Università di Trieste
LAUREA MAGISTRALE IN GEOSCIENZE
Curriculum Esplorazione
Curriculum Geologia applicate e ambientale

Anno accademico 2022 – 2023

Geologia Marina

Modulo 6.1.1 Offshore Research and Economic Activities

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Con contributi di Daniel Praeg (Geosciences Azur)

Offshore Research and Economic Activities

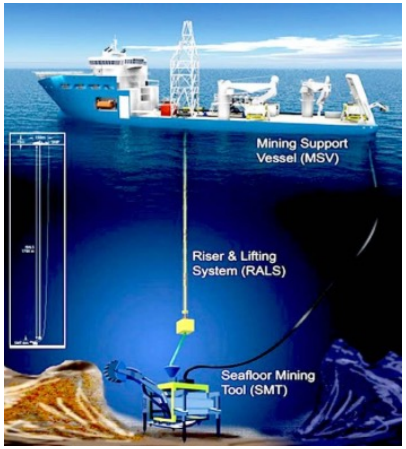
- Knowledge gap in the deep-sea and the role of the Blue Growth
- Offshore (geo-) economic activities
  - Most common:
    - cables
    - Pipelines
    - foundations/installations
    - deep sea mining
  - Regulatory framework
- Economic Exclusive Zone

- **Average ocean water depth: 3,682.2 m**
- **Equivalent to a pressure of 36,121.3 kP, 361.21 bar o 356.49 atmospheres**
- **Light is rapidly absorbed in water. From about 100 m down there is absolute darkness**

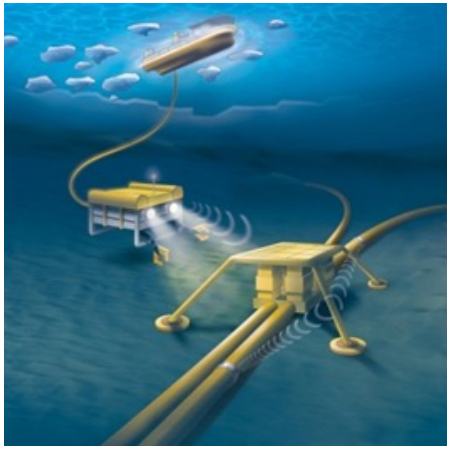
Less than 50% of the oceans have been explored

DESPITE THE HOSTILE ENVIRONMENT, THE USE OF THE SEABED IS GROWING, AS THE BLUE ECONOMY IS GROWING

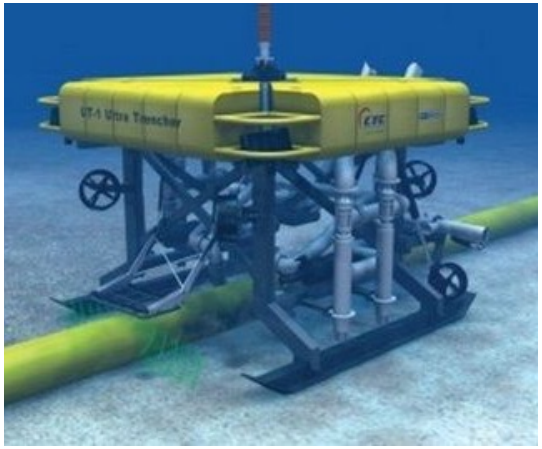
DEEP SEA MINING



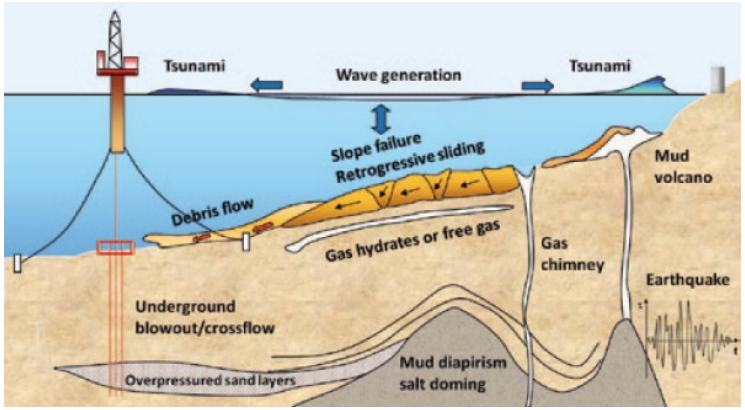
SUBSEA OIL & GAS TECHNOLOGY



COMMUNICATION CABLES



KNOWLEDGE GAP:



- **IN THE WATER COLUMN**
- **ON THE SEABED**
- **BELOW THE SEABED**

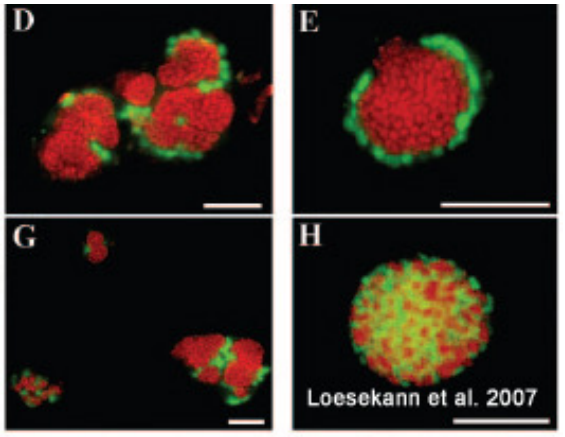
NOT ONLY:

Oceans represent a resource to e discovered for new chemical and biological products with a potential use in pharmaceutic industry

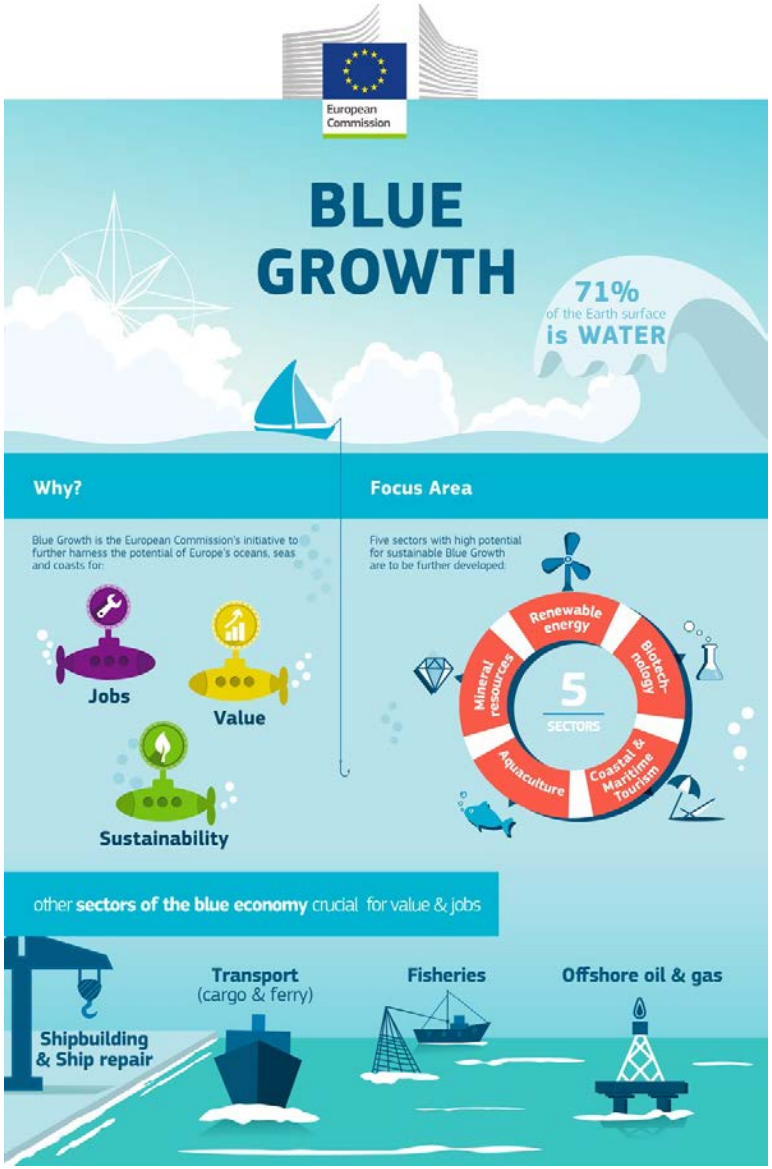
Monsoons to Microbes: Understanding the Ocean's Role in Human Health.

National Research Council (US) Committee on the Ocean's Role in Human Health. Washington (DC): National Academies Press (US); 1999.

- **The Marine Environment as a Source of Chemical Diversity**
- **The Discovery and Development of Marine Pharmaceuticals: Current Status**
- **Marine Microorganisms as a Novel Resource for New Drugs**
- **The Marine Environment as a Source of Molecular Probes**
- **The Ocean as a Source of New Nutritional Supplements**



https://ec.europa.eu/research/environment/pdf/deepseefrontier.pdf



Blue Growth is the long term strategy to support sustainable growth in the marine and maritime sectors as a whole.

Organisation for Economic Co-operation and Development (OECD)

Ocean industries bear a potential of an **important contribution to employment growth**, which could result in the creation of approximately 40 million full-time equivalent jobs globally in 2030

http://bluegrowth.inogs.it/

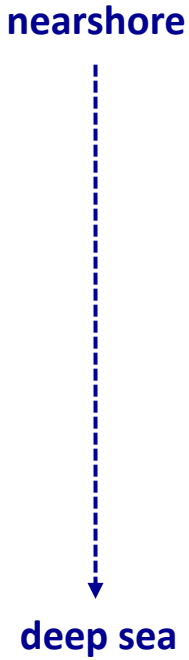
Offshore (geo-) economic activities

- Submarine cables & pipelines
- Renewable energies (wind farms)

Seabed installations, old & new

- Seabed mapping (a service industry)
- Nearshore sand and gravel mining
- Deep sea mineral mining
- Bio-prospecting (sub-seabed)
- Hydrocarbon exploration
- Methane hydrates

Natural resources, nearshore to deep-sea



Working at sea is expensive

survey vessels cost 10,000-100,000€/day

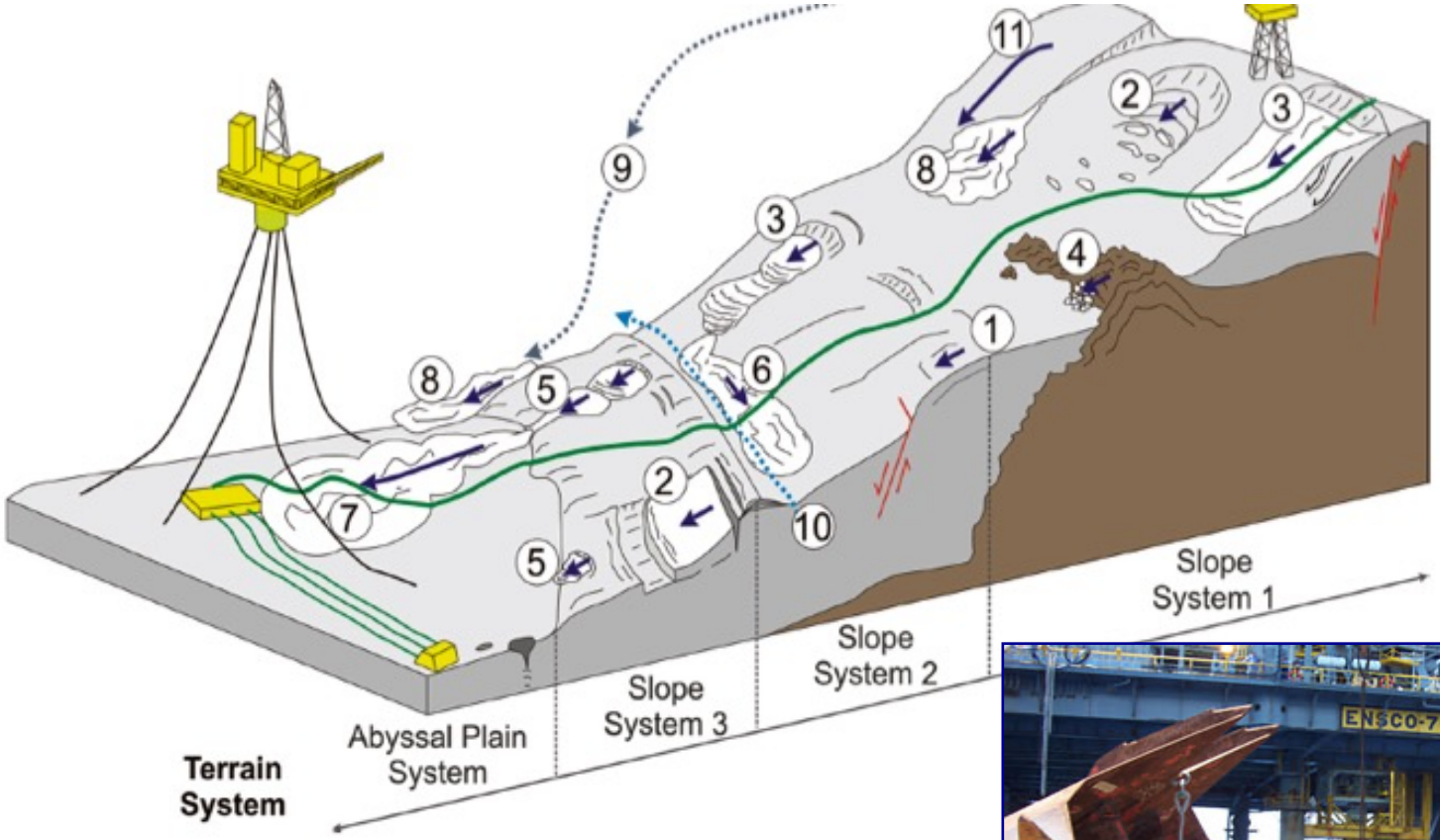
Drilling vessels for hydrocarbons can cost more than 500,000 €/day

MOST COMMON USES OF THE SEAFLOOR

- SUBMARINE CABLES
- PIPELINES
- PLATFORMS FOUNDATIONS and SUBSEA INSTALLATIONS
- DEEP SEA MINING

GEOLOGICAL COMPLEXITY OF CONTINENTAL MARGINS

The majority of economic activities are on continental shelves and slopes
Concern for safety of economic activity



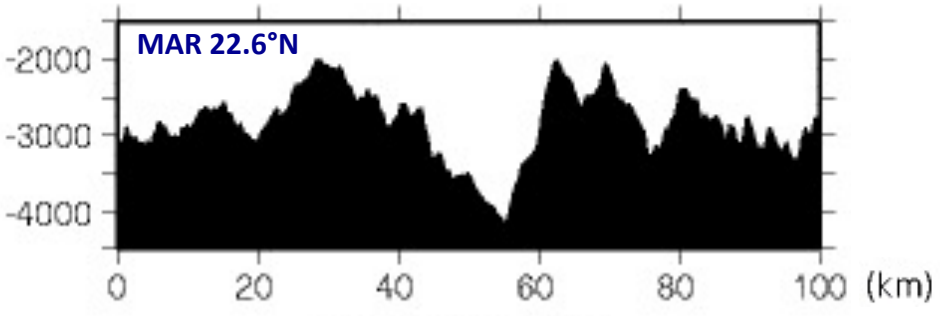
Mosher, 2010.

R. Craig Shipp, Shell International E&P Inc. IODP Geohazard Workshop, Portland 2008

Submarine Cables

1875: Challenger Expedition (1st oceanographic campaign) finds evidence of the Mid-Atlantic Ridge…

Source: Buck & Poliakov (1998, Nature)

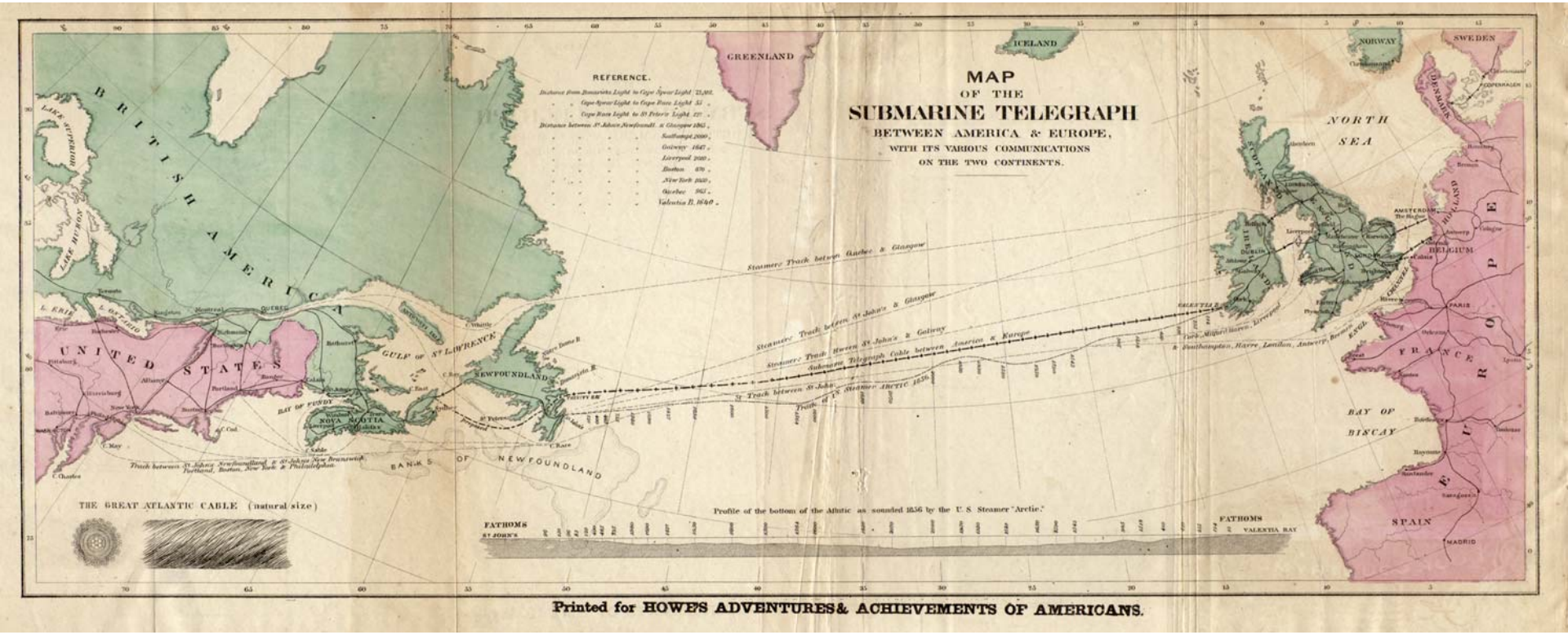


Source: Berann (1968) from Doel et al. (2006, J Hist Geog)

1901: global network of telegraph cables (that often failed)

http://industrialhistoryhk.org/submarine-cables-maps-1901-1991-worldwide-hong-kong-networks/

SUBMARINE CABLES

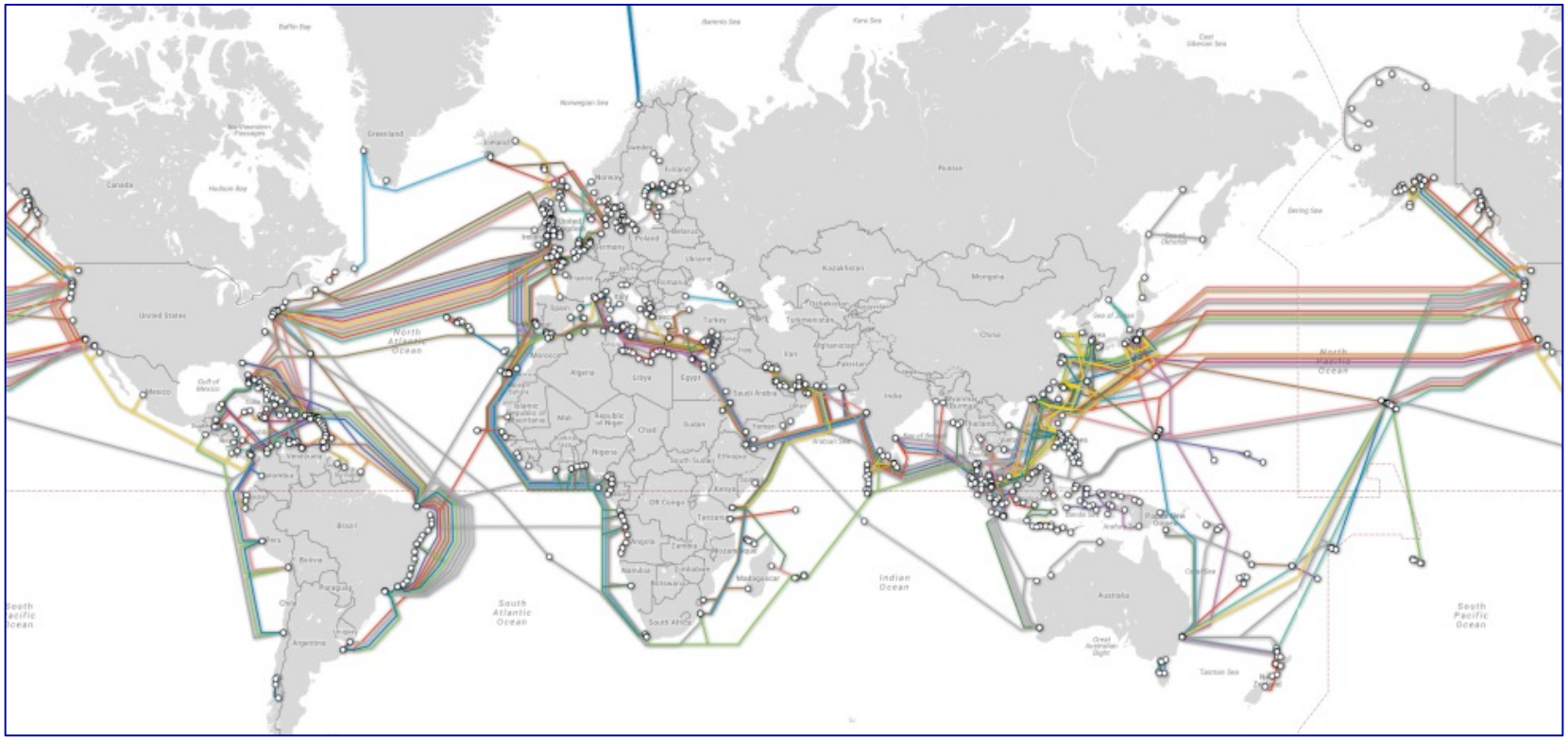


Data Transmission

- Satellites orbits 36.000 km
- Transmission time 0,250 sec
- 1000 megabits per second

- Transatlantic cable (Rome-NY about 7.000 km)
- Transmission time 0,065 sec
- Terabits per second

SUBMARINE CABLES



Data Transmission

- 1975/1980 - 45 Mb/s, repeaters every 10 km
- 1987 - 1.7 Gb/s, repeaters every 50 km
- 1990 - 2.5 GB/s, repeaters every 100 km
- 1992/2001 10 Tb/s, repeaters every 160 km
- Recent times 14 Tb/s

Reel-lay vessel

Plough system

Late 20th century – developments in cable (& pipeline) technology

1940s: cable technology adapted to oil pipelines ('Operation Pluto', France-UK)

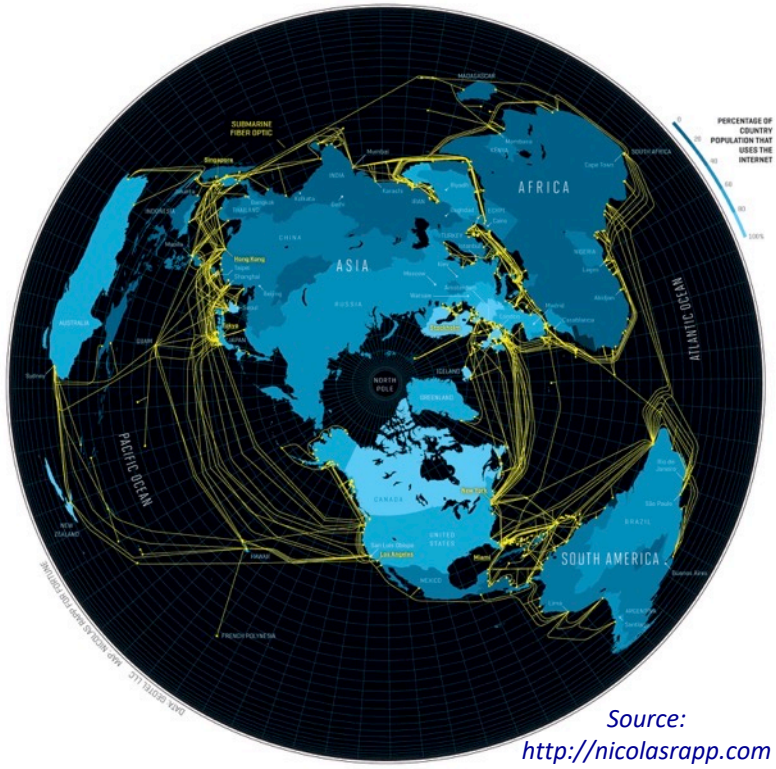
1956: 1st trans-Atlantic telephone cable (TAT-1)

1961: 1st undersea power cable (France-UK)

1988: 1st trans-Atlantic fibre optic cable (TAT-8)

21st century global network of optic cables

- Undersea fiber optic cables carry 99% of world telecommunications (= internet)
- Sources of damage: fishing and anchors (Egypt 2008)
- To protect them, cables (& some pipelines) are now buried - in water depths up to 2500 m!

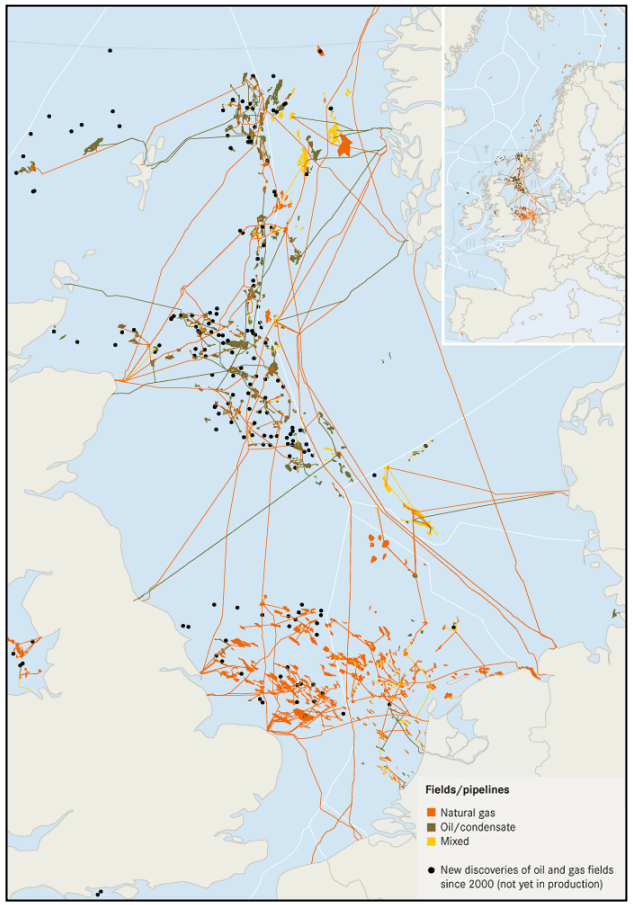


Source: http://nicolasrapp.com

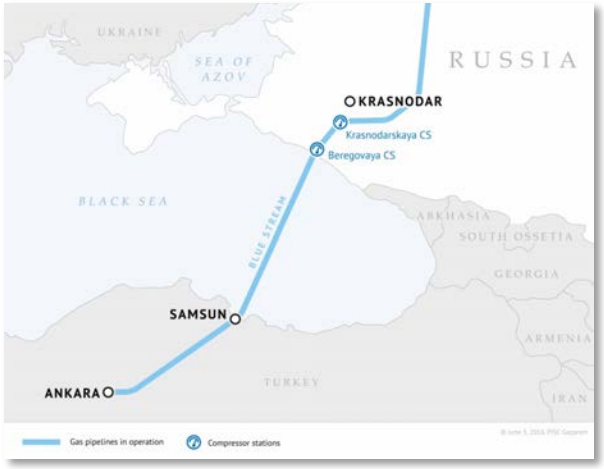
Cable (& pipeline) routes guided by **seabed mapping** (geomorphology + geology)

PIPELINES

- Connect offshore oil and gas field to land
- Connect islands to land
- Shorten the pipe route



(GALSI maximum WD 2824m)



(Blue Stream Maximum WD 2200m)

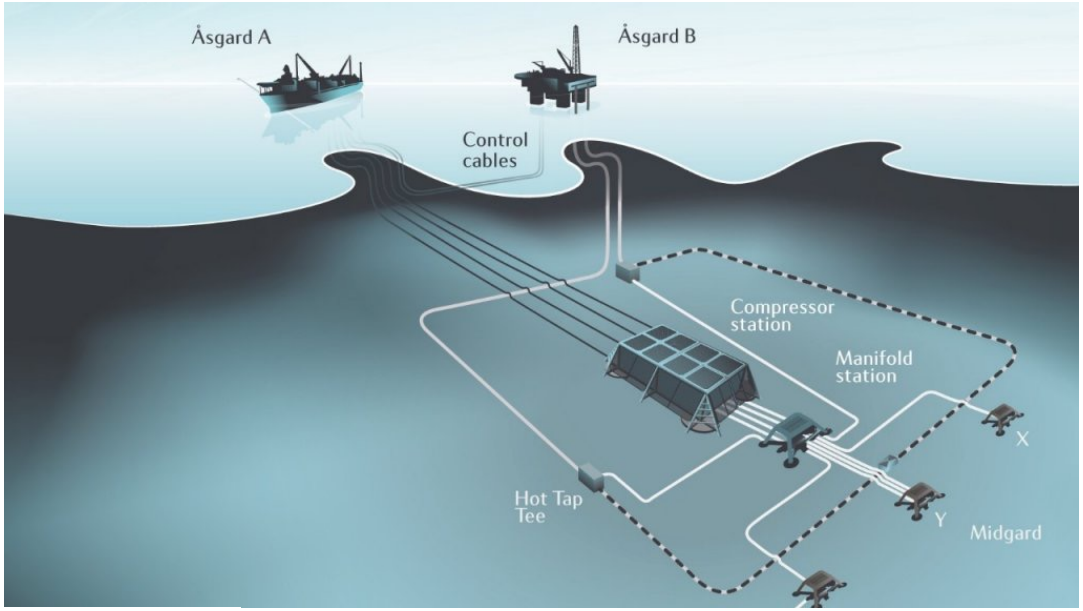
Trans Adriatic Pipeline

Trans Adriatic Pipeline (TAP)

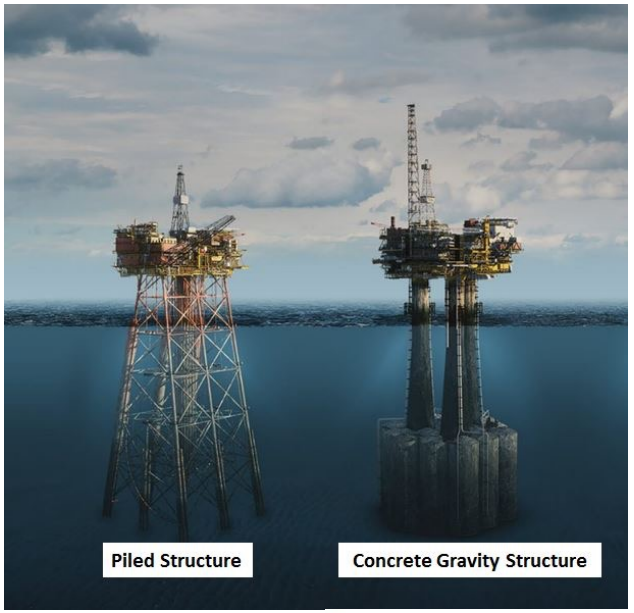
TAL transalpine pipeline

PLATFORMS FOUNDATIONS and SUBSEA INSTALLATIONS

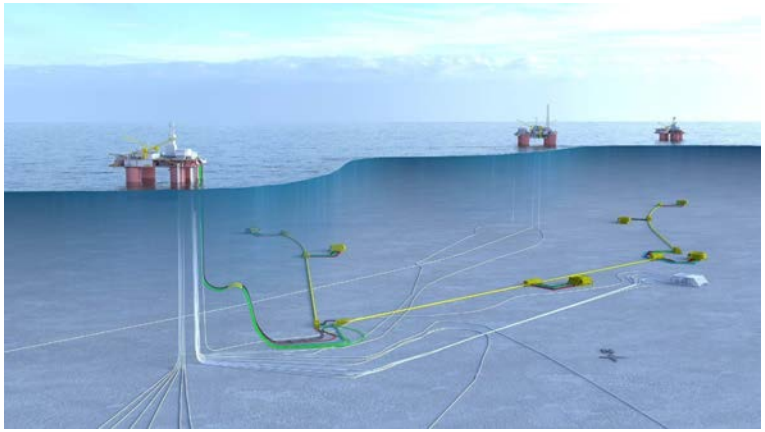
Mikkel (Norway)

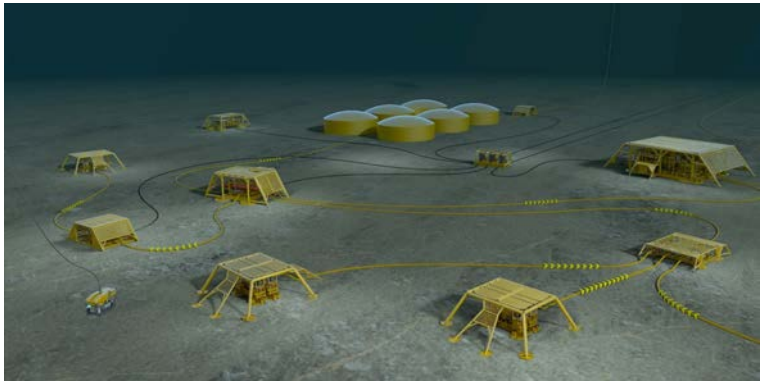


Statoil



DrillingFormulas.Com



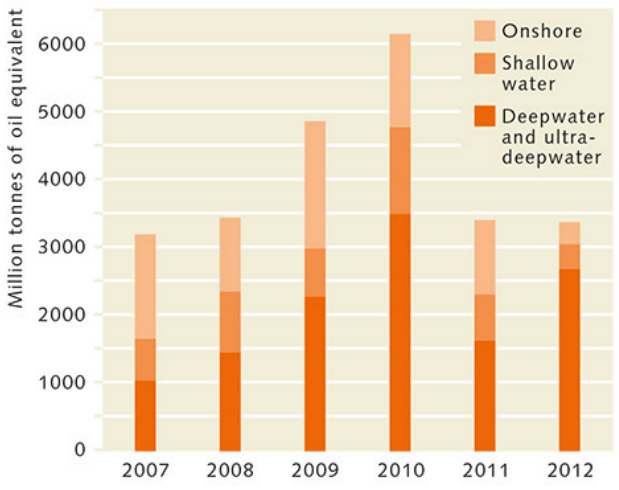


Subsea installations

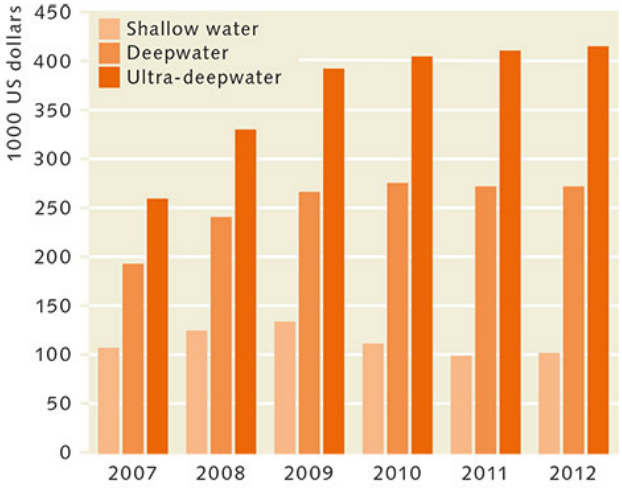
Åsgard Statoil subsea installation (Norway)

https://www.youtube.com/watch?v=GIu8U3XHXpE

Global oil & gas discoveries



Costs of drilling



Source: World Ocean Review (http://worldoceanreview.com)

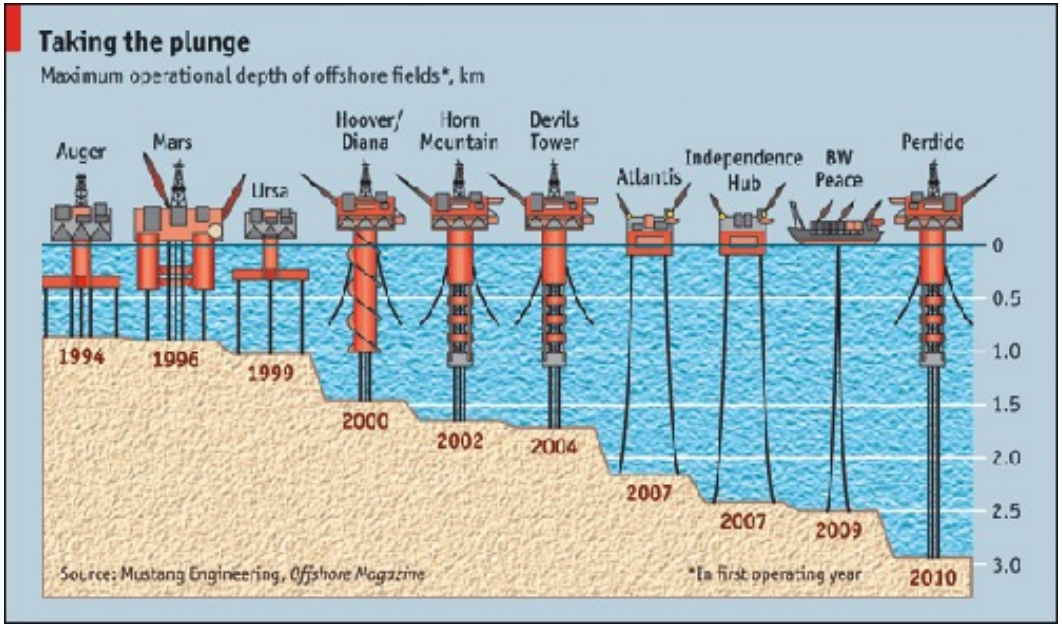
Shallow : 0-400 m

Deep : 400-1500 m

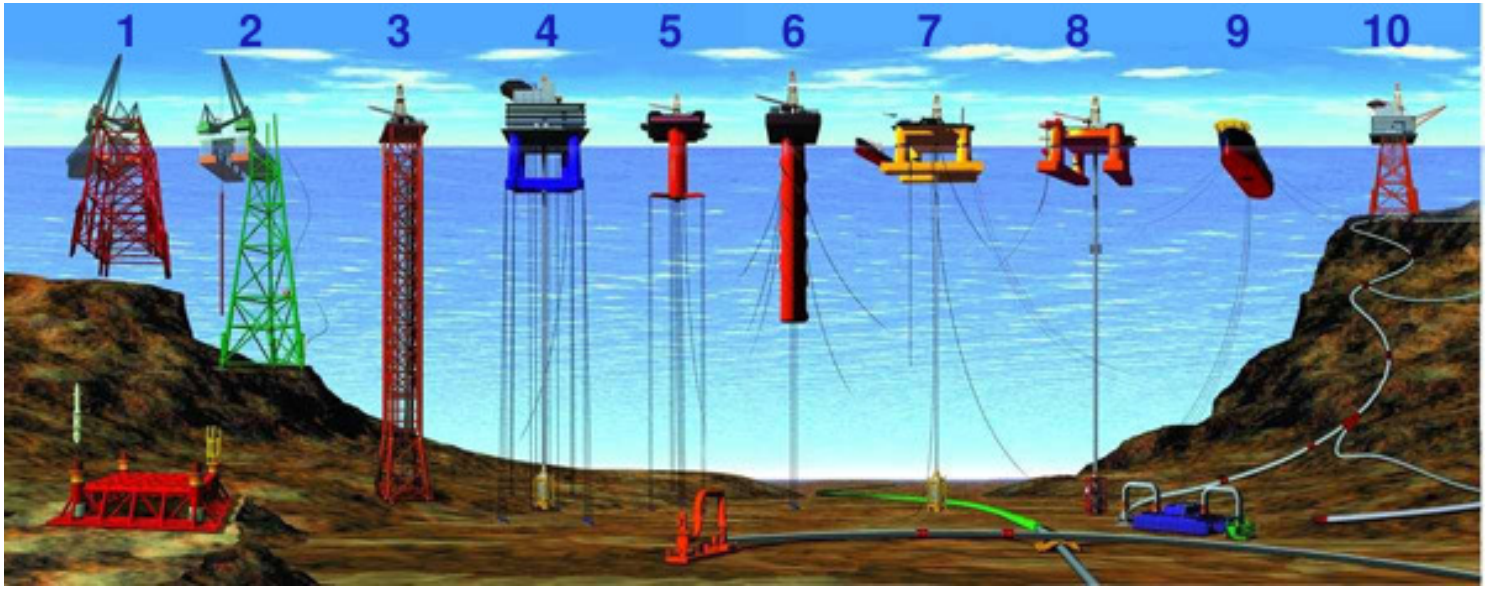
Ultradeep : >1500 m

Most global discoveries are offshore in deep and ultra-deep water (and cost a lot more)

- Petroleum industry is progressively moving into ultra-deep water, 3174 m in 2013 (offshore eastern India)
- Still within national jurisdictions – EEZ/'Continental Shelf'



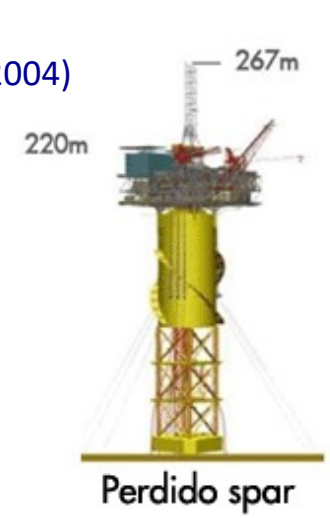
Source: www.energyandcapital.com/articles/oil-rigs-drilling-ever-deeper/



Types of Offshore Oil and Gas Structures (in 2005)

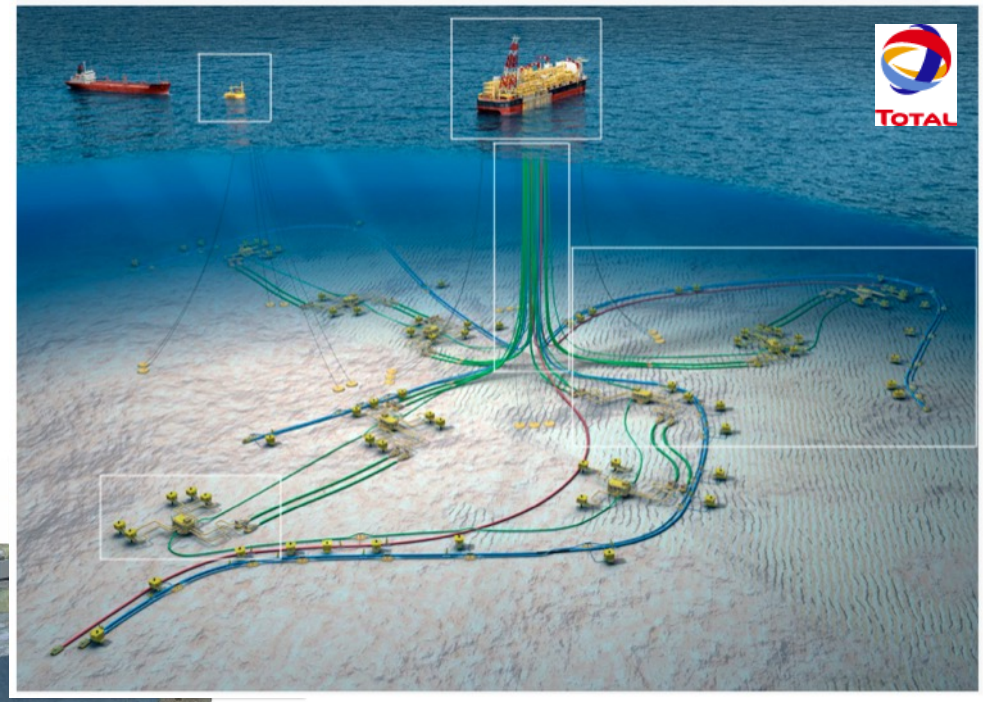
1 & 2) Conventional fixed platforms (deepest: 412 m GOM, 1991)
3) Compliant tower (deepest: 534 m GOM, 1998)
4 & 5) Vertically moored tension leg platforms (deepest: 1,425 m GOM, 2004)
6) Spar (deepest: 1,710 m GOM, 2004)
7 & 8) Semi-submersibles (deepest: 1920 m GOM 2003)
9) Floating production, storage, and offloading facility (deepest: 1,345 m Brazil, 2005)
10) Sub-sea completion and tie-back to host facility (deepest: 2,307 m GOM, 2004)

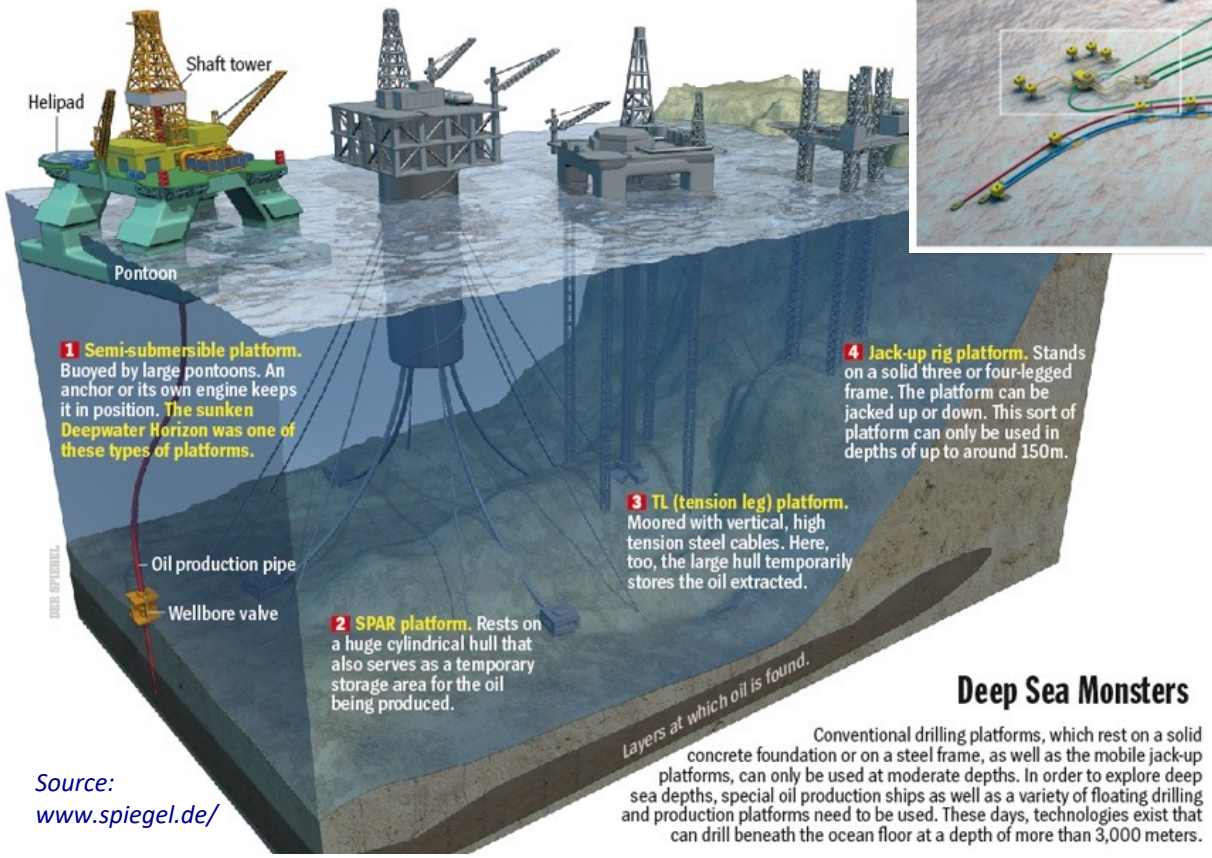
Source: http://commons.wikimedia.org/wiki/File:Types_of_offshore_oil_and_gas_structures.jpg



Source: www.shell.com

Enormous investments, technical challenges, and achievements by offshore industry in exploration, drilling and (only in some cases) production…





Source: www.spiegel.de/

"The conquest of the deep offshore, the oil industry's latest and perhaps most extra-ordinary adventure…" (www.total.com)

Seabed Mapping – an offshore service industry

Supports the siting and maintenance of seabed installations (cables, pipelines, wind farms, platforms…)

- Multibeam & sidescan sonar bathymetry
- Subottom profiling (seismic)
- Magnetic measurements

remote methods

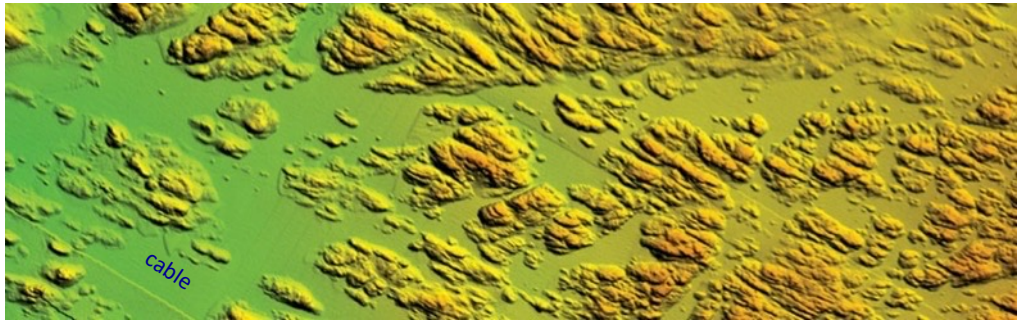
- Sediment sampling (coring and grabs)
- Remotely Operated Vehicles (ROVs)

direct methods

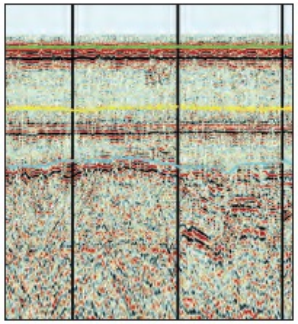
Source: downloads.n-o-s.eu/partners/mmt-ab/

Source: www1.gardline.com

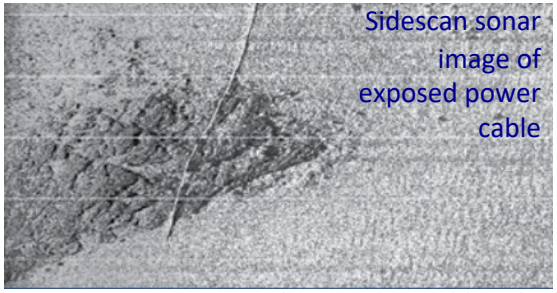
multibeam sonar image

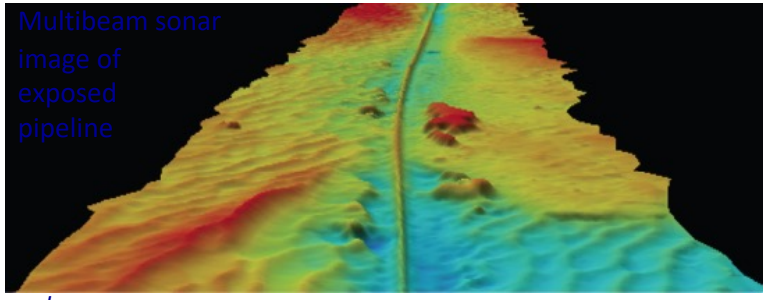


seismic profile



Cable plough





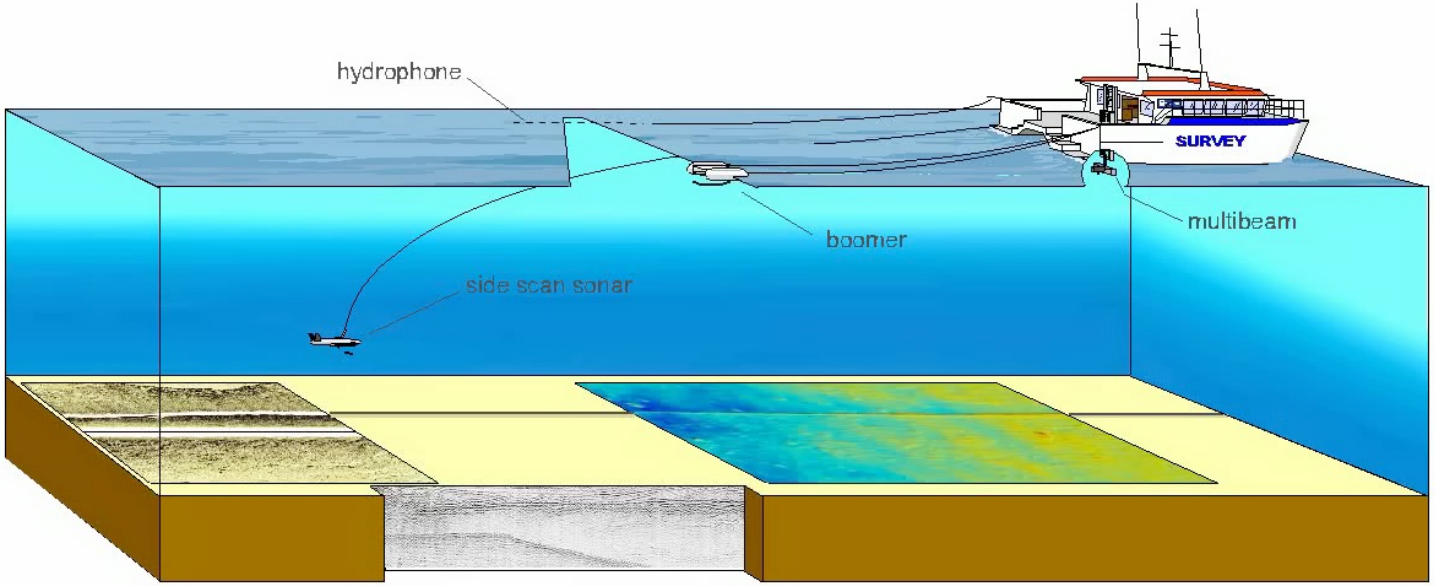
Source: www.osirisprojects.co.uk

Trenching ROV

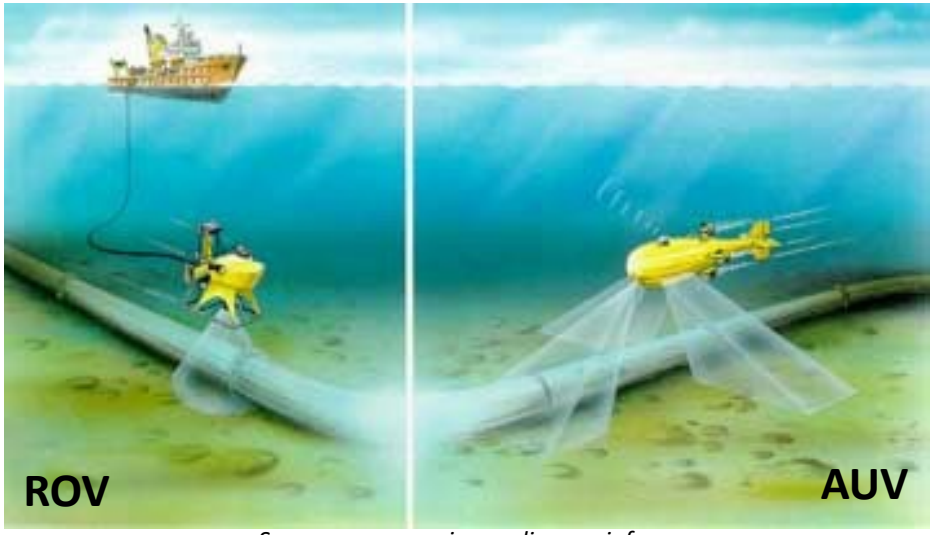
Sources: www.pharos offshoregroup.com

> OGS Explora has undertaken several commercial cable surveys

Seabed mapping - geophysical methods (swath & profile data)



Source: www.osirisprojects.co.uk

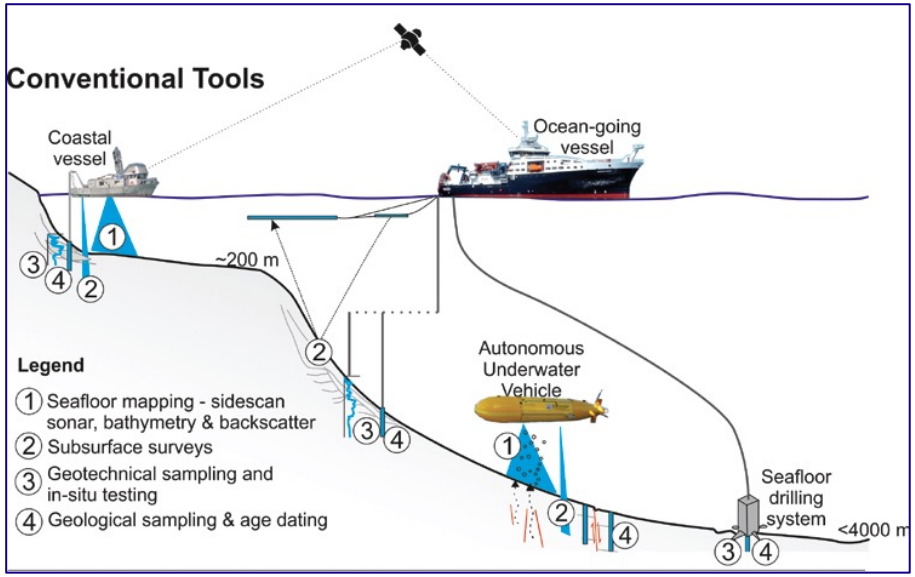


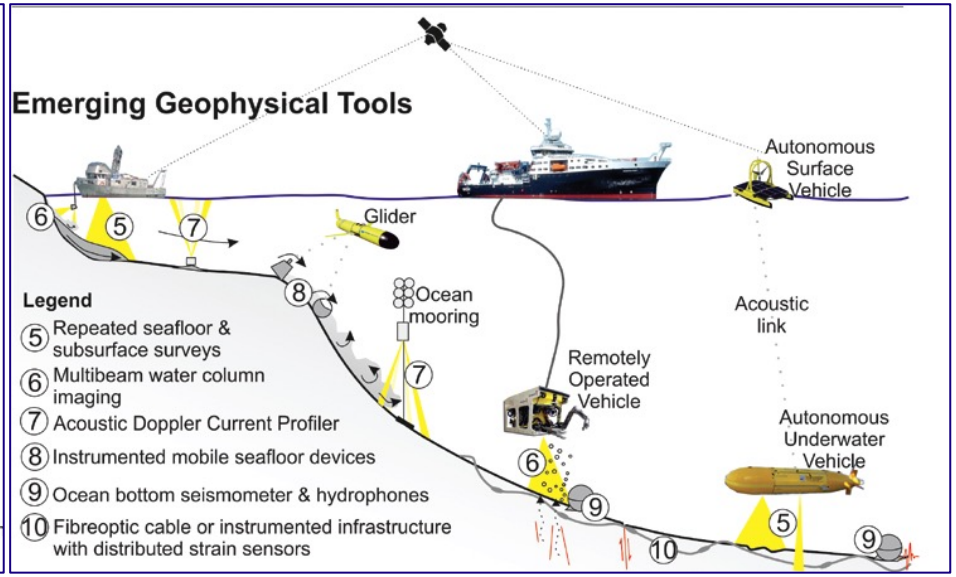
Source: www.ogniwa-paliwowe.info

Deployment to seabed of :

- Remotely Operated Vehicles (ROVs)
- Autonomous Underwater Vehicles (AUVs)

Multi-national offshore industries

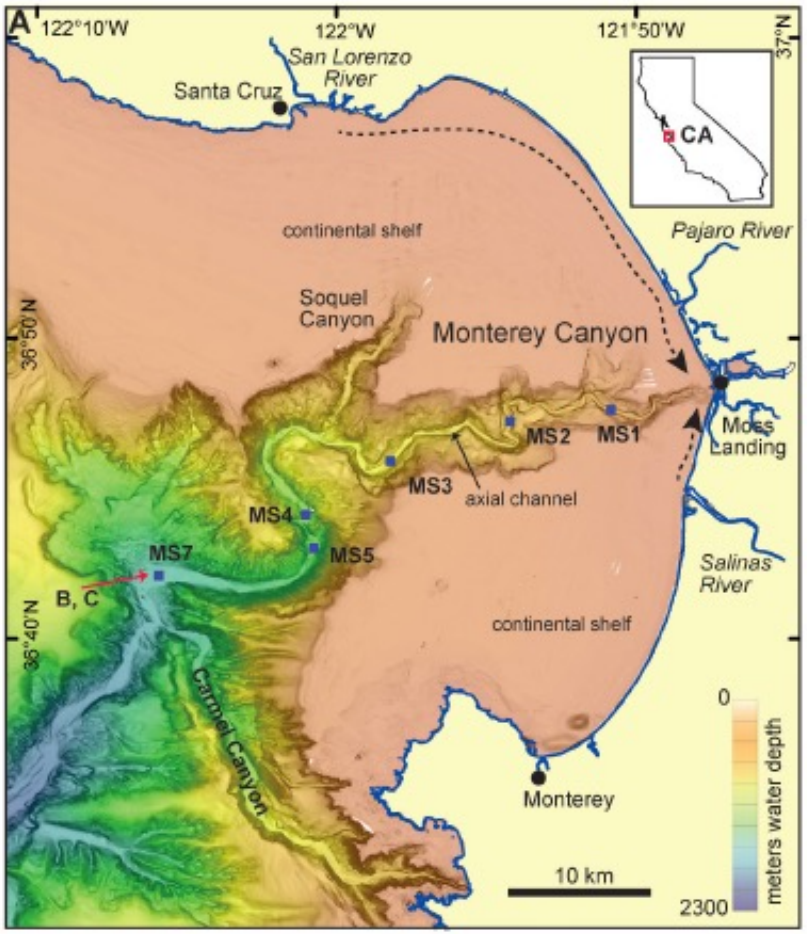


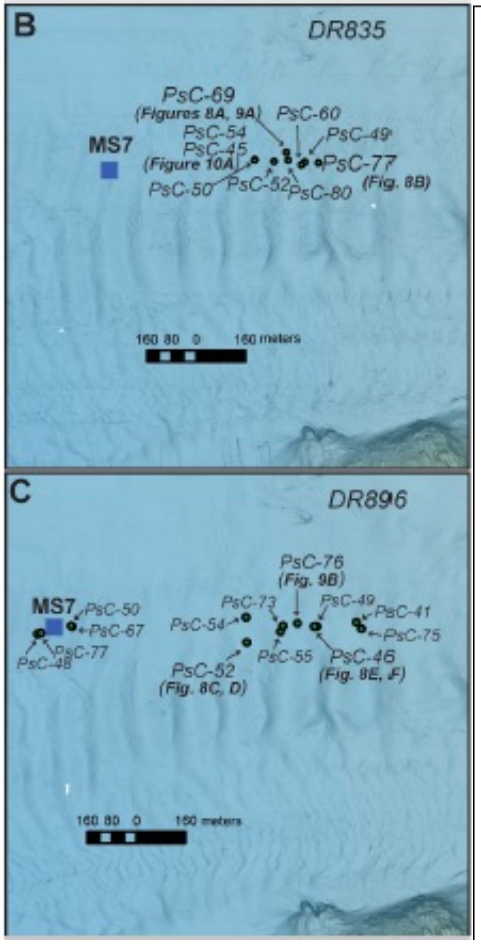


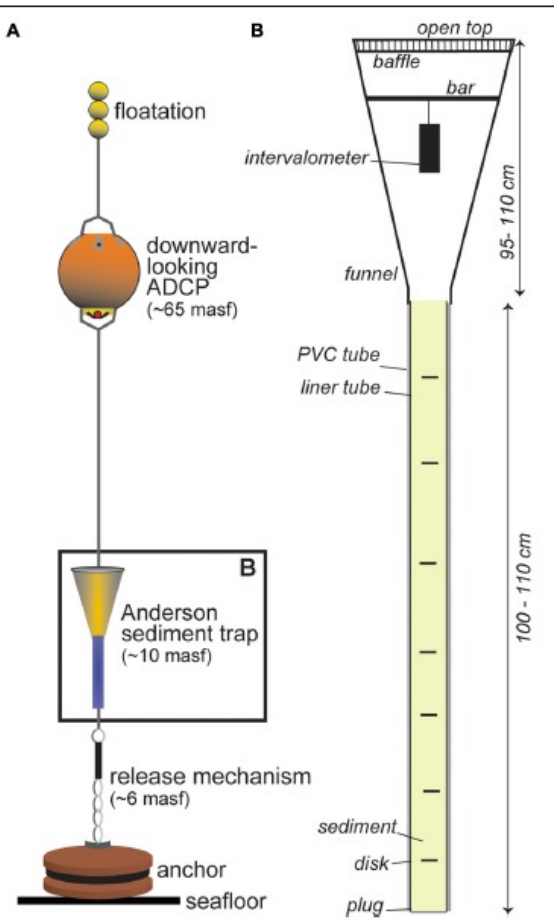
Clare et al., 2017, Near Surface Geophysics

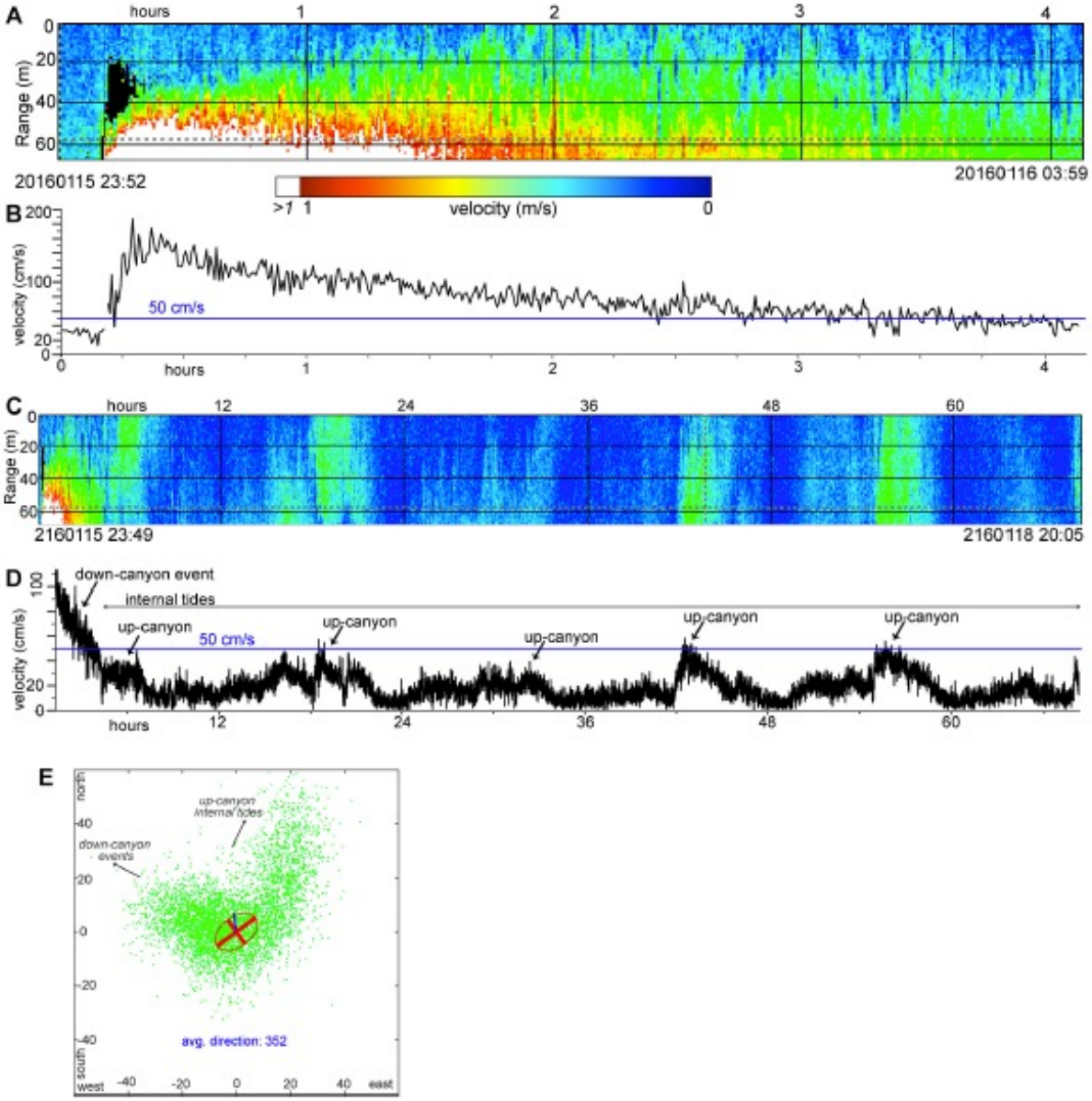
Linking Direct Measurements of Turbidity Currents to Submarine Canyon-Floor Deposits

Maier et al., 2019. Linking Direct Measurements of Turbidity Currents to Submarine Canyon-Floor Deposits. Front. Earth Sci. 7:144. doi: 10.3389/feart.2019.00144








A
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Range (m)
0
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60
20160115 23:52
20160116 03:59
>1
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velocity (m/s)
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B
velocity (cm/s)
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C
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36
48
60
Range (m)
2160115 23:49
2160118 20:05
D
down-canyon event
internal tides
up-canyon
50 cm/s
velocity (cm/s)
hours
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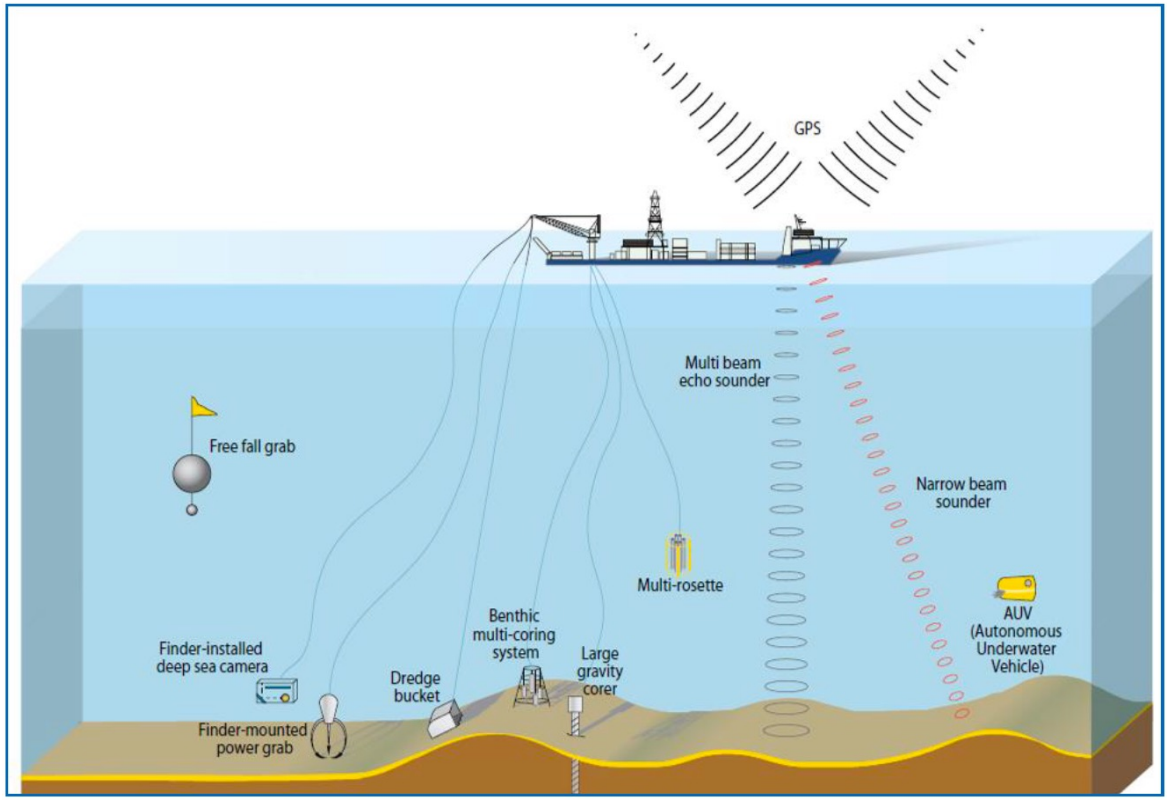
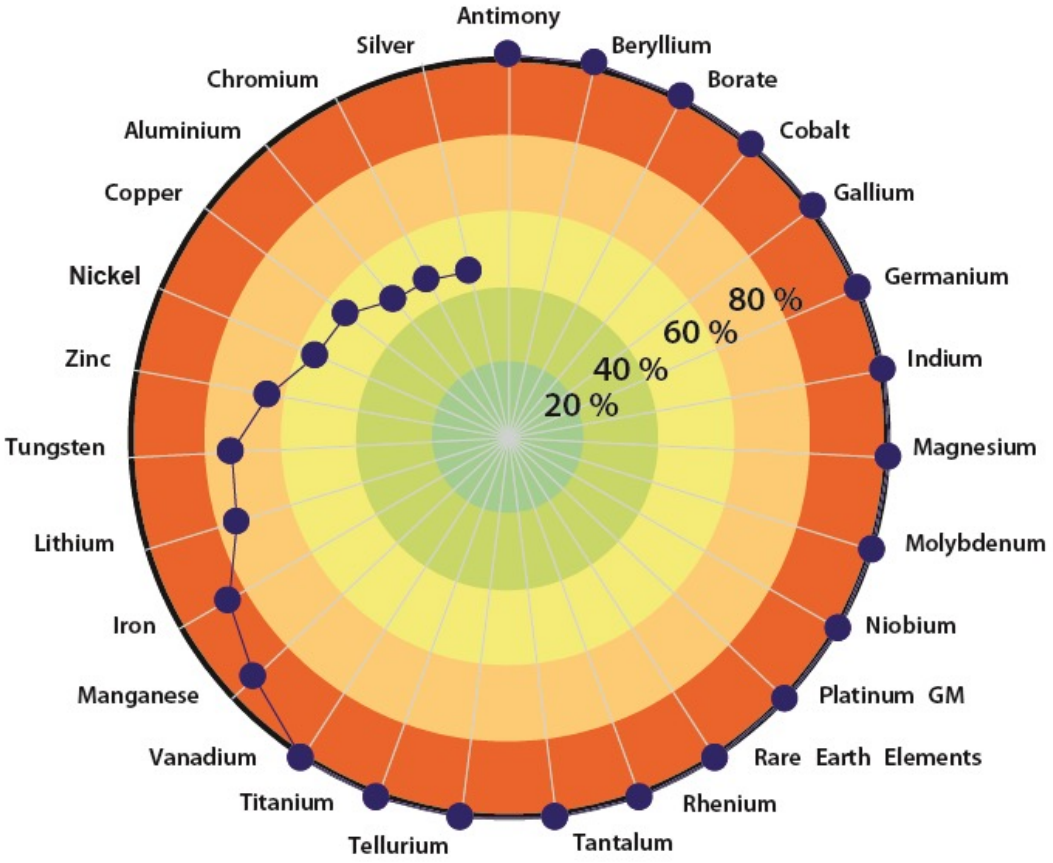
north
south
west
east
up-canyon internal tides
down-canyon events
avg. direction: 352

DEEP SEA MINING



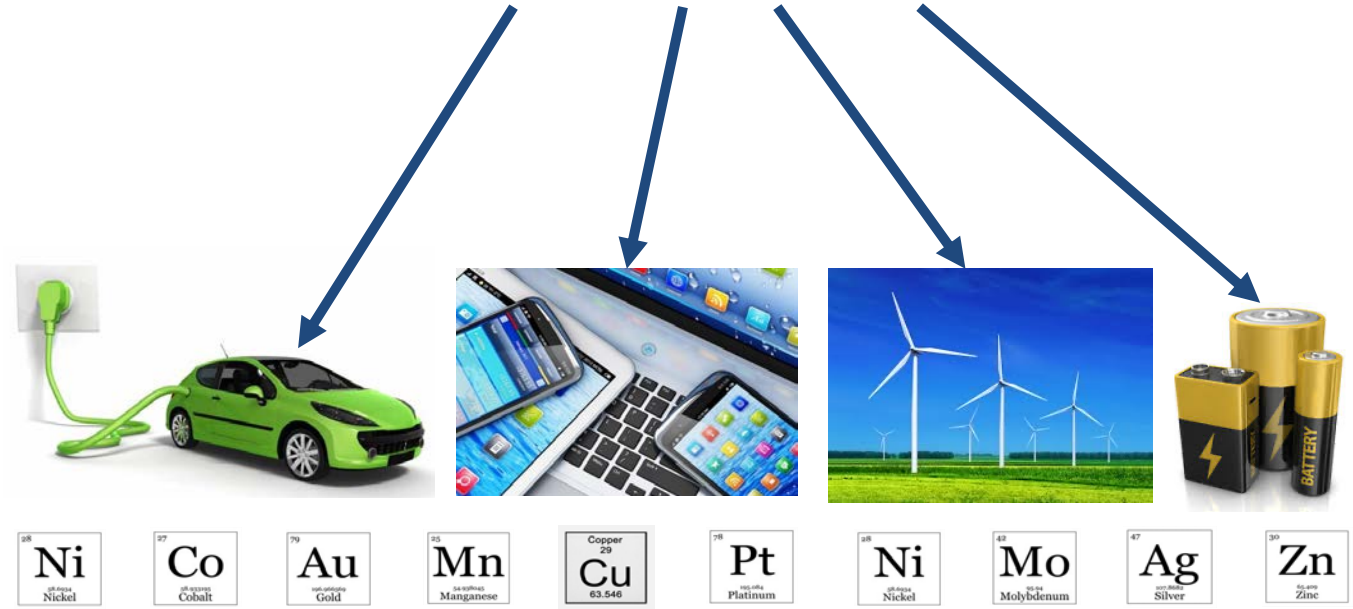
- Securing sustainable access to raw materials and strategic material reducing country's dependency from import.
- Developing advanced technology that could keep Italy as one of the leading exporters of advanced offshore exploration technologies, creating specialized jobs
- Identify possible industry alternative for companies operating in the oil & gas sector.

Source: Study to investigate the state of knowledge of deep-sea mining
Final Report under FWC MARE/2012/06 - SC E1/2013/04

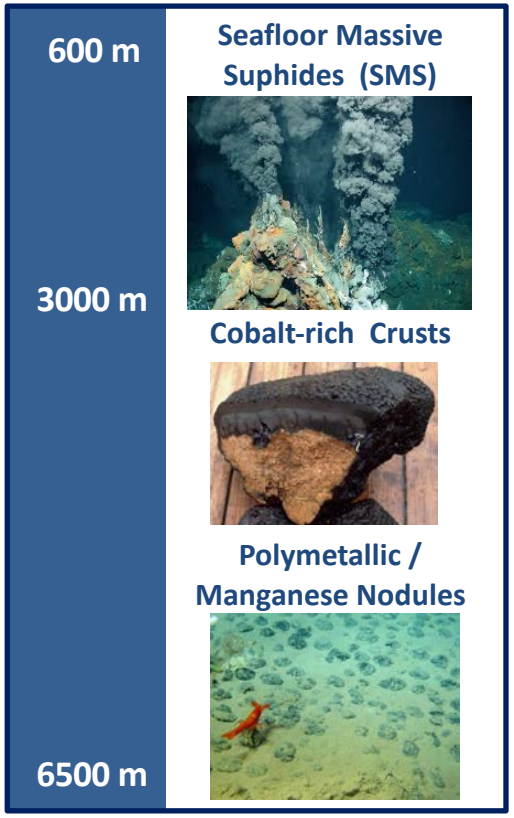


Import dependence of Europe in 2006, for selected critical raw materials, as published in a Report by the European Commission. Note that the value for Gallium is not reliable, due to significant changes for different years.

Sustainable and strategic sourcing of minerals for energy production and consumption.



- Mineral resources in progressive reduction in all land mines (Australia, Africa, South America)
- Worldwide population growth will lead to further increases in requests
- Ocean beds (> 4000 m) extremely rich in mineral resources (manganese, cobalt, indium nodules) as well as many rare and precious metals.
- These resources are in open ocean areas outside national jurisdictions
- The international authority granting the concessions is the International Seabed Authority
- Many countries are already in the exploration phase: USA, Germany (very actively), France, Japan, Russia and Belgium.
- The exploratory concessions are expected to be reopened



Three types of mineral resources of the deep sea

polymetallic / Manganese nodule

Cobalt-rich crust

Hydrothermal sulfides

Minerals in the Deep Sea (Polymetallic Nodules, Crusts, Sulphides)

1. 'Manganese' nodules

- 97% Mn-Fe hydroxides, 3% cobalt, copper, nickel, traces of platinum & tellurium
- up to 20 cm in diameter (size of potatoes to cabbages)
- concretions precipitated from seawater or pore waters *very very slowly* (1-3 mm/Myr)
- lie at seabed over vast areas (Pacific & Indian oceans), in depths > 4000 m

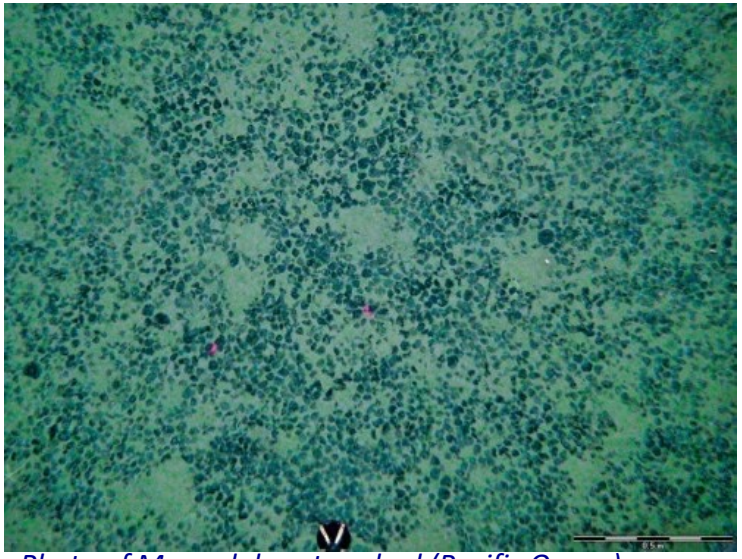
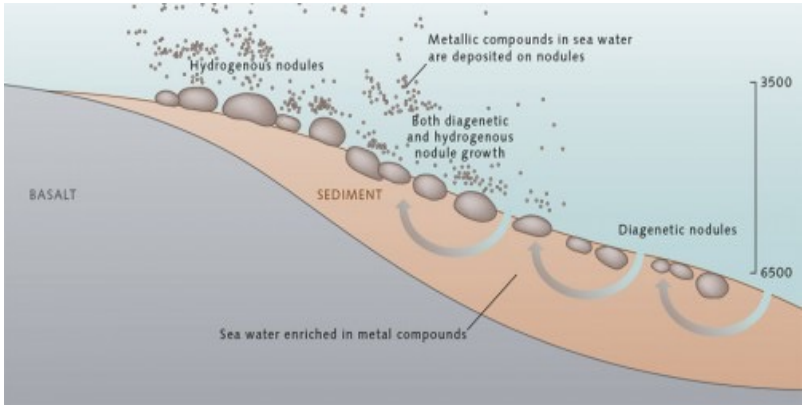
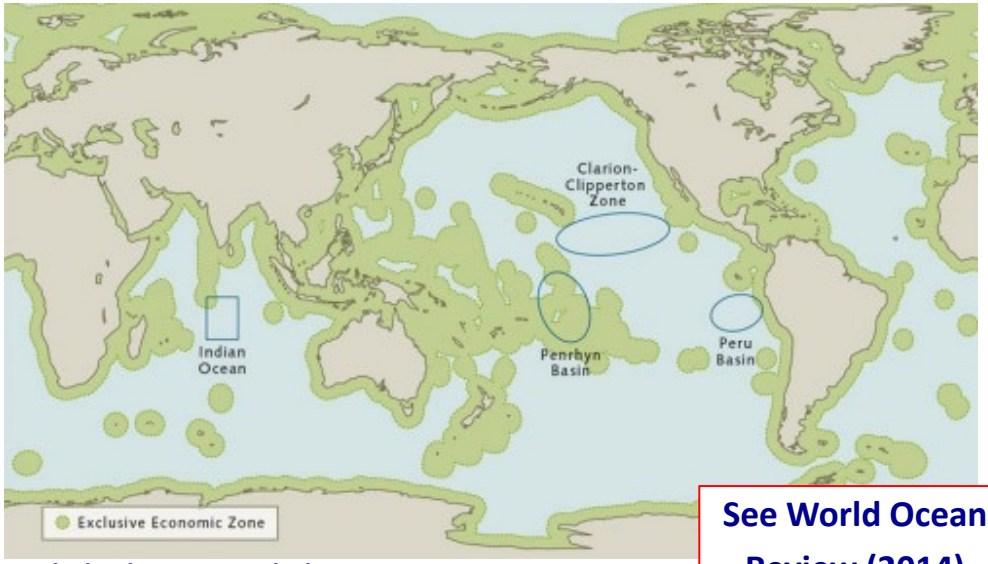


Photo of Mn nodules at seabed (Pacific Ocean)



Schematic of Mn nodules formation processes



Global Mn nodule concentrations

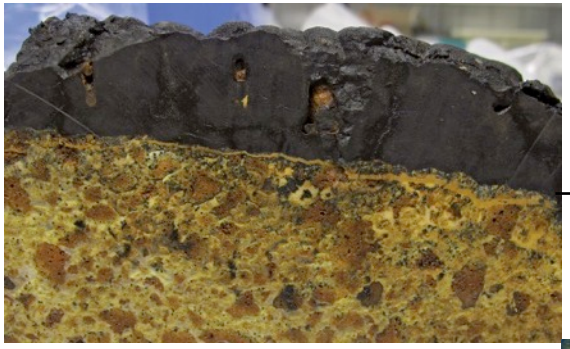
See World Ocean Review (2014)

Source for all: World Ocean Review (http://worldoceanreview.com)

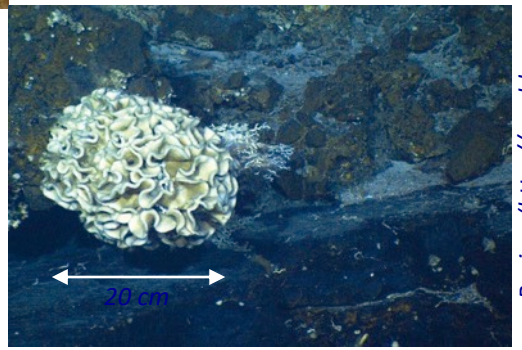
Minerals in the Deep Sea

2. Cobalt crusts

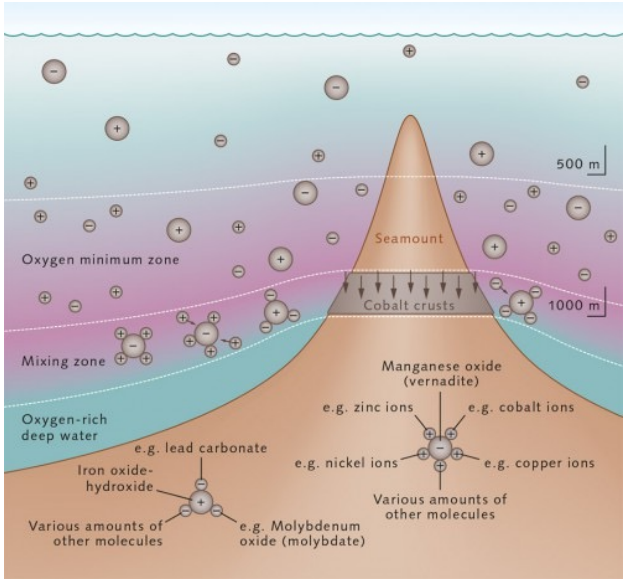
- composition similar to Mn-Fe nodules, more cobalt and platinum
- also precipitates, formed very very slowly (millions of years)
- found on flanks of seamounts (currents), in water depths 1000-3000 m
- differing distribution than nodules, but overlap; mainly in Prime Crust Zone



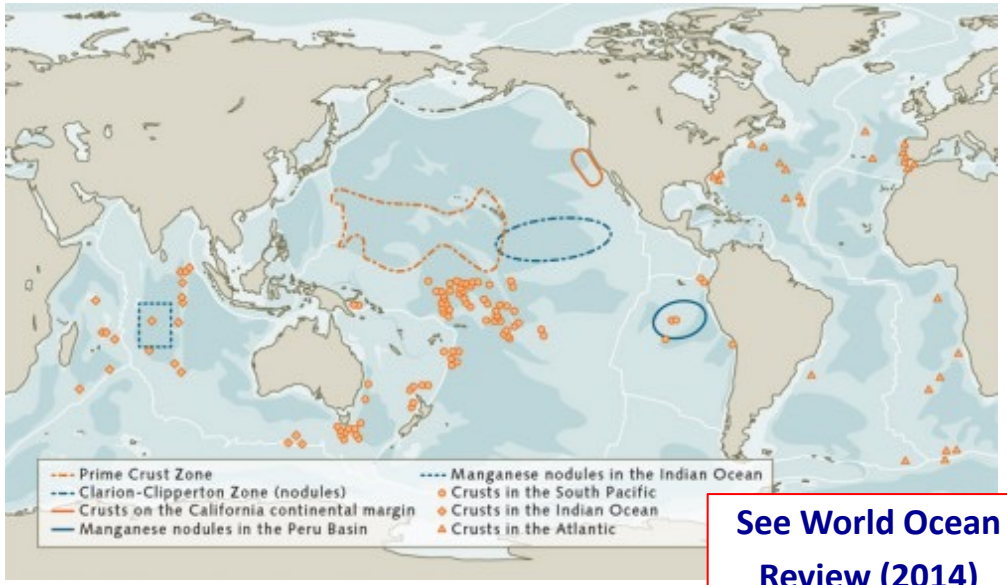
Cross-section of cobalt crust (SW Pacific)



Single-celled organism at seabed on cobalt crusts



Schematic of cobalt crust formation on seamount flanks



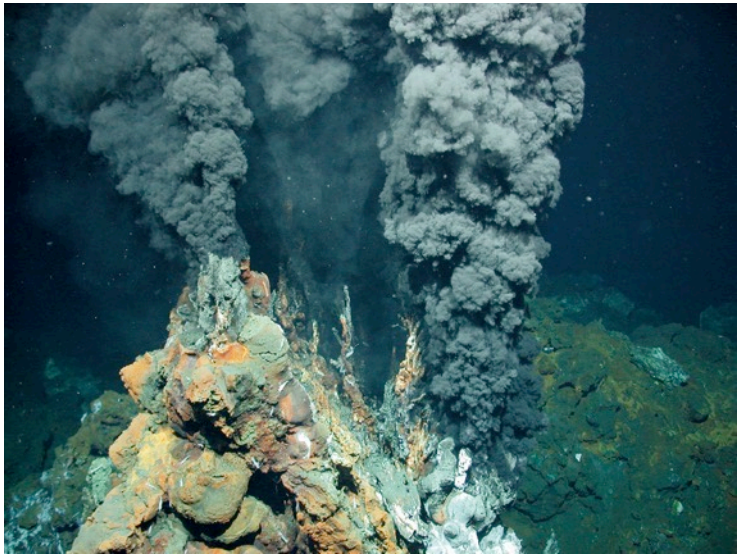
Source for all: World Ocean Review (http://worldoceanreview.com)

See World Ocean Review (2014)

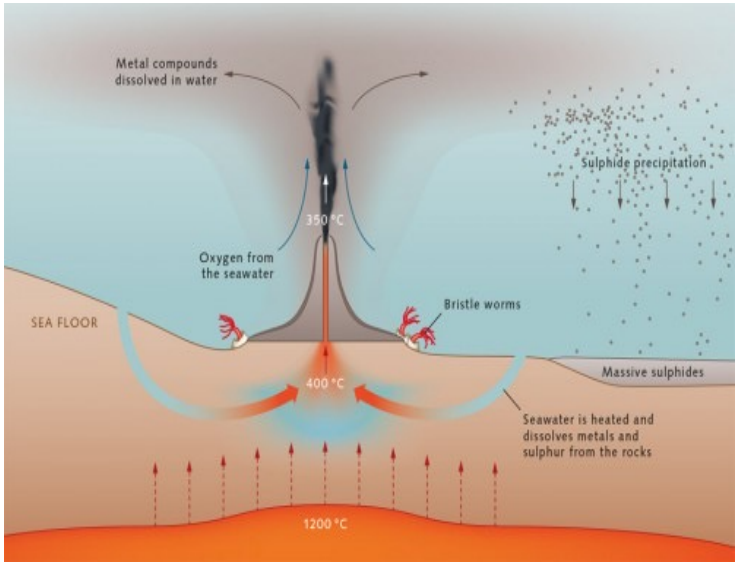
Minerals in the Deep Sea

3. Massive sulphides

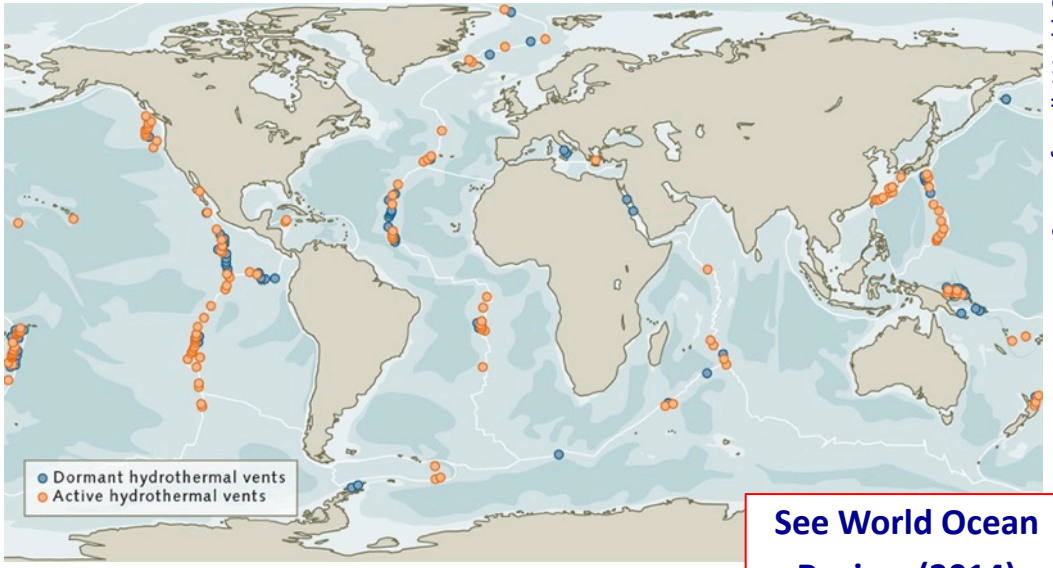
- Iron sulphides with copper, gold, zinc & silver
- Sulphides and other metals precipitate from seawater near volcanoes
- 'Black smokers' discovered in 1978 – hydro-thermal vents (metal-rich fluids up to 400°C)
- Found in areas of recent and present volcanism, in water depths 500-4000 m (including offshore Italy)



Black smoker hydrothermal vent



Schematic of massive sulphide precipitation next to volcano



See World Ocean Review (2014)

Source for all: World Ocean Review (http://worldoceanreview.com)

Mining Deep Sea Minerals

Still in exploration phase

- 1960-70s: 'boom' - huge interest, 10^8 spent
- 1980-90s: 'bust' (prices fell)
- Today - prices are high again… and ability to map the seabed has significantly improved

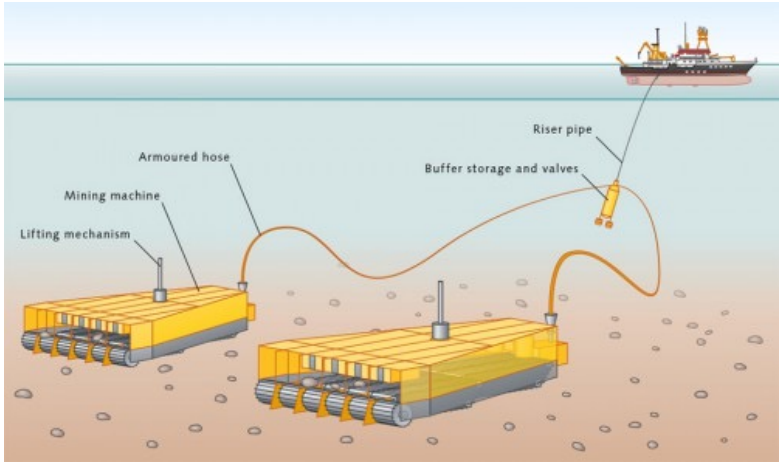
→ drove the signing of UNCLOS (1982) and the creation of the International Seabed Authority (ISA 1994) to regulate the 'boom'

- ISA issued 6 licences from 1984-2011; issued 21 licences in the last 5 years (all beyond EEZs, none being developed)

Precious metals (Mn, Co, Cu, Ni, Pt, Te, Au, Zn, Ar) just lying at seabed…

How do you pick them up?

- Nodules – various concepts proposed
- Impact on ecosystems?
- Crusts, how to detach from seabed?
- Main current interest is in sulphides…
  (relatively small volumes globally, but concentrated precipitates)

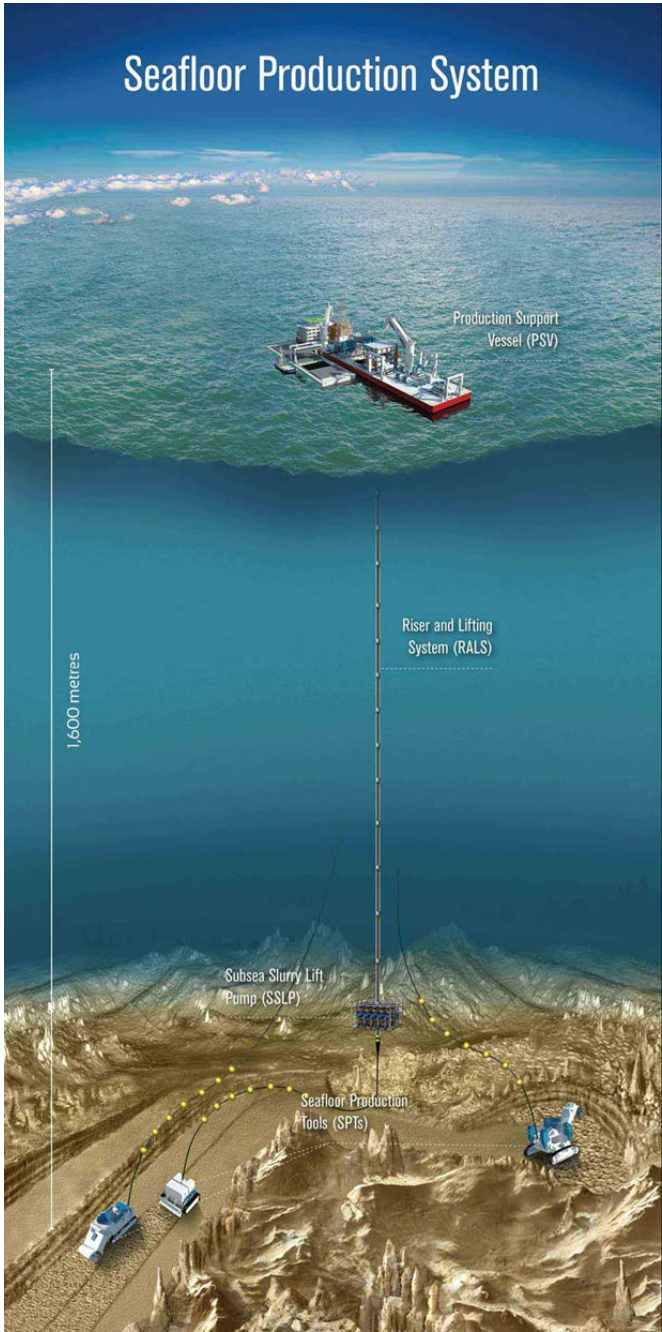


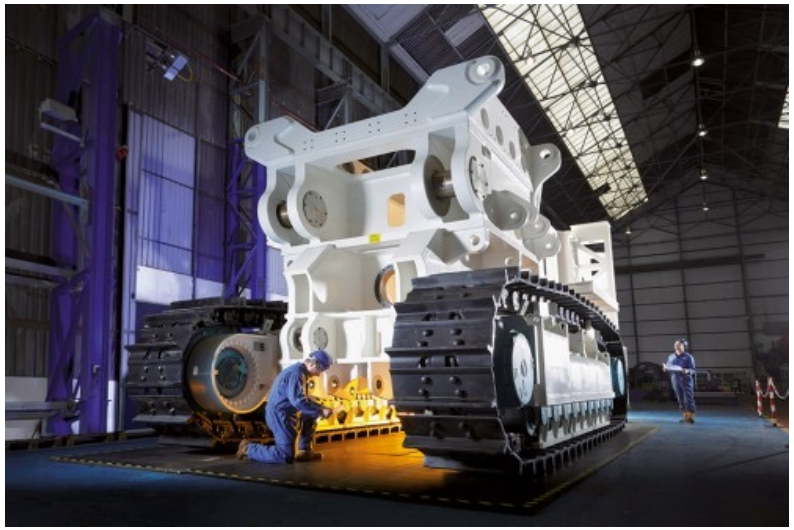
These machines have not been built !

Mining Deep Sea Minerals

Solwara 1 Project, Papua New Guinea

- 'world's first commercial seafloor copper-gold project from Seafloor Massive Sulphides (SMS)'
- Within EEZ of Papua New Guinea
- Launched in 2008, still on paper…
- now (re)scheduled for 2016



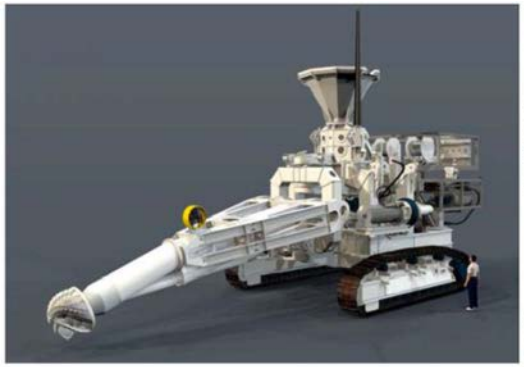


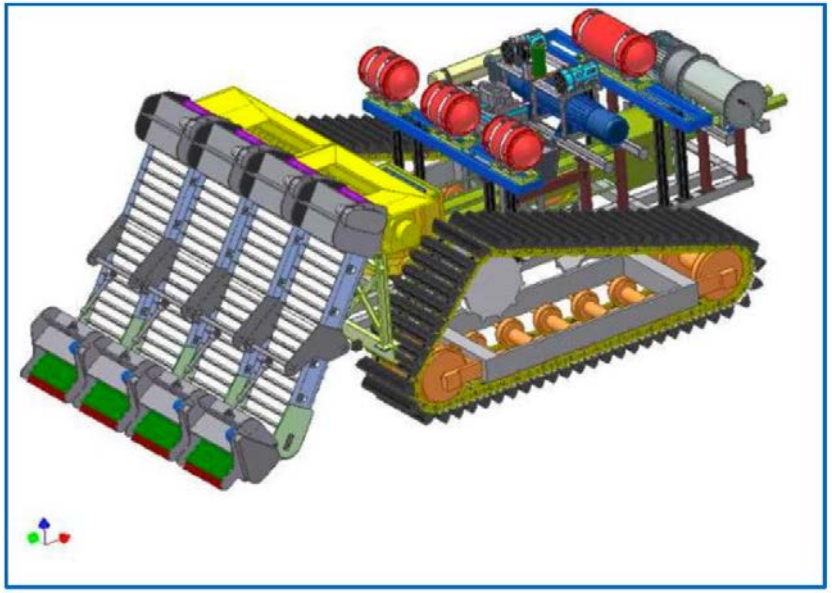
Chassis of seabed rock cutter (adapted cable trencher)

Sources: www.nautilusminerals.com

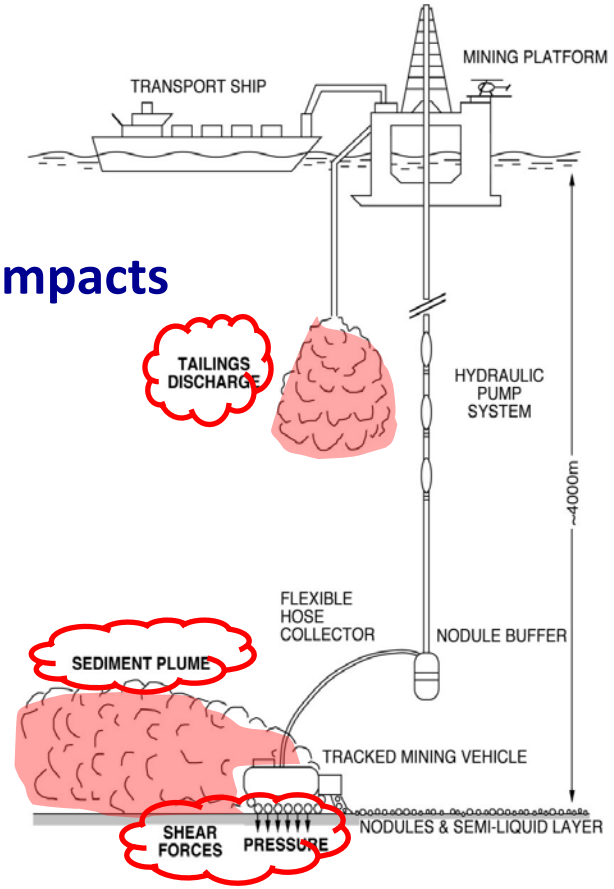
NAUTILUS Minerals Niugini

DEEP SEA MINING

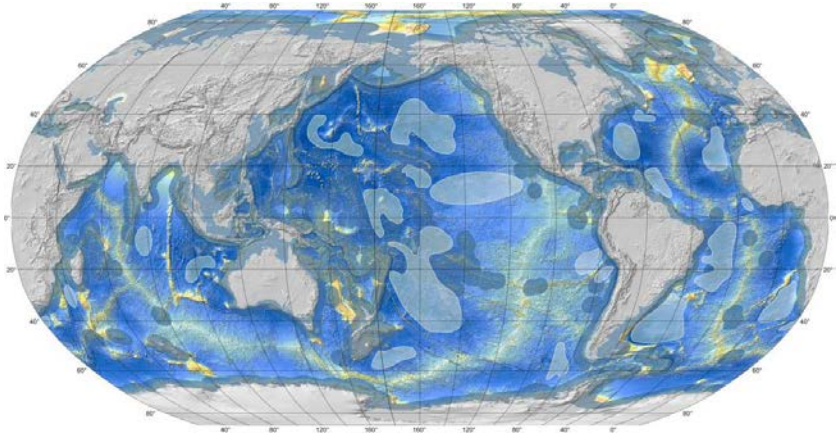




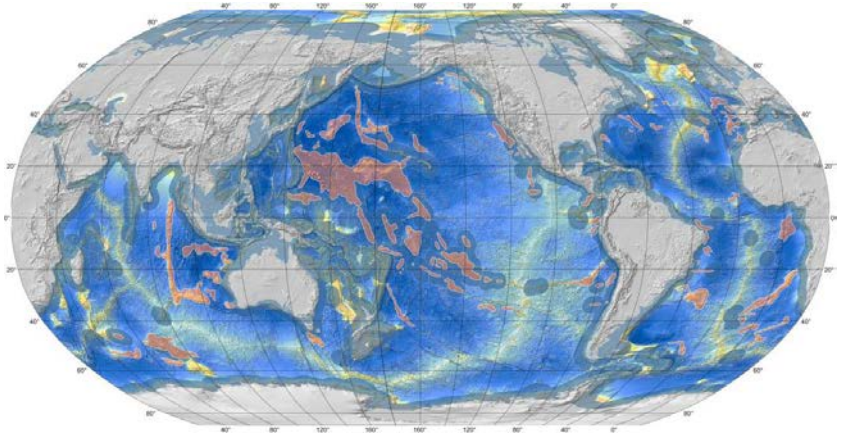
Impacts



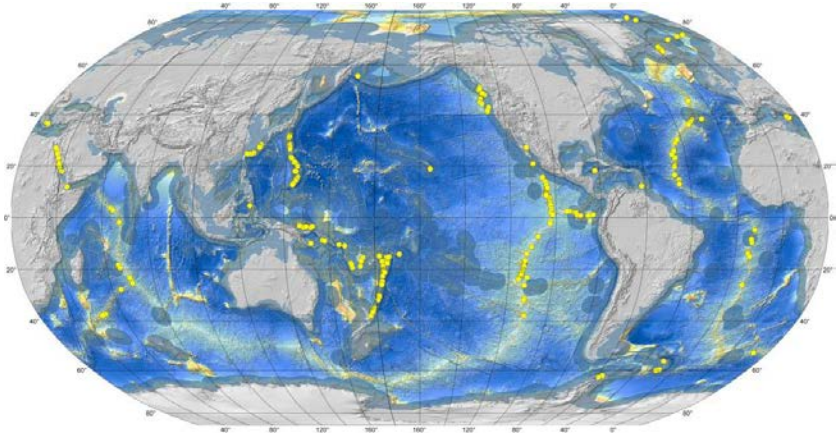
Source: Study to investigate the state of knowledge of deep-sea mining
Final Report under FWC MARE/2012/06 - SC E1/2013/04



Area with highest manganese nodule potential



Area with highest ferromanganese crust potential

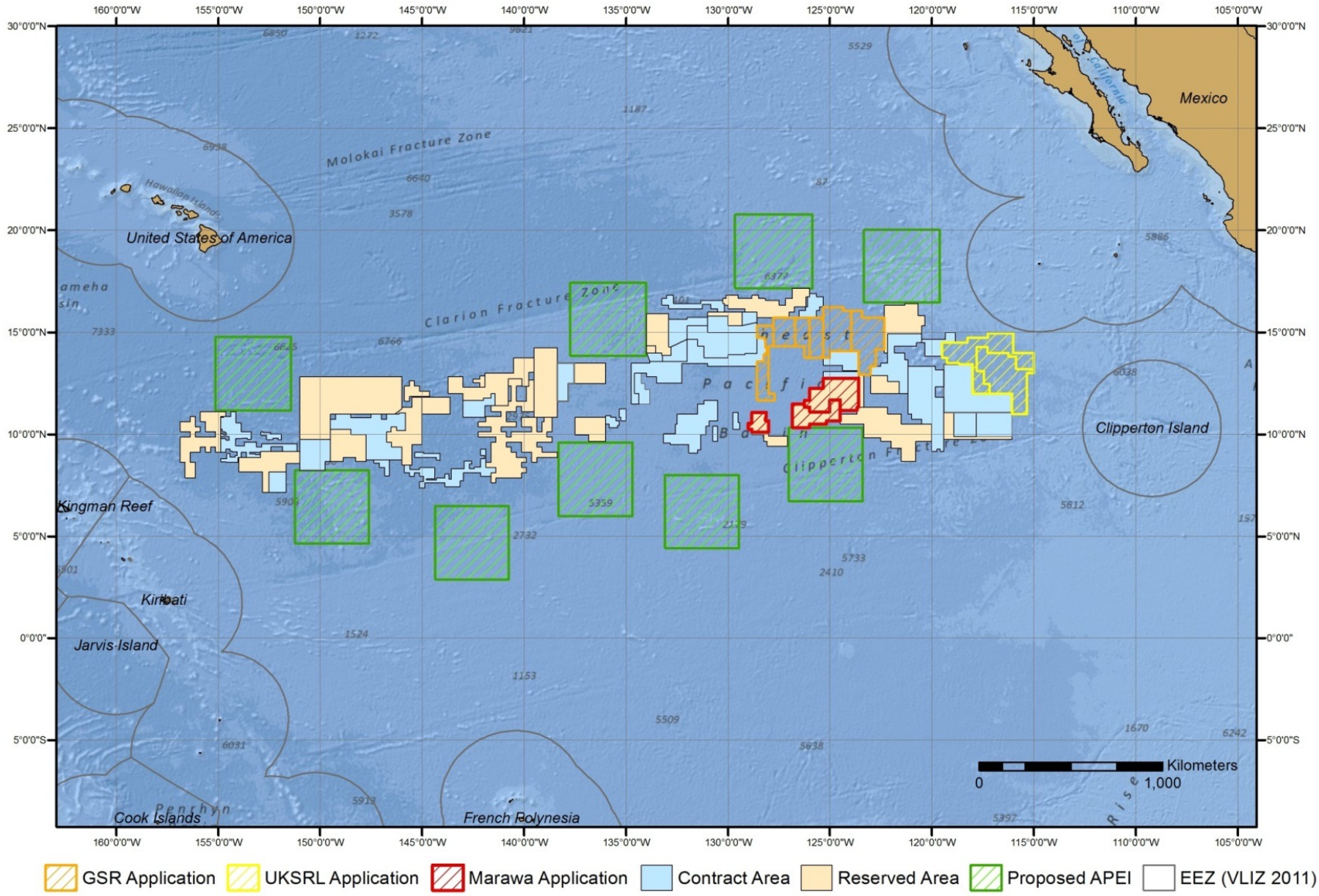


seafloor massive sulphide occurrences

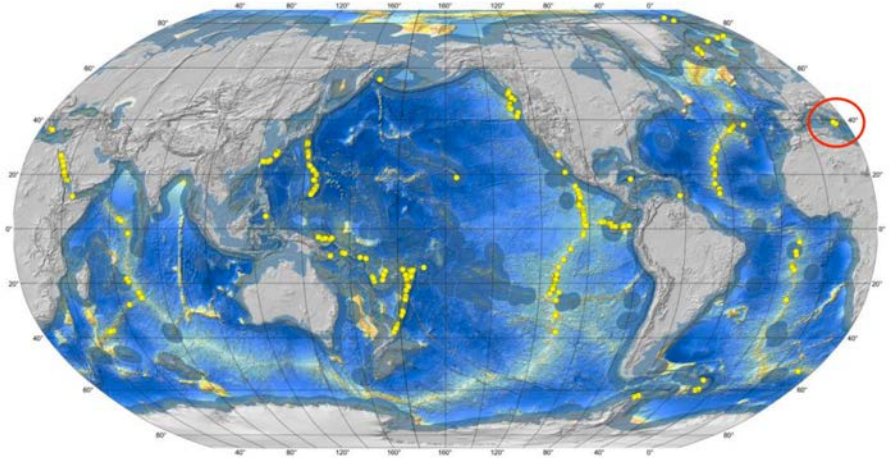
Study to investigate state of knowledge of deep sea mining
Final report Annex 1 Geological Analysis
FWC MARE/2012/06 – SC E1/2013/0

New Applications for Polymetallic Nodules Exploration as of July 2012

ISA, 01 July 2012 - Confidential



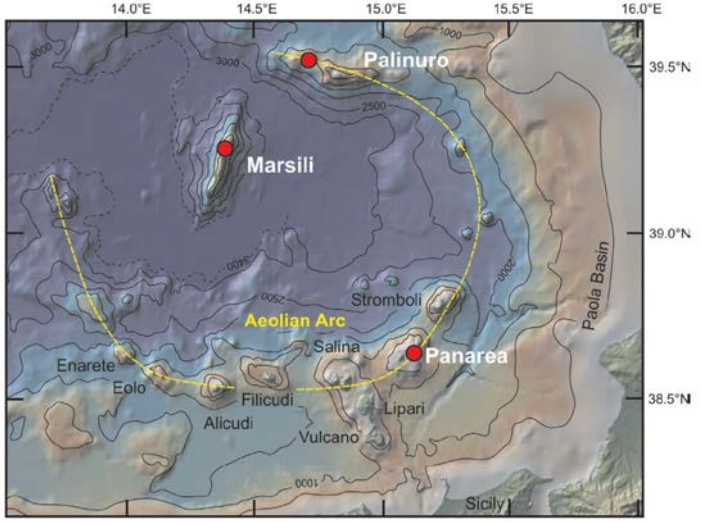
Tyrrhenian Sea



Seafloor massive sulphide occurrences (306 sites) cpnsidered in the Study to investigate state of knowledge of deep sea mining

Final report Annex 1 Geological Analysis
FWC MARE/2012/06 – SC E1/2013/04

AN OPPORTUNITY FOR RESEARCH AND TECHNOLOGICAL DEVELOPMENT IN OUT BACKYARD



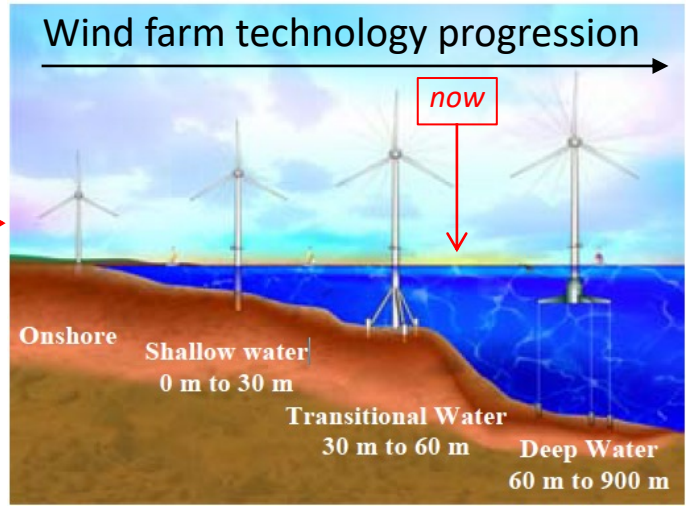
Submarine Shallow-water Hydrothermal Systems in Volcanic Arcs of the Tyrrhenian Sea.

Petersen et al., 2008. InterRidge News

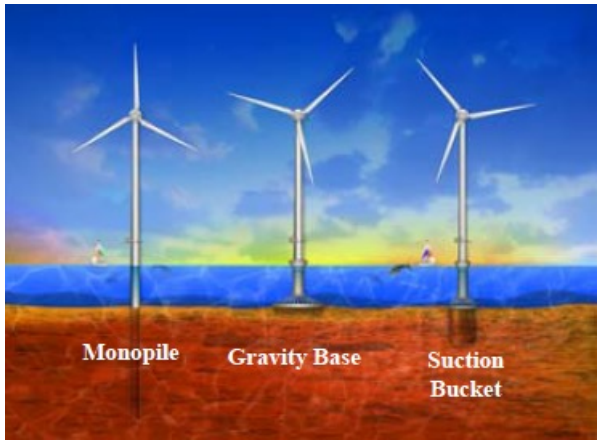
Seabed Installations - for Renewable Energies

- **Wind**, wave, tide, ocean currents, temperature & salinity differences…

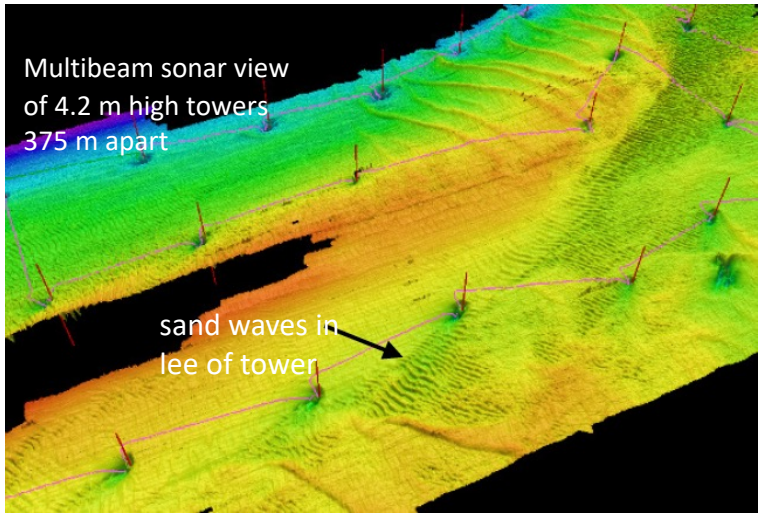
Wind farm seabed installations >40 projects world-wide

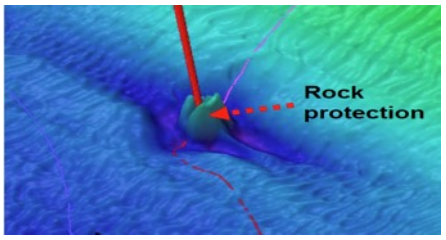


Sources: Musial et al. (2006, OTC 18355)



Different foundations…
all require knowledge of seabed





Source: Scroby Sands Offshore Wind Farm – Coastal Processes Monitoring. Cefas, UK, 2006

Seabed mapping

+ monitoring surveys:

- sand wave migration
- scour of foundations

Same companies as cables

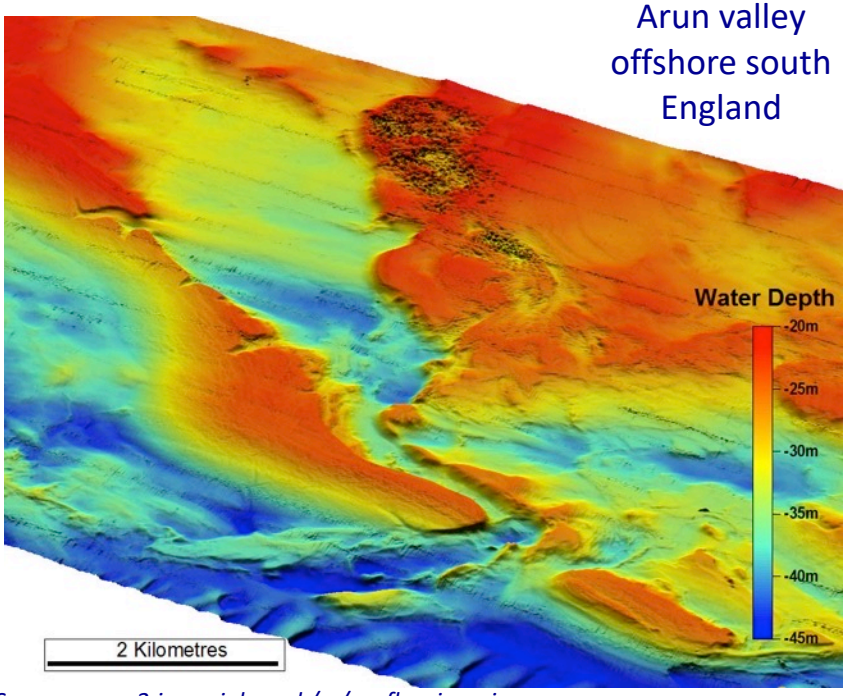
Webinar: https://www.youtube.com/watch?v=58EYcYbRKqk

Seabed Sand and Gravel Mining

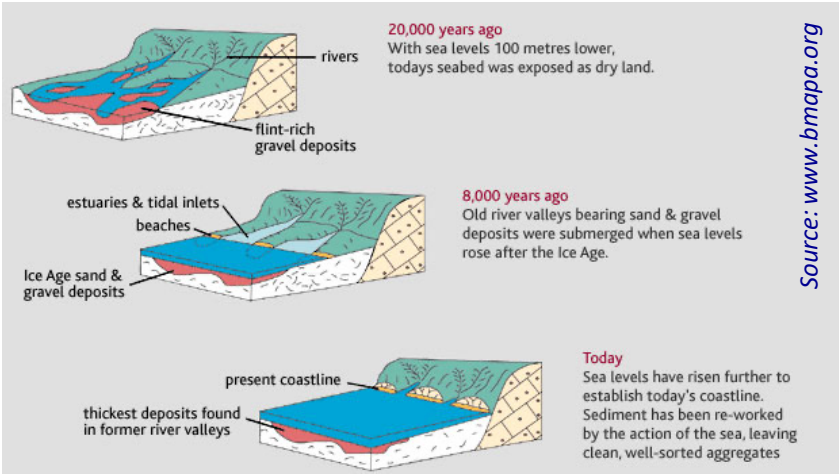
Not very 'glamorous' minerals… but a big business

- Used worldwide in construction, coastal engineering…
- Suction dredging from surface vessels
- Minimal science until recently – low value, large volumes…
- Science overlap - post-glacial sea level rise, early human civilisations (submarine archaeology)…

Arun valley offshore south England



Source: www3.imperial.ac.uk/.../seafloorimaging



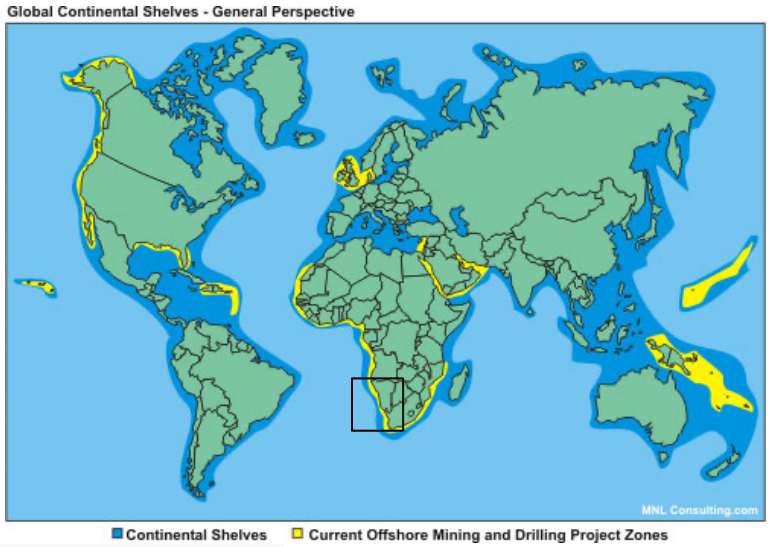
- An industry 2nd to oil & gas in the US (in Europe, mainly North Sea countries*)
- Globally, we use >40 x 10^9 tonnes/yr = twice the sediment carried by all the rivers of the world

*(*Velegrakis et al.2010, Journal of Coastal Research 51, 1-14)*

Seabed Diamond/Gold Mining

- More glamorous - but similar dredging techniques, in depths up to 150 m
- Exploration activity off South Africa, Australia & Asia, Alaska… →

Diamond mining off Namibia (De Beers)

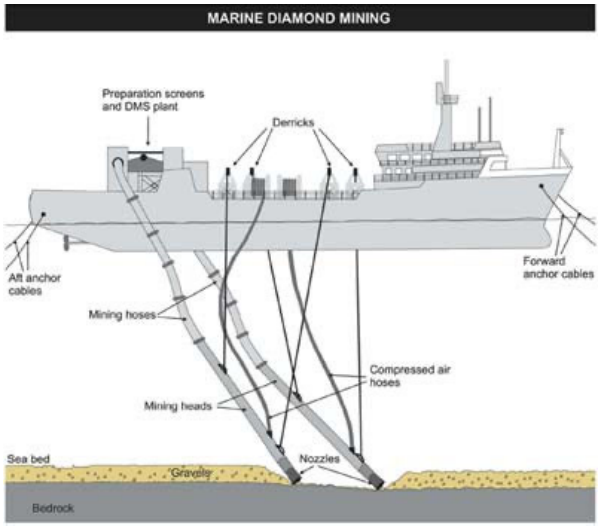


Source: www.mnlconsulting.com

Various mining techniques

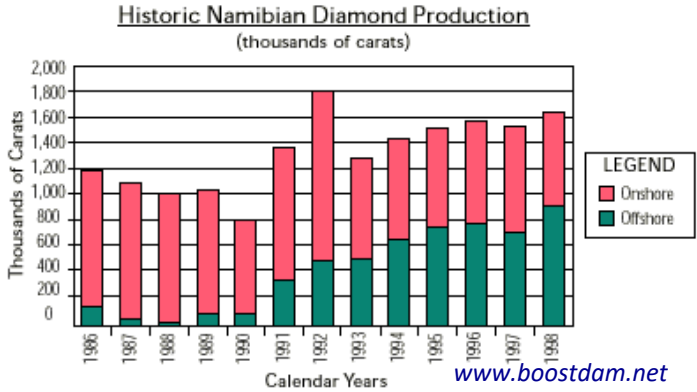
- Horizontal – seabed crawlers →
- Vertical – suction drilling (water jets)
- Airlift – compressed air jets

www.marinelog.com



Source: 2011.polarhusky.com

Diamonds from offshore Namibia (www.imdhgroup.com)



www.boostdam.net

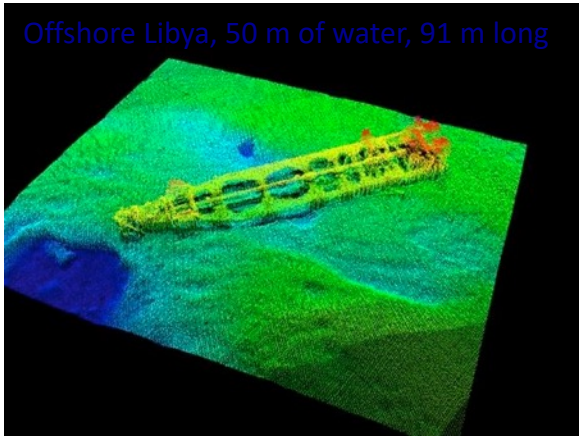
Seabed Treasure Hunting

Glamorous! Salvage companies involved in raising wrecks (e.g. Costa Concordia) or in looking for 'sunken treasure' – using the remote and direct techniques of seabed mapping

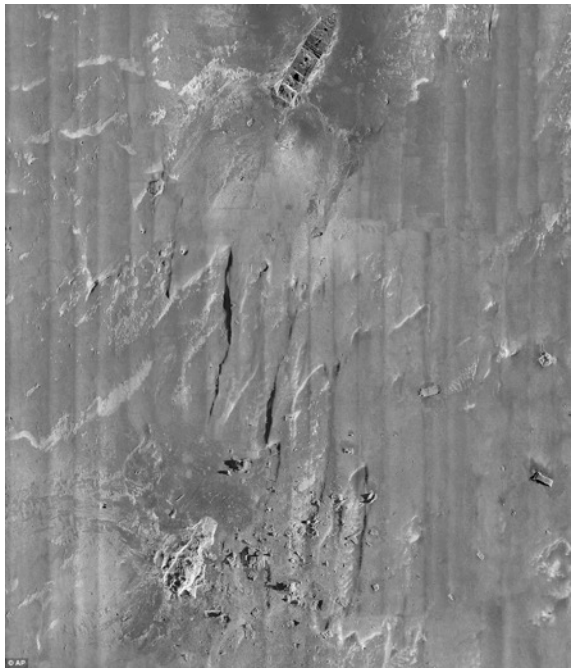
http://shipwreck.net/

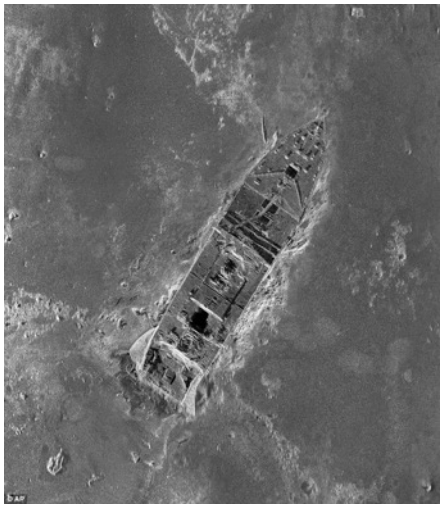
ODYSSEY MARINE EXPLORATION

Source: www.osirisprojects.co.uk



http://subseaworldnews.com/2013/07/25/hms-echo-finds-18-wrecks-in-mission-offshore-libya/

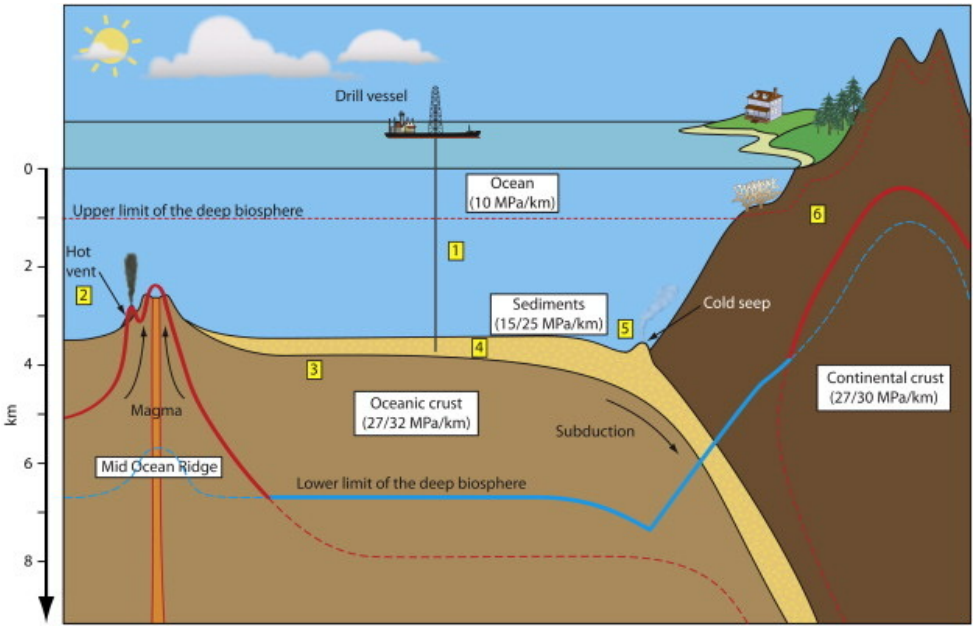




RMS Titantic debris field on sonar imagery (3800 m)
(www.dailymail.co.uk 09.03/2012)

Earth's deep biosphere

- Postulated by Thomas Gold (1992, 1999) - *The Deep, Hot Biosphere* (Springer)
- Earth's crust to depths of kilometers – sustained by thermally-driven fluid circulation : geosphere-biosphere coupling
- Microbial life, ½ to 2/3 of all biomass
- Largely chemosynthetic (primitive) life forms, living in 'extreme environments'



Source: Oger & Jebbar 2010, Research in Microbiology

(Geo-) Bio-prospecting

- "The development of drugs [pharmaceuticals] from marine organisms" - UN Atlas of the Oceans
- There already exist (highly profitable) 'bioactive compounds' from sponges and corals (primitive organisms, metabolic pathways in many ways similar to ours)
- Modern genetic methods simplify the search → growing commercial interest
- Japan spends a billion dollars a year (80% private sector)… big business
- Opposing views on whether genetic resources beyond the 'shelf' are covered by UNCLOS/IAS ("the common heritage of mankind") or are private? *See World Ocean Review*

Sedimentary Basin Analysis vs Petroleum System Analysis

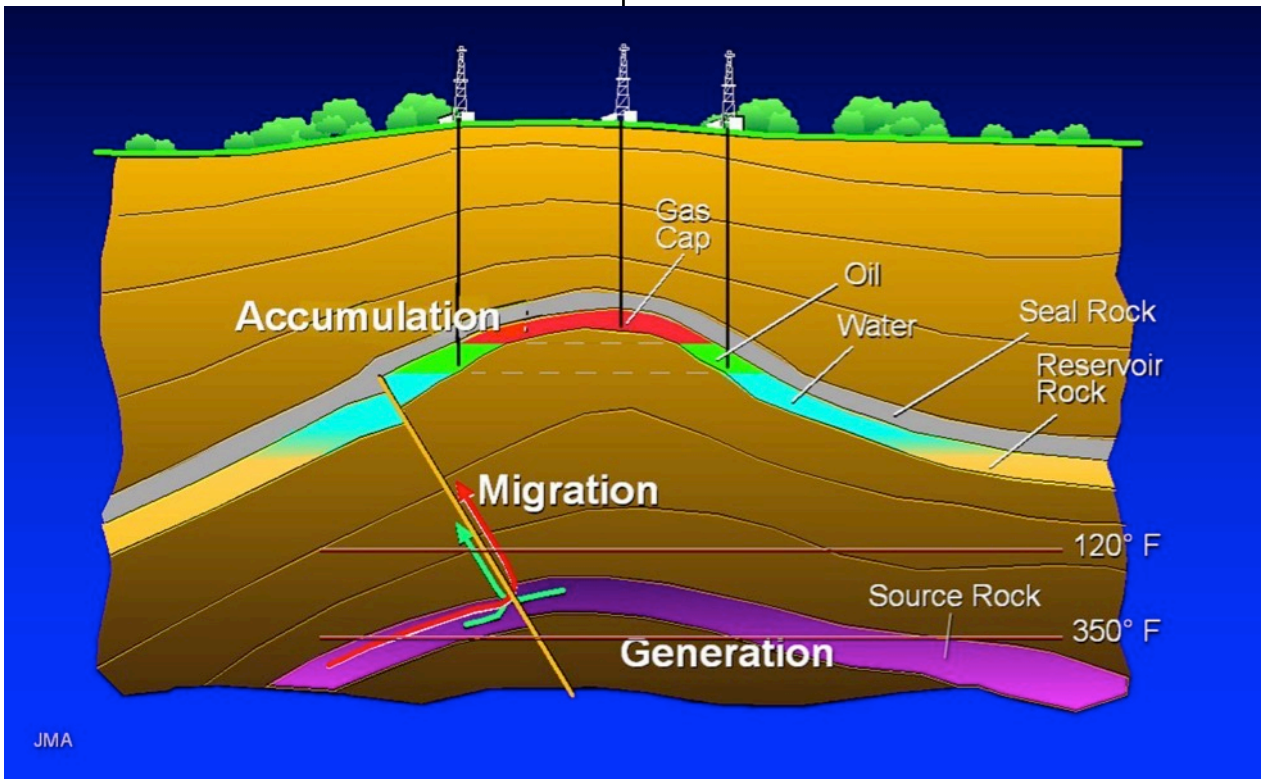
The academic geologist sees…

- deposition of strata
- folding
- faulting
- uplift & erosion

The petroleum geologist looks for…

- source rocks (organic rich)
- migration pathways
- reservoirs
- traps & seals

Understand-ing Earth systems



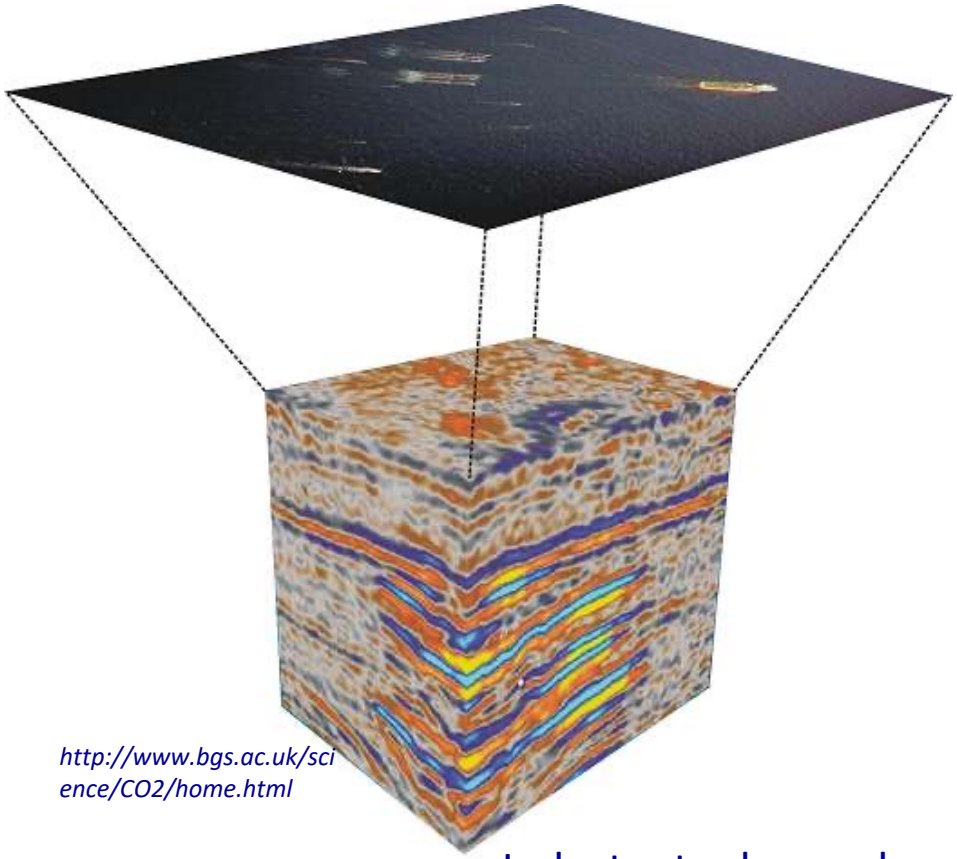
Finding oil & gas

Source: petroleumsupport.com/reservoir-system-to-accumulate-hydrocarbon.html/petroleum-system/

Academic and petroleum geologists use basically the same tools…

Geophysics (remote)

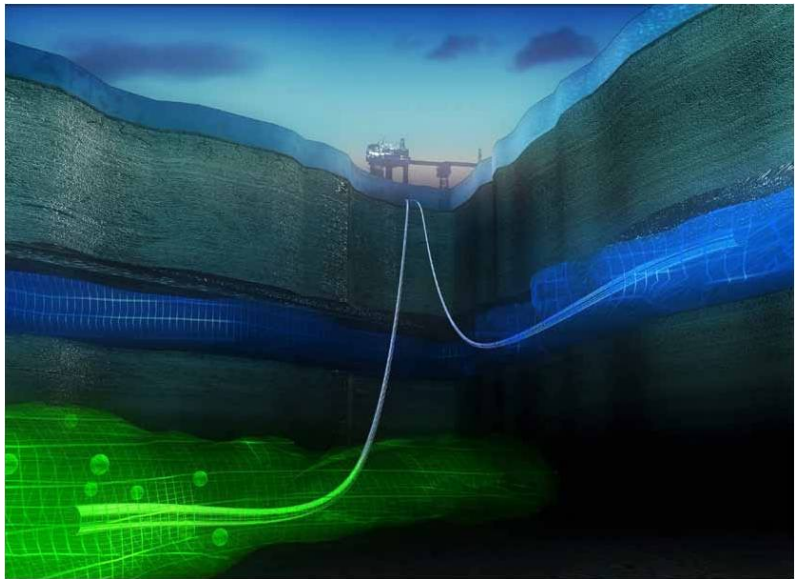
- Gravity & magnetic fields
- Seismic data (2D & 3D)



http://www.bgs.ac.uk/science/CO2/home.html

Geology/geochemistry (samples)

- Sediment cores
- Drillsites/wells



Source: seriousgamesmarket.blogspot.it/2010/09/serious-games-as-oil-drilling-3d.html

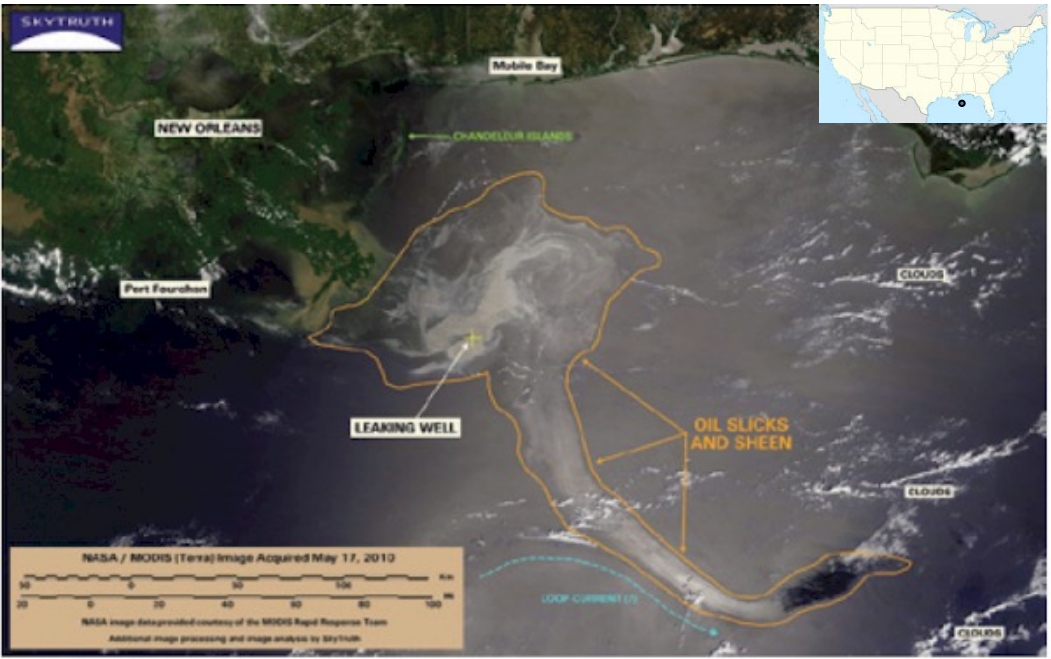
Industry tools are almost always bigger & better
(with eventual benefits to science)

corresponding risks…

Blowout = uncontrolled release of hydrocarbons after pressure control systems fail

Deepwater Horizon drilling rig (semi-submersible), Gulf of Mexico, April 20 2010 : blowout

Sources: eijournal.com/2011/deepwater-horizon-revisited



Explosion, fire, 11 deaths, massive oil spill…

Source: www.greenpeace.org - Shrimp boat

Rig: GSF Adriatic IV Jack-Up
Date: 10 August 2004
Location: Temsah, Mediterranean Sea, Egypt
Operator: Platform run by Petrobel

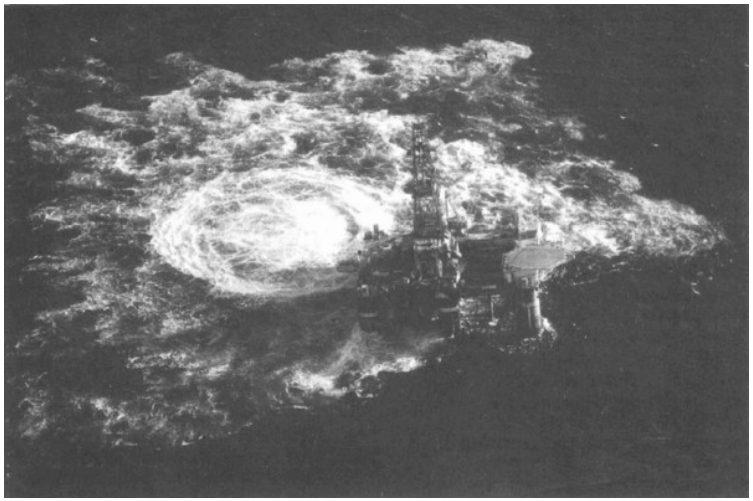
GSF Adriatic IV at Temsa before the blowout

Blowout → explosion, fire, rig sank
(no loss of life)

Source: home.versatel.nl/the_sims/rig/index.htm

Rig: Smedvig West Vanguard Semi-Sub
Date: 06 October 1985
Location: Haltenbanken, Norwegian Shelf
Operator: Statoil

Blowout, explosion, fire, 1 death (missing);
rig eventually restored



Source: home.versatel.nl/the_sims/rig/index.htm

Rig: Petromar V Drillship
Date: 27 Aug 1981
Location: Off Natuna Island, South China Sea
Operator: Mobil

Several dozen incidents (mainly blowouts) since 1964 – every year or so

Source: home.versatel.nl/the_sims/rig/index.htm

Fine prima parte