Seafloor Massive Sulfides and potential future minerals

Georgy Cherkashov

VNIIOkeangeologia

St Petersburg, Russia

Outline

- Seafloor Massive Sulfides (SMS)
  - Distribution
  - Exploration methods
  - Resource potential
  - Mining perspectives
  - Challenges and constrains
- Deep-sea muds enriched by Rare Earth Elements (REE)

Milestones of Seafloor Massive Sulfides (SMS) study

- 1873-76 First recovery of metalliferous sediments in the Pacific (HMS Challenger)
- 1886-89 First record of temperature/salinity anomalies in deep of the Red Sea (RV Vityaz)

- 1963-65 Discovery of metalliferous muds and hot brines in the Red Sea
- **1978-79 Discovery of Black Smokers at the East Pacific Rise**
- 1985 Discovery of SMS deposit at the Mid-Atlantic Ridge (TAG area)
- 1986 Discovery of SMS deposits at the Island Arc System (Manus basin)

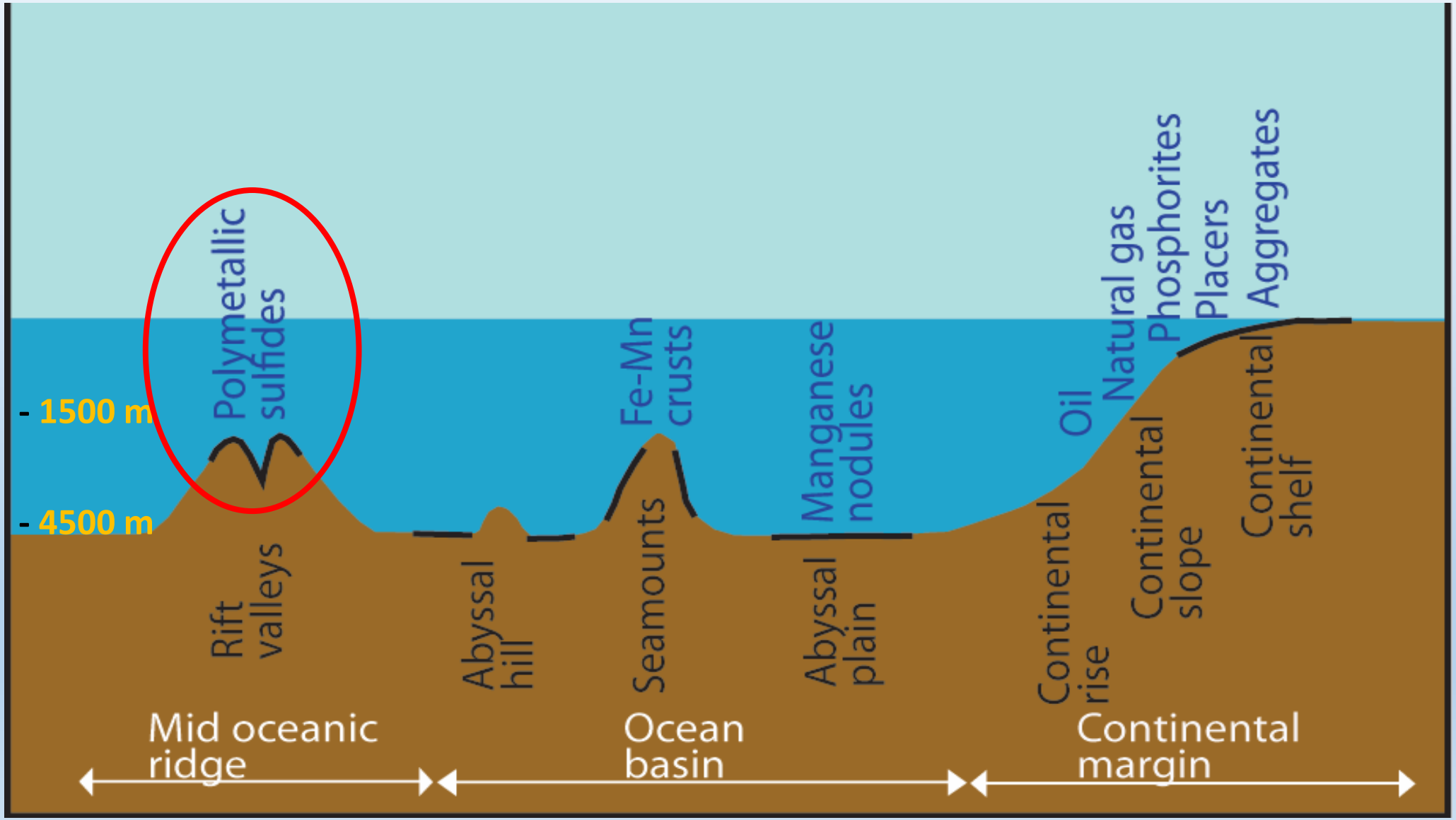
- 2010 Approval of SMS Exploration Regulations by International Seabed Authority
- 2011 First contract of SMS Exploration signed

- 2017 First pilot test of excavation and ore lifting system (Okinawa Trough, Japan)

Characteristics of deep-sea mineral deposits

Deposits type	Setting/ Depth, м	Major components	Discovery, year	Status/ Stage of works
Nodules	Basins (4000-5000)	Cu, Ni, Co, Mn, Mo, REE	1872-1876	Exploration
Crusts	Seamounts (1000-2000)	Co, Cu, Mn, Pt, REE	1872-1876	Exploration
SMS	**Volcanic structures (1500-4000)**	**Cu, Au, Zn, Ag, Pb**	**1978-1979**	**Exploration**

Morphostructural setting of marine minerals



Global distribution of hydrothermal vents and SMS deposits

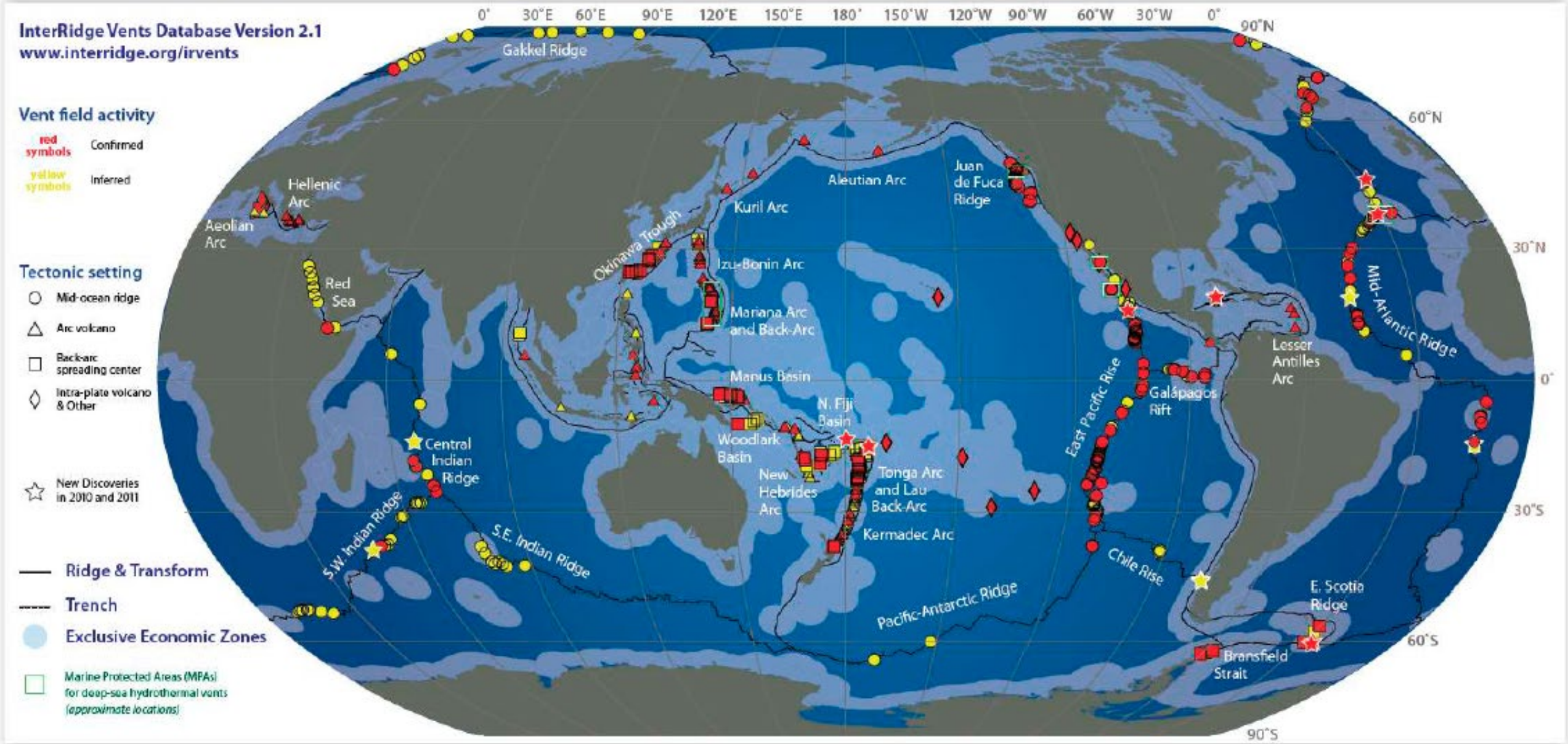


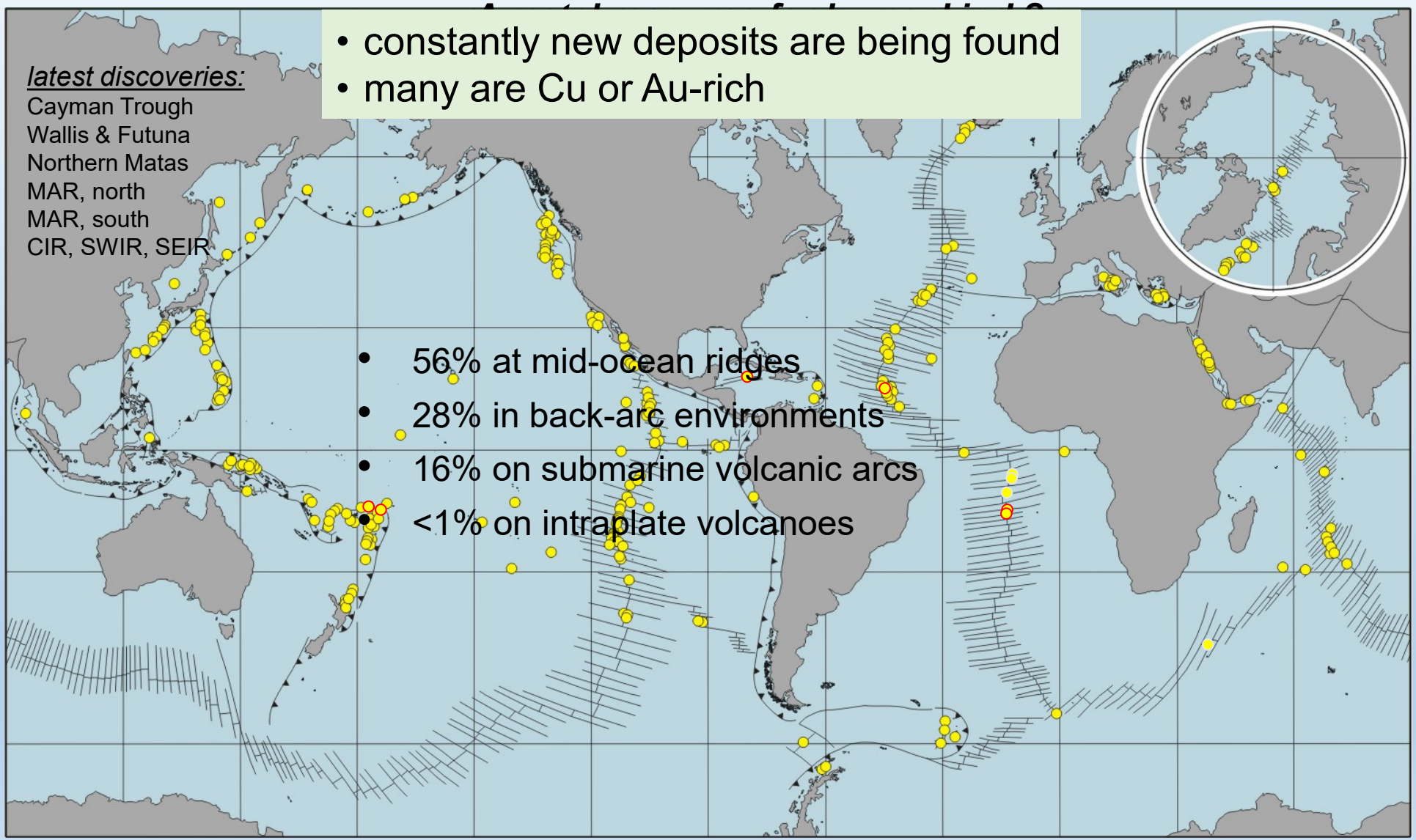
Image: Stace Beaulieu, Woods Hole Oceanographic Institution

Marine minerals in the Area versus EEZ/ECS

	Seabed	Nodules	Sulphides	Crusts
• **ISA jurisdiction - The Area**	**~ 55%**	**~ 80%**	**~ 60%**	**~ 45%**
• **Coastal State continental shelf**	**~ 45%**	**~ 20%**	**~ 40%**	**~ 55%**

Brekke, 2018

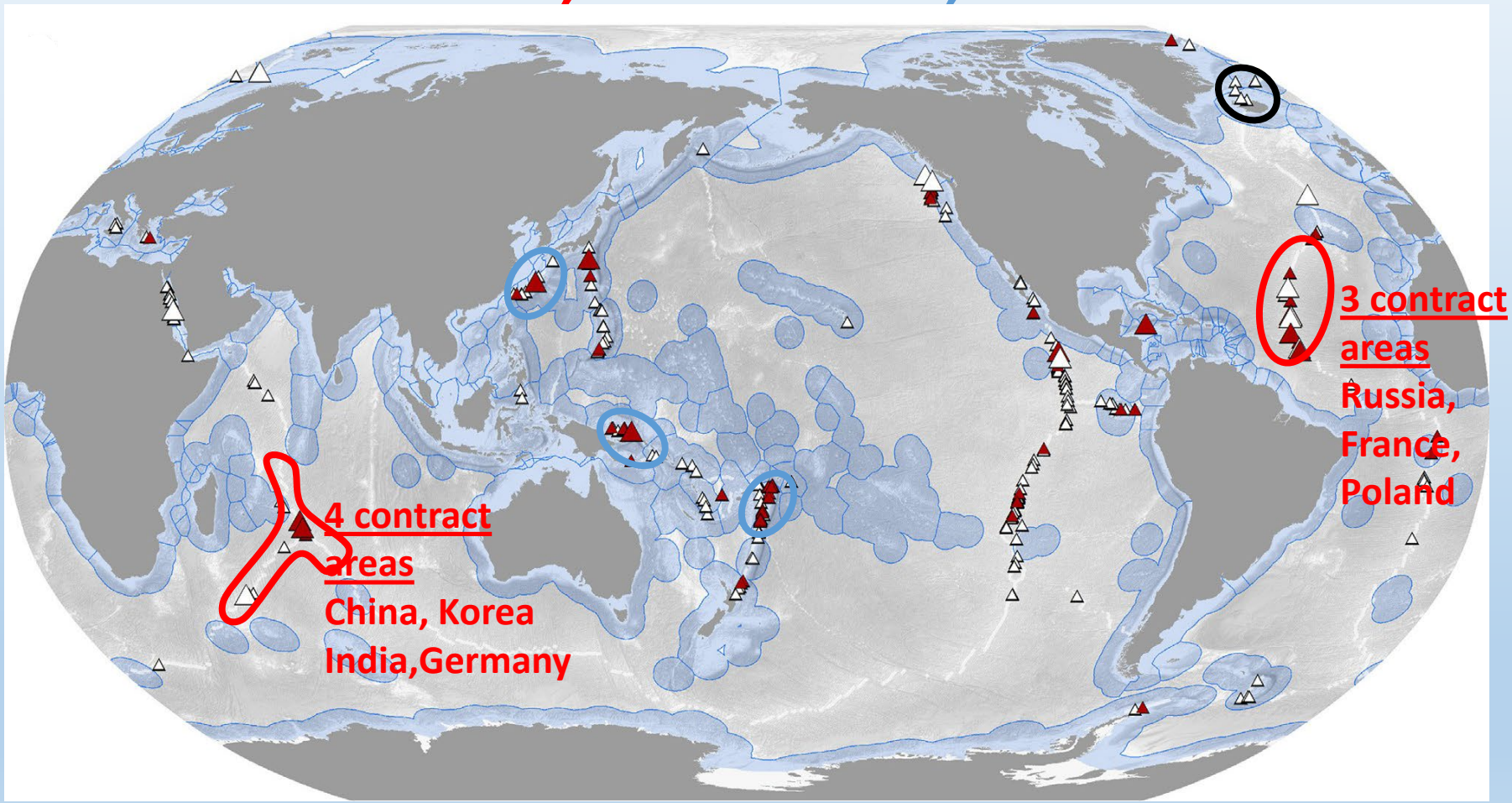
- >400 known sites of hydrothermal activity
- 280 sites of polymetallic massive sulfides
- 190 active (black) smoker sites



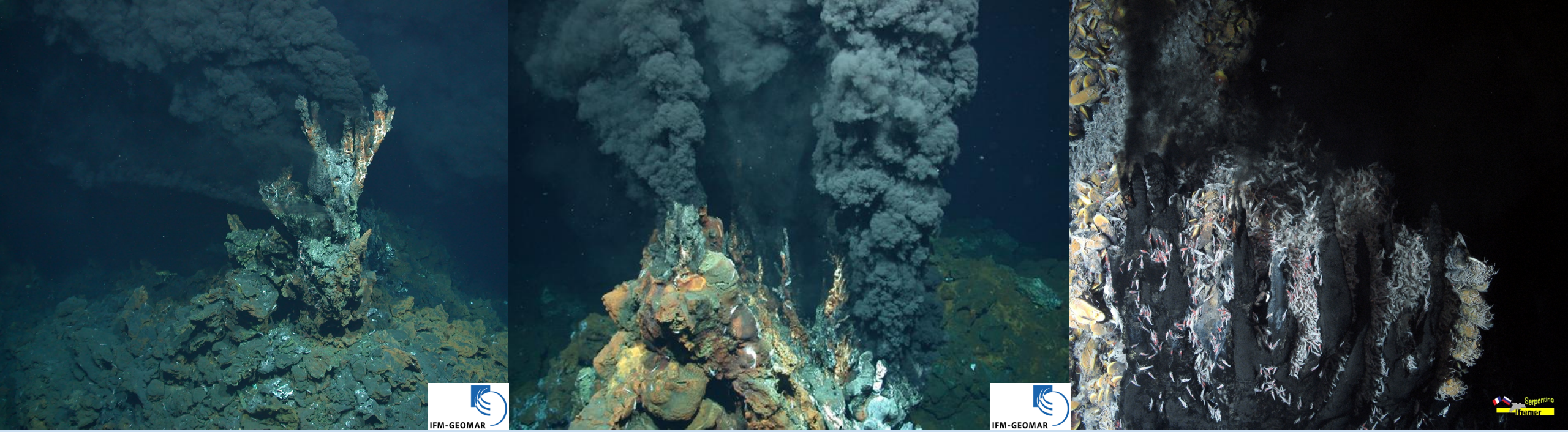
Distribution of seafloor hydrothermal systems in the ocean

Seafloor Massive Sulfides: Totally > 400 sites

Area - 58%, EEZ - 36%, ECS - 6%.

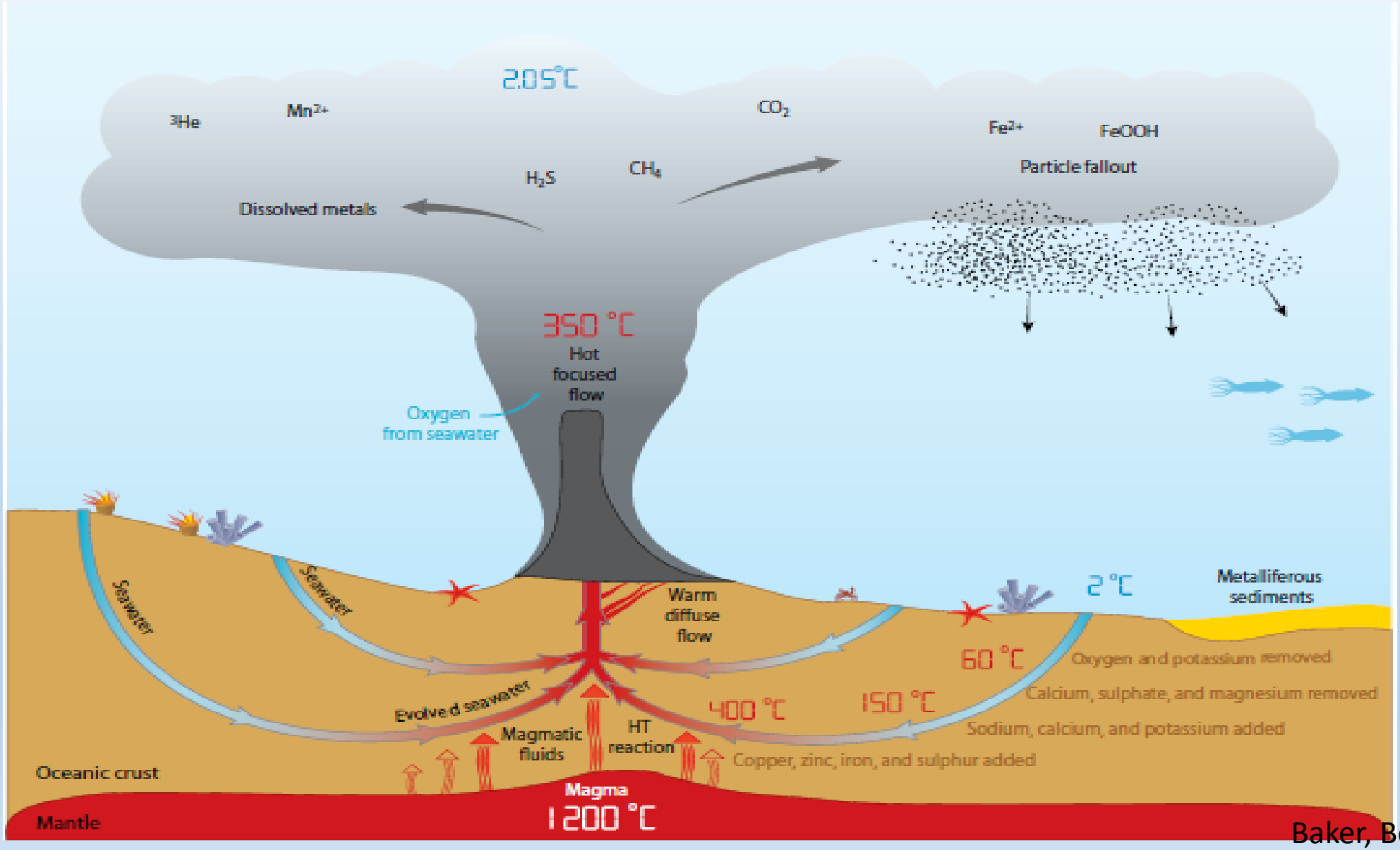


Petersen et al., 2016
with additions


IFM-GEOMAR
IFM-GEOMAR
Serpentine
Ifremer


Ifremer

General scheme of hydrothermal system and SMS deposit formation

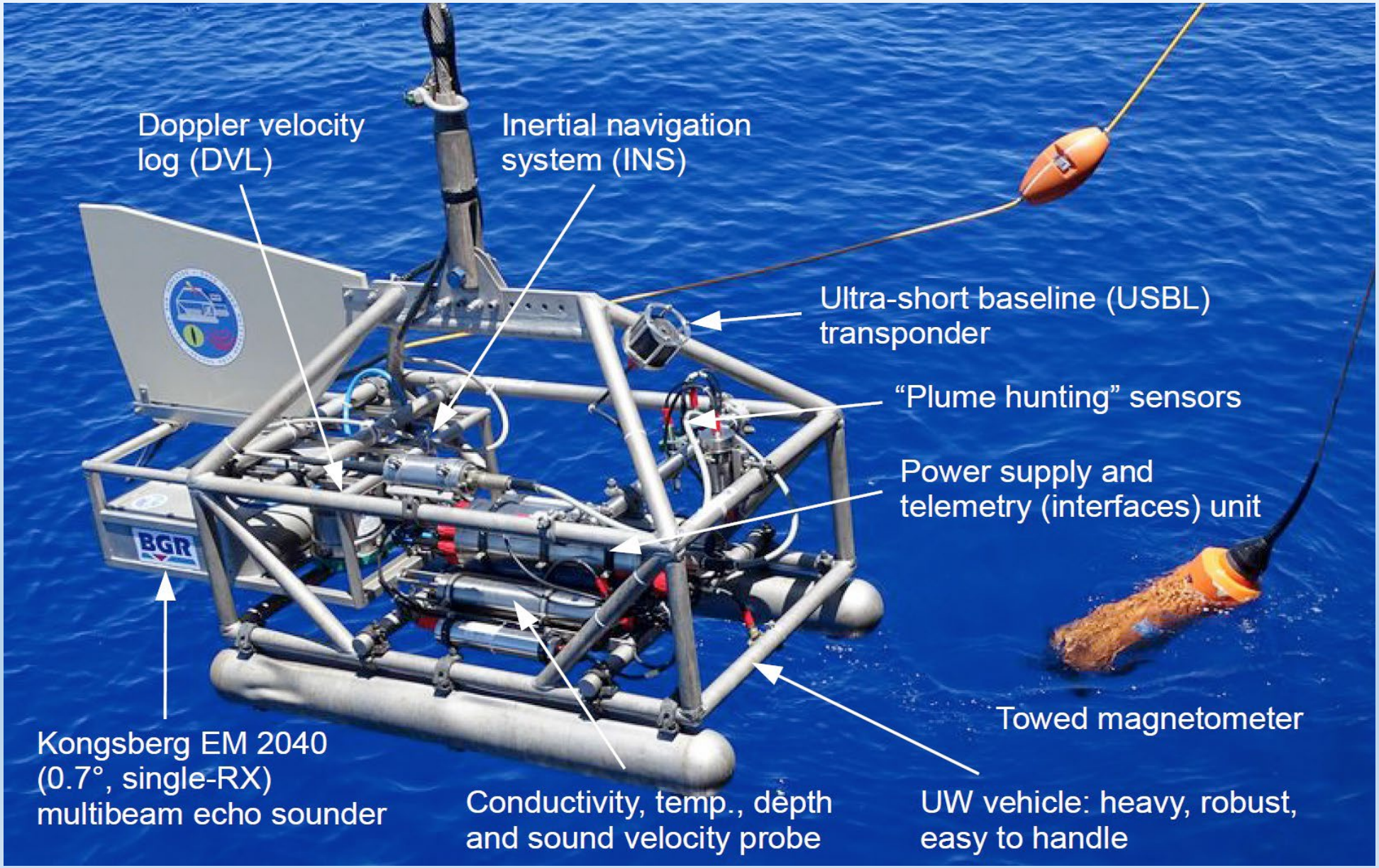


Baker, Beaudoin 2013

Exploration methods for SMS deposits

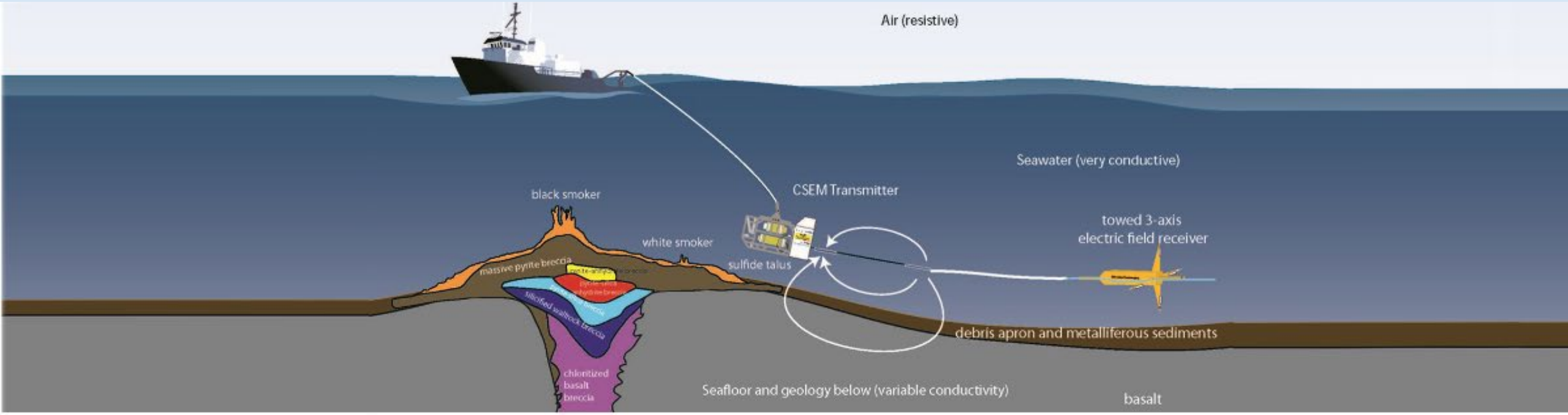
HOMESIDE underwater vehicle:

An Advanced Tool for Hydrothermal Plume Hunting and Polymetallic Sulphide Exploration



Freitag et al., 2019

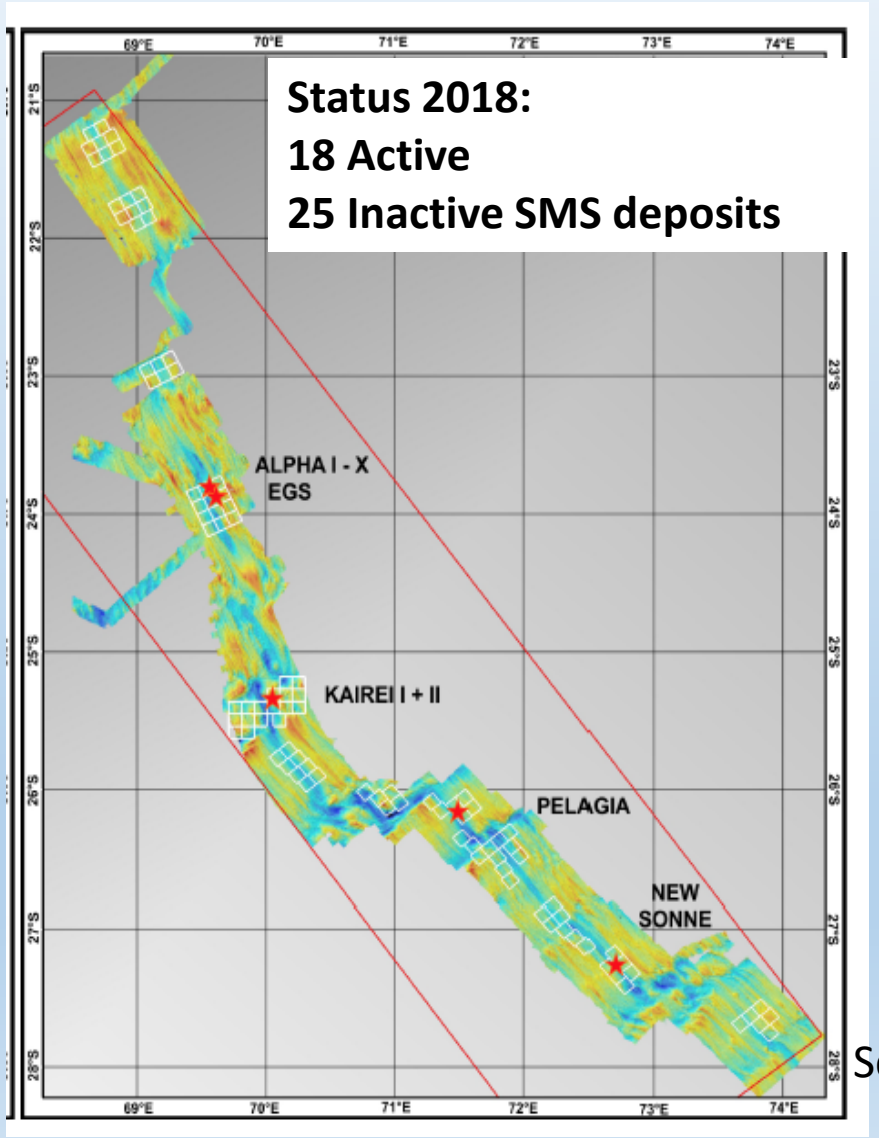
Deep-towing system for detection of SMS deposit



Blue mining project

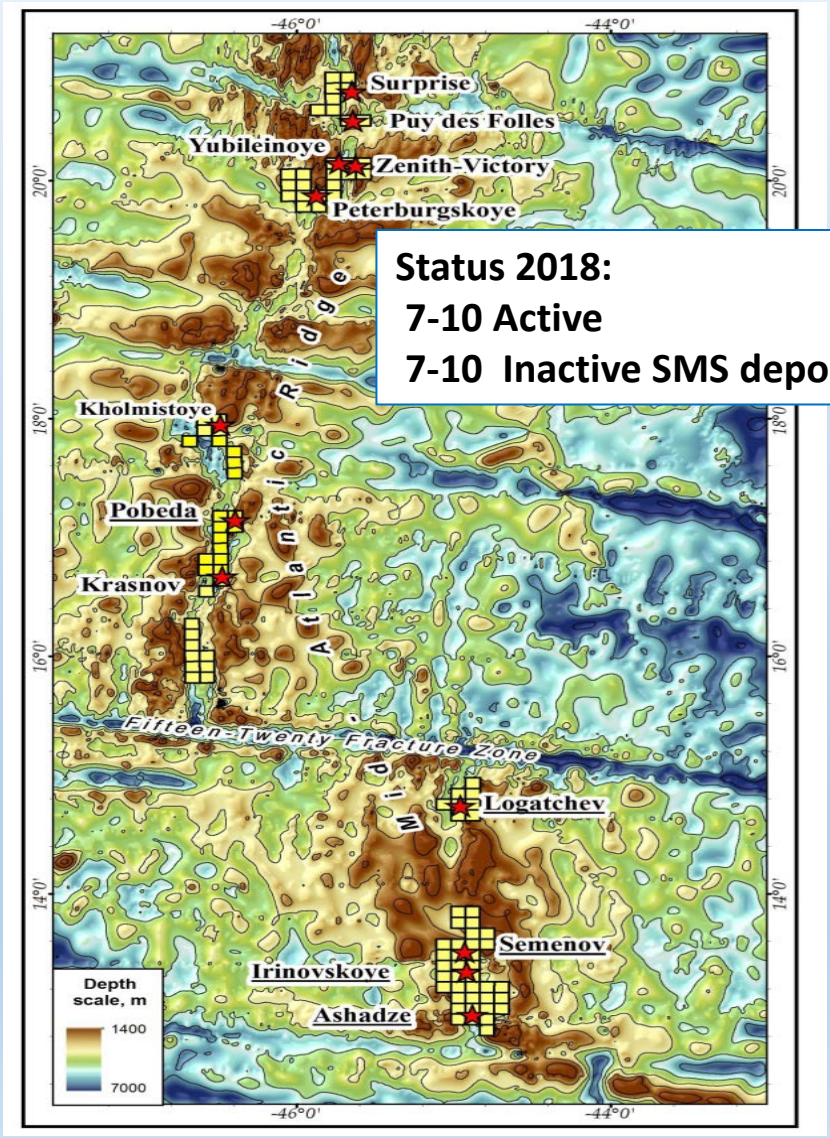
Active and inactive **SMS** in Atlantic and Indian oceans

Indian ocean, German Exploration Area



Schwarz-Schampera et al, 2018

Atlantic Ocean, Russian Exploration Area



Characteristics of deep-sea minerals

Parameters	Nodules	Crusts	Massive sulfides
Morphology	2-D deposits on the bottom sediments	2-D deposits on the rocks	**3-D deposits on the rocks and sediments**
Mineralogy	Oxides & Hydroxides	Oxides & Hydroxides	**Sulfides**
Chemistry/Major elements	Mn, Ni, Co, Cu	Co, Mn, Cu (REE?)	**Cu, Zn, Pb, Au, Ag**
Grade distribution*	Homogeneous on regional scale	Homogeneous on regional scale	**Very heterogeneous on regional and local scale**
Formation	Hydrogenetic & Diagenetic From cold ambient sea/pore waters	Hydrogenetic From cold ambient seawaters	**Hydrothermal** **From hot fluids**
Age (max), years **Growth rates**	n x 10^7 mm/10^6	n x 10^7 mm/10^6	**n x 10^5** **Fast**
Ancient analogues	No	No	**Volcanogenic Massive Sulfides (VMS)**
Footprint of 2 mln mining activity on the seafloor*	150 km^2	25 km^2	**0.2 km^2**
Processing technology	New	New	**Exist/traditional for VMS**

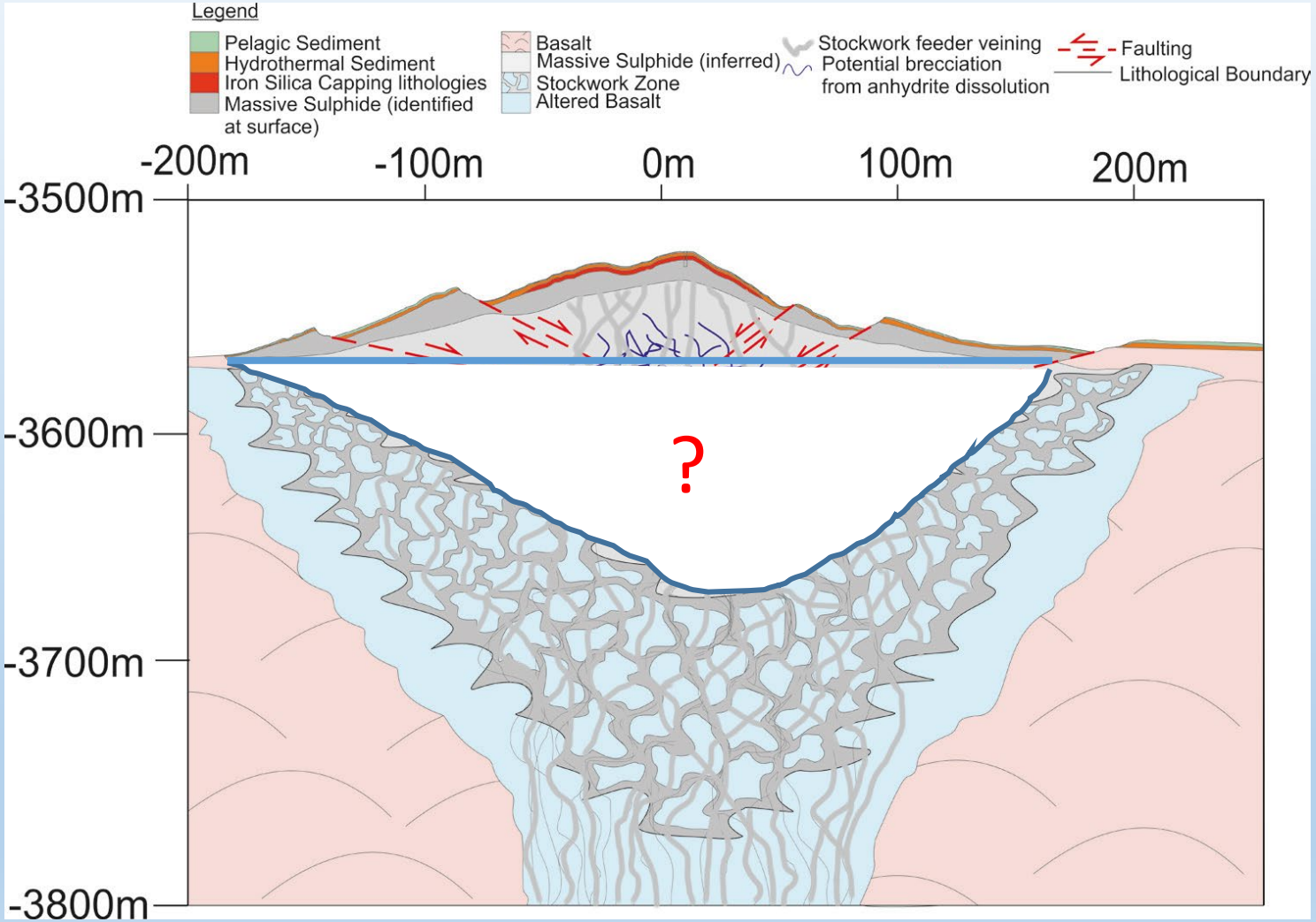
* Petersen et al., 2016

Components and global resources of deep-sea mineral deposits

	Nodules	Crusts	SMS
Major components	Mn, Ni, Co, Cu	Co, Mn, Cu, REE	**Cu, Zn, Pb, Au, Ag**
Minor components/ Byproducts	Mo, Li, REE, Tl, Zr, Ti, Ge	Te, Mo, Bi, W, Ti, Pt, V, Nb, Y	**Se, Te, Ge, Bi, As, Cd, Ga, Tl, In**
Global resources, mln t	38 900 (Sergeev et al., 2017)	35 100 (Halbach et al., 2017)	**4 000**
Resources in "Prime zones", mln t	21 100 (CCZ) (Hein et al., 2013)	7 533 (NPPCZ) (Hein et al., 2013)	**100 (NAEZ)**

CCZ – Clarion-Clipperton Zone
NPPCZ – North Pacific Prime Crust Zone
NAEZ – North Atlantic Equatorial Zone

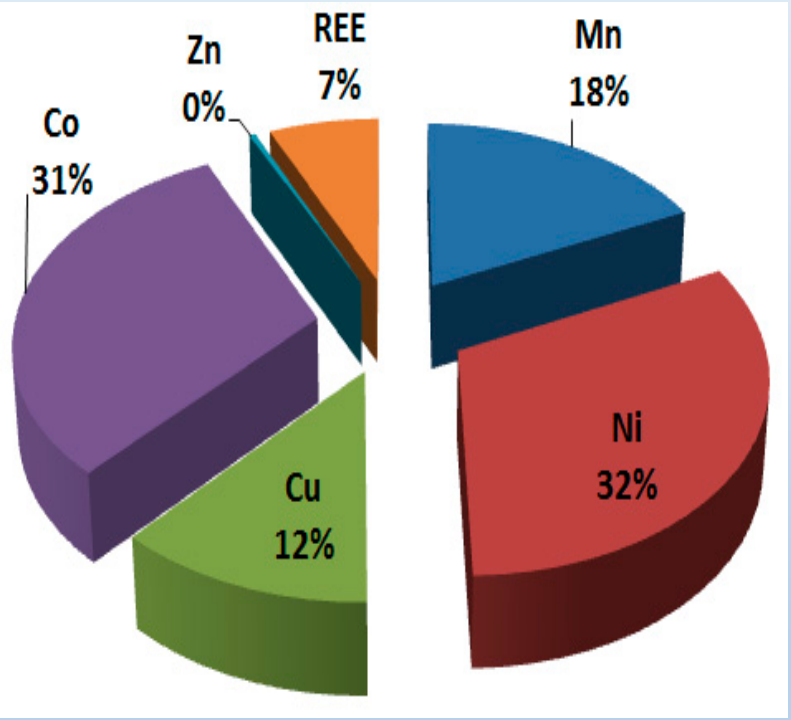
Model of SMS hydrothermal mound based on geophysical data (seismic and conductivity)



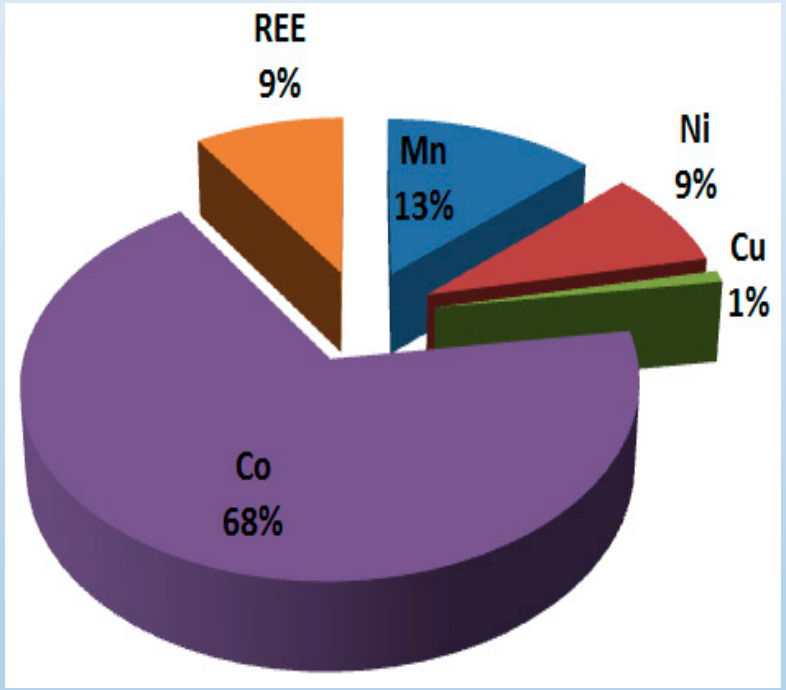
Sub sea-floor Massive sulfides Not confirmed by drilling!

Blue mining, 2018

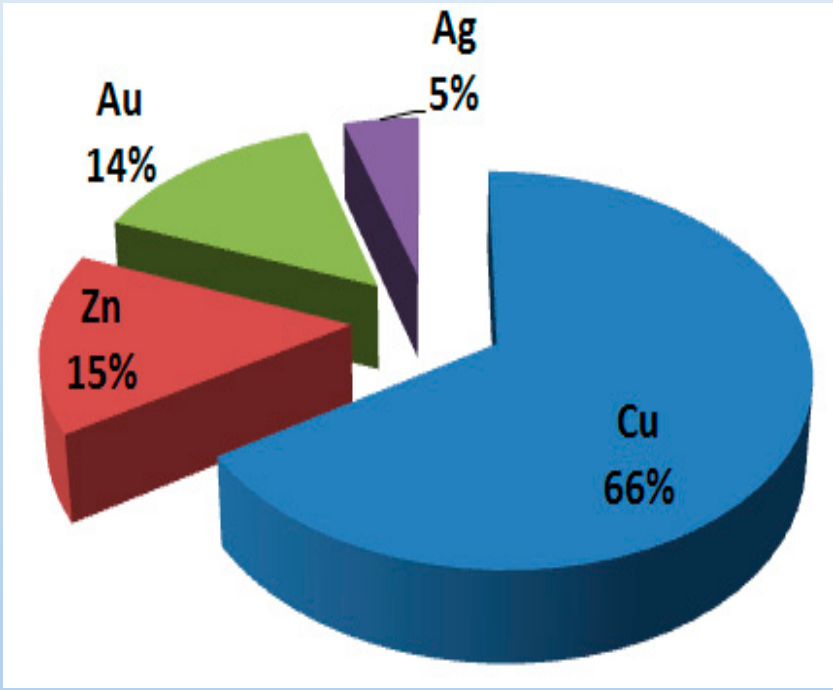
Potential value of metals in different types of deep-sea deposits



Nodules

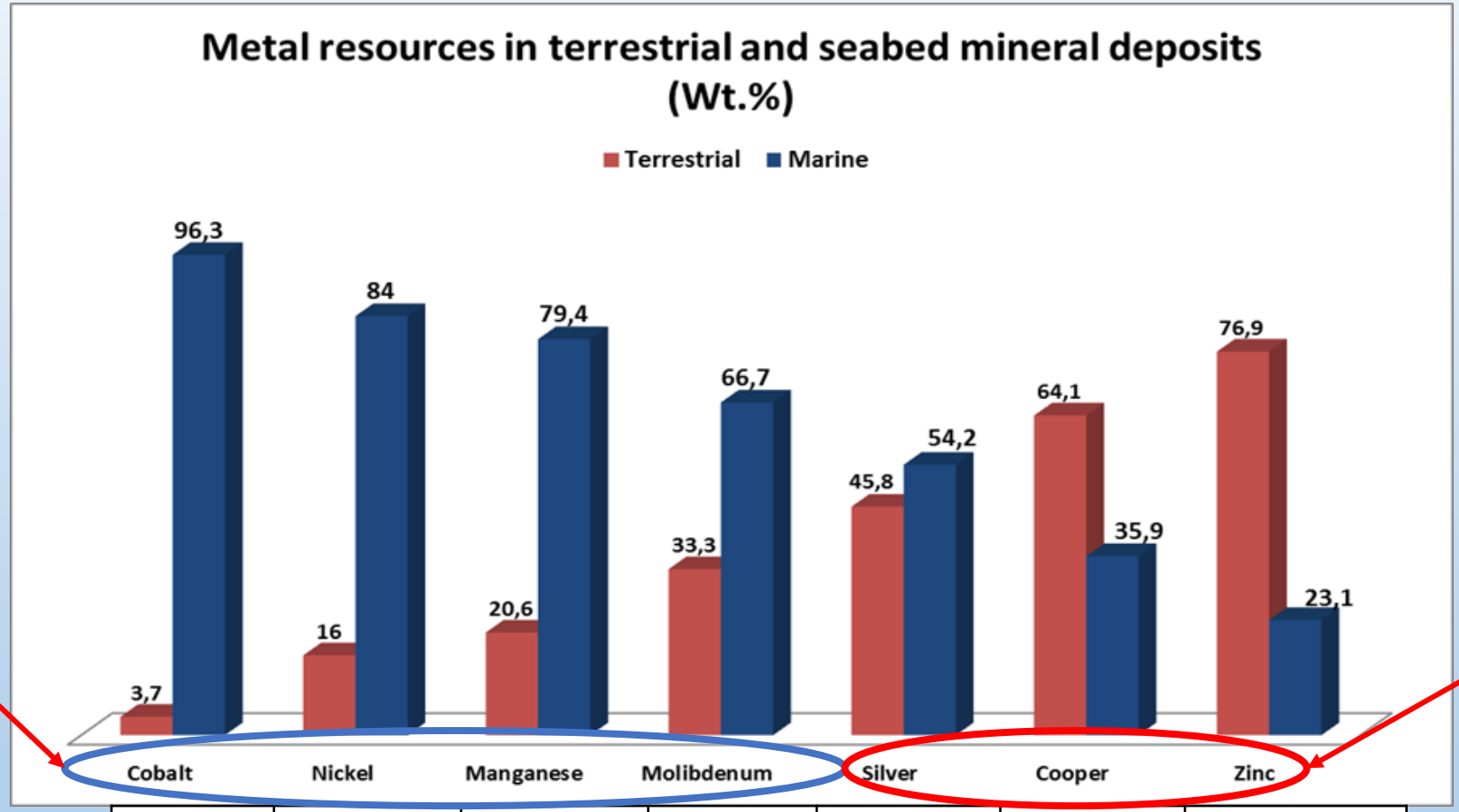


Crusts



SMS

Graphical of estimated metals percentage of resources and millions of tons reserves in terrestrial versus submarine mineral deposits.



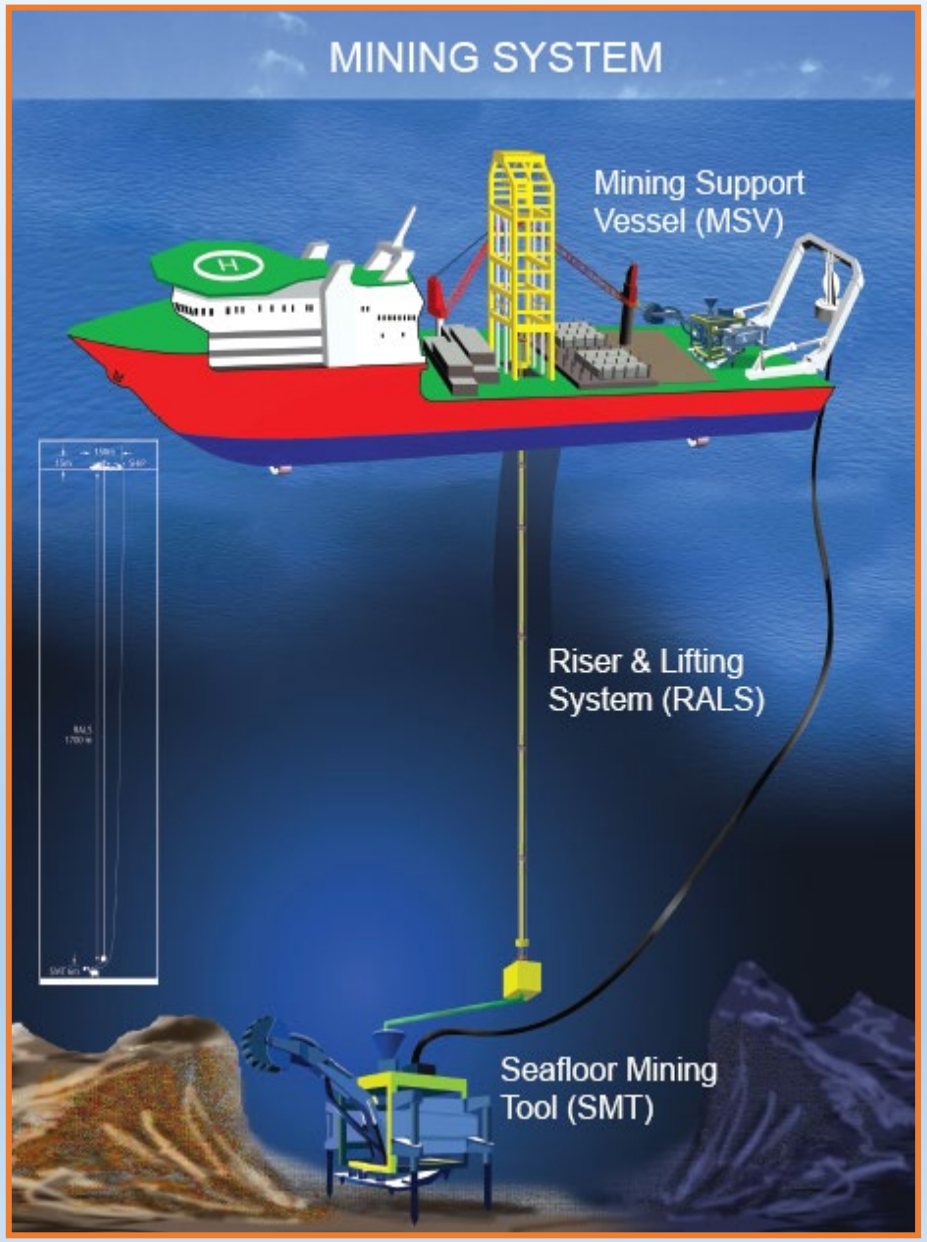
Nodules Crusts

SMS

446	*684*	*22,586*	*40*	*1.3*	*761*	*540*
17	*130*	*5,846*	*20*	*1.1*	*1,360*	*1,800*

Source: USGS

Mining technology and perspectives



Leading companies/countries in SMS mining systems development

- Nautilus Minerals
- Bauer (Germany)
- Japan
- China
- India
- ???

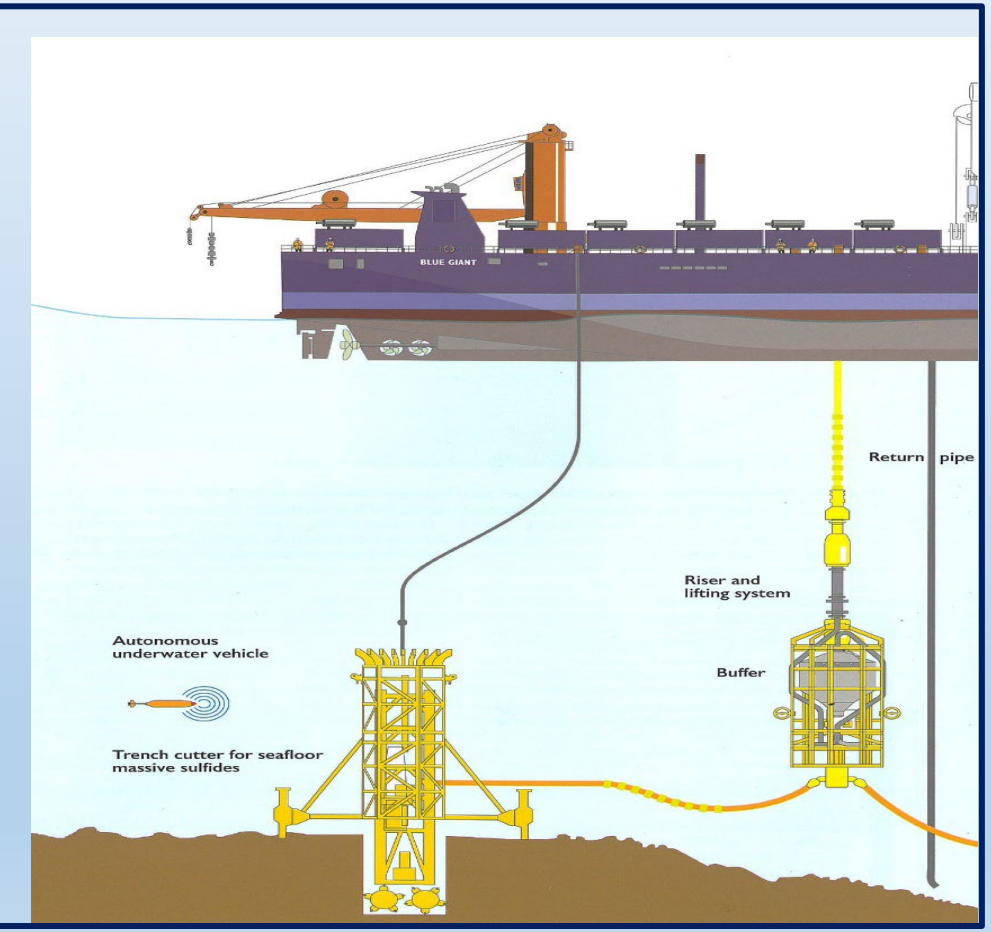
www.nautilusminerals.com

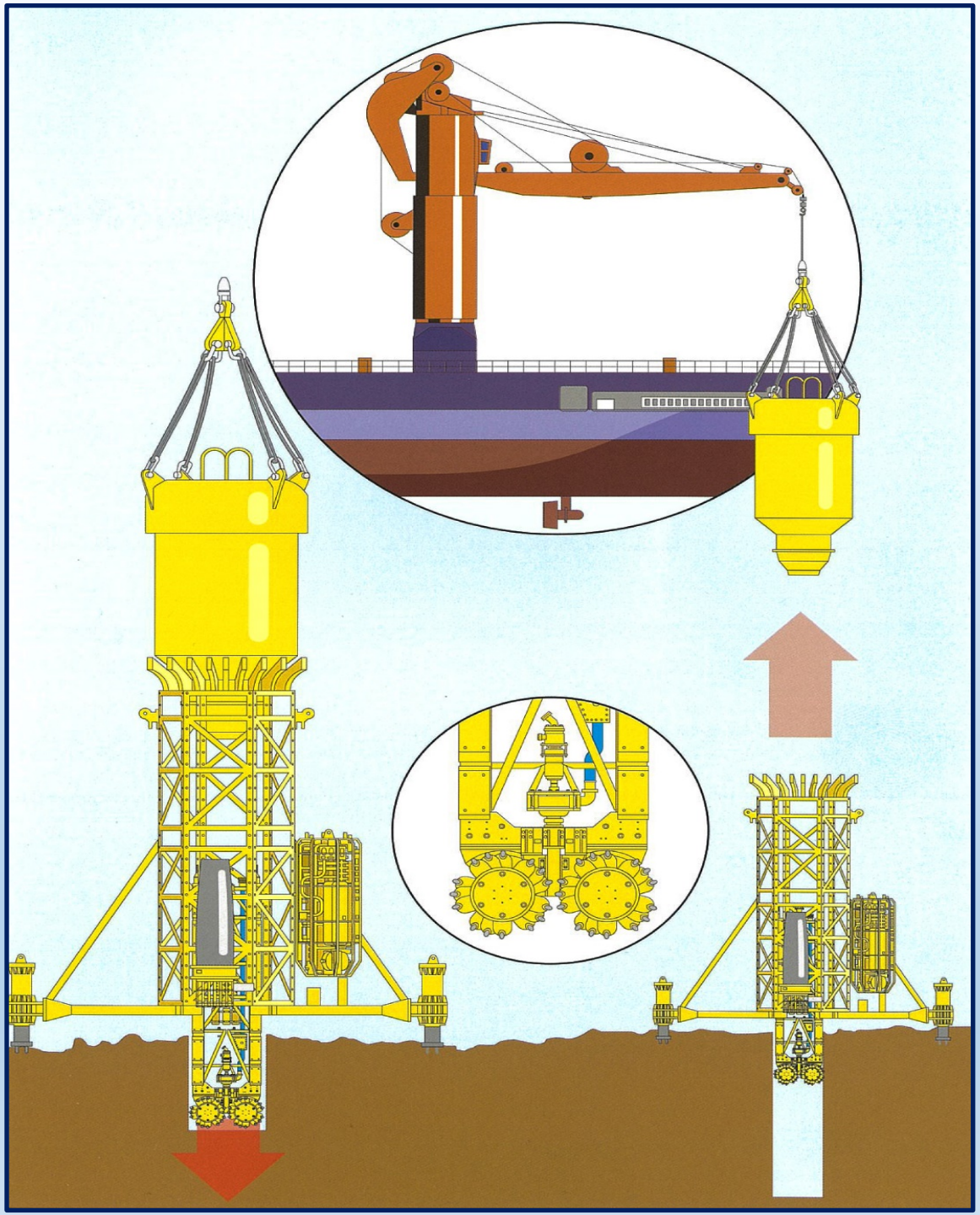
Nautilus Minerals Update

June, 2016

Seafloor Mining Tools

Building Momentum





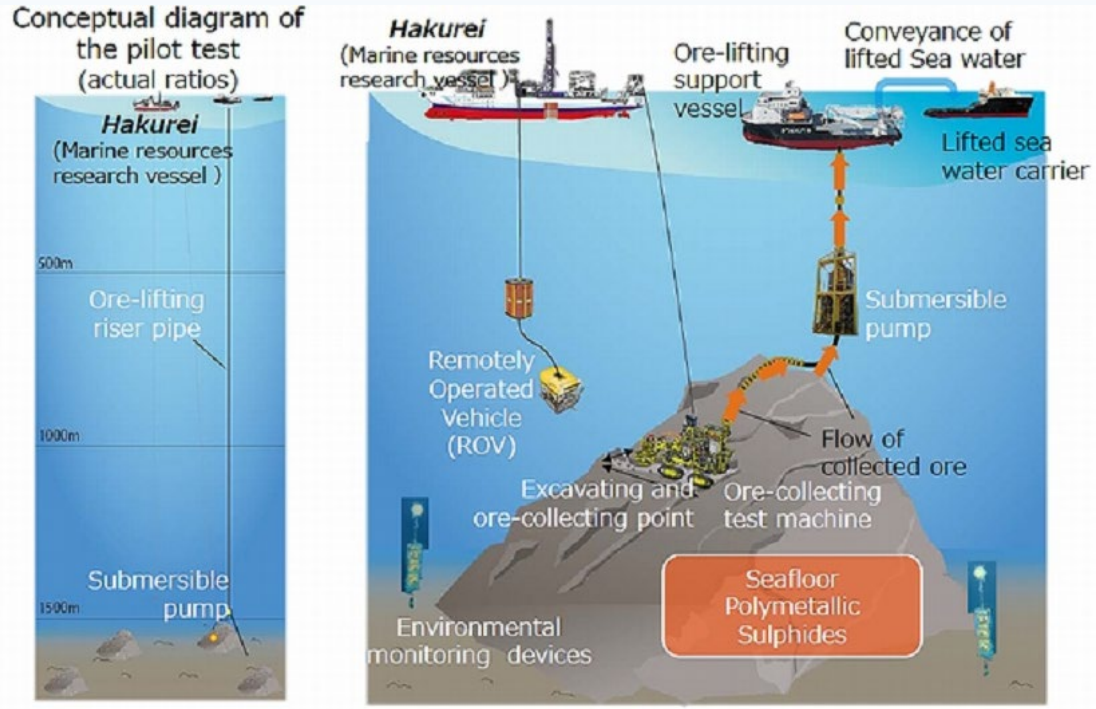
BAUER MASCHINEN

BAUER Maschinen GmbH

Drilling equipment for offshore foundations and subsea exploration, sea-bed drill rigs

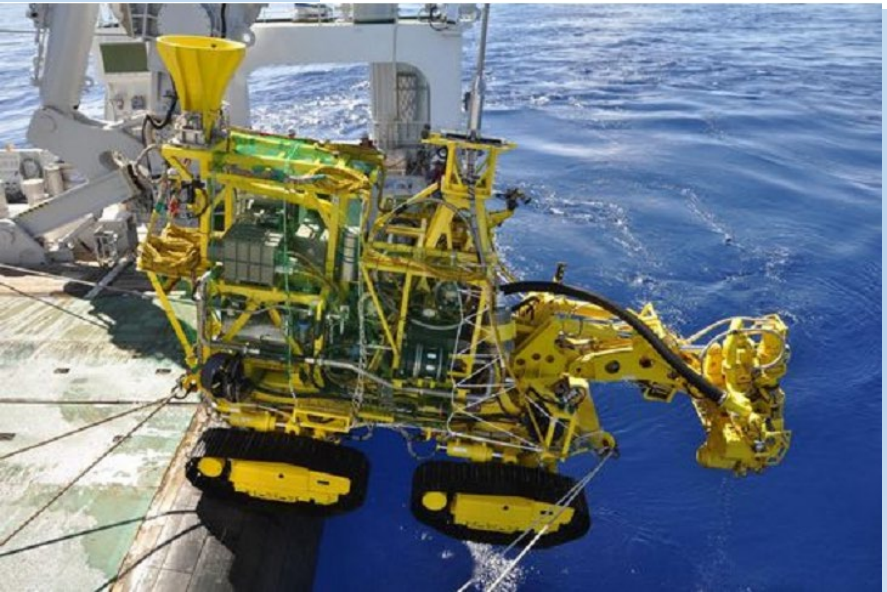
26.09.2017

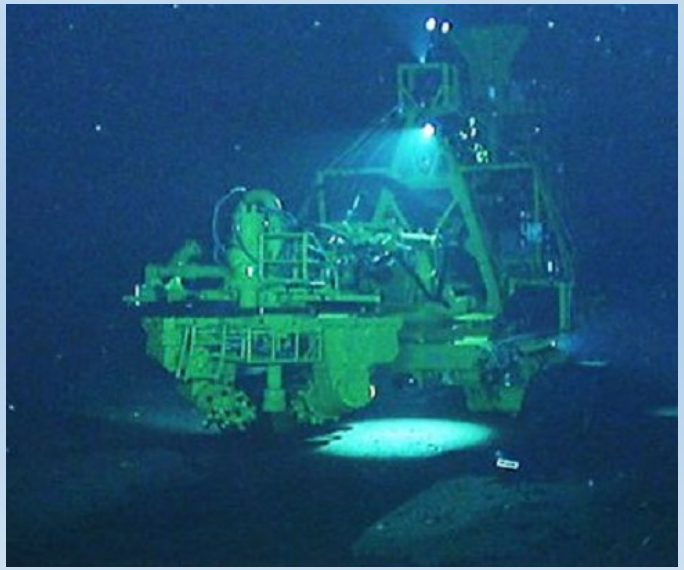
METI
Ministry of Economy, Trade and Industry



World's First Success in Continuous Ore Lifting test for Seafloor Polymetallic Sulphides

Pilot test of excavating and ore lifting conducted for seafloor polymetallic sulphides under the sea area near Okinawa Prefecture





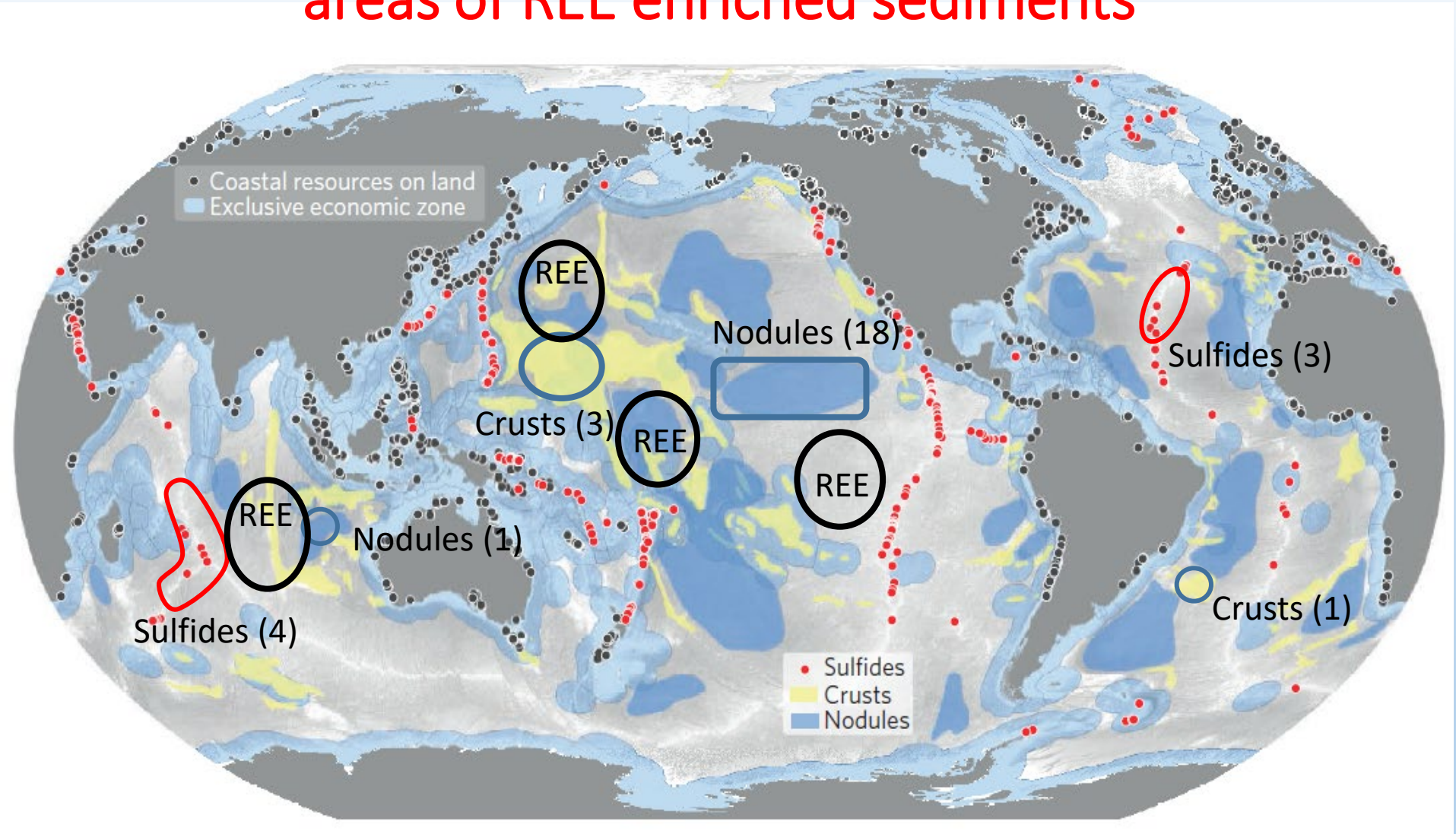
Conclusive remarks

- Seafloor massive sulfides (SMS) have been discovered later and studied less than the two other main types of marine minerals - ferromanganese nodules and crusts.
- Nevertheless, the data available indicates that SMS are characterized by highly significant (higher than on land) grades of major and rare metals used in high-tech and green technologies.
- New areas for SMS application are still available in the Atlantic and Indian oceans
- Available exploration methods are efficient for prospecting SMS deposits
- Due to limited data available resource estimates of SMS still uncertain, have a wide range and could be revised after further exploration studies (drilling!).
- The ratio of active/inactive deposits is still unclear. Further geological studies and environmental consideration (REMP) should be taking into account in the strategy of SMS deposits exploitation

Conclusive remarks

- Economic model for SMS (similar to nodules one which is currently discussing in ISA) is not established yet
- Extraction of metals from seafloor massive sulfides will not impact on metal market considerably (opposite to nodules and crusts cases)
- The first test mining was conducted in 2017 but development of the mining production systems is still far from completion

Global distribution of seabed minerals, areas under contract with ISA and areas of REE enriched sediments



(Hannington et al, 2017) with adds

REE enriched deep-sea muds as potential future minerals

- The interest to the REE enrichment in pelagic sediments has been initiated by publication of Kato et al in 2011
- The rare earth deposits in the deep-sea sediments belong to the strata-bound type ore deposits. The thickness of REY-rich sediments ranging from a few meters to more than 30 meters
- The central basins of the Pacific and the northwestern Pacific basin have been determined to be the metallogenic prospective area of deep-sea rare earth resource, and more than one million square kilometers area have been delineated as the metallogenic prospective area in the Pacific Ocean with the content of ΣREY 700 ppm as the cut-off grade (similar to onshore REE deposits)
- Similar sediments have been recovered in the Indian Ocean
- The pelagic clay sediments with high P and phillipsite content are the most favorable REY-rich pelagic sediments.
- **However the economic value of this type of marine mineral is still uncertain**


THANK YOU!