Session 10-11: HISTORICAL & CURRENT MARINE OPERATIONS; HYDROTHERMAL MANGANESE DEPOSITS

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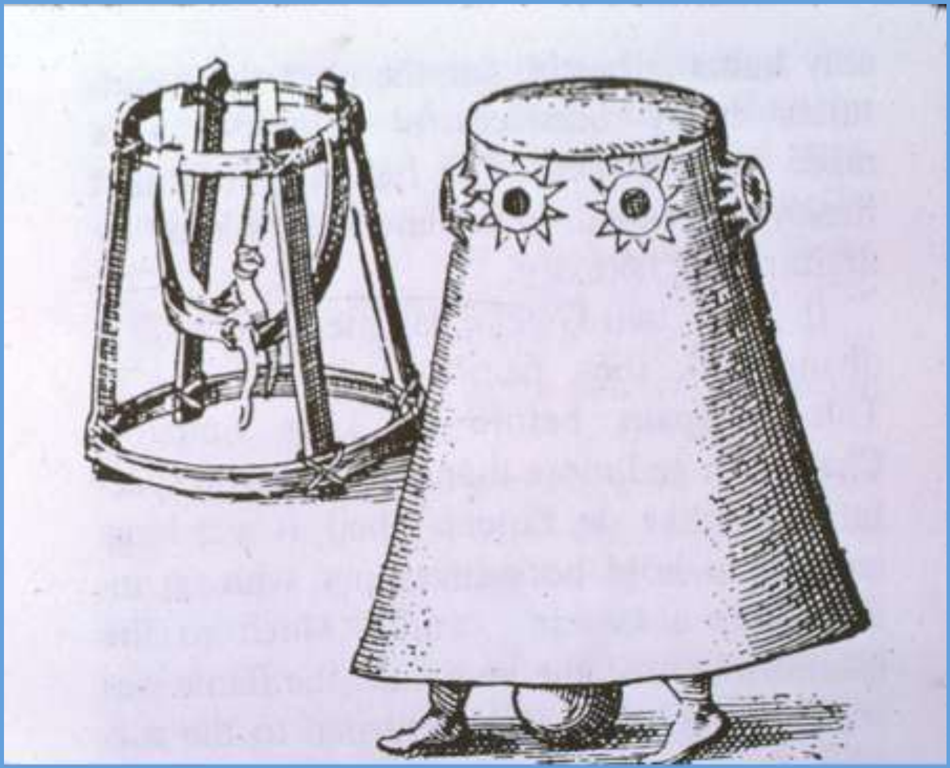
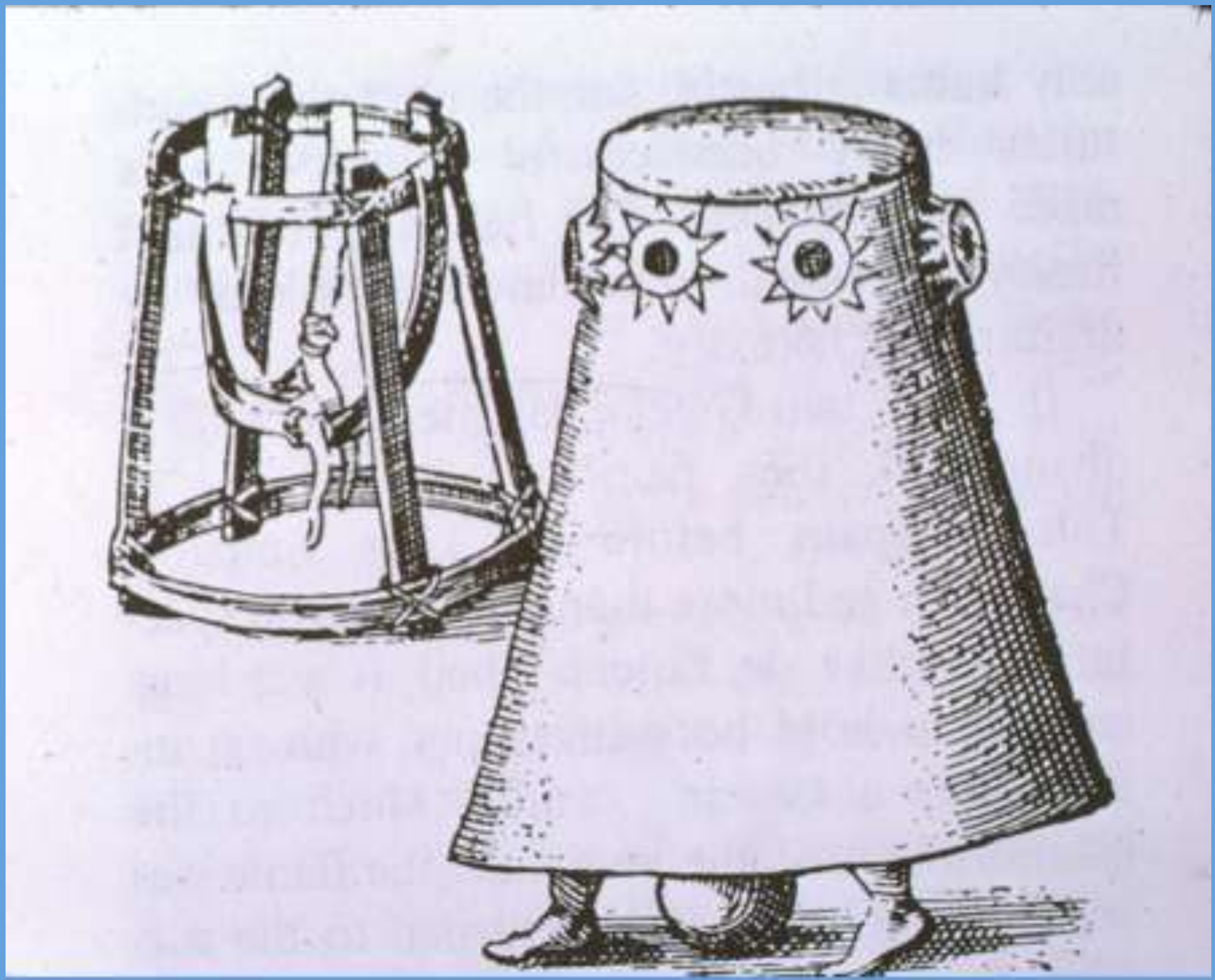


SPC-EU EDF10 Deep Sea Minerals (DSM) Project: ***Regional Training Workshop on Geological, Technological, Biological and Environmental Aspects of Deep Sea Minerals***

Nadi Fiji 13-17 August 2012



1616 German, Fran2, Kessler-Diving Bell
With no connection to the surface

Historical Marine Mining Activities

- Oil and gas production
- Placer near-shore deposits: Sn, Ti, Au, Zr, REEs
- Placer diamond mining: Namibia, S. Africa
- Sand, Gravel, and Limestone (Reef) Mining (aggregate): UK and Japan

Future Energy

- Gas Hydrates (Methane) Production

Land-based and marine placer deposits

SE Asia Placer Deposits

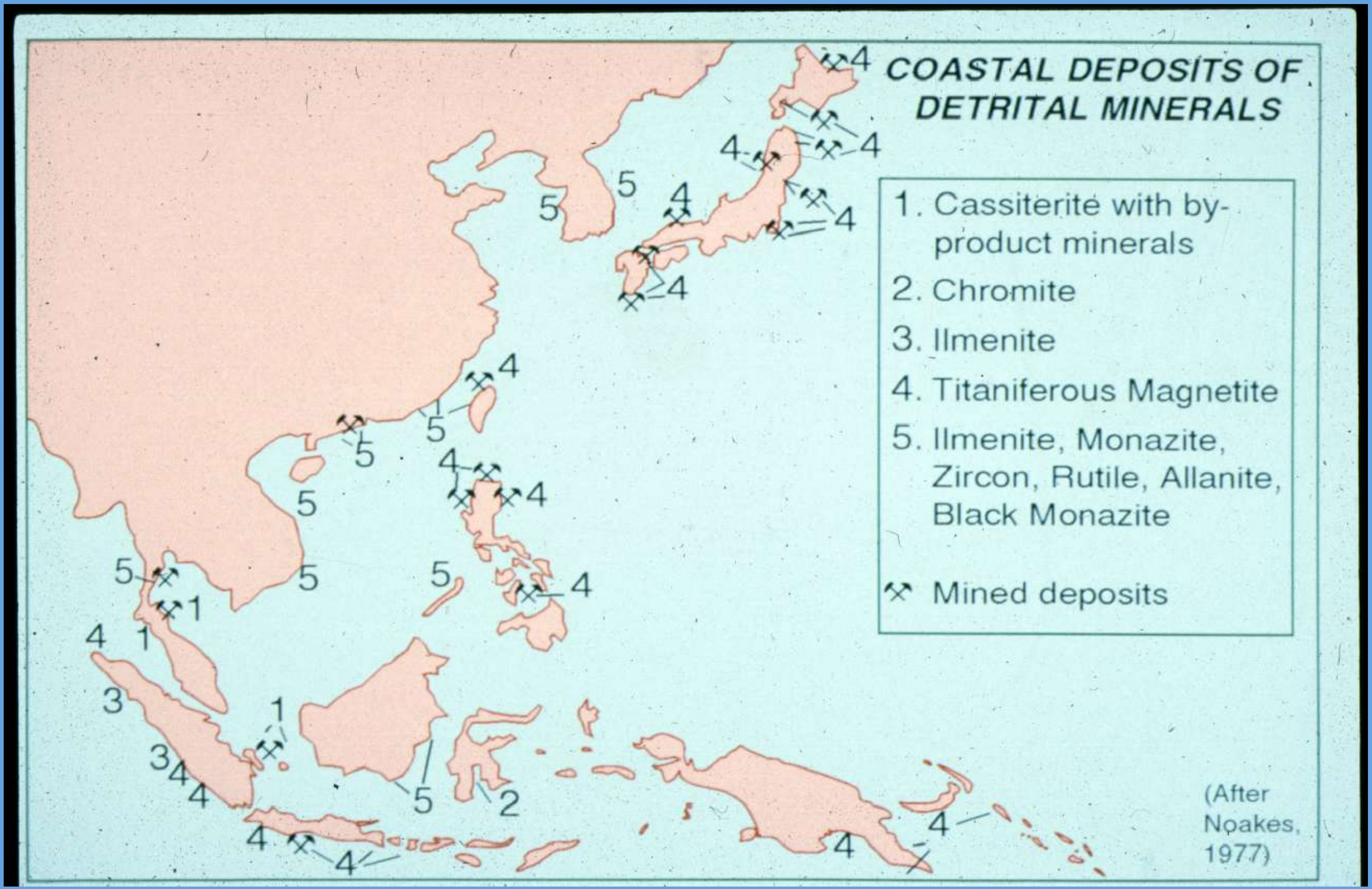
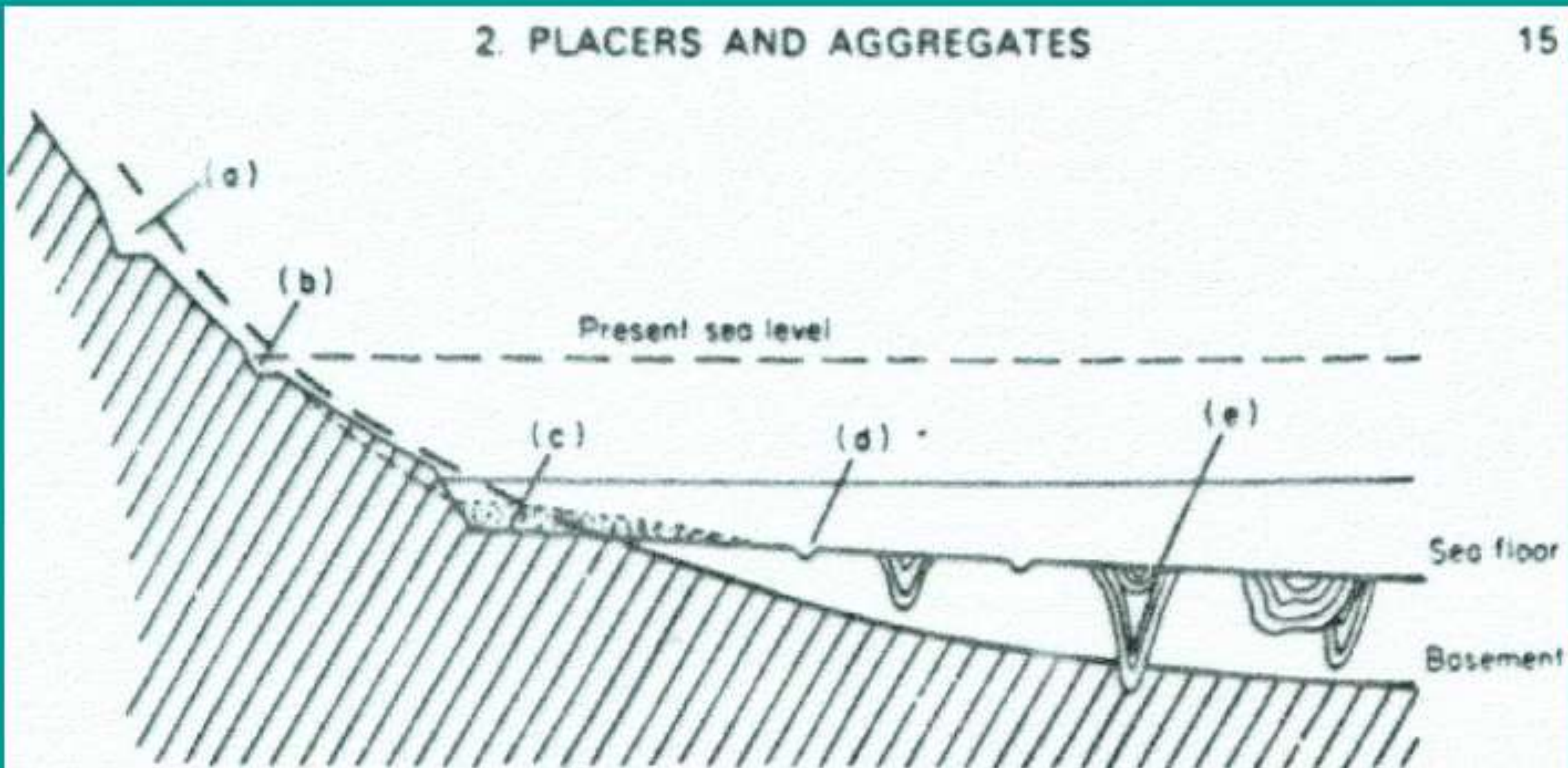


Table P1 Principal placer minerals and their composition (from Cronan, 1992)

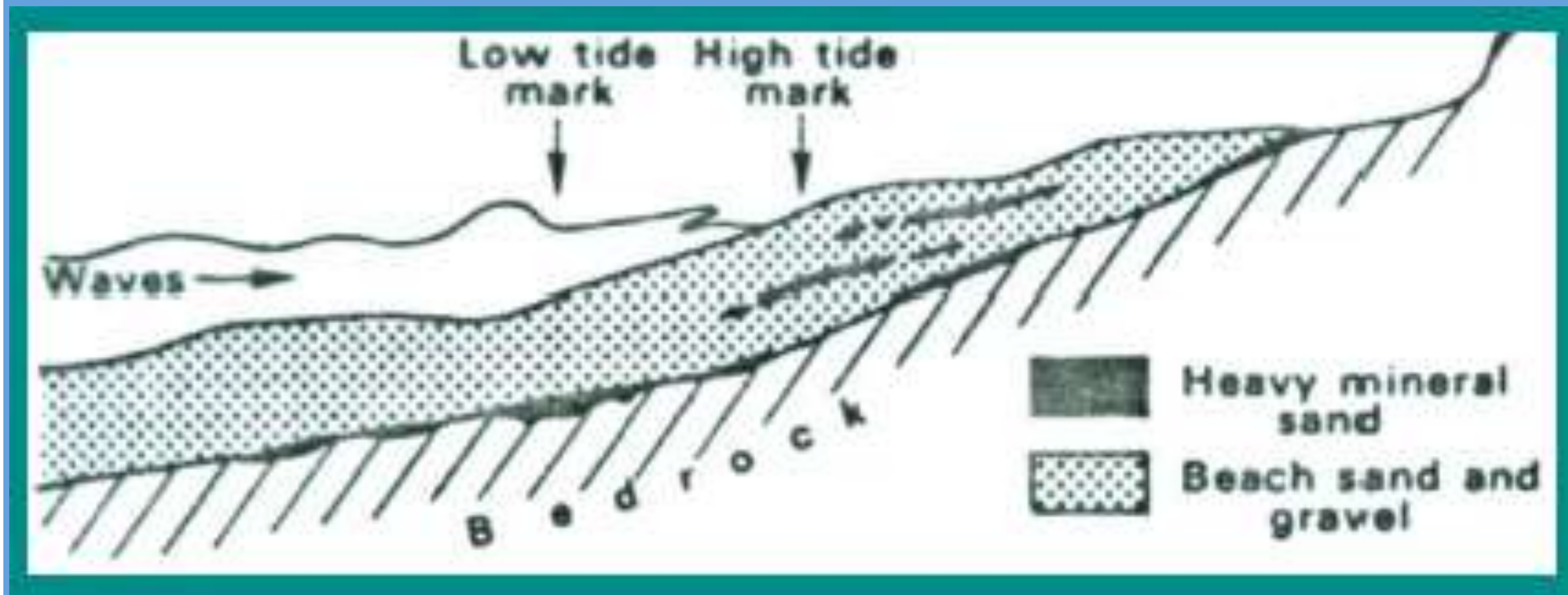
	Specific gravity
Gems	
Diamond	3.5
Garnet	3.5–4.27
Ruby	3.9–4.1
Emerald	3.9–4.1
Topaz	3.4–3.6
Heavy noble metals	
Gold	20
Platinum	21.5
Light heavy minerals	
Beryl	2.75–2.8
Corundum	3.9–4.1
Rutile	4.2
Zircon	4.7
Chromite	4.5–4.8
Ilmenite	4.5–5.0
Magnetite	5.18
Monazite	5.27
Scheelite	5.9–6.1
Heavy heavy minerals	
Cassiterite	6.8–7.1
Columbite, Tantalite	5.2–7.9
Cinnabar	8–10

Beach placer deposit of heavy minerals (dark) in a quartz sand (Chennai, India)

Environments of Possible Placer Mineral Occurrence



Cronan (1980)


Low tide
mark
High tide
mark
Waves
Bedrock
Heavy mineral
sand
Beach sand and
gravel

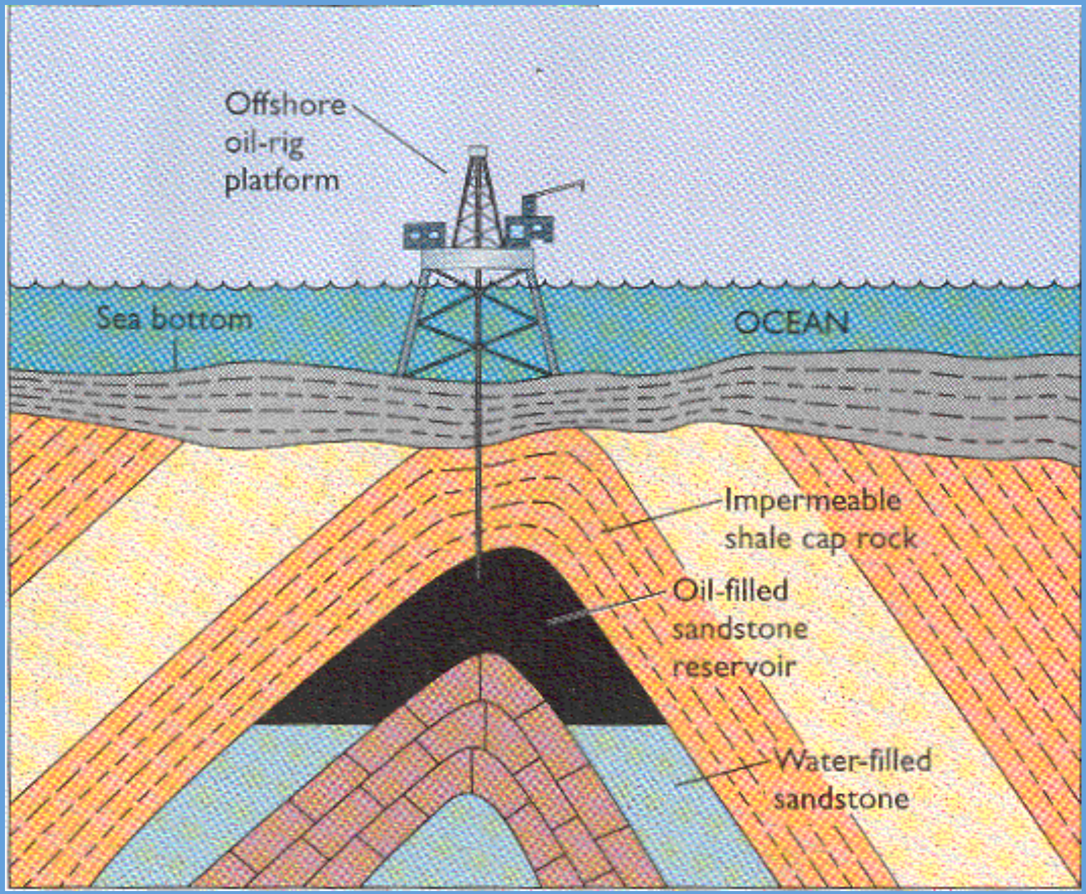
Oil and Gas Production Example

Petroleum (oil and gas) is a hydrocarbon derived from heating of organic matter in sedimentary rocks that were deposited in productive regions with anoxic or low-oxygen bottom waters

1. **Deep burial resulting in high temperature and moderate pressure converted the organic remains into hydrocarbons**
   - Initially get oil (liquid window) but at higher temperatures and pressures, methane (CH_4) and other natural gases are generated; and at lower temperatures tar is produced

2. Pressure forces the oil and gas from the source rock into water-filled porous and permeable strata above = the reservoir rock.

3. Because oil and gas are less dense than water, they migrate up until their path was blocked by an impermeable layer.

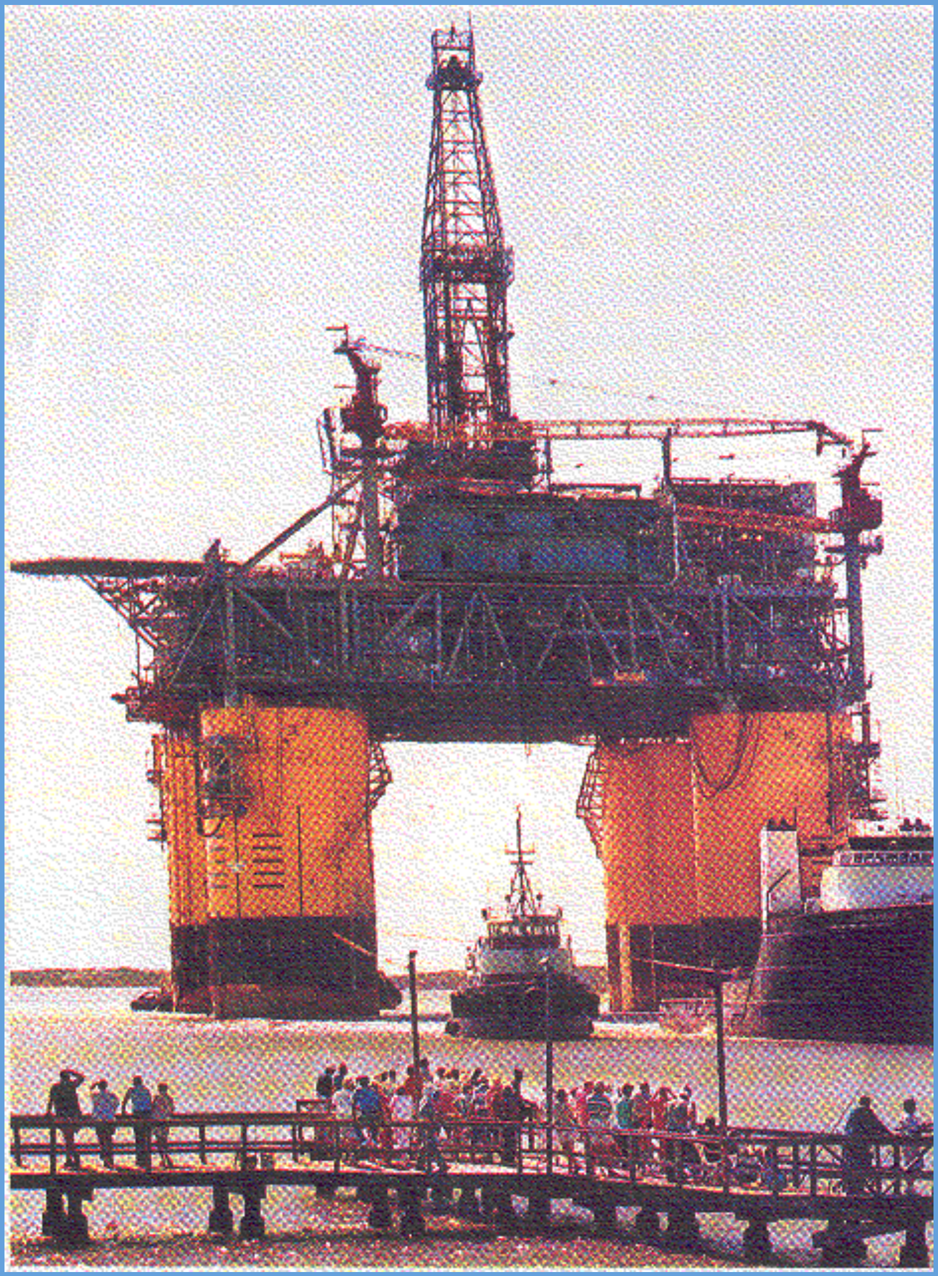


4. Oil and gas accumulate, forming a large deposit within the pores of the rock, usually sandstone.

5. Only in the last 45 years has technology been able to efficiently extract petroleum from beneath the seas

6. Location of possible accumulations of oil and gas can be determined using seismic reflection and refraction methods to determine the configuration of rock layers.

6. Advances in drilling technology have allowed oil companies to explore in deeper offshore environments, 2000 m



Issues with Oil and Gas Production

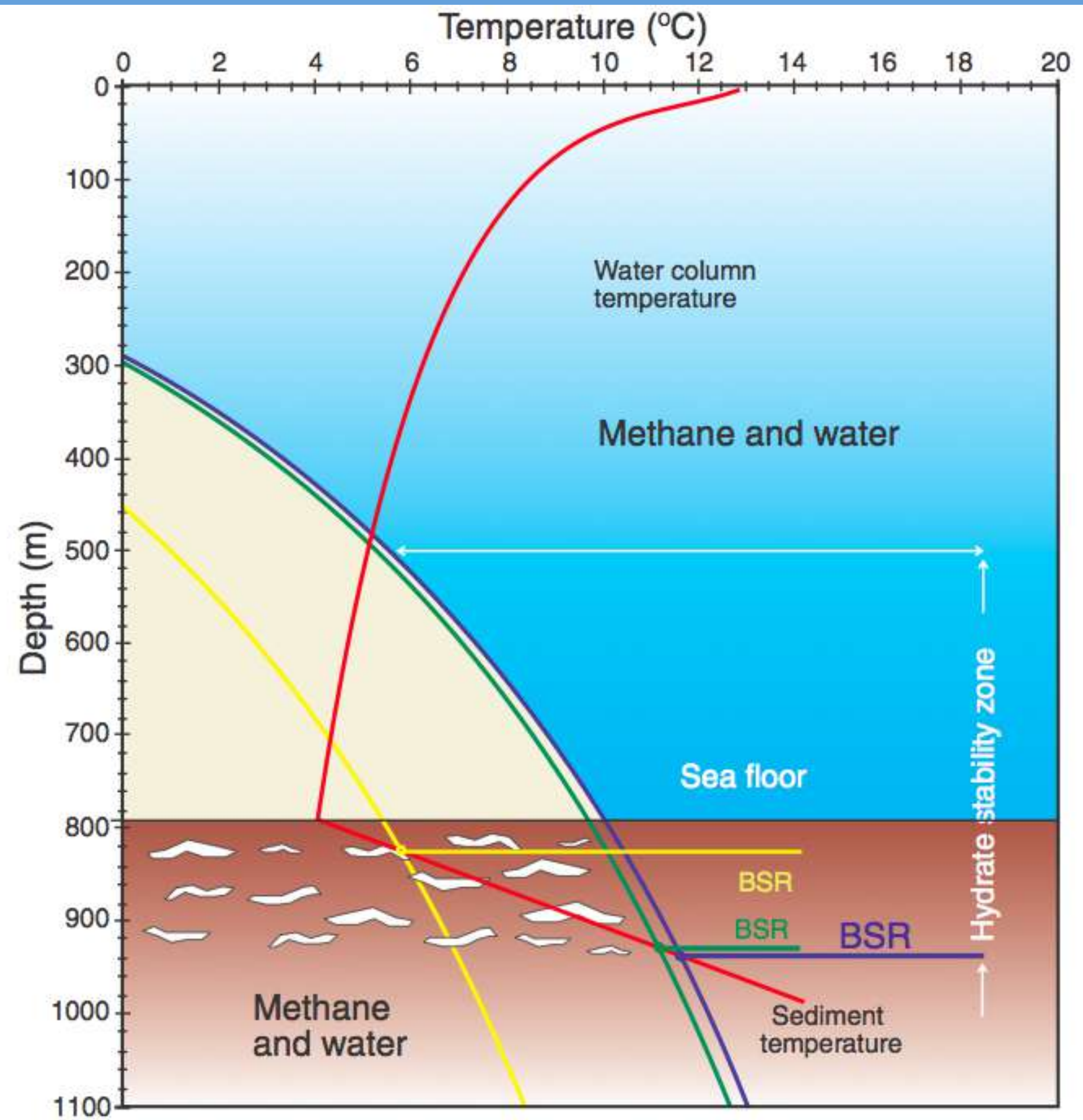
- Petroleum Resources are not unlimited--reliance of global economy on petroleum production is not a sound way forward and has significant environmental consequences.

- Frequent Oil spills from tankers and platforms damage marine and coastal ecosystems and other coastal resources

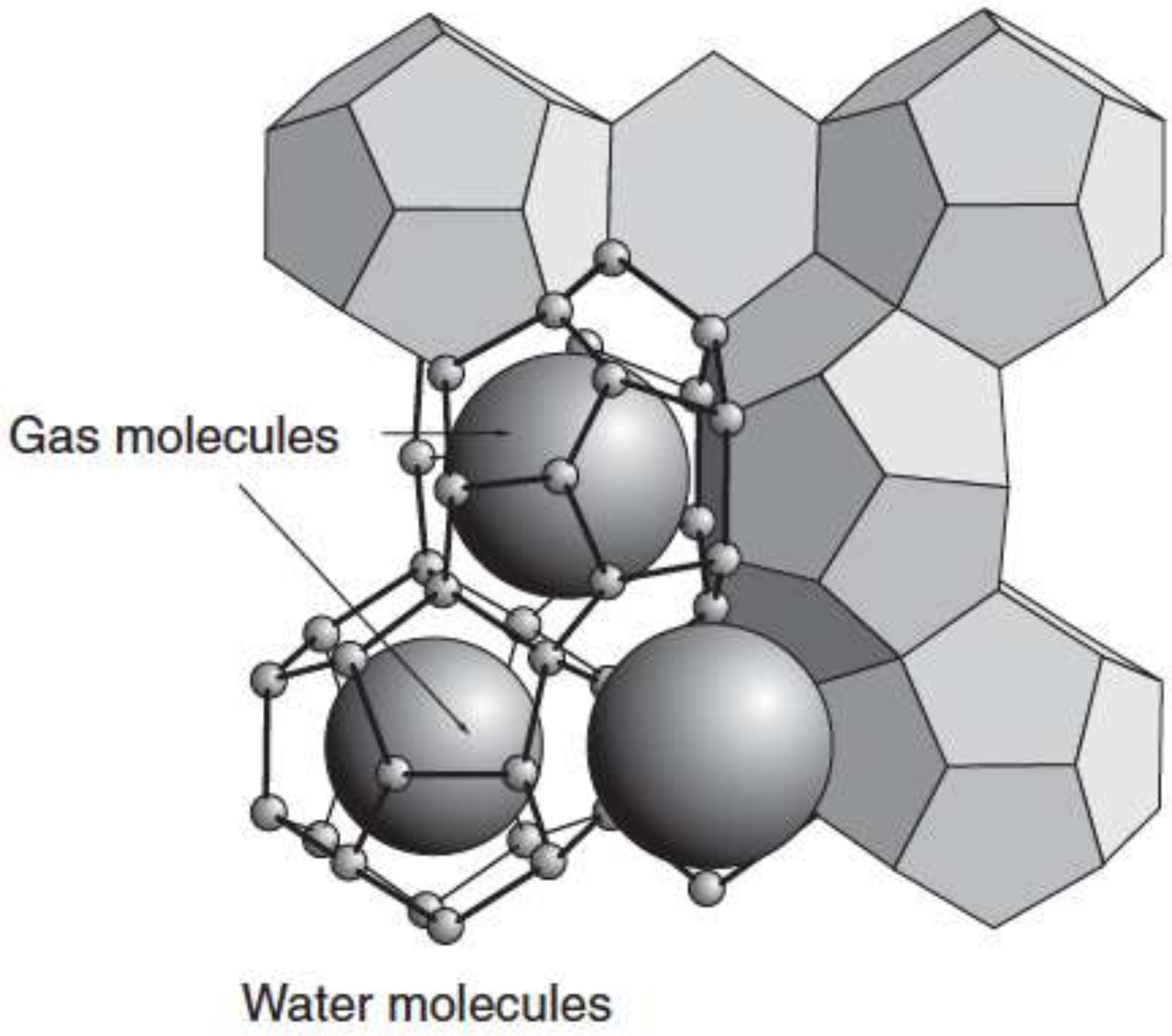
Oil spills are relatively common, tanker fires less common

GAS HYDRATES (CLATHRATES) AN ENERGY SOURCE FOR THE FUTURE

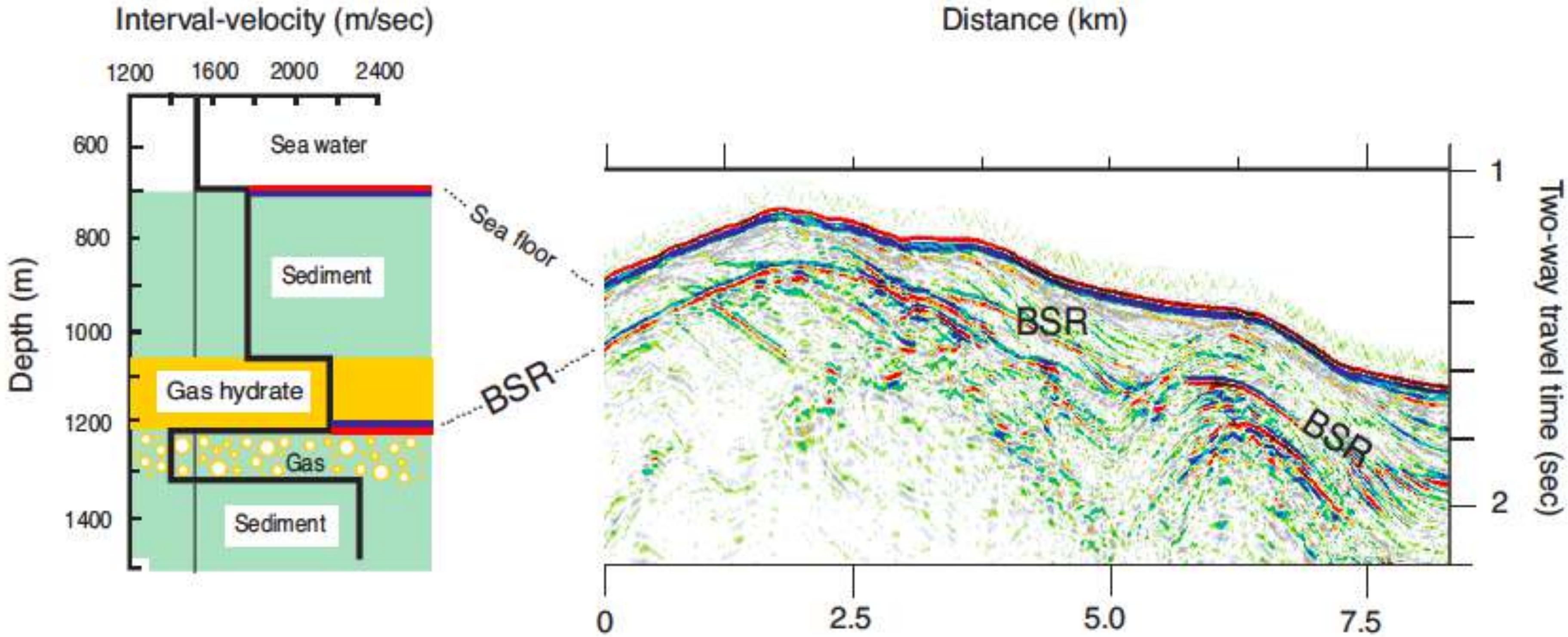
Stability and phase boundaries of gas hydrates superimposed on depth-T distribution (red) in ocean & upper sediment column. Phase boundary of pure methane hydrate in SW (green), the phase boundary with 3 mol-% H_2S in SW, (blue), and phase boundary of pure methane hydrate in 5 times SW salinity (yellow). Intersection of temperature profiles with phase boundaries define stability zone (HSZ) and the BSR for each of the 3 hydrate compositions



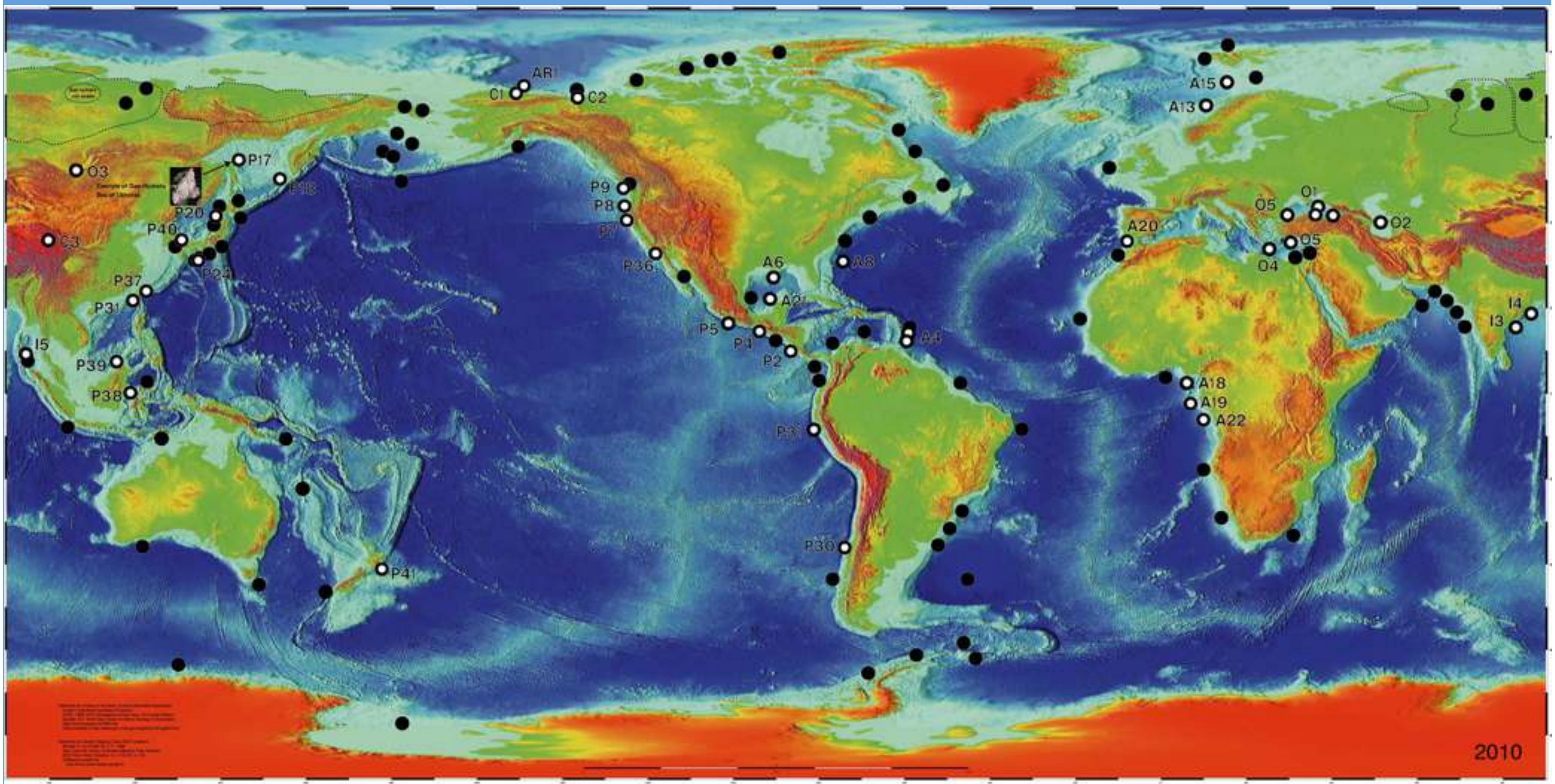
Methane gas is trapped under pressure in a cage of water ice



The bottom-simulating reflector is an isothermal boundary, the lower boundary of the gas hydrate, under which occurs free gas



Global Occurrence of gas hydrates, open circles recovered hydrate, closed circle, inferred hydrate



(From Kvenvolden and Lorenson, 2010)

Other Technologies for Marine Resarch
Updates on old ideas

- Re-Visiting Mining System Components
- Upgrades to Historic Technology
- Ideas From Other Industries’ Progress
- Deposit-Specific Designs
- R.V. Natushima and ROV Hyper-Dolphin
- Nautilus Missions
- New Data Analysis Techniques
- Deep-ocean drilling (DSDP, ODP, IODP)

Revisiting Mining System Components

Mining Systems

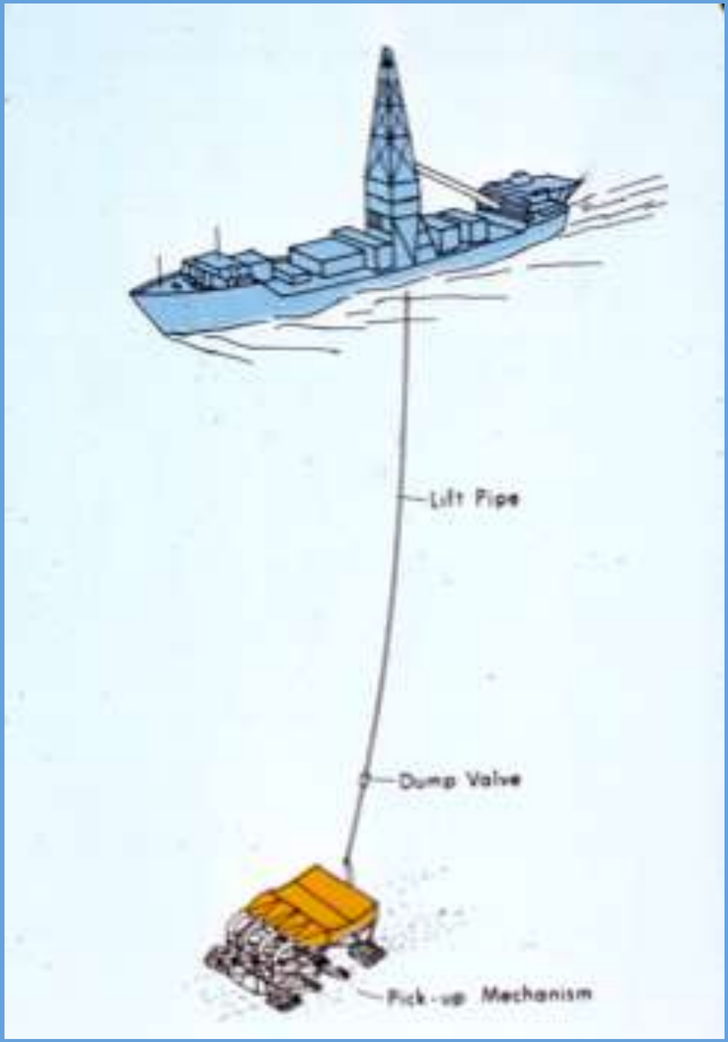
- Operations
  - Fragmentation
  - Crushing
  - Lifting
  - Pick-up
  - Separation

- Ore Extraction Methods
  - Bottom-crawling vehicle
  - Articulated cutters
  - Water-jet stripping
  - Sonic fragmentation
  - Continuous-line bucket
  - In-situ leaching

- Ore Dressing Methods
  - Froth flotation
  - Magnetic separation
  - Gravity concentration
  - Vibration table
  - Color intensity separation

- Extractive Metallurgy

Deposit-Specific Designs

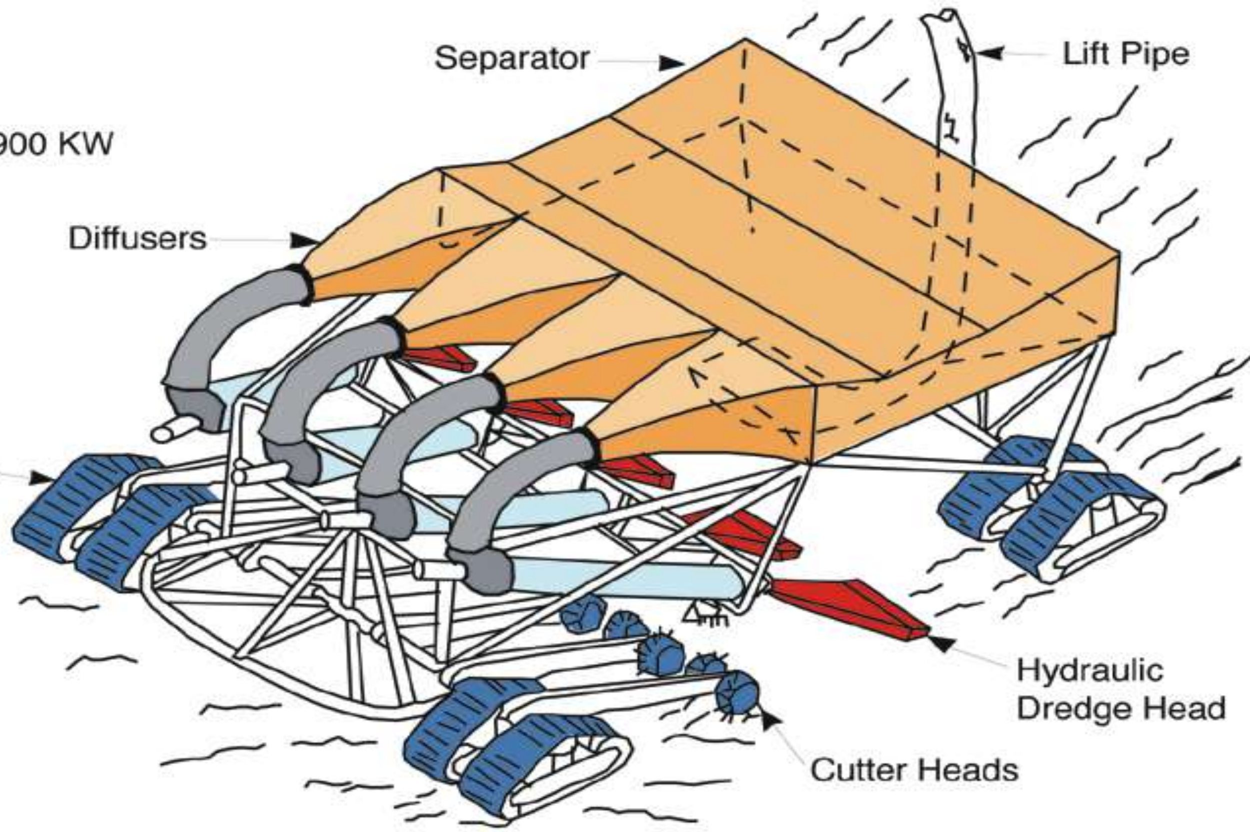


AES1-36 Crust Miner
DJ-3 (John Halkyard)

Deposit-Specific Designs

MAJOR DIMENSIONS

Length : 13 m
Width : 8 m
Height : 6 m
Weight : 100 t
Installed Power : 900 KW



From DOI-MMS (1990); designed by J. E. Halkyard, OTC Corporation

State-of-the-art ROV control center
R.V. Natsushima and ROV Hyper-Dolphin
JAMSTEC, Japan

Scientists ROV Lab and Work Room

Scientists ROV logging Lab and Work Room

Two TV monitors in lab

ROV control room with 6 flat screens, 3 ROV control Personnel, and 6 scientists

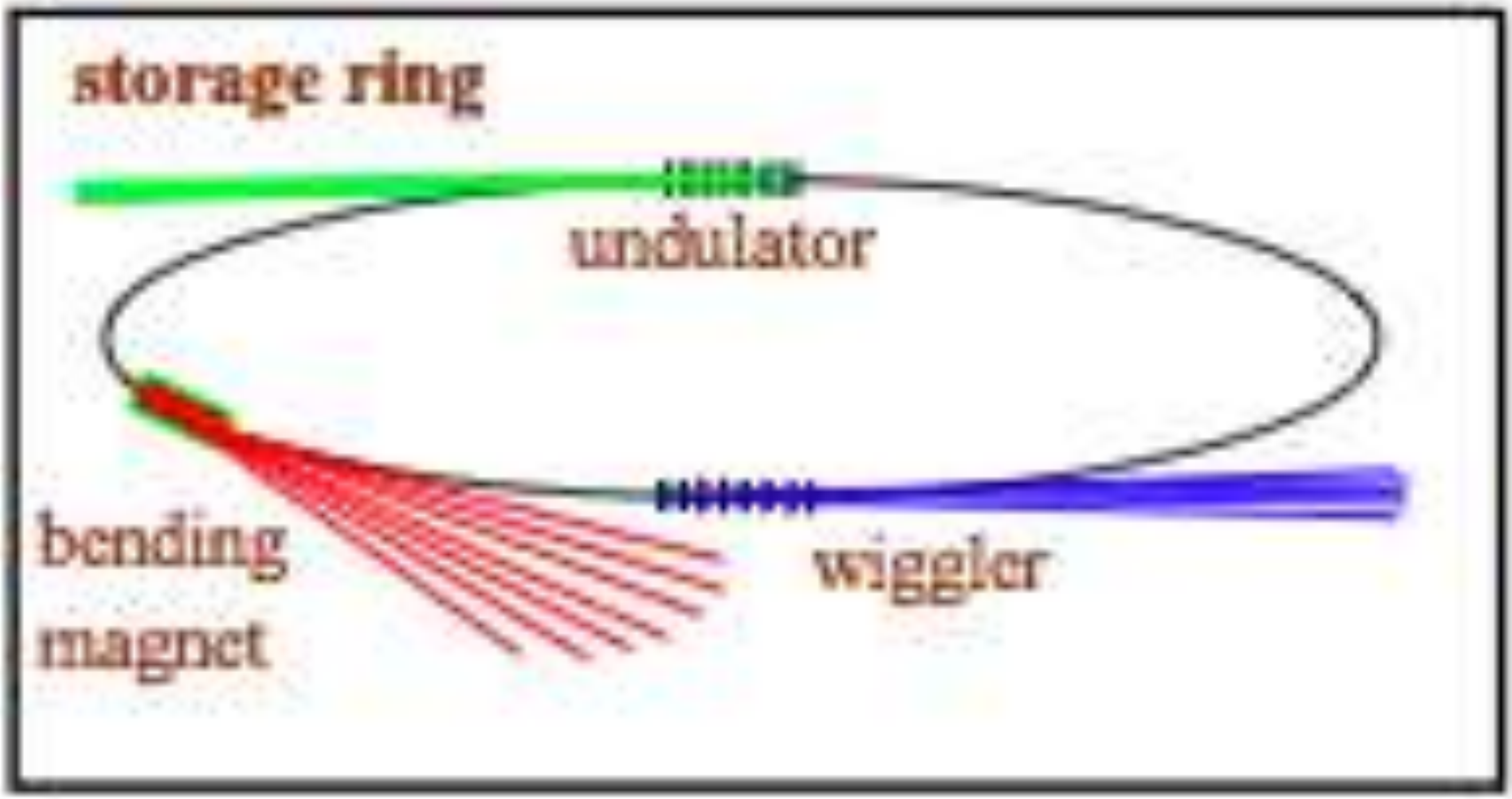
Room for 6 Scientists, each with different duties
In direct communication with ROV lab

Recovery of Hyper-Dolphin ROV

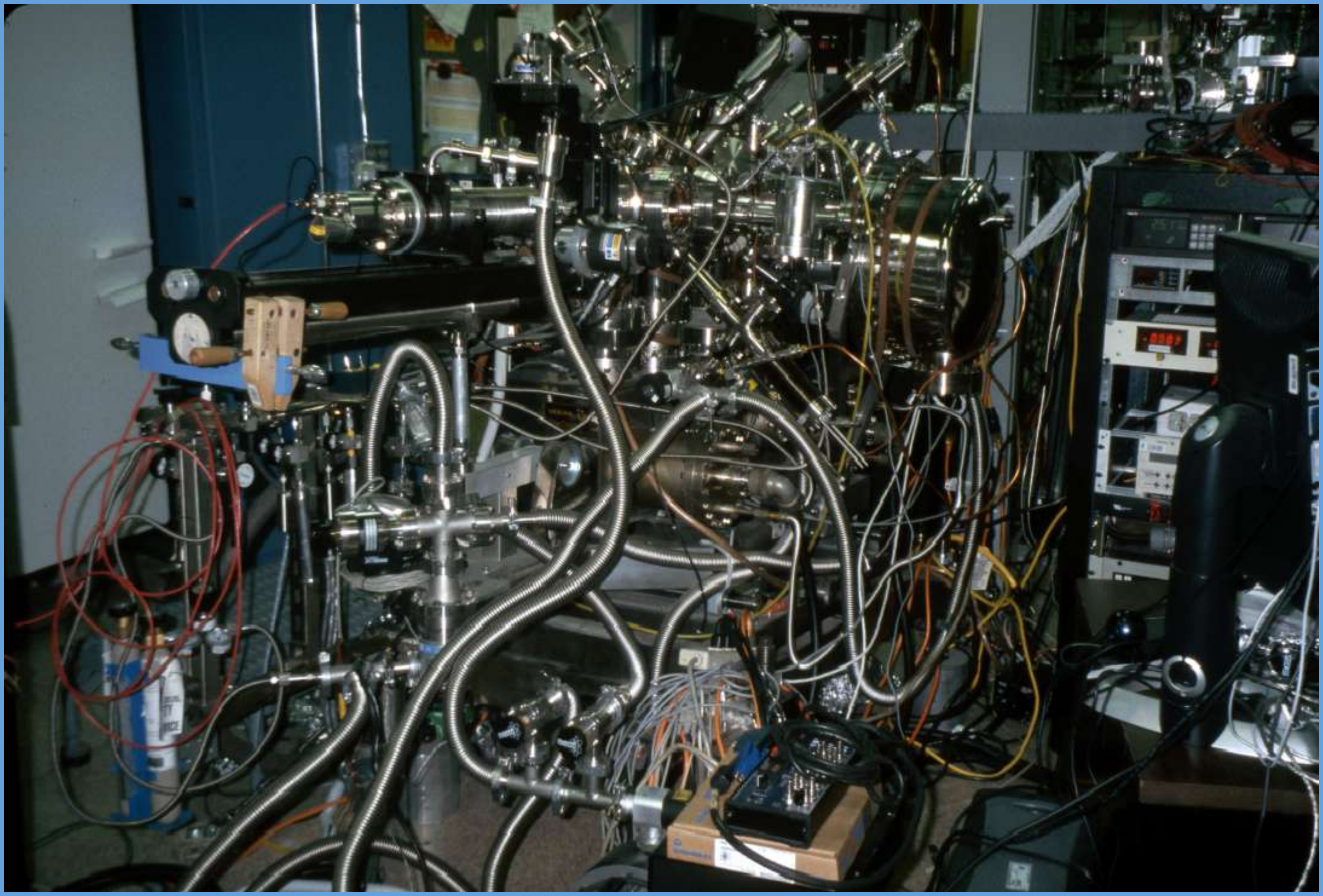

3 HPD

150 kg Sumo-wrestler Chimney, E. Diamante Caldera, CNMI

SSRL Cyclotron

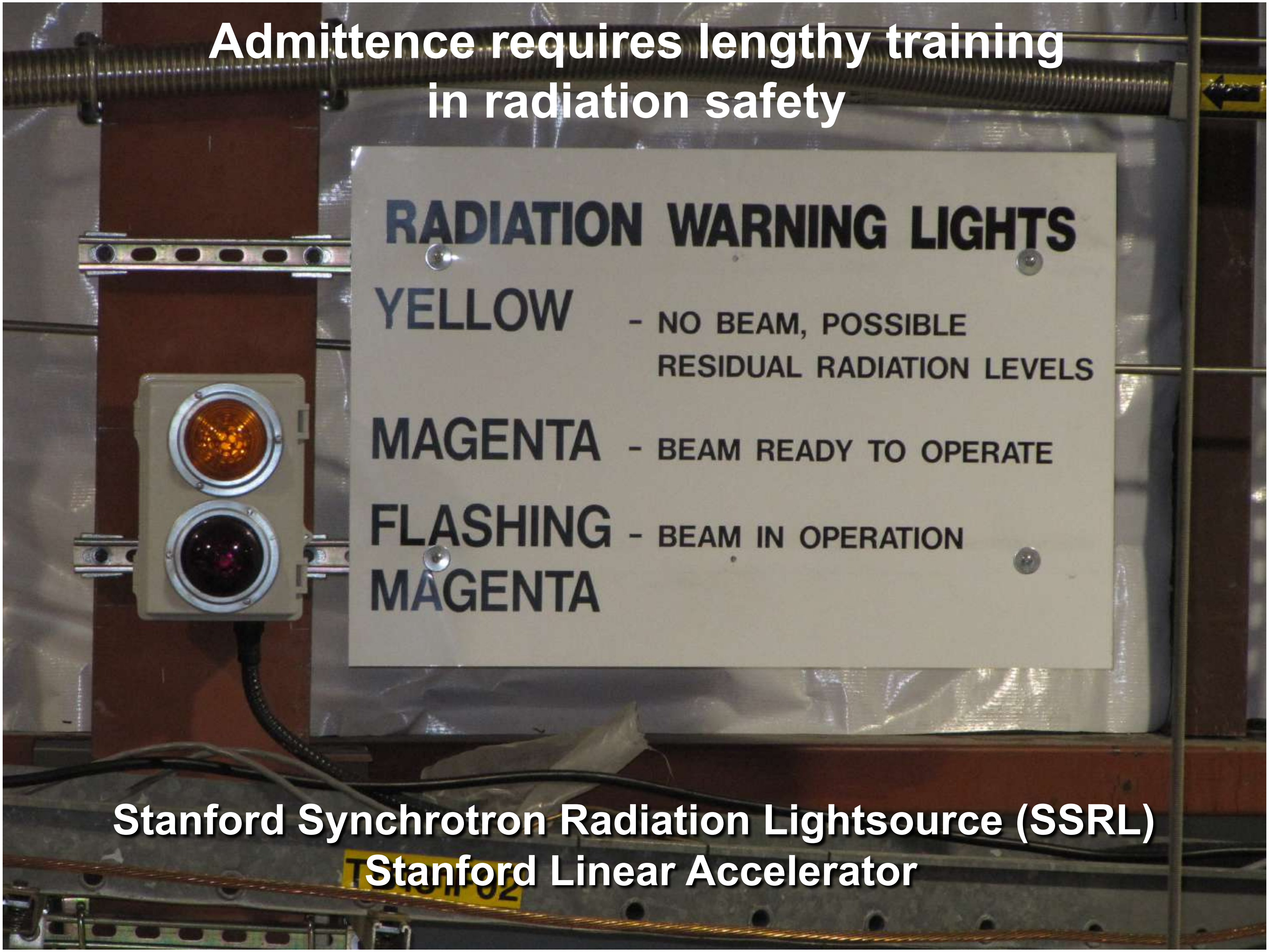


New Data Analysis Techniques



Stanford Synchrotron Radiation Lightsource (SSRL)
Stanford Linear Accelerator

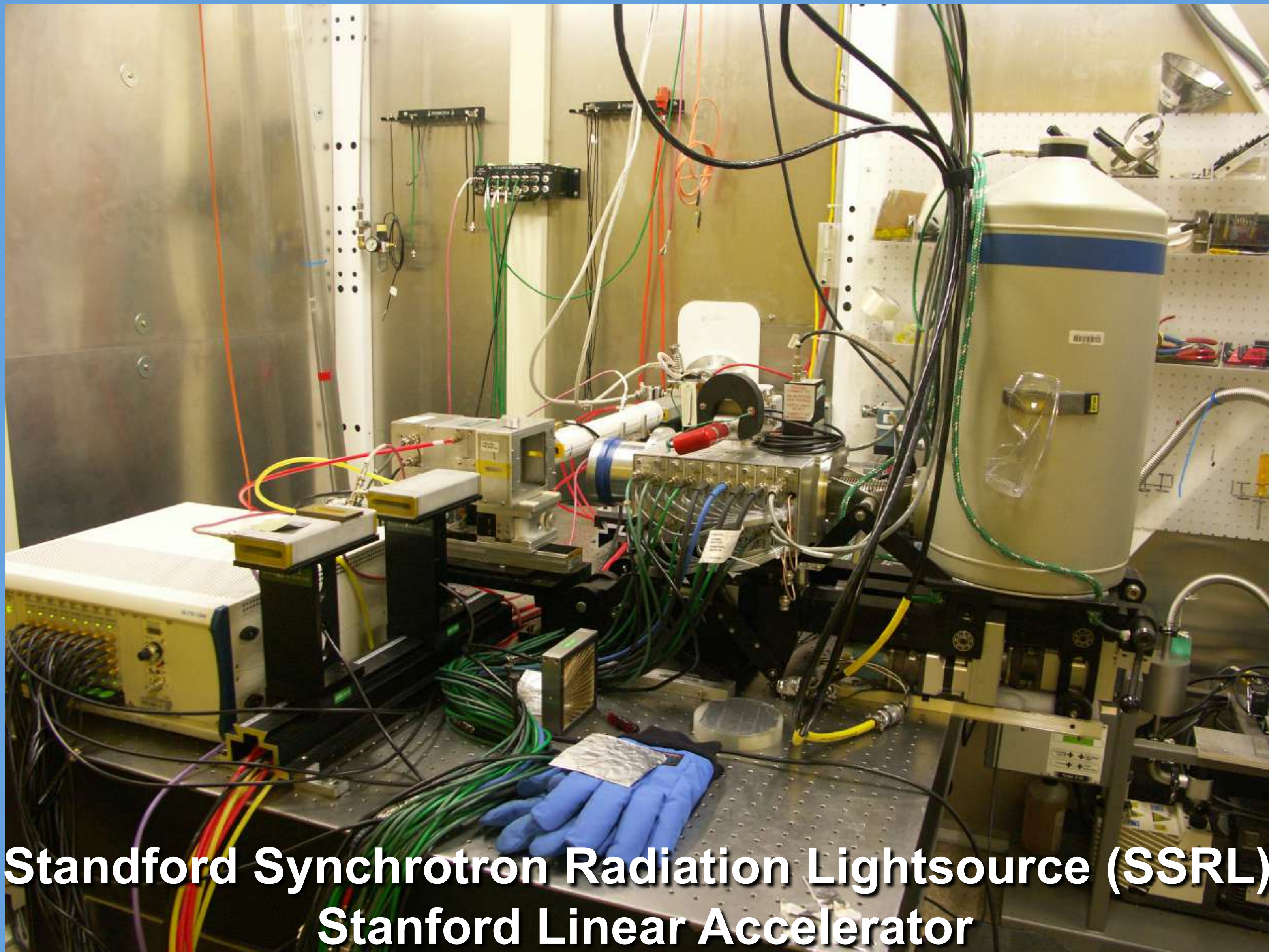
Admittence requires lengthy training in radiation safety



Stanford Synchrotron Radiation Lightsource (SSRL)
Stanford Linear Accelerator

High Energy Beam Line 11-2 Hutch

High Energy Beam Line 11-2

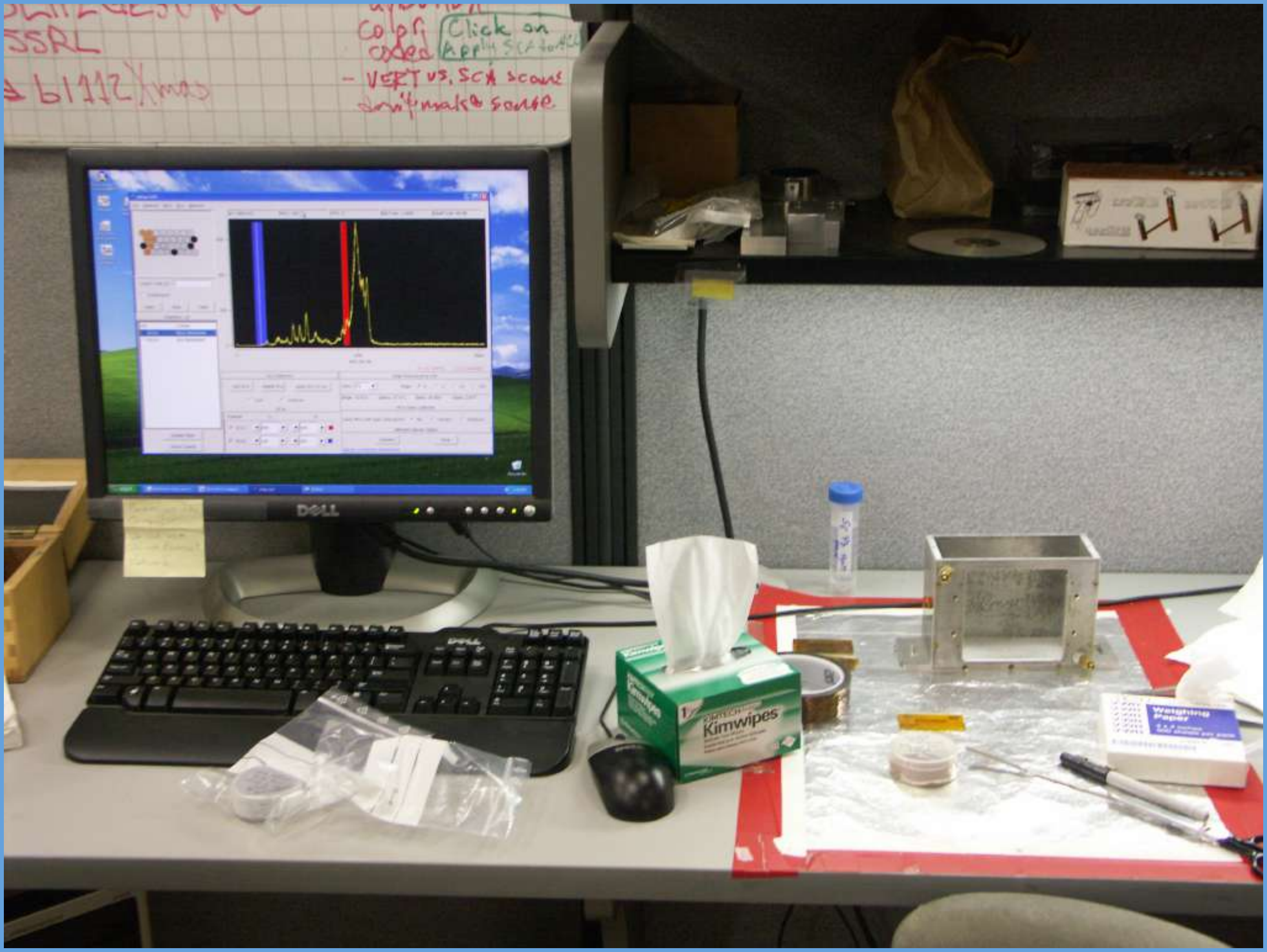


Standford Synchrotron Radiation Lightsource (SSRL)
Stanford Linear Accelerator

Jim at High Energy Beam Line 11-2, Analyzing Tellurium

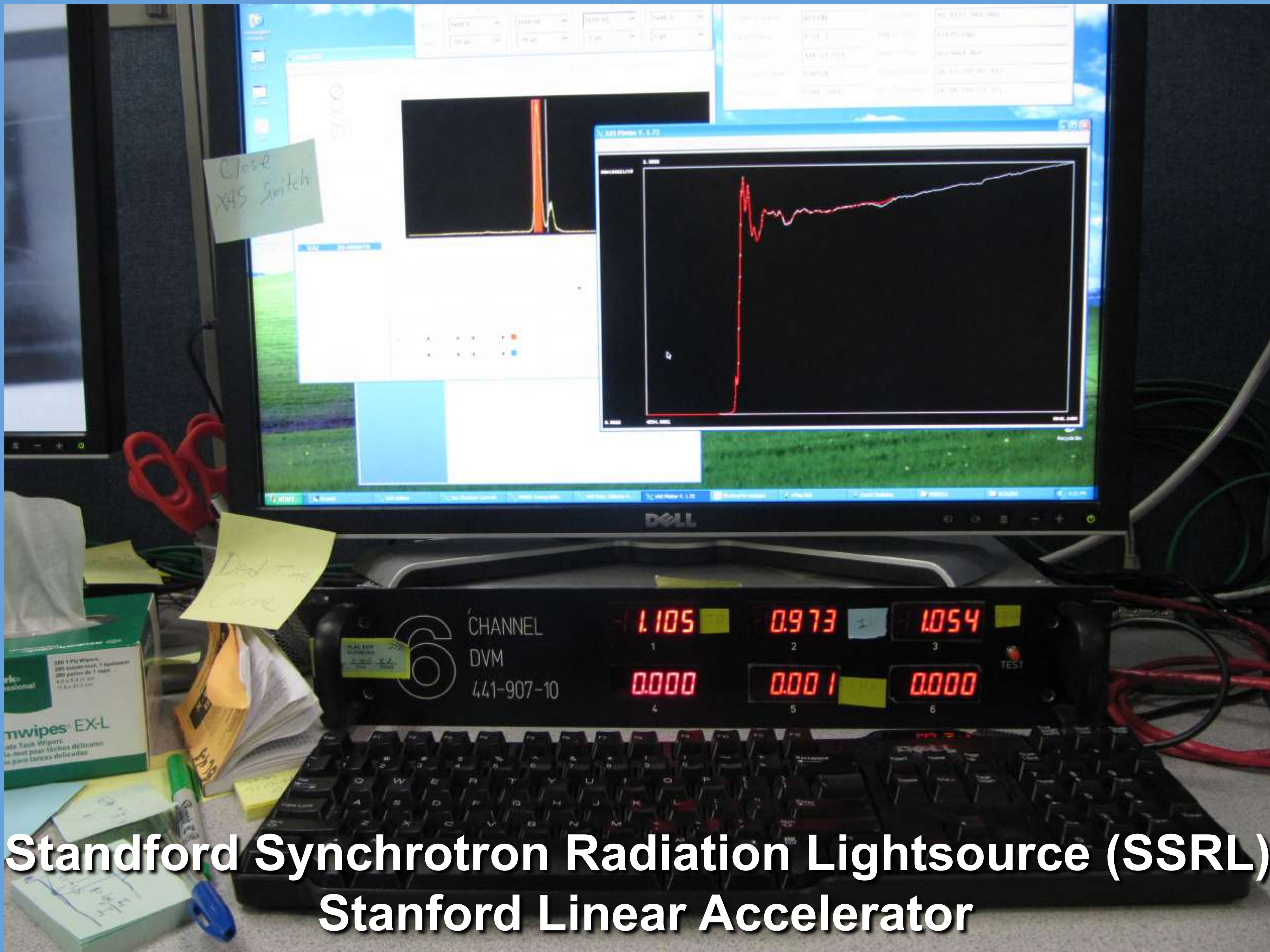
Standford Synchrotron Radiation Lightsource (SSRL)
Stanford Linear Accelerator

XANES and EXAFS Spectral of Molybdenum



Standford Synchrotron Radiation Lightsource (SSRL)
Stanford Linear Accelerator

XANES and EXAFS Spectral of Titanium; BL 4-3



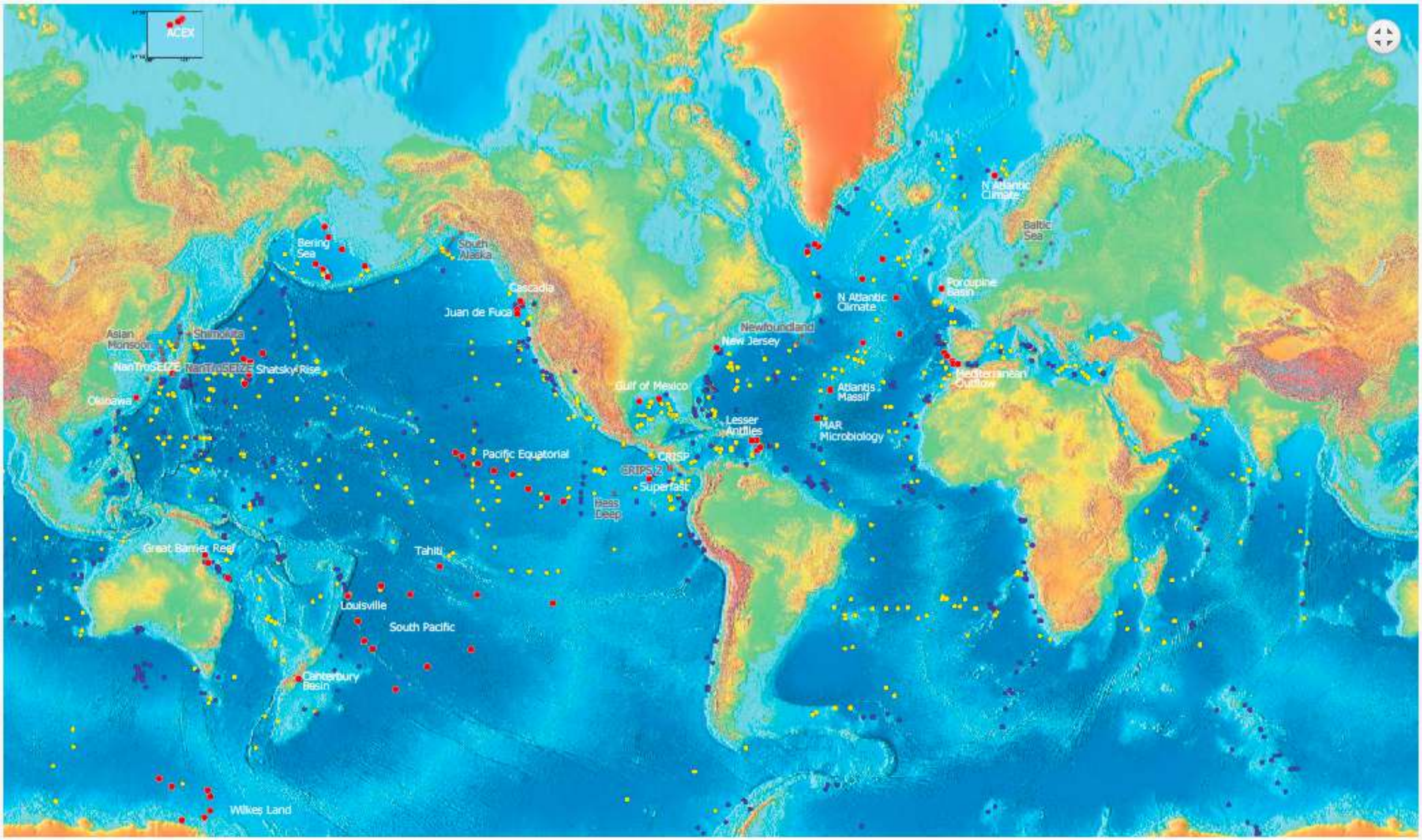
Standford Synchrotron Radiation Lightsource (SSRL)
Stanford Linear Accelerator

The Ocean Drilling Program has drilled into four SMS mineral deposits:

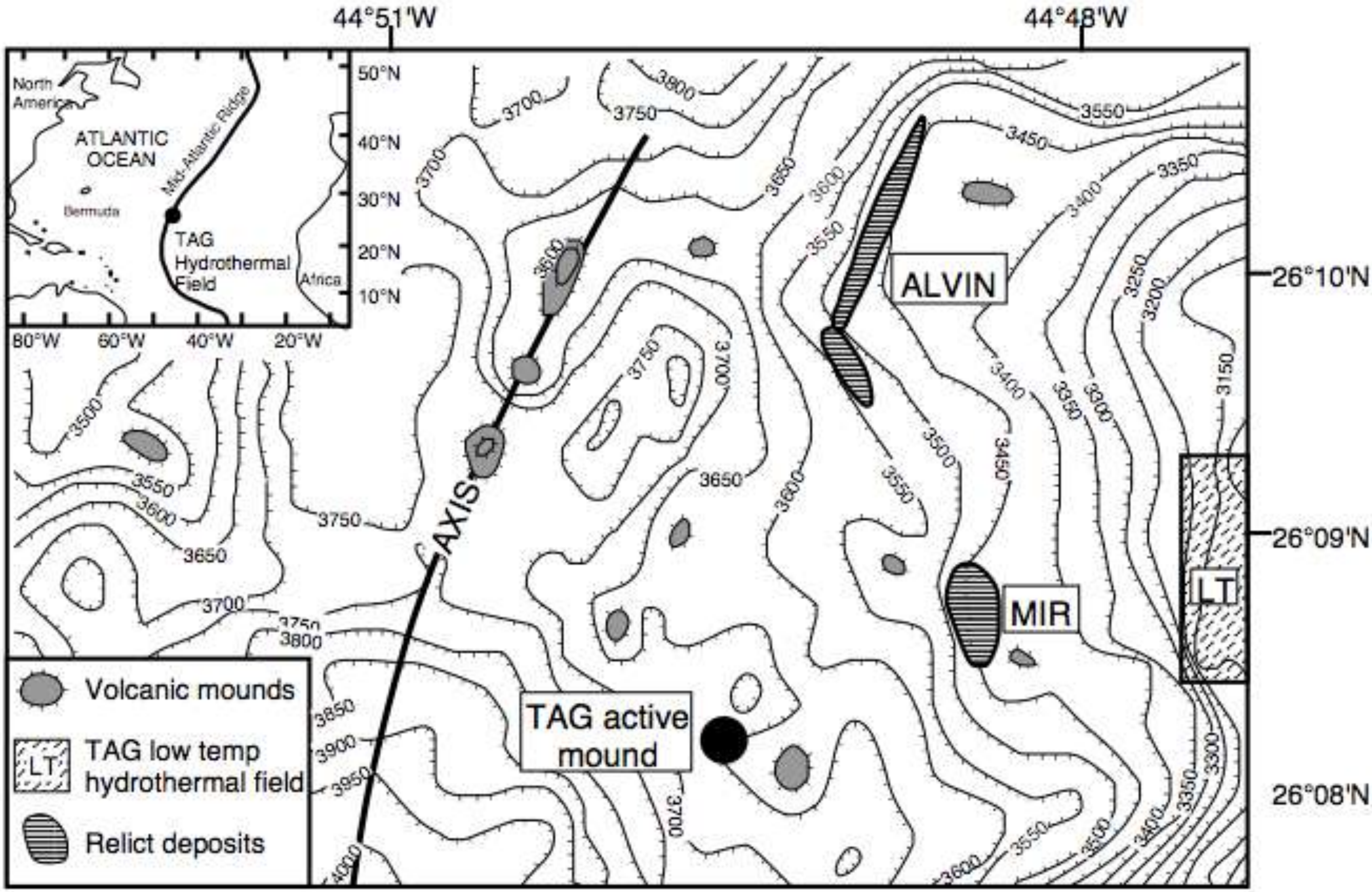
1. TAG on the Mid-Atlantic Ridge (Trans-Atlantic Geotraverse)
2. Juan de Fuca Ridge, NE Pacific
3. Okinawa Trough, W Pacific
4. Manus Basin, SW Pacific

JOIDES Resolution Drill Ship

Compilation of Drill Sites

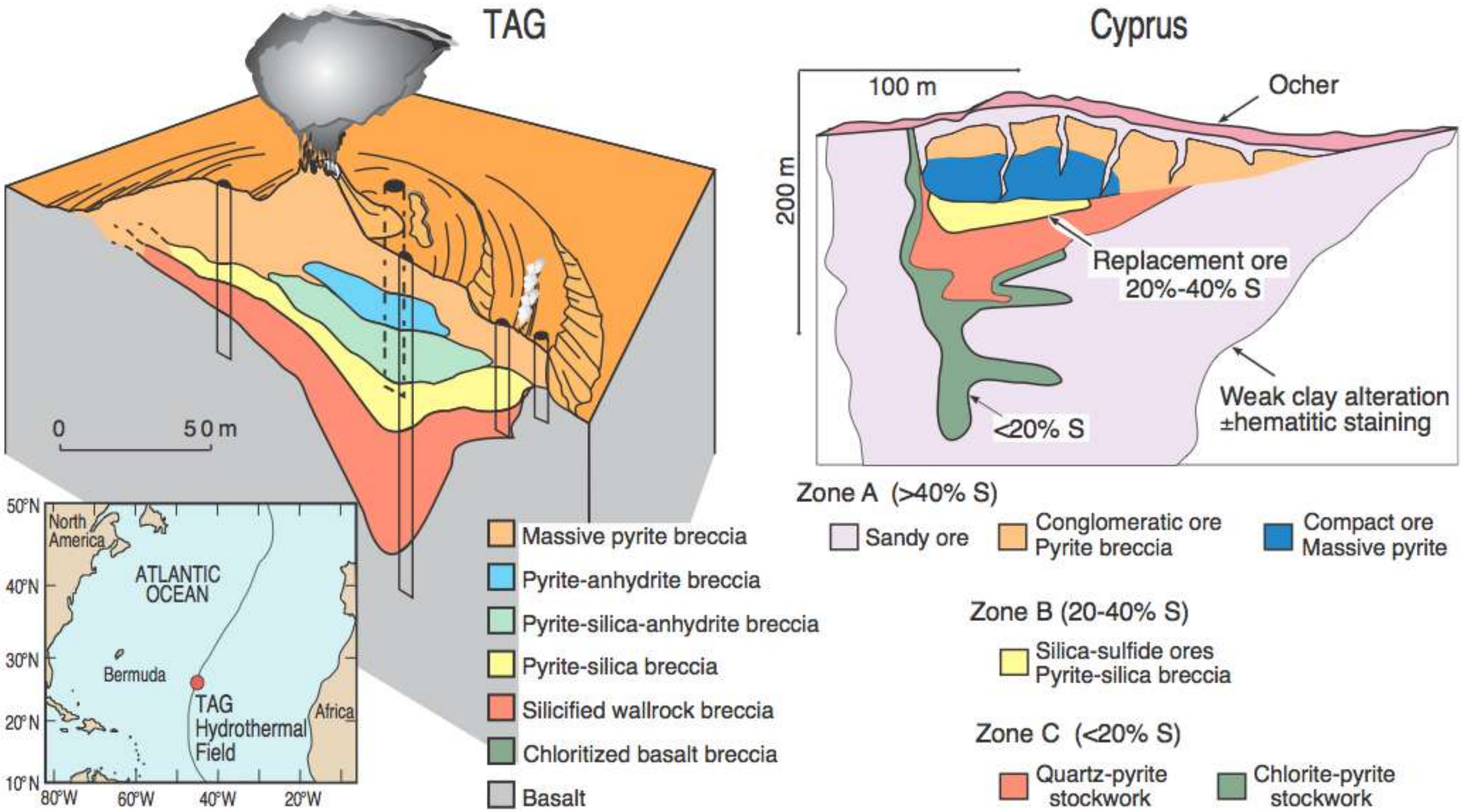


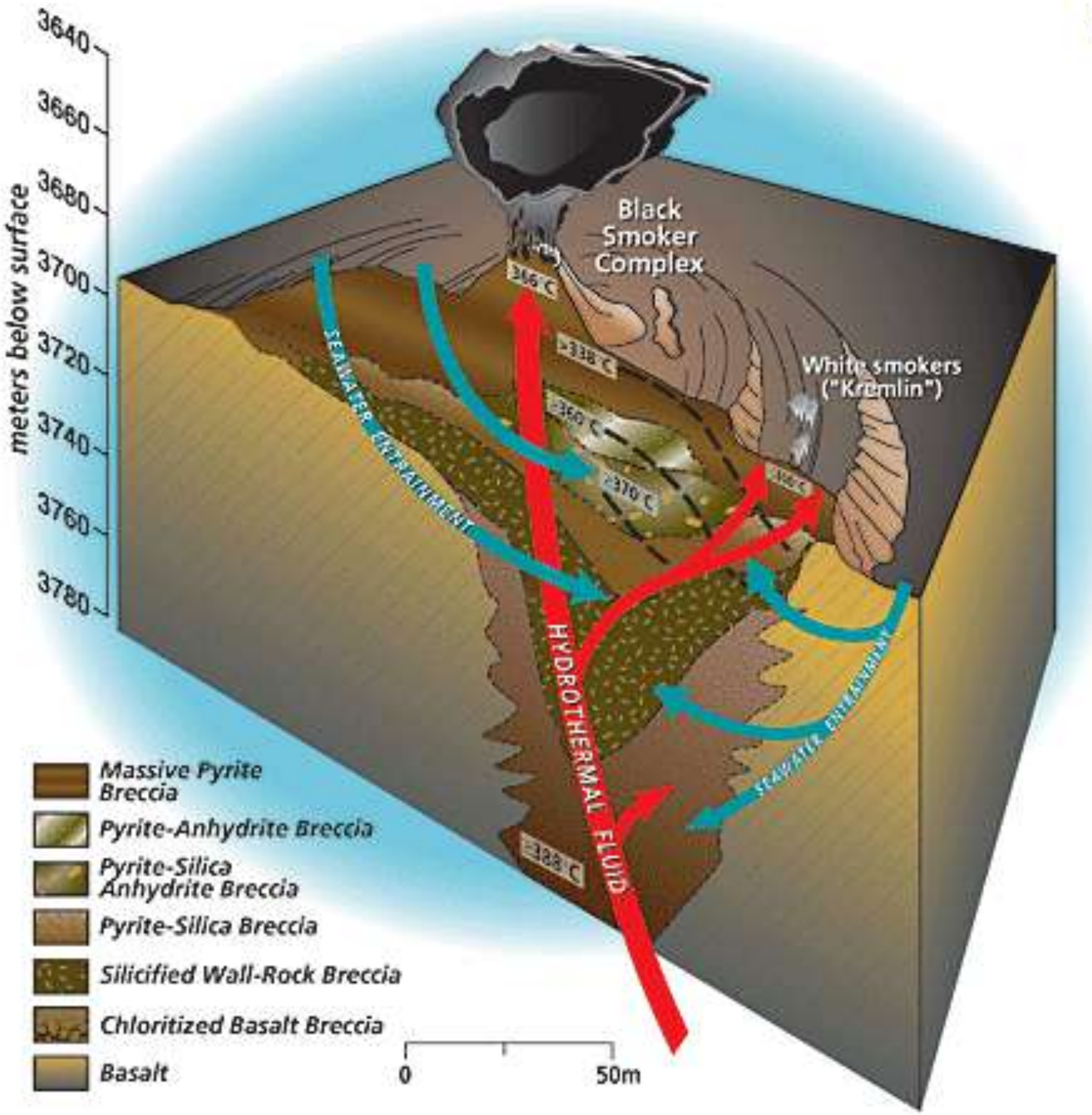
TAG Mound and Surrounding Sites
Area Now Contracted by France (10,000 km²)



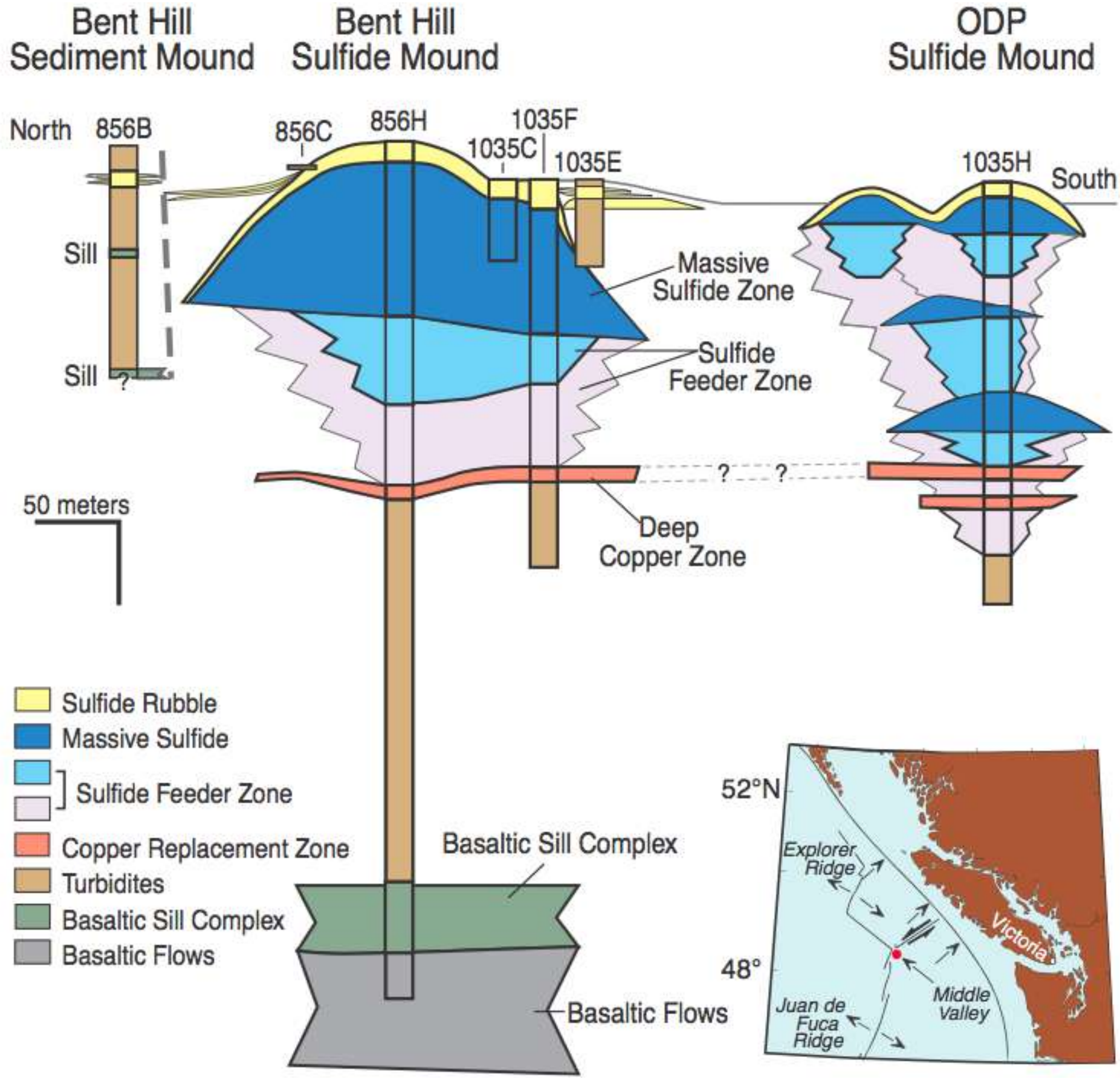
Cross-section and drill holes of TAG Mound, compared to Cyprus-type massive sulfide. Okinawa Trough deposit considered analog to Kuroko-type massive sulfide

3-5 million tonnes




3640
3660
3680
3700
3720
3740
3760
3780
meters below surface
Black Smoker Complex
>338°C
>360°C
>370°C
White smokers ("Kremlin")
SEAWATER ENTRAINMENT
HYDROTHERMAL FLUID
SEAWATER ENTRAINMENT
Massive Pyrite Breccia
Pyrite-Anhydrite Breccia
Pyrite-Silica Anhydrite Breccia
Pyrite-Silica Breccia
Silicified Wall-Rock Breccia
Chloritized Basalt Breccia
Basalt
0
50m

Middle Valley Juan de Fuca Spreading Ridge



Sessions 10-11 Continued: Hydrothermal Manganese Deposits

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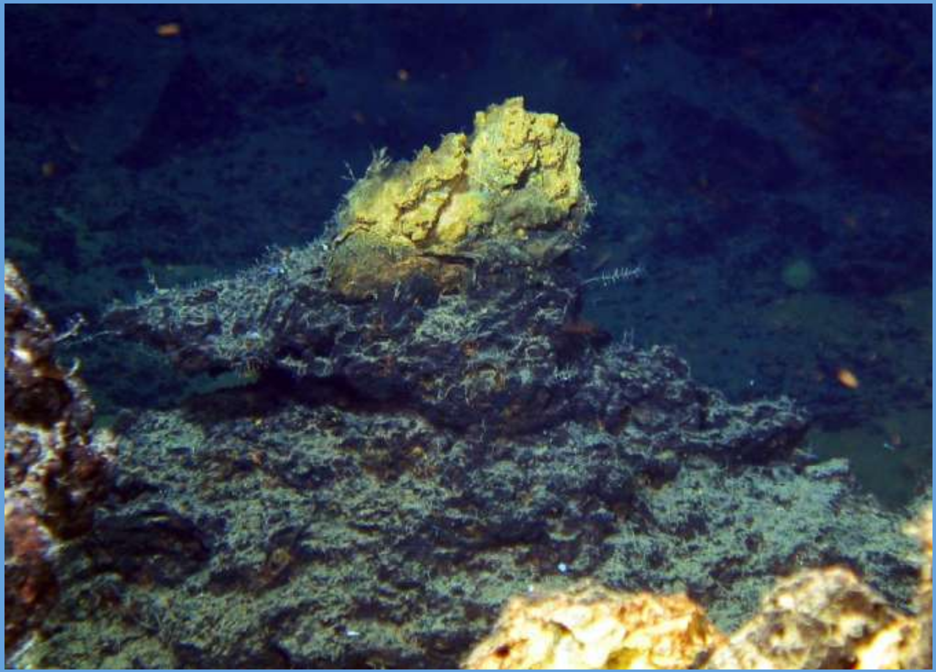
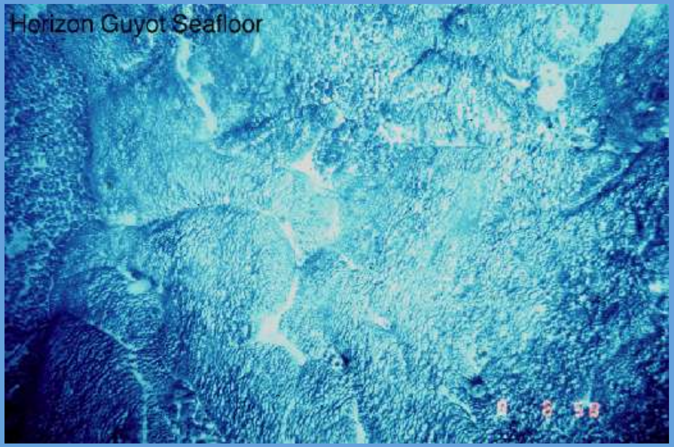


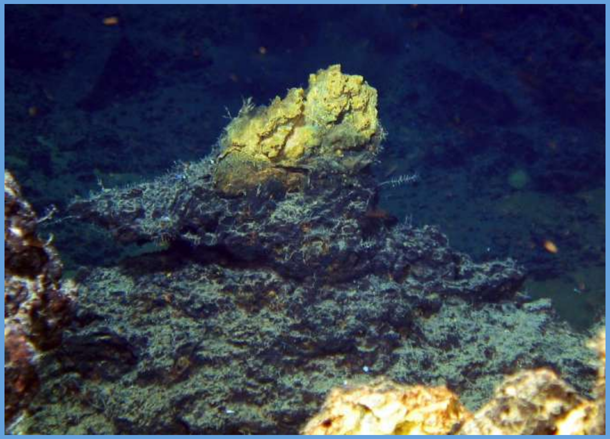
SPC-EU EDF10 Deep Sea Minerals (DSM) Project: ***Regional Training Workshop on Geological, Technological, Biological and Environmental Aspects of Deep Sea Minerals***
13-17 August 2012, Nadi Fiji

Deep-ocean mineral deposits

- **Manganese nodules**
  - Form on the vast deep-water abyss



- **Ferromanganese crusts**
  - Form on 100,000 seamounts



- **Hydrothermal manganese**
  - Form along volcanic arcs, mid-ocean ridges, and at hot-spot volcanoes

Terminology and Deposit Types

<u>Stratabound hydrothermal Mn-oxide</u> layers: Form below the seabed as layers within sediments: volcaniclastic, foraminiferal sands, siliceous sands; these are dense, metaliic to submetallic layers

<u>Hydrothermal manganiferous sandstones</u>: sandstone cemented by Mn oxide thereby forming a rock these form black sandstones

Seafloor hydrothermal Mn-Fe Oxide deposits; porous, friable to unconsolidated deposits

Potential future resource for Mn, Mo, Li,

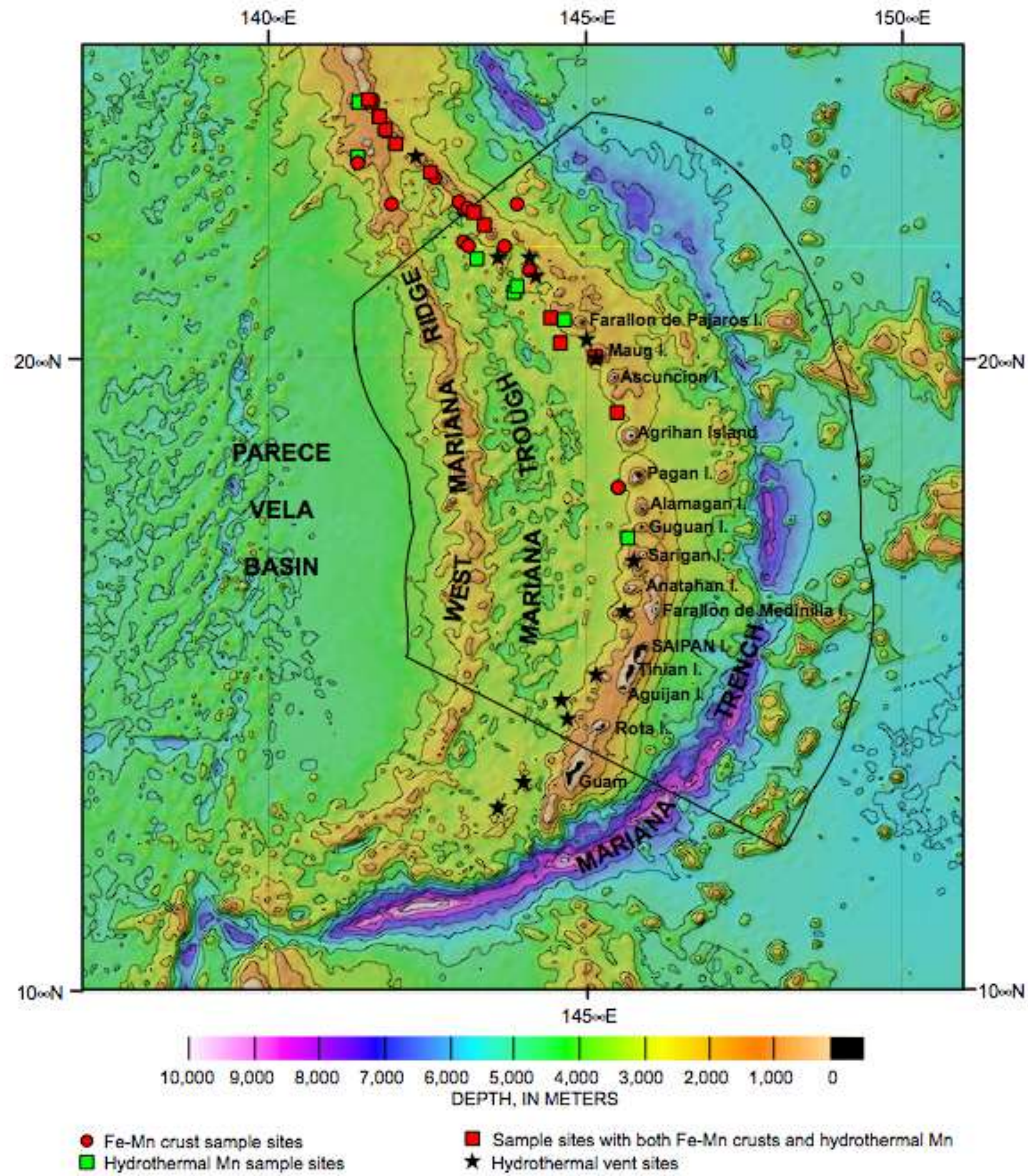
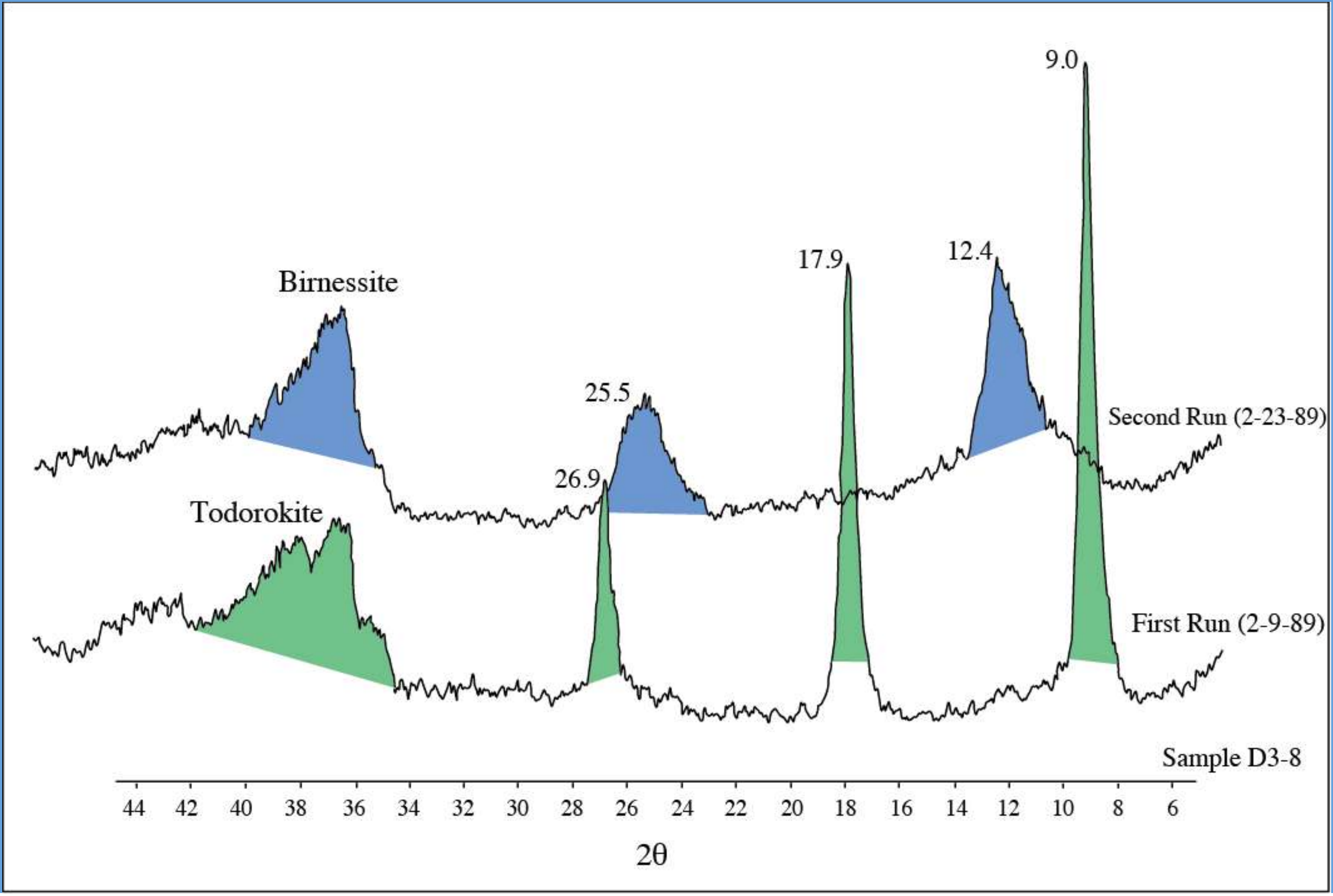
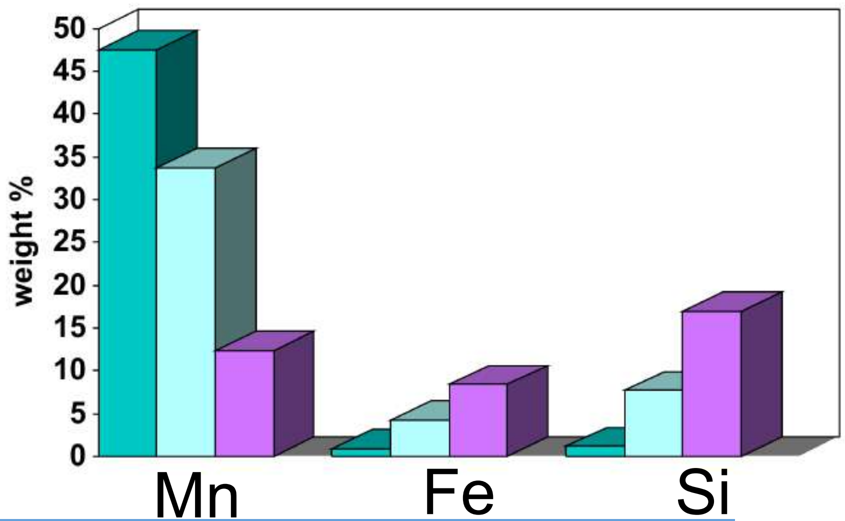


Figure 19. Bathymetric map of the Exclusive Economic Zone (EEZ) of the Commonwealth of the Northern Mariana Islands ("K" on fig.1); black line shows EEZ boundary. Contour interval is 1,000 meters. The Guam and Japan EEZs border the Commonwealth of the Northern Mariana Islands EEZ to the south-southwest and north-

X-ray diffractograms of a hydrothermal Mn oxide sample that was todorokite when collected and collapsed to birnessite after stored in the lab for two weeks; Mariana Is.



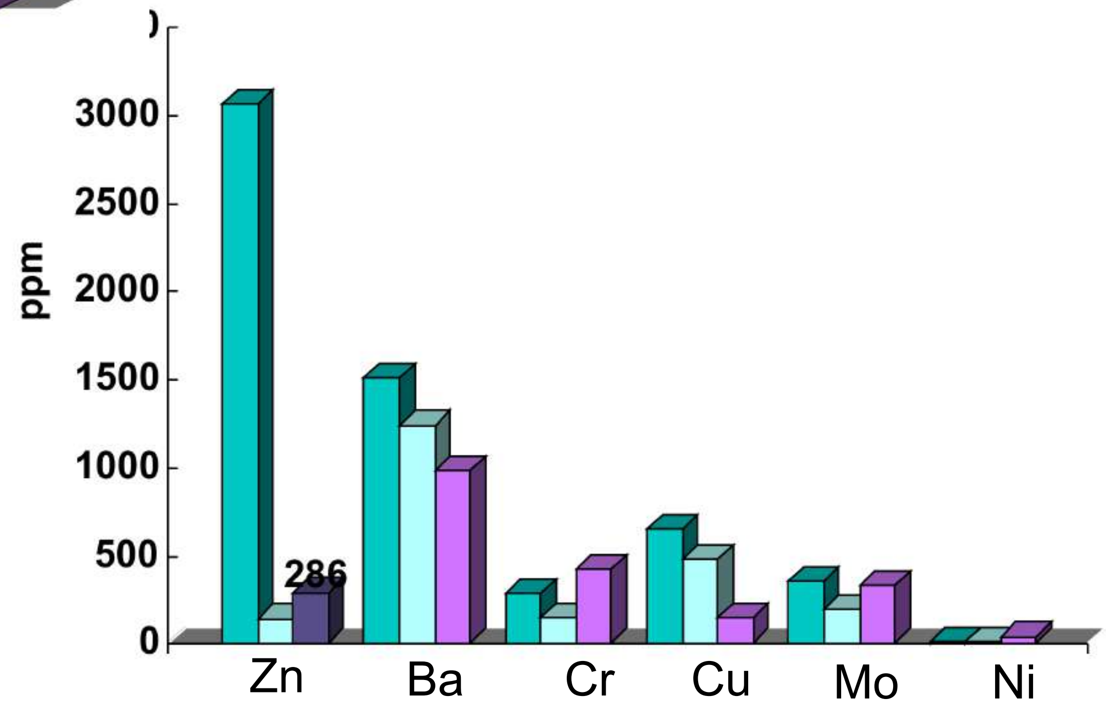
Average Composition of Mariana Volcanic Arc Hydrothermal Mn Deposits



- Statabound Mn: N=28
- Mixed: N=12
- Mn sandstones: N=21

Potential Mn ore

(Mo, Li)



Mariana arc hydrothermal Mn-oxide samples

(a) Mixed hydrogenetic/ hydrothermal Fe-Mn crust

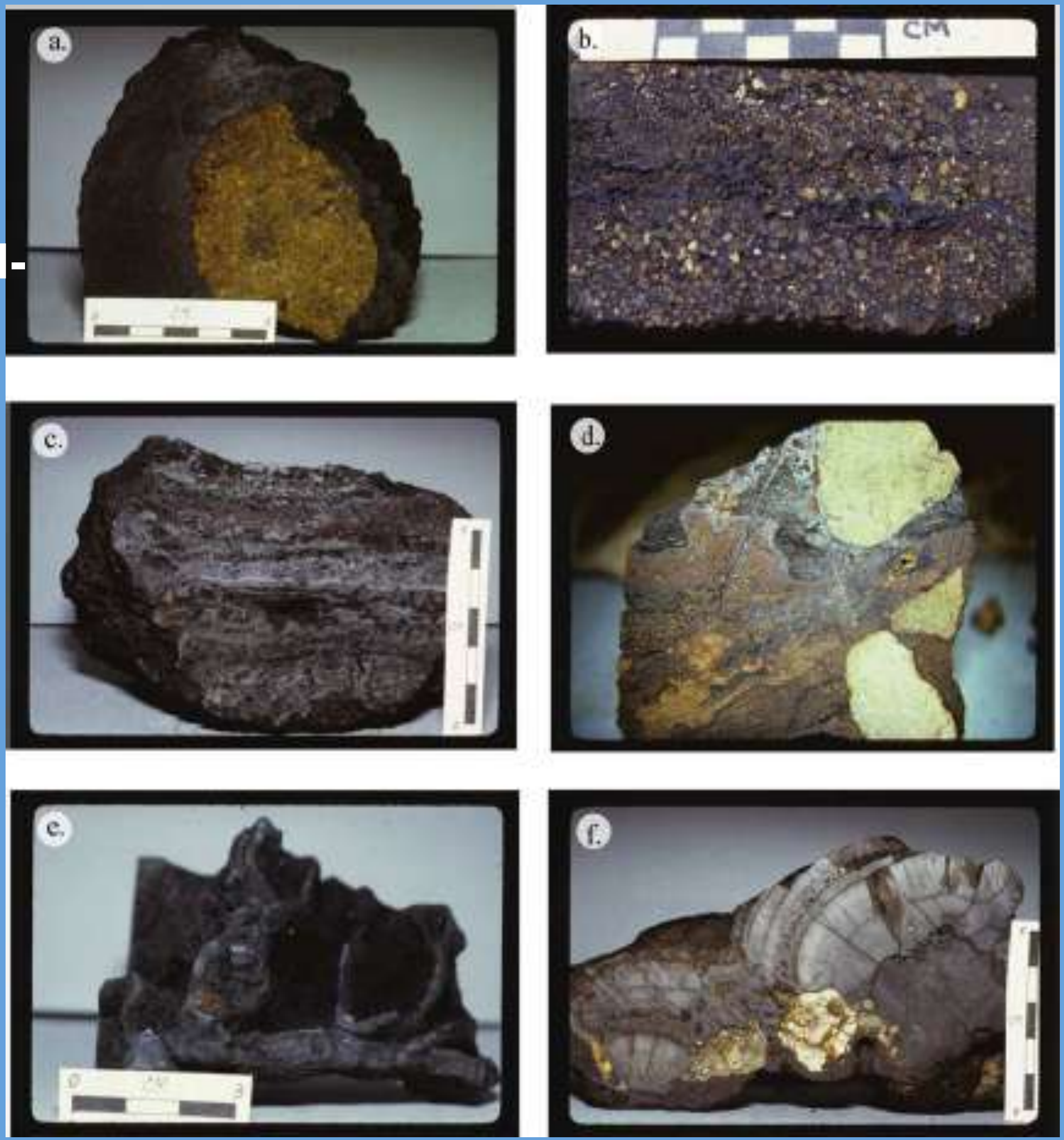
(b) Mn-oxide cemented sand-stone w/ Mn-oxide stringers

(c) Stratabound Mn-oxide bed

(d) Breccia with Mn-oxide veins, vug fill, and cement

(e) Mn-oxide cobble formed in red Fe-oxide mud

(f) Layered Mn-oxide bed with high zinc



Hydrothermal Mn rich in Zn (n= 7) 0.6-1.3 wt. % Zn; TT192-D28-1

Hydrothermal Mn-oxide layers, Mariana volcanic arc

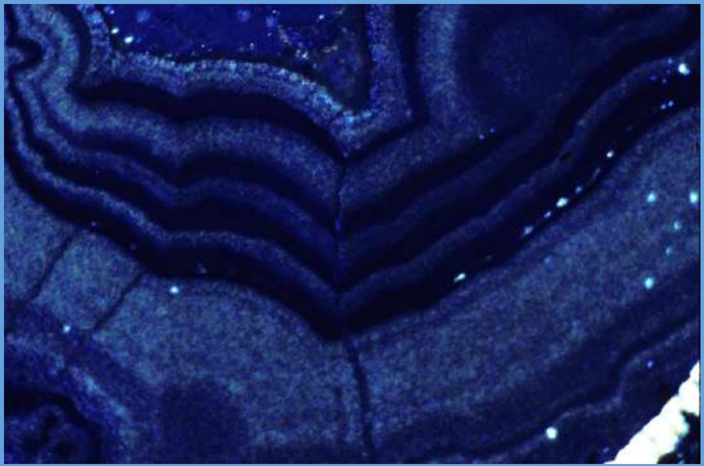
Hydrothermal Mn-oxide cement in breccia from the Mariana volcanic arc

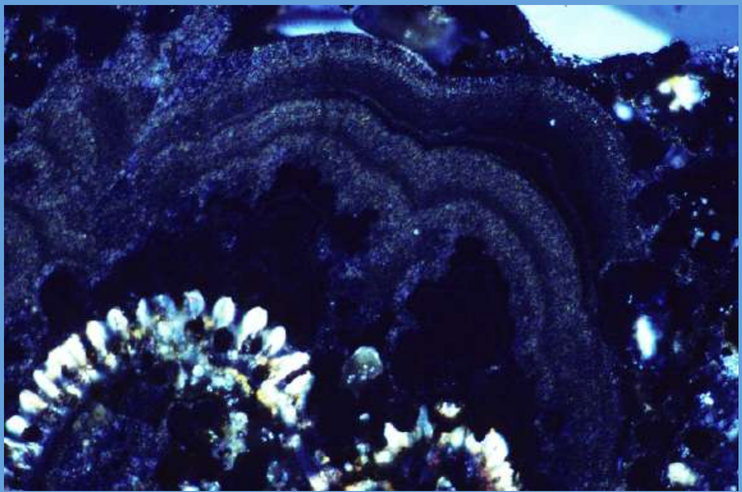
Mn oxide-cemented sandstone from Mariana volcanic arc

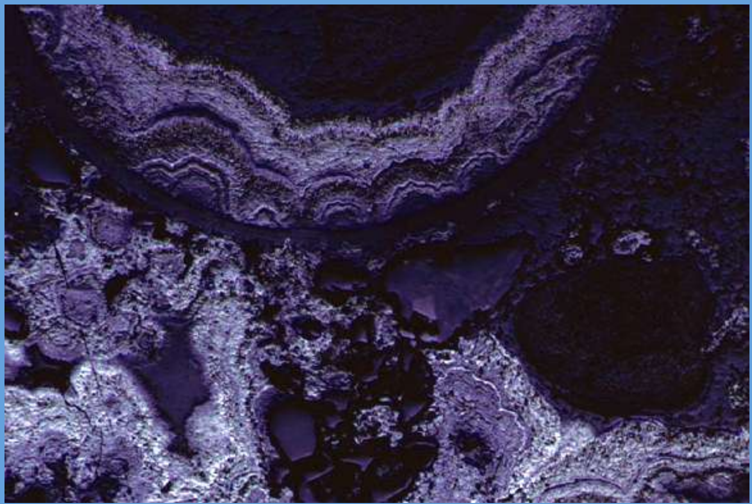
D8-3

D8-15

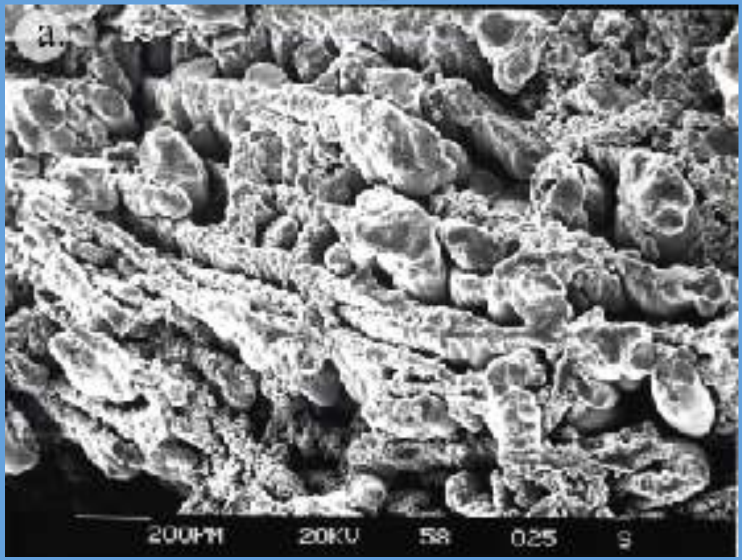
Mn-cemented sandstone (TT192-D8-2) with polished sections



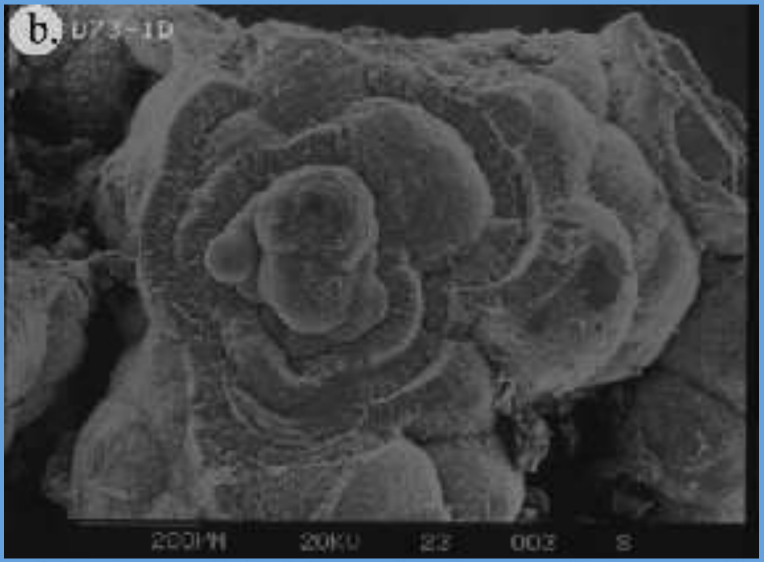




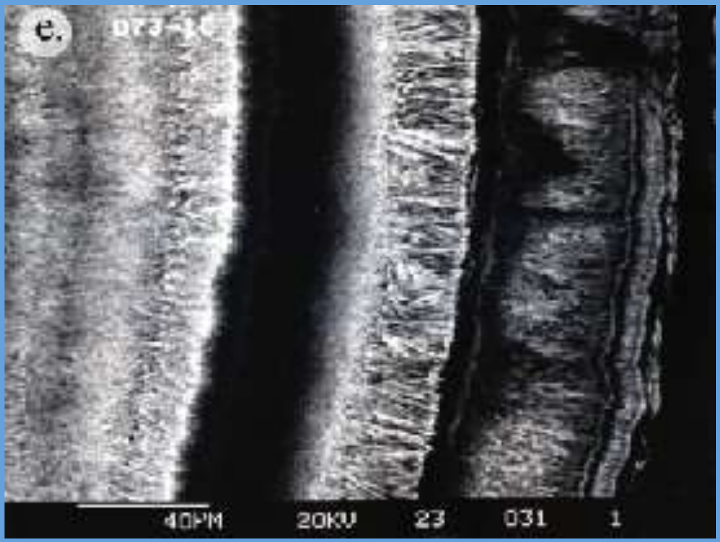
Mariana hydrothermal Mn-oxide SEM photos



Fibrous porous Mn oxides from a fracture surface (D3-3)



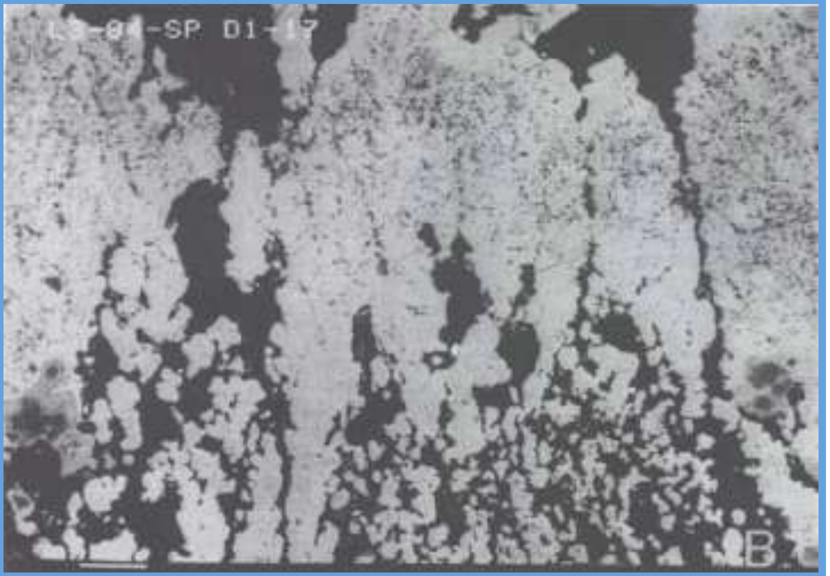
Botryoidal/colloform Mn oxides from a fracture surface (D7-1D)



Backscatter-electron image, showing alternating laminae of aligned crystallites and amorphous cryptocrystalline black layers with high water contents (D73-1C)

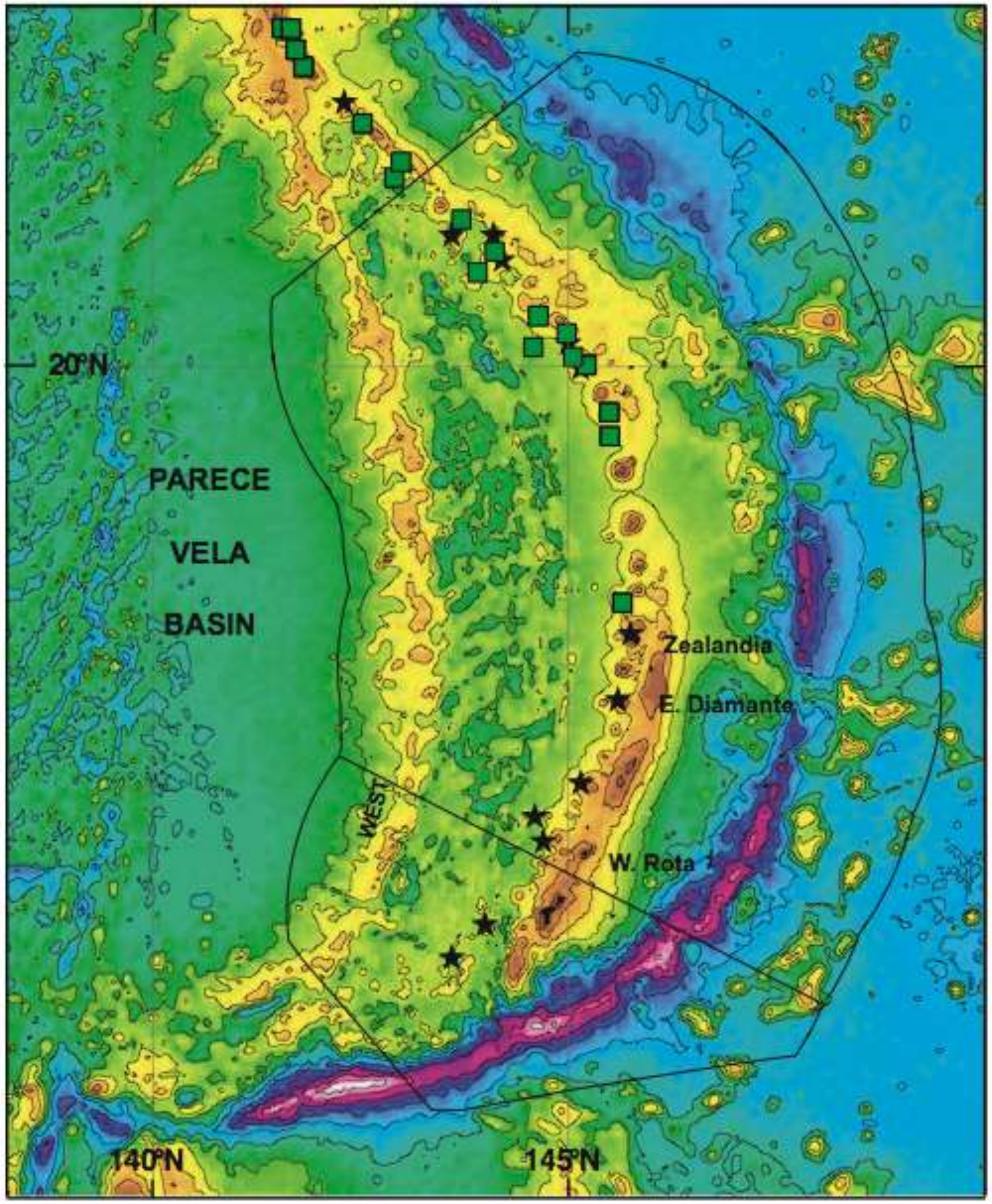
SEM photos, polished sections of hydrothermal Mn oxides, Valu Fa (Tonga) back-arc spreading center

A series of couplets, each consisting of an upper dense layer & a lower porous layer, reflecting waxing & waning hydrothermal pulses (scale bar = 1 mm)



Close-up of one couplet with radial fibrous texture (scale bar = 100 microns)

Mariana Volcanic Arc

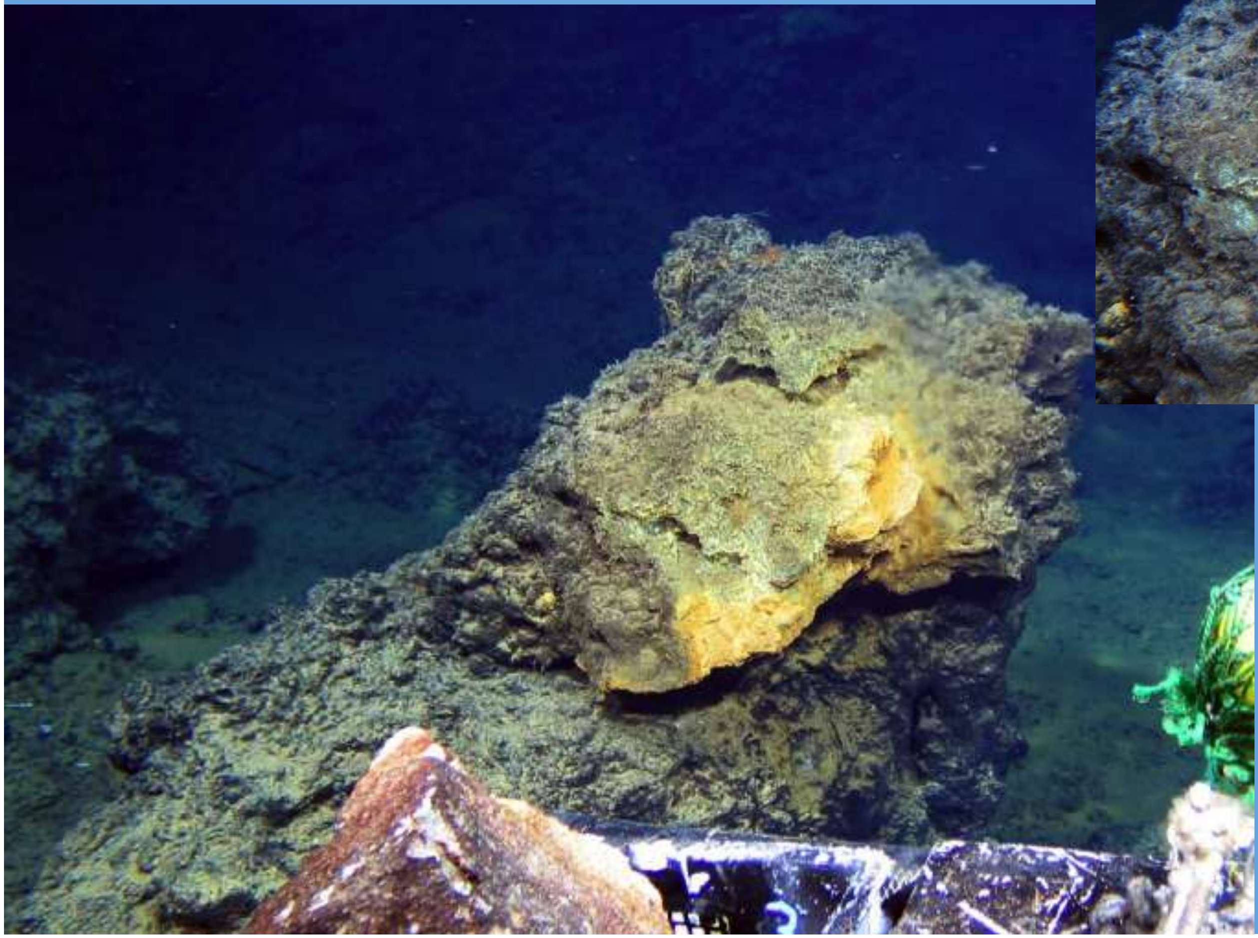


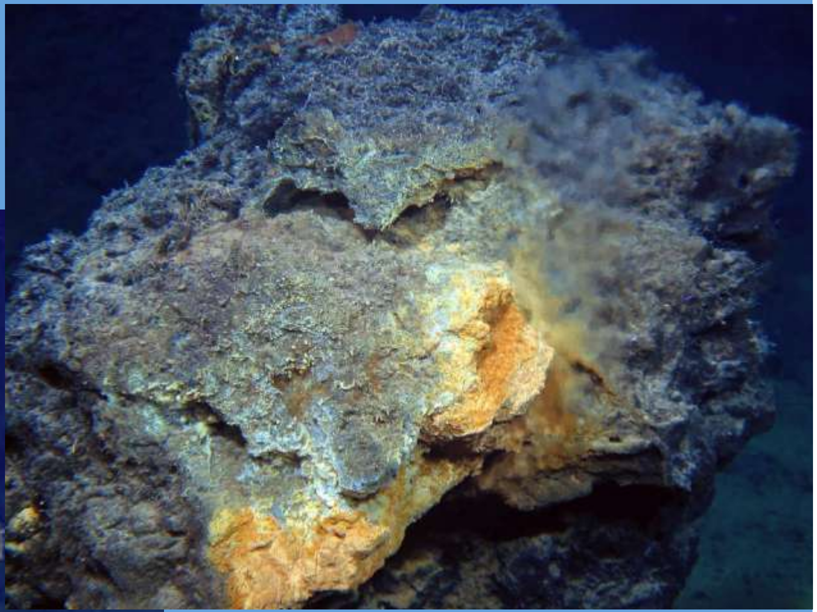
June 2009, a new type of hydrothermal Mn found at East Diamante seamount

■ Hydrothermal Mn sample sites

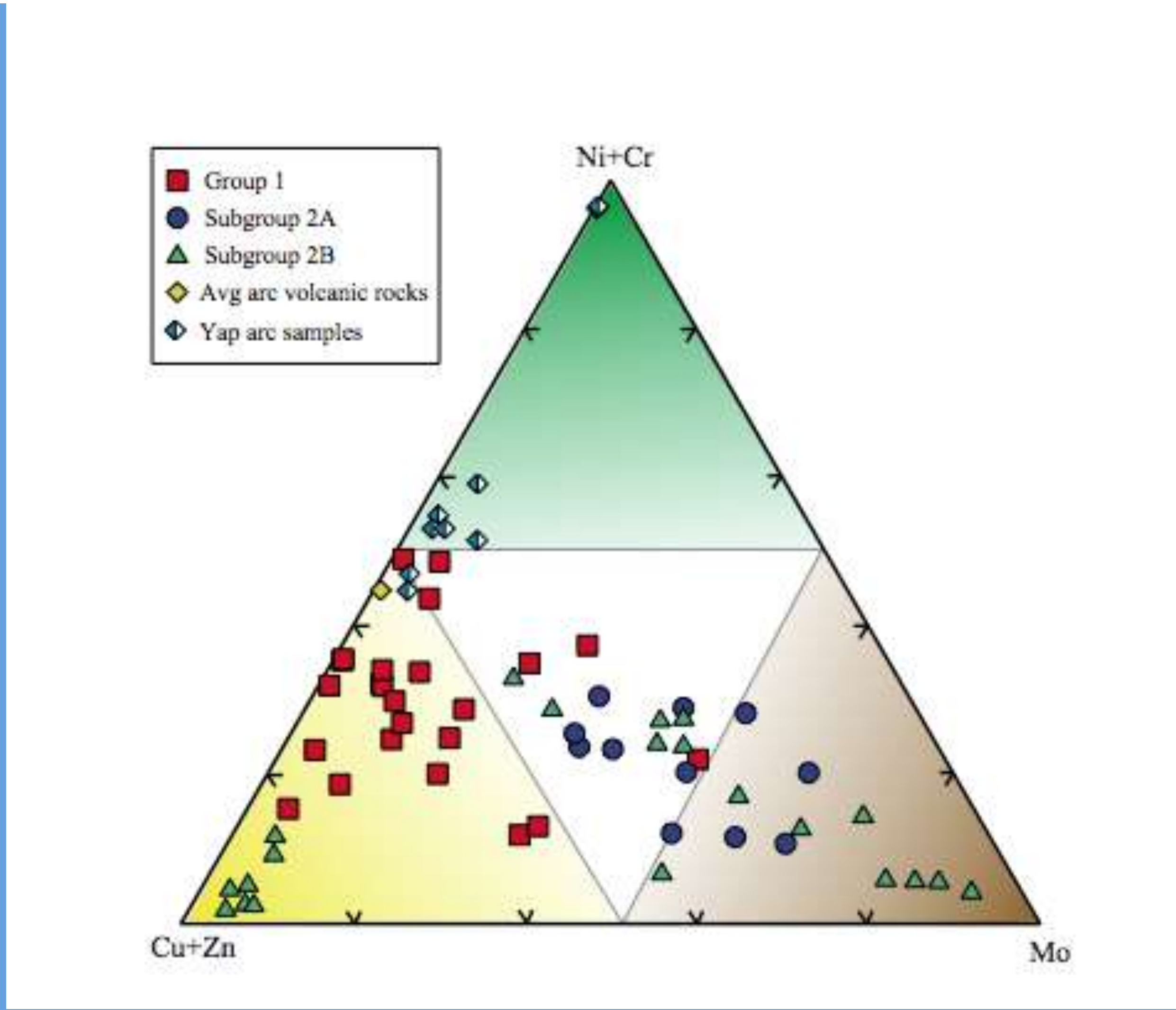
★ Hydrothermal vent sites

Hydrothermal mounds on E. Diamante seamount, Mariana volcanic arc, cruise NT0908

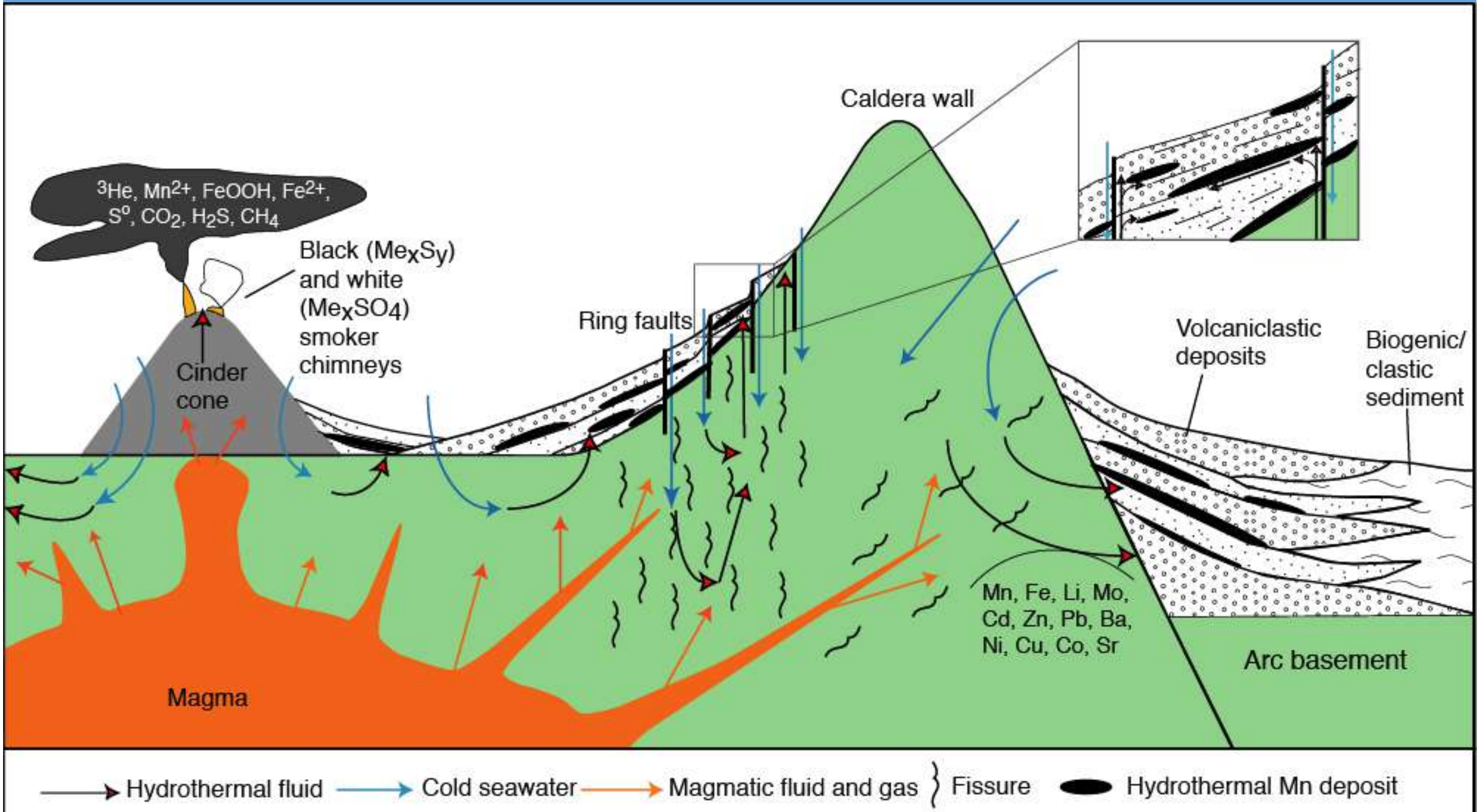




Hydrothermal Mn and Fe oxides from, E. Diamante hydrothermal mounds

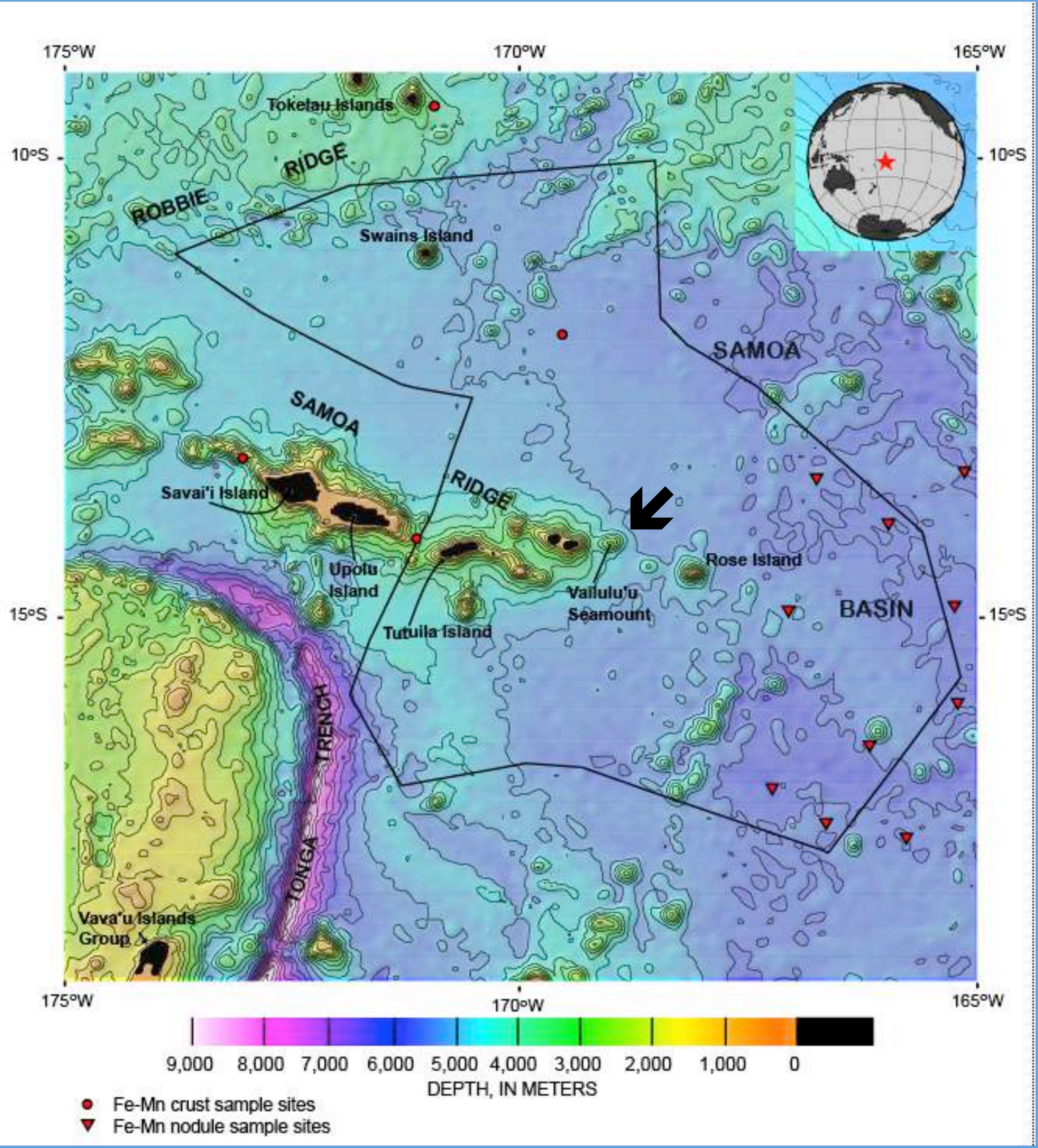


Discriminant ternary plot showing possible sources of trace metals in hydrothermal Mn deposits: Ni+Cr, leaching of ultramafic end-member; Cu+Zn, leaching of sulfide end-member, or non-deposition of sulfides at depth; Mo, high-temperature leaching of intermediate to acidic volcanic arc rocks (from Hein et al. 2008)



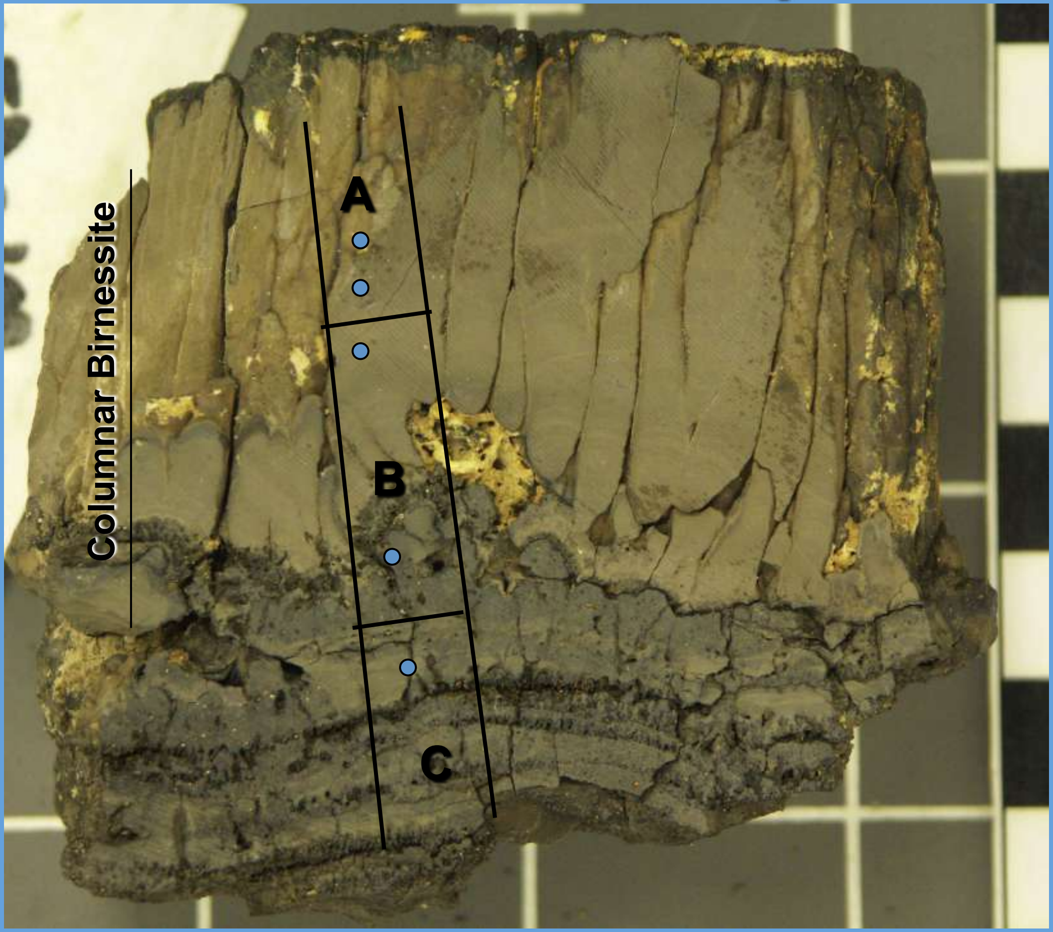
Genetic model for the formation of hydrothermal Mn around a submarine caldera in an active volcanic-arc; Mn predominantly deposited within volcaniclastic-biogenic sediments & stock-work veins; Mn precipitates adjacent to fractures and faults, along bedding planes, and in coarse-grained sediment (from Hein et al. 2008)

Vailulu'u Samoa Hot Spot seamounts



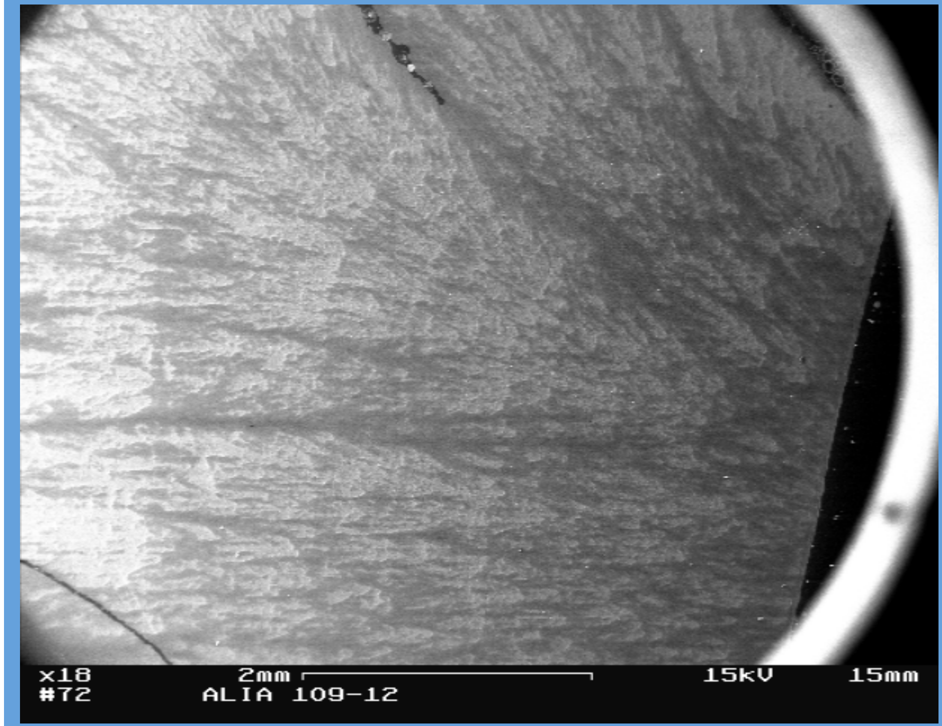
Hydrothermal Mn from the Samoan Hot Spot

Hydrothermal Mn from Samoa Hot Spot: Cross Section of Sample 109-12

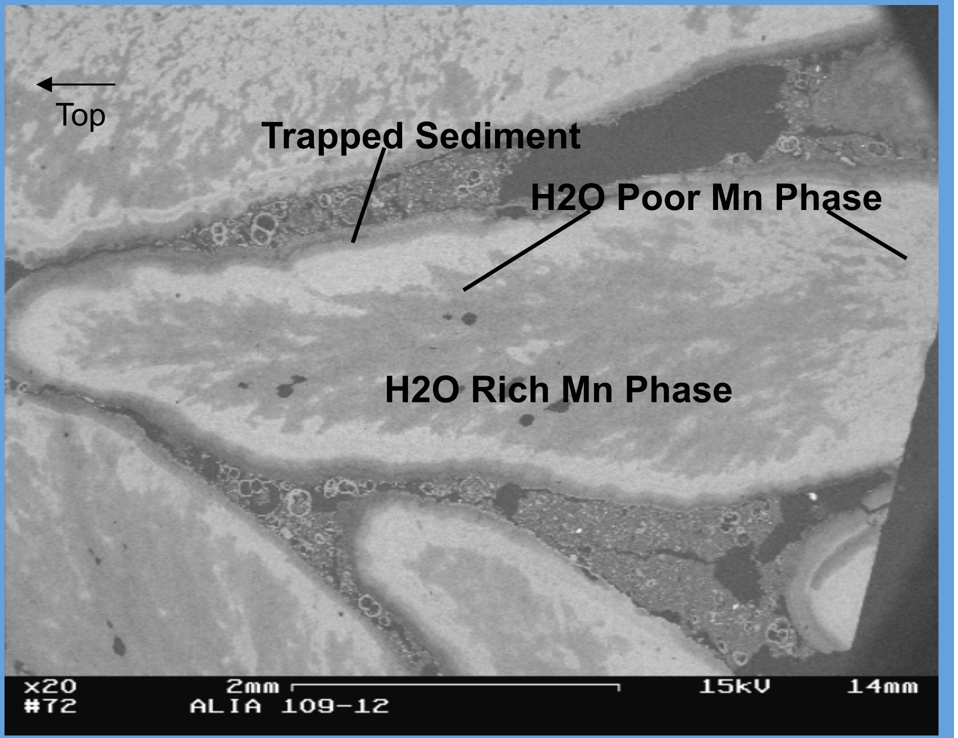


Intervals for polished sections used for SEM and petrographic studies are indicated by letters. The following SEM photos were taken in areas marked by blue circles and are in stratigraphic order through the sample with the top to the left.

Polished Section A

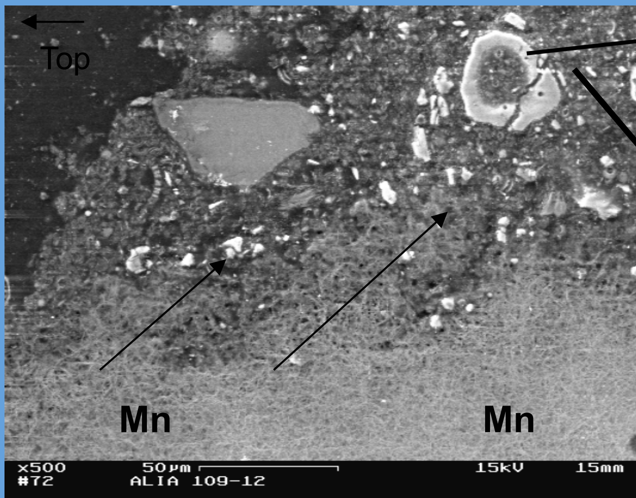


Fan texture at center of 40 mm long columns; fan texture is produced by growth laminae between dendrites

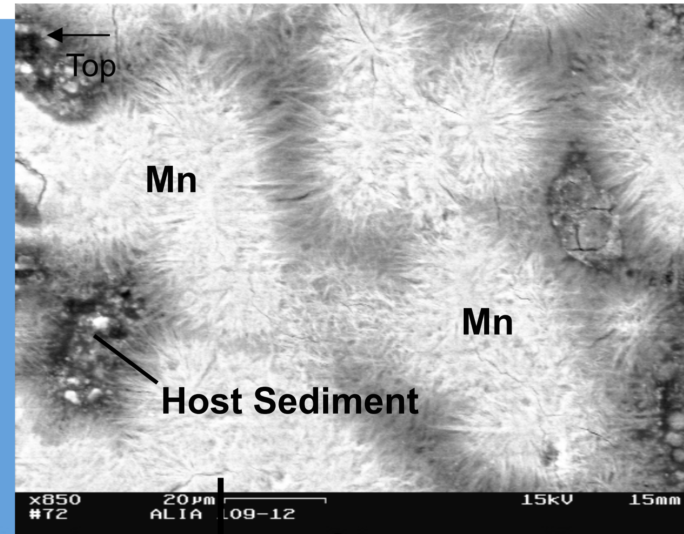


Carbonate sediment trapped between columns with dendritic texture [back-scatter electrons]

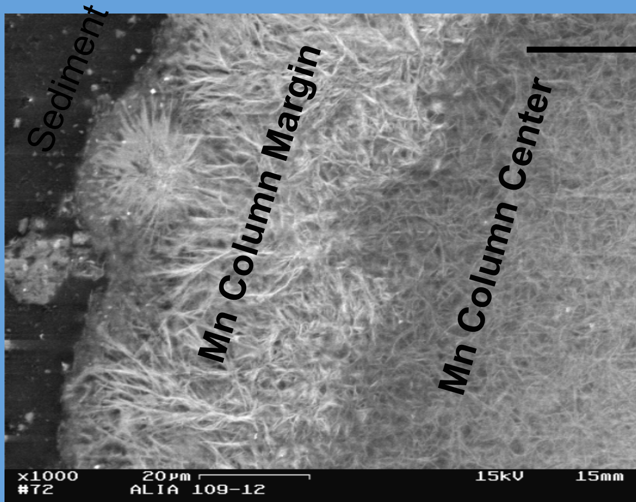
Polished Section B



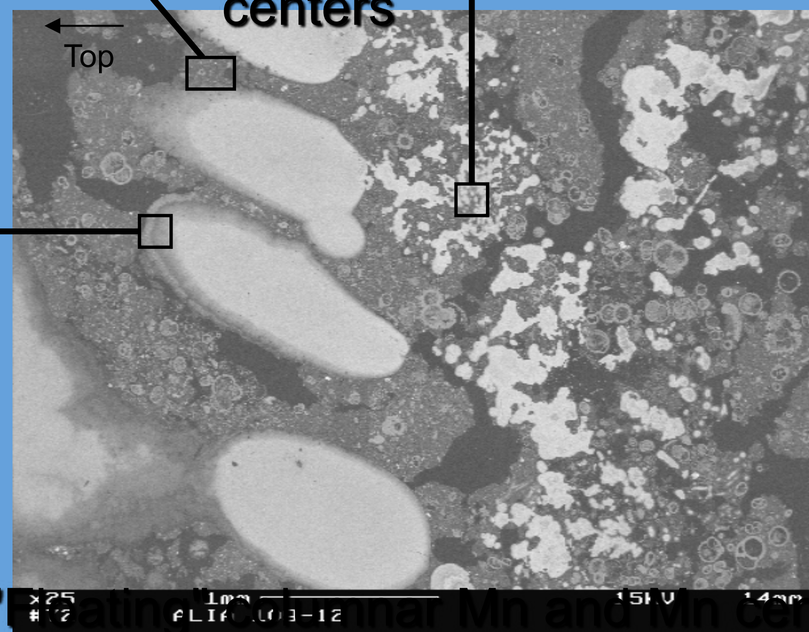
Margin of Mn column; Fe, Si, Al increase and Mn decreases in direction of arrows



Replacement of host sediment by Mn that grew out from nucleation centers

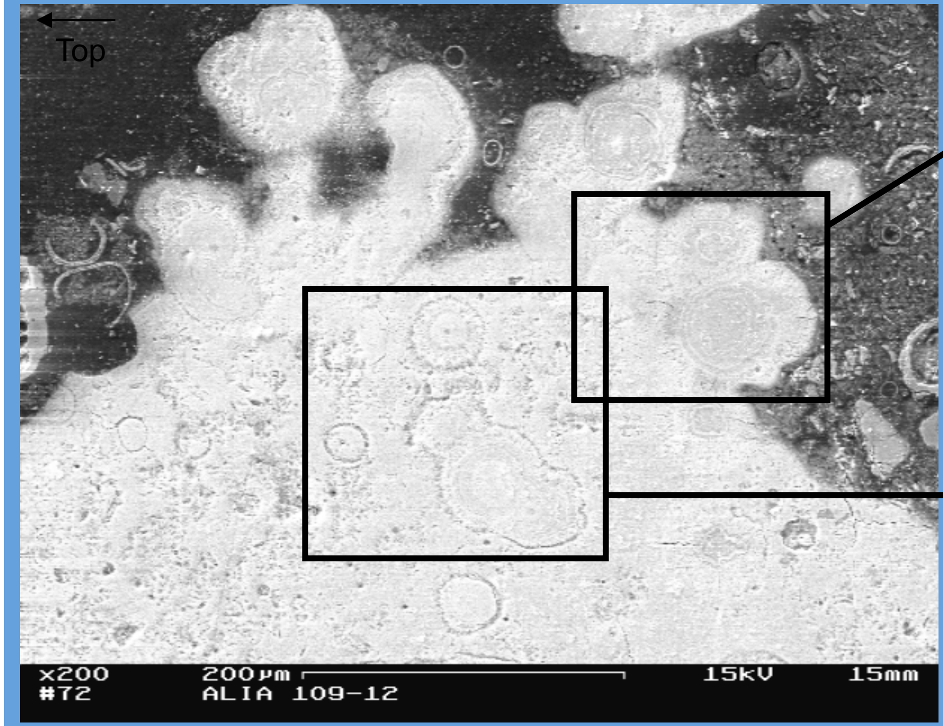


Margin of column

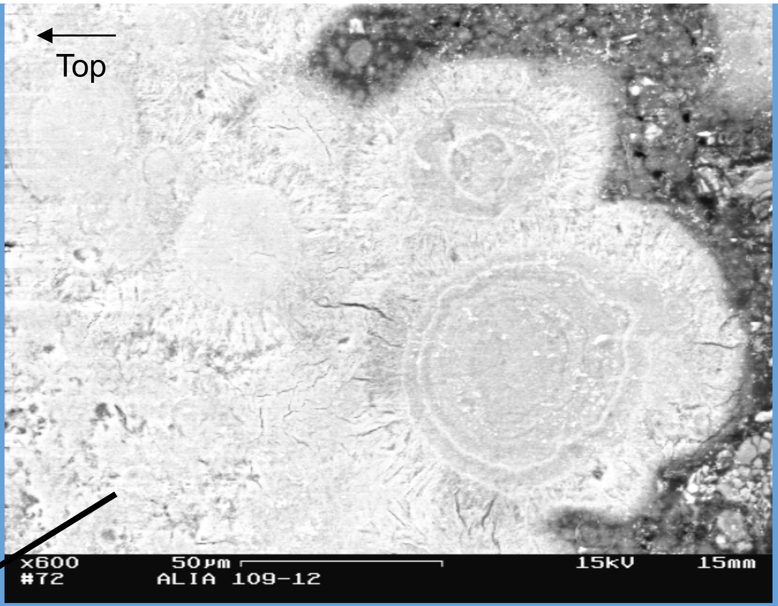


"Floating" Columnar Mn and Mn cement in volcaniclastic/biogenic sediment (dark)

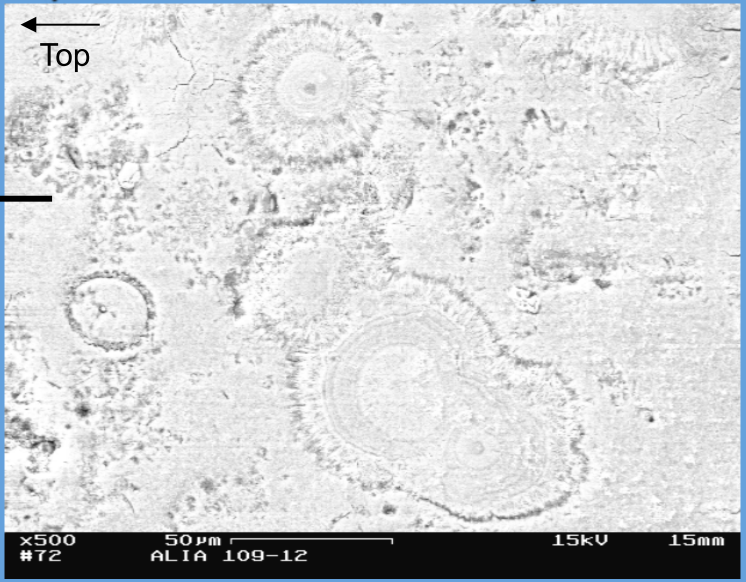
Polished Section B



Replacement of host carbonate sediment by Mn oxide

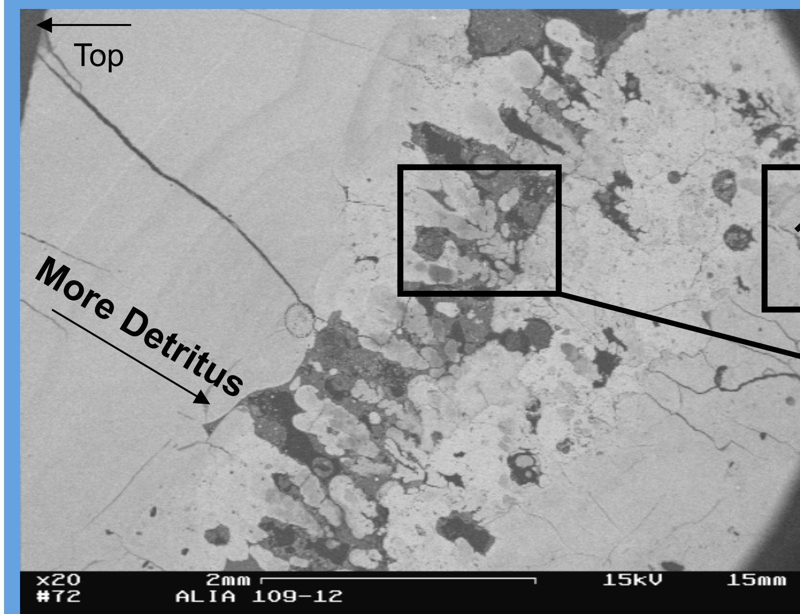


Mn mineralization includes grain growth by several generations of rim cement, precipitation in void, and replacement

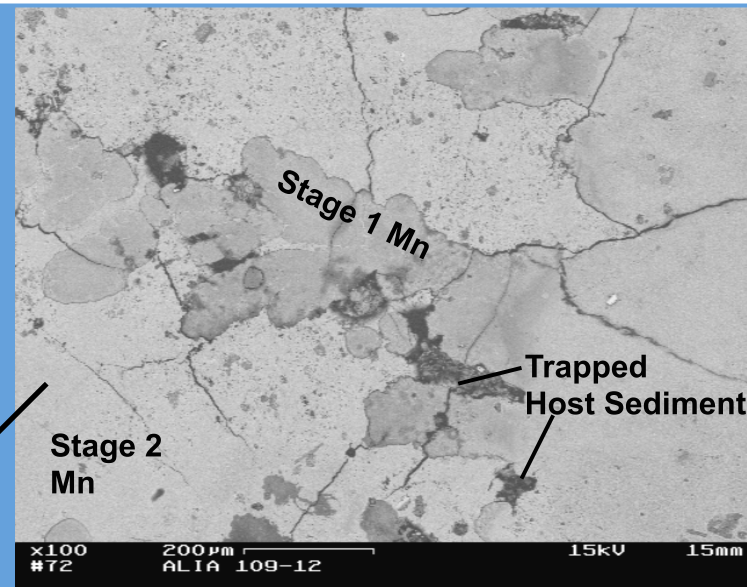


Mn-replaced forams and sediment

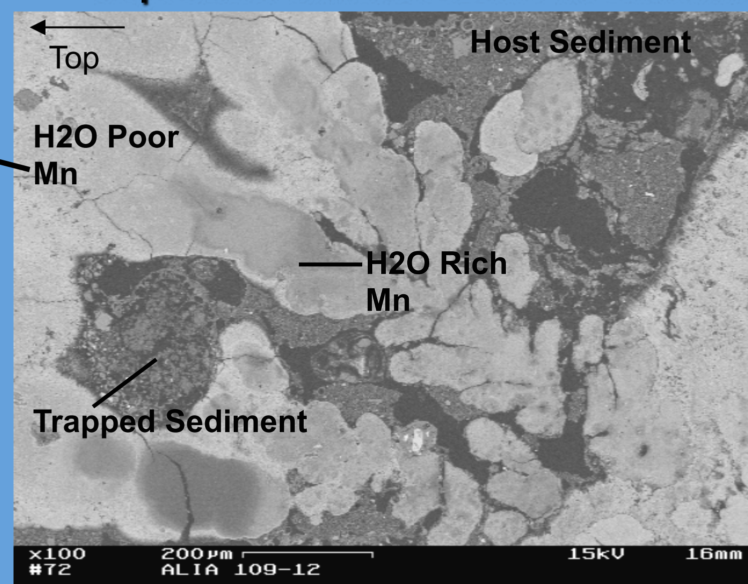
Polished Section C



2 massive Mn layers separated by columnar, porous layer with 1 mm tall columns; botryoidal Mn at top of lower massive layer/bottom of porous layer

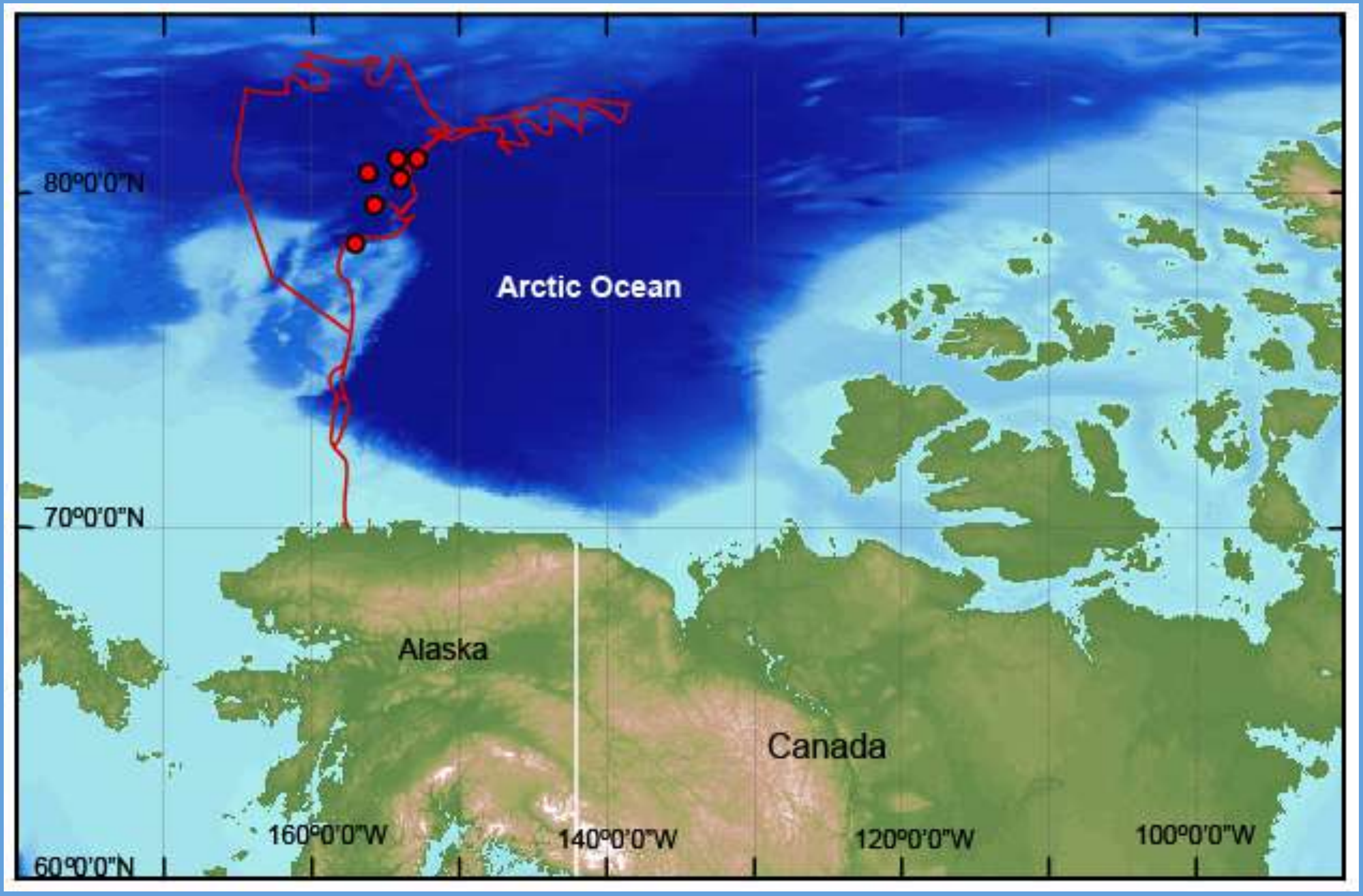


Branching columnar Mn in porous layer replaced microfossils in columns



Branching columnar Mn (dark) grew in porous layer with late-stage massive Mn cement

Location map for Cruise HLY0805



Coast Guard Cutter Healy used to collect Arctic samples for cruise HLY0805

Rocks with Hydrothermal Mn Cement from the Arctic Ocean Cruise HLY0805


Thank You