Marine Mineral Resources of the AREA (with an emphasis on the Mid-Atlantic Ridge and south Indian Ridge) - Types, distribution, and the role of marine scientific research in their discovery

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ISA, Kingston, Jamaica

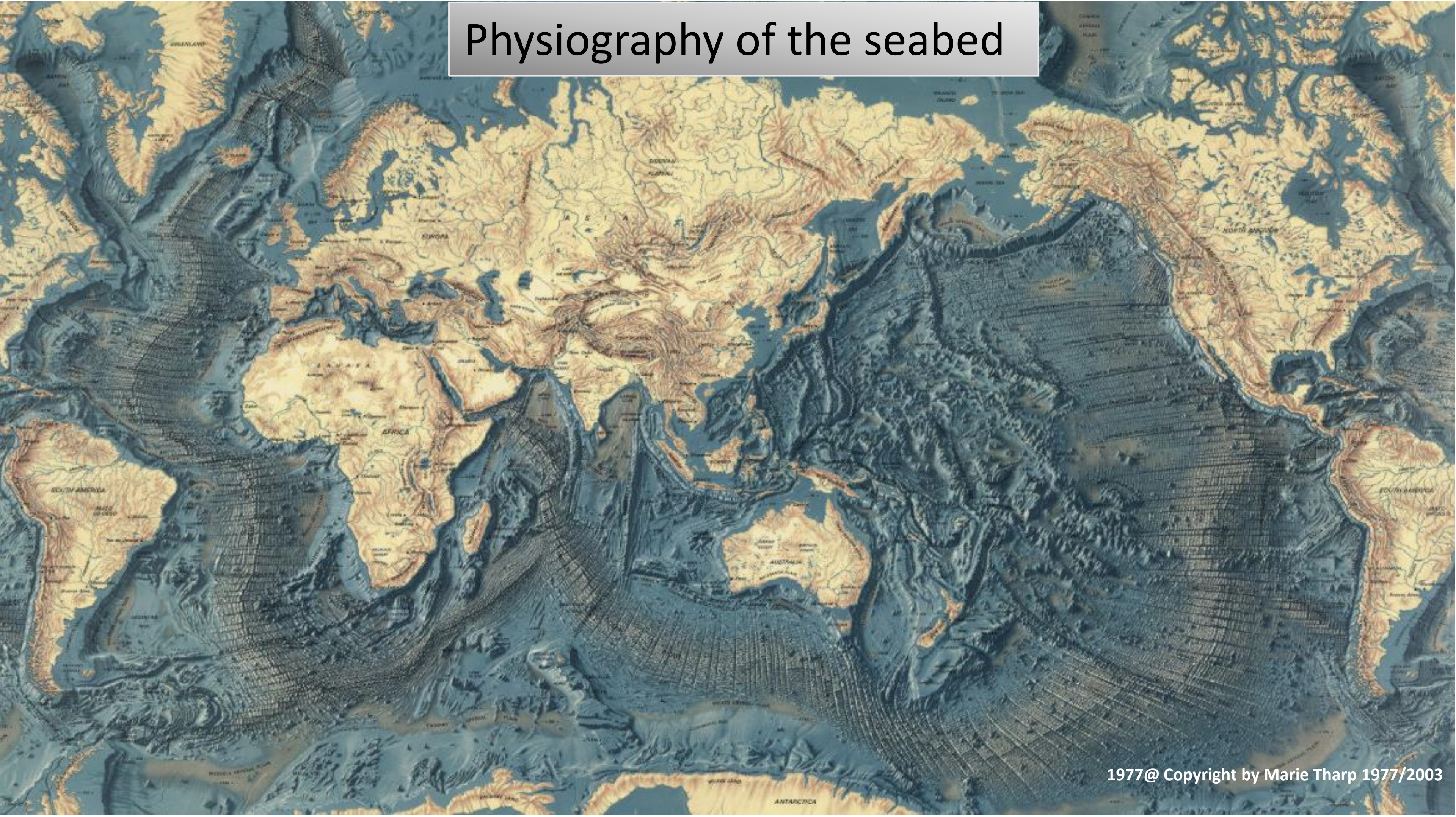
ISA - CONTRACTORS

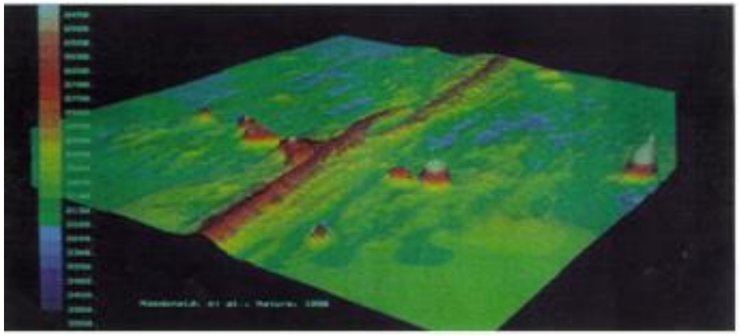
Mineral Type	Pacific Ocean								Indian Ocean	Atlantic Ocean
Polymetallic Nodules	IOM[07] [2001]	Yuzmorgeologiya, Russia [2001]		Korea [2001]	China [2001]	Japan [2001]	France [2001]		India [2002]	
	Germany [2006]	Nauru [2011]	Tonga [2012]	UKSRL [2013]	GSR [2013]	Marawa	Singapore	Cook Island		

Co-crust	Japan [2014]	China [2014]	Russia [2015]		Brazil

PM-Sulphides		China (2011), Korea (2014) and India and Germany	Russia (2012) and France (2014) [Mid-Atlantic]

Physiography of the seabed

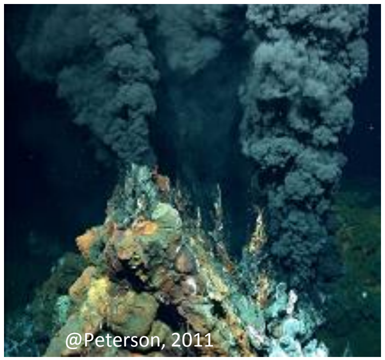




Mid-ocean Ridges Back Arc Basin

Sea mounts, Ridges Plateau

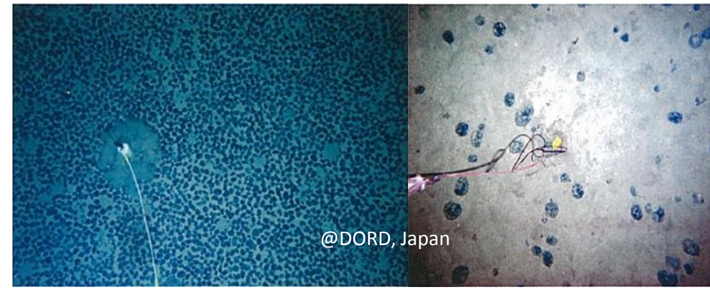
Abyssal Plains



@Peterson, 2011

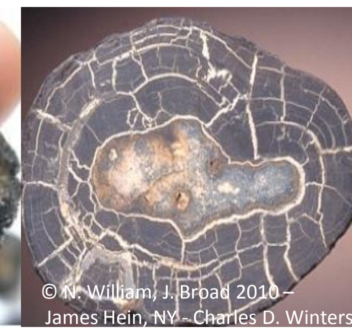
@ocean explorer NOAA

Halbach2009



@DORD, Japan

@ India



© N. William, J. Broad 2010 – James Hein, NY - Charles D. Winters

	Mid-ocean Ridges Back Arc Basin	Sea mounts, Ridges Plateau	Abyssal Plains
Depth (m)	1,500-5,000	4,00 - 4,000	4 – 6,000
Major Minerals	Copper, Zinc, Lead	Manganese, Iron	Manganese, Iron
Minor Minerals	Gold, Silver, REE	Cobalt, Nickel, Platinum, REE	Copper, Nickel, Cobalt, REE

What are Polymetallic Nodules?

- They are small (typically pea to golf ball sized) deposits, occur at sediment covered Abyssal plains in around 4000-6000 depth.

- They contain a relatively high percentage of the metals such as Mn, Fe, Ni, Cu, Co, Zn, Mo

- They are of economic interest because of their high nickel, copper and cobalt content

- Form in situ in various shapes, by precipitation of metals from bottom sea water and from sediment pore fluids around a nucleus

@James Hein (2012)

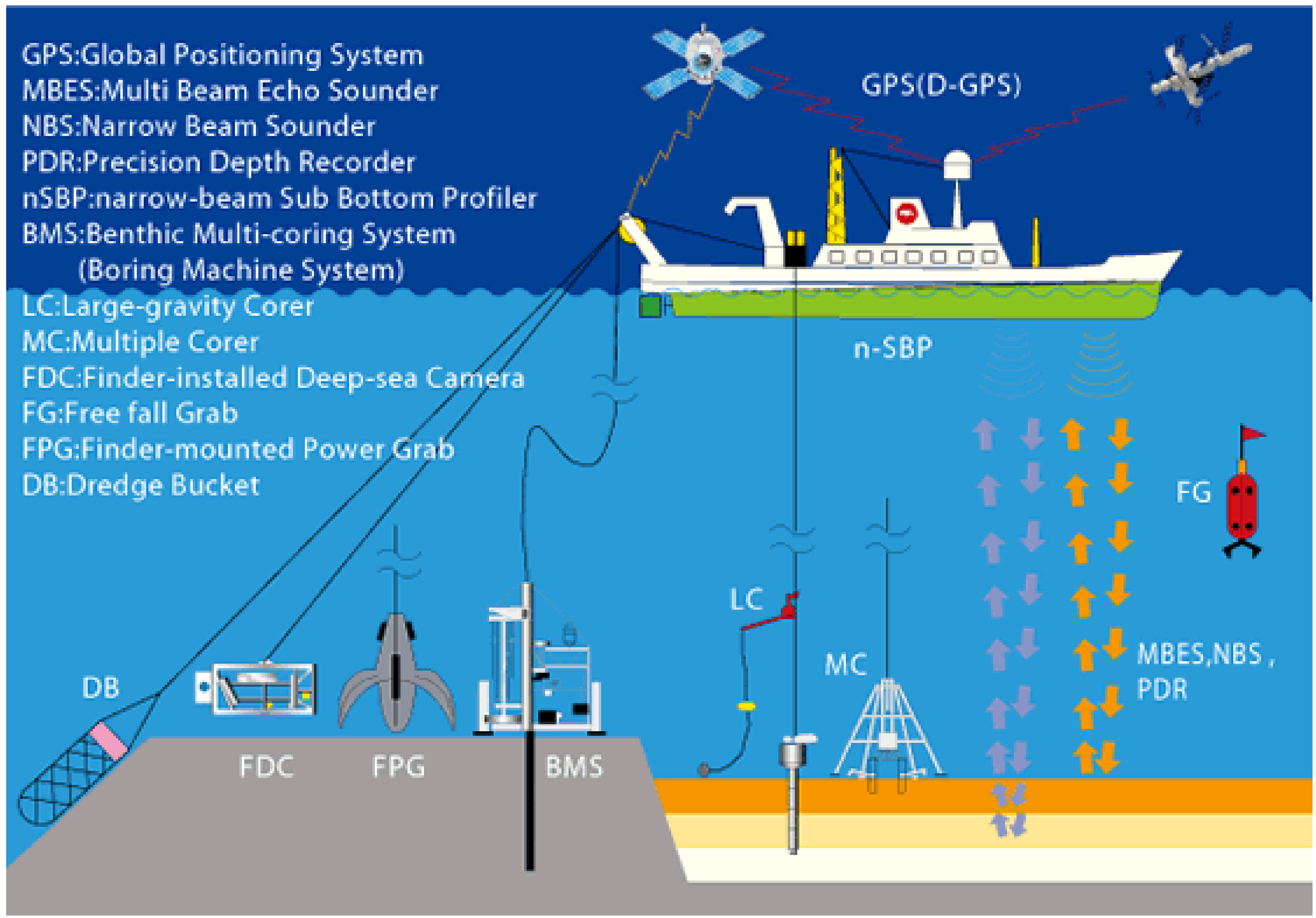
- Common core materials include rock pieces, shark teeth, whale bone or meteorite fragment.
- They grow very slowly (~mm/million years) and can be tens of million years old.
- They exist in most oceanic basins. They are most abundant in oceanic regions where sedimentation rates are low, and in areas where non-biogenic sediments dominate (red clay).

Elemental concentration- PMN

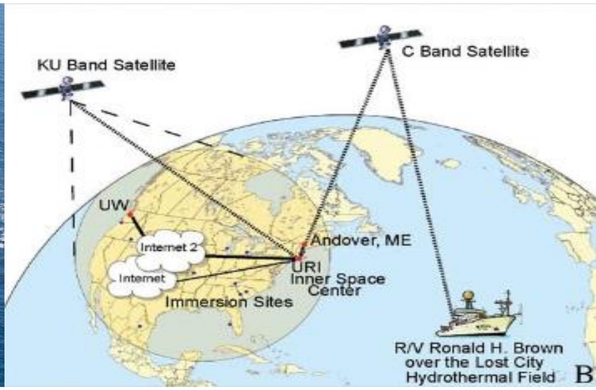
Element	Atlantic	Pacific	Indian	World Oceans
Manganese (wt. %)	13.25	20.10	15.25	18.60
Iron	16.97	11.40	14.23	12.40
Nickel	0.32	0.76	0.43	0.66
Copper	0.13	0.54	0.25	0.45
Cobalt	0.27	0.27	0.21	0.27
Zinc	0.12	0.16	0.15	0.12
Lead	0.14	0.08	0.10	0.09

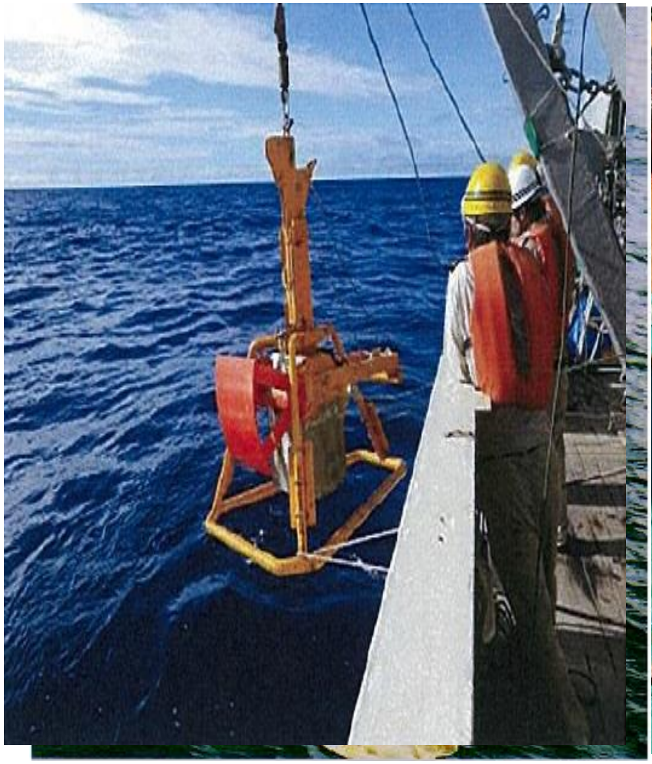
[Source: **Ghosh and Mukhopadhyay, 2000**]

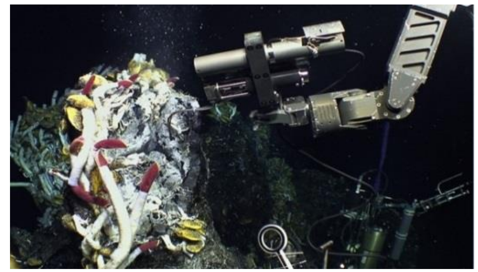
Equipment for exploration and sampling - schematic

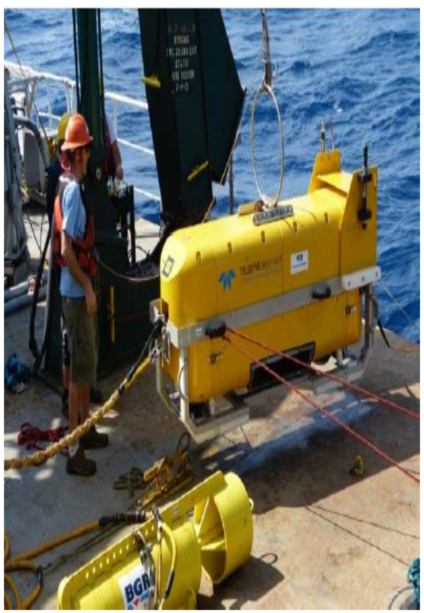


Some Equipment



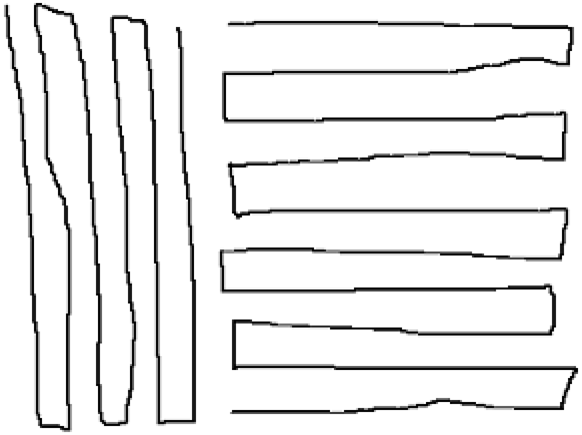


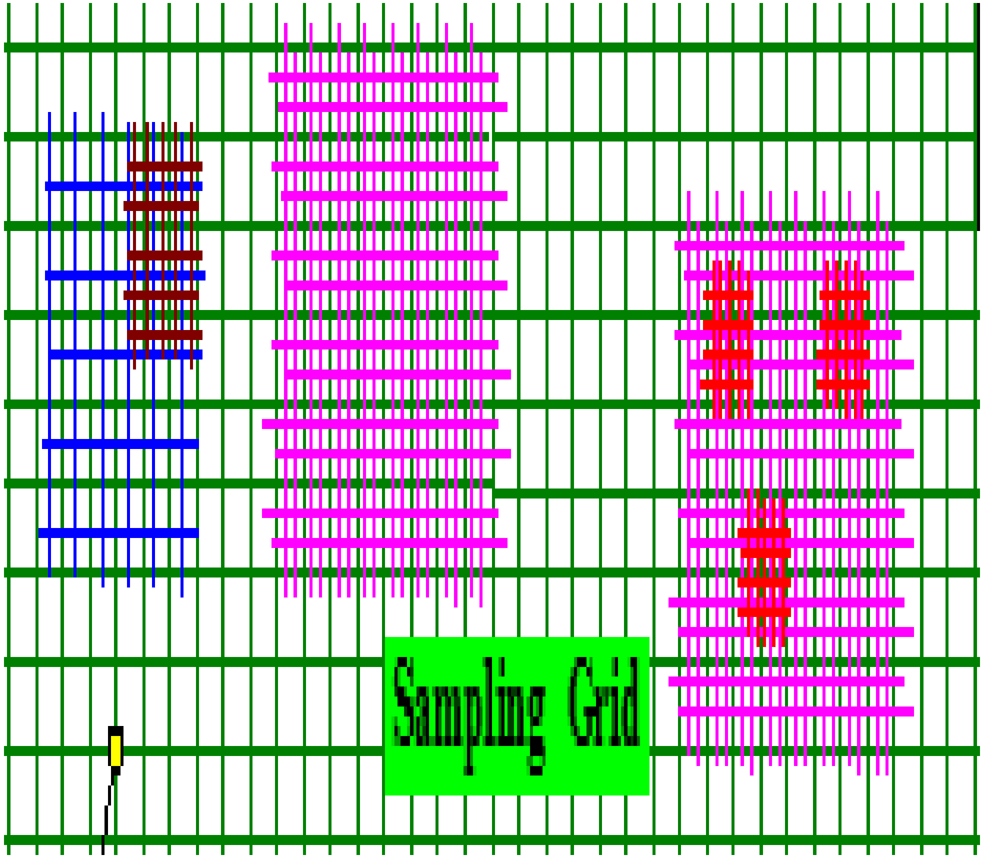




Autosub6000, http://www.sea-technology.com/

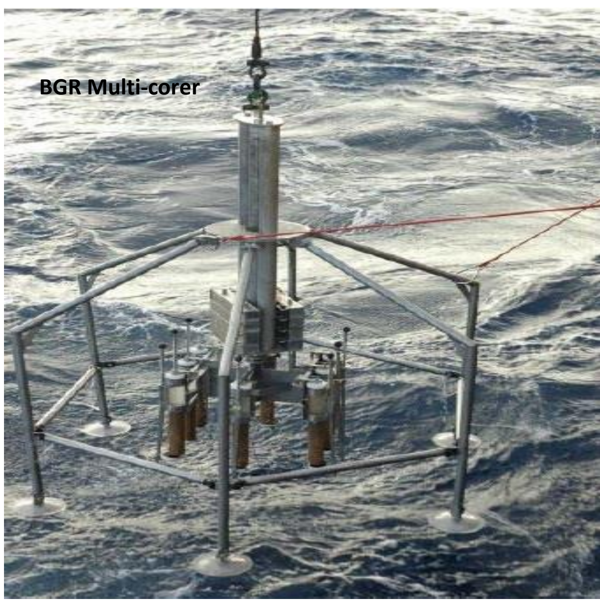
Sampling methodology

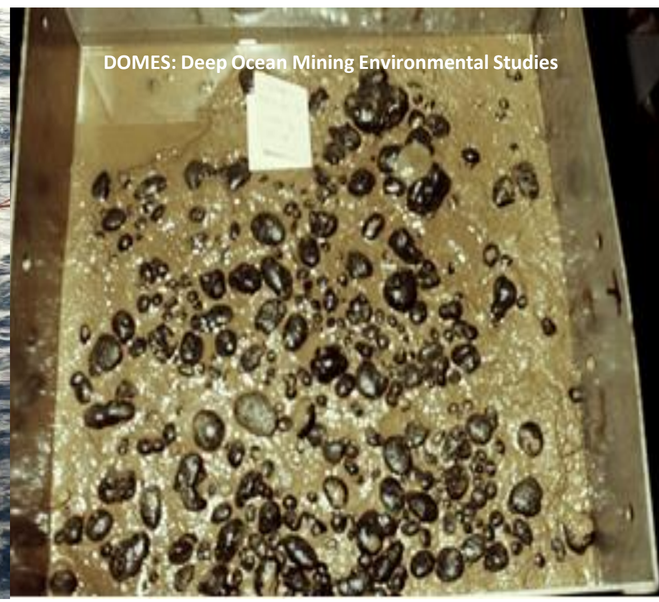


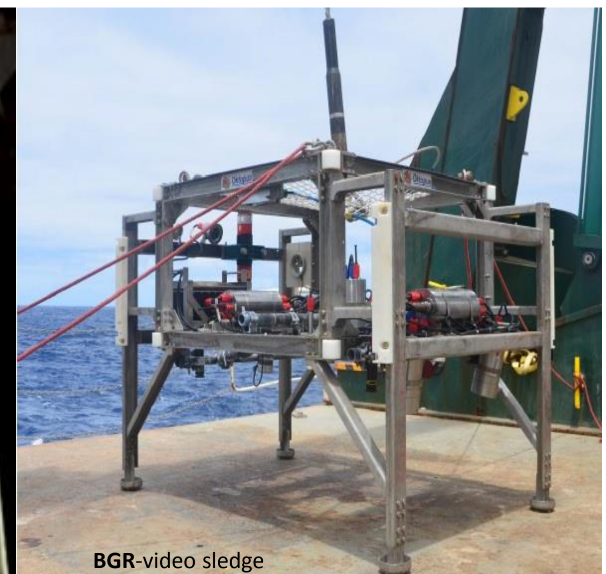



IOM

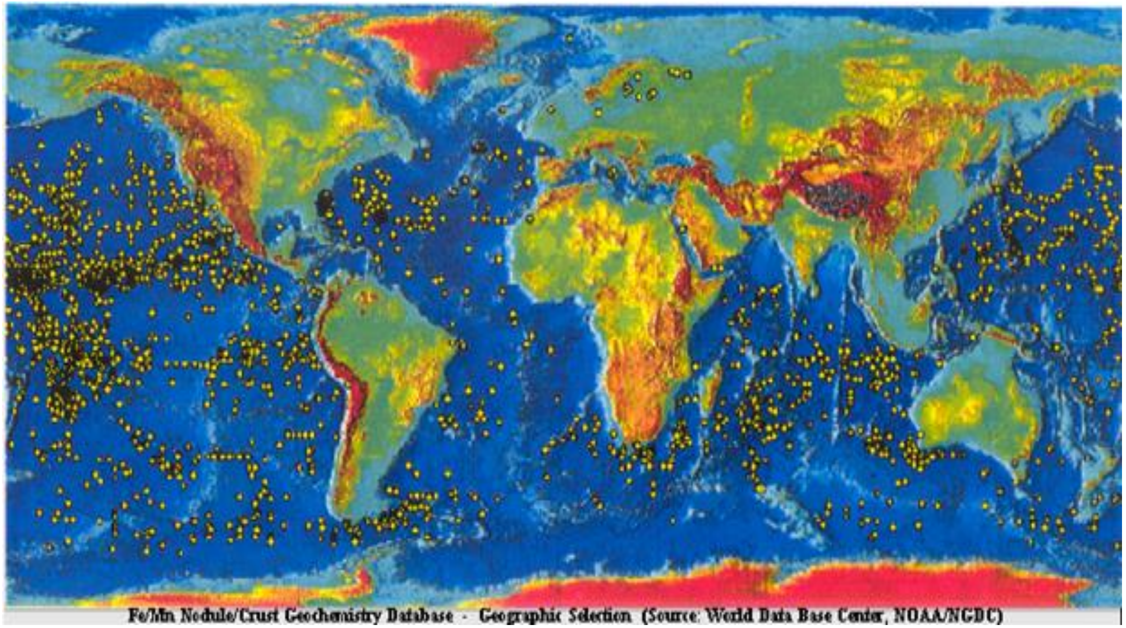

INDIA

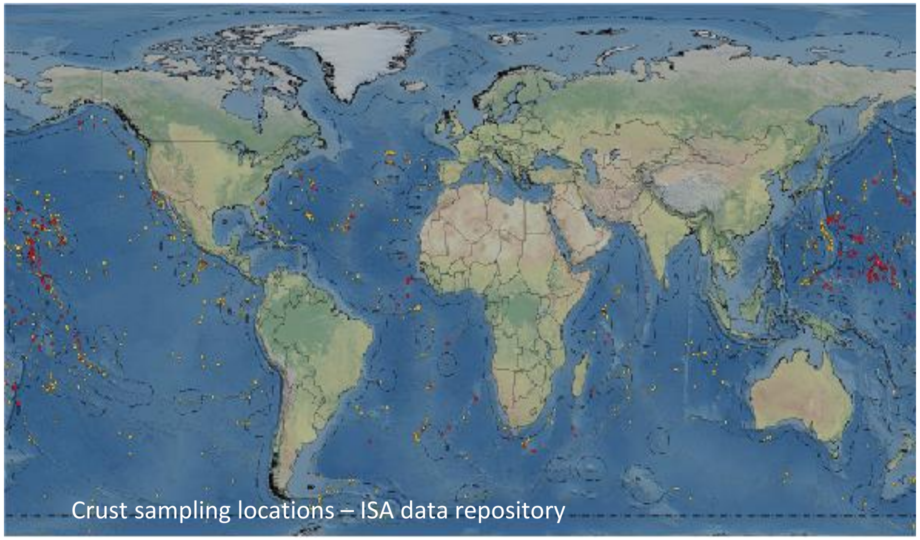

BGR Multi-corer

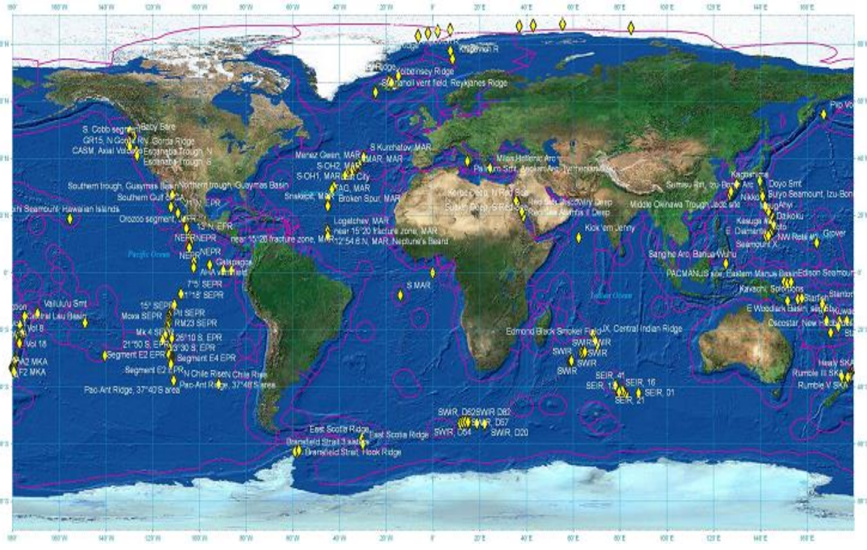

DOMES: Deep Ocean Mining Environmental Studies


BGR-video sledge

World location – deep sea bed minerals

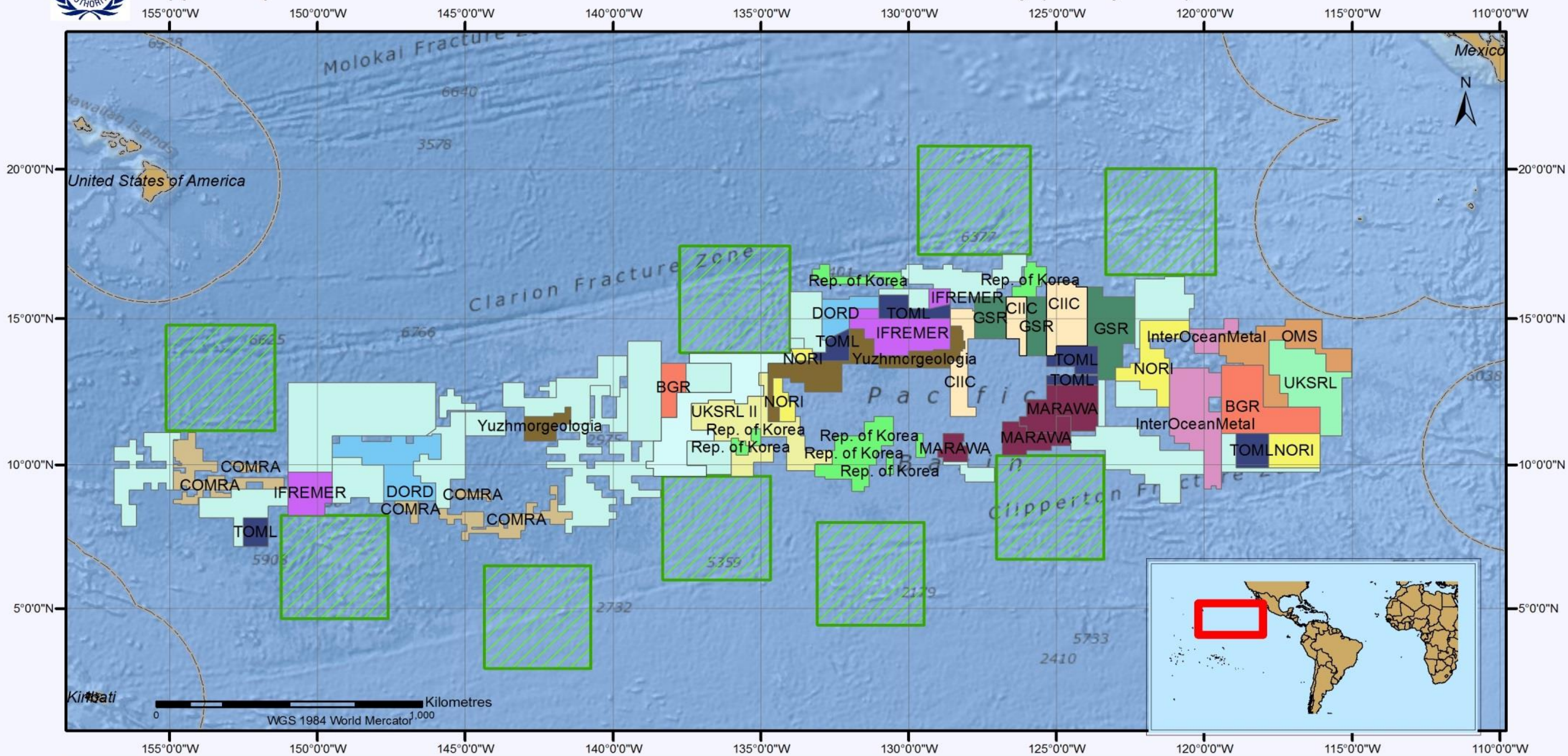






Polymetallic Nodules Exploration Areas in the Clarion-Clipperton Fracture Zone

Approved plans of work and areas reserved for the International Seabed Authority (25 July 2014)



Contract area or contract approved as of 25 July 2014

©International Seabed Authority, 2014. Background map: ESRI

- Ocean Mineral Singapore Pte Ltd. (OMS)
- Cook Islands Investment Corporation (CIIC)
- Marawa Research and Exploration Ltd (Kiribati)
- Bundesanstalt für Geowissenschaften und Rohstoffe (BGR; Germany)
- China Ocean Mineral Resources Research and Development Association (COMRA; China)
- Deep Ocean Resources Development Company (DORD; Japan)
- G-TEC Minerals Resources NV (GSR; Belgium)
- Government of the Republic of Korea
- Institut français de recherche pour l'exploitation de la mer (IFREMER; France)
- Interoceanmetal (IOM; Bulgaria, Cuba, Czech Republic, Poland, Russian Fed., Slovakia)
- Nauru Ocean Resources Inc. (NORI; Nauru)
- Tonga Offshore Mining Ltd (TOML, Tonga)
- UK Seabed Resources Ltd (UKSRL, UK)
- Yuzhmorgeologia (Russian Federation)
- UK Seabed Resources Ltd. (UKSRL-2nd plan of work)

Reserved area* **Area of particular environmental interest (APEI)**** **Exclusive Economic Zones**

* In the case of polymetallic nodules, the so-called parallel system provides that each application for exploration by a developed State must cover two parts of "equal estimated commercial value". One part is allocated to the applicant and the other is to become the reserved area, which is set aside for the conduct of activities by the Authority or developing States.

** In July 2012, the Authority adopted an environmental management plan for the Clarion-Clipperton Zone to be implemented on a provisional basis over an initial three-year period. The plan includes the designation of a network of areas of particular environmental interest (ISBA/18/C/22).

Co-rich Crusts

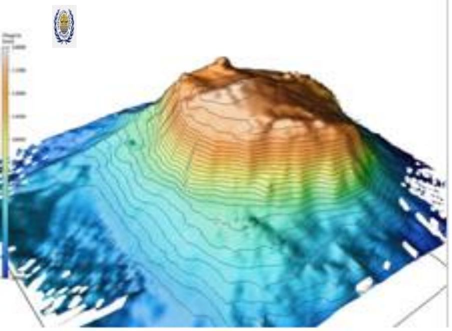
- Grow on hard rock surfaces on sea mounts, ridges and plateaus, where pelagic sedimentation is generally very low or nil.

- Economic potential was assessed in early 80s by German scientists
- Extremely slow rates of growth (1-7 mm/m.yr). Thickness of oxide layer varies from <1 up to 250 mm
- Metals precipitates from surface adsorption of seawater.
- Contain Fe, Mn, Ni, Co, Zn, Ba, Mo, Sr, REE & other minerals
- Crusts have more REE over other marine minerals.


Halbach (2009)

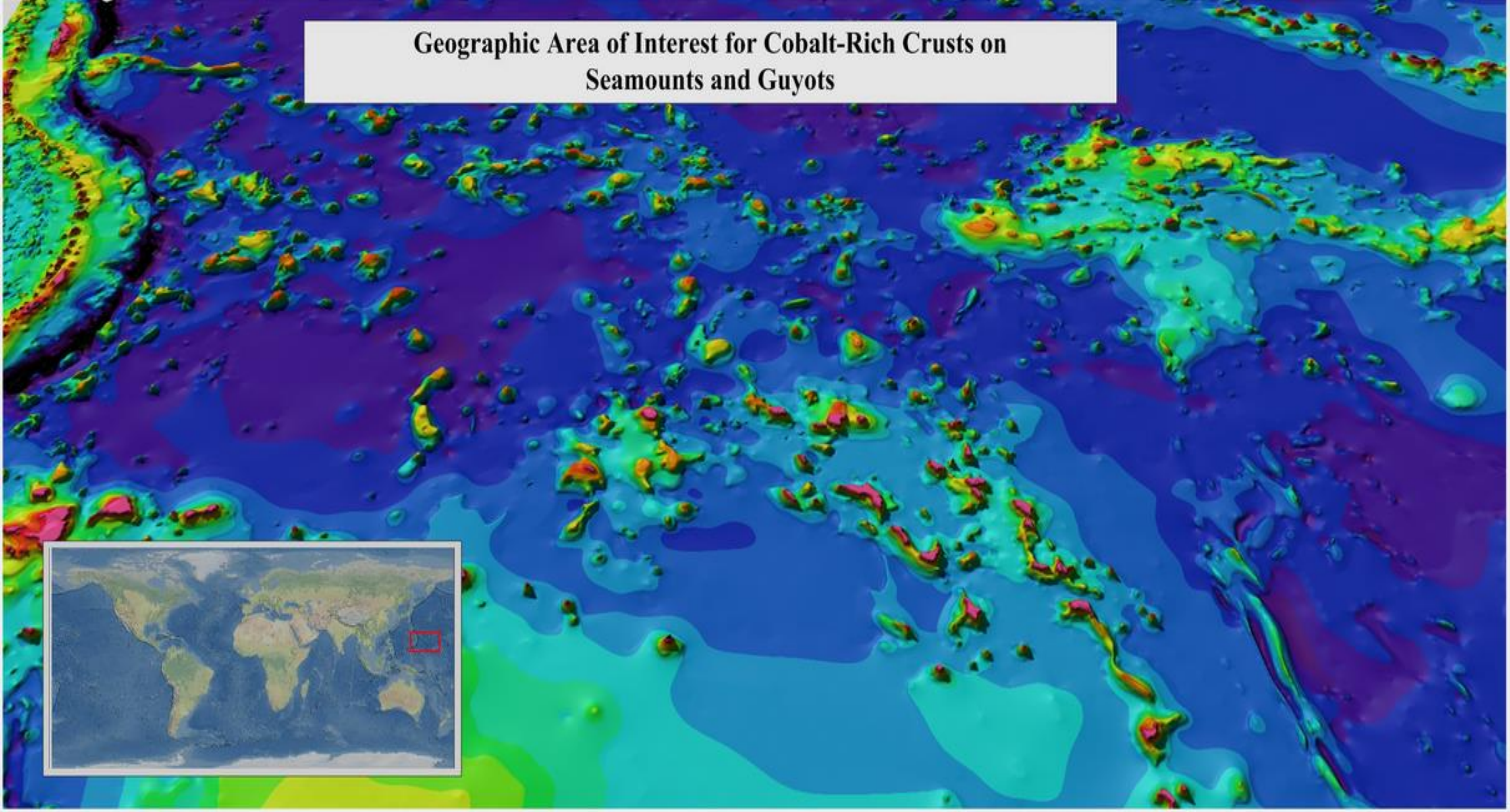
- The seamounts show diverse morphology, scale, water depth on top, slope angle, substrate and pelagic sediments

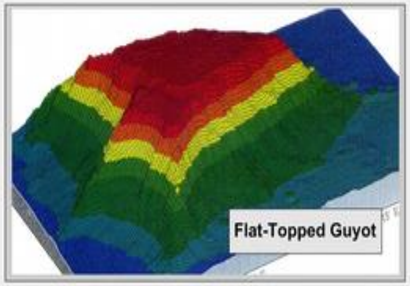
- They are mostly Guyots (large and small), conical & some other types. Large guyots can be 100 km or more on the major axis and the most promising
- Grade, abundance and accessibility are important for resource estimation. Abundance is thickness, metal contents & density
- Have high porosity (60%) & specific surface area (300 m^2/g)
- Majority substrate rocks are breccia, basalts, phosphorite, limestone
- Topography is most important to determine crusts distribution
- Stability of seamount basement is important in determining the economic potentiality of the crusts

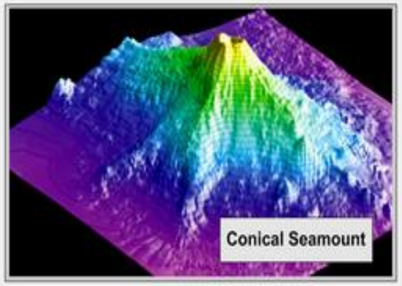


Composition of Co- crust

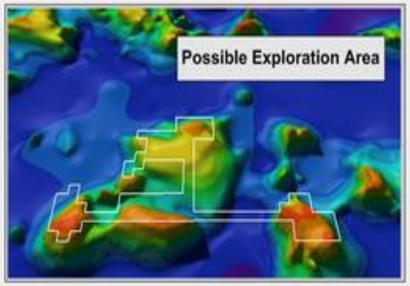
Iron	**15.1-22.9**
Manganese	13.5 - 26.3
Nickel [ppm]	3,255 - 5,716
Copper	713 - 1,075
Cobalt	3,006 - 7,888
Zinc	512 - 864
Barium	1494 - 4,085
Molybdenum	334 - 569
Strontium	1,066 -1,848
Cerium	696 - 1,684


Geographic Area of Interest for Cobalt-Rich Crusts on
Seamounts and Guyots

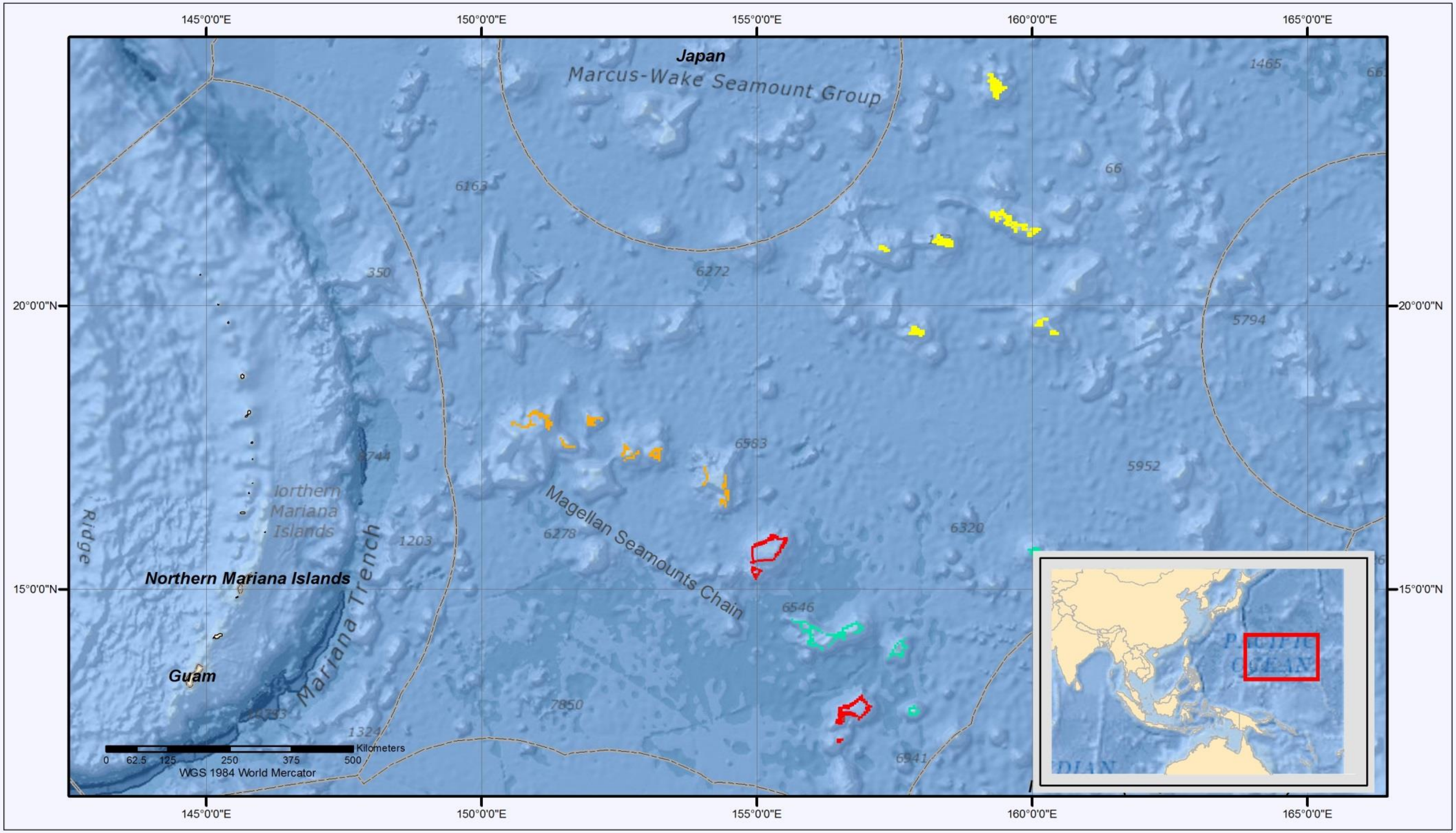

Flat-Topped Guyot


Conical Seamount


Cobalt Crust


Possible Exploration Area

Cobalt-Rich Ferromanganese Crust Exploration Areas in the Pacific Ocean



China Ocean Mineral Resources Research and Development Association (COMRA) (150 blocks)

Japan Oil, Gas and Metals National Corporation (JOGMEC) (150 blocks)

Government of the Russian Federation (150 blocks)

Reserved area**

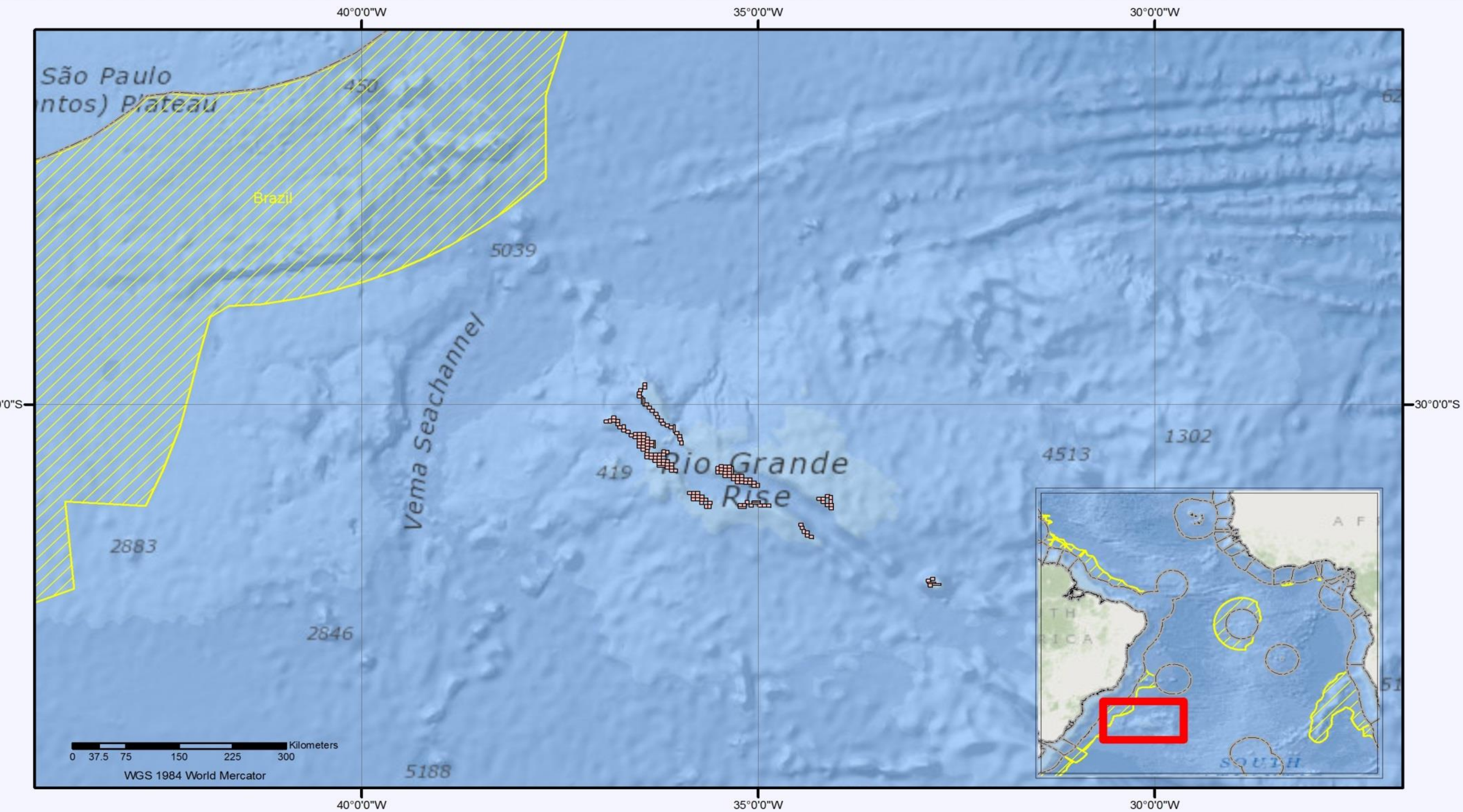
Exclusive Economic Zone (VLIZ, 2013)

* Blocks must not exceed 20 sq km and must be located within an area measuring not more than 550 x 550 km.

** The Russian Federation contributed a reserved area under the so-called parallel system, which provides that the application for exploration must cover two parts of "equal estimated commercial value". One part is allocated to the applicant and the other is to become the reserved area, which is set aside for the conduct of activities by the Authority or developing States.

Cobalt-Rich Ferromanganese Crust Exploration Areas on South Atlantic Seamounts

Approved plans of work



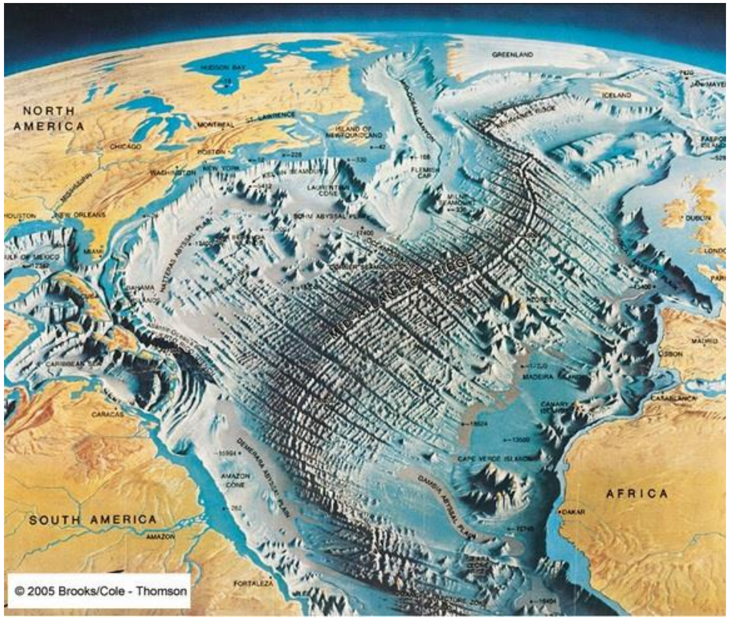
Companhia de Pesquisa de Recursos Minerais (Brazil) exploration area (150 blocks*)

Exclusive Economic Zone

ECS Submission

* Blocks must not exceed 20 sq km and must be located within an area measuring not more than 550 x 550 km.

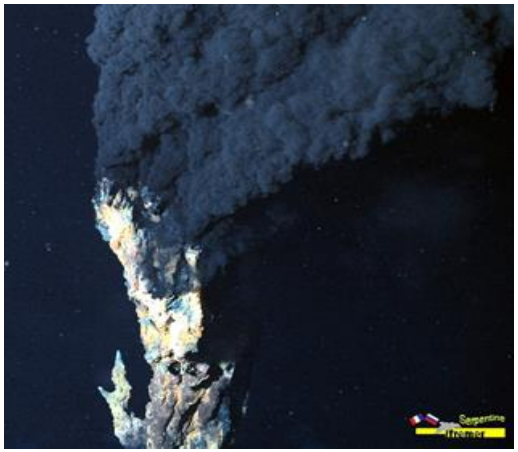
Polymetallic Sulfide Deposits



- Mid ocean ridges extend about 65,000 km across the ocean floor. New crust is created along these ridges. Polymetallic sulfides mainly occur along the rift valleys of ridges

- The first discovery of sub-marine hydrothermal venting in mid seventies and associated bio-communities changed the perception how we looked at life earlier.

- Hydrothermal circulation happens when the water enters the earth's through these fractures. Water gets very hot there in contact with the host rock and leaches their metals, thus changing its composition.



- This extremely hot (sometime above 400° C) mineral rich water rises up again, and in contact with the cold bottom water, solidifies.

- Sulfide deposits contain iron, copper, zinc, silver and gold in variable concentrations and are precipitated beneath and on the seafloor where high-temperature hot springs discharge through mineralized chimneys, also called Black smokers.

Composition of sulphide deposits

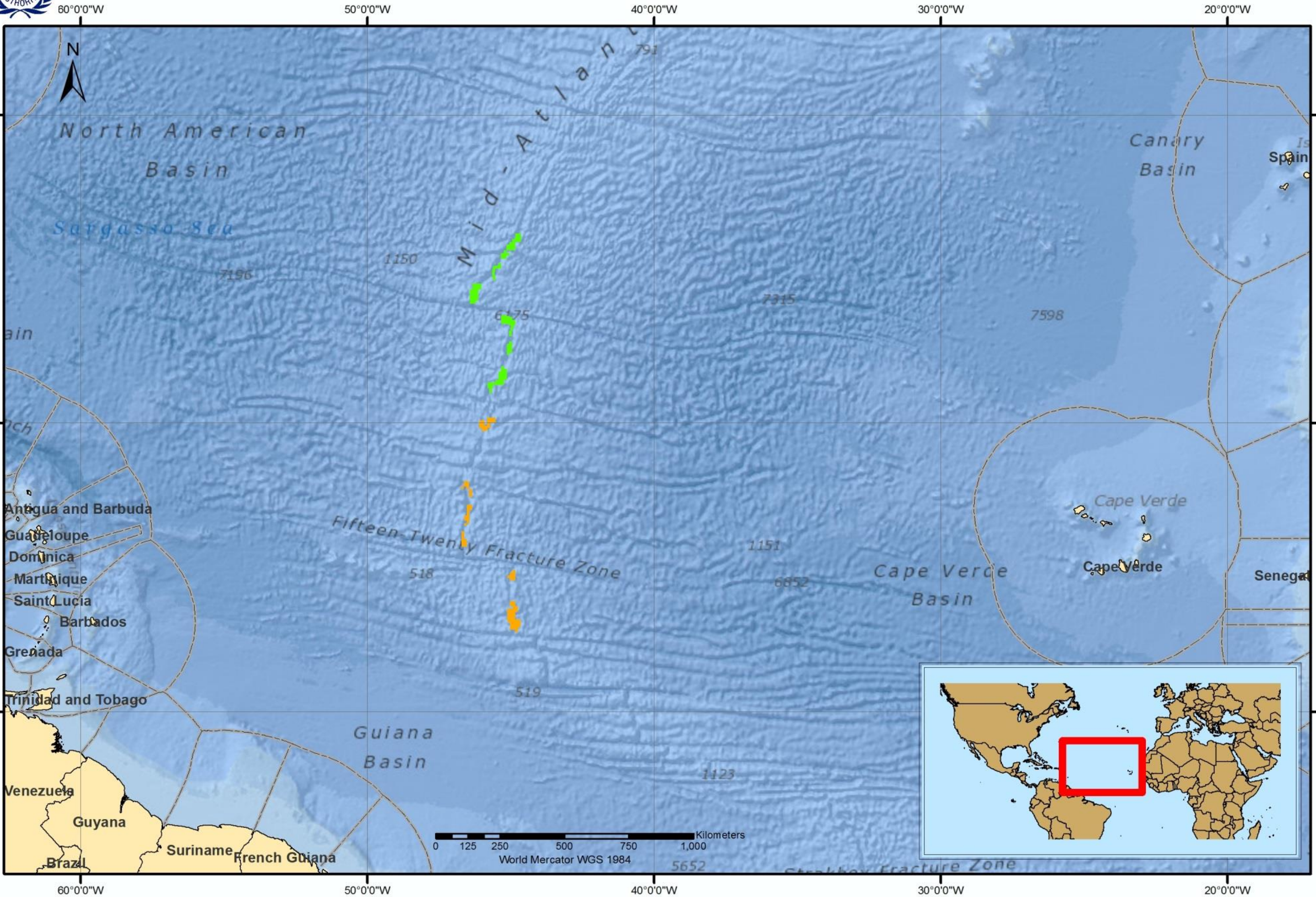
Element	Mid-Ocean Ridges at Divergent Plate Boundaries	Volcanic Island Chains at Convergent Plate Boundaries (range of composition)
Lead (weight percent)	0.1	0.4 – 11.8
Iron	26.4	6.2 – 13
Zinc	8.5	16.5 – 20.2
Copper	**4.8**	**3.3 – 4.0**
Barium	1.8	7.2 – 12.6
Arsenic [ppm]	235	845 – 17,500
Antimony	46	106 – 6,710
Silver	**113**	**217 – 2,304**
Gold	**1.2**	**4.5 – 3.1**
Number of samples analyzed	1,259	613

Source: **Herzig and Hannington (2000)**

Techniques of detecting Sulphide mineralization

- Geo-Acoustic profiling and mapping
- Seismic and electromagnetic technologies
- Remote detection through deep-towed vehicles - ROV
- Detecting and determining the physical and chemical anomalies in the water column above the ridge system
- Sampling and analysis of fluids and structures
- Mineralogical and detailed petrological studies

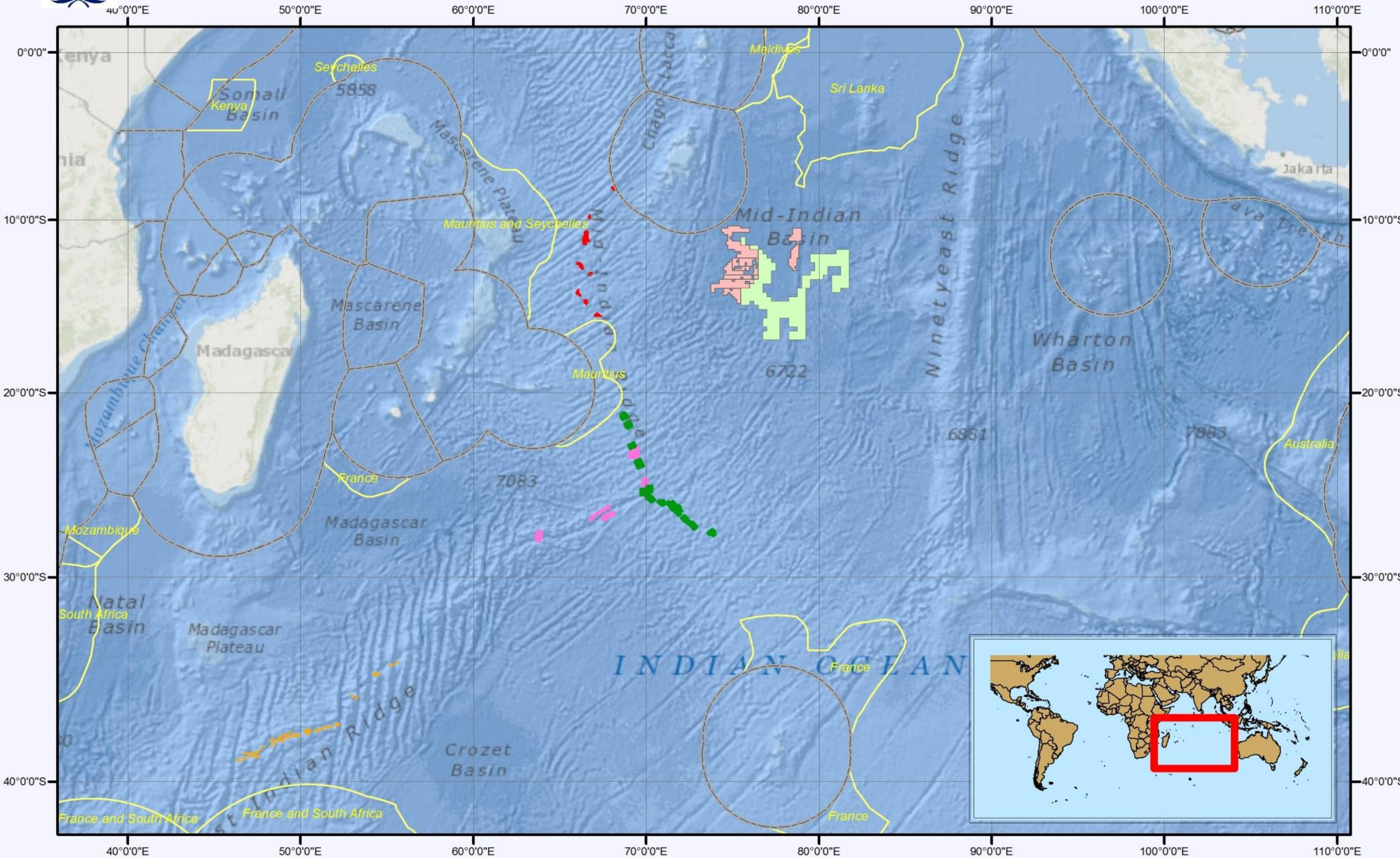
Polymetallic Sulphides Exploration Areas on the Mid-Atlantic Ridge



Government of the Russian Federation IFREMER (FRANCE) EEZ Boundaries (VLIZ 2013)

Polymetallic Nodules and Polymetallic Sulphides Exploration Areas in the Indian Ocean

Approved plans of work and areas reserved for the International Seabed Authority



- India - polymetallic sulphides exploration area
- BGR (Germany) - polymetallic sulphides exploration area
- COMRA (China) - polymetallic sulphides exploration area
- Republic of Korea - polymetallic sulphides exploration area
- India - polymetallic nodules exploration area
- Area reserved for the Authority
- Exclusive Economic Zones
- ECS Submissions

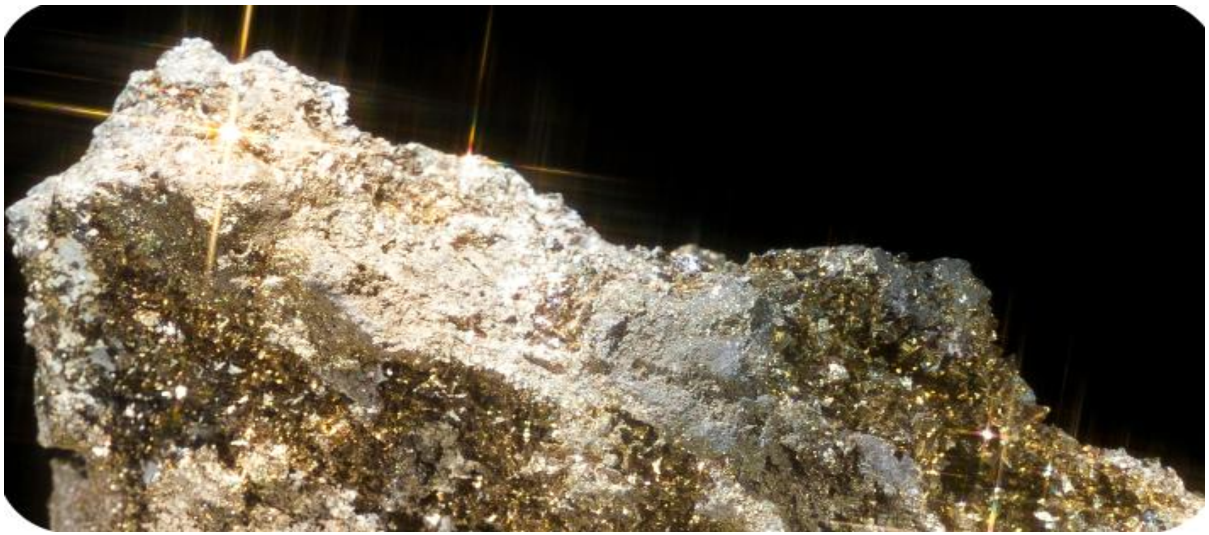
Environment objectives

- Environmental regulations require understanding of Ecosystems in different seafloor settings
- Developing an environmental database, publications and scientific expertise

- Standardization of data collection and production of standardized sampling strategies
- Coordination of projects; consultations on sampling protocols

- Marine species diversity in oceans can be compared to that of rainforests [May, 1994]
- A new species is found every sq m of seafloor sediment [Grassle & Maciolęk, 1992]
- Each hydrothermal field has its unique species [Tunnicliffe et.al., 1998]
- Microbes associated have great scientific and industrial value
- ISA has organized several workshops to understand these bio-diversities and ecosystems

Metal extraction



http://www.neptuneminerals.com/met /

HISTORY
Ocean Mining Incorporated

Mining

PRESENT
Single collector fluid Dredge system

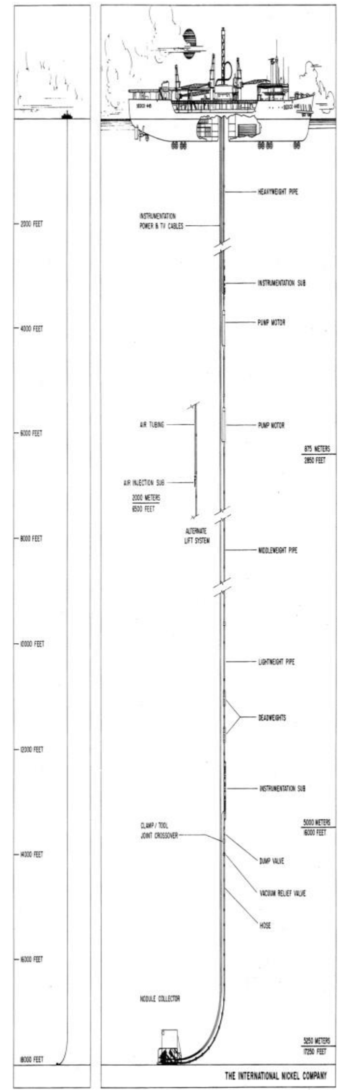


*Photo credits: **Ted Brockett**, SOSI*

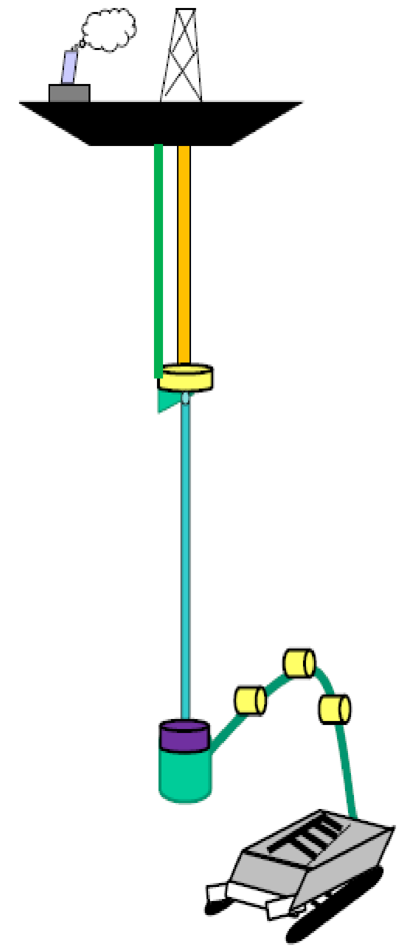
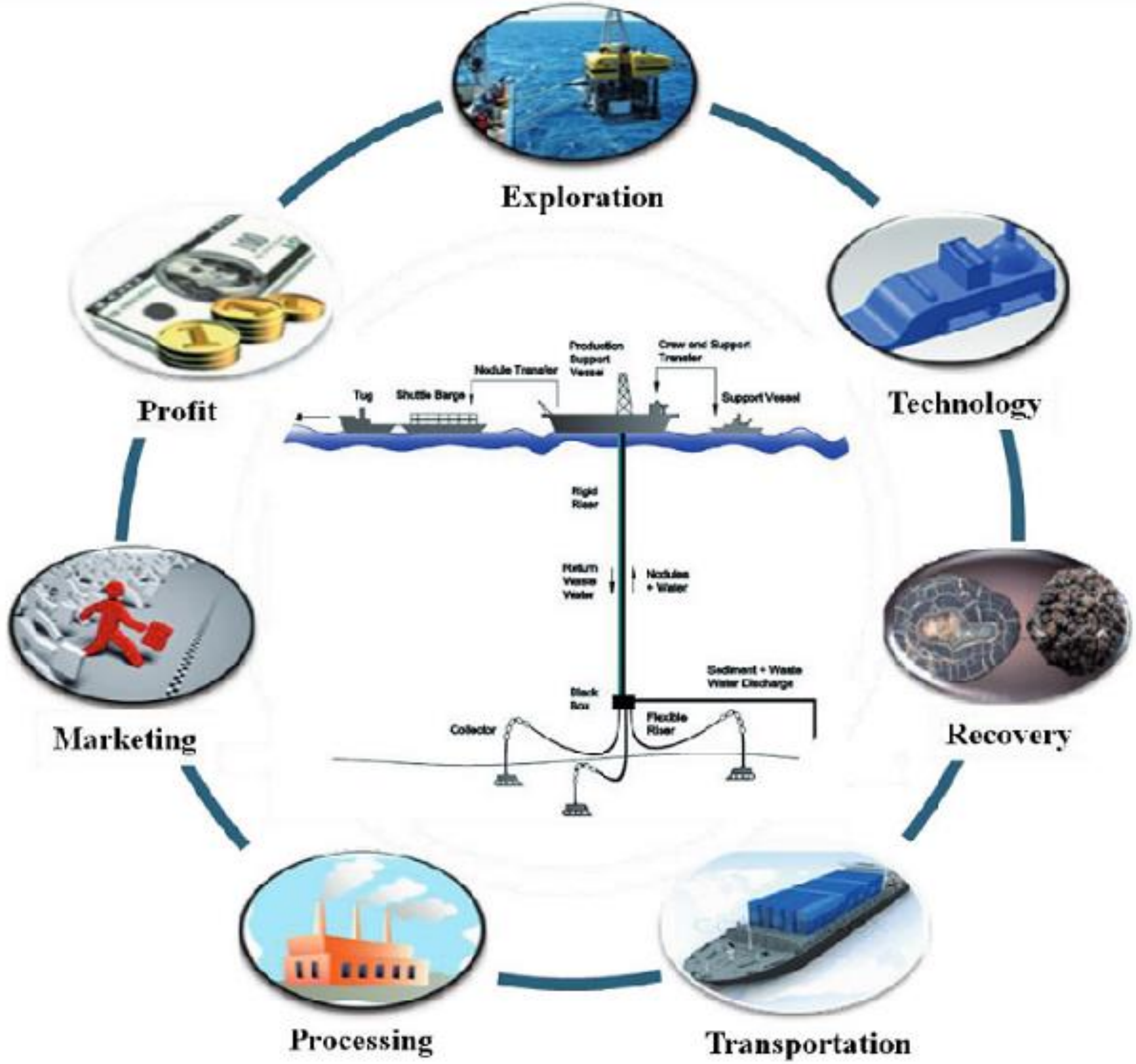


Photo –**DORD** Japan

Deep sea mining - PMN

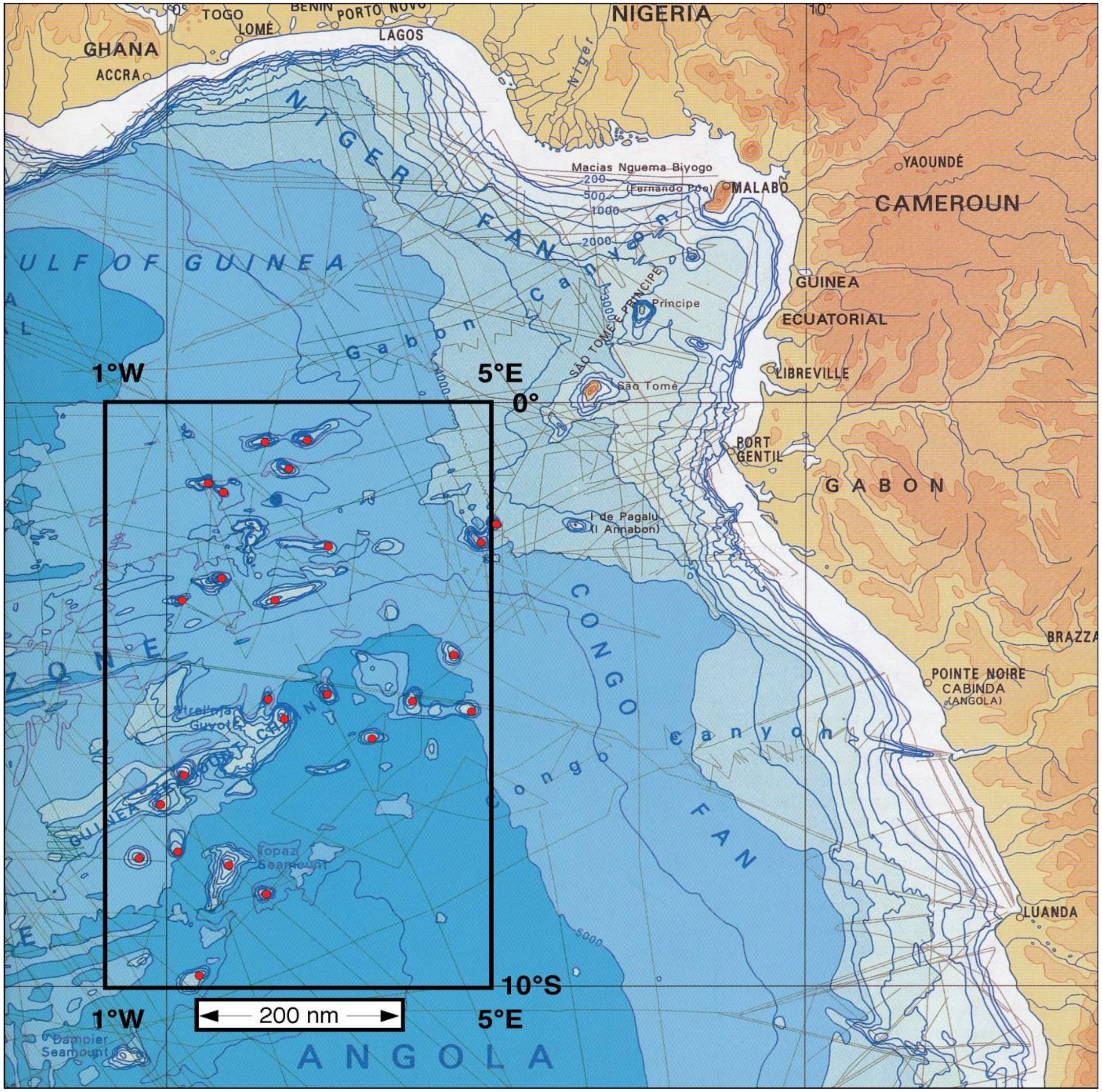
- Depth of deposit and Harsh environment
- Distance from main land
- Technology Development- Processing and mining costs, Environment issues
- Techno-economic feasibility

- No over burden to remove
- Two dimensional, vast deposits
- Three to four metals from same site
- Mobile mining platform which can be taken from one part to other
- No roads



@**Agrawal et. al (2012)** – University of Southampton, The LRET Collegium 2012 Series, Volume 2

THANK-YOU!



Seafloor map of the Equatorial East Atlantic Seamount Province located offshore equatorial west Africa with 25 prospective seamounts (red dots). Halbach (2009)