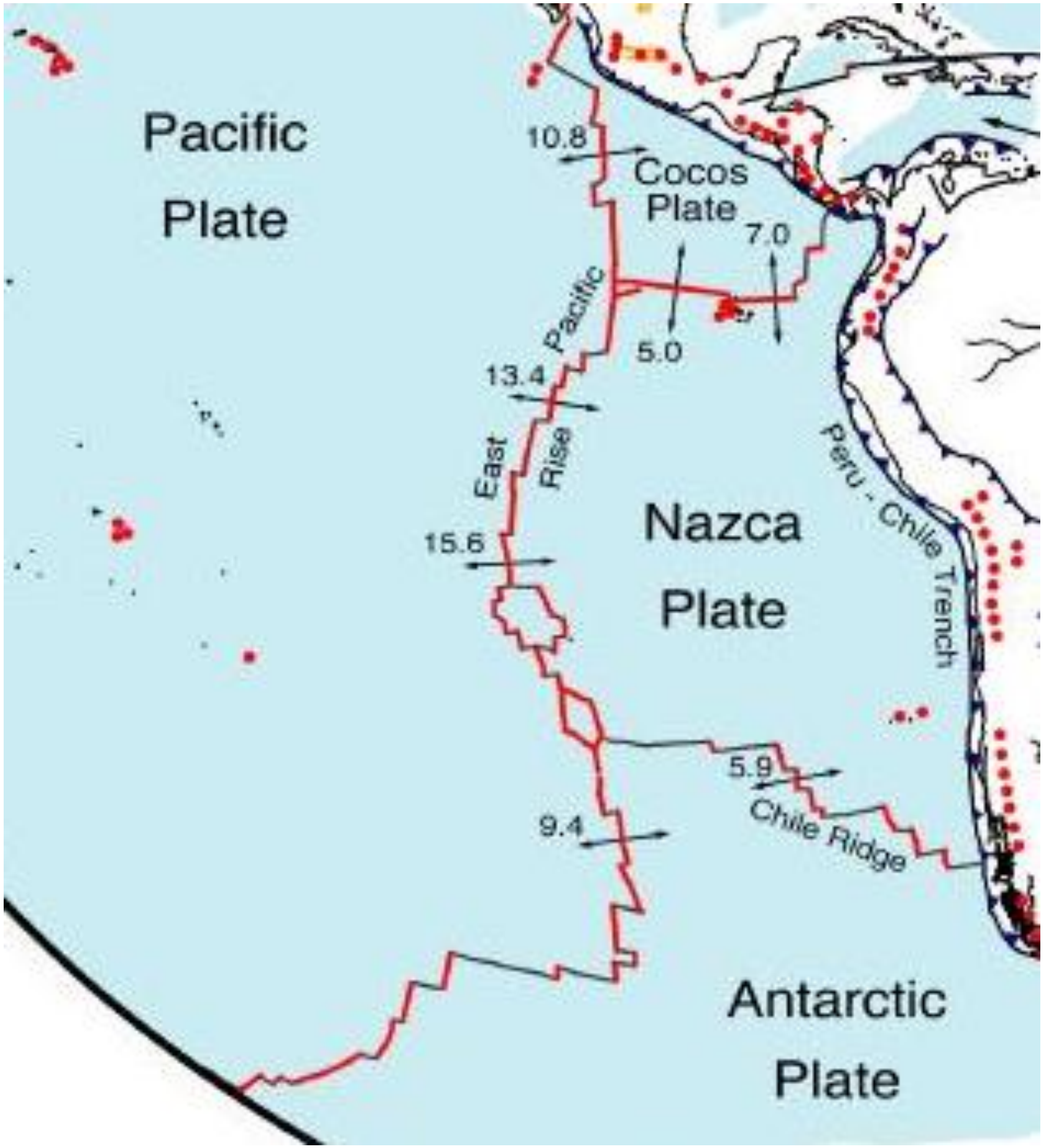
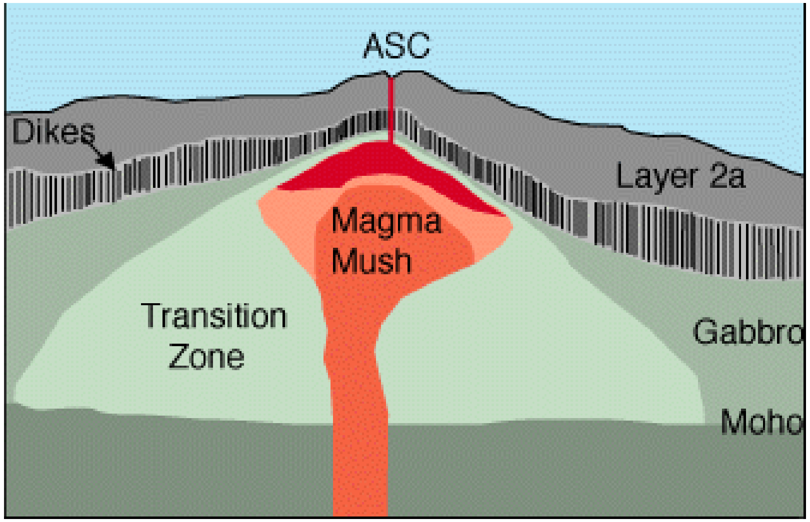
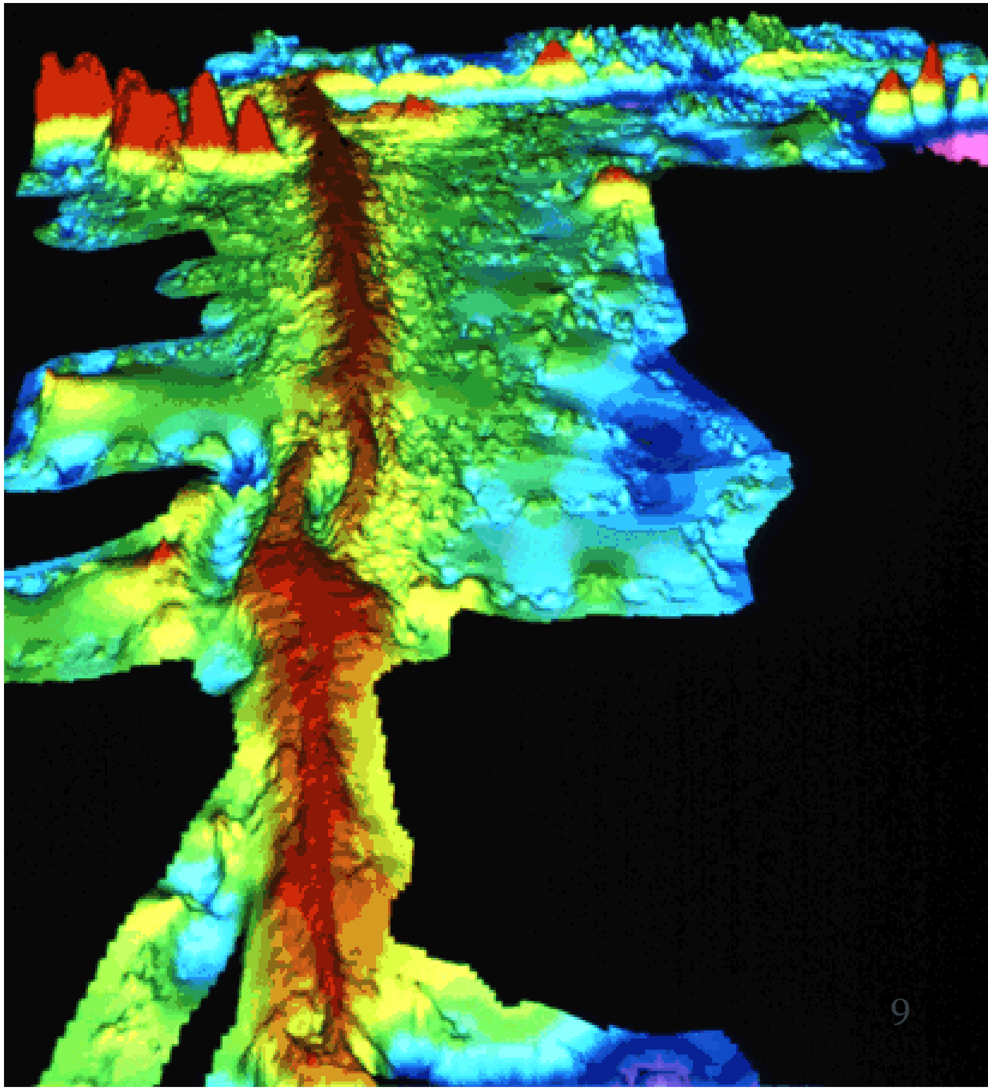


Schematic cross section through the East Pacific Rise



ASC = Axial Summit Caldera



High temperature fluid expulsion at seafloor

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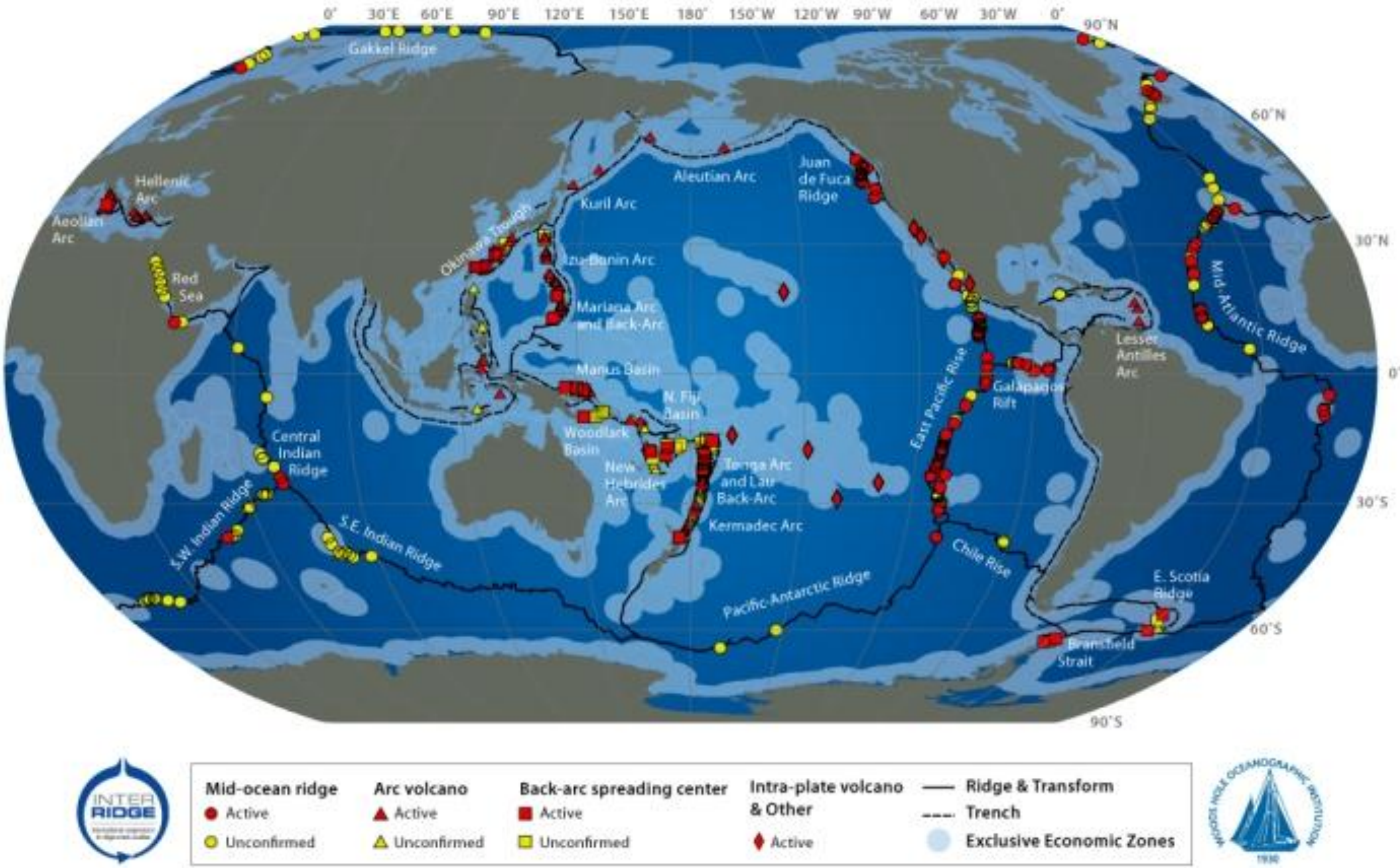
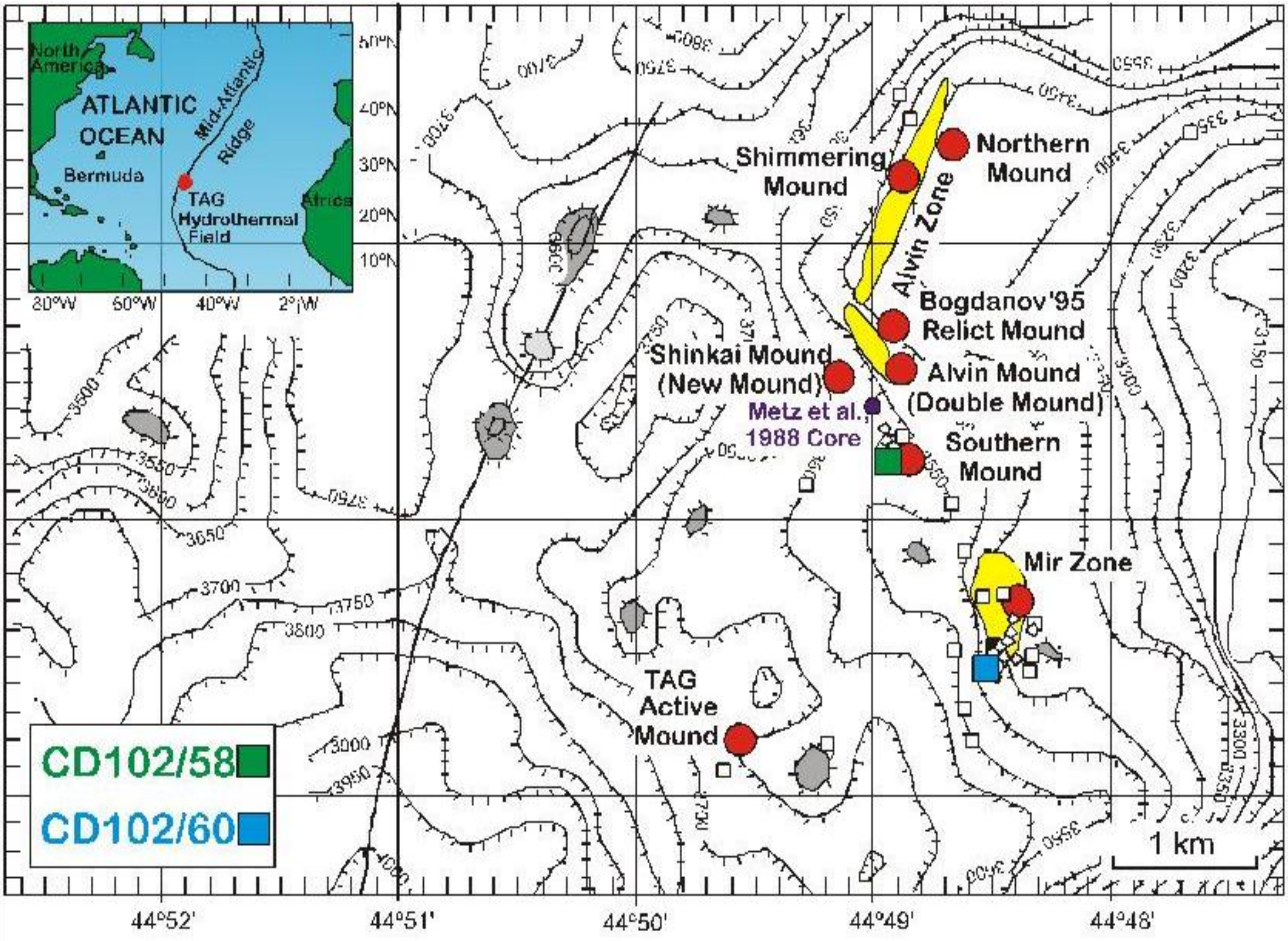
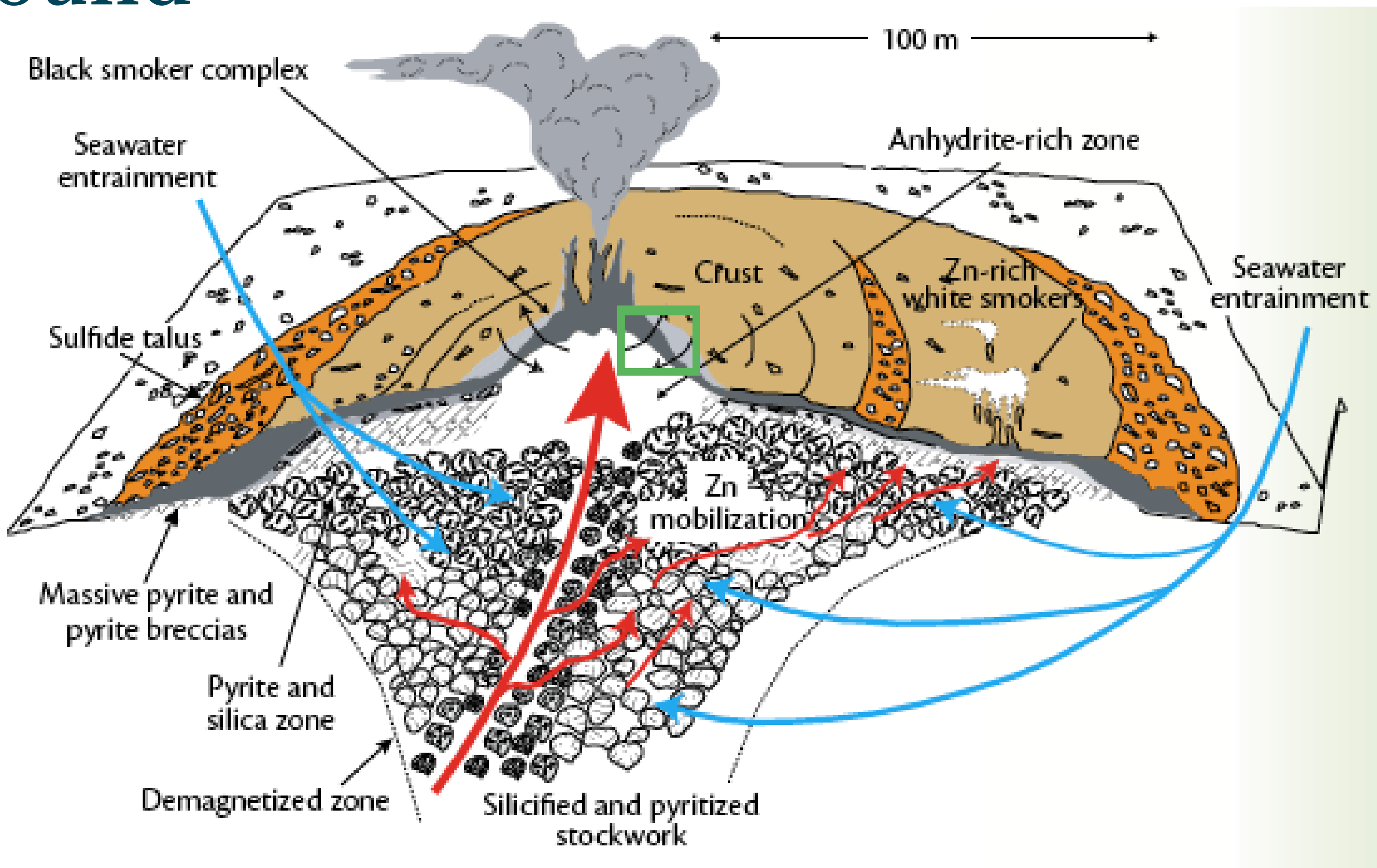
Global Distribution of Hydrothermal Vent Fields



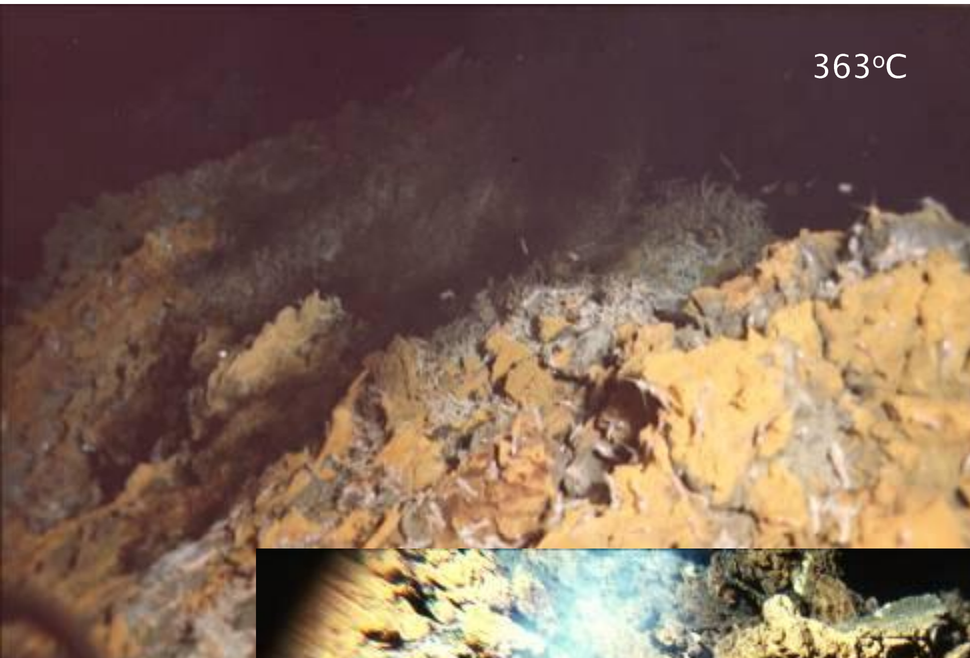

North America
ATLANTIC OCEAN
Mid-Atlantic Ridge
Bermuda
TAG Hydrothermal Field
Africa
50°N
40°N
30°N
20°N
10°N
80°W
60°W
40°W
Shimmering Mound
Northern Mound
Alvin Zone
Bogdanov'95 Relict Mound
Shinkai Mound (New Mound)
Alvin Mound (Double Mound)
Metz et al., 1988 Core
Southern Mound
Mir Zone
TAG Active Mound
CD102/58
CD102/60
1 km
26°10'
26°09'
26°08'
44°52'
44°51'
44°50'
44°49'
44°48'

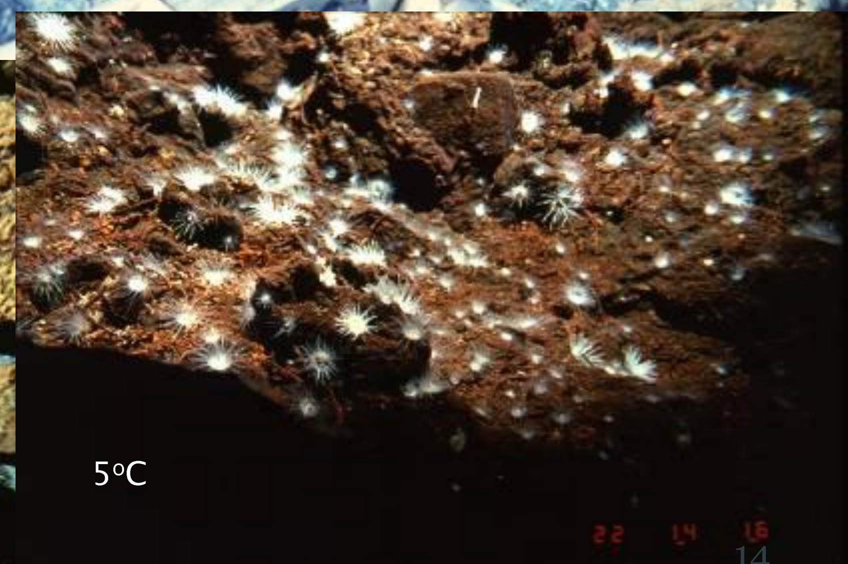
Anatomy of an active hydrothermal mound



Tivey, 2008, adapted from Humphris et al., 1995

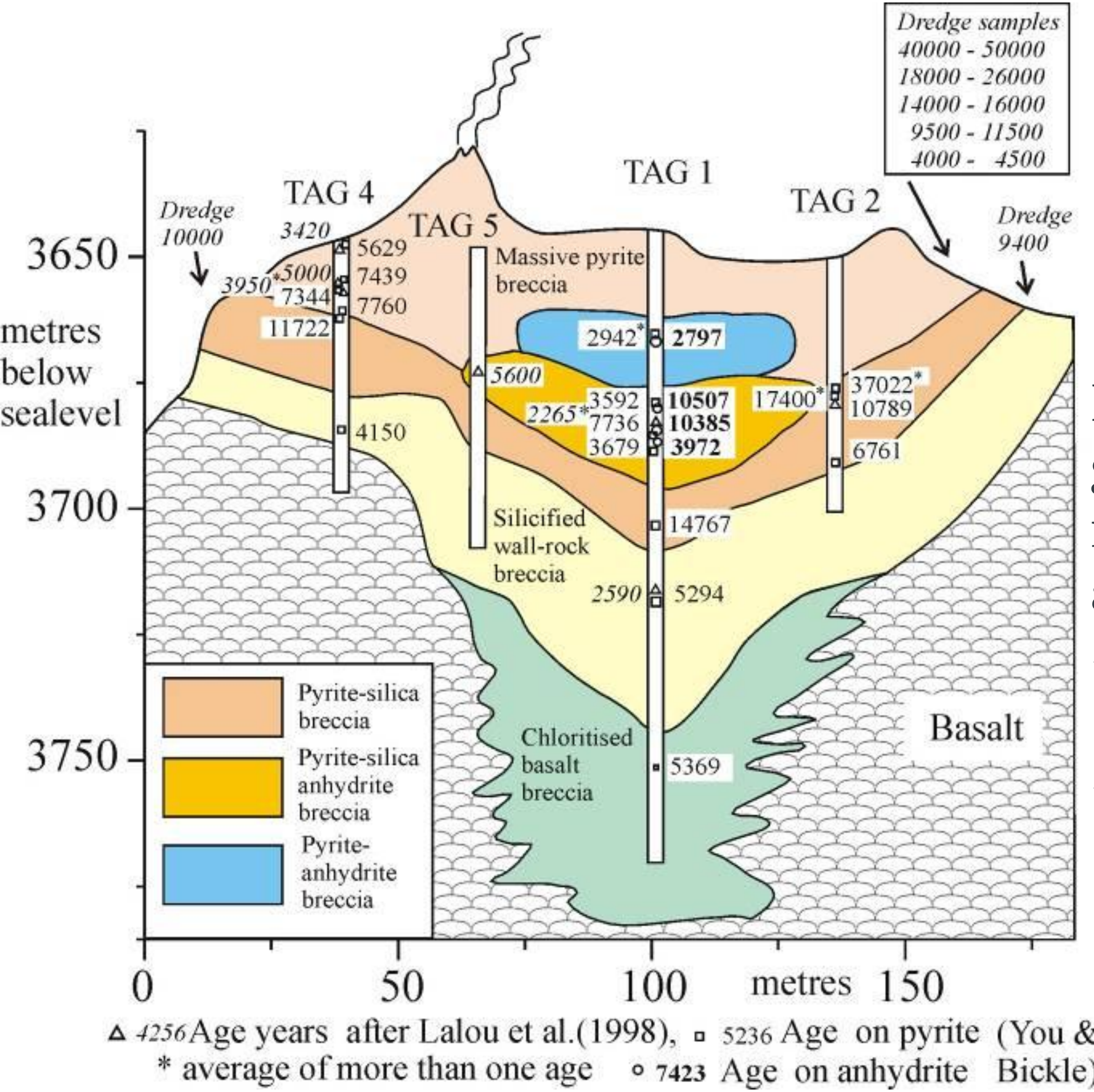
Fluid flow out of an active hydrothermal deposit





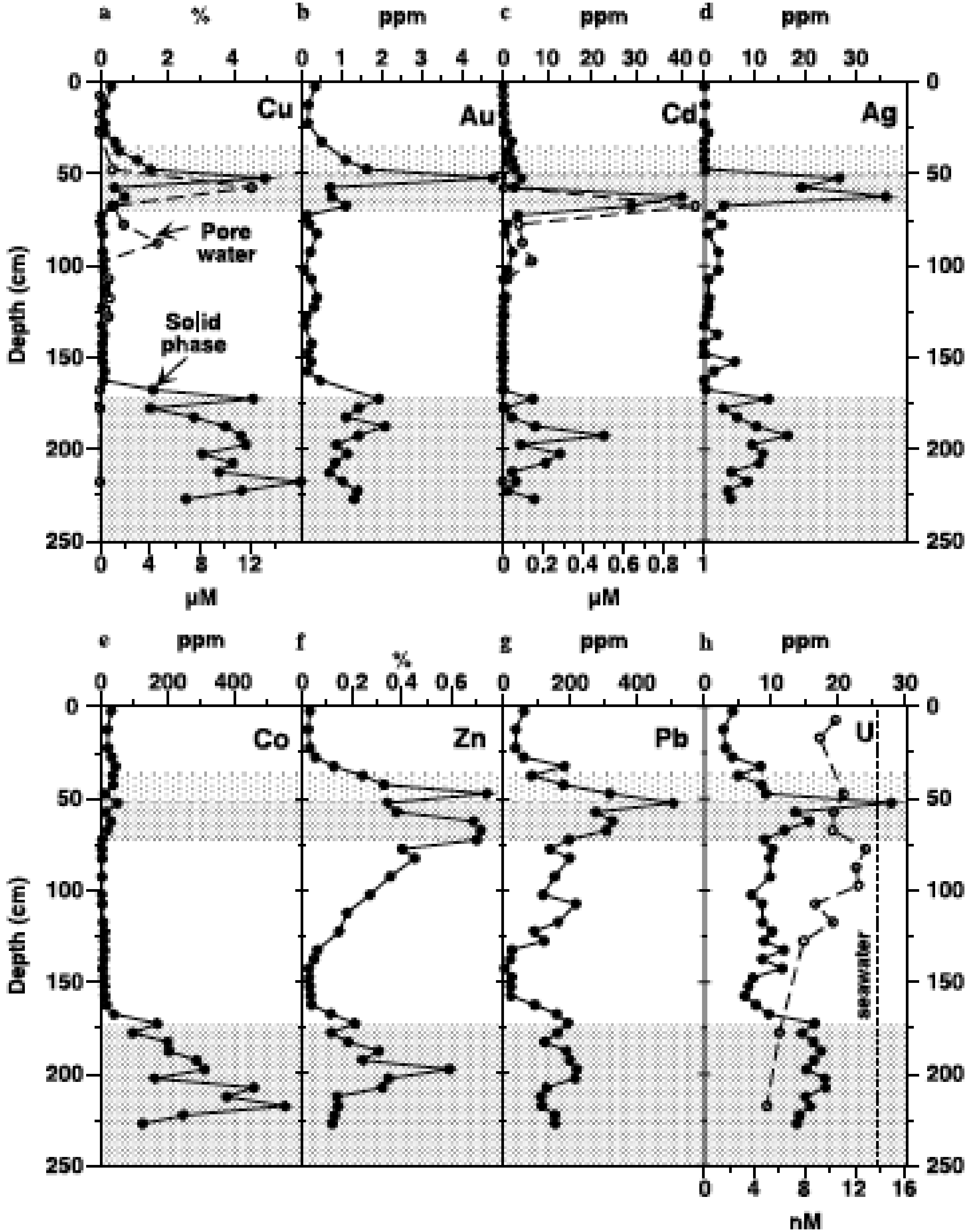
Photos: WHOI and NOCS

How fast do deposits form?



Episodic mound growth, oxidation, reworking of sulfide and anhydrite over ~10 000 years

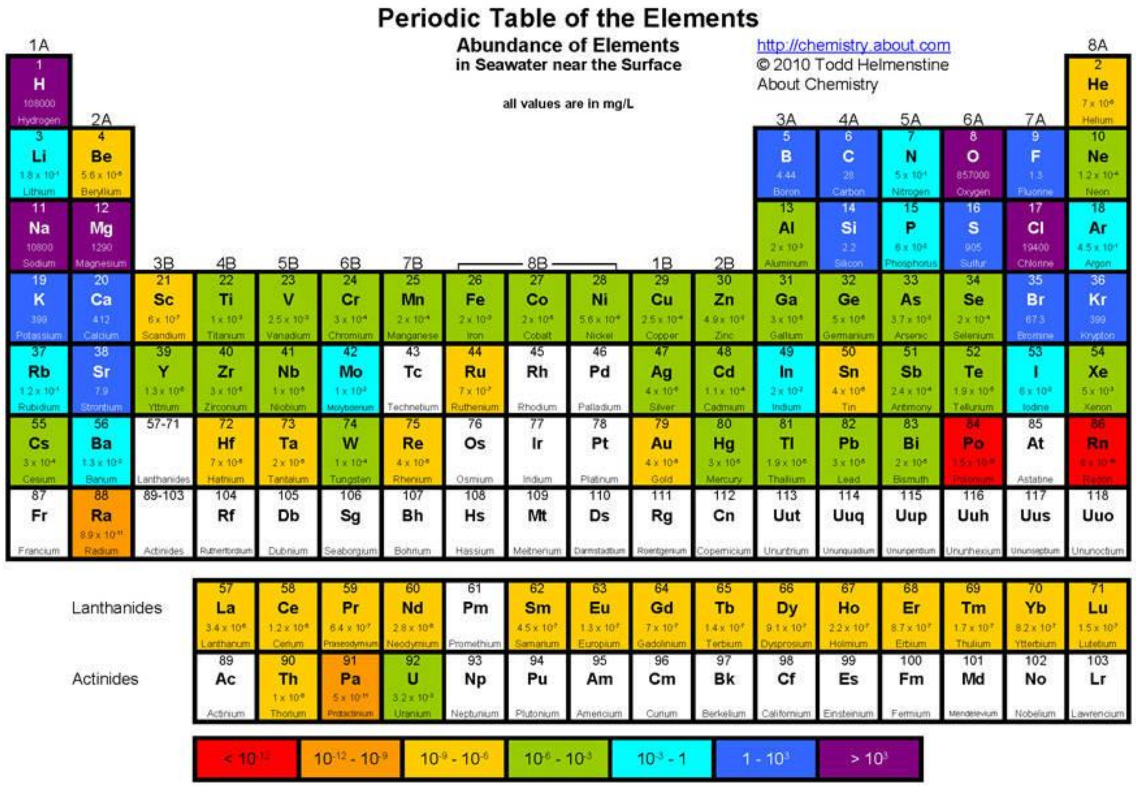
~ 5 Mtonnes sulfide



High grade metal enrichment (several parts per million to %) indicates significant redox recycling and secondary mineralisation over thousands of years

Severmann et al., 2006

Seawater and the Rare Earth Elements (Lanthanides)

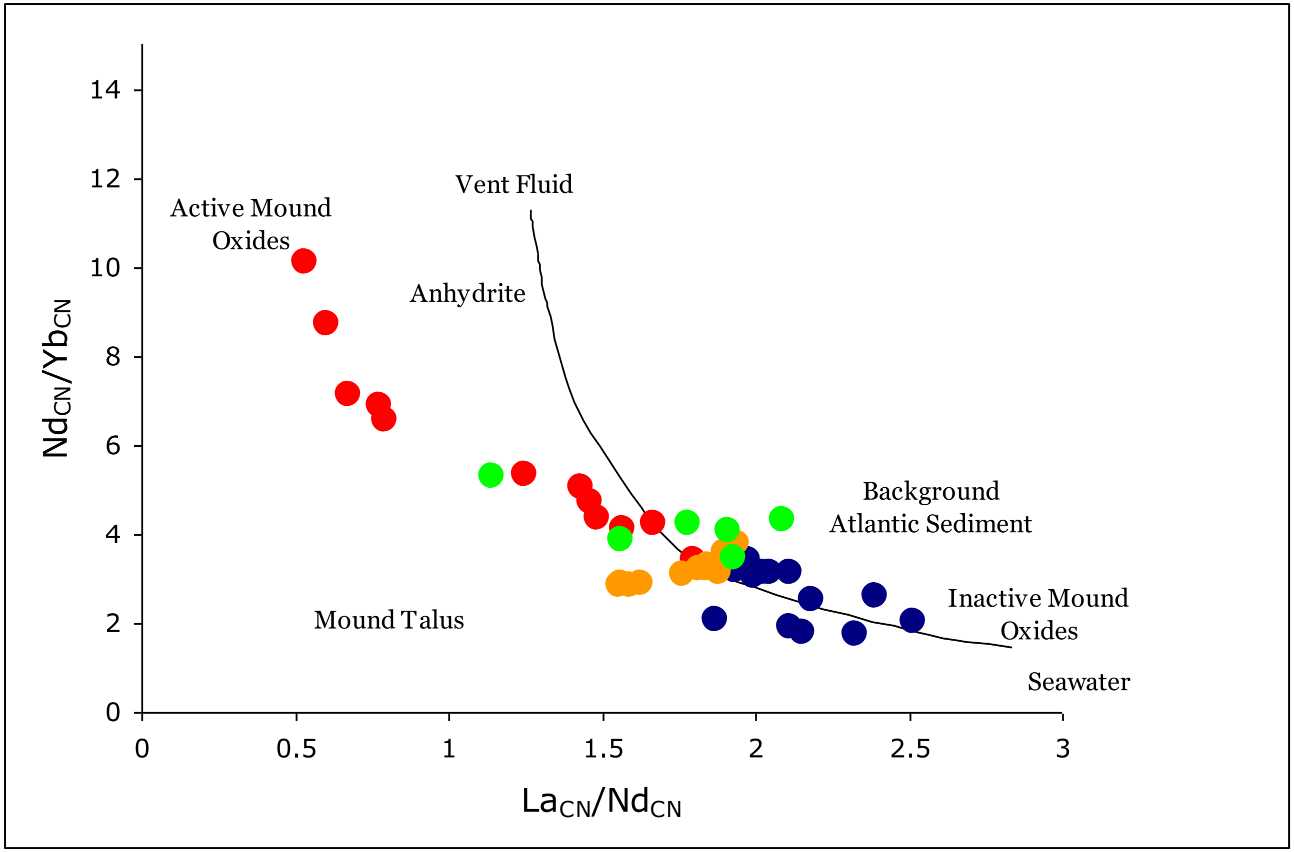


http://chemistry.about.com

Rare Earth Elements (REE)

- Relatively abundant (~ppm) in crust but dispersed widely
- Global commercial reserves of REE, particularly the heavy REE are diminishing rapidly
- Global requirement (120 000 tonnes yr^{-1}) exceeds current supply
- Very low abundance in seawater (~10^{-7} ppm)
- Forming minerals from seawater fractionates and concentrates the REE

REE fractionation in hydrothermal minerals



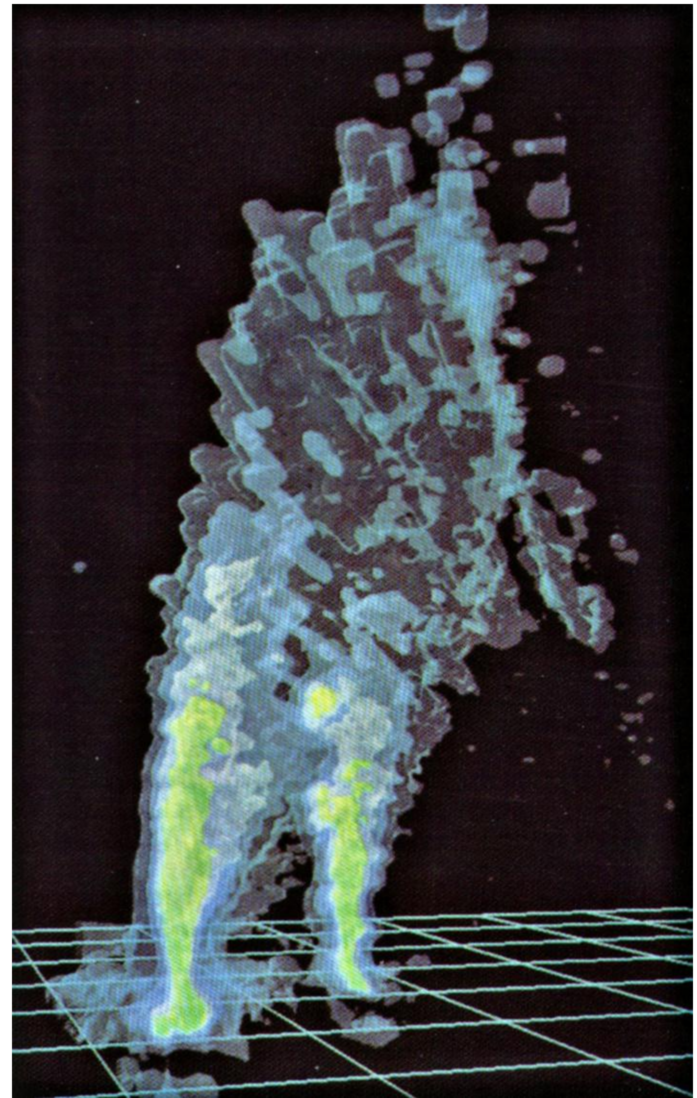
Data from Mitra et al., 1990; German et al., 1993; Mills and Elderfield, 1995; Humphris, 1998; Goulding et al., 1998; Severmann et al., 2004; Mueller et al., 2009

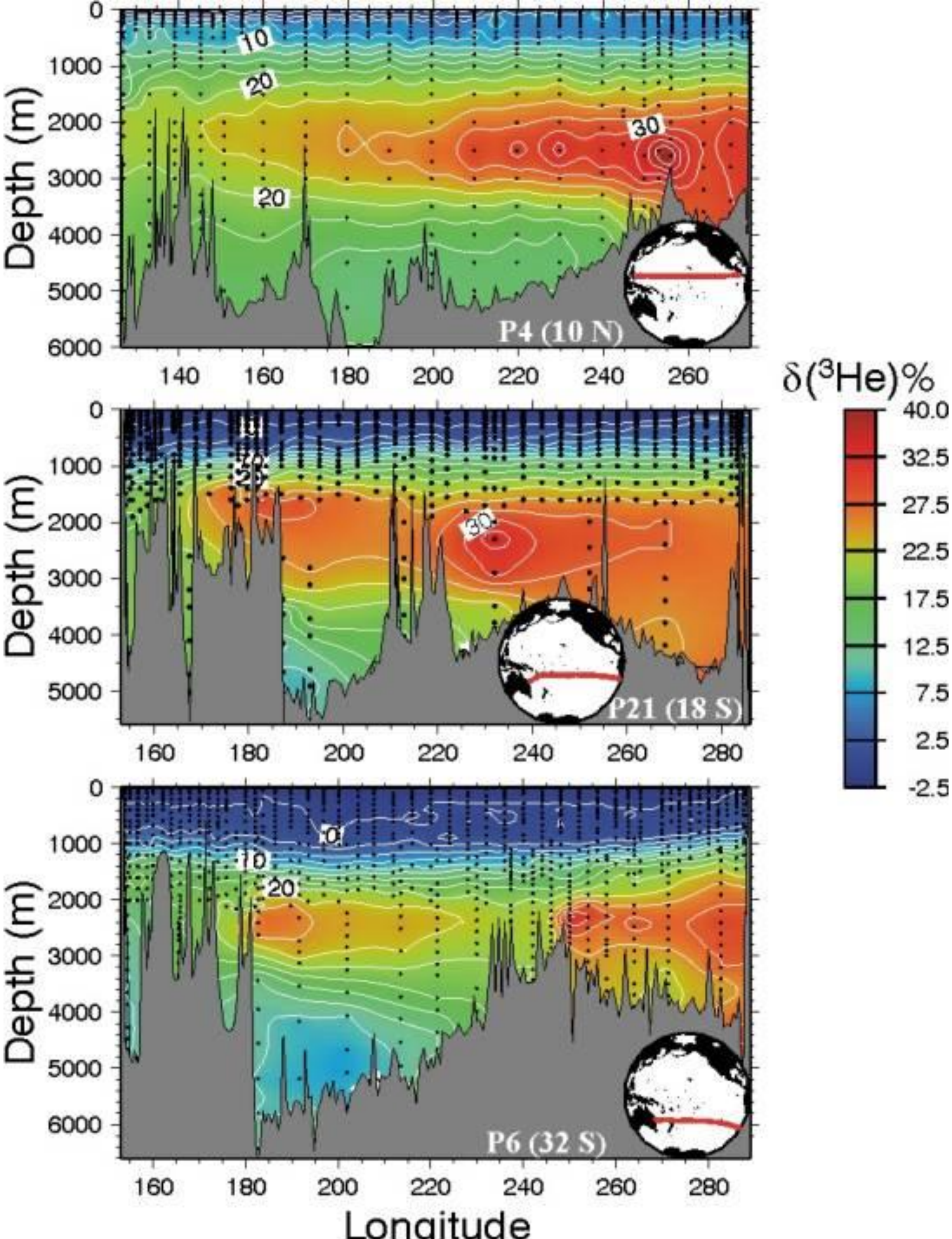
Hydrothermal plumes

- Vent fluid mixes rapidly with seawater and is dispersed through the ocean basin as a plume of particles

- Whole ocean is cycled through global plume system in ~10 000 yrs

- Plumes particles scavenge REE from seawater





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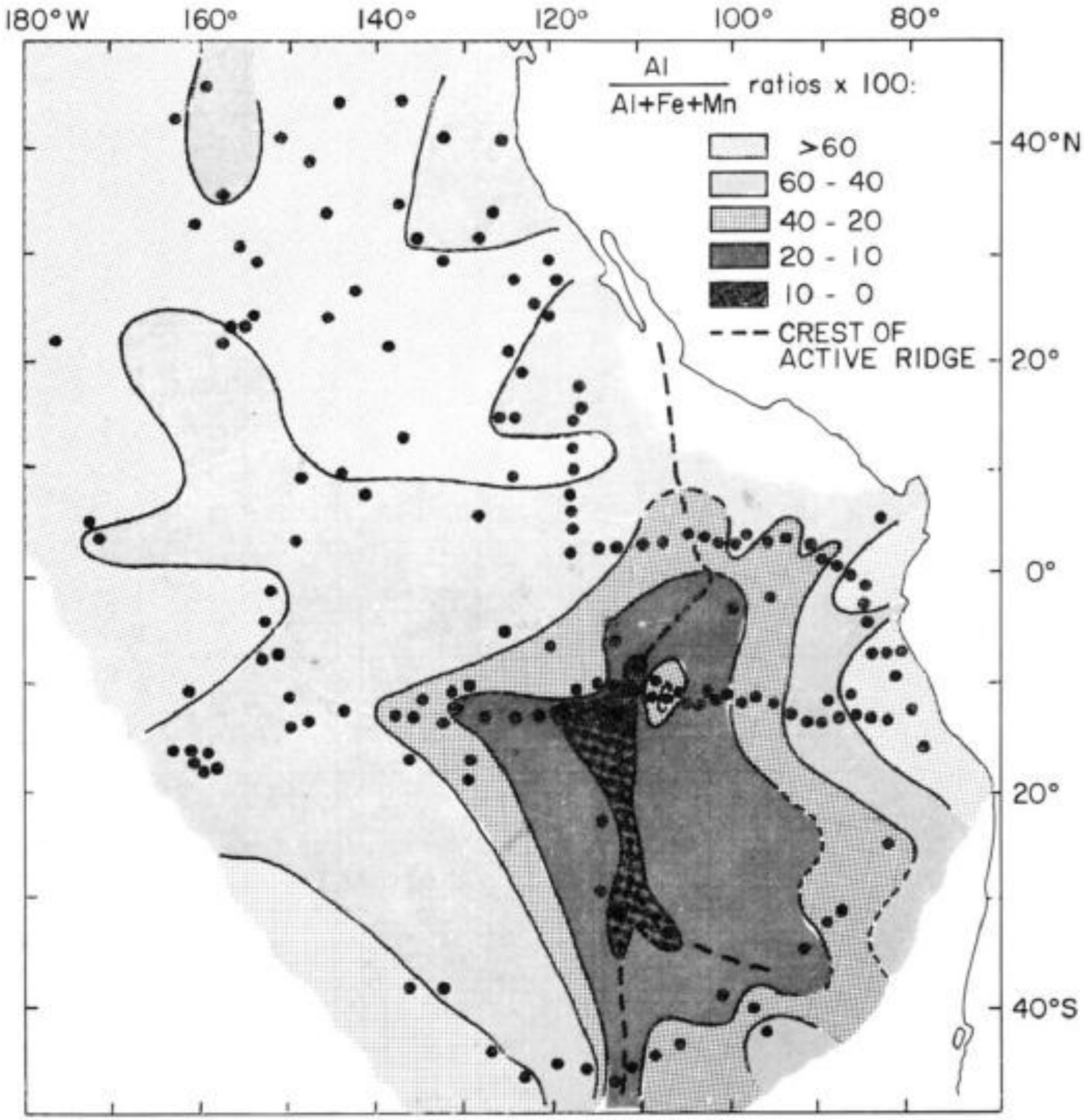
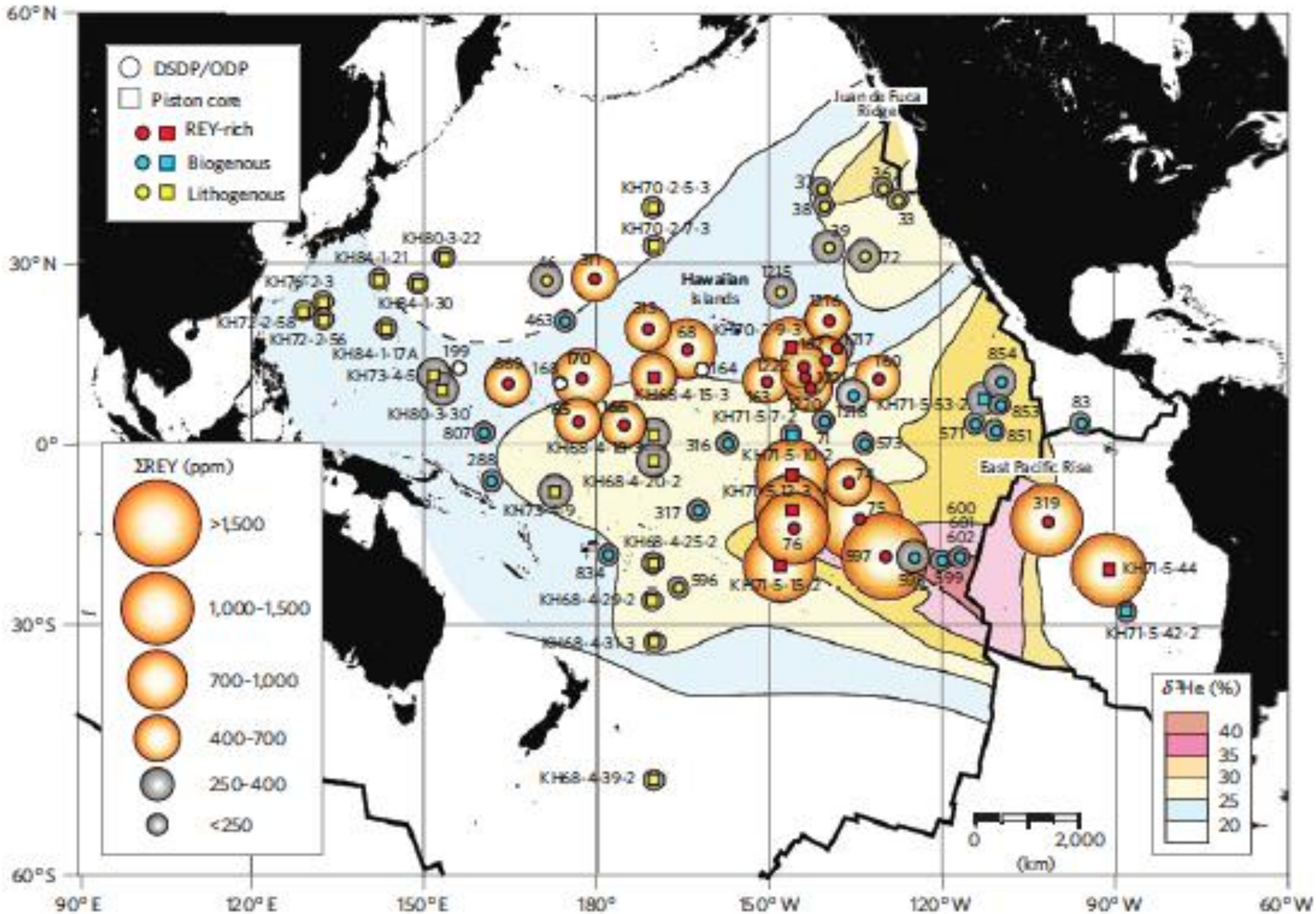
Inert tracer shows that hydrothermal plumes are dispersed right across ocean basins

Metalliferous sediments



Plume particles settle to sea floor and form metalliferous sediments over ~Ma (million years)

Bostrom and Peterson, 1969



Kato et al., 2011

REE resources in metalliferous sediments

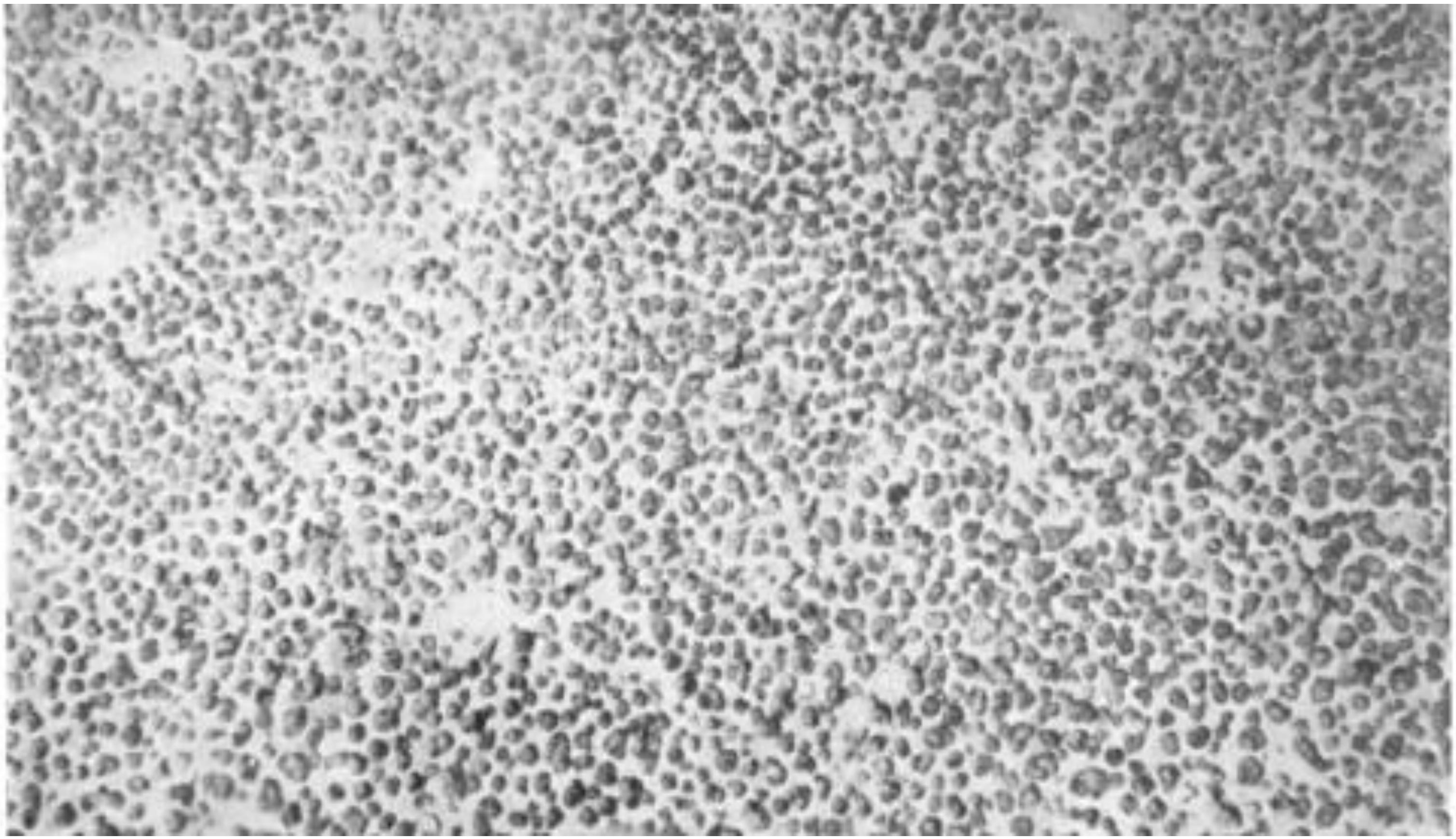
- 1 – 5 km^2 area of Pacific sediment, 10-70 m thick would supply significant proportion of the global REE demand

- REEs could be recovered through simple acid leaching of the sediment

BUT……

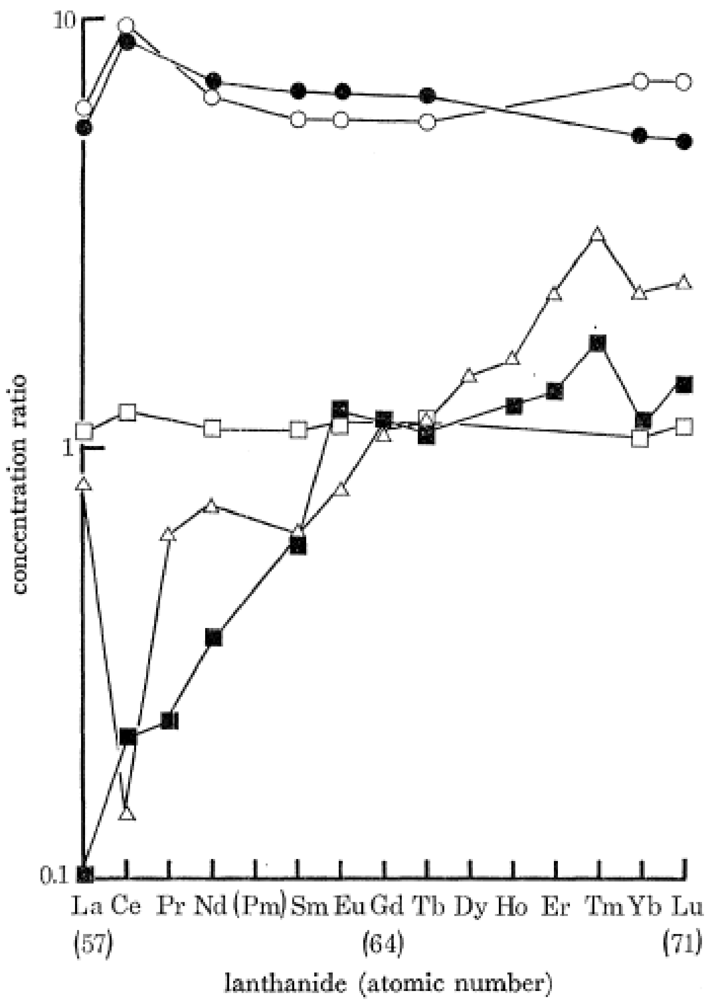
- Detailed mapping of the resource required and there are significant logistical issues around deep sea mining

Manganese nodules cover the Pacific seafloor at 4-6 km depth □



2-5 cm diameter; 10-40 kg m^{-2}□ *Calvert and Cronan, 1978*

REE in Mn nodules



Mn nodules

Seawater x 10^7

Pelagic clay

Calvert and Cronan, 1978

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Mn nodule accumulation rates

- Mn nodules grow at mm Ma^{-1}
- Enriched in Mn, Fe, Cu, Ni, Co and REE
- Deep sea sediments accumulate at m Ma^{-1}
- How do the nodules remain at the sediment surface?
- Are growth rates underestimated? Are accumulation rates variable? Do burrowing organisms move nodules to the surface? Do bottom currents winnow the sediments?

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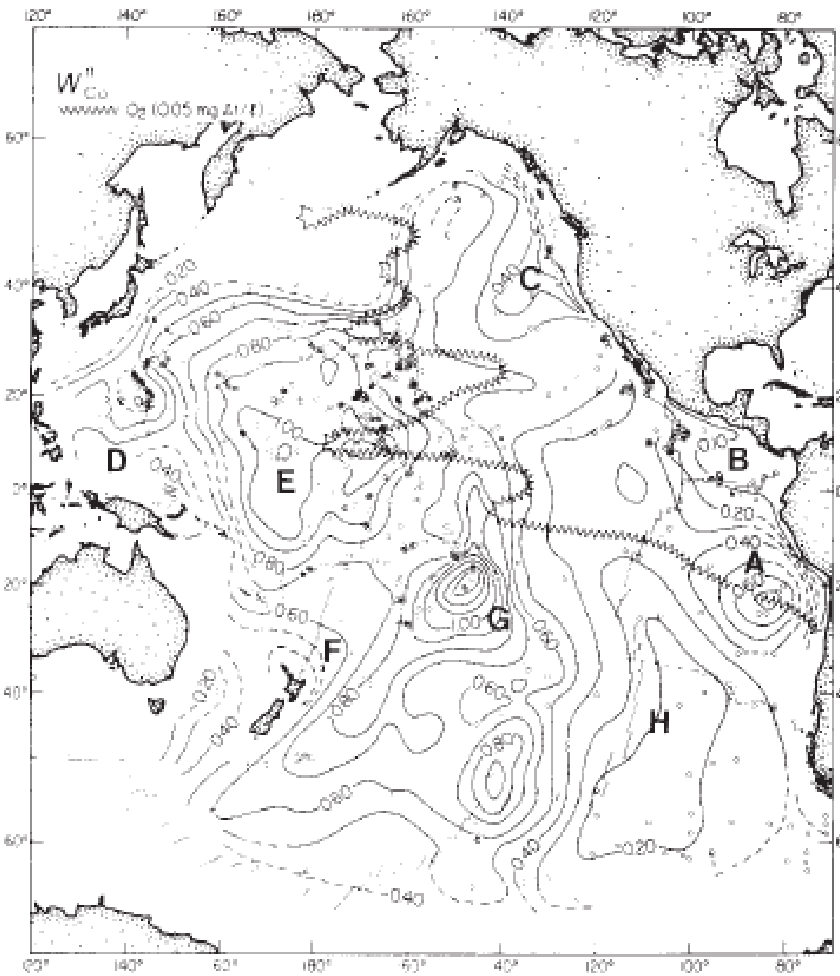
Cobalt in Mn crusts



Mn crusts accumulate on hard substrates exposed on seafloor

Co content negatively correlates with growth rate

High Co accumulation = very slow crust growth

Co chronometer provides crust growth rates

Manheim and Lane-Bostwick, 1988

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Are deep sea mineral deposits a viable resource?

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Deep sea mineral resources

- Nautilus Minerals Inc are developing a production system to extract copper and gold from a relict hydrothermal deposit offshore Papua New Guinea in ~1550m water depth
- The extreme depths and location in International Waters mean that mining of Mn nodules, crusts and REE enriched sediments is logistically extremely challenging and unlikely to be developed in the next few decades

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Summary

- Seafloor hydrothermal deposits can be substantial in size (several million tonnes of sulfide)
- Low temperature alteration of deposits generates significant metal enrichment (up to high grade ore)
- Hydrothermal plumes are rich in iron oxides that scavenge metals out of seawater and deposit them at the seafloor (significant deposits of REE)
- At extremely low sediment accumulation rates, minerals form at the seafloor with large metal enrichment (Mn nodules and crusts)

Find out more:

- http://www.noc.soton.ac.uk/chess/
- http://www.whoi.edu/workshops/deepseamining/
- Kato, Y. et al, Deep-sea mud in the Pacific Ocean as a potential resource for rare-earth elements, Nature Geoscience, doi: 10.1038/NGEO1185.
- http://www.nautilusminerals.com/s/Home.asp
- http://www.geotraces.org

Questions?