

Mineral resources of the deep ocean:

characteristics
of the major deposit types and
advances in exploration technology

IFREMER

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Mineral Resources of the Deep Ocean

- ❑ Why the Oceans ?
- ❑ Different types of mineralisations
- ❑ Environment, Ecosystems
- ❑ Technical expertise and equipments

Why the oceans ?

- ❑ Increase of metal demand at the world scale
- ❑ Recent interest of the industry
- ❑ Diversify sources of supply
- ❑ 2/3 of the earth (60% > 2000m)
- ❑ Scientific exploration => various types of mineralisation
- ❑ Minerals are on the seafloor

Copper prices

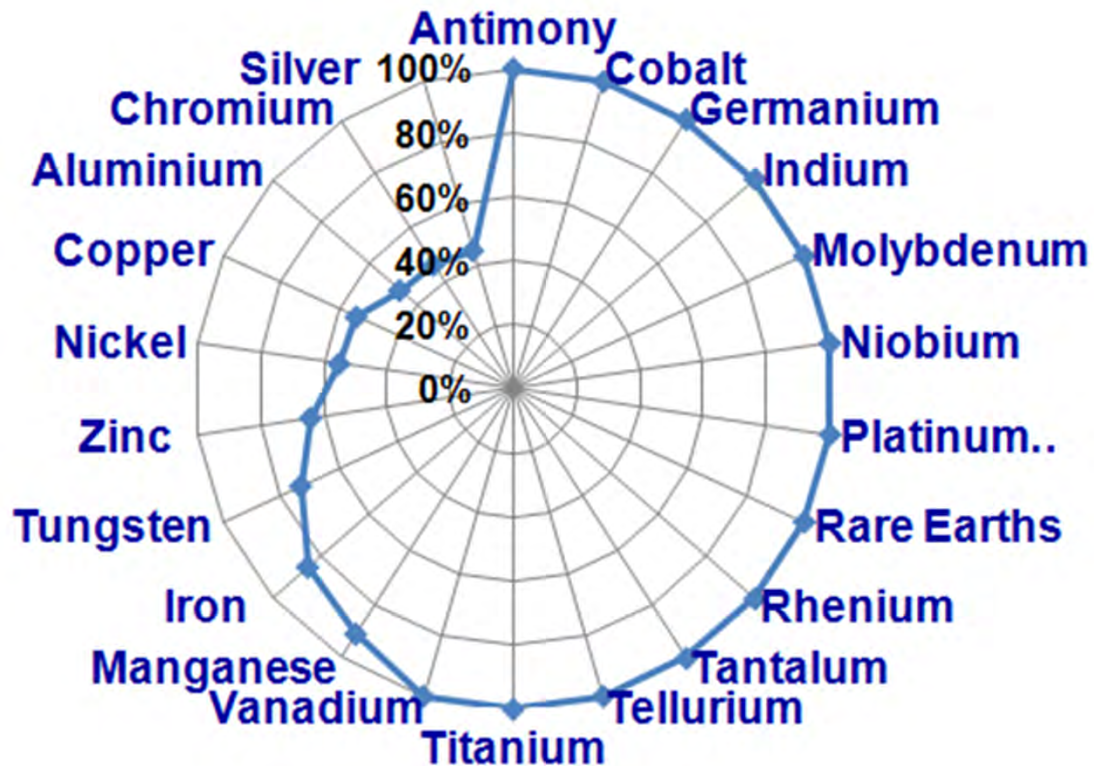


« Strategic » / « Critical » Metals

Criticality : Economic Importance + Supply Risk

- ❑ Rare Earths (95 % China): green energy , electric vehicles, defense industry, lighting, flat screens ...
- ❑ Lithium: batteries (electric vehicles)
- ❑ Niobium (90% Brasil): superalloys, aeronautic and automobile industry
- ❑ Beryllium: aeronautic and future energy (ITER)
- ❑ Rhenium: high temperature superalloys
- ❑ ...

Strong dependance of Europe



- ❑ Base metals : Cu, Fe, Zn, Pb
- ❑ High technology metals
- ❑ Metals for green energy

- ❑ Why the Ocean ?
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Oceanic minerals

Margins, Shelf

Hydrocarbons, hydrates,
sands, gravels, placers...

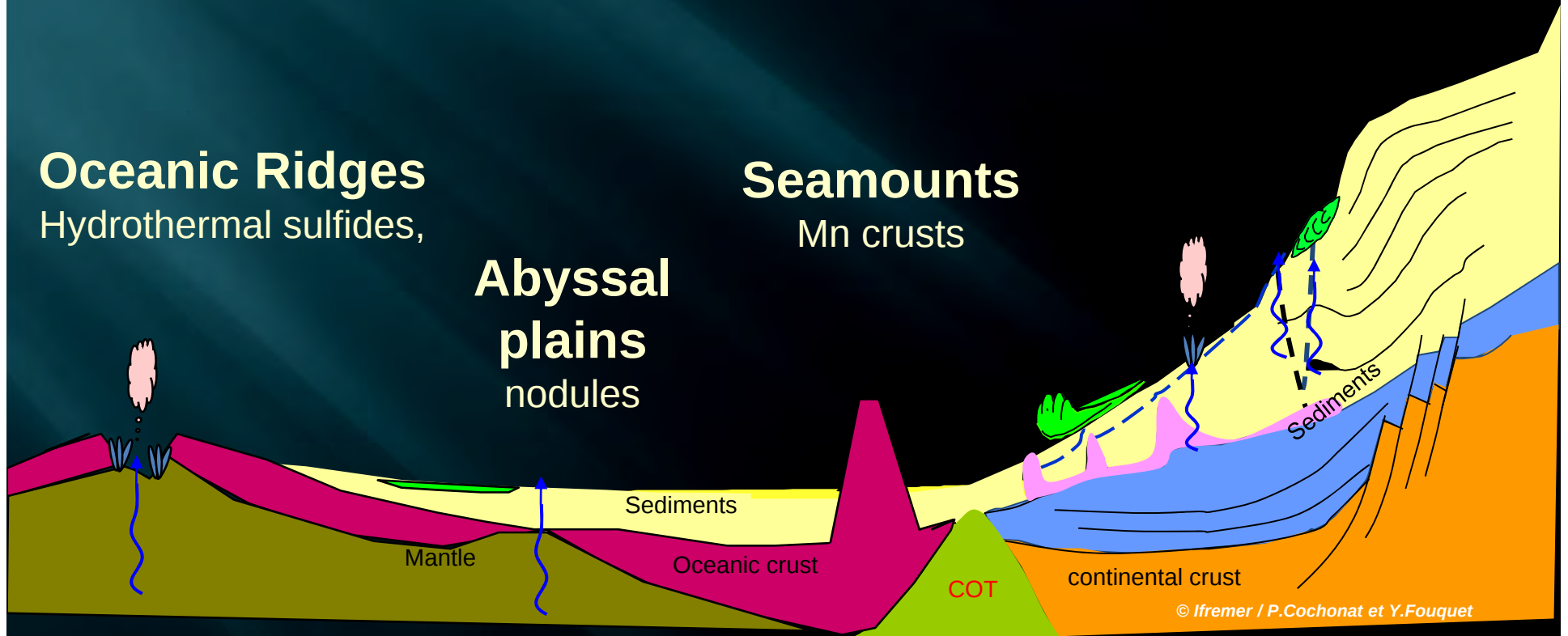
Oceanic Ridges

Hydrothermal sulfides,

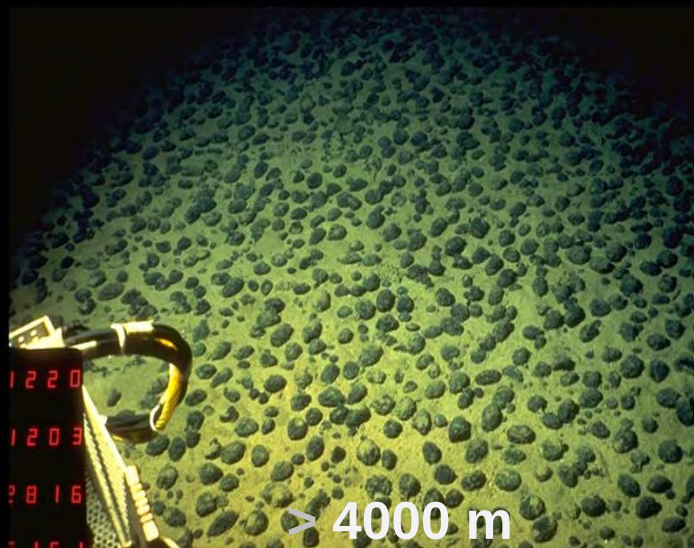
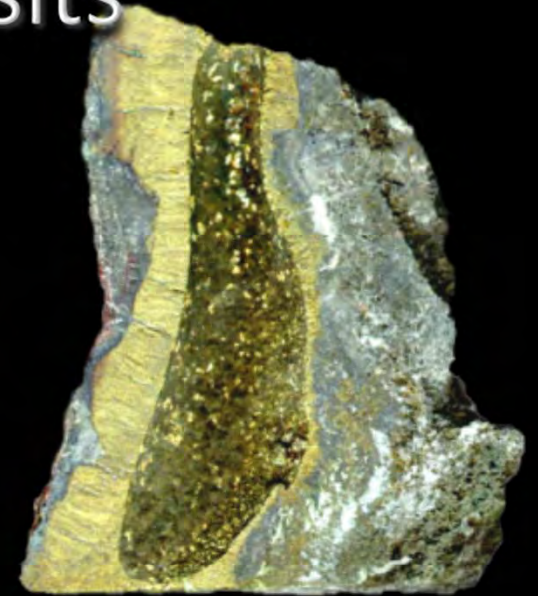
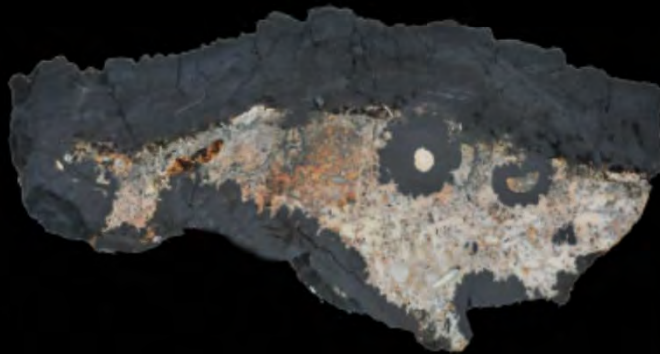
Abyssal plains nodules

Seamounts

Mn crusts

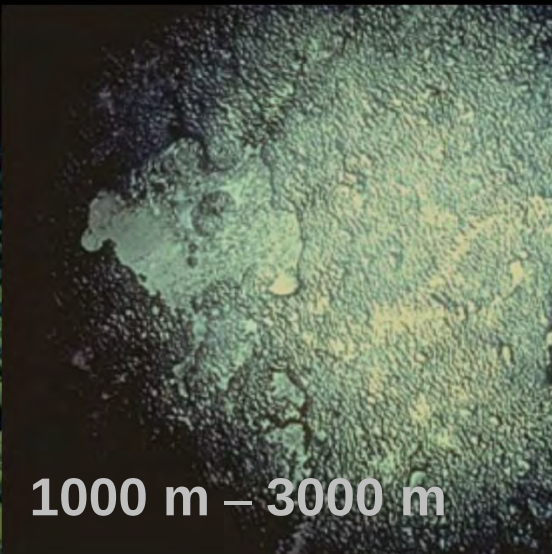


Types of mineral deposits



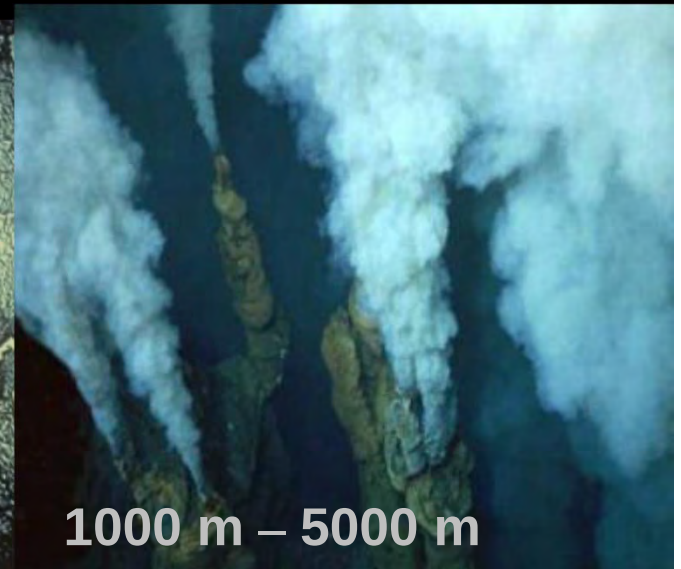
> 4000 m

Polymetallic Nodules



1000 m – 3000 m

Mn crusts

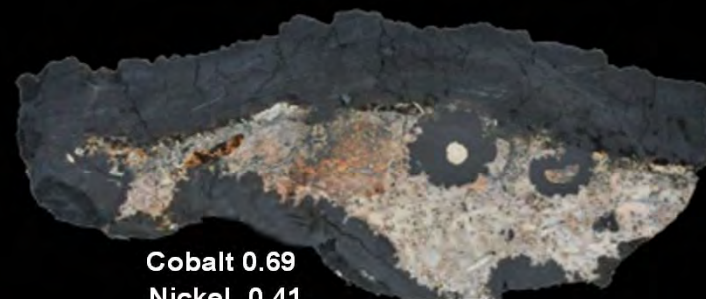
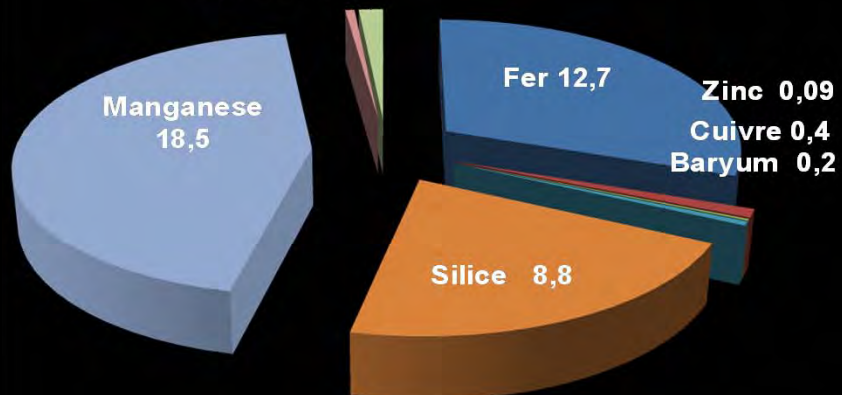


1000 m – 5000 m

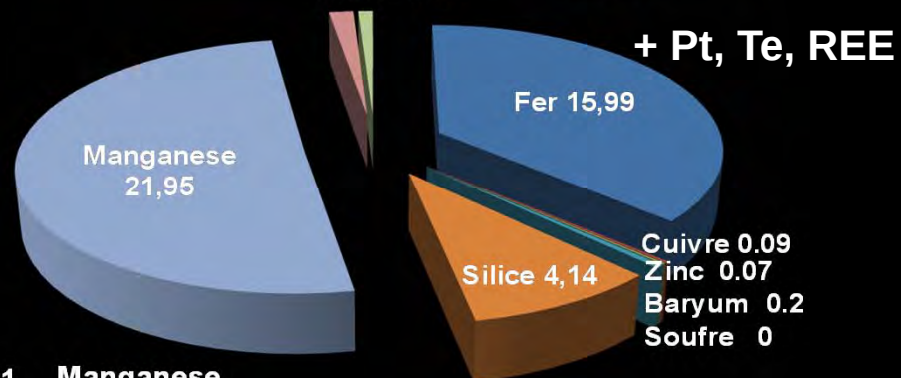
Sulfides

Compositions

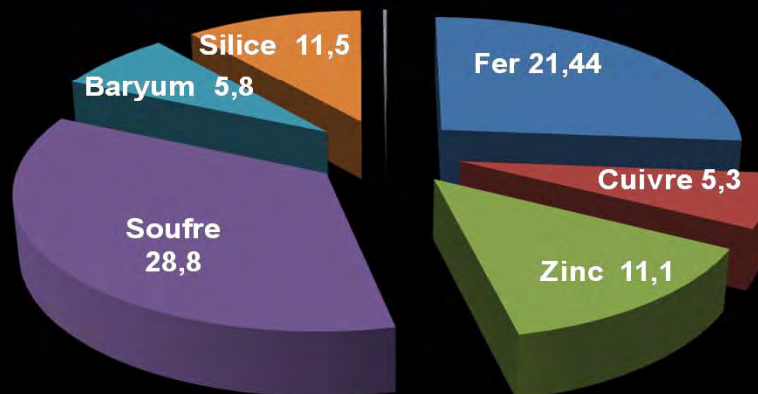
Nickel 0.63
Cobalt 0.24



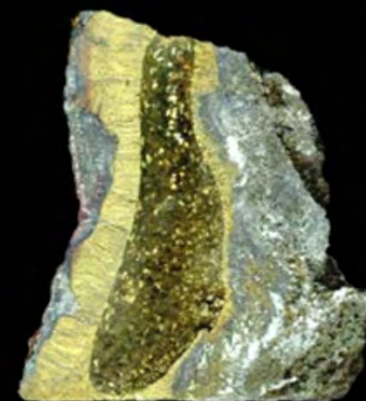
Cobalt 0.69
Nickel 0.41



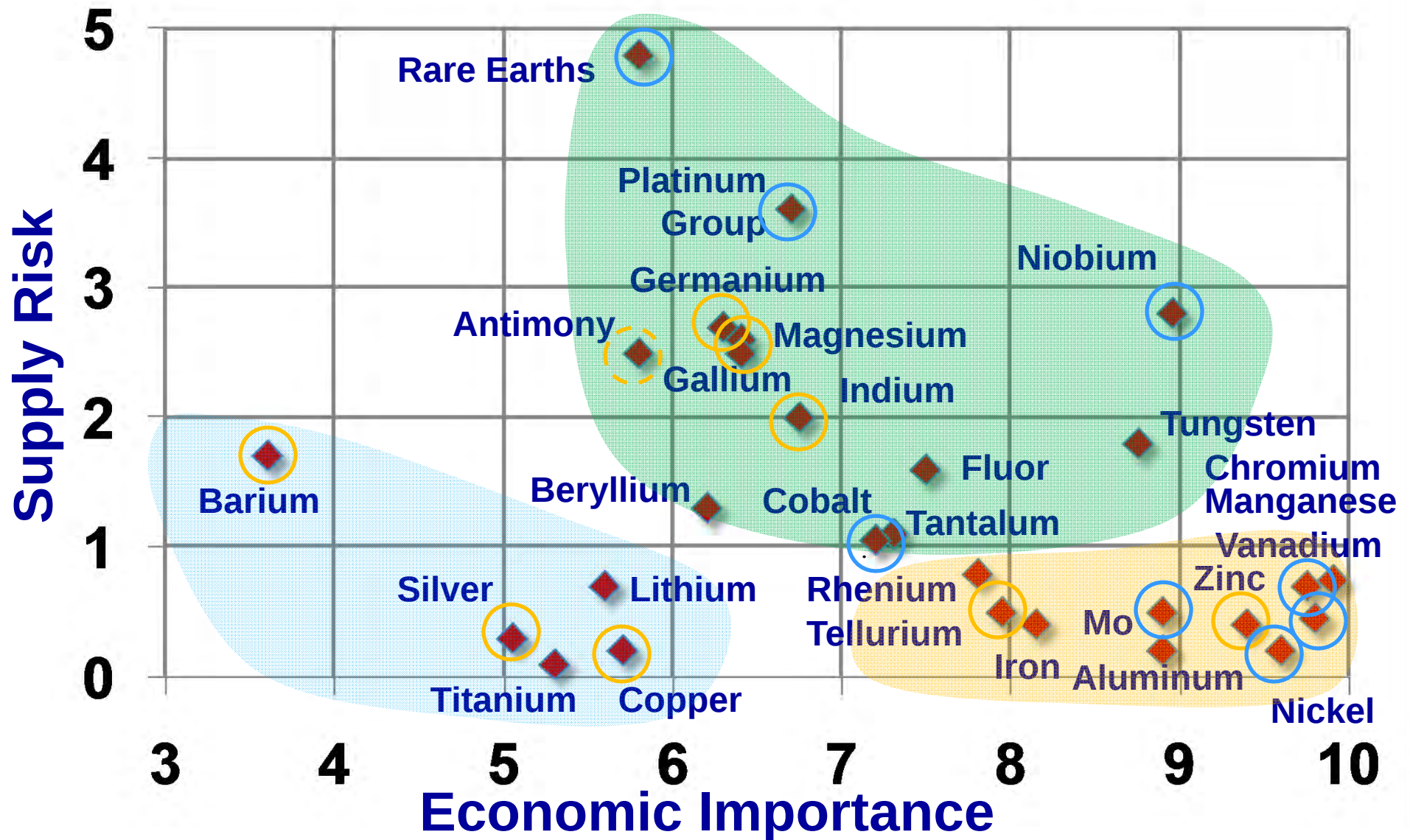
Nickel 0.01
Cobalt 0.05
Manganese 0.09



+ Au, Ag, Pb, Co
In, Ge, Se, Co, Cd,
Bi, Te, Ga, Ge

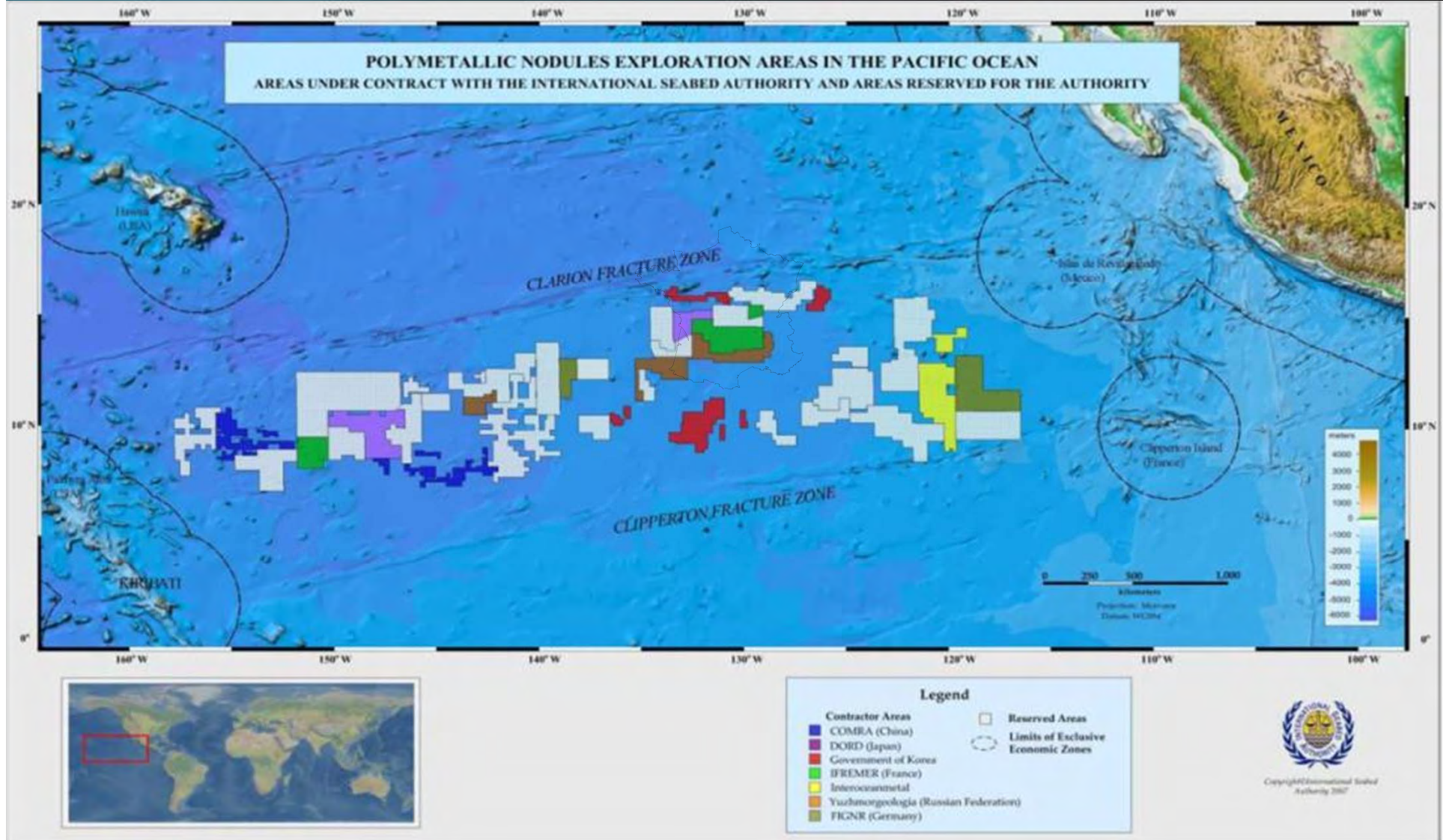


“Criticality” of metals

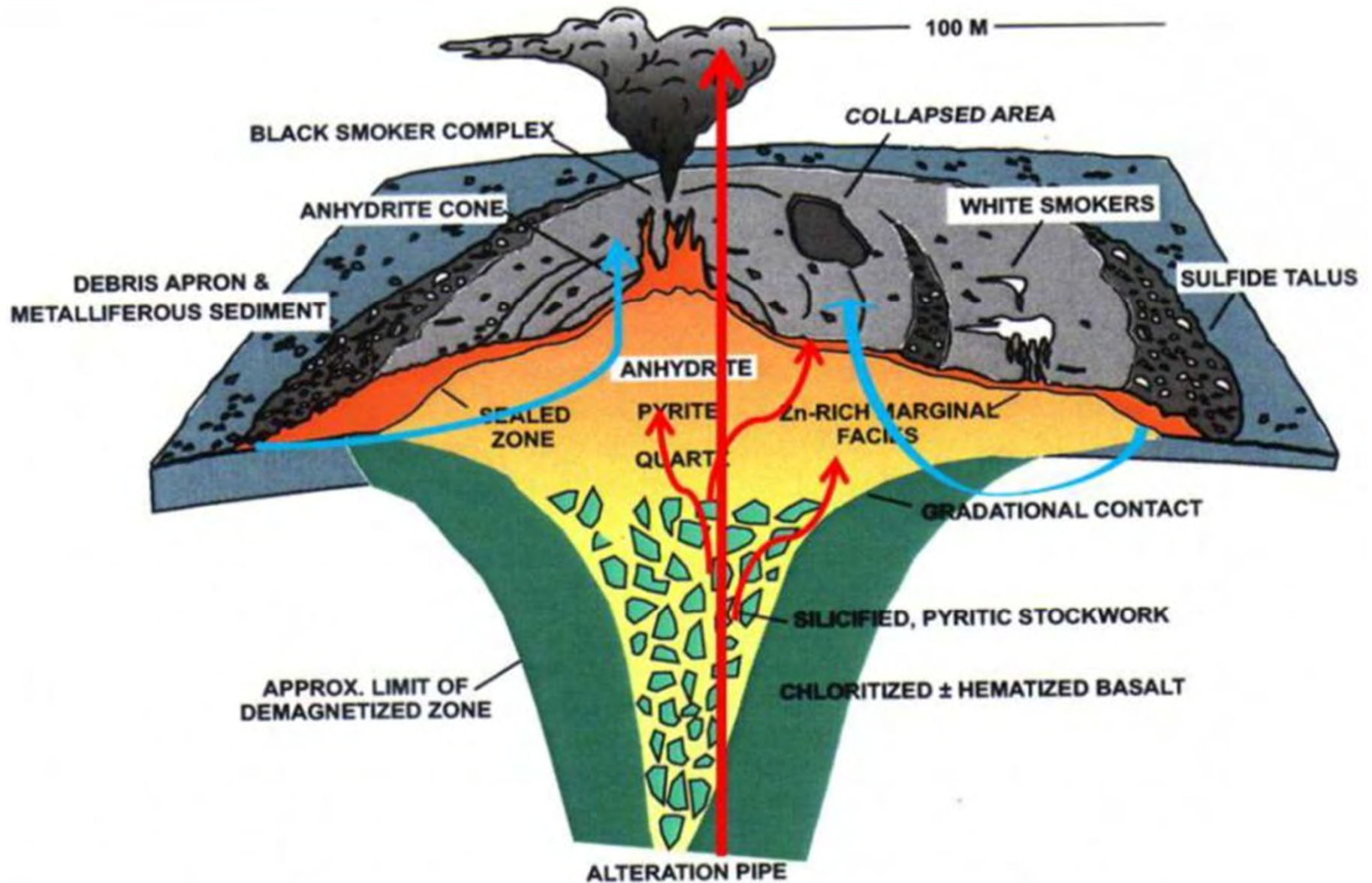


http://ec.europa.eu/enterprise/policies/raw-materials/files/docs/report-b_en.pdf

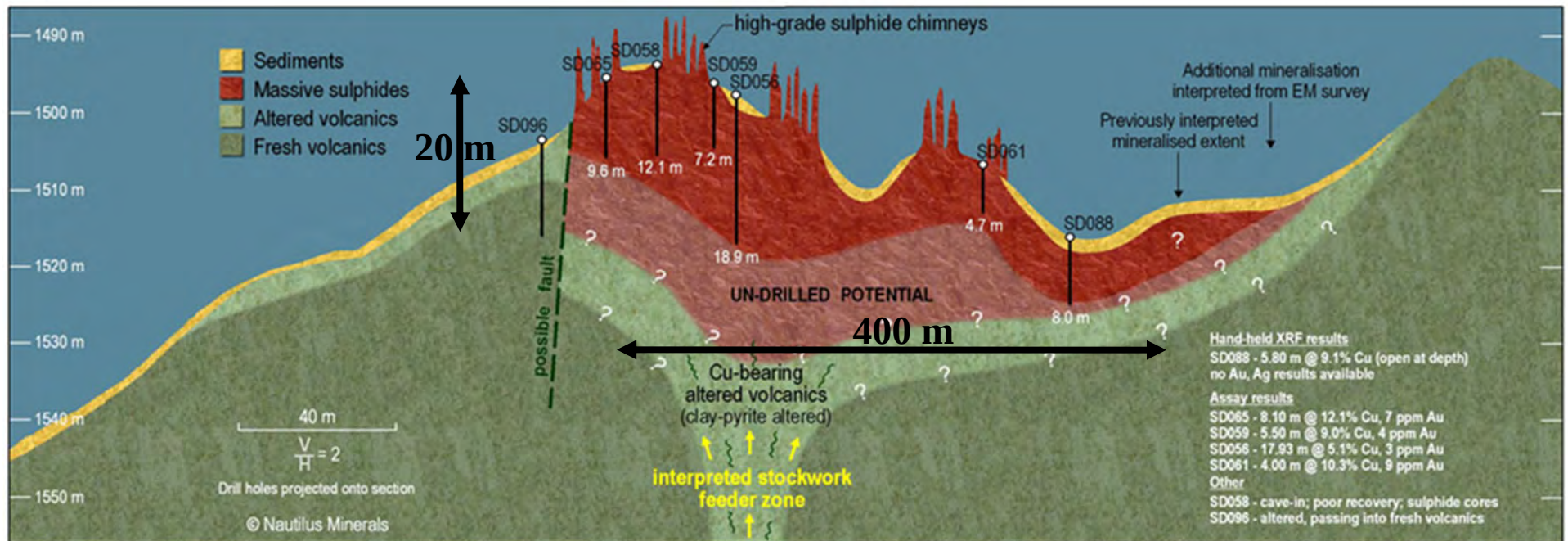
Size of nodule fields and exploration licenses



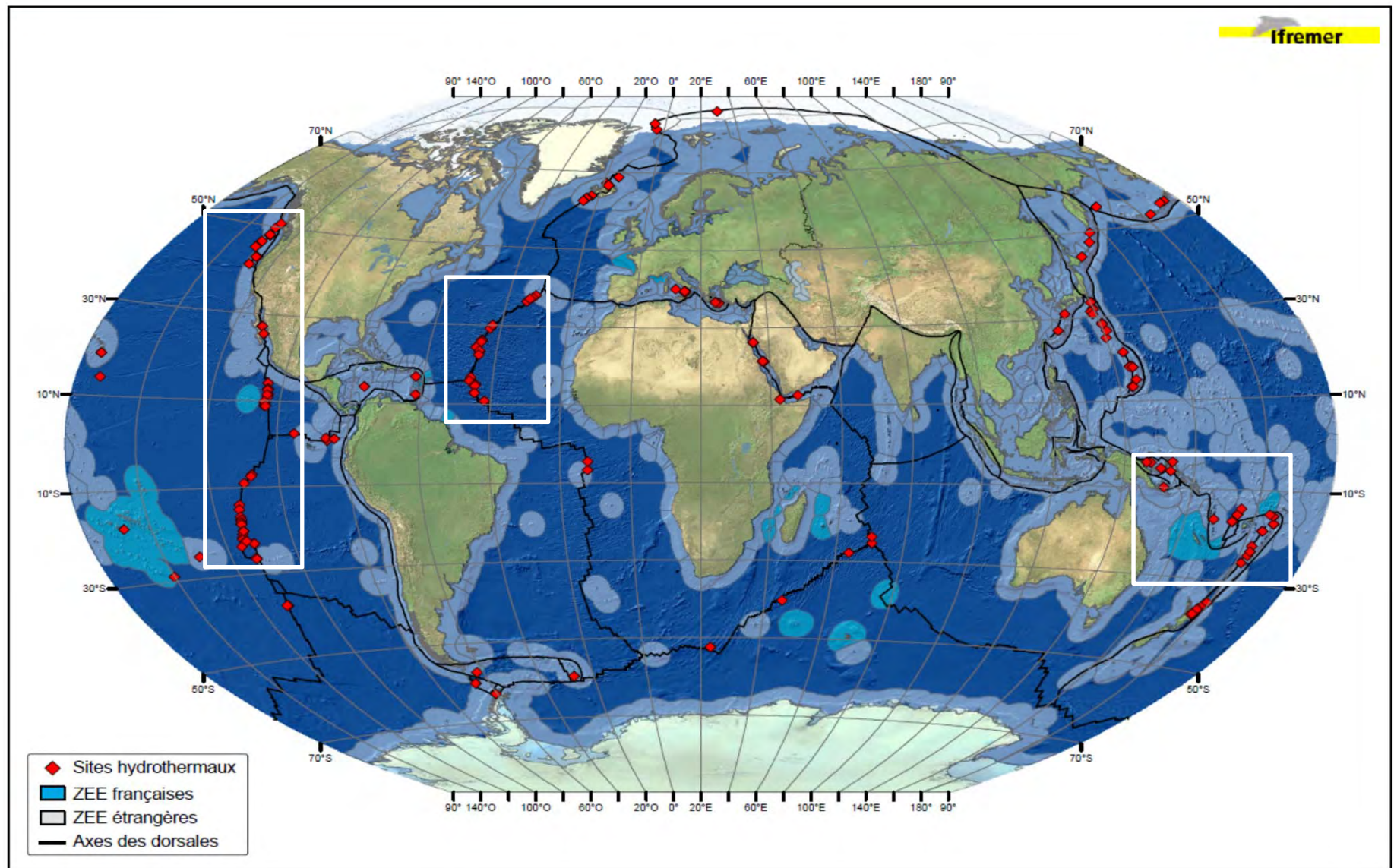
Size of sulfide deposits



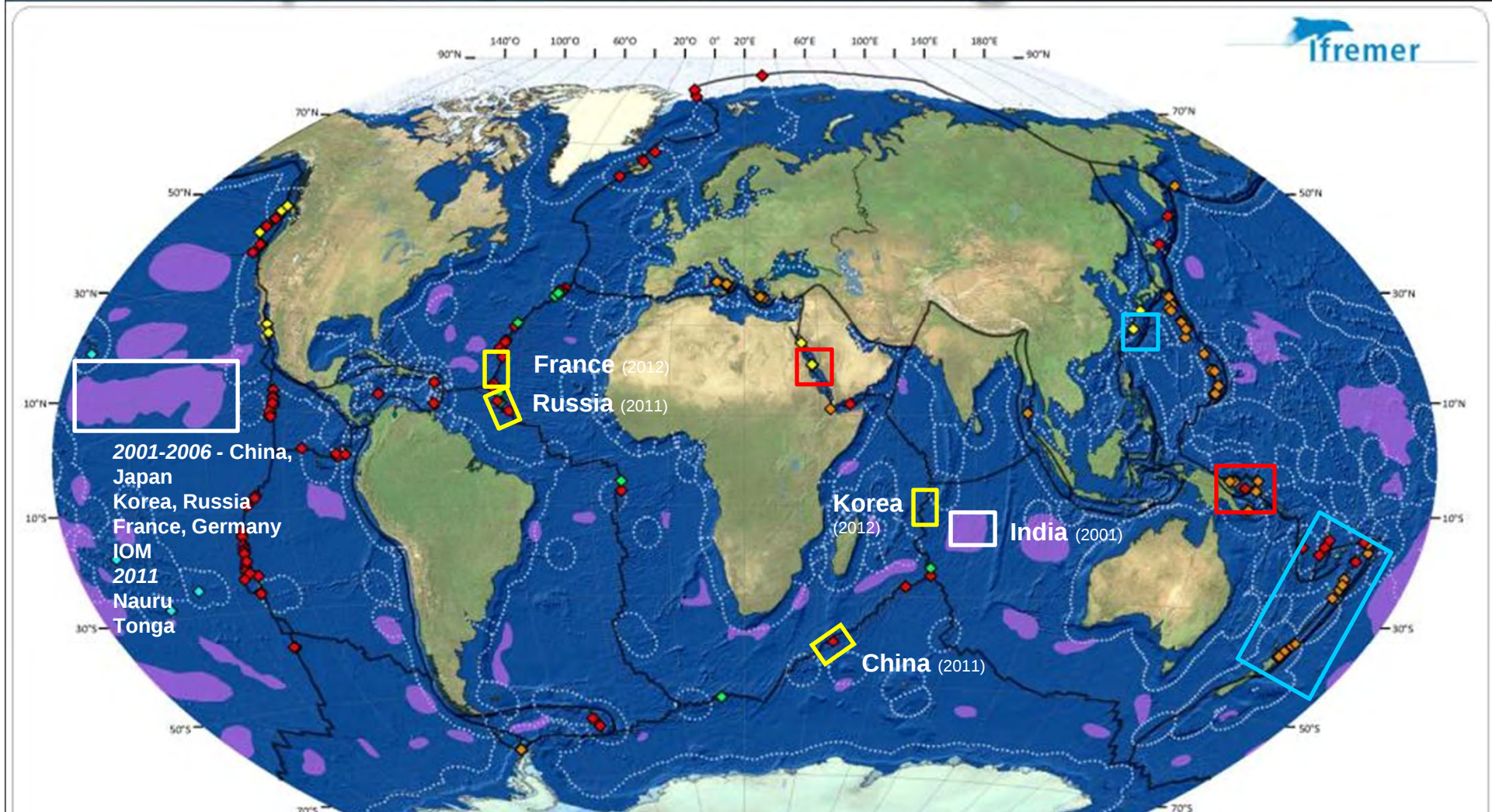
Solwara_1 (PNG)



French experience on hydrothermal deposits



Exploration and mining licenses



Exploration licenses - International water

Nodules

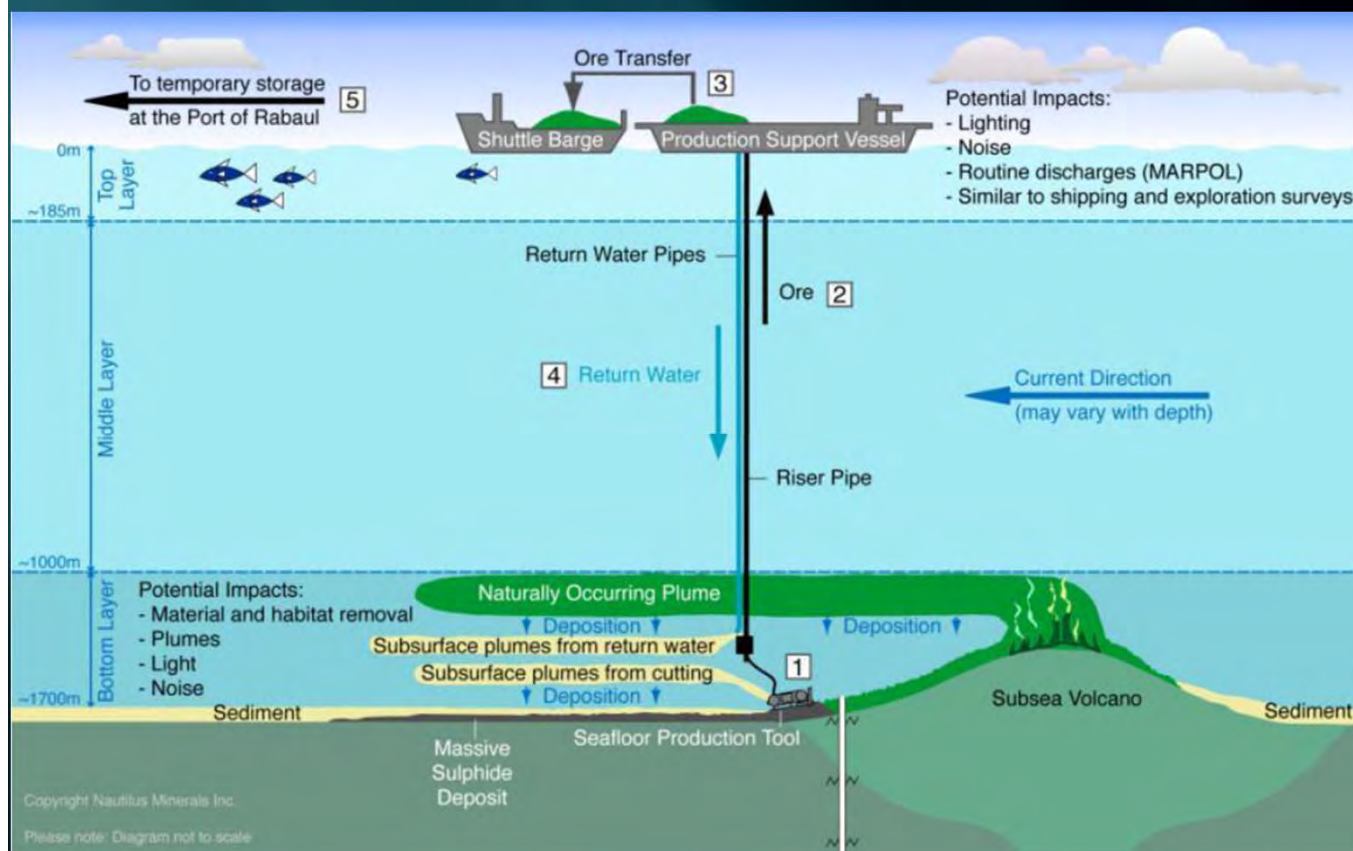
Sulfides
(July 2012)

- ❑ Why the Ocean ?
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Potential impacts: Nature - Scale

Direct Impact : extraction = total destruction of habitats

Indirect Impact : particules plumes = ???



Massive sulfides (3-5 years)

Direct Impact :
< 50 km²

Indirect Impact :
??

Polymetallic Nodules (15 years)

Direct Impact :
10 000 km²

Indirect Impact :
20 000 – 50 000 km²

Deep Sea environments

Hydrothermal sites

Abyssal plains

Seamounts

Sulfides

Nodules

Mn crusts

•Hydrothermal Ecosystems

High biomass, Weak diversity,
High endemism

Sedimentary faunas

Weak Biomass, High diversity
Weak endemism

Seamounts faunas

Variable biomass and diversity,
Variable endemism?

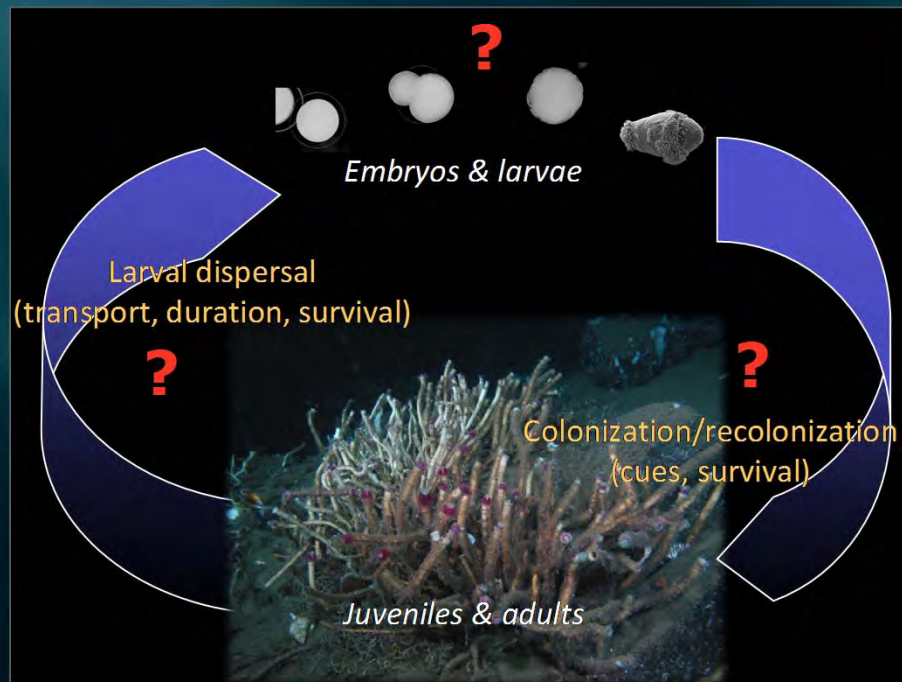


Vulnerability, Resilience, of Ecosystems

Endemism, Connectivity

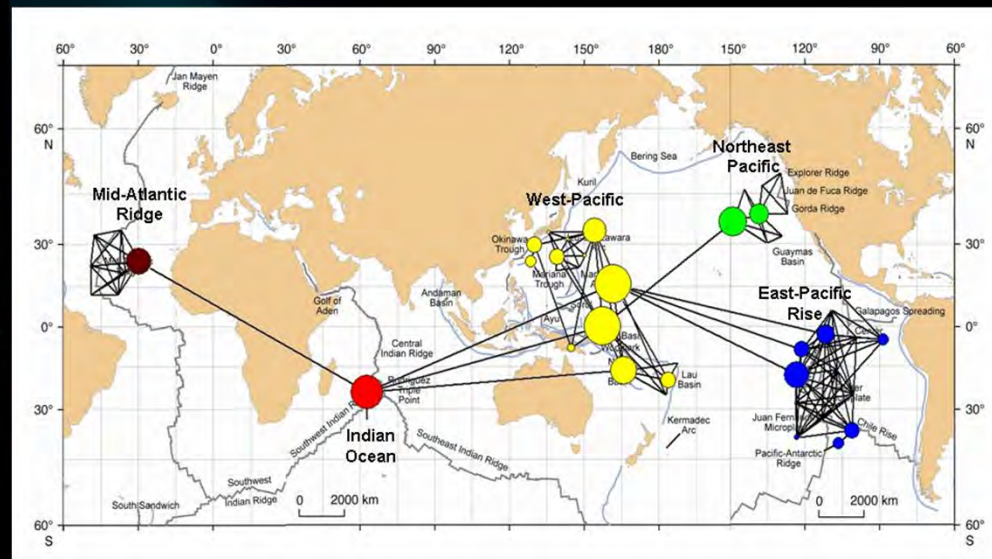
Are populations connected and what are the patterns of connectivity (e.g. source-sink)?

Phylogeographic analyses, Phylogenetic analyses, Larval ecology ...



Biogeography of vent communities

Five biogeographic provinces



From Moalic et al., 2011

- ❑ Why the Ocean ?
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R.V. L'Atalante

- 85 m long – 16 m wide – 3550 T – Built 1989
- Multibeam deep echosounder Simrad EM 122
- Multibeam shallow echosounder EM 710
- Single beam echosounder ER 60
- Doppler current meter , gravimeter, magnetometer.
- Ultra short positioning system
- 30 scientists
- Can operate ROV, Nautilie, AUV



R.V. Pourquoi Pas ?

- 108 m long – 20 m wide – 6600 T – Built 2005
 - Deep Multibeam echosounder dual frequency
 - Single beam echosounder ER 60
 - Doppler current meter , gravimeter, magnetometer.
 - Ultra short positioning system
- 40 scientists
 - Can operate ROV, Nautilie, AUV, Sonar, ...



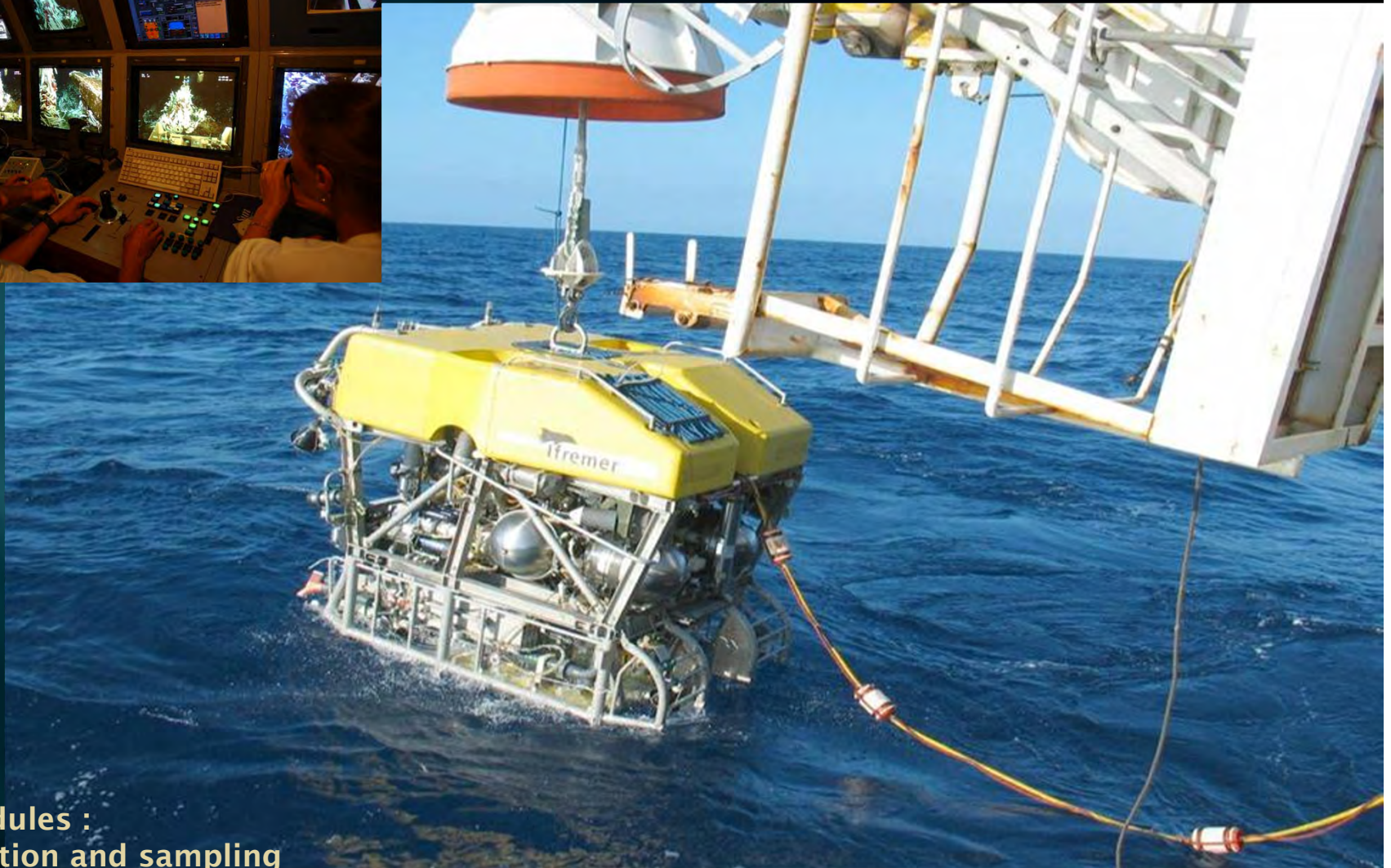
Autonomous vehicle : AUV-AsterX

Near seafloor (70 m) high resolution survey

- Microbathymetry (~1 m)
- Acoustic imagery (~1 m)
- Water column signal
- Magnetic survey



Remote Operated Vehicle : ROV-Victor



Two modules :

- Exploration and sampling
- Detailed observation, measurements and sampling (Rocks, Sediments, Fluids, Animals)

The Nautilé :

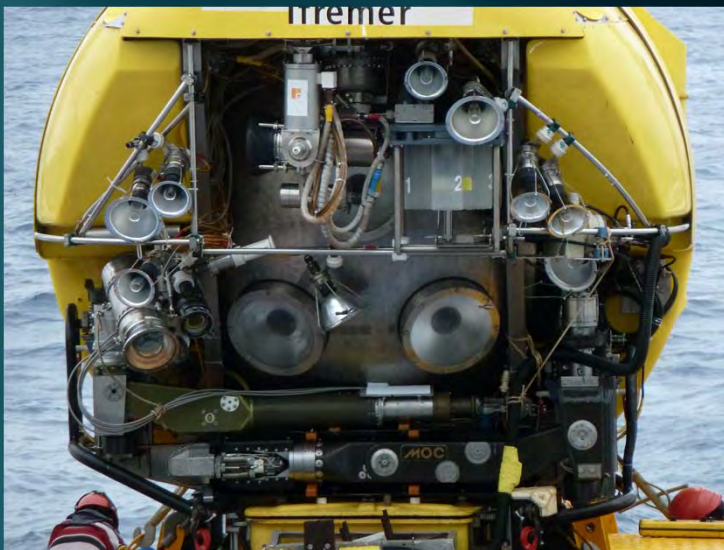
Manned submersible (< 6000m)



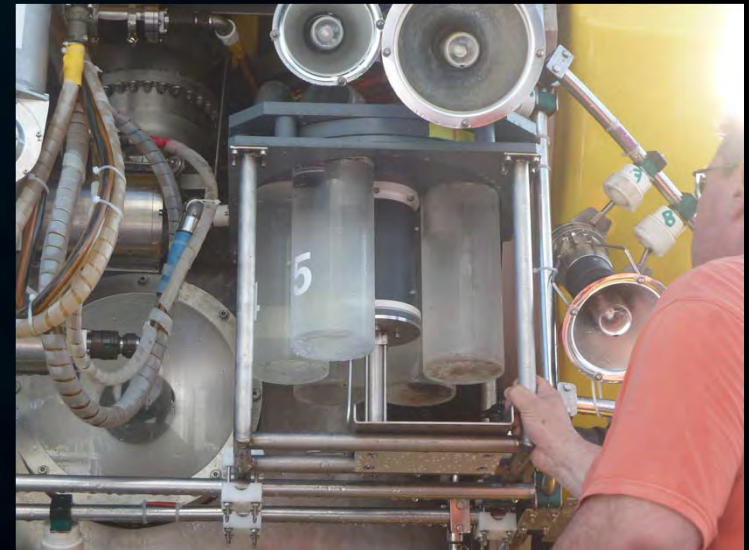
Interior of the Nautilé



Detailed observation, measurements
and sampling (Rocks, Sediments, fluid
Animals)



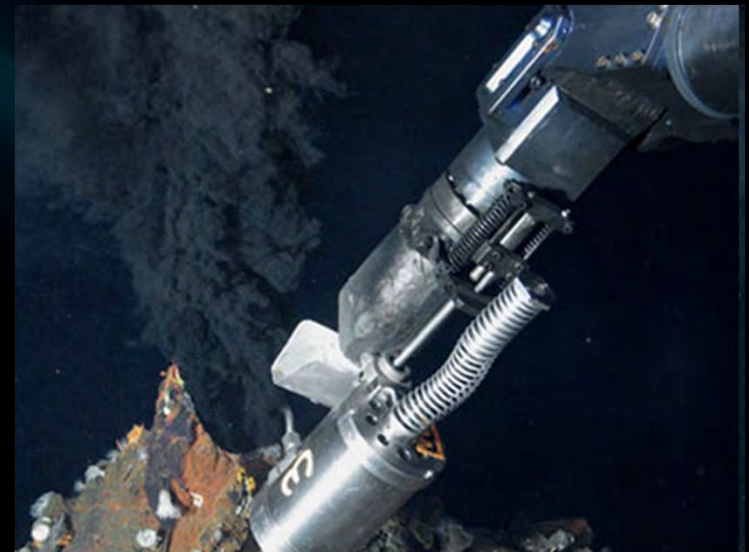
Front of the Nautilie with the suction sampler (up left) and the arms



Bowls of the suction sampler dedicated to faunal collection

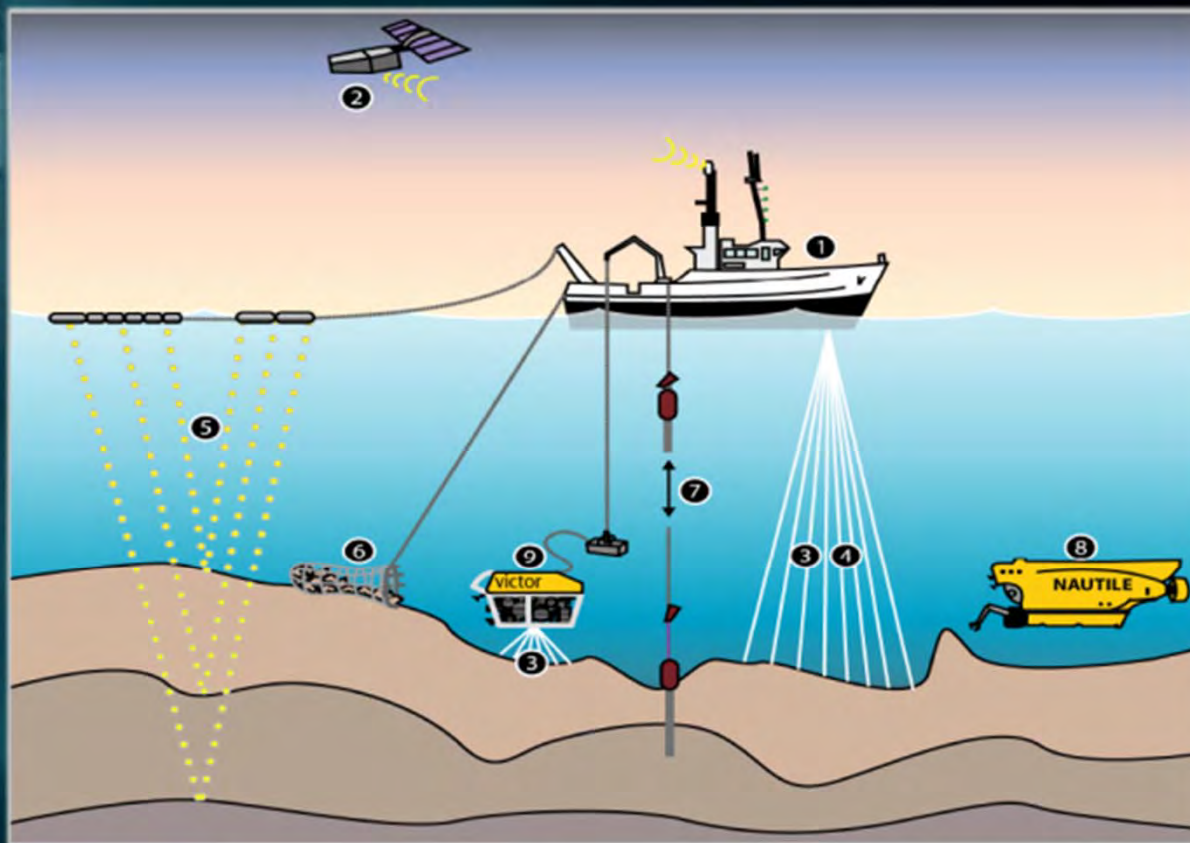


Sampling box (here open)



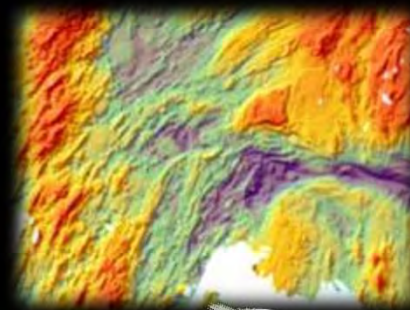
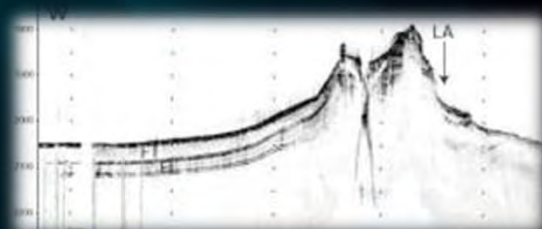
Titanium bottles for high temperature fluids sampling

Exploration technologies



Légende :

- ① Navire océanographique
- ② Positionnement par satellite (GPS)
- ③ Sondeur multifaisceau
- ④ Sonar à balayage latéral
- ⑤ Sismique réflexion
- ⑥ Drague
- ⑦ Carottage
- ⑧ Nautil
- ⑨ Victor (ROV)



Processing and analytical facilities

Onboard

- **Bathymetry**: processing of maps, images and water column
- **Water samples**: lab. container CH_4 , Mn, H_2S , SiO_2 , Salinity, gas extraction, gas chromatography, in situ measurements (Mn, CTD, nephelometry)
- **Rocks**: mineral and chemical analyses (XRF, XRD), microscopy,
- **Geophysics**: processing of near seafloor magnetic data
- **Biology**: preservation of samples In-situ probes, analyzers for O_2 , H_2S , CH_4

Onshore

- **Map and images** : tectonic volcanic interpretations, types of habitats
- **Rocks** : minor elements analyses (XRF, ICP-MS) ; Isotopes analyses (S, Pb, Sr, Fe, Cu, Ni, Sb, (TIMS, MC-ICP-MS)
- **Water and gas samples** : major and minor elements, C H2 isotopes; He isotopes
- **Geophysical data** : processing of water column data and magnetic data
- **Biology** : Faunal sorting and identification, video mosaic, DNA barcoding, C and N isotopes (food webs)

Major Issues

- ❑ Science: Exploration - Geosciences + Biology
- ❑ Environment : Biodiversity, Ecosystem functioning
- ❑ Economy: potential Resources
- ❑ Technology : Exploration, Evaluation , Exploitation, Preservation
- ❑ Legal : ZEE and international
- ❑ Geopolitical : diversify sources of supply
- ❑ Education et formation: geology, biology, technology

Thank you for your attention

http://wwz.ifremer.fr/drogm_eng/Mineral-resources

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Martin Patriat

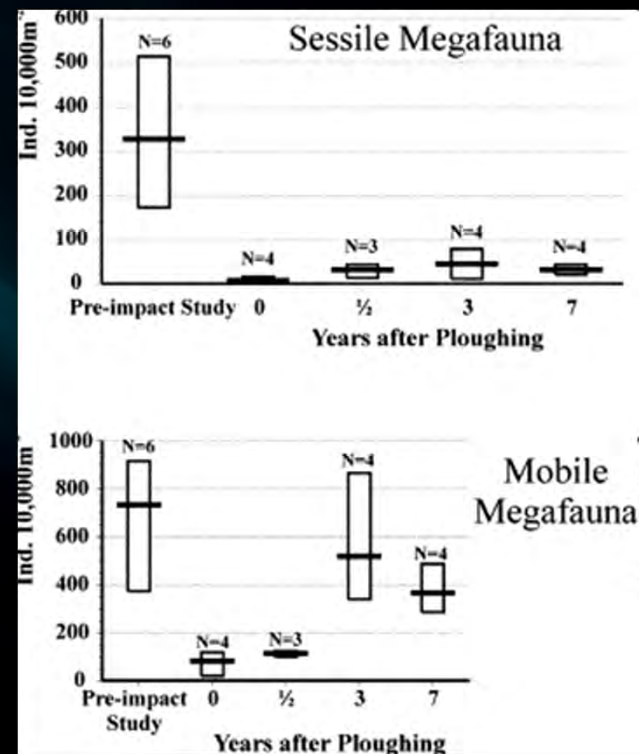
Géosciences marines / Nouméa

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Mining Impact



Impact of harrow on seafloor faunas



Bluhm, H., 2001. Re-establishment of an abyssal megabenthic community after experimental physical disturbance of the seafloor. Deep Sea Research II 48 (17-18), 3841-3868.