Environmental Monitoring and Surveillance Challenges in Marine Geology and Deep Sea Exploration

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Marine Mineral and Energy Resources

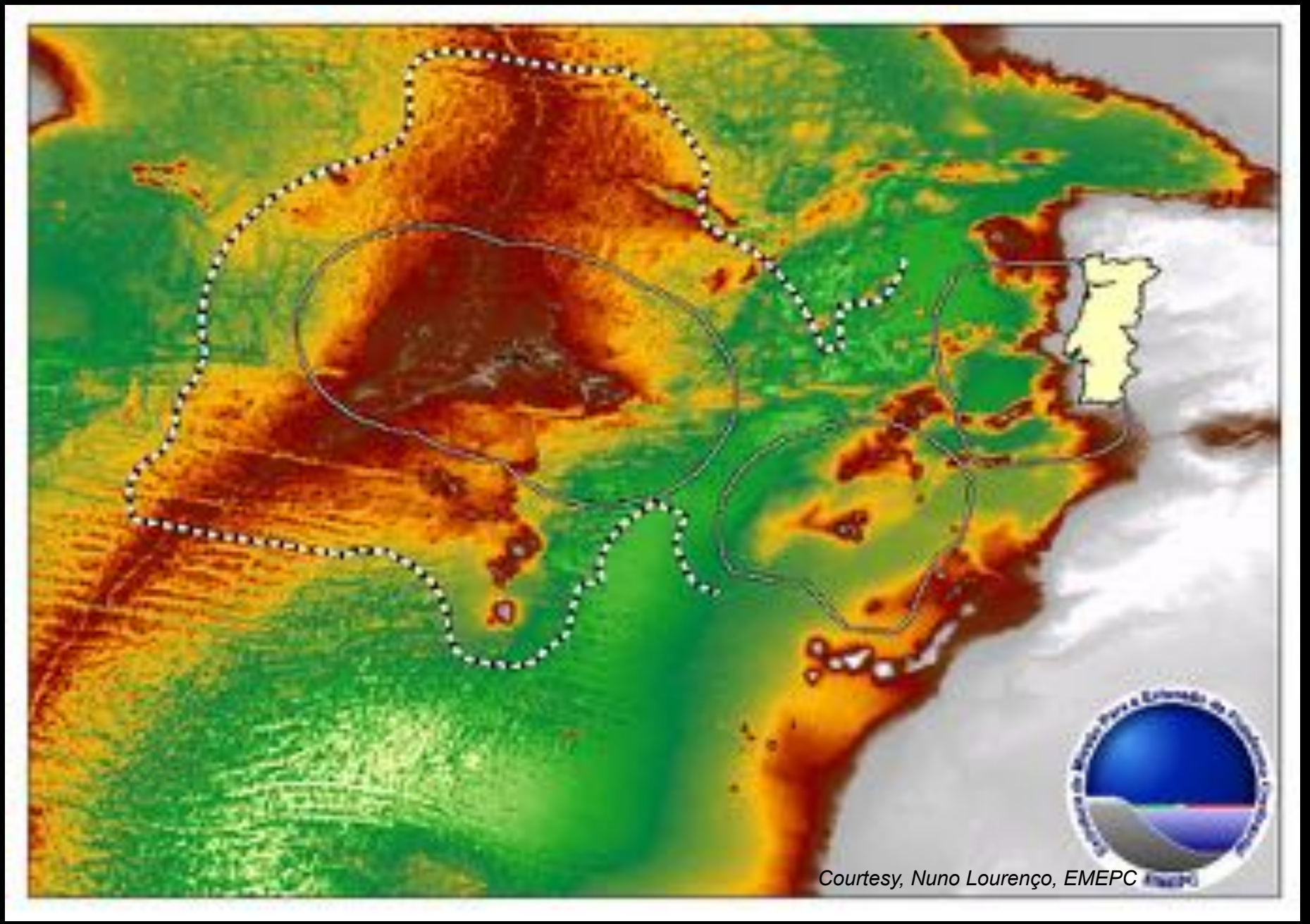
- Most **natural mineral and energy resources**, many of them **strategic,** with a crescent demand and fundamental to support our societal and technological development, are becoming **scarce** onland, but many of them are **abundant in the deep ocean**, although their true potential is **virtually unknown – Oceans represent 2/3 of Earth's surface!**

- We now have the **technology** for **deep and ultra-deep water oil and gas exploration** which opens the way to the many challenges associated with deep sea mining. There is however the **need to develop innovative, cost-effective exploration, habitat mapping, exploitation and monitoring technologies and methods that minimize the associated impacts**, largely based on **underwater robotics** and **real time monitoring**.

- In spite of our very limited knowledge, **mineral and energy resources with a potential economic interest** have been identified worldwide (conventional and new resources), some of which with applications in new materials, biotechnology, medicine and pharmacology.

- **The extreme ecossystems** and the recent discovery of the **deep biosphere,** in the marine subsoil, **which probably duplicates the total Earth's biomass,** open new science frontiers with inumerous potential **applications.**

Portuguese Proposal for the Extension of the Continental Shelf (Subm. UN 2009)

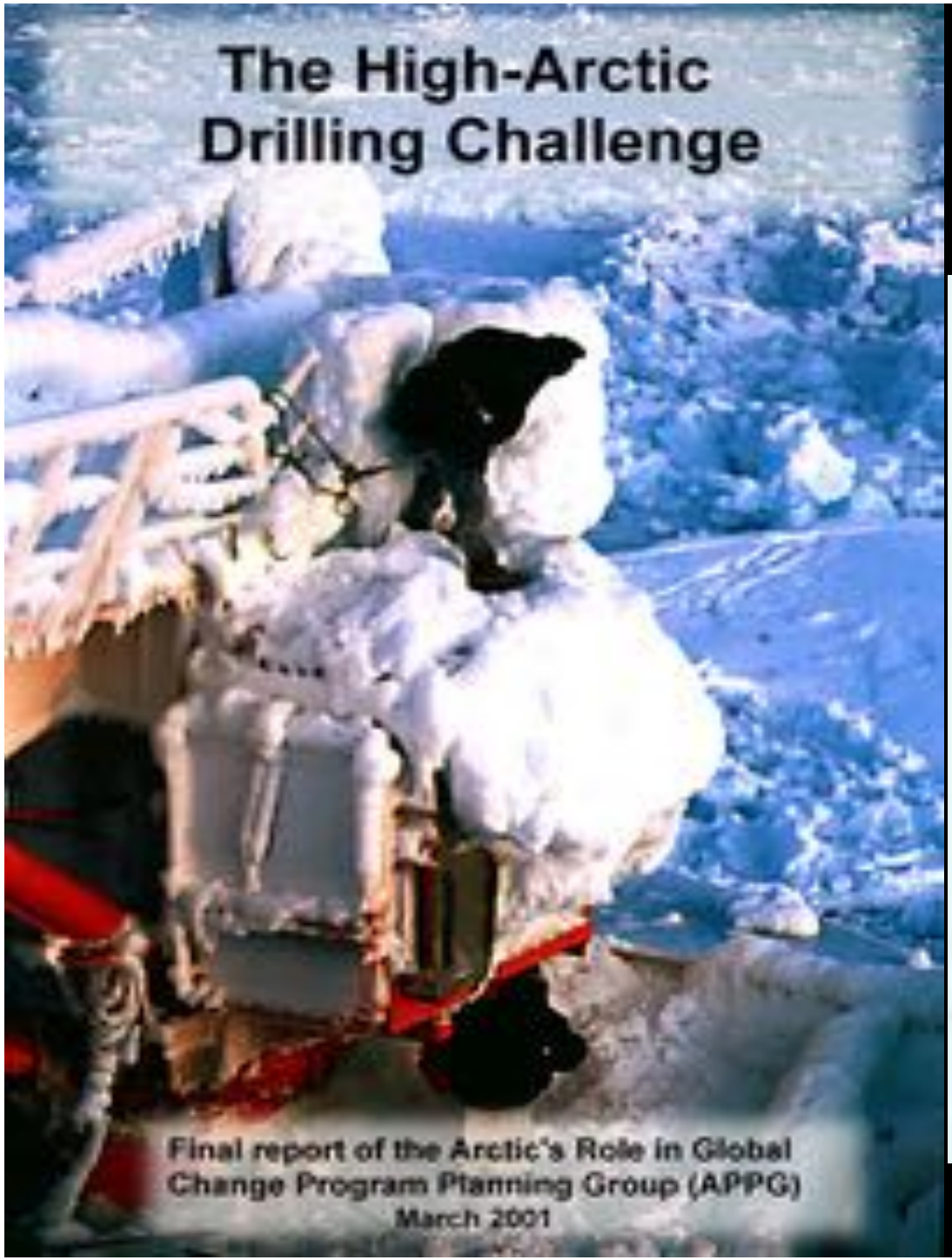


Integrated Ocean Drilling Program - IODP

Exp. 302 - Arctic Coring Expedition – ACEX (2005)

The Artic Challenge!

Courtesy Jan Backman



Integrated Ocean Drilling Program - IODP
Exp. 302 - Arctic Coring Expedition - ACEX

Courtesy Jan Backman

Co-rich Fe/Mn Polimetalic nodules – Abyssal plains

Known since the HMS Challenger Expedition (1872-76).

20-30% Mn, 10-20% Fe oxides, 1.5% Ni and less than 1% de **Co**, Cu, Zn and Pb.

Koelle, personal photo

Fe/Mn Nodules from the Peru Basin
(~4100m deep - Sonne cruise SO-79)

Co-Rich Fe/Mn Polymetalic crusts – Submarine Seamounts

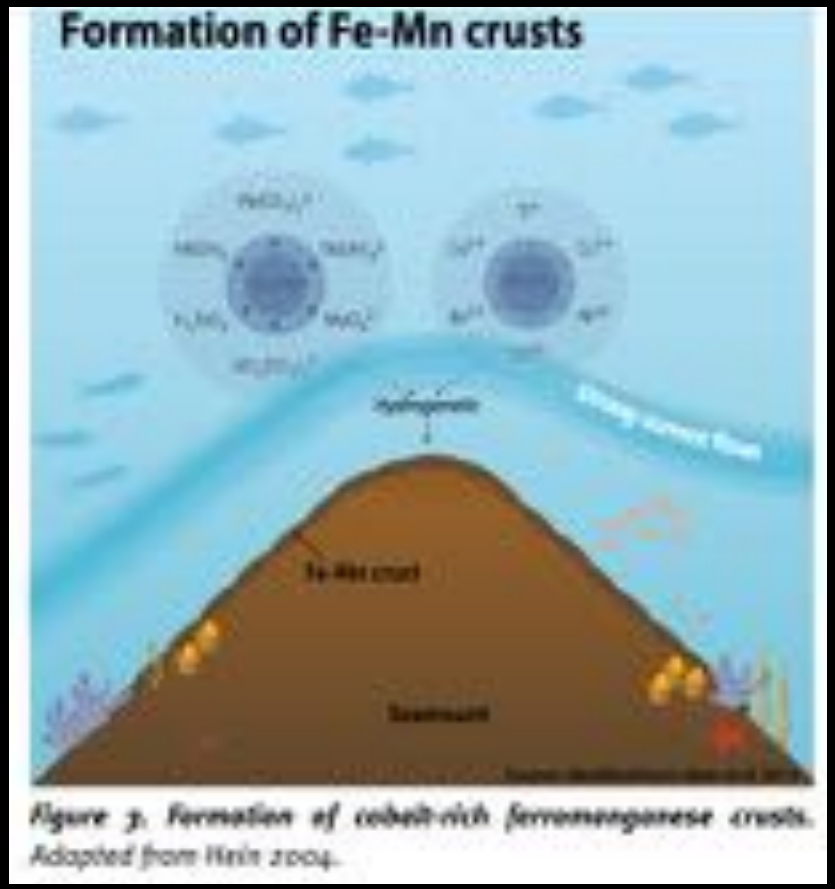


Figure 3. Formation of cobalt-rich ferromanganese crusts. Adapted from Hein 2004.

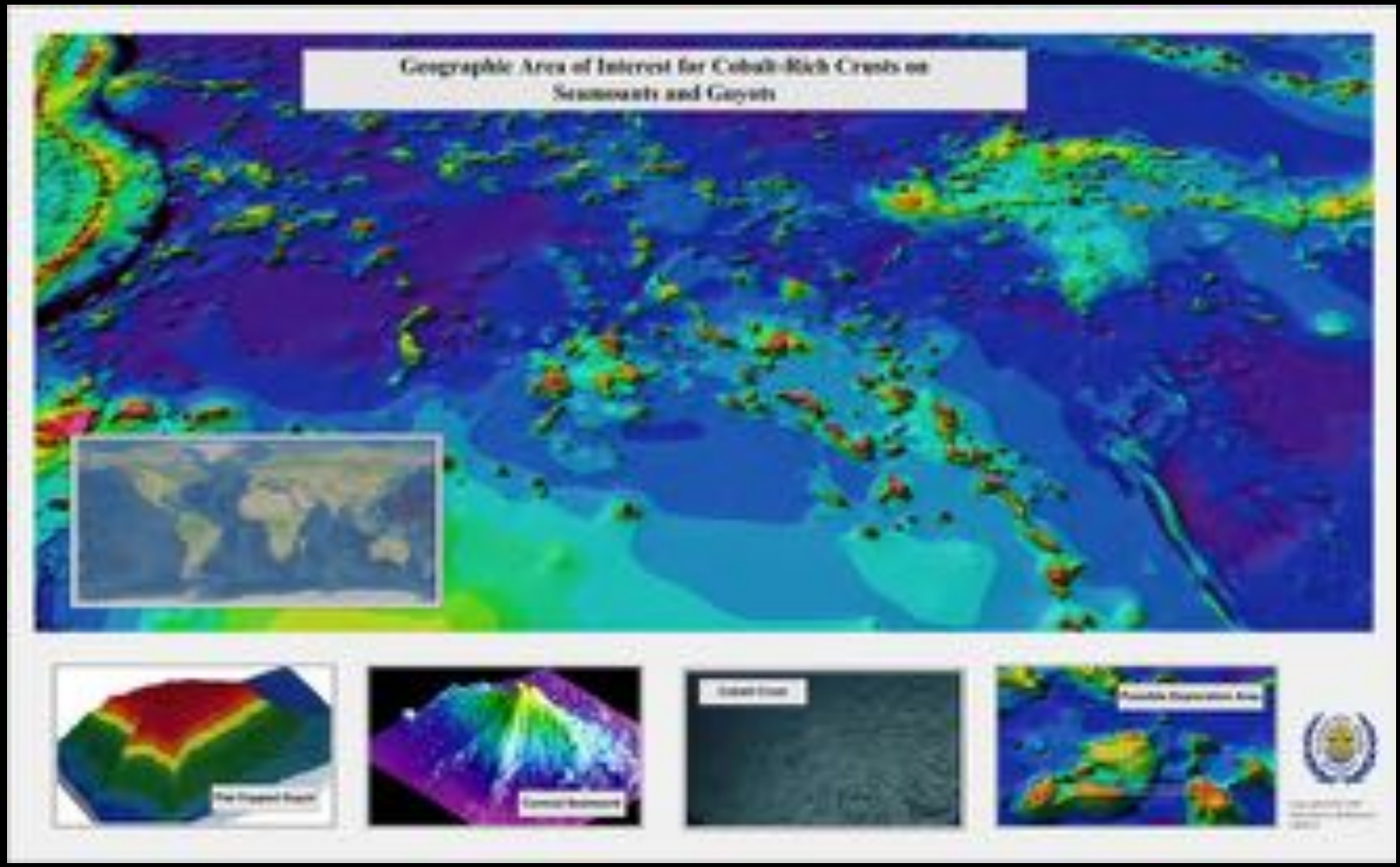
Metals: Co, Ni, Cu

Rare Metals: telurium, platinum, zircon, niobium, tungsten and bismuth

Rare- Earths: La, Ce, Nd, Eu, Tb

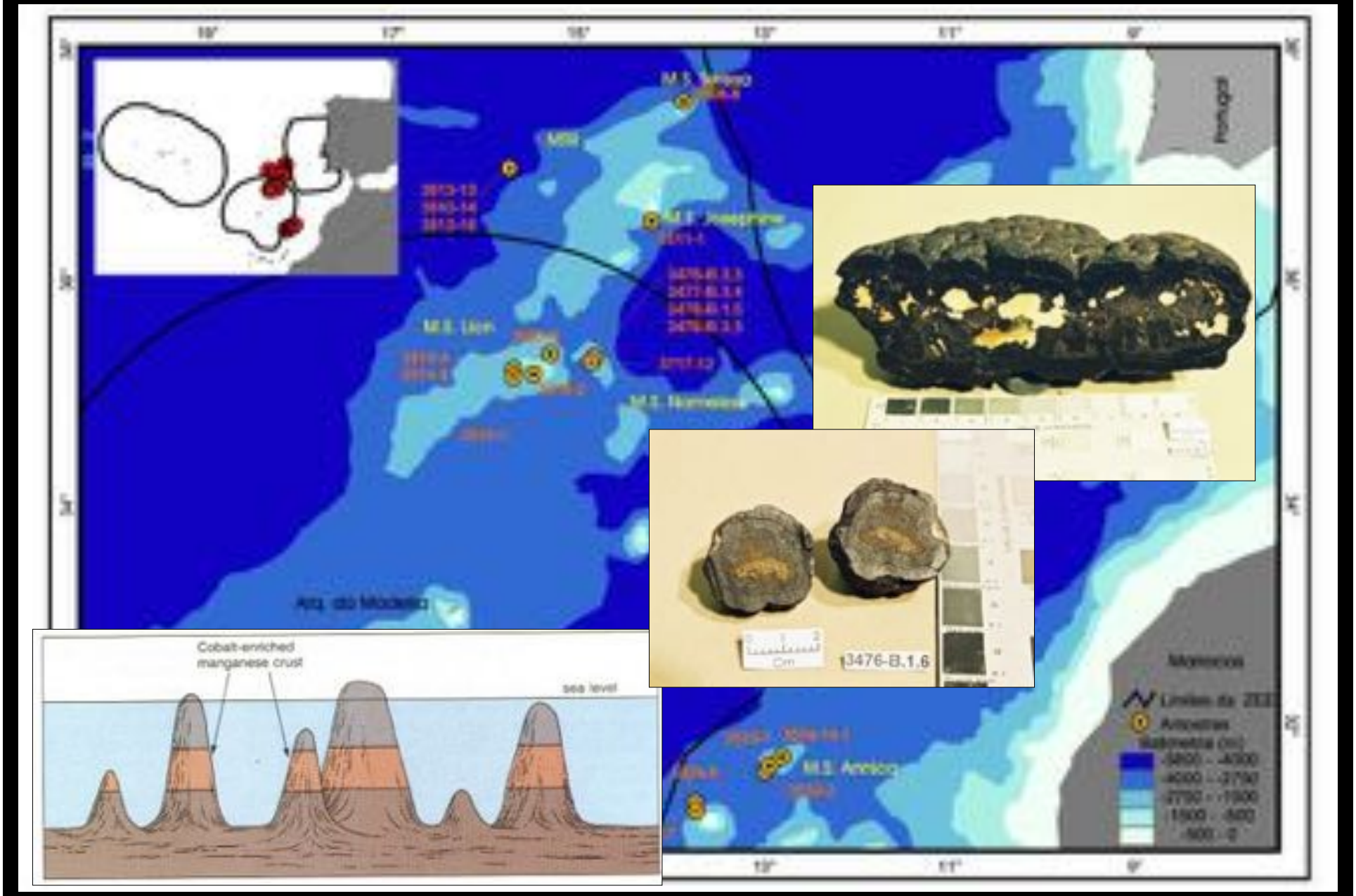
Potential source of many metals used in traditional, emergent and cutting-edge technologies.

Co-Rich Fe/Mn Polymetalic crusts – Submarine Seamounts



Cobalt is a strategic metal, used in the aerospace industry, high-resistance alloys, paints, medicine, radioactive tracer, gamma ray production for industrial use.

Cobalt-rich Fe/Mn Crusts – Madeira EEZ



S. Muiños (2005)

Cobalt-rich Fe/Mn Crusts – Madeira EEZ

Area	South Pacific	North Pacific	Indian	Atlantic
Elements (%)				
Mn	16.61	12.29	13.56	16.10
Fe	13.92	12.00	15.77	21.82
Ni+Cu+Co (%)	1.213	0.860	0.782	0.715

Area	Lion	Nameless	Josephine	Lion South
Ni+Cu+Co (%)	1.096	0.960	0.865	0.801

Muinos, 2005

Co-Rich Fe/Mn Crusts

Madeira EEZ TTR11 Research Cruise - 2001

Co-Rich Fe/Mn Crusts

Madeira EEZ TTR11 Research Cruise - 2001

Co-Rich Fe/Mn Crusts

Madeira EEZ TTR11 Research Cruise - 2001

Co-Rich Fe/Mn Crusts

Potential source of Rare-Earths
Genreally strongly attached to the underlying rocks
How to extract minimizing non-mineralized material
Water depths between 800 and 2500m Growth Rates ~ 1-10mm/Milllion Years

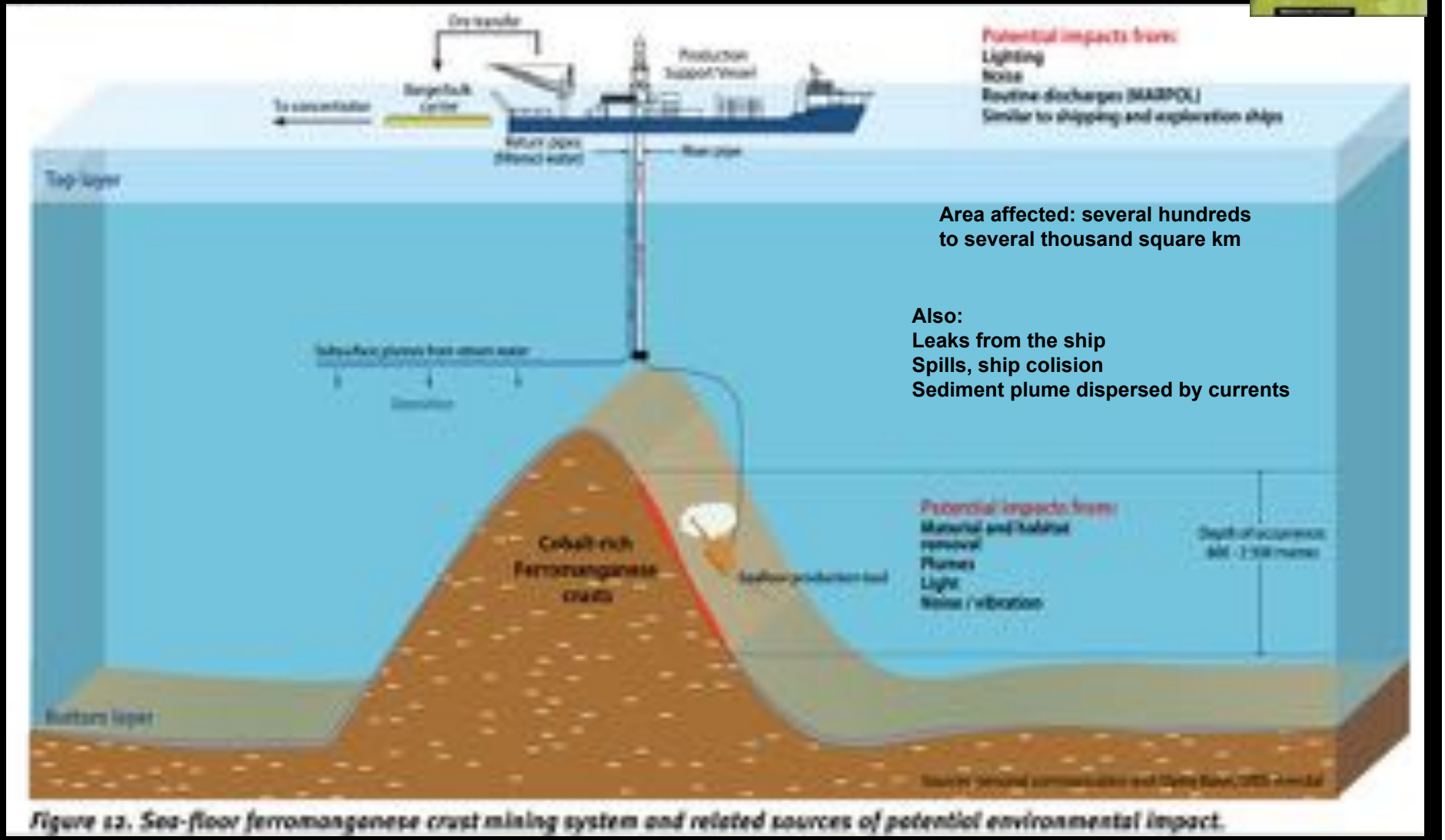
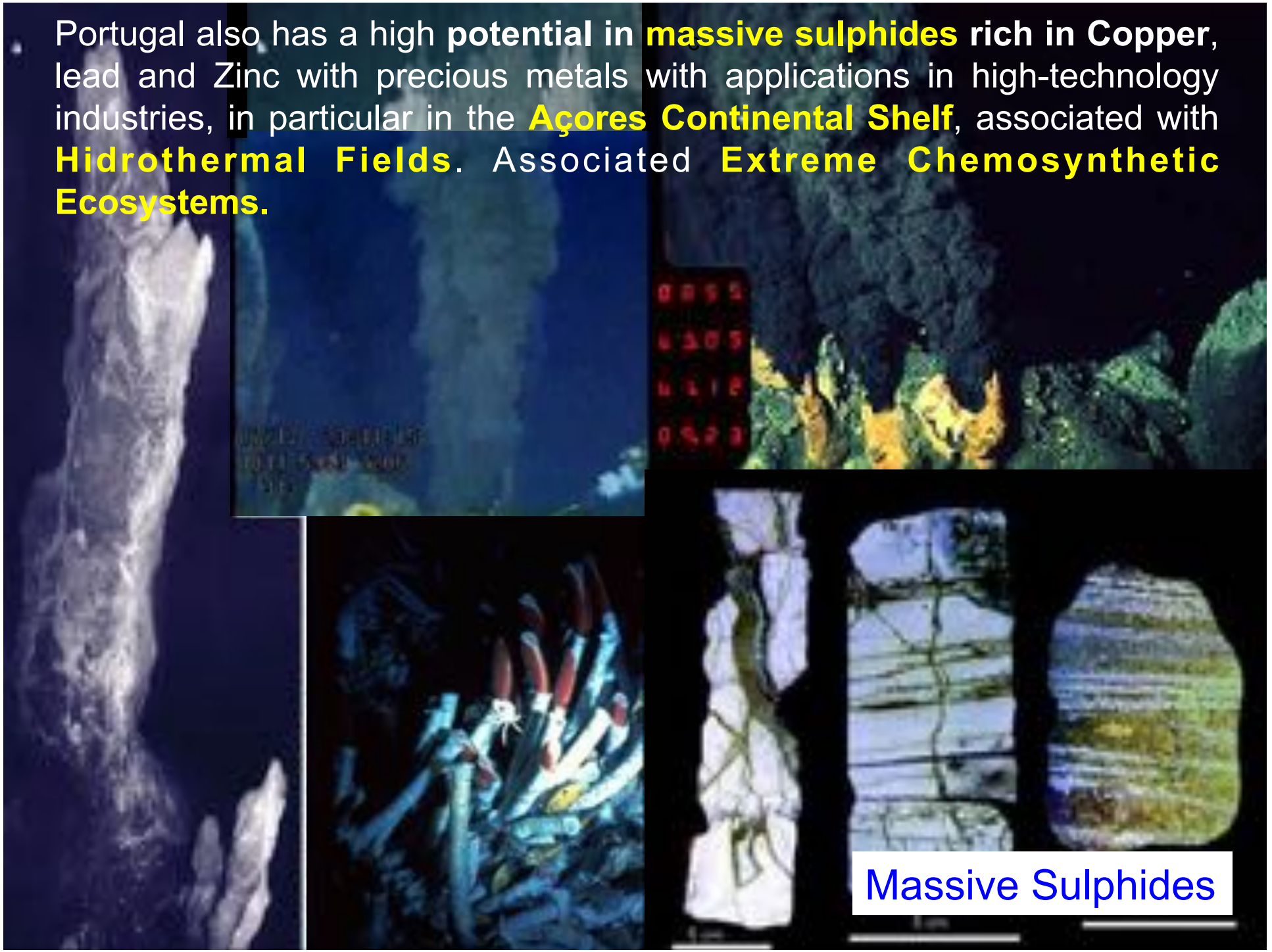
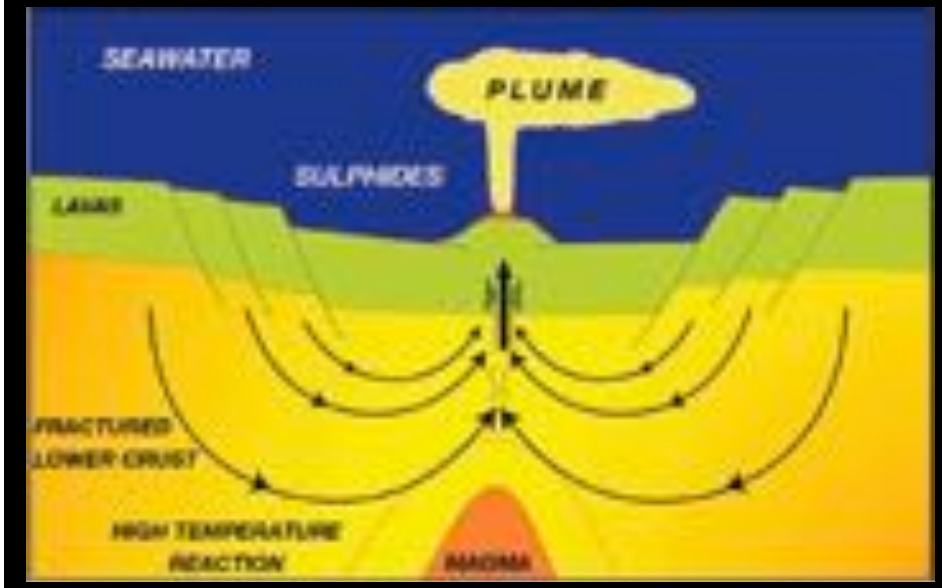


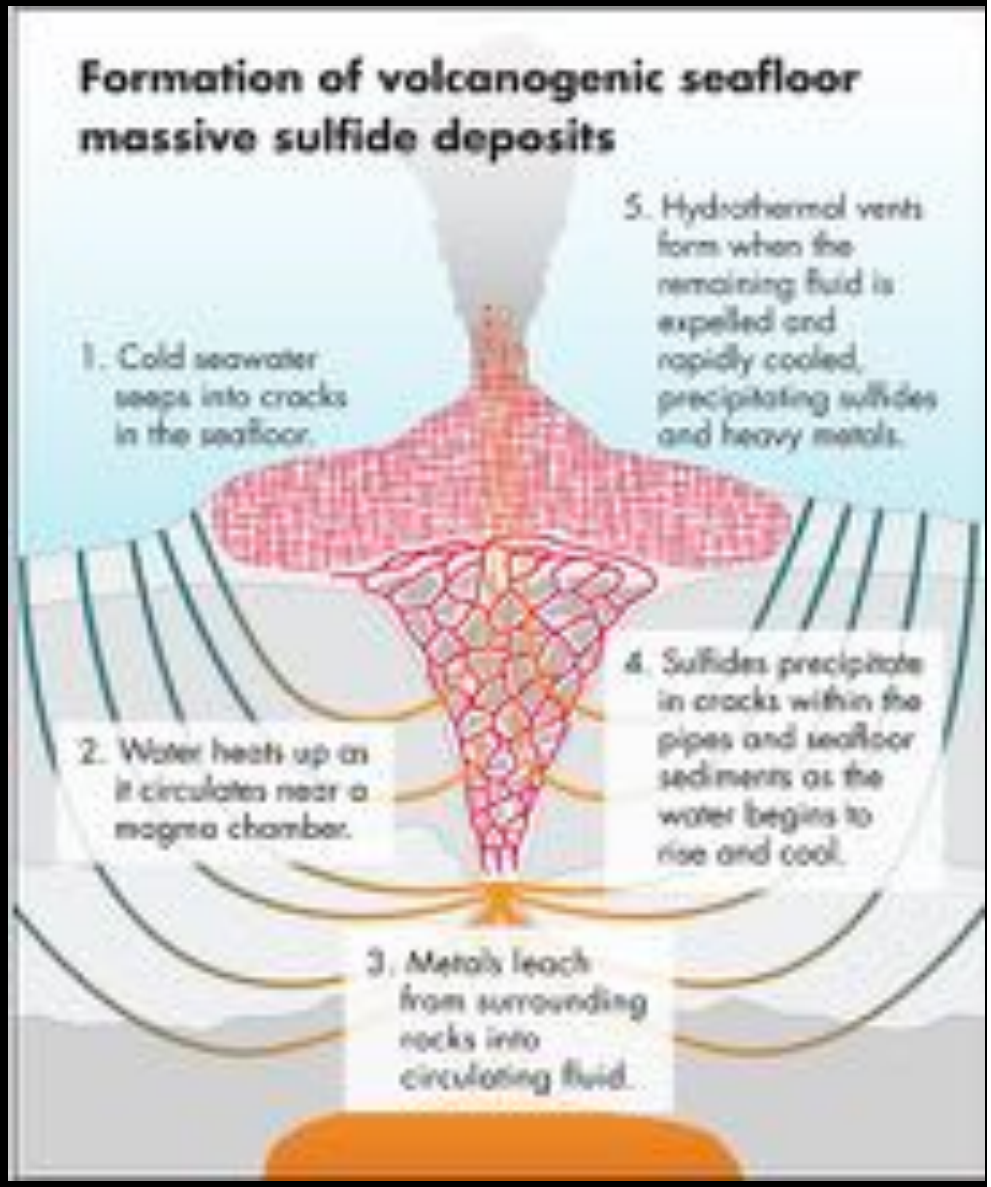
Figure 12. Sea-floor ferromanganese crust mining system and related sources of potential environmental impact.

Portugal also has a high **potential in massive sulphides rich in Copper**, lead and Zinc with precious metals with applications in high-technology industries, in particular in the **Açores Continental Shelf**, associated with **Hidrothermal Fields**. Associated **Extreme Chemosynthetic Ecosystems.**



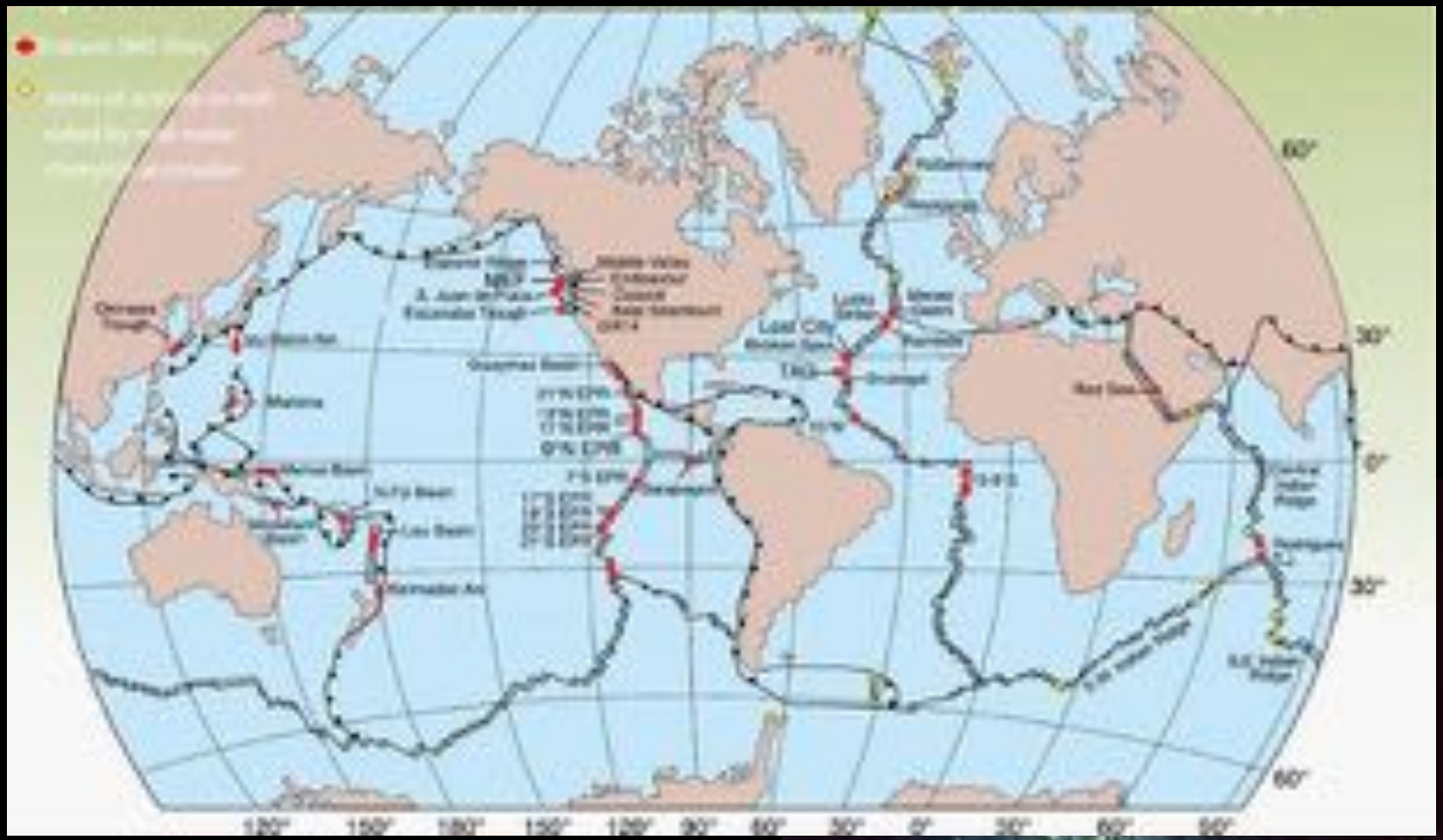
Massive sulphides – Hidrothermal Systems



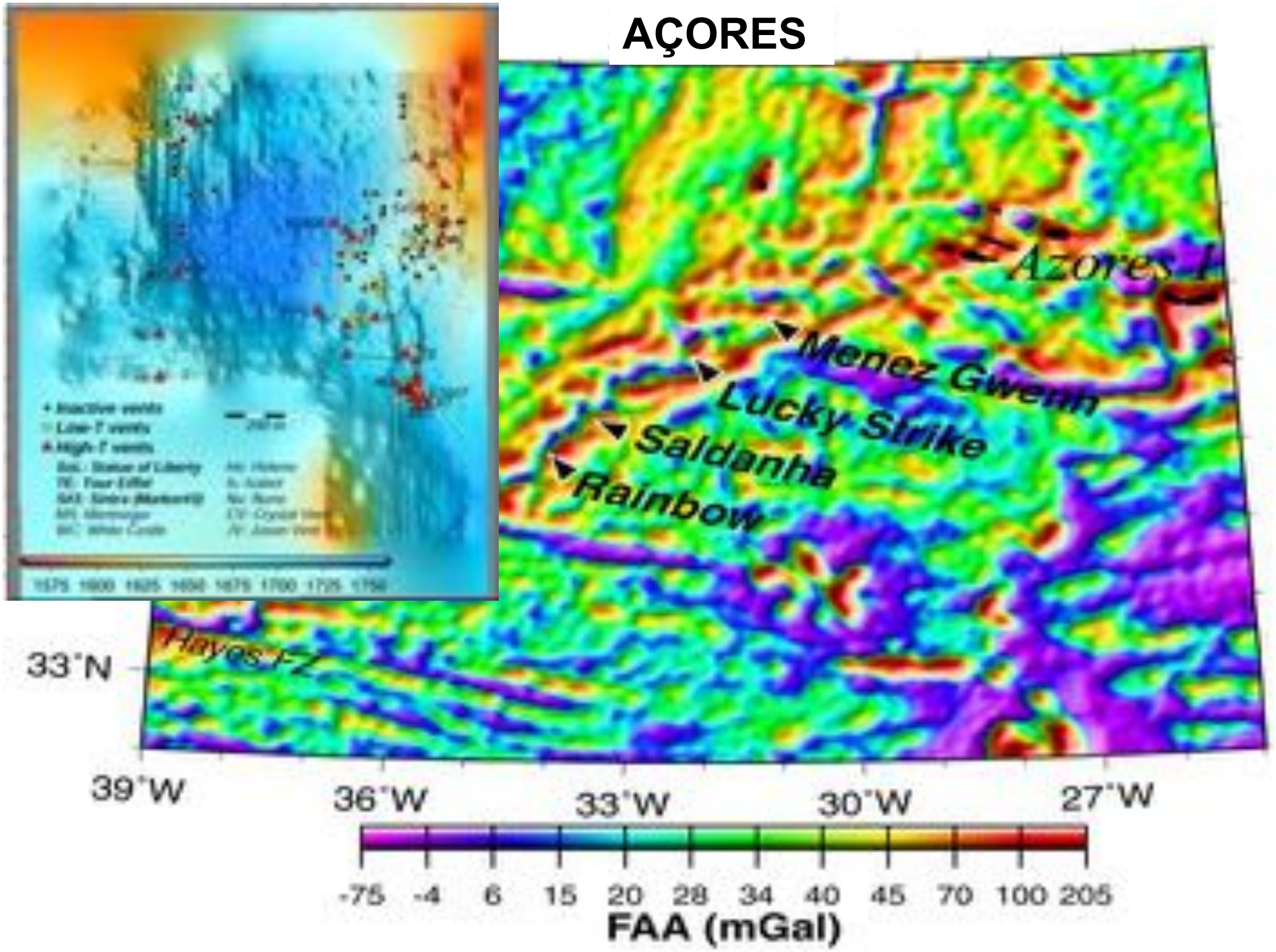


Credit: Kathleen Cantner, AGI.

Massive sulphides – Hidrothermal Systems

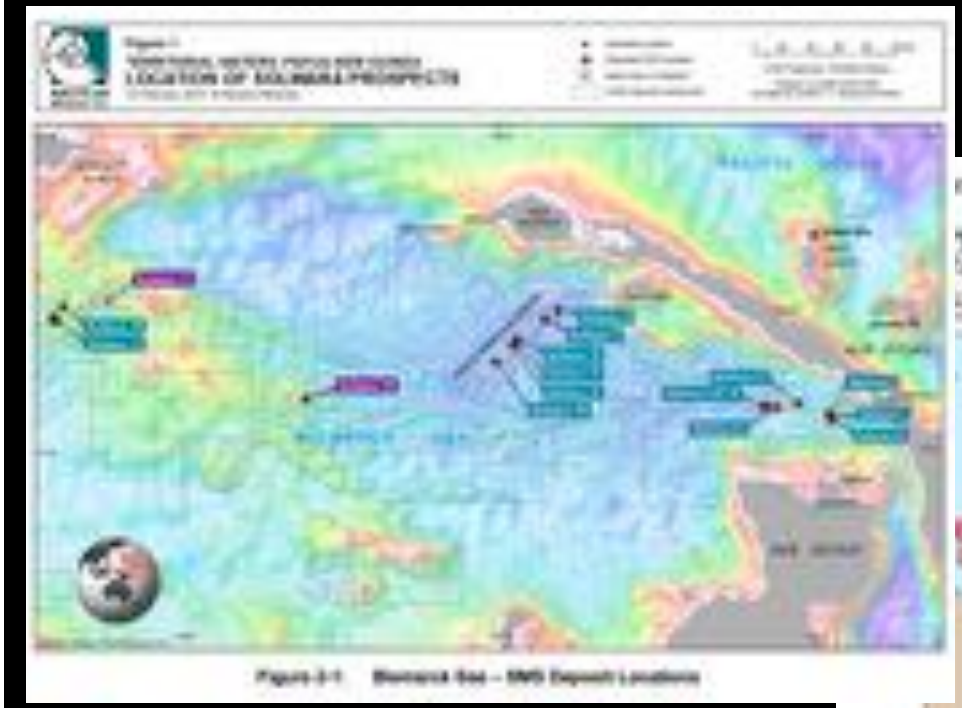


Volcanogenic Massive Sulphide ("VMS") deposits such as Kidd Creek in Canada. VMS deposits are a major source of the world's copper, zinc, lead, gold and silver


AÇORES
Azores I.
Menez Gwenn
Lucky Strike
Saldanha
Rainbow
Hayes FZ
33°N
39°W
36°W
33°W
30°W
27°W
-75 -4 6 15 20 28 34 40 45 70 100 205
FAA (mGal)

Massive sulphides – Hidrothermal Systems – Solwara 1 (Nautilus Minerals)

Papua New-Guinea



The SMS deposits at Solwara 1 are associated with high grade polymetallic sulphide systems, which are particularly rich in copper and gold. The viability of the Project is underpinned by the high grades of Solwara 1. Indicated resources are 870,000 t of ore containing 6.8% copper and 4.8 g/t gold. **Inferred resources are 1,300,000 t of ore containing 7.5% copper and 7.2 g/t gold**.

NAUTILUS

Figure 1

SOLWARA 1 PROSPECT, EL 1196

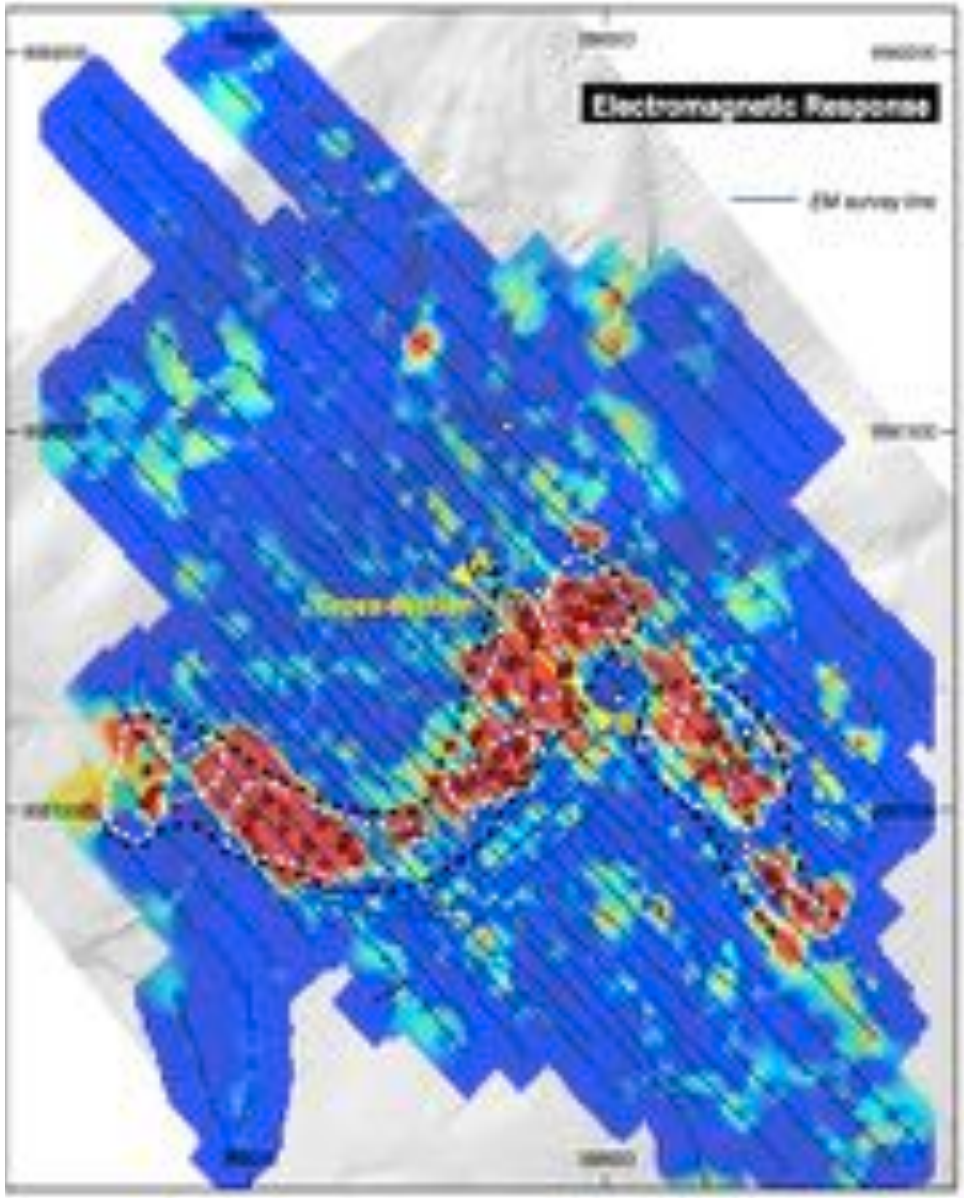
ELECTROMAGNETIC RESPONSE vs BATHYMETRY

19 November 2007 © Nautilus Minerals

Drill hole, mineralised
Drill hole, non-mineralised
Drill hole, awaiting assay results
Surface extent of mineralised system
Observed sulphide outcrop

0 100 200 300 400 500m

UTM Projection. Zone 56. WGS84 Datum



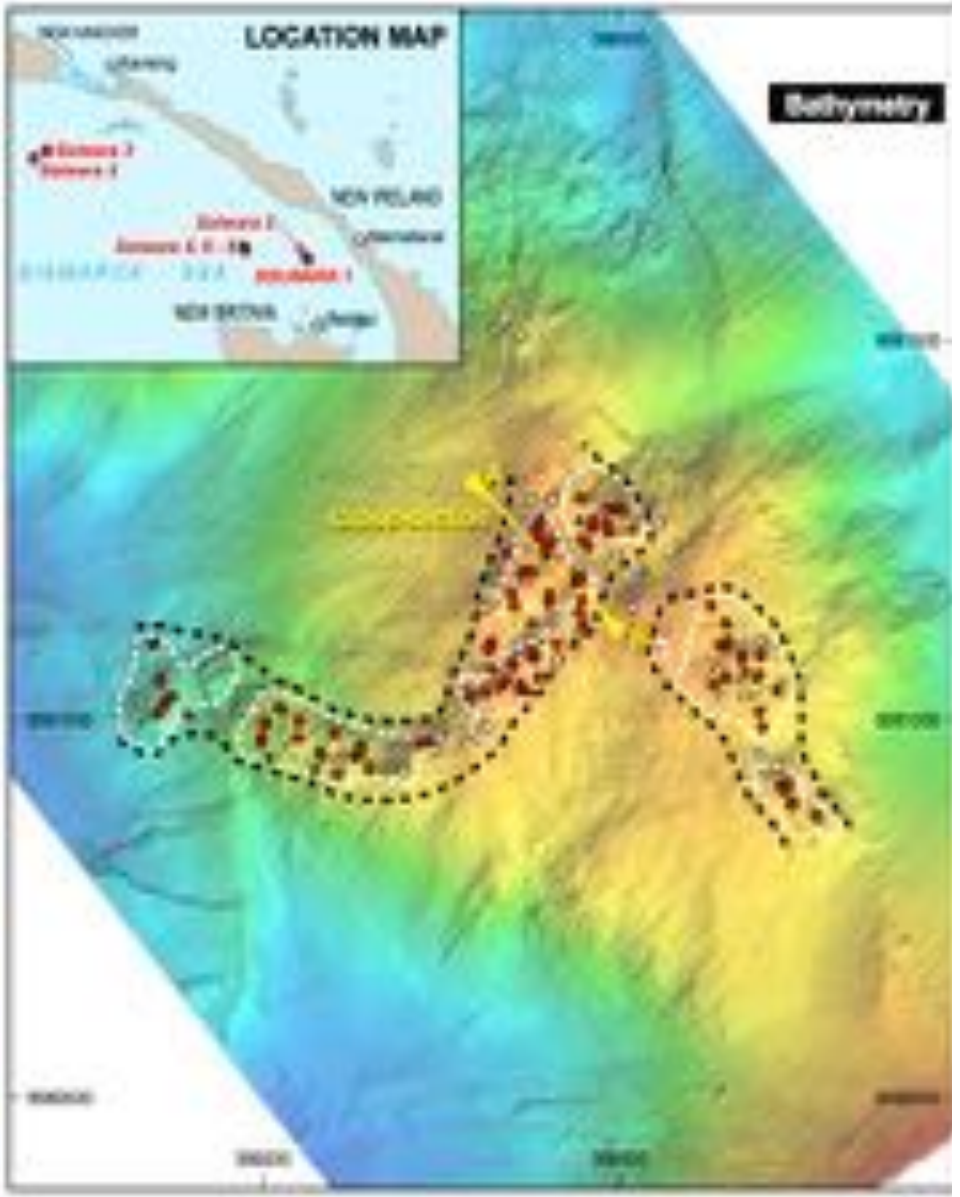
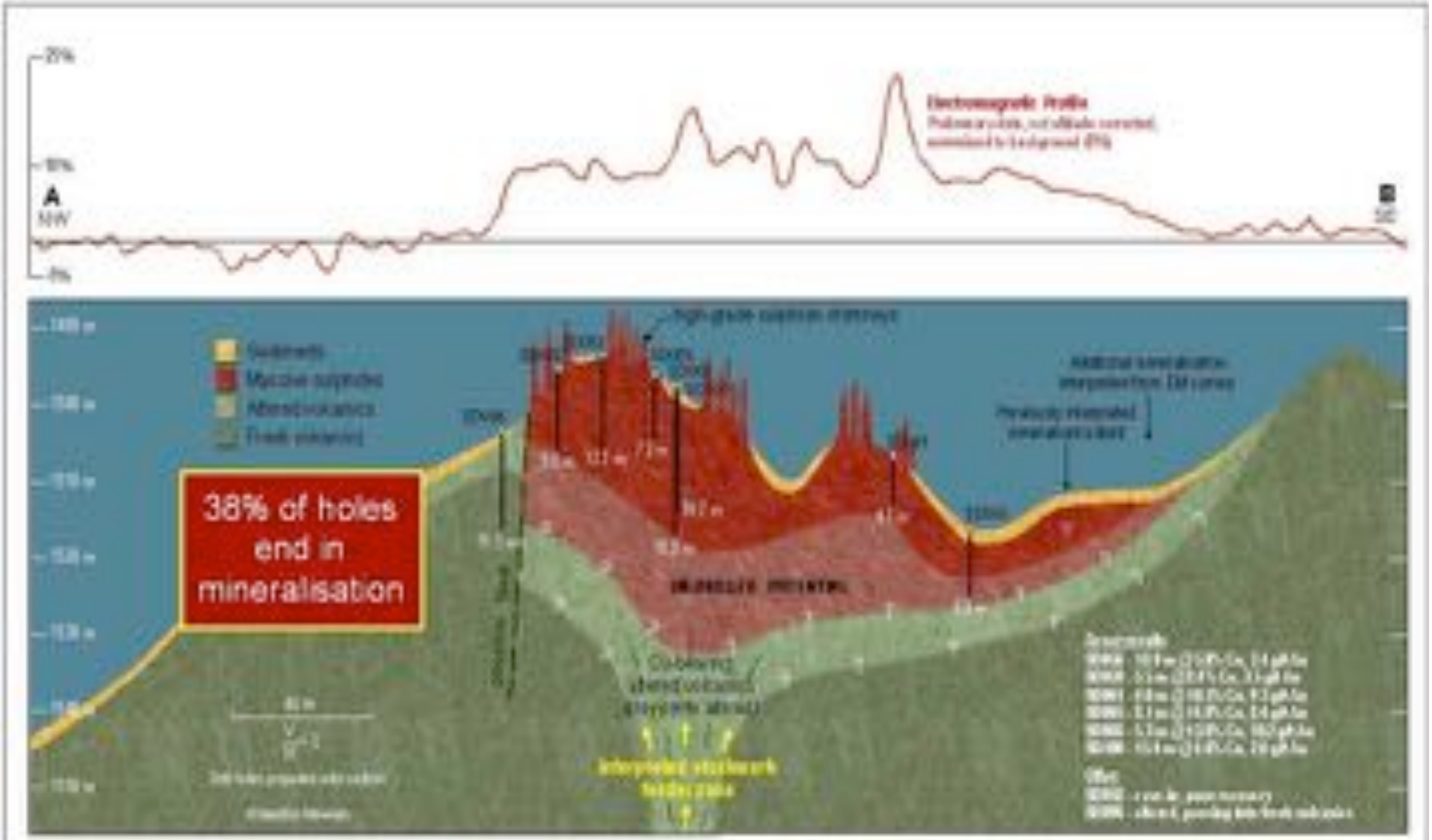
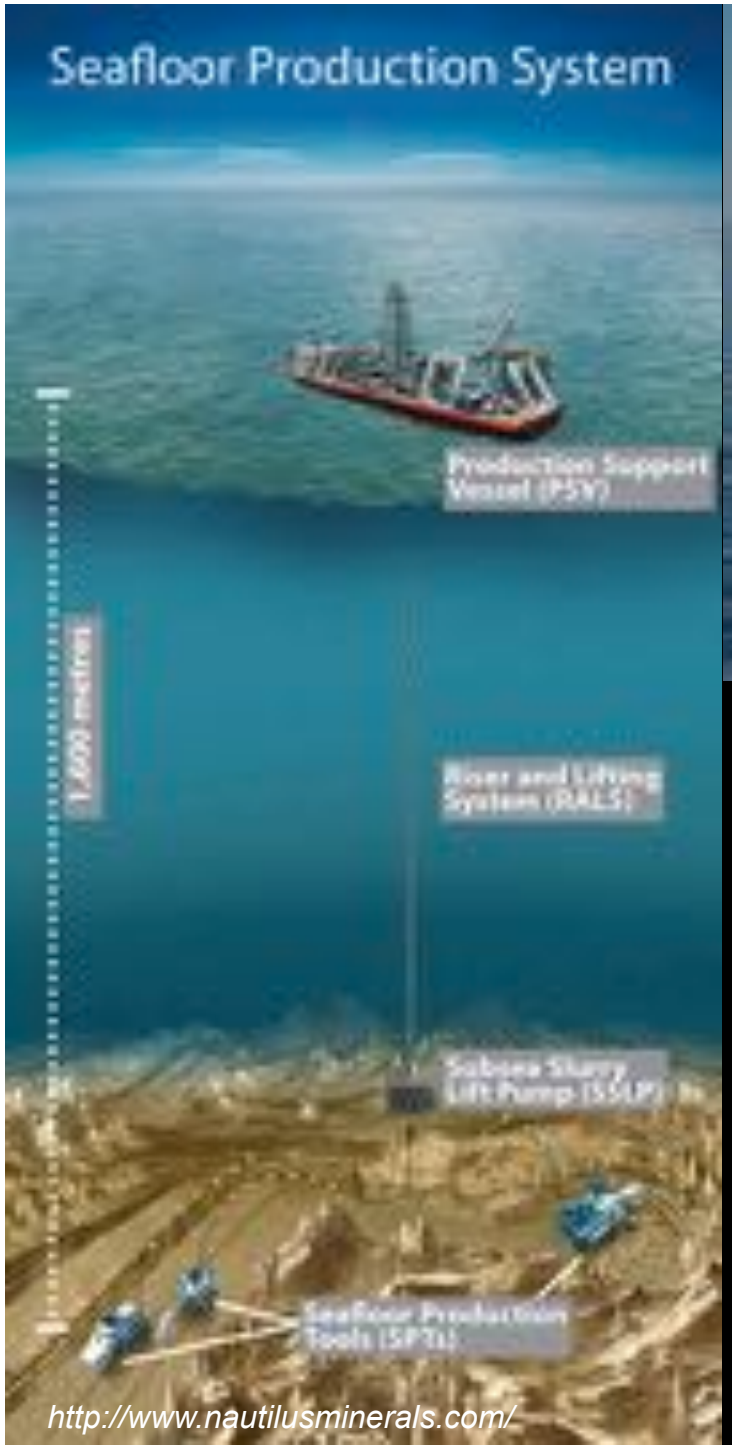


Figure 2

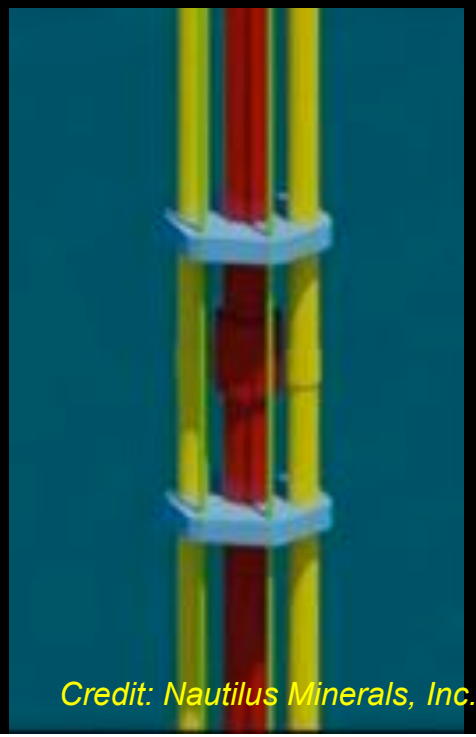
SOLWARA 1 PROSPECT, EL 1196

SCHEMATIC CROSS-SECTION




Seafloor Production System
Production Support Vessel (PSV)
1,600 metres
Riser and Lifting System (RALS)
Subsea Slurry Lift Pump (SSLP)
Seafloor Production Tools (SPTs)
http://www.nautilusminerals.com/

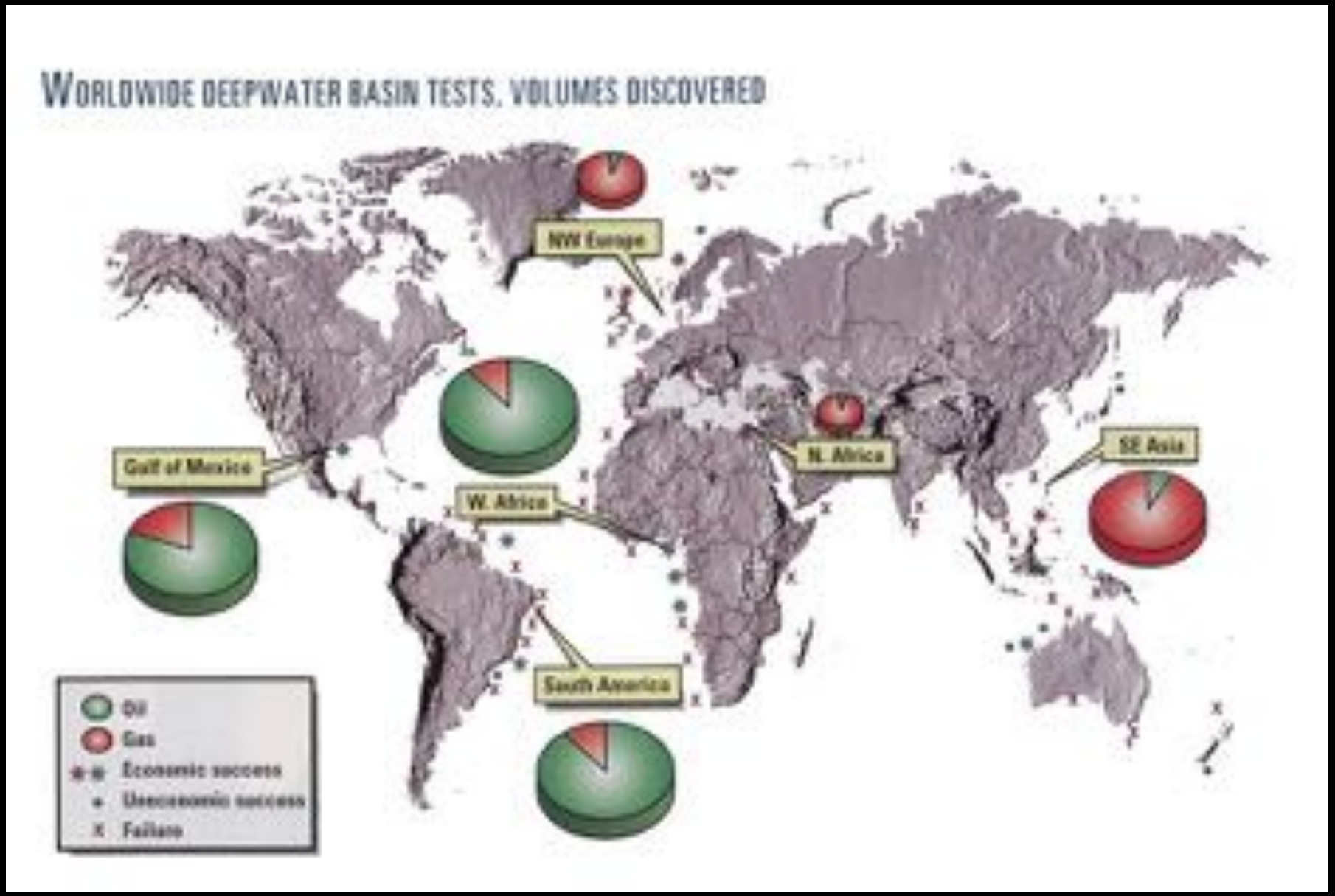

Nautilus Minerals: Solwara 1 project
Papua New Guinea


Credit: Nautilus Minerals, Inc.

Energy Resources

- Deep Water Exploration >3000m
- Sub-Salt / Pre-Salt
- Complex non-conventional Reservoirs
  - *Carbonate R.*
  - *Fractured R.*
  - *Shale oil & gas*
  - *Gas Hidrates*

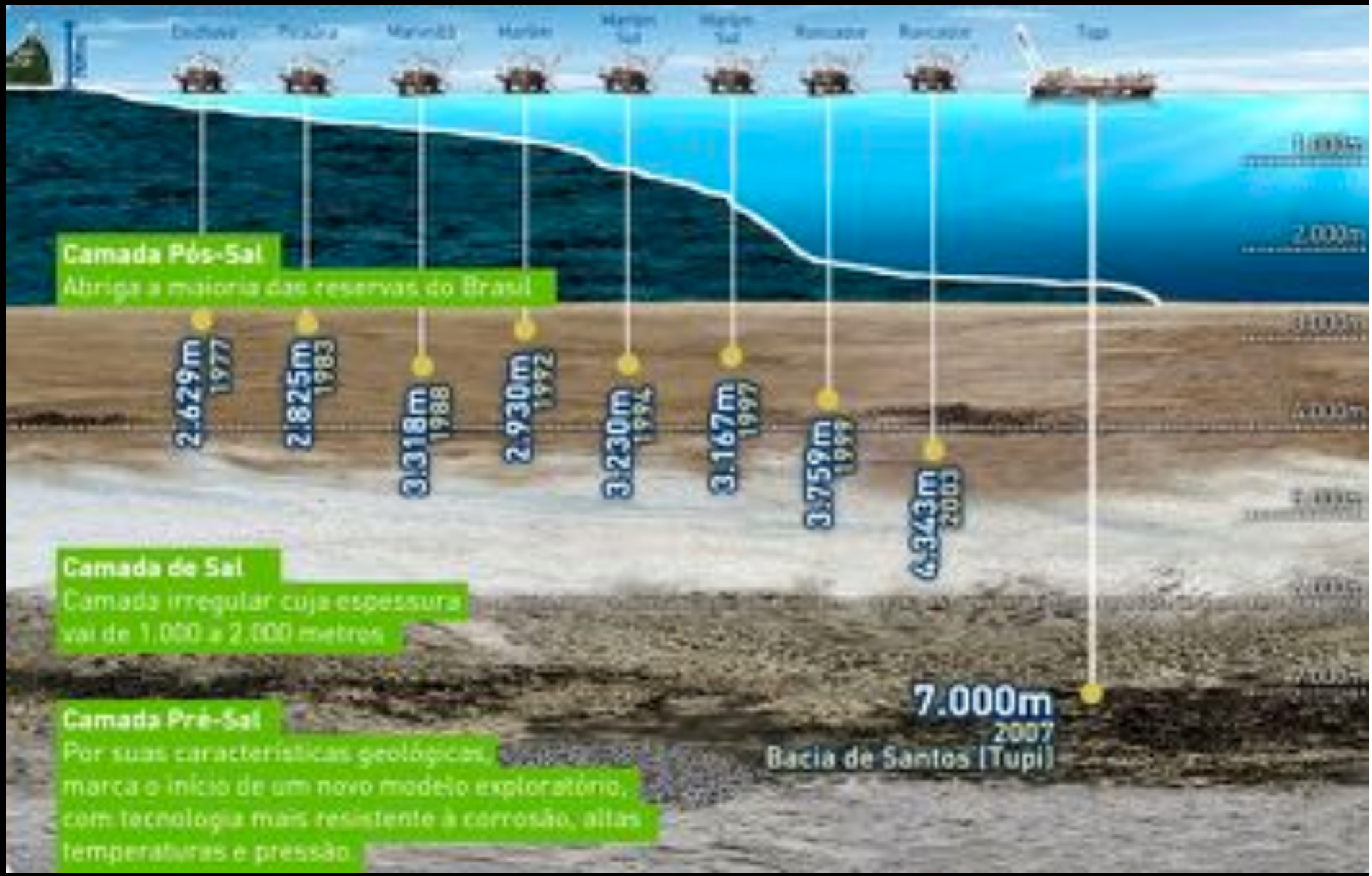
Deepwater Oil and Gas Basins



Deepwater Basins of the world:

Production areas in excess 3000m water depth

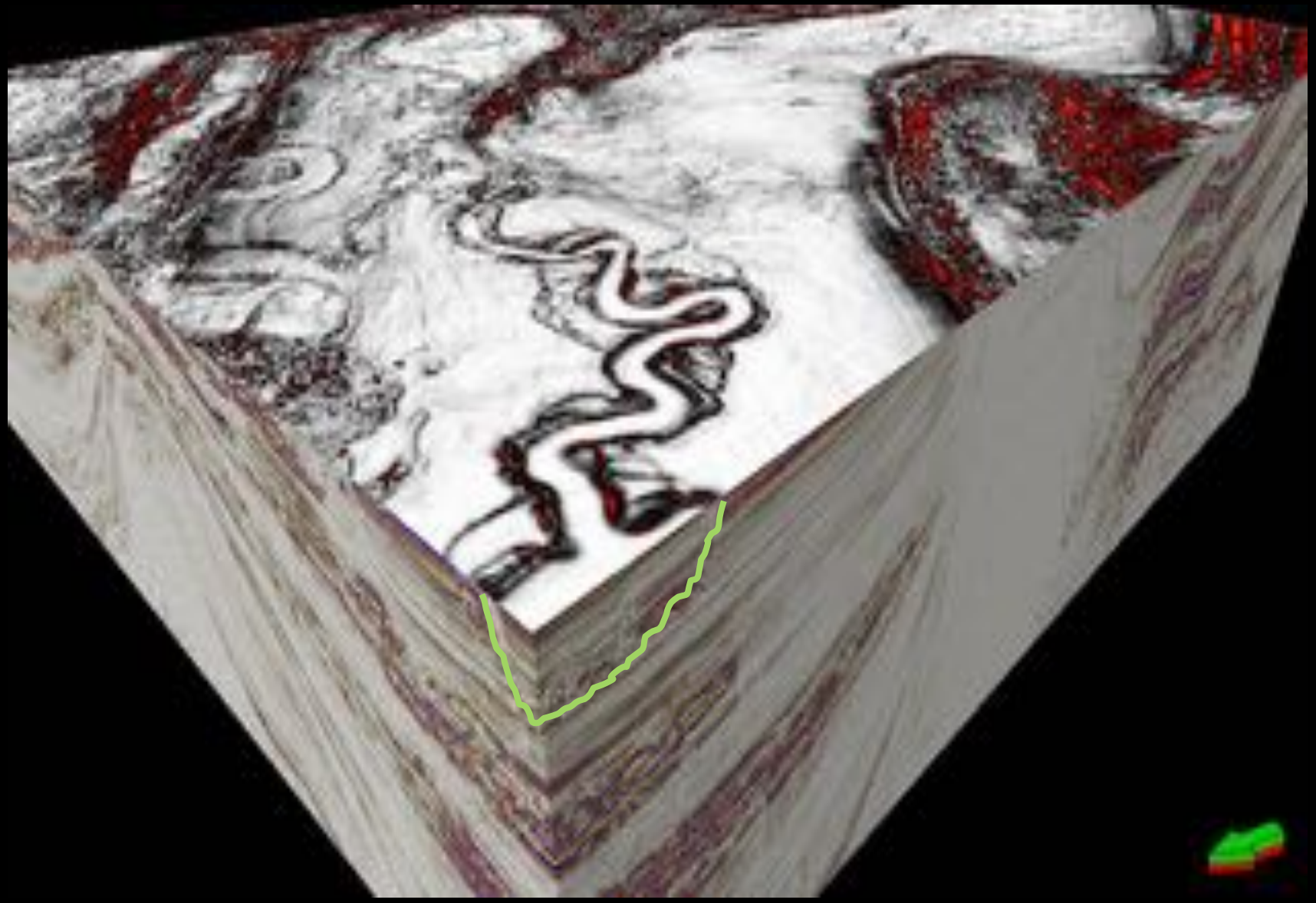
Ultra-deepwater exploration



FPSOs - Floating Production, Storage and Offloading

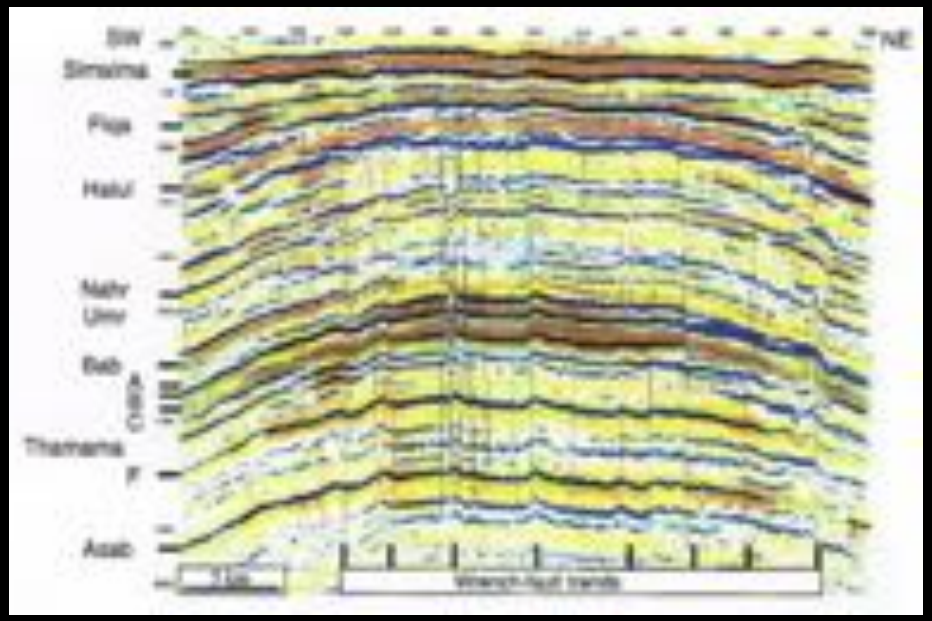
Wiki

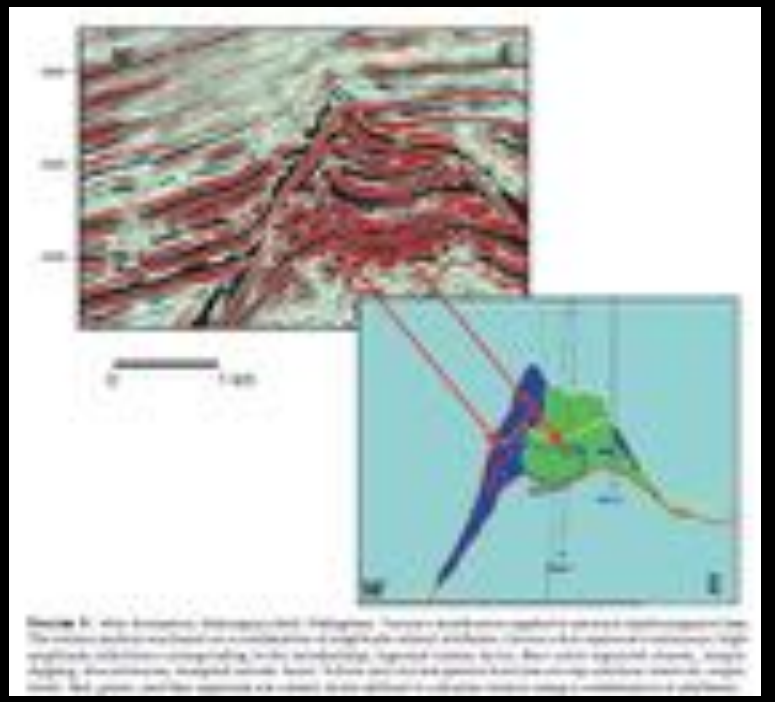
Deep Siliciclastic Reservoirs – 3D/4D 4C seismics

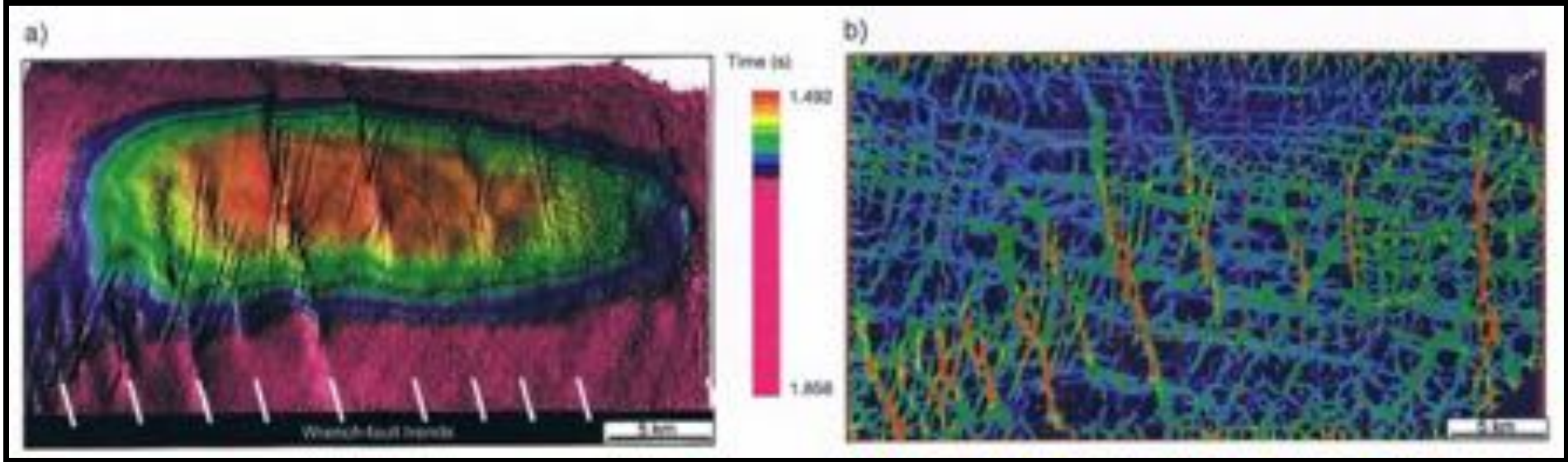


L. Azevedo, 2009

Carbonate and fractured reservoirs

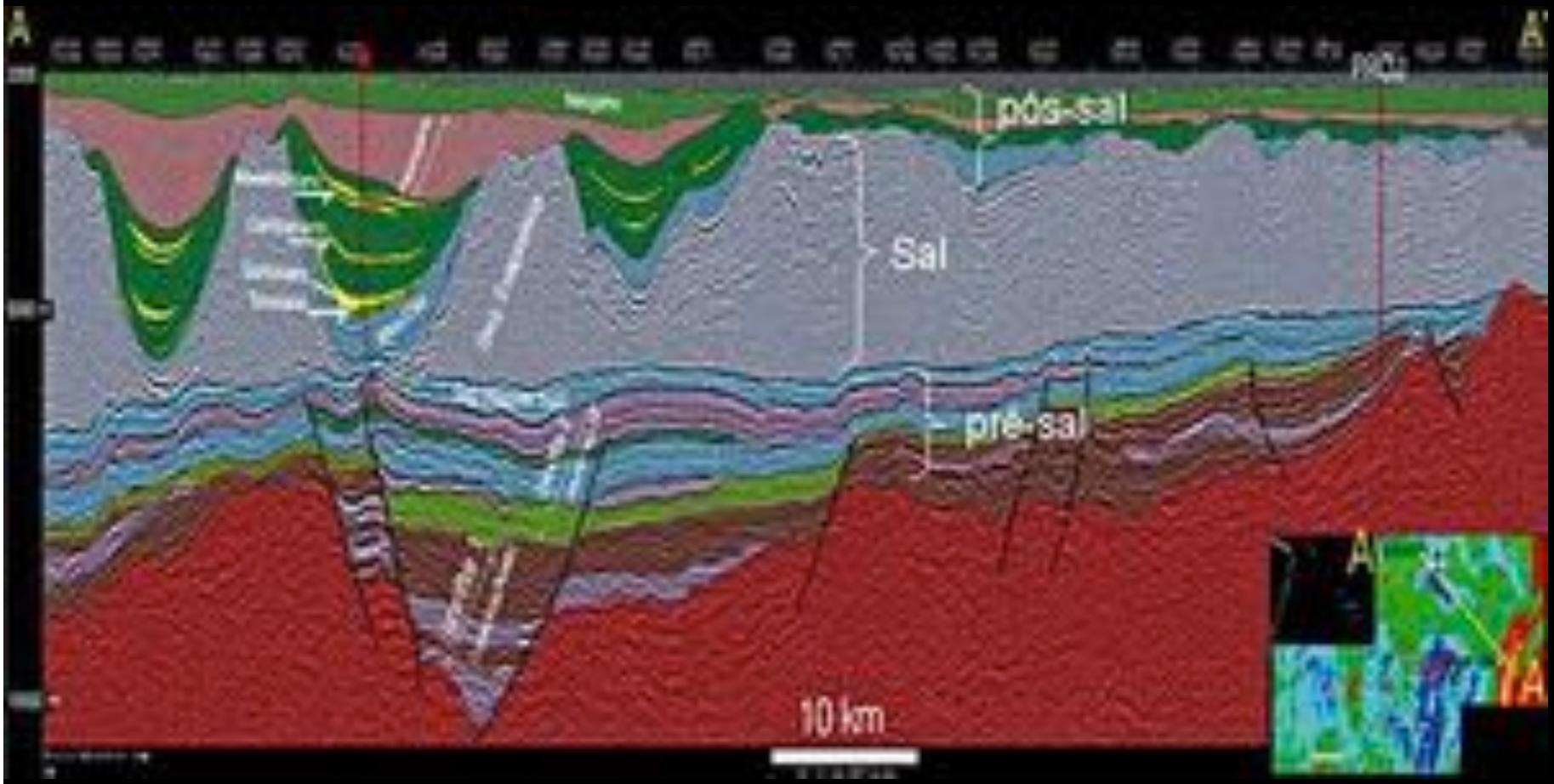




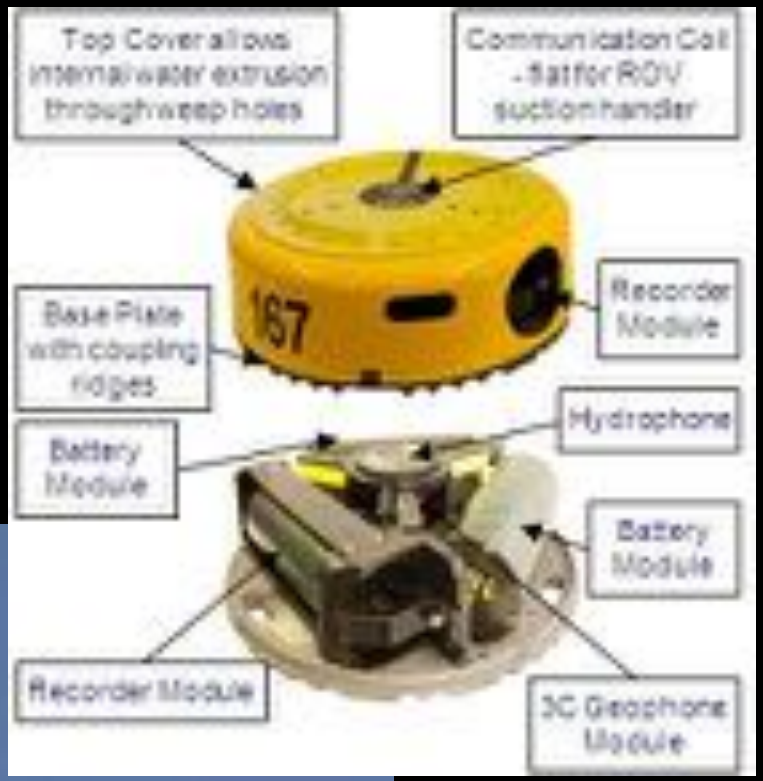


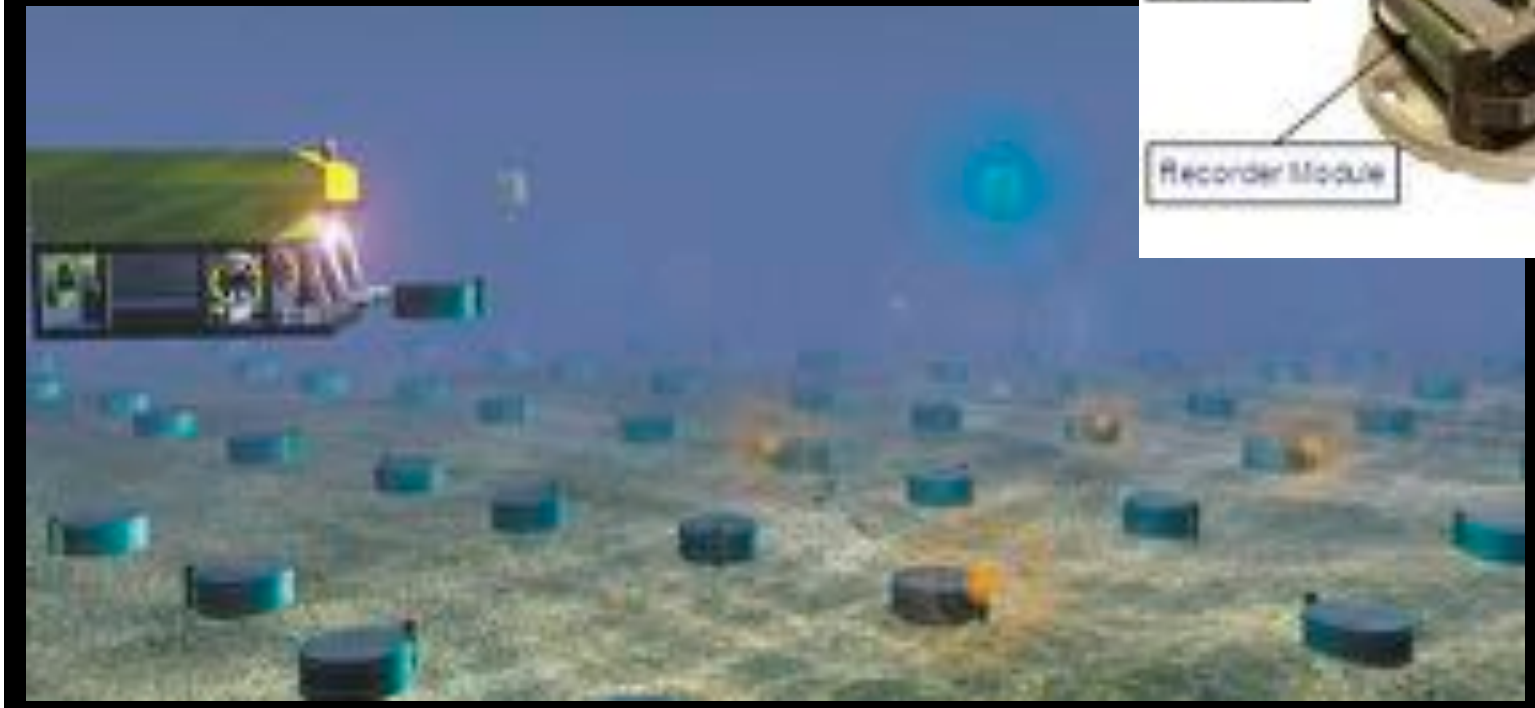
Massaferro

Deepwater Basin Exploration. Fixed Platforms



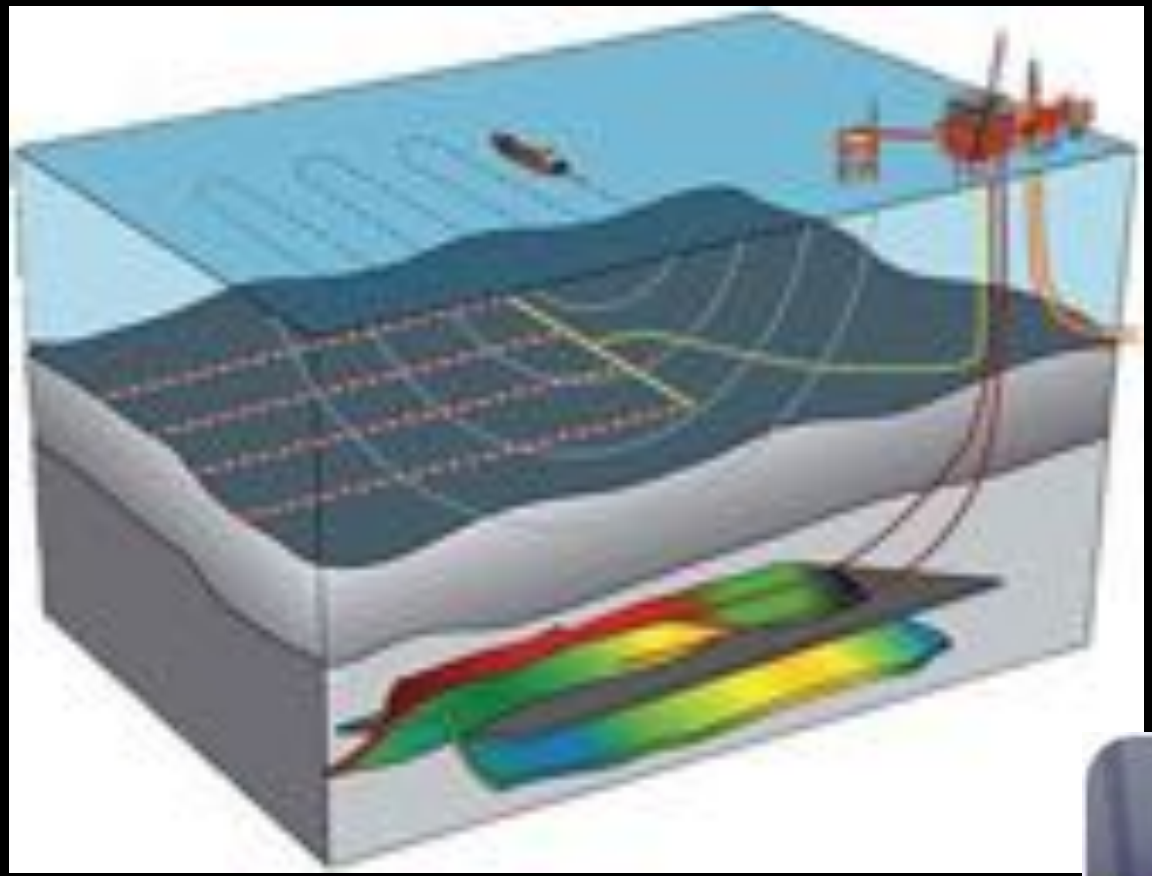
3D/4D Seismics - Ocean Bottom Seismometers (OBSs) e NODES (4C)

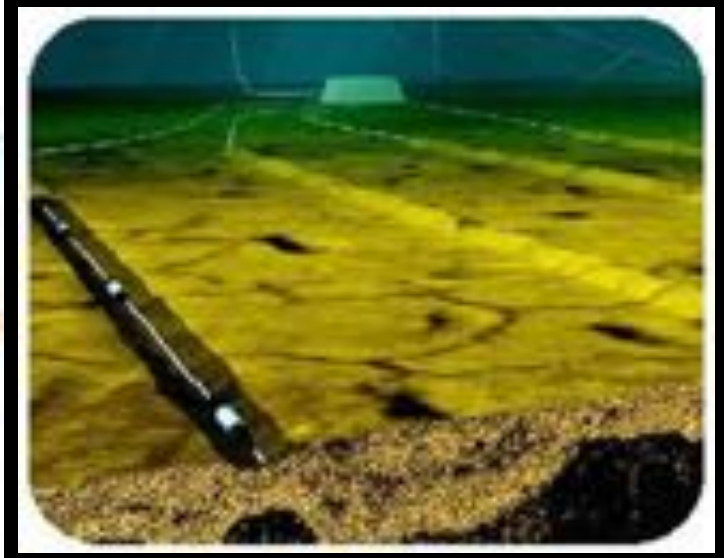




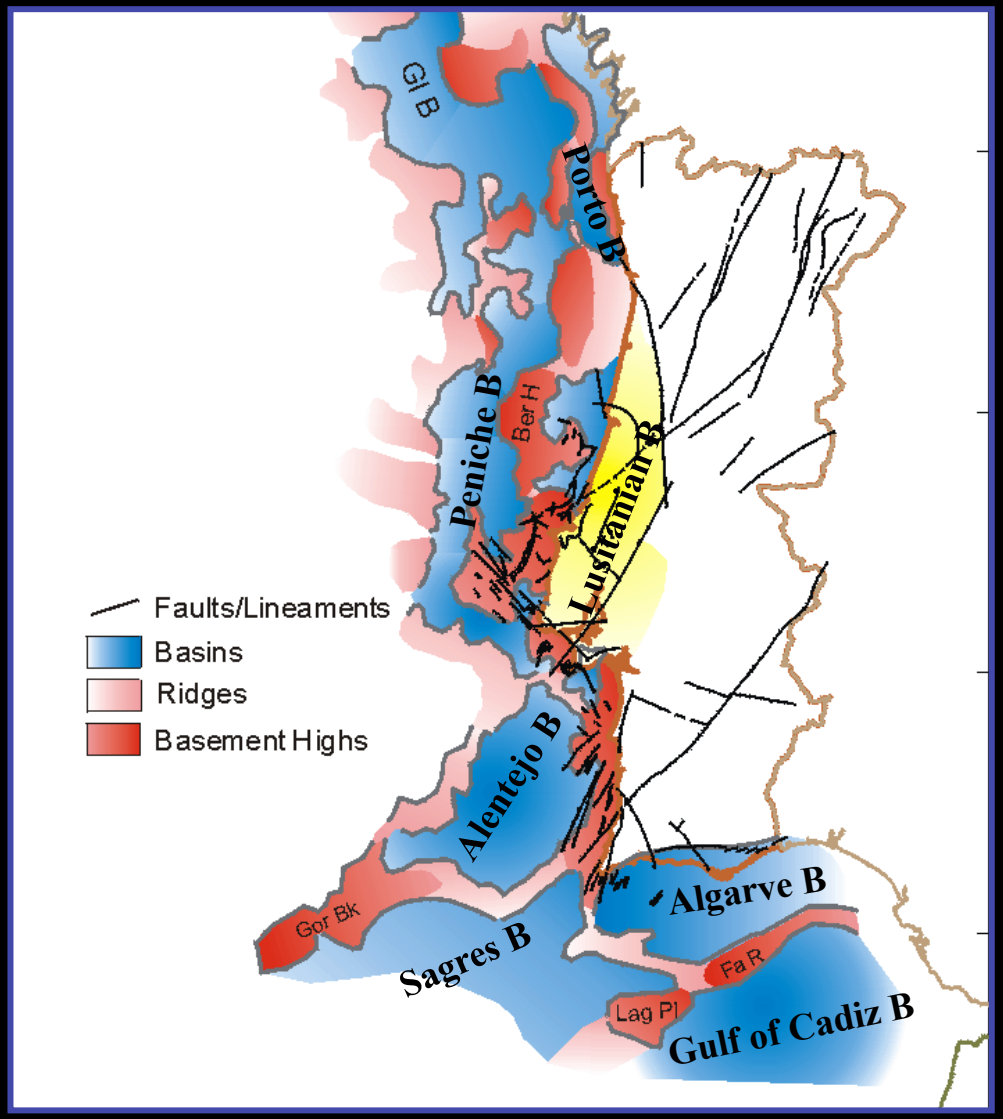
NODE 4C
4 components
(3C geophone
+ 1 Hydrophone)

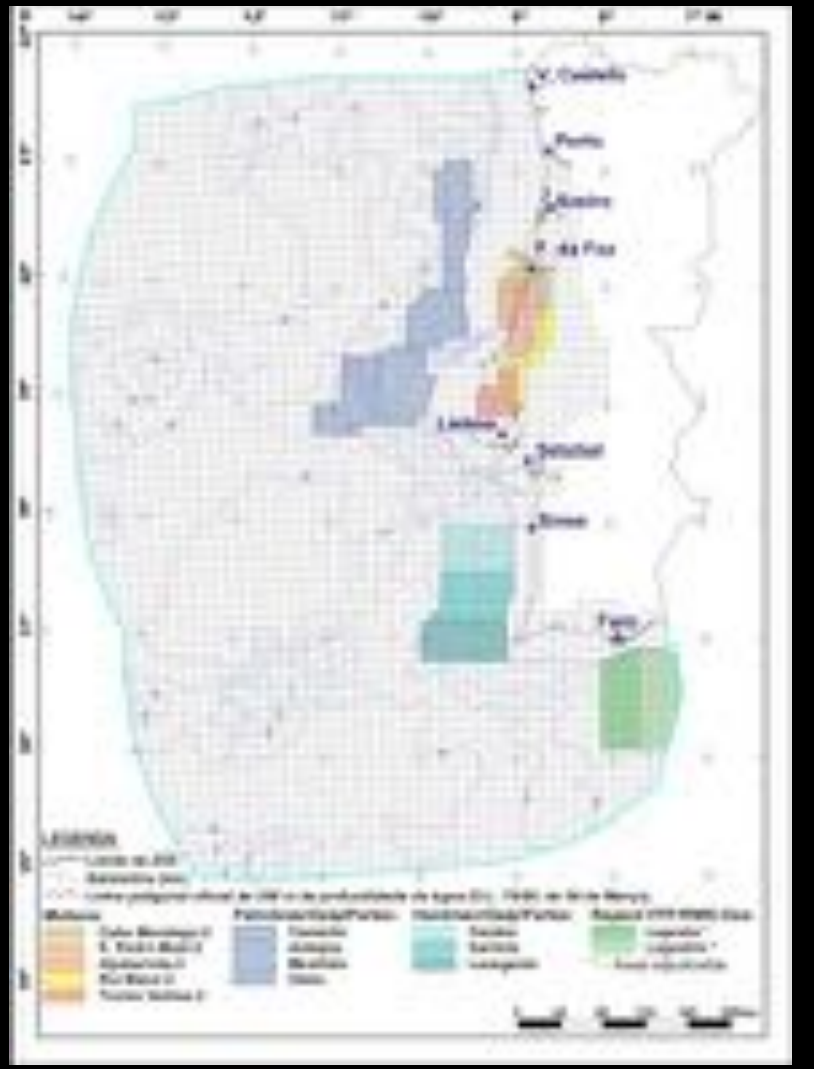
4D Seismics - Ocean Bottom Cables Reservoir monitoring



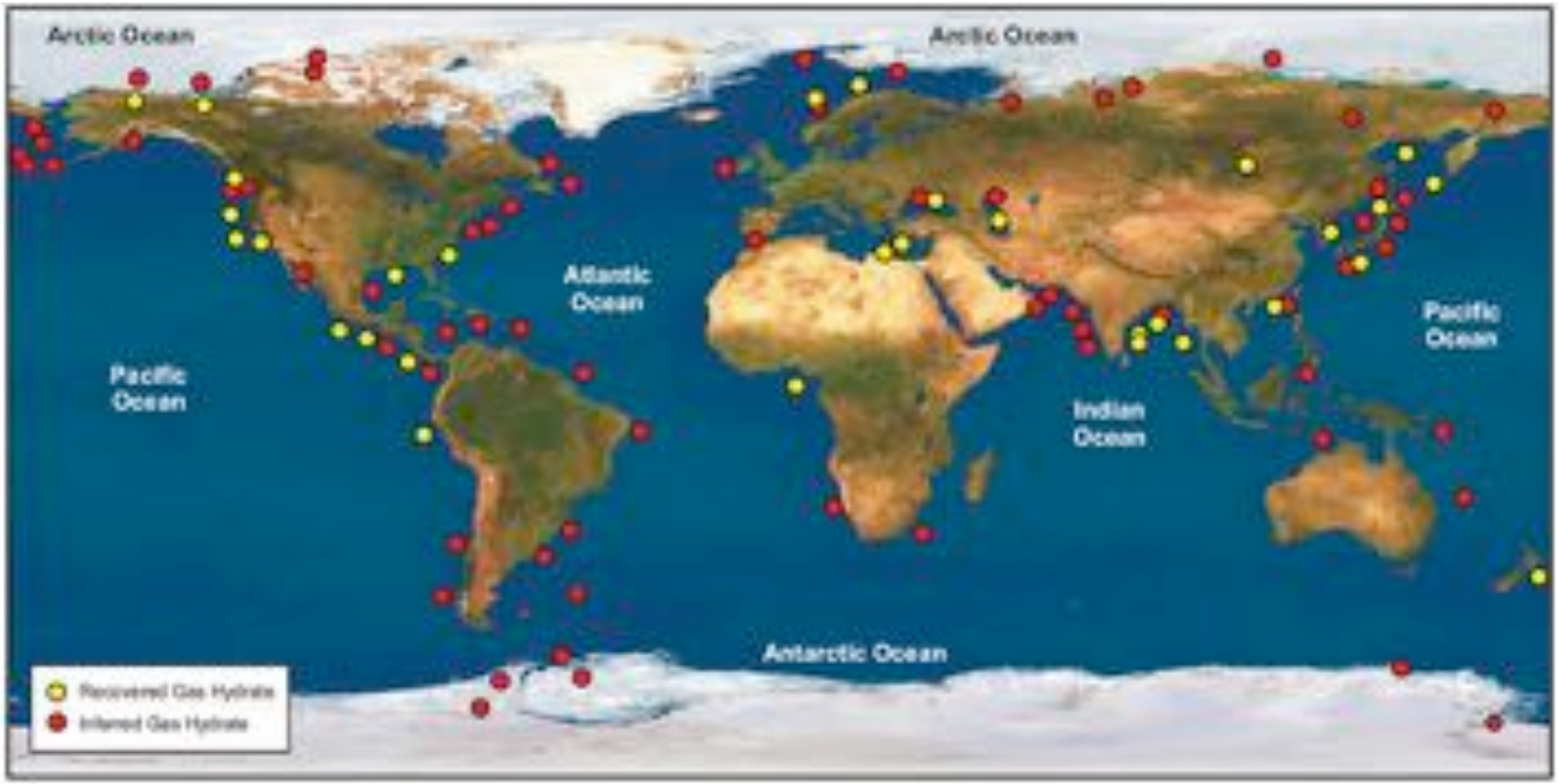


Deep Portuguese Basins



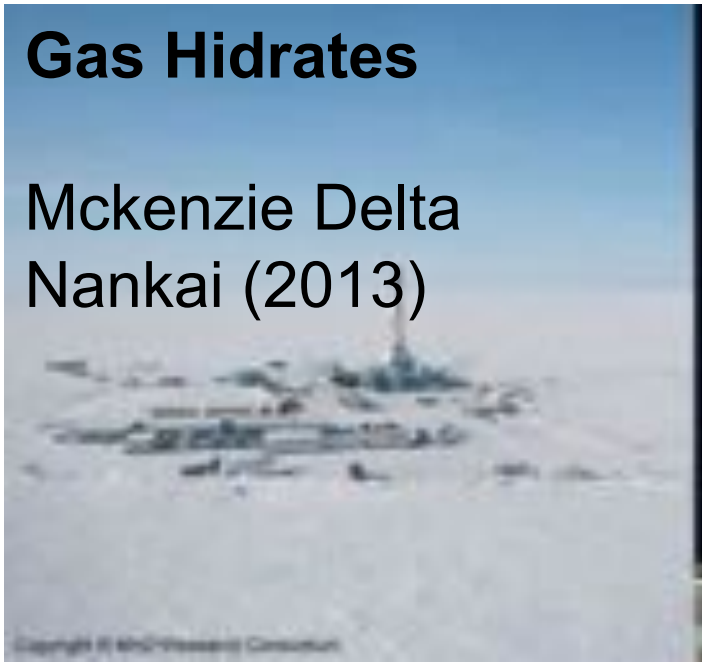


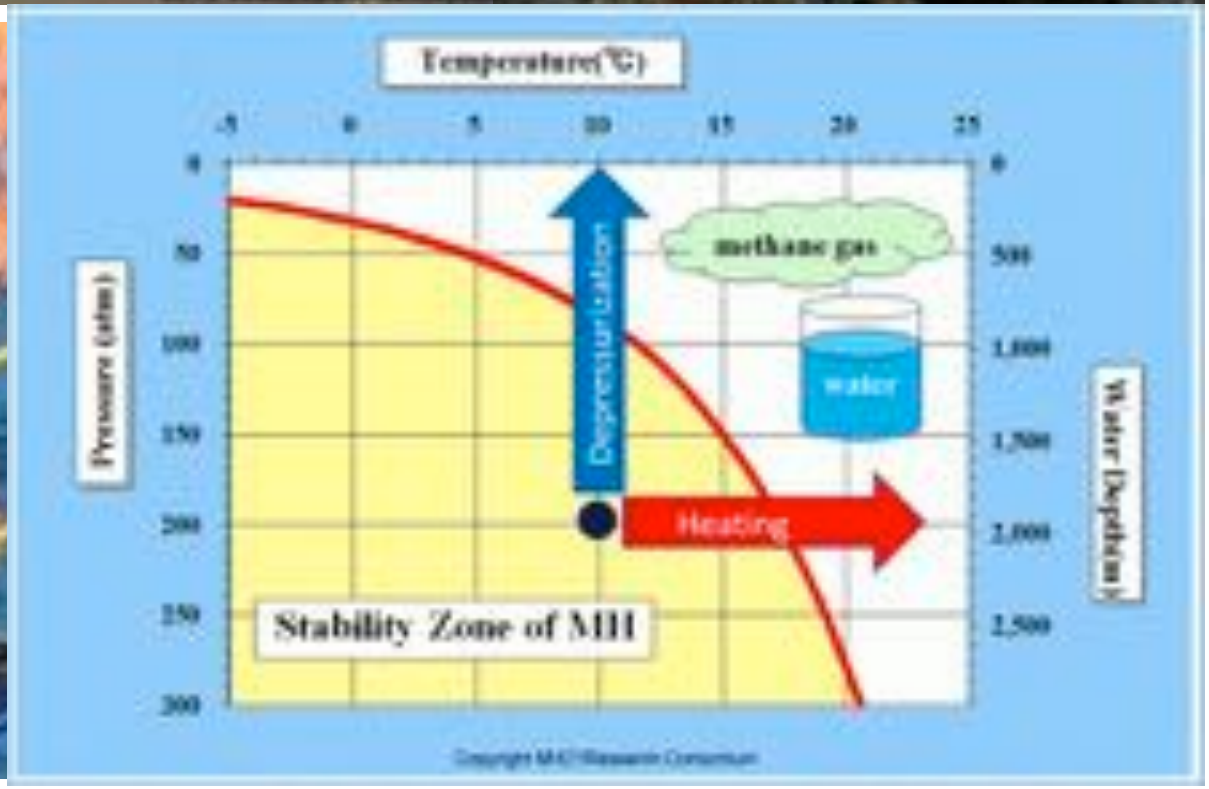

Gas Hydrates
Geomar, 2000


Arctic Ocean
Arctic Ocean
Atlantic Ocean
Pacific Ocean
Pacific Ocean
Indian Ocean
Antarctic Ocean
Recovered Gas Hydrate
Inferred Gas Hydrate

Gas Hidrates

Mckenzie Delta
Nankai (2013)

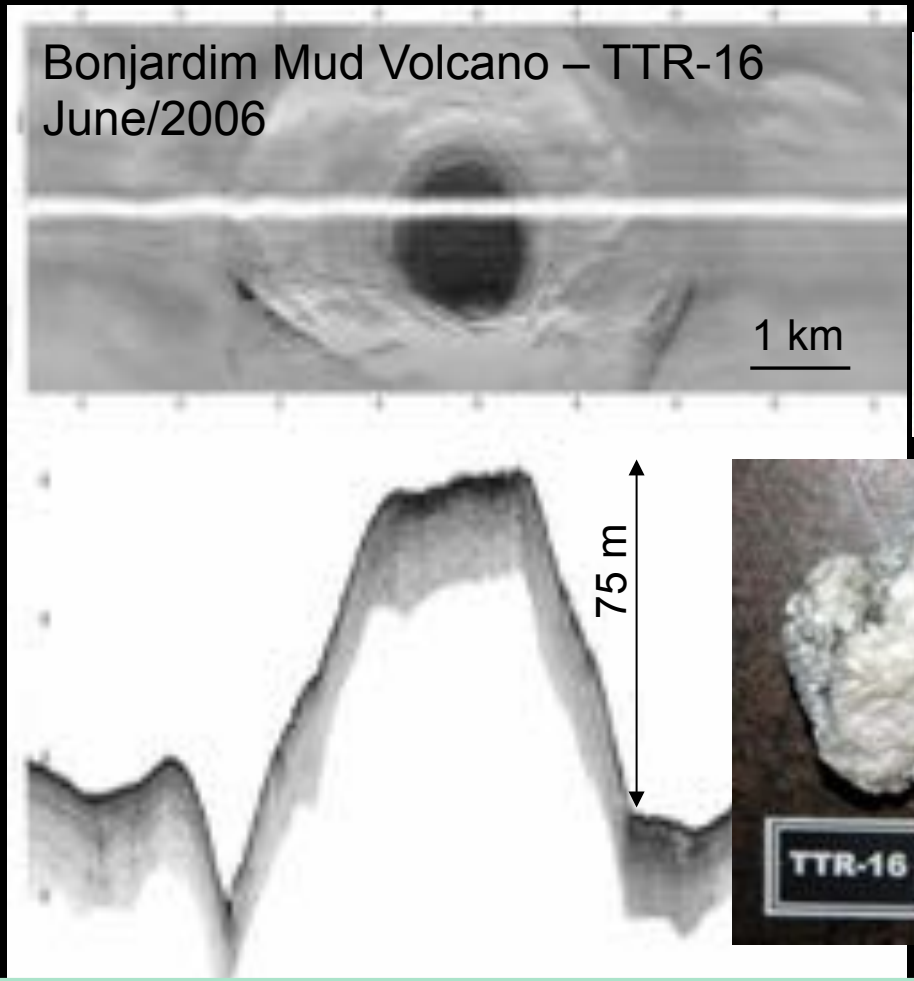


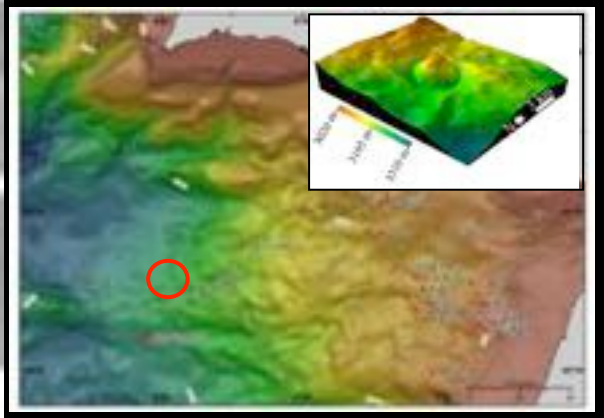


Mud volcanoes: Gulf of Cadiz

Gas Hydrates, South Portuguese Margin

MvSeis





Crystalline solids. 1 cm^3 HG ⟶ 160 cm^3 gas.

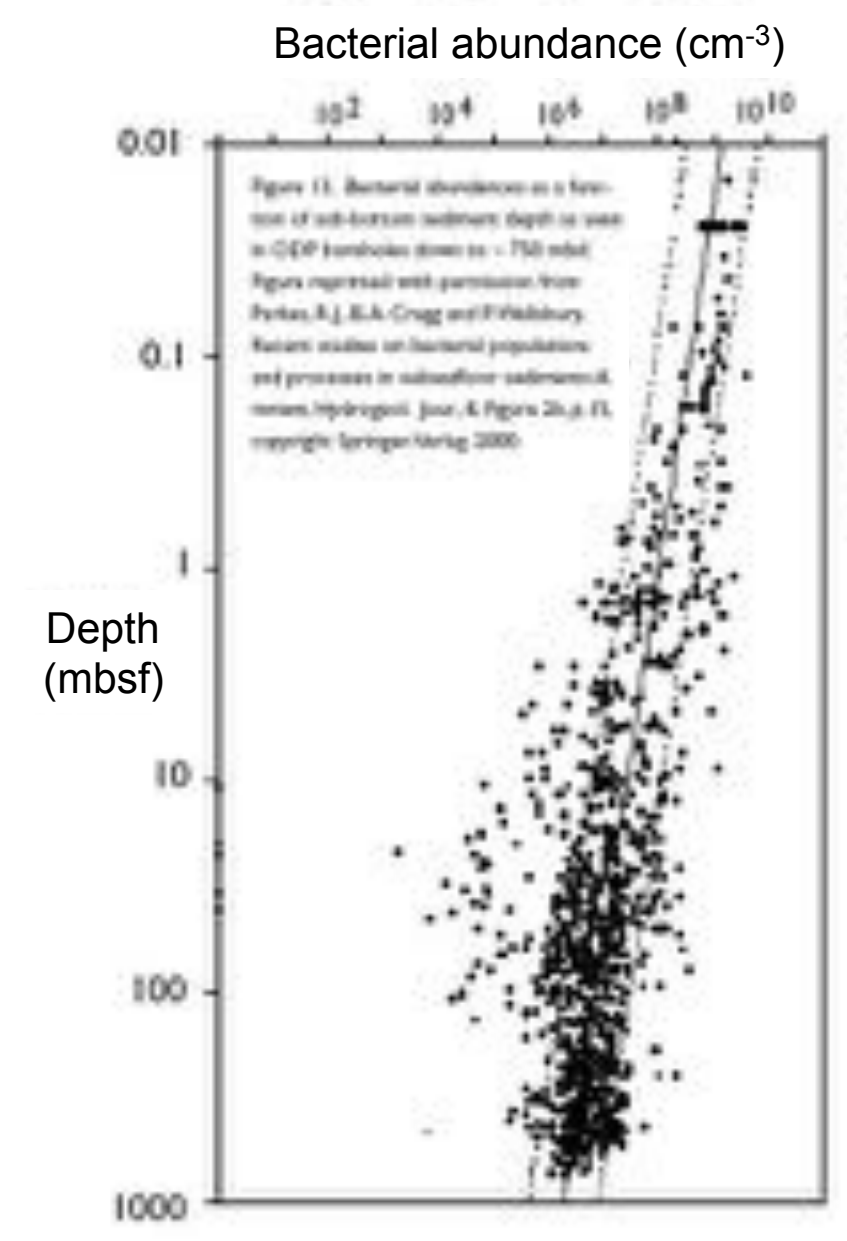
Mud volcanoes Bonjardim, Porto, Ct. Arutjunov & Ginsburg.

Thermogenic gas 81%-88% methane; 12-19% C_2-C_5.

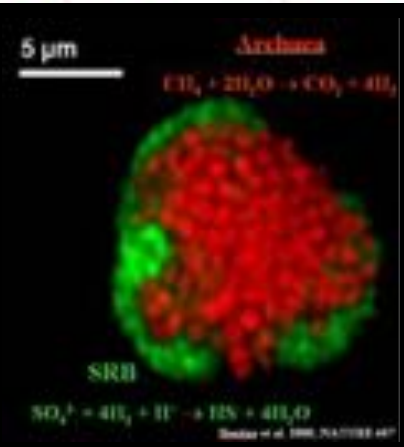
Oil Reservoirs at depth?

Deep Water Corals

Deep Biosphere. Deep Ocean Drillling ODP/IODP

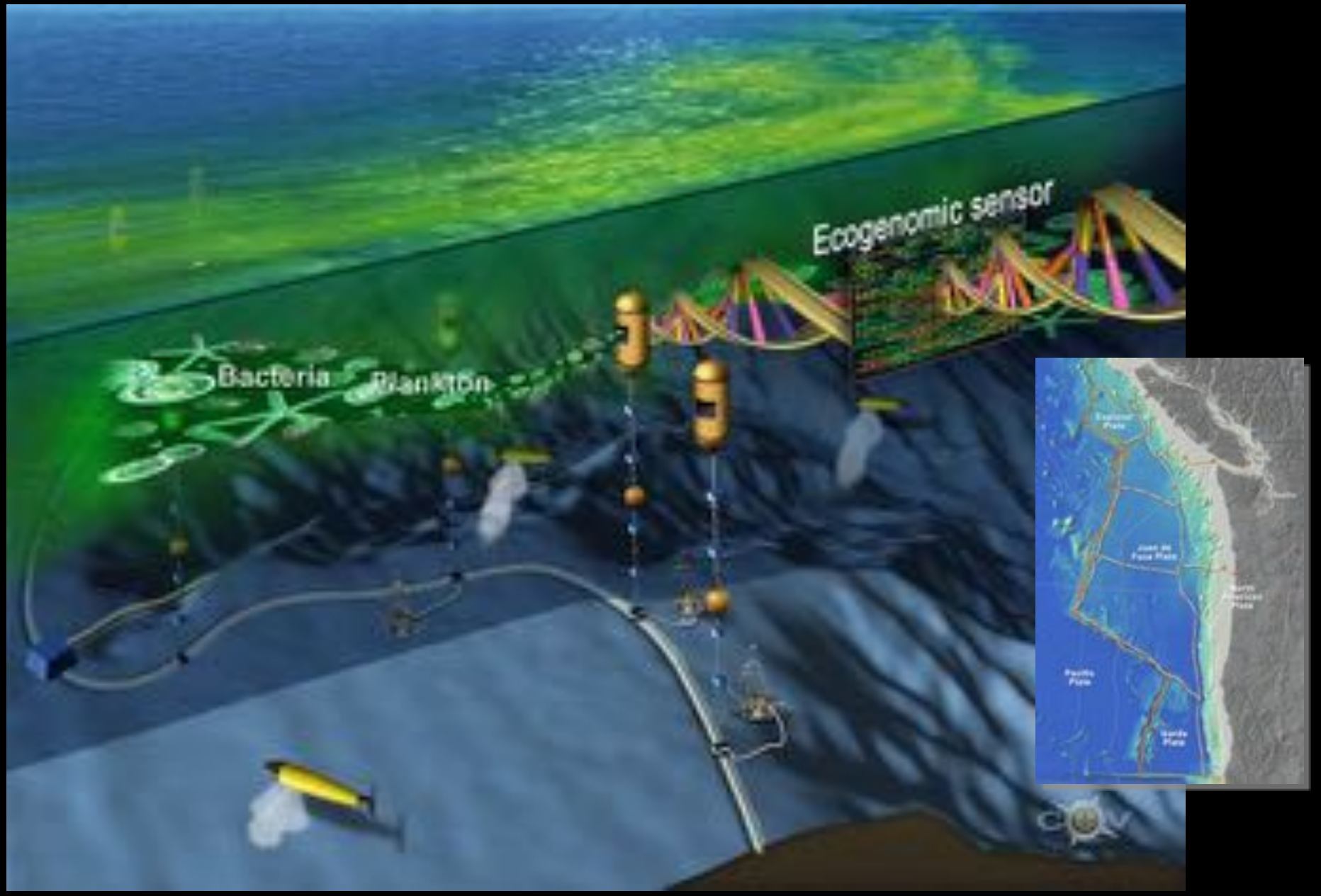


The Deep Biosphere and the Subseafloor Ocean



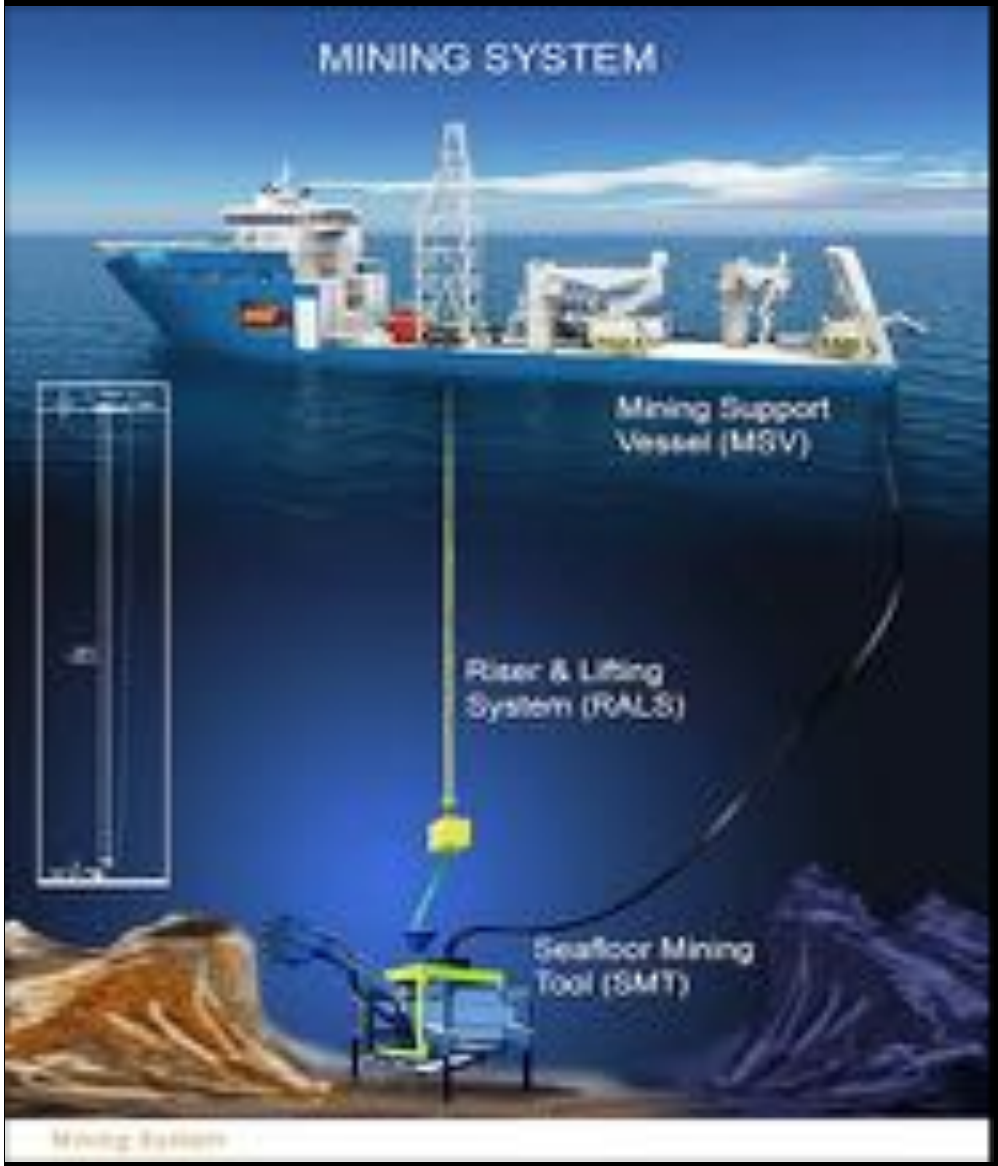
ROV´s (Remote Operated Vehicles)

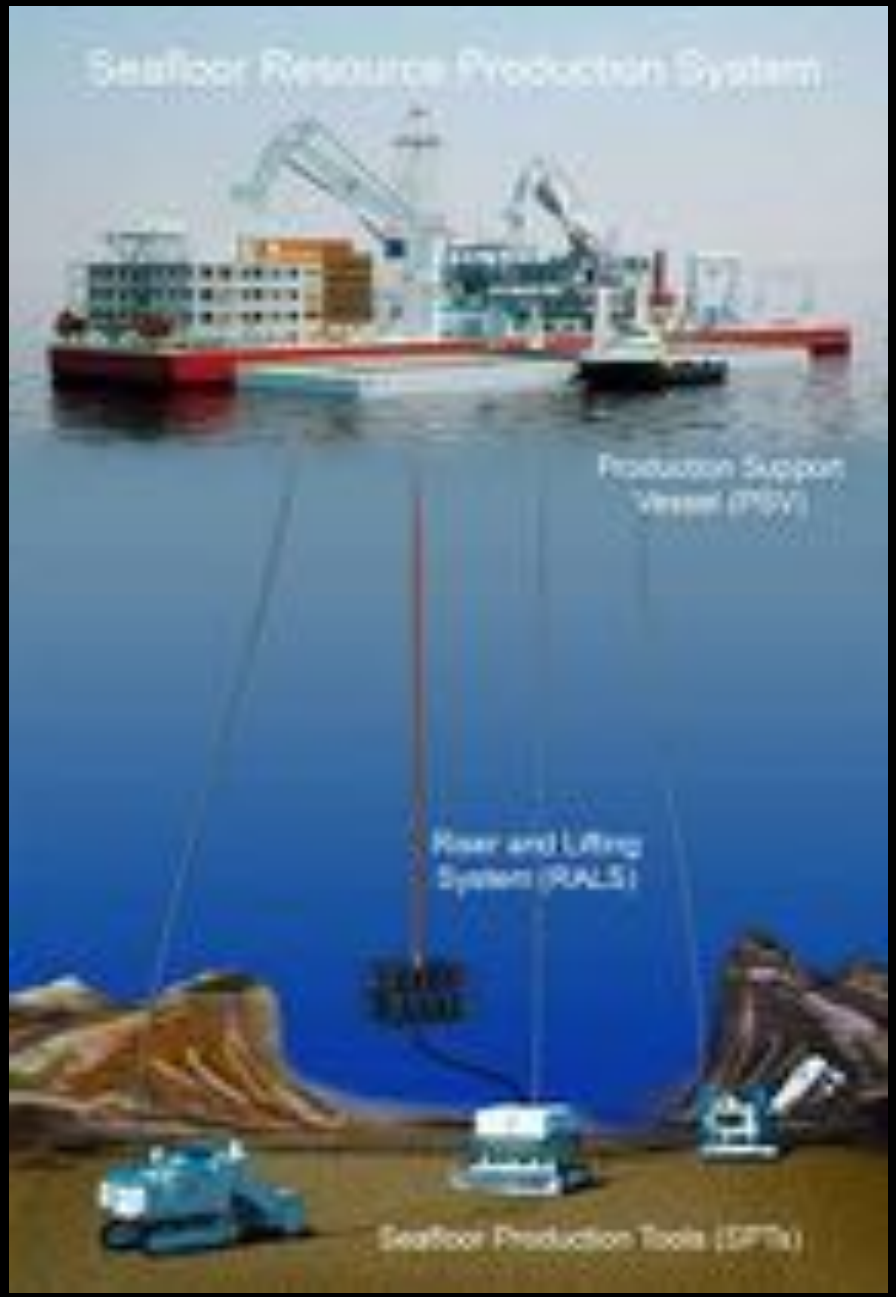
Submarine Laboratories and monitoring – new sensors



Courtesy J. Delaney

Deep Sea Mining





ROV/AUV Exploration, Monitoring impacts and real-time surveying

Technological Challenges

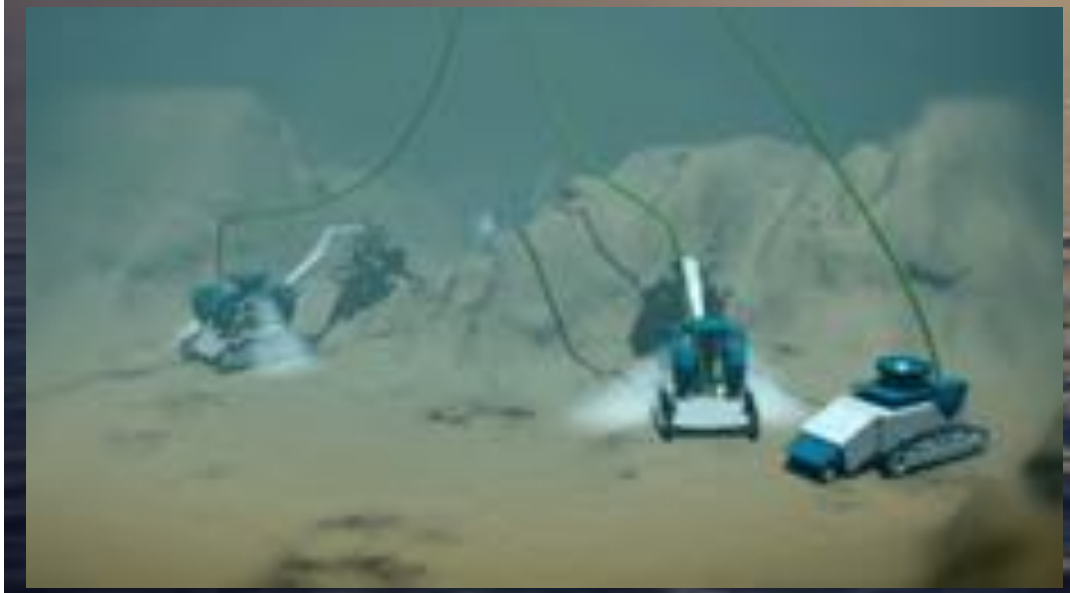
- **Cost-effective, fast and high resolution geophysical seabed and subseabed resources and habitat mapping and investigation tools**, together with sampling techniques and instrumentation/platforms for identification/characterization of oil & gas reservoirs and mining sites.

- New **exploitation methods and instrumentation for deep sea mining** (mining tools, transport e ore processing) economically feasible and with minimization of environmental impacts (FPSOs, exploitation tools, ore fragmentation and transport).

- **Cooperative underwater robotics and new sensors – real-time large dataset transmission - monitoring/surveillance**.

- **New materials, equipments and structures capable of operating in extreme working conditions** (corrosion/pressure/temperature/sea and atmospheric severe conditions, natural hazards, great depths).

- Cost-efectice technology **for habitat mapping and real-time monitoring of production sites and environmental impacts.**



Many thanks for your attention!

CESAM
Centre for Environmental and Marine Studies