Are seafloor hydrothermal sulphides deposits valuable mineral resources?

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Outline

Why do we need new sources of metals?

What are seafloor mineral deposits

Where do they occur and why:

Why are they economically valuable?

How do we explore for them?

When might we exploit them?

Seamounts and Cobalt-Rich Ferromanganese Crusts

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Seafloor Minerals as a Resource Potential
E-tech elements for tomorrow's technology

Tellurium in solar panels

Rare Earth Elements for green electrical generation and propulsion

Base metals for all aspects of modern life.

Why do we need new sources of metals?
94% of Rare Earth metals are produced exclusively from mainland China.

Solar PV panel production is increasing exponentially but limited by the global supply of Tellurium.

Why do we need new sources of metals?
What are seafloor mineral deposits?

Mineral deposits rich in e-tech elements and base metals, include:

- Iron-manganese nodules
- Cobalt-rich crusts
- Seafloor massive sulphide deposits

Found globally on:
- Abyssal plains,
- Seamounts and flanks of ocean islands
- Mid-ocean ridges.
Ferro-manganese nodules

Potato-sized nodules of iron and manganese, rich in copper, nickel found on ancient and deep abyssal plains.

Grow at rates of millimeters per million years

Of interest as a source of base metals since the 1970’s

Recently of interest as a source of rare earth metals
Ferro-manganese nodules

Global distribution: largely in the Pacific but with important occurrences in the Atlantic and Indian Oceans. Mn-nodules occur largely on abyssal plains at depths of 5000-6000m.
Ferro-manganese nodules

The area of greatest interest for Fe-Mn nodules is the Clariton-Clipperton fracture zone region of the Pacific Ocean.

After Murton et al., 2000

Iron-manganese nodules

Density of manganese nodules and crusts (kg/m²), contoured every 2 kg/m²

no data
Ferro-manganese nodules

FeMn nodule exploration licensing is seeing a global ‘gold-rush’ as the ISA release blocks for commercial activity.

Leaders include UK Seafloor Resources Ltd., a subsidiary of US-based corporation Lockheed Martin Inc.
The E-tech element potential of submarine cobalt-rich crusts

*Mn-crusts have extreme concentrations of e-tech elements essential to ‘green’ technologies, such as tellurium, rare earth elements, and cobalt.*
The E-tech element potential of submarine cobalt-rich crusts

The challenge is to understand controls on crust formation and e-tech element composition.
Developing prospectivity models for Cobalt and Te-rich crusts

Seafloor depths
Seafloor age
Seafloor <2000m
Low sedimentation

High productivity
Known seamounts
Known crusts

Cobalt-rich crusts
The total estimated global abundance of iron-cobalt-rich crust is one billion metric tonnes, with an estimated net worth value of 714 billion USD.
Seafloor Massive Sulphides

Despite occurring in extreme environments, SMS are becoming increasingly attractive as a future resource. There are three reasons for this:

(i) the base and non-ferrous metal grades (including gold) are high compared with on-land deposits.

(ii) the mineral resources are exposed at or close to the seabed and, unlike their continental counterparts, not buried under hundreds of metres of rock.

(i) 400% increase in the price of copper in the past 12 years. Driven by increasing demand, despite global economic downturn.
Economic Viability

Advantages of SMS compared with continental mineral ore deposits:

• SMS have higher metal grades
• Are not buried under 100s of metres of rock
• Are relatively easily accessible
• Can be exploited from mobile infrastructure.

Seafloor Minerals as a Resource Potential

(10M euros EC R&D programme ‘Blue Mining’)
Active hydrothermal systems generate Seafloor Massive Sulphides, driven by volcanic heat

- Geological setting and water depth effect metal content and deposit size.
- The largest and most enriched are at slow spreading ridges that comprise 60% of the global mid-ocean ridges.

Seafloor Minerals as a Resource Potential
Over 400 active hydrothermal SMS mineral deposits have been located to date on mid-ocean ridges and in back-arc basins. There are between 10 and 100 more deposits that are hydrothermally inactive and yet to be found.
Seafloor Massive Sulphides

SMS deposits range from several tens of thousands of tonnes to several million tonnes. Although small by terrestrial comparison, their full potential is yet to be realised.

With over 4000 miles of Mid-Ocean Ridge already licensed for SMS exploration by the ISA, there is also a ‘gold rush’ in these resources.
Seafloor resource exploration: Research in extreme environments

Key requirements for seafloor exploration:

• A sophisticated seagoing capability
• New technology
• Innovative science
• Expert knowledge base

How do we explore for seafloor massive sulphides?
Imaging the seafloor

TOBI is NOC’s deep-towed sonar vehicle capable of 6000m depth operations, deploying a dual 30kHz sidescan sonar, phase bathymetry, 3-axis magnetometer, CTD and LSS and Eh plume sensor.

How do we explore for seafloor massive sulphides?
Autonomous underwater vehicles

NOC’s 6000m-diving AUV, Autosub 6000 makes mission of up to 36 hours with up to 300 km of surveys at 3-5 kts.

For hydrothermal vent exploration, a nested box approach is used with 150m altitude swath sonar and plume sensing surveys followed by 10 and 5m altitude photographic and Eh surveys.

How do we explore for seafloor massive sulphides?
Remotely operated vehicles

HyBIS is a low-cost modular Robotic Underwater Vehicle capable of 6000m operations. It carries manipulators, sonars and HD cameras. Developed at NOC with UK SME Hydro-Lek Ltd., it is used as a deep-diving reconnaissance vehicle.

Isis is a Remotely Operated Vehicle capable of 6500m operations. It carries swath sonars, manipulator arms, cameras and a biological samplers.

How do we explore for seafloor massive sulphides?
Discovery of the deepest hydrothermal vents on Earth: the Cayman Trough

The Cayman Trough hosts the deepest and most isolated mid-ocean ridge on Earth: the Mid-Cayman Spreading Centre at over 5000m deep

Discovering the Beebe hydrothermal vent field: the deepest on Earth
Geology of the MCSC

- Axial Volcanic Ridges
- Ultramafic & Gabbro massif
- Volcanoes
- Sheet flows
- Major fault scarps

bathymetry
Sonar imagery
Geology

7000m
2000m
10km
EM120 shaded relief of the axial volcanic ridge area where strong water-column plume signals were found.

Discovering the Beebe hydrothermal vent field: the deepest on Earth
EM2000 ultra-high resolution (Autosub 6000) shaded relief of hummocky axial volcanic ridge terrain centered on the strongest JC44 plume signals (left). Note the prominent inward facing fault and fissure that runs NE-SW along the crest of the volcanic spur.

Discovering the Beebe hydrothermal vent field: the deepest on Earth
AUV-survey: Eh anomalies

Strong, negative Eh anomalies (Autosub 6000 mission) indicated the location of a sea floor source of reduced fluids at a depth of ~5000m.

Discovering the Beebe hydrothermal vent field: the deepest on Earth
Beeb Vent Site: High-resolution AUV bathymetry

3D perspective view of the vent mound, viewed from the southwest

SMS deposits
And active hydrothermal chimneys

Fault control

Volcanic mounds

Discovering the Beebe hydrothermal vent field: the deepest on Earth
Beeb Vent Site: High-resolution ROV bathymetry

Discovering the Beebe hydrothermal vent field: the deepest on Earth

- Active vents
- Inactive mounds
- Hydrothermal sediment
- Fault control
- Volcanic mounds

3D perspective view of the vent mound, viewed from the southwest

20m
The Beebe VF comprises chimneys, copper-rich (atcamite) rubble on the flanks and a basement of basaltic pillow lavas.
Images of the Beeb Vent Site, 5000m

HD video stills from the HyBIS RUV of chimneys at ~5000m water depth
At 5000m depth the water pressure is ~500 bars. The Beebe vent fluid plume has salinity fluctuations indicating phase separation and hence super-criticality (temperatures in excess of 480 °C) close to the surface.
Discovery of the first known hydrothermal system north of the Azores

Expedition funded by:
- the Irish Research Foundation
- University College Cork
- Marine Institute, Galway
- National Oceanography Centre
- National Geographic Expeditions Council

Using the research ship RV *Celtic Explorer*, and the ROV *Holland 1*
Hunting the plume using a towed CTD
Plume signals: a ‘smoking gun’.
Verifying target: using the ROV “Holland I”
Axial volcanic ridge, hummocky volcanics and an axial valley wall setting.
ROV-acquired high-resolution multibeam bathymetry

Fault control

Active vents
ROV-acquired high-resolution multibeam bathymetry

Fault control

Active vents

30m
ROV-acquired high-resolution multibeam bathymetry

Fault control

‘Balor’ active hydrothermal stack – 20m tall
15m high chimneys

Balor

Fomorians

Mag Mell
Active and inactive chimneys
Finally – but not least

Hydrothermal vent sites are home to unique chemosynthetic animals.

Their adaption to life in extremely hostile conditions may prove to be the most valuable resource at hydrothermal vents.
alvinocaridid shrimp: Rimicaris Hybisi on sulphide chimney
Images from the northern Site

alvinocaridid shrimp: Rimicaris Hybisi

20cm
bacterial mats
bacterial mats
anemones and bacterial mats
anemones and bacterial mats
Hydrothermal vent sites are home to unique chemosynthetic animals.

The adaption of life to extremely hostile conditions may prove to be the most valuable resource at hydrothermal vents.