Università di Trieste
LAUREA MAGISTRALE IN GEOSCIENZE
Curriculum Geofisico
Curriculum Geologico Ambientale

Anno accademico 2015 – 2016

Geologia Marina

Parte I

Modulo 6.1 Ricerca e Attività Economiche Offshore / Offshore Research and Economic Activities

Docente/Lecturer: Daniel PRAEG
OGS & Géoazur (Nizza)

.....

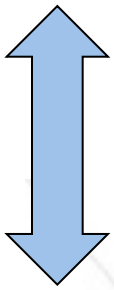
Two ways to see the world :

Pure Research (Natural SCIENCE)

- Exploring the 'blue planet' - 71% oceans
- Onshore geology dominated by submarine deposits
- 'No geology without marine geology' (Kuenen 1958)
- To understand *how the Earth works* (in the past, present and future), we need to study what goes on in and beneath the oceans over time

Applied Research (Natural R€$OURC€$)

- Using the seabed (for cables, pipelines, platforms…)
- Exploring for opportunities (solid, liquid & gas)
- All offshore activities require some understanding of how the Earth works, for exploration/exploitation
- In turn, an important driver for pure research activity (both technologically and financially)



Sources: Wikimedia commons

➢ Working at sea is expensive - vessels cost 10,000-100,000€/day

OGS Explora: a publicly-funded research vessel

- acquired by OGS in 1989, only ocean-going ship owned by a research institute
- scientific campaigns worldwide (from Antarctica to the Arctic)
- € 10^6/year from Italian government for use & maintenance

OGS Explora *in Galway harbour, Ireland, 2009 (International Polar Year campaign)*

Operating costs offshore : €15-25,000/day In port : €6-10,000/day)

Secondary activity: commercial service work

- contracted to offshore companies (e.g. Fugro)
- geophysical/geological surveys (e.g. cables, exploration…)
- return to origins: originally a Geco-Prakla seismic boat (1973-1989)

OUTLINE

- The Law of the Sea – who owns what?

discussion / pause

- Offshore (geo-) economic activities
  - Submarine cables & pipelines
  - Renewable energies (wind farms)
  - Seabed mapping (a service industry)
  - Nearshore sand and gravel mining
  - Deep sea mineral mining
  - Bio-prospecting (sub-seabed)
  - **Hydrocarbon exploration**
  - Methane hydrates?

Seabed installations, old & new

Natural resources, nearshore to deep-sea

- Career paths for (potential) young marine geoscientists

what kind of activity might interest you?

WHO OWNS THE SEAS?

Roman Empire : *Mare nostrum* (Mediterranean), based on control of surrounding coasts; seas not territorial, i.e. not 'owned'

Republics of Venice, Genoa : local forms of *Mare clausum*: in parts of Mediterranean, control of shipping by military force

15-16th centuries : *Mare clausum* – Age of Discovery, Iberians claim vast areas of globe --> conflict with French, Dutch, British…

17th century : *Mare liberum* (Hugo Grotius 1609) →

> the High Seas are the *common property of all…*

18th century: codified by Bynkershoek in *De dominio maris* (1702) :

> coastal waters = one cannon shot = 3 nautical miles

Source of images: Wikimedia commons

Nautical Miles

Earth divided into 360°, equator to pole 90°
Each degree divided into 60 minutes

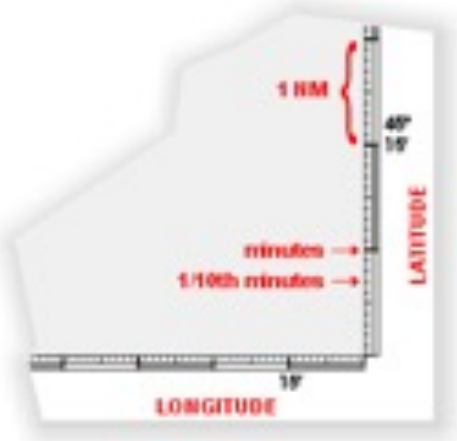
1 nautical mile = 1 minute of latitude
(= 1843 m at the equator,
1861 m at the poles,
mean length 1852.216 m)

1 International Nautical Mile = exactly 1852 m

Source of image: Wikimedia commons

http://moblog.whmsoft.net

http://www.sailingissues.com

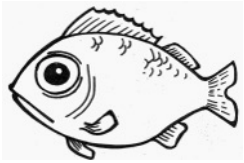


http://www.coastalnavigation.com/

WHO OWNS THE SEAS?

19-20th centuries (ever bigger cannons …) ⟶

- *Mare liberum* respected by most nations – 'territorial' seas to 3 nm, Spain to 6 nm (although control of high seas disputed during wars)
- Growing interest in *marine resources* (mineral, but mainly biological)



1945 : something new (from the USA)

- Presidential Proclamations (2667, 2668) established jurisdiction and control of natural resources & fisheries in high seas adjacent to the coastline, across the 'Outer Continental Shelf'

See http://www.trumanlibrary.org/proclamations/index.php

- Many nations responded, extending their territorial waters to 12 nm (eastern Europe, Middle East) or even to 200 nm (Peru, Ecuador, Chile)

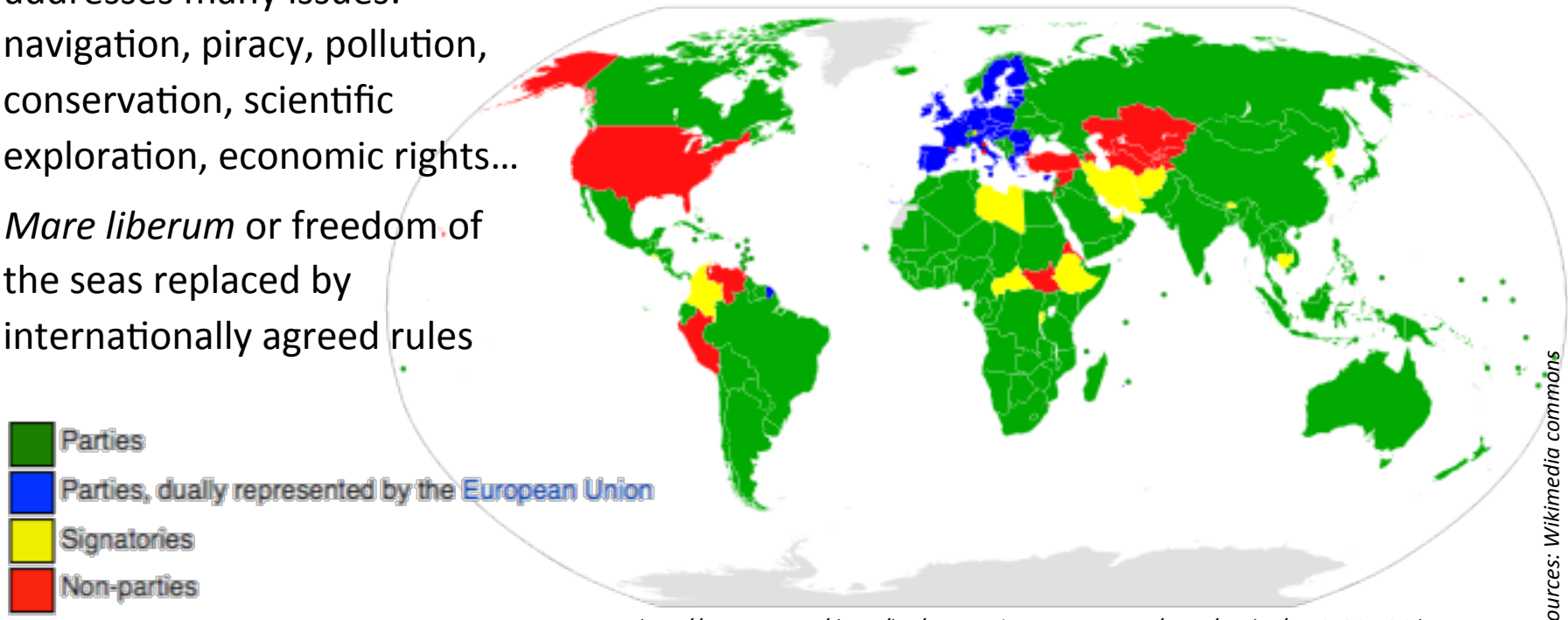
1947: 1st offshore oil platform (Gulf of Mexico, <6 m of water, but out of sight of land)

1949 : International Law Commission of the United Nations, 1st session

> added to agenda the question of determining legal extent of offshore waters

United Nations Convention on the Law of the Sea = UNCLOS

- based on a series of international conferences from 1958-1982
- convention in force since 1994 (when 60th signatory ratified)
- not a law, but a treaty currently ratified by 166 parties plus the European Union
- one of the longest treaties in history – 320 articles + 9 annexes
- addresses many issues: navigation, piracy, pollution, conservation, scientific exploration, economic rights…
- *Mare liberum* or freedom of the seas replaced by internationally agreed rules



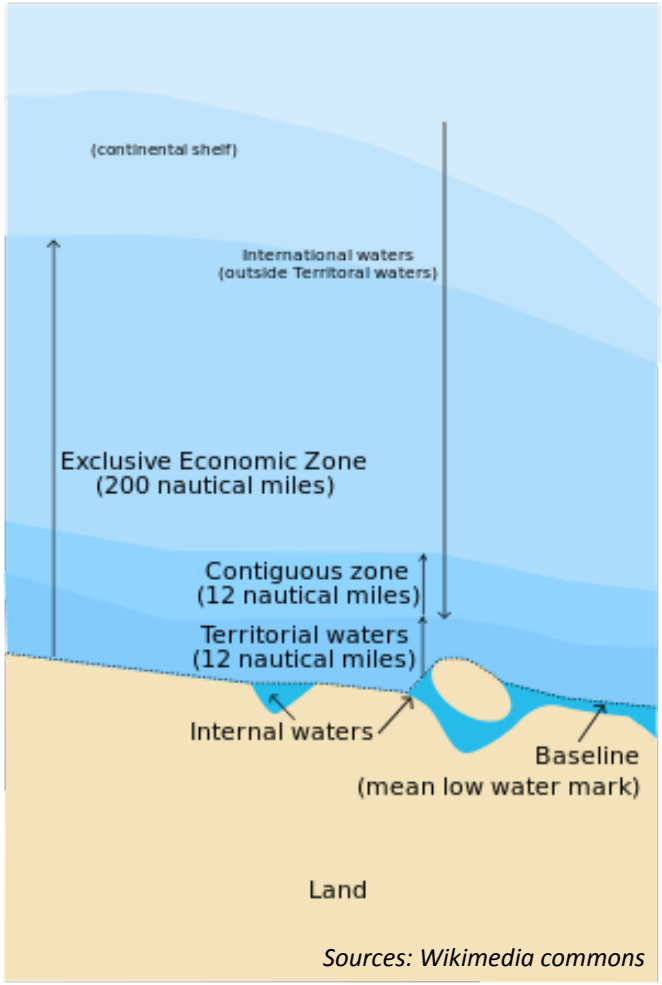
http://www.un.org/depts/los/convention_agreements/texts/unclos/UNCLOS-TOC.htm

Sources: Wikimedia commons

UNCLOS & CONTROL OF NATURAL RESOURCES

- extends national jurisdiction of biological and mineral resources seaward to the edge of 'the Continental Shelf':
  - *Article 77.1 : The coastal State exercises over the continental shelf sovereign rights for the purpose of **exploring it and exploiting its natural resources**.*
  - *77.4: The natural resources referred to … consist of the **mineral and other non-living resources** of the seabed and subsoil together **with living organisms belonging to sedentary species**… unable to move except in constant physical contact with the seabed or the subsoil.*

- creates a series of defined maritime zones, *Exclusive Economic Zone* (EEZ) extends to 200 nms, beyond which is the '*Continental Shelf*' …
- beyond the Shelf, international jurisdiction and management of the resources of *The Area* (Part XI)



Sources: Wikimedia commons

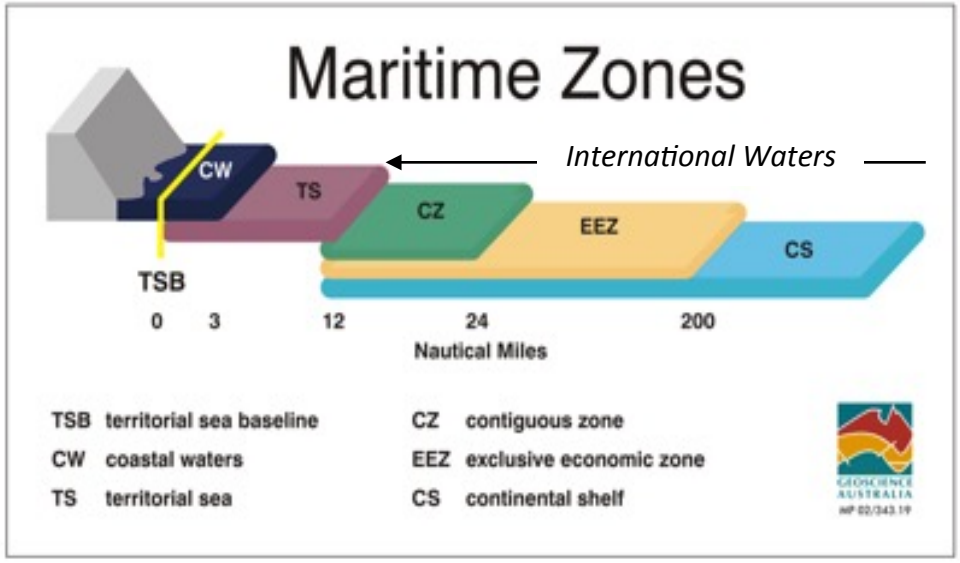
UNCLOS MARITIME ZONES

- Baseline = low water line (or straight line between headlands)
- 3 nm = Coastal Waters (one cannon shot…)
- 12 nm = Territorial Seas (right of 'innocent passage')
- 24 nm = Contiguous Zone (zone of 'hot pursuit')
- 12-200 nm = Exclusive Economic Zone (EEZ)
- 12-350 nm *or more* = Continental Shelf

National control of resources in & beneath the seas

National control of resources at & beneath seabed

Sources: Wikimedia commons



Relationship of maritime features, limits and zones

- Beyond: *The Area*

Internationally managed

The Exclusive Economic Zone (EEZ)

- Simple definition: extends up to 200 nm offshore (from a baseline)
- International waters, in which coastal nation has rights to all resources in and beneath the seas
- Contains 99% of world's fisheries, and >80% of hydrocarbon reserves

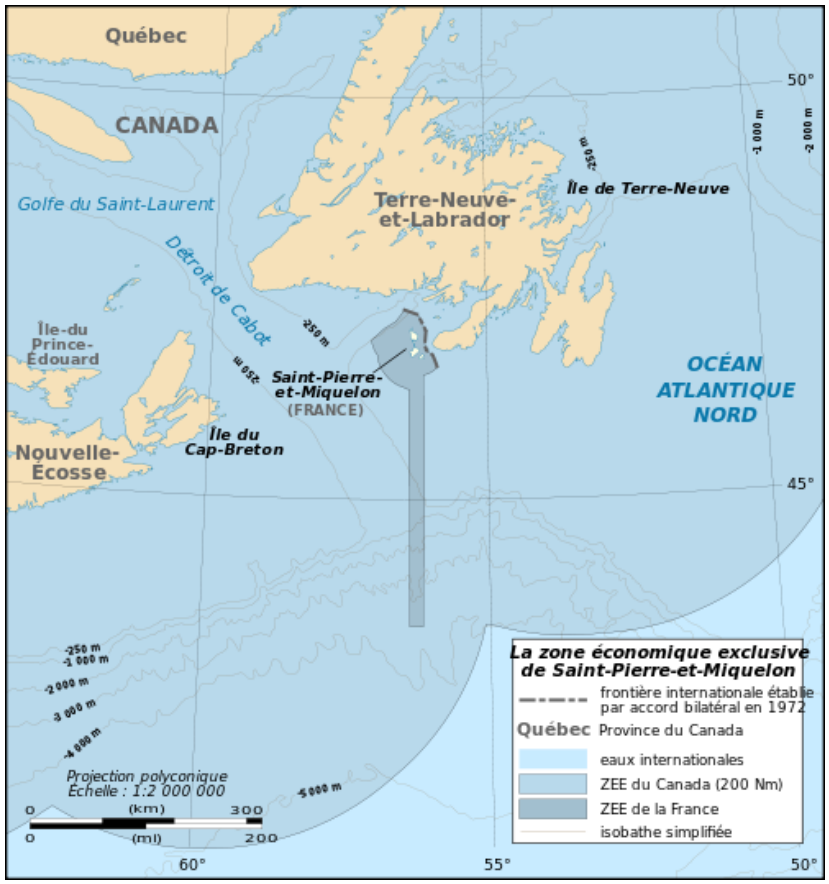
  (see http://www.eoearth.org/view/article/156775)

Sources: Wikimedia commons

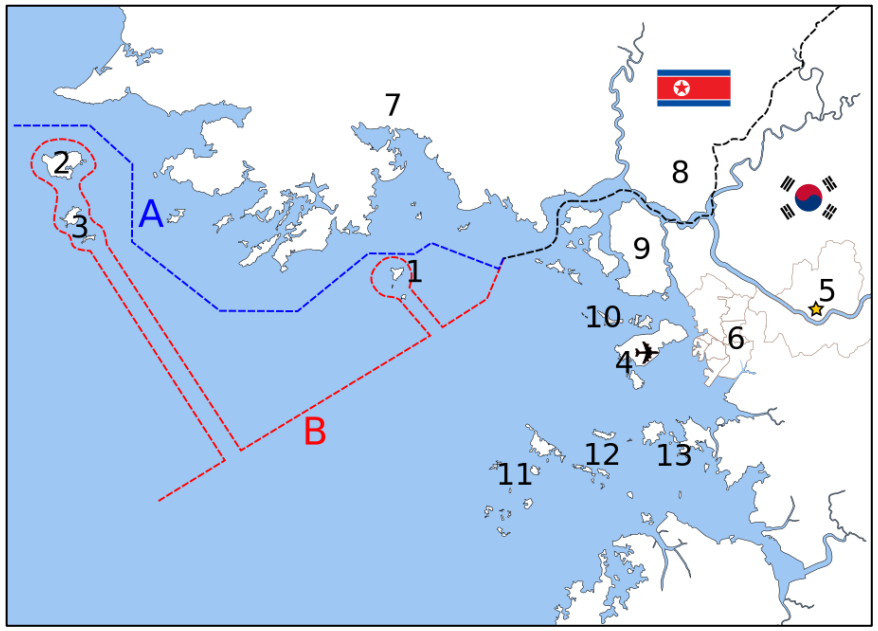
Nonetheless, there are disputes

- Where nations are <400 nm apart, they must agree (or not) on median lines
- *International Tribunal for the Law of the Sea* (Hamburg) - separate from UN

Examples of EEZ disputes :



Canada vs France (Saint-Pierre-et-Miquelon)
RESOLVED



The two Koreas (unresolved…)

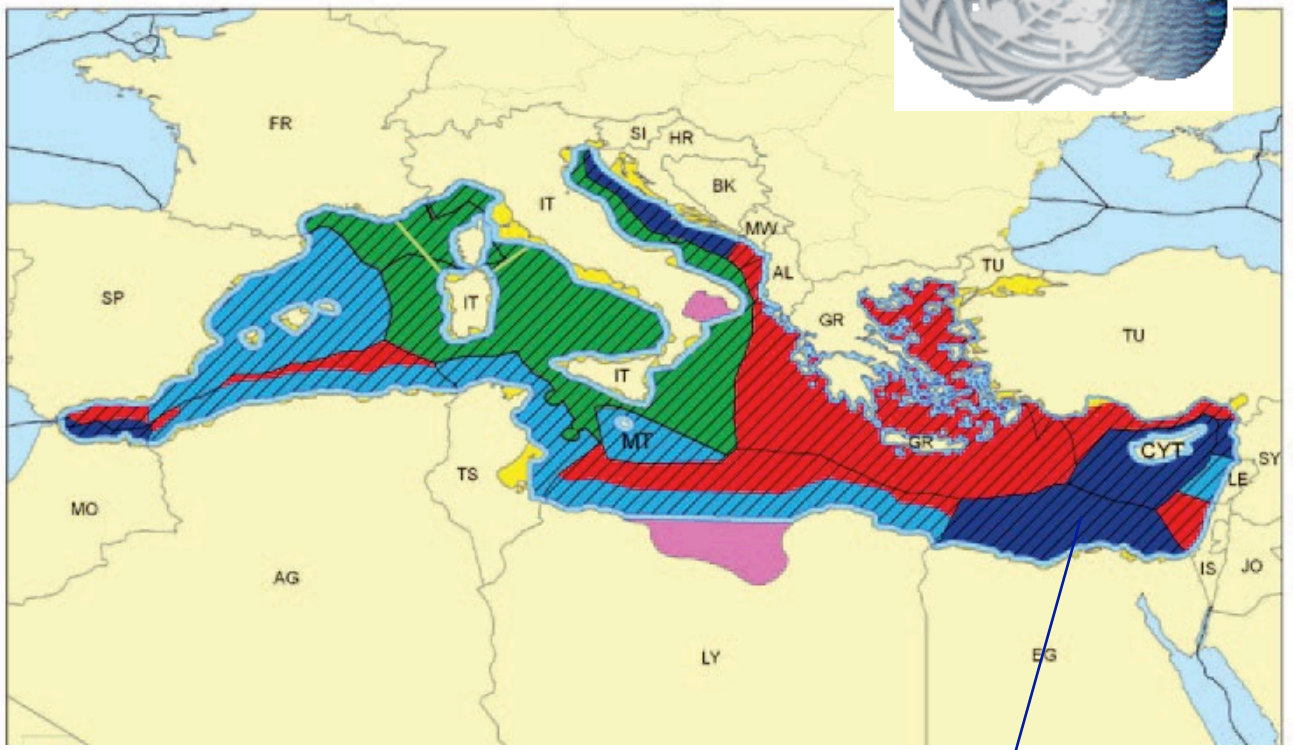
A: Northern Limit Line, created by the United Nations in 1953[18]

B: "Inter-Korean MDL in the Yellow Sea", declared by North Korea in 1999

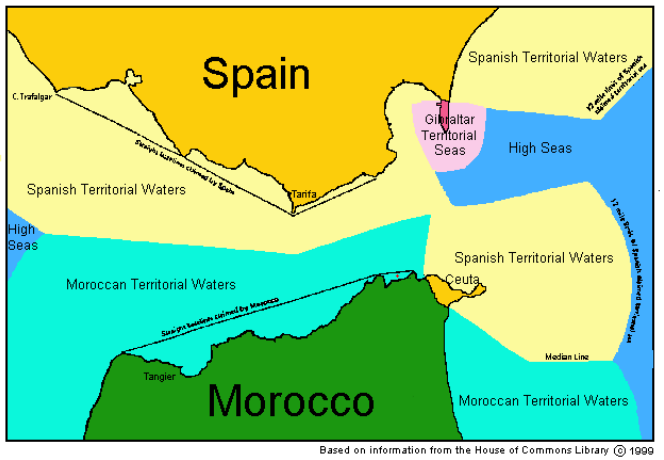
Sources: Wikimedia commons

Mediterranean EEZs

- Inland waters
- Territorial sea
- Fishing zone
- High seas
- Historical Bay
- EEZ
- Ecological protection zone
- Sanctuary of cetaceans
- Freedom of navigation



Example:



One possible representation of Mediterranean maritime jurisdictions
(Suarvez de Vivero 2007) (http://www.guidopicchetti.it - UNEP-MAP, The Mediterranean Sea)

Consequence: increasing difficult for research vessels to conduct international surveys in eastern Med (e.g. myself offshore Egypt in 2007, Greece-Turkey 2014)

Sources: Wikimedia commons

A Mediterranean EEZ continuing dispute :

http://en.wikipedia.org/wiki/Croatia%E2%80%93Slovenia_border_disputes

Border dispute in the Gulf of Piran.

Dragonja's original flow, according to Croatia

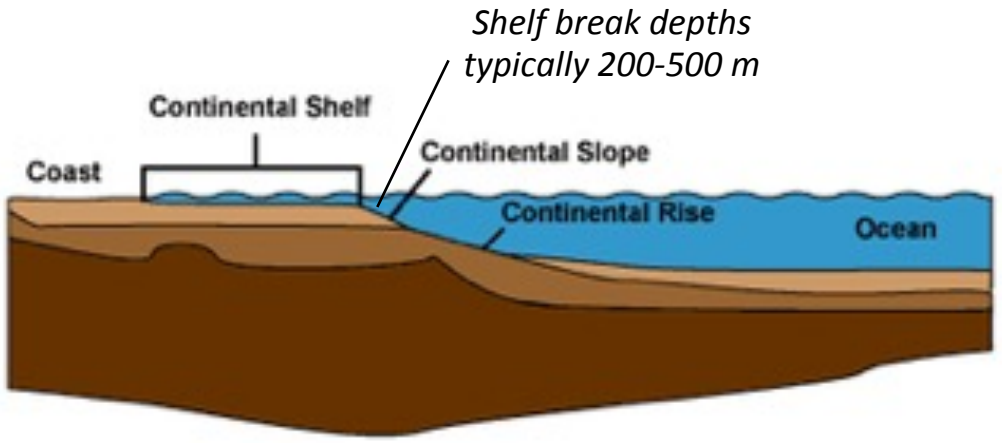
The artificial canal of St. Odoric

Slovenian claimed border

Since 1992, based on differing interpretations of UNCLOS and Slovenian wish for access to International waters)

Note that EEZ disputes do not involve geology

The 'Continental Shelf'

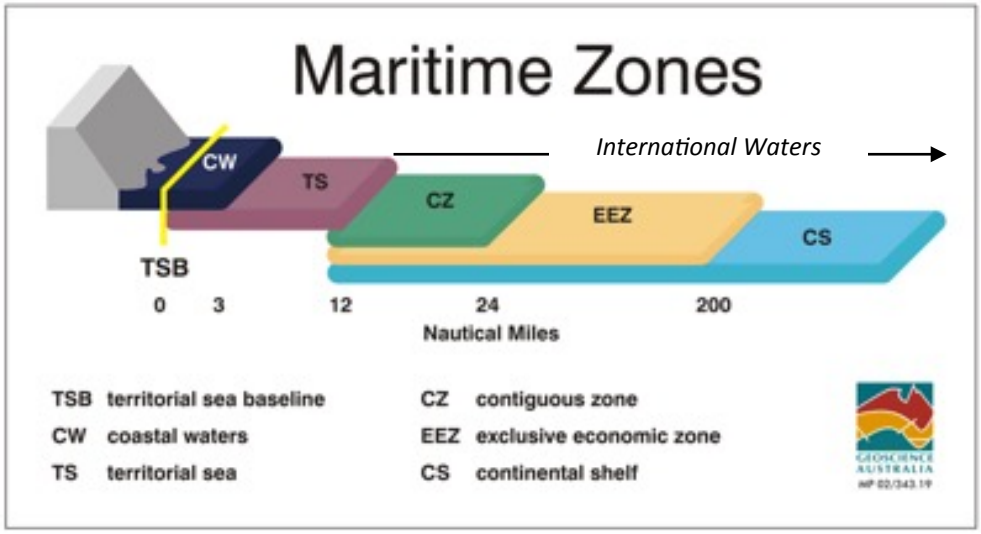


- To a geologist, the continental shelf (*la piattaforma continentale*) is a physiographic feature, based on geomorphology and geology

- For UNCLOS, the continental shelf mixes geology with a legal concept - a 'natural prolongation of land areas' in which a coastal nation has exclusive rights to mineral and biological resources (Article 76)

- The Continental Shelf lies beneath the EEZ (200 nm) and extends past it as the 'Extended Continental Shelf' (ECS) to *at least* 350 nm

- ECS may extend well beyond the geological platform, but geology is still used to define it…



'Extended Continental Shelf' Limits Defined

UNCLOS Article 76 :

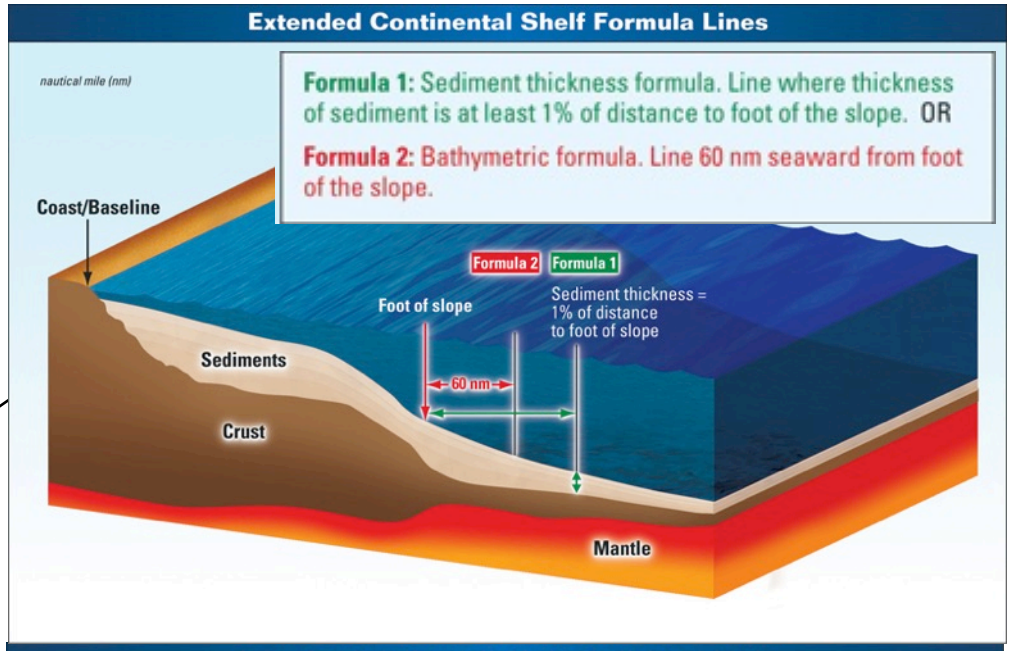
- criteria of geomorphology and geology used to define…

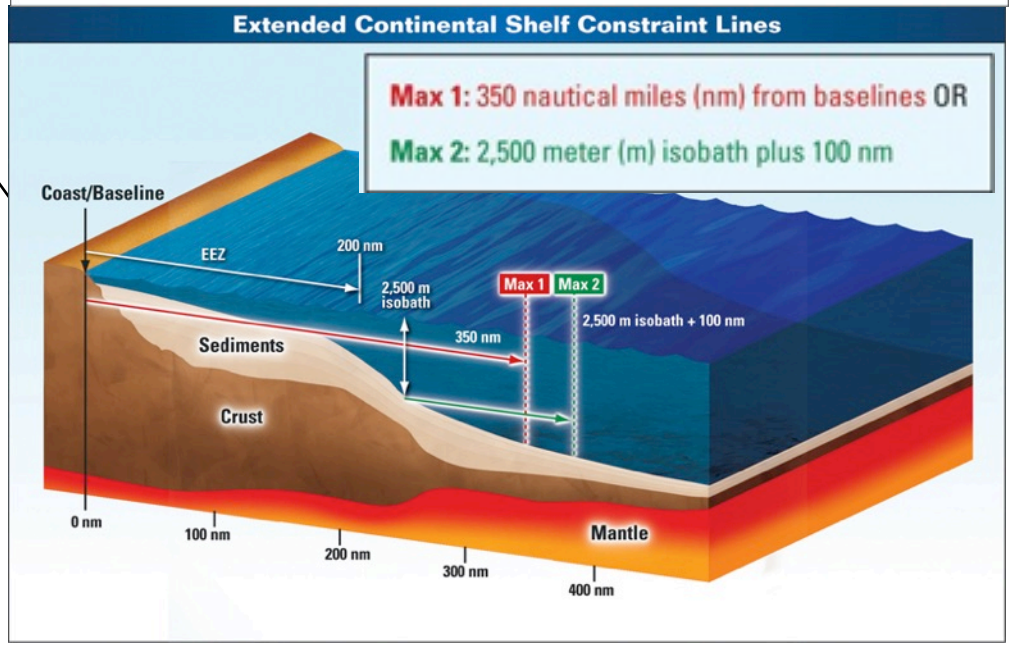
Formula lines
(maxima?)

Constraint lines
(minima?)

Each in any combination; used together to define (maximise) the Extended Continental Shelf (ECS)

US Extended Continental Shelf Project, http://www.continentalshelf.gov/)



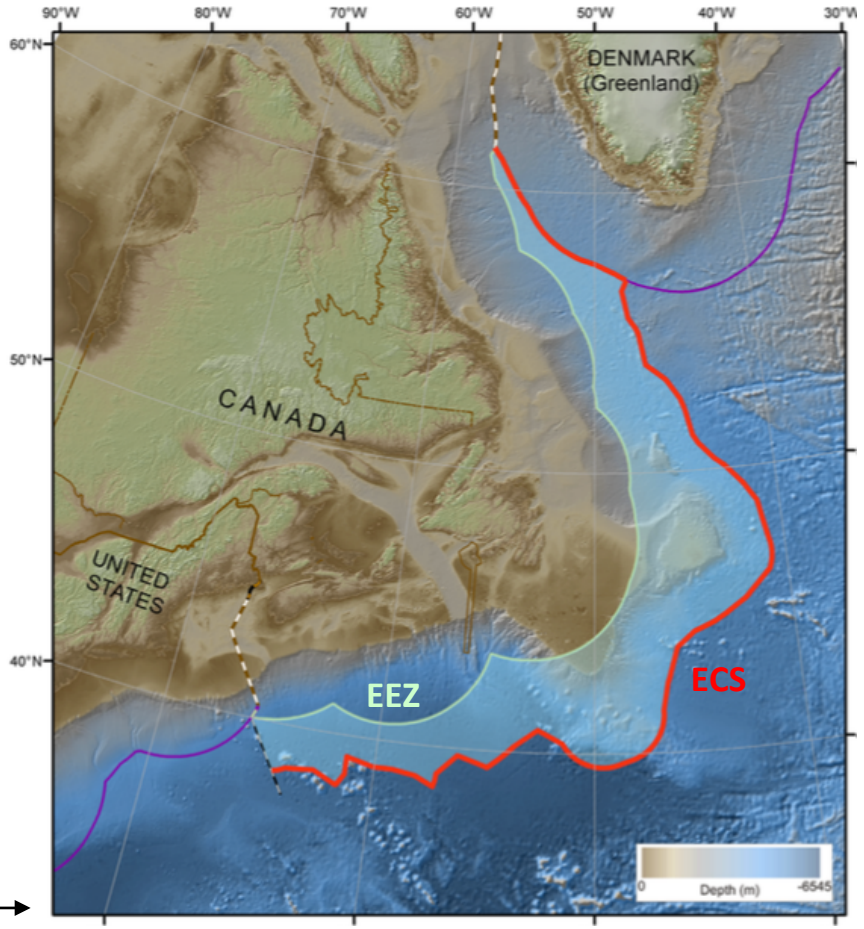


Extended Continental Shelf claims

- Based on submissions to the *UN Commission on the Limits of the Continental Shelf* (CLCS), within 10 years of ratifying UNCLOS
- Require supporting information on:
  - bathymetry (multibeam sonar data)
  - sediment thickness (seismic profiles)
- Preparation of 'Law of the Sea claims' can mean national funding for marine geoscience (e.g. USA, Canada, Australia…)
- OGS Explora has been contracted to acquire data for Canada's ECS program

Partial submission of Canada to the CLCS regarding its continental shelf in the Atlantic Ocean, 2013

(precedes submission on Arctic shelf)



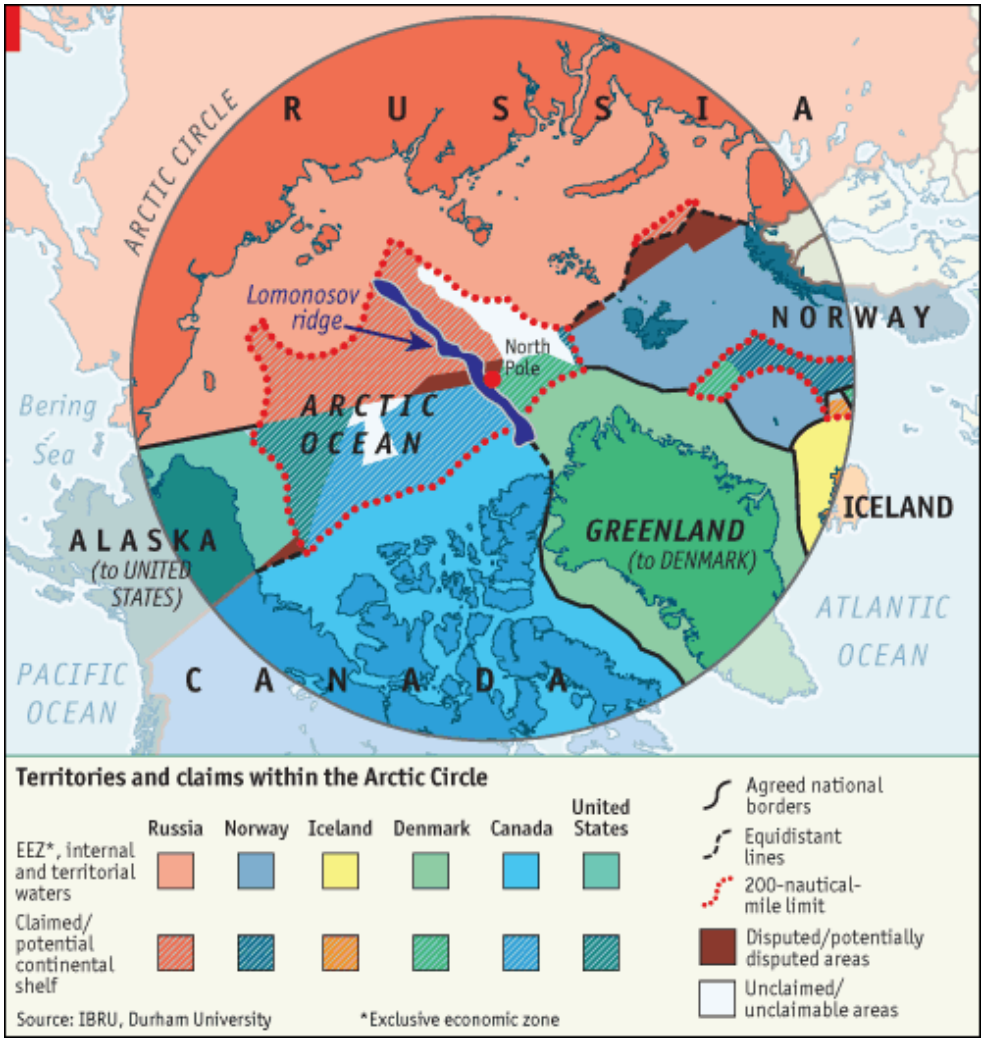
Source: http://continentalshelf.gov/

Submitted limits of the 'Extended Continental Shelf' of Atlantic Canada

Extended Continental Shelf claims also lead to disputes…

'The race for the Arctic'
(The Economist, 14 May 2009)

- A race for control of resources, arbitrated through the UN via submissions to the CLCS
- A slow race: within 10 years of ratifying UNCLOS, many still in preparation (joined at different times, or not joined yet – USA)
- Arctic disputes have made the news (e.g. North Pole), but over relatively small areas…
- Versus national jurisdiction of almost the entire Arctic Ocean (and its resources)

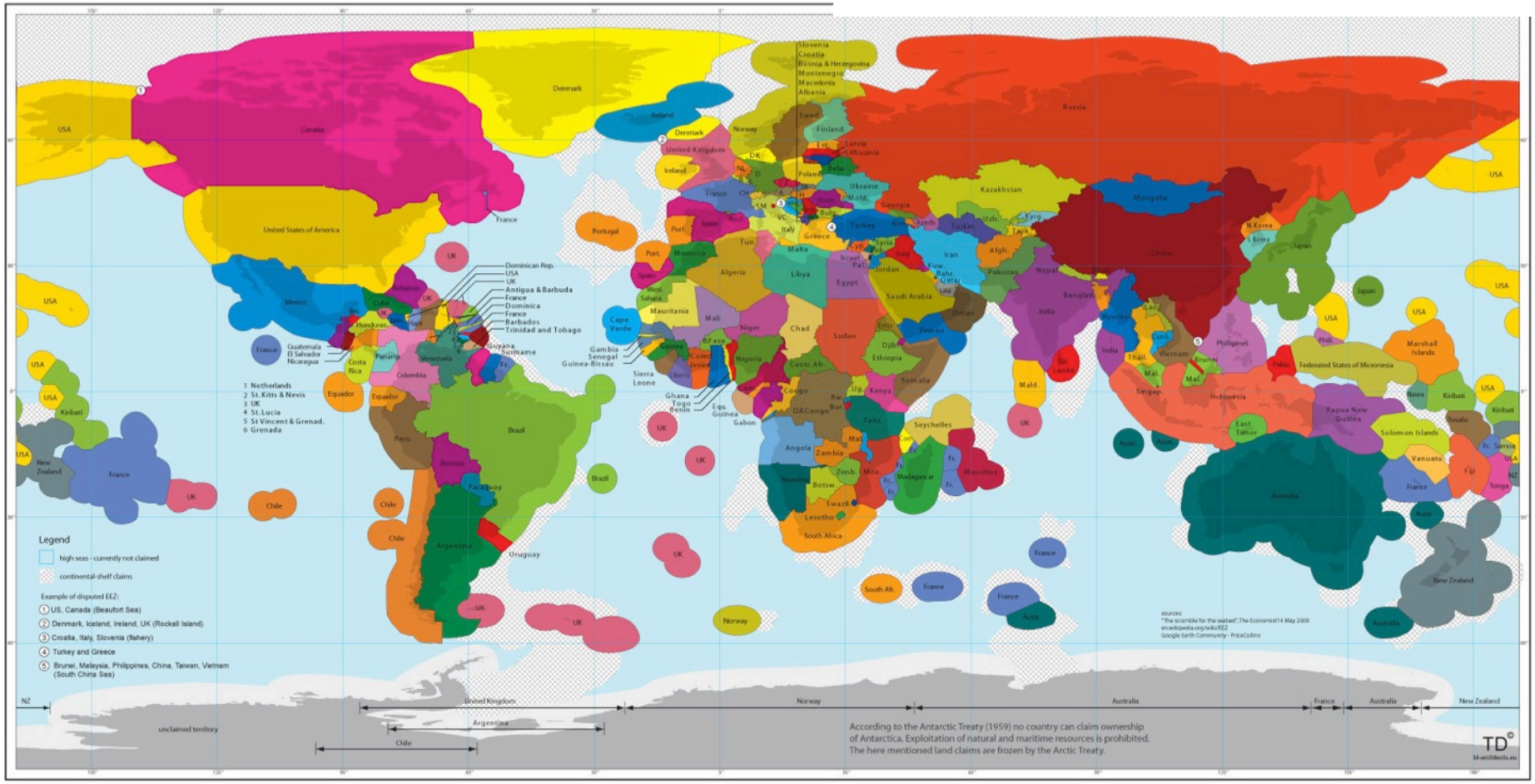


Source: The Economist, 14 May 2009

One way to see EEZs :

'a rock in the ocean = 430,000 km² exploitable surface offshore' (Theo Deutinger)

Source: http://td-architects.eu (2009)



EEZs represent approximately 1/3 of the oceans (or 1/4 of the planet)

an 'invisible global chessboard' for control of world's natural resources

Beyond the ECS and national jurisdiction lies…

‘The Area’ = more than 50% of the Earth’s surface

- **International jurisdiction**

> *UNCLOS Preamble & Part XI :*
>
> …the seabed and ocean floor and the subsoil thereof, **beyond the limits of national jurisdiction**, as well as its resources, are **the common heritage of mankind…**

- ‘freedom of the seas’ replaced by the international management of marine resources
- called for wealth and technology transfers from developed to undeveloped nations

International Seabed Authority (ISA), Jamaica

founded 1994

Opposed and weakened by developing nations e.g. USA (‘market forces…’)

ISA retains control over geo-resources (mining)

Being (con)tested in regard to bio-prospecting

Publications: T. Scovazzi (2004, 2006), Prof of Intl Law, Milano-Bicocca

Pausa

Offshore (geo-) economic activities

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

Seabed installations, old & new

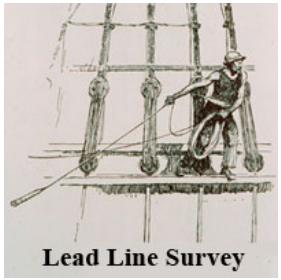
- Seabed mapping (a service industry)
- Nearshore sand and gravel mining
- Deep sea mineral mining
- Bio-prospecting (sub-seabed)
- **Hydrocarbon exploration**
- Methane hydrates?

Natural resources, nearshore to deep-sea

nearshore

deep sea

Submarine Cables (and the need of scientific research)



Oldest (?) offshore economic activity requiring knowledge of geology :

seabed depth, form, composition?

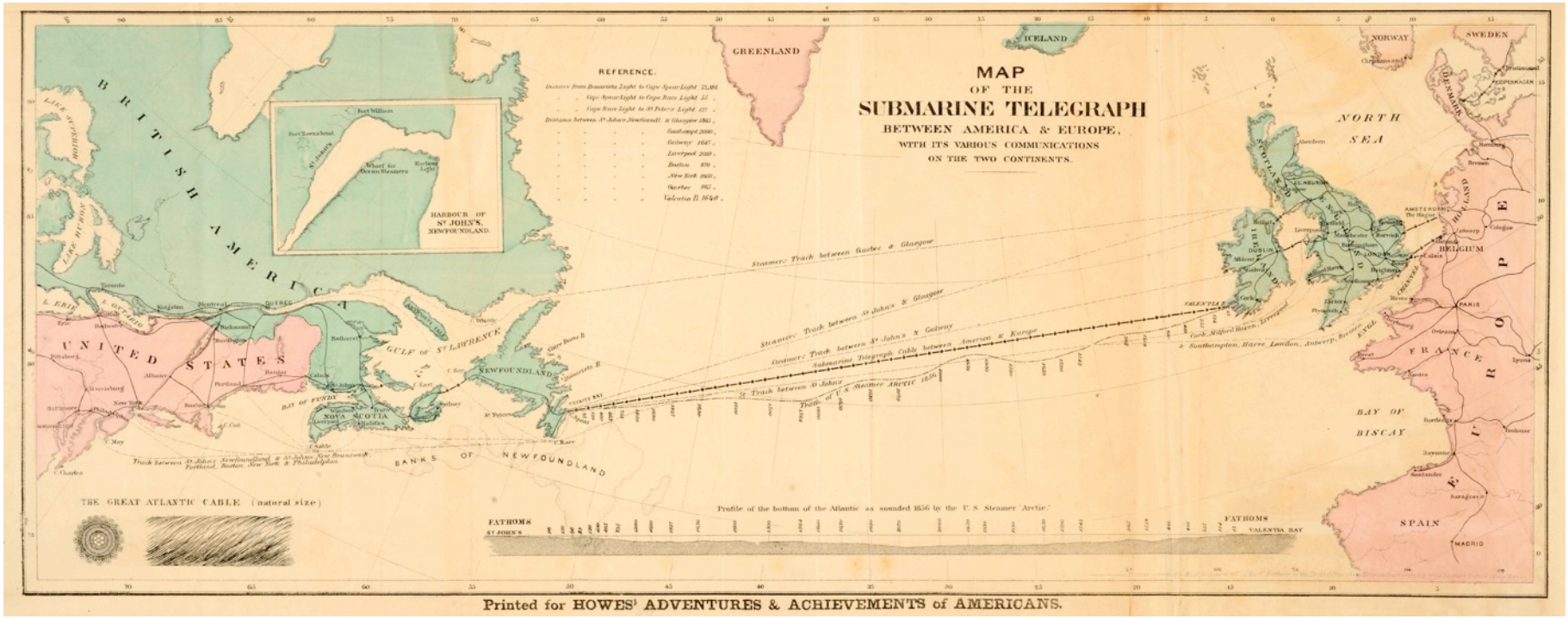
1850-1853 : 1st undersea telegraph cables

UK to France, Ireland, the Netherlands – water depths <50 m

1857-1858 : 1st trans-Atlantic telegraph cable

Ireland to Newfoundland - 3000 km, 4600 km of cable

"...the bottom of the sea between the two places is a plateau, which seems to have been placed there especially for the purpose of holding the wires of a submarine telegraph." (US Navy report 1854)

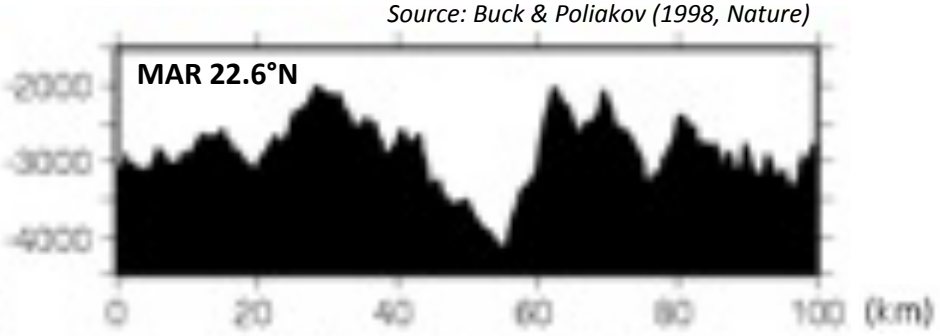


http://libweb5.princeton.edu/visual_materials/maps/websites/thematic-maps/qualitative/telegraph.html

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/

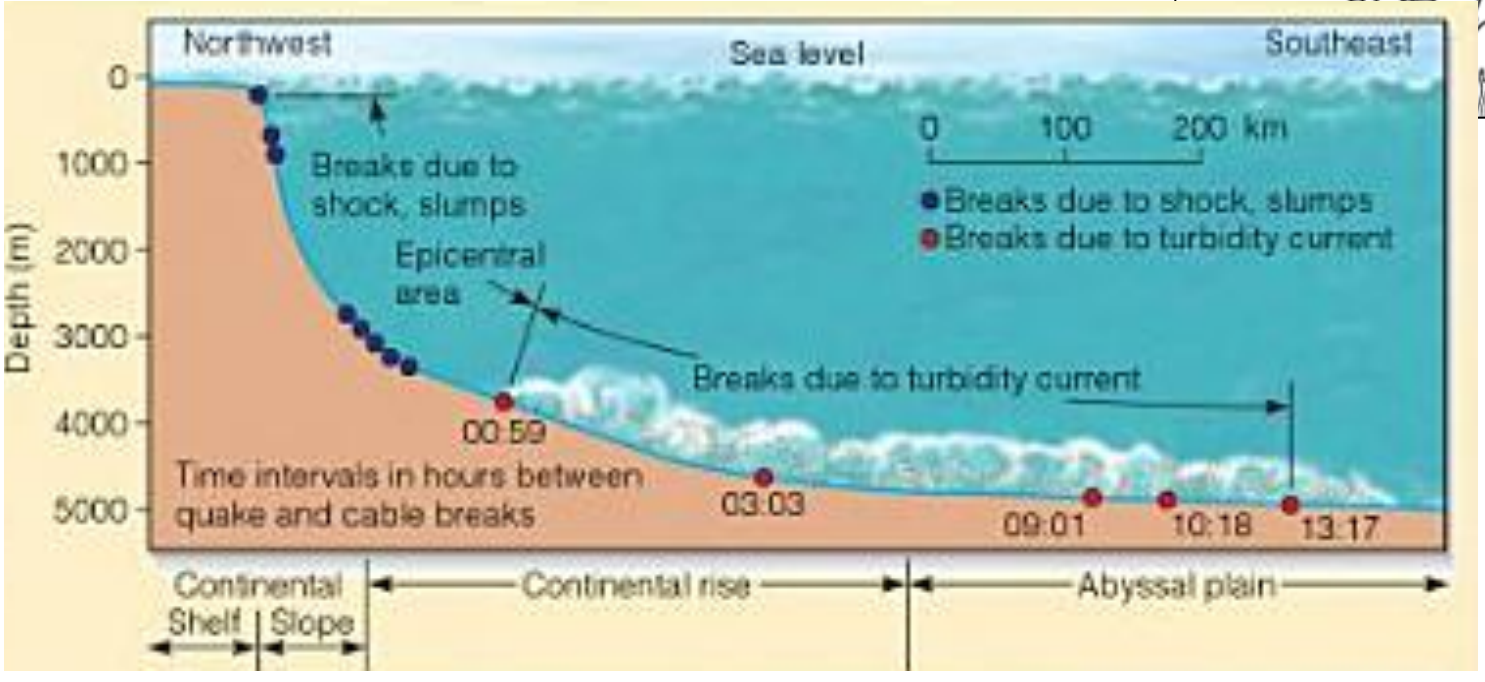
Submarine cable breaks and the advancement of science

Eastern Canada & the Grand Banks earthquake

- 18 Nov 1929, *earthquake* off NS/Nfld (magnitude 7.2)
- Followed by submarine *cable breaks* (12 cables)
- Breaks younger downslope (over 13 hours, 600 km)
- *Landslide* evolved downslope into a *density current*

  (1st direct evidence) - speeds up to 100 km/hr

Source: Heezen & Ewiing (1952, Am J Sci)



Source: Heezen & Hollister (1972) The Face of the Deep

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)

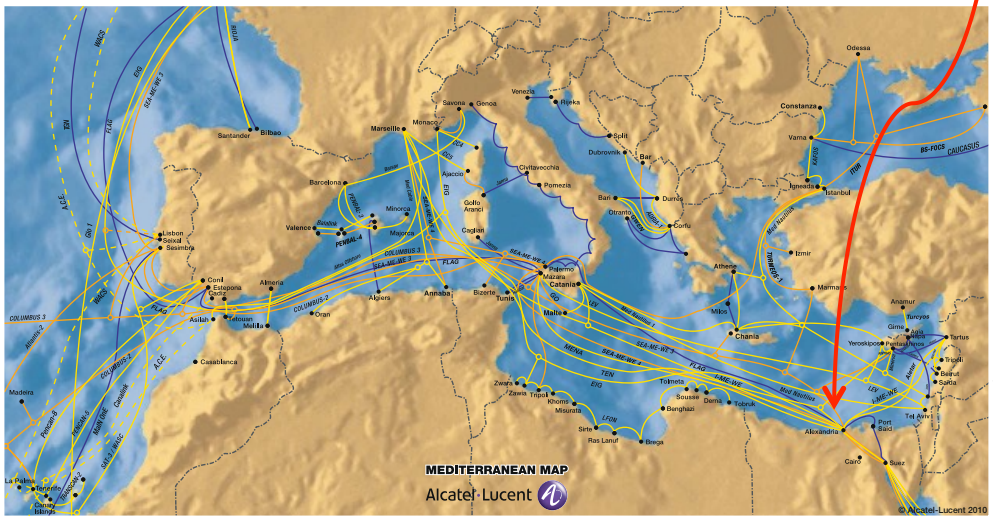
1961: 1st undersea power cable (France-UK)

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

21st century global network of optic cables

- Undersea fibre 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)

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

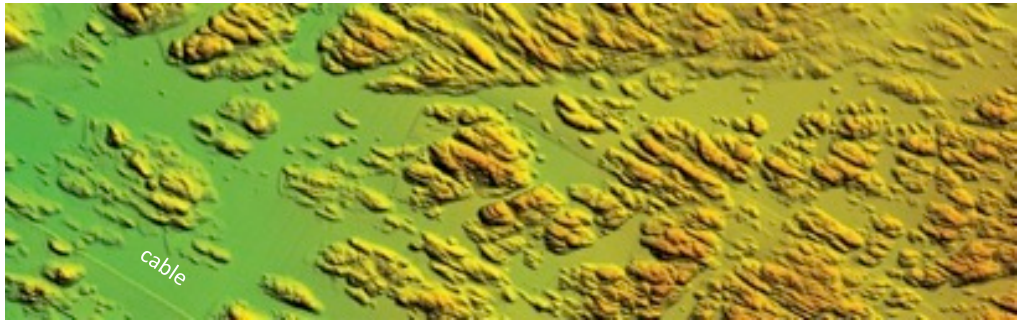
- Sediment sampling (coring and grabs)
- Remotely Operated Vehicles (ROVs)

direct methods

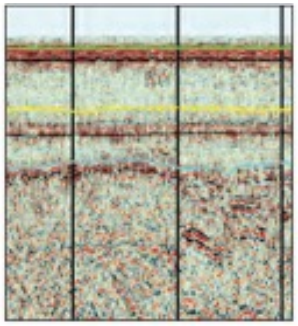
Source: downloads.n-o-s.eu/partners/mmt-ab/

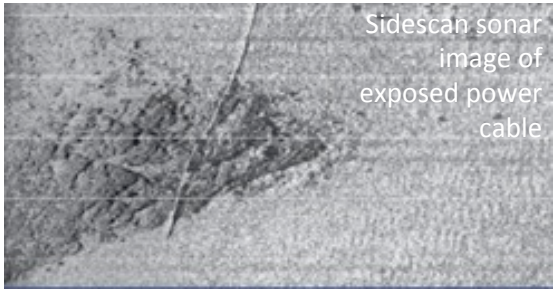
Source: www1.gardline.com

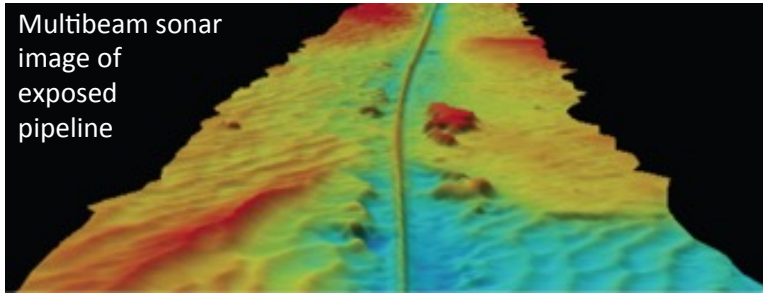
multibeam sonar image



seismic profile







Source: www.osirisprojects.co.uk

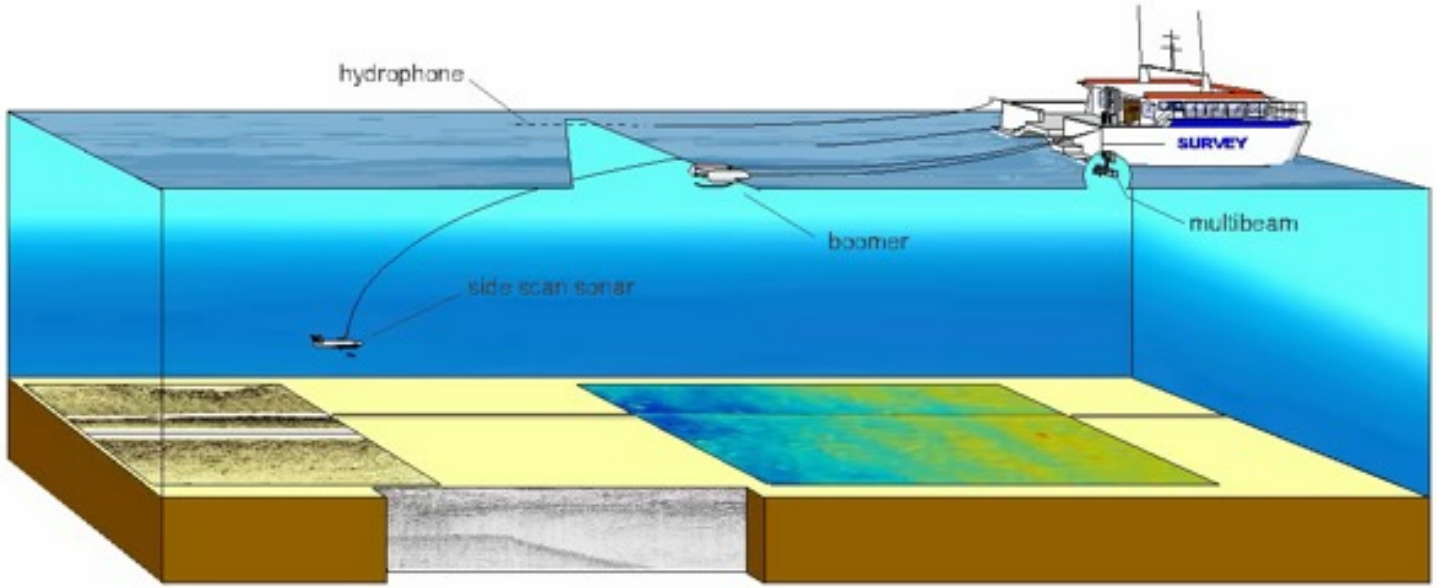
Cable plough

Trenching ROV

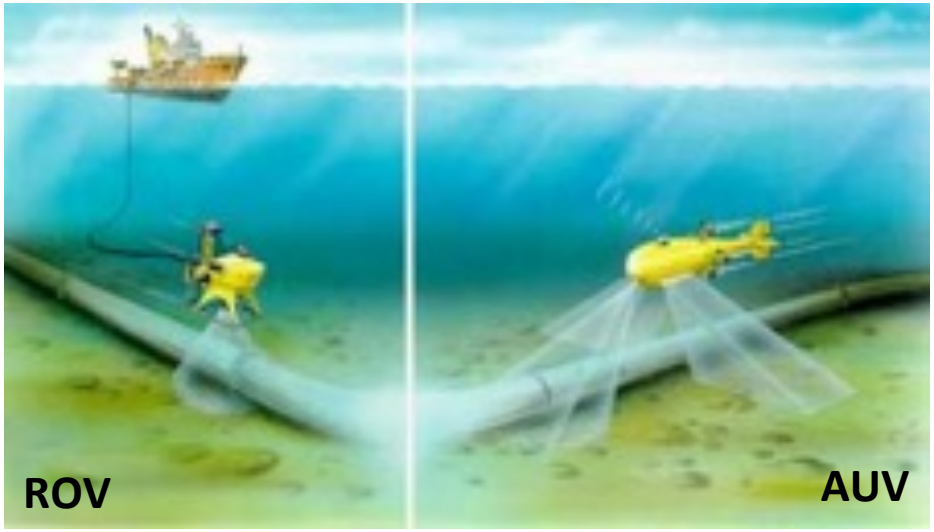
Sources: www.pharos offshoregroup.com

> 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 :

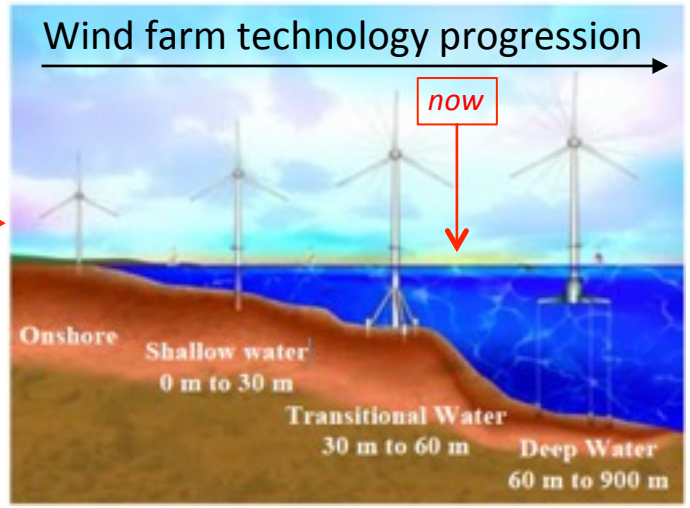
- Remotely Operated Vehicles (ROVs)
- Autonomous Underwater Vehicles (AUVs)

Multi-national offshore industries

Seabed Installations - for Renewable Energies

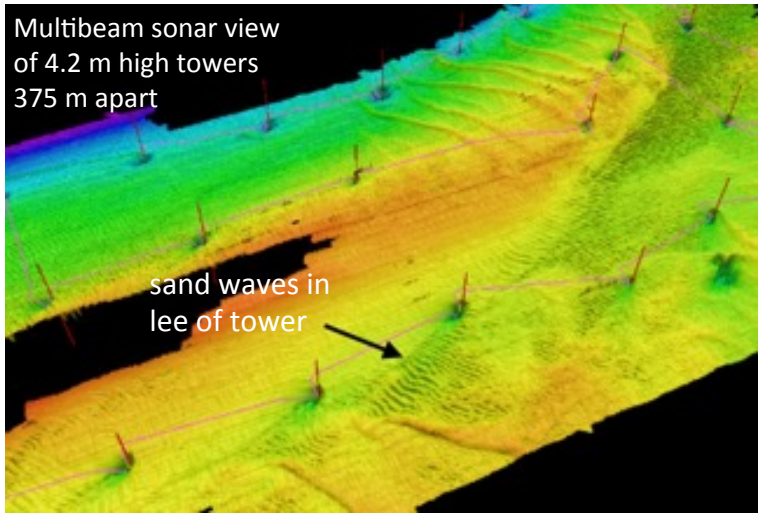
- **Wind**, wave, tide, ocean currents, temperature & salinity differences…

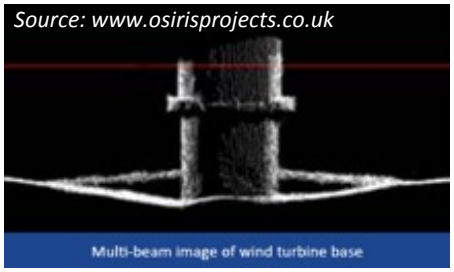
Wind farm seabed installations >40 projects world-wide

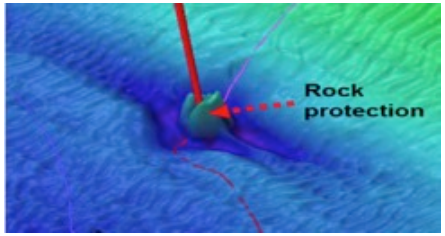


Sources: Musial et al. (2006, OTC 18355)

Different foundations…
all require knowledge of seabed







Seabed mapping

+ monitoring surveys:

- sand wave migration
- scour of foundations

<u>Same companies as cables</u>

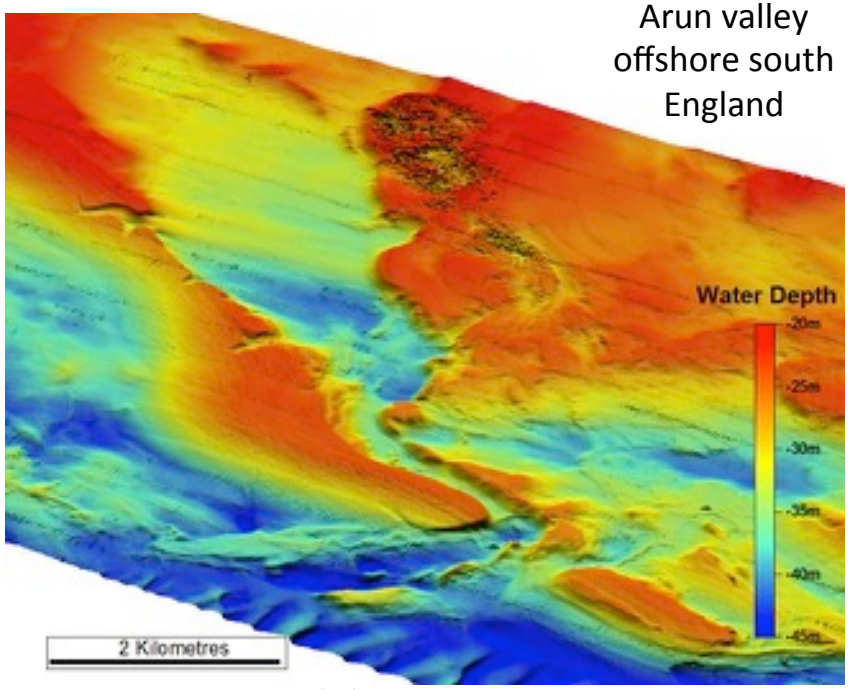
Source: Scroby Sands Offshore Wind Farm – Coastal Processes Monitoring. Cefas, UK, 2006

Seabed Sand and Gravel Mining

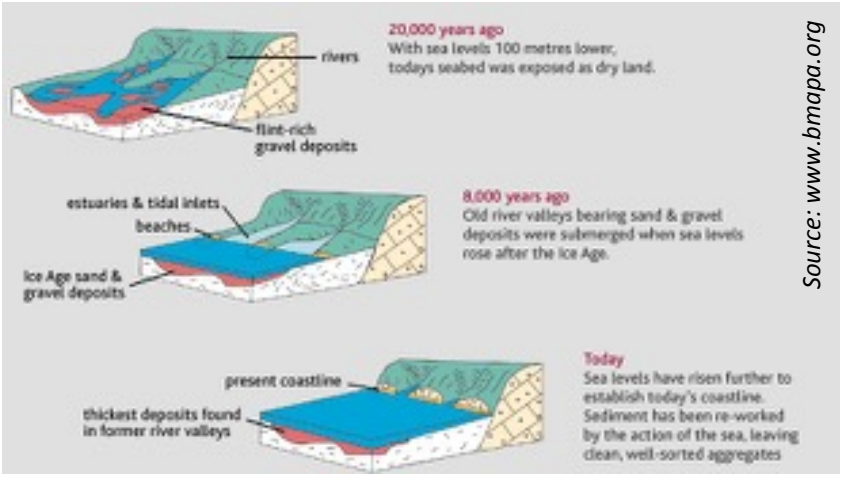
Not very 'glamorous' minerals… but a big business

- 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… →

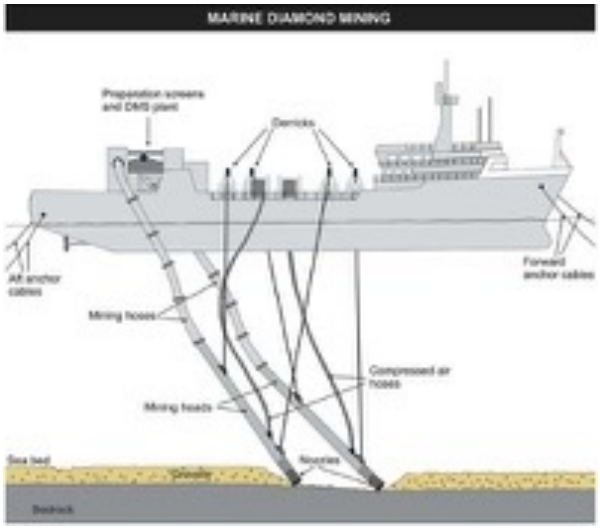
Diamond mining off Namibia (De Beers)

Source: www.mnlconsulting.com

Various mining techniques

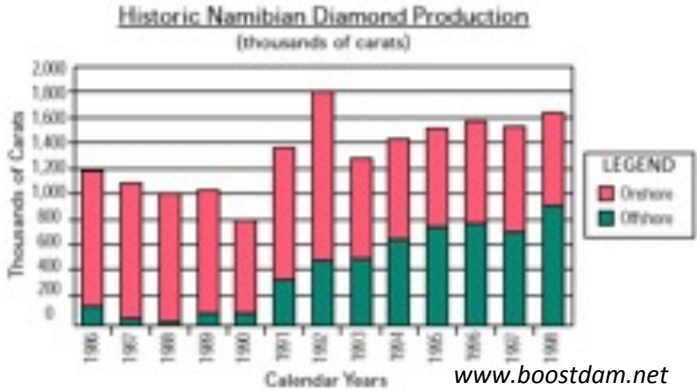
- Horizontal – seabed crawlers →
- Vertical – suction drilling (water jets)
- Airlift – compressed air jets

www.marinelog.com



Source: 2011.polarhusky.com

Diamonds from offshore Namibia (www.imdhgroup.com)



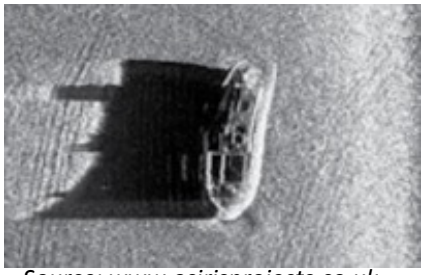
www.boostdam.net

Seabed Treasure Hunting

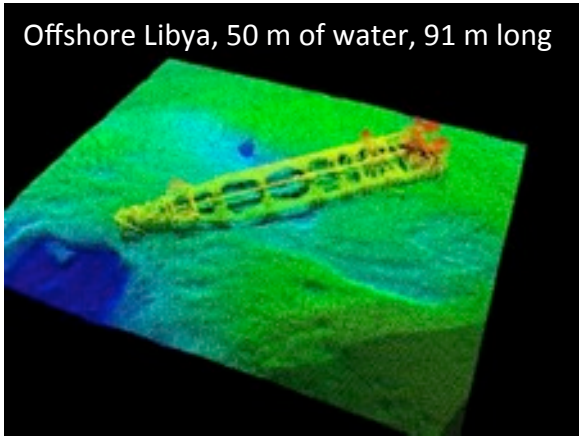
Glamorous! Salvage companies involved in raising wrecks (e.g. Costa Concordia) or in looking for 'sunken treasure' – using the remote and direct techniques of seabed mapping

http://shipwreck.net/

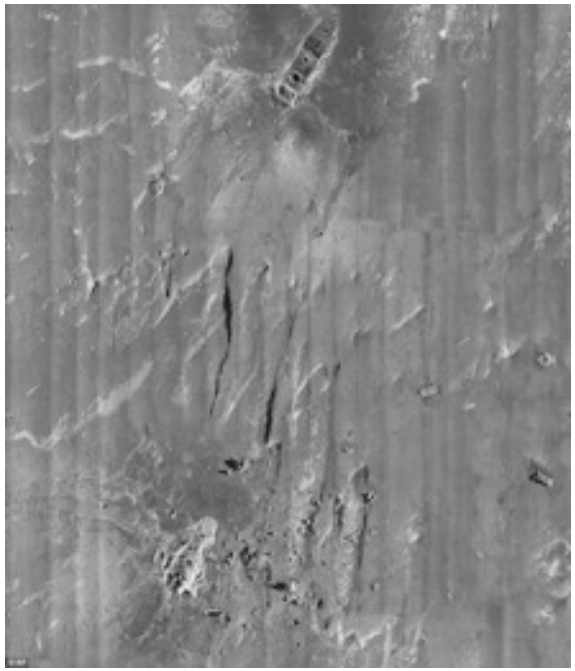
ODYSSEY MARINE EXPLORATION



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)

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

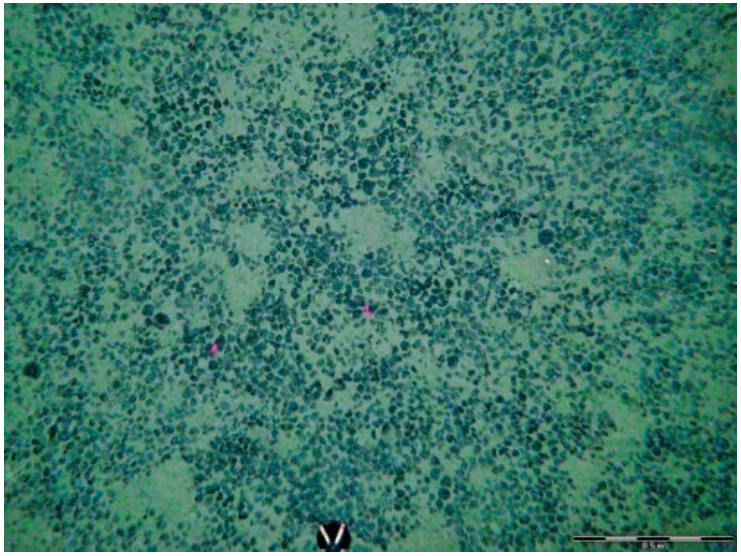
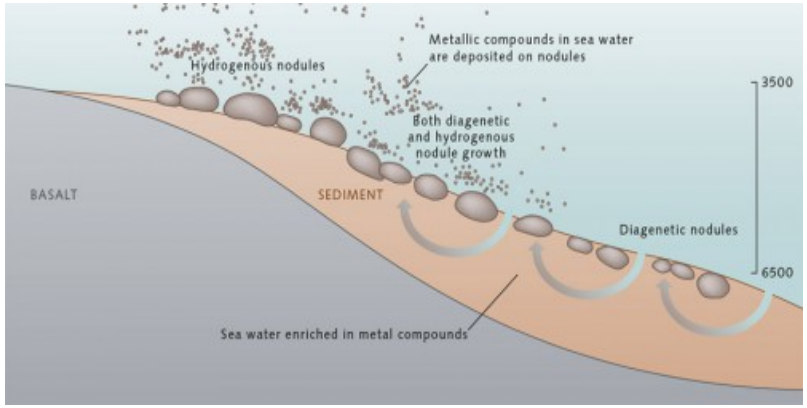
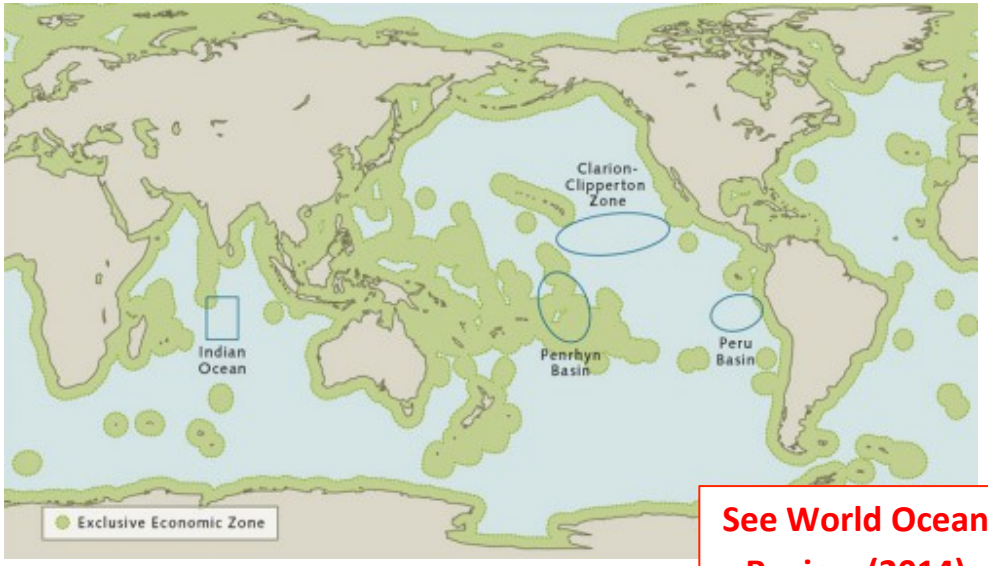


Photo of Mn nodules at seabed (Pacific Ocean)

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



Schematic of Mn nodules formation processes



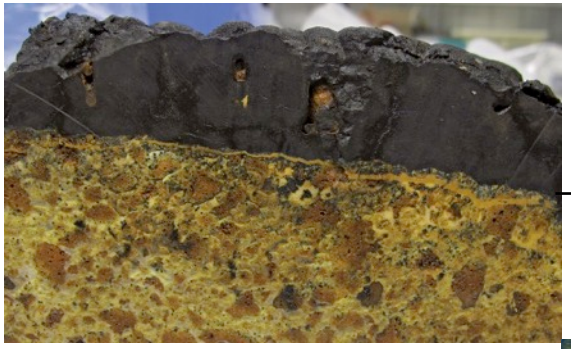
Global Mn nodule concentrations

See World Ocean Review (2014)

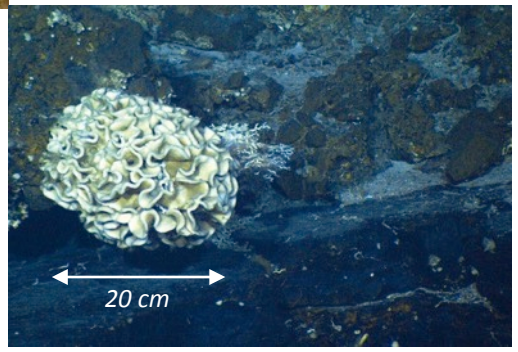
Minerals in the Deep Sea

2. Cobalt crusts

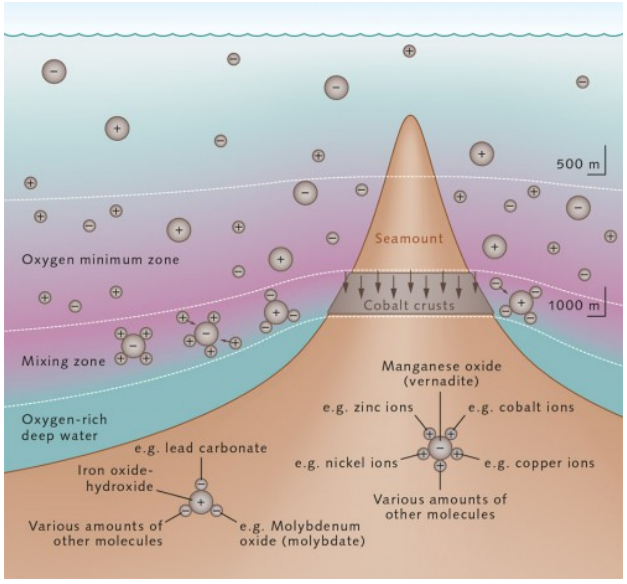
- composition similar to Mn-Fe nodules, more cobalt and platinum
- also precipitates, formed very very slowly (millions of years)
- found on flanks of seamounts (currents), in water depths 1000-3000 m
- differing distribution than nodules, but overlap; mainly in Prime Crust Zone



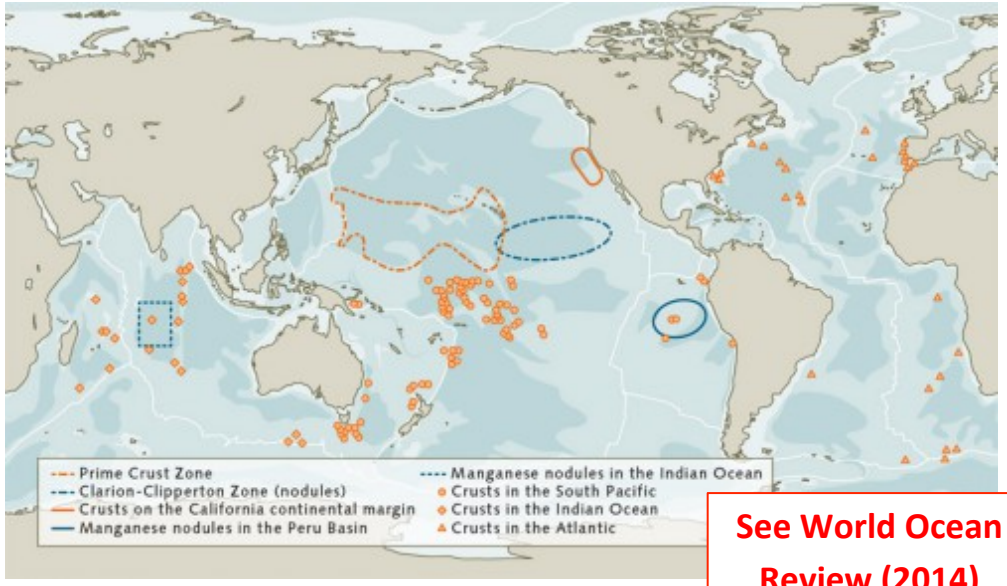
Cross-section of cobalt crust (SW Pacific)



Single-celled organism at seabed on cobalt crusts



Schematic of cobalt crust formation on seamount flanks



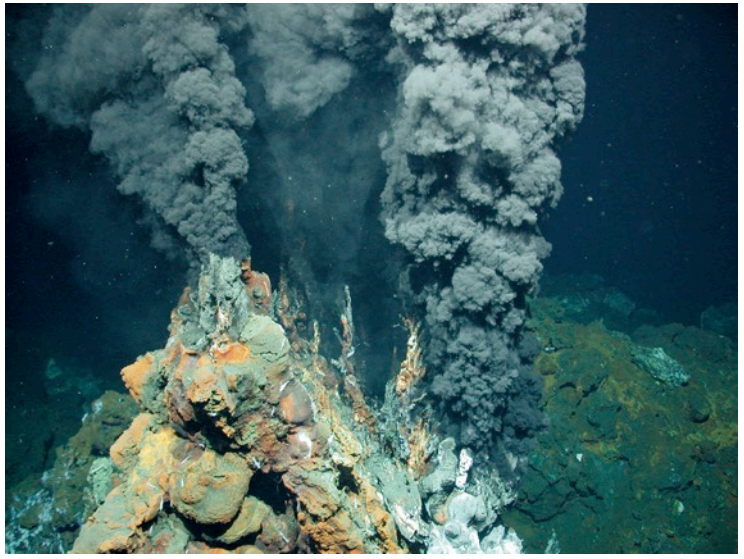
See World Ocean Review (2014)

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

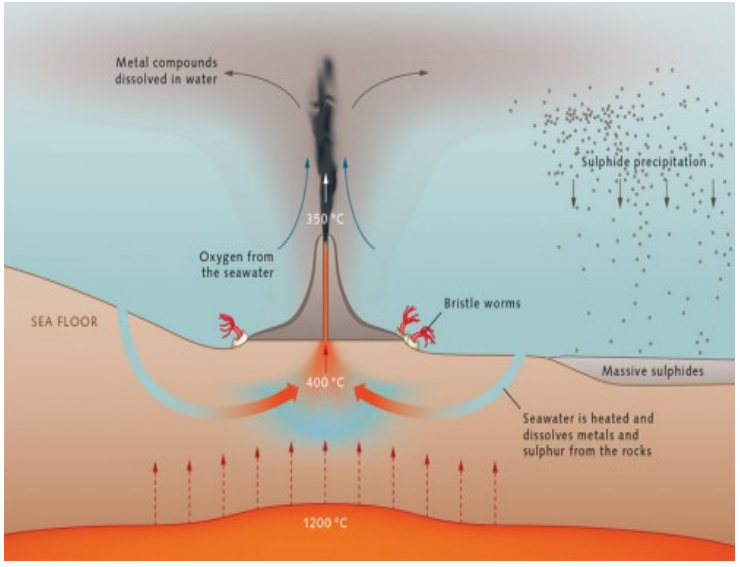
Minerals in the Deep Sea

3. Massive sulphides

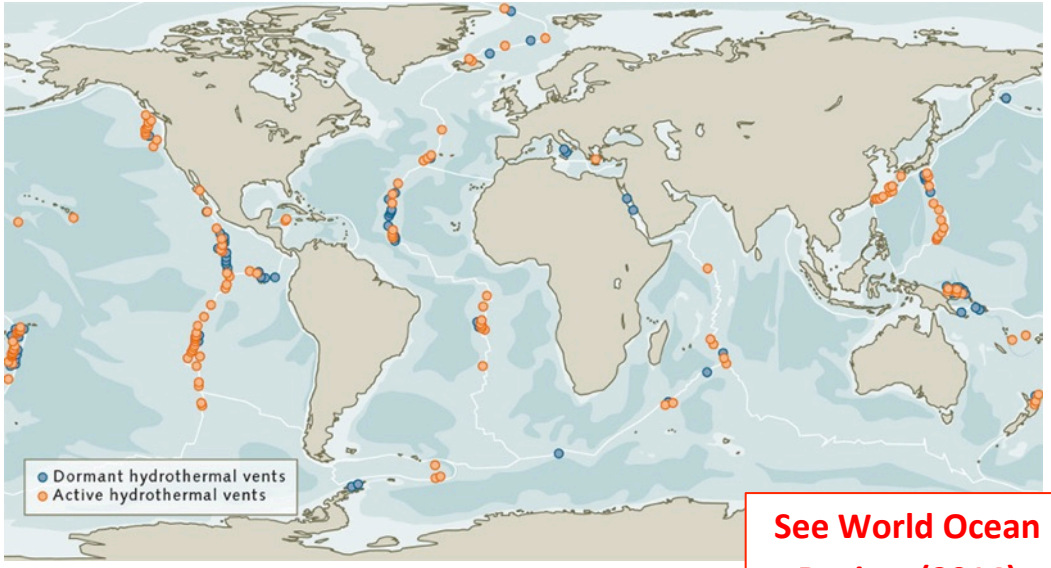
- Iron sulphides with copper, gold, zinc & silver
- Sulphides and other metals precipitate from seawater near volcanoes
- 'Black smokers' discovered in 1978 – hydro-thermal vents (metal-rich fluids up to 400°C)
- Found in areas of recent and present volcanism, in water depths 500-4000 m (including offshore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

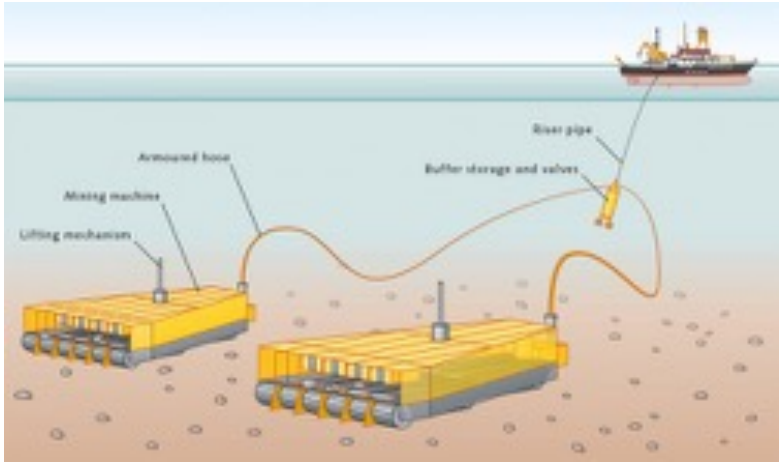
→ drove the signing of UNCLOS (1982) and the creation of the International Seabed Authority (ISA 1994) to regulate the 'boom'

- 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)

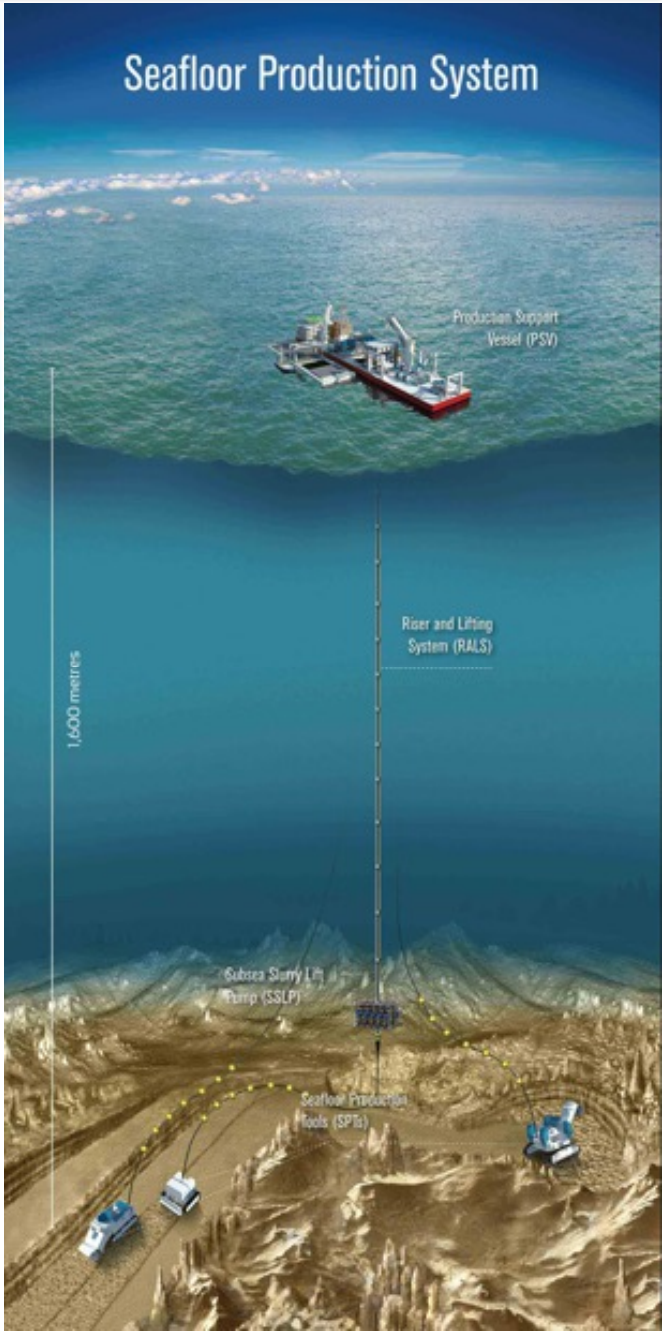


These machines have not been built !

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

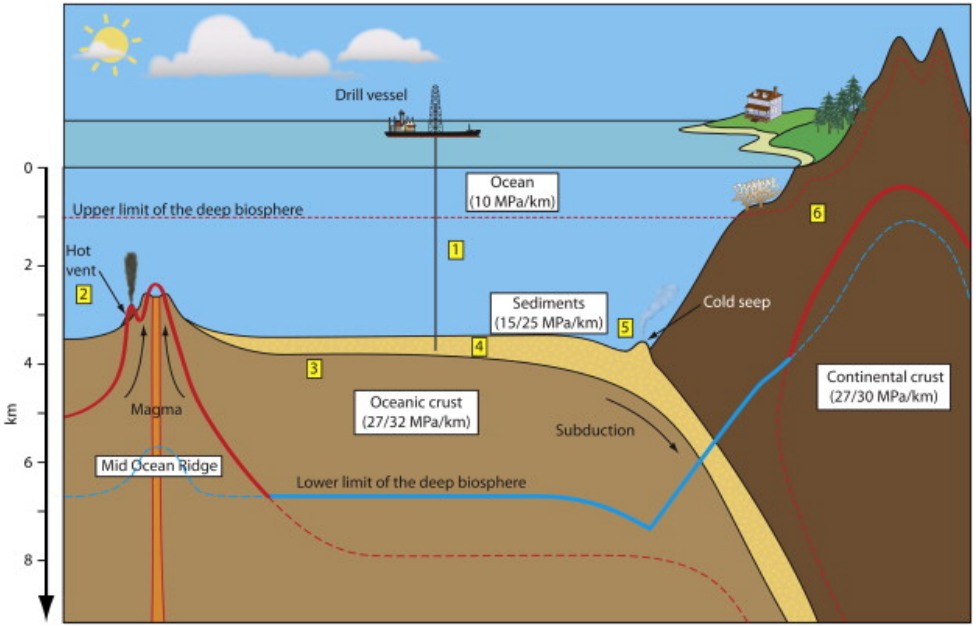


Chassis of seabed rock cutter (adapted cable trencher)

Sources: www.nautilusminerals.com

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

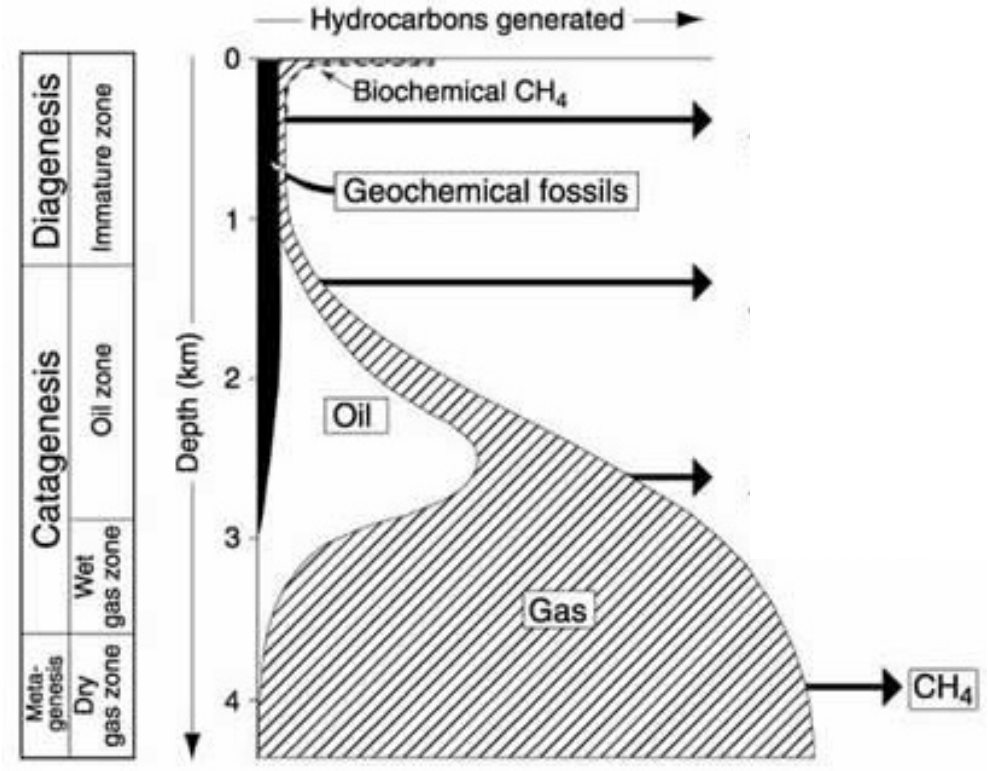
(Geo-) Bio-prospecting

- "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*

HYDROCARBONS = Oil & Gas = Petroleum = Fossil Fuels

> a very short course in petroleum geology (in 4 slides)

- Formed from organic carbon (dead plants/animals) buried in (mainly marine) sedimentary successions → burial = increasing Temperaure & Pressure (cooking)
- Shallow diagenesis → kerogens → deeper thermogenesis



shallow (biogenic) methane

oil window

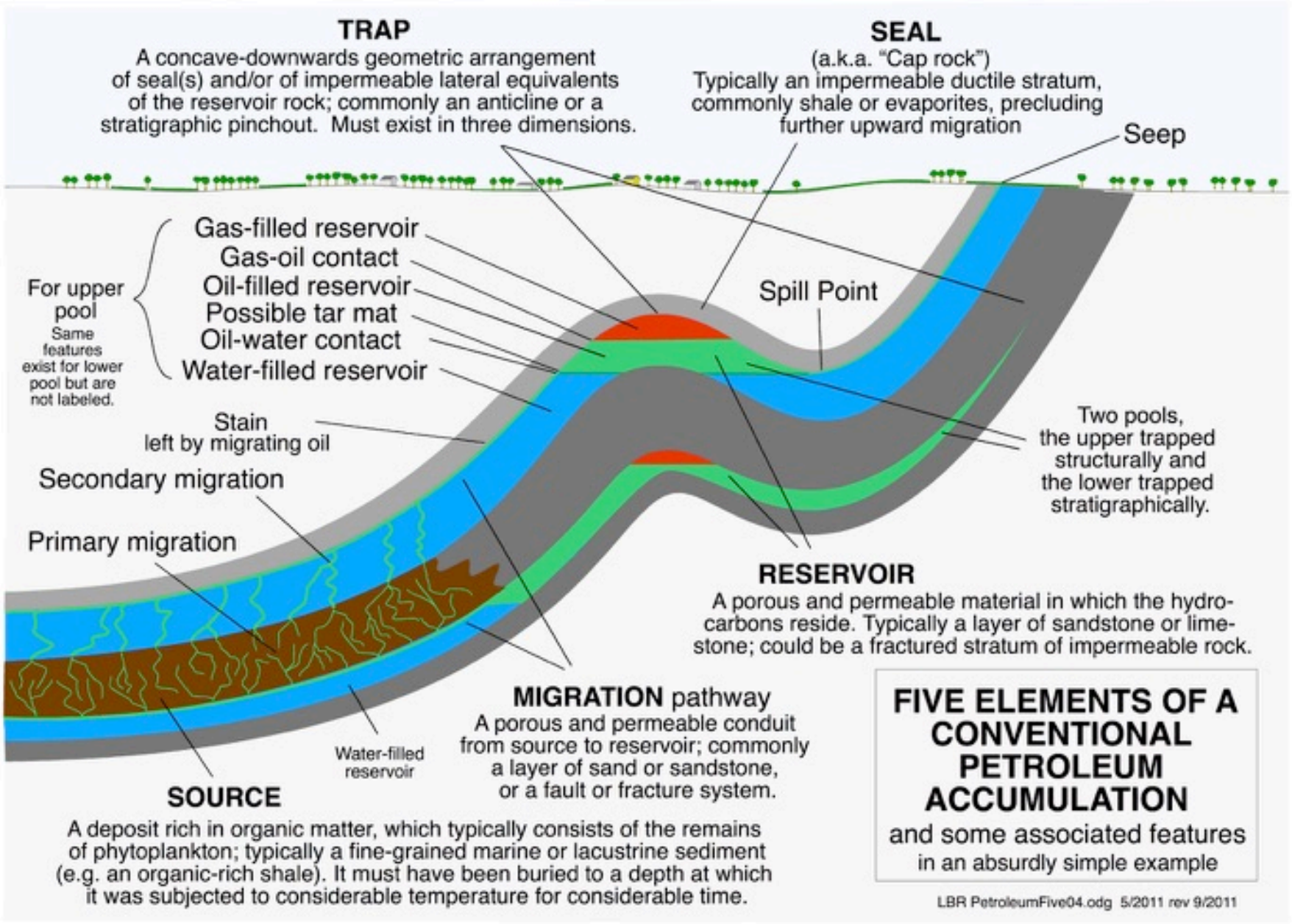
gas window

thermogenic oil & gas

Source: Tissot and Welte (1992) – Petroleum Formation and Occurrence (Springer)

- As they form, they migrate →

Railsback's *Petroleum Geoscience and Subsurface Geology*



Sedimentary Basin Analysis vs Petroleum System Analysis

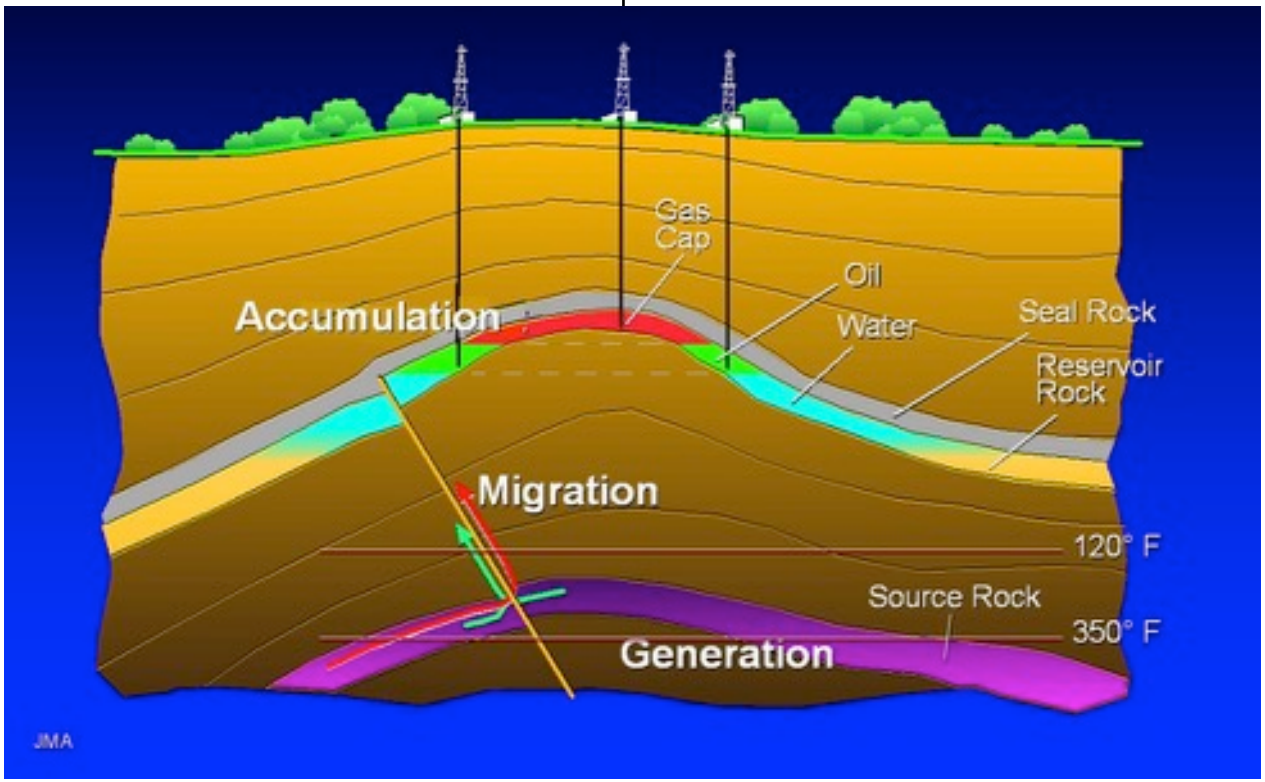
The academic geologist sees…

- 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



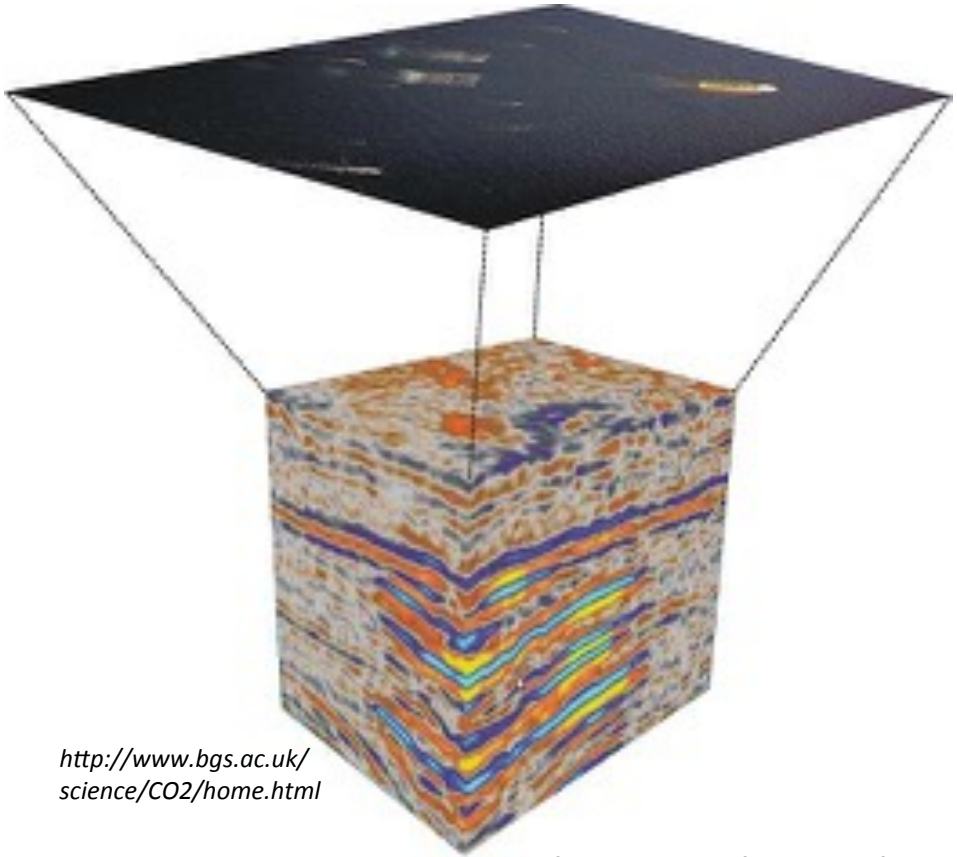
Finding oil & gas

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

Academic and petroleum geologists use basically the same tools…

Geophysics (remote)

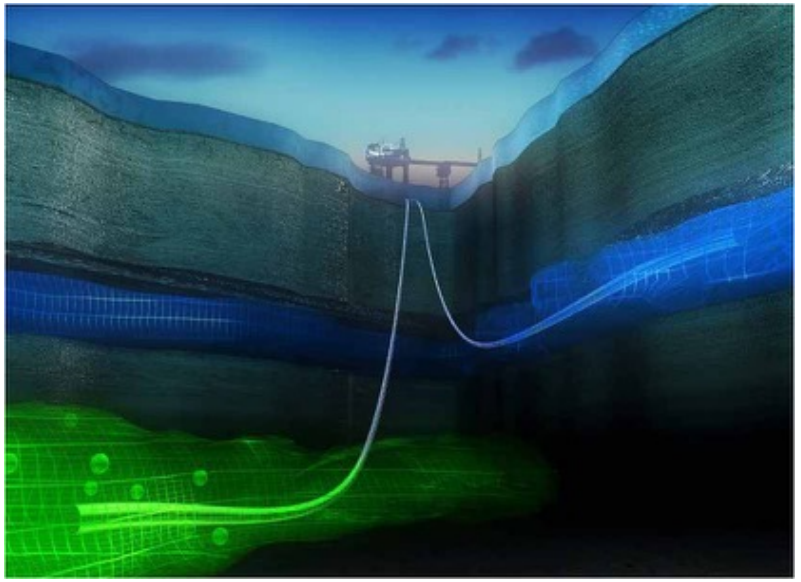
- Gravity & magnetic fields
- Seismic data (2D & 3D)



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

Geology/geochemistry (samples)

- Sediment cores
- Drillsites/wells



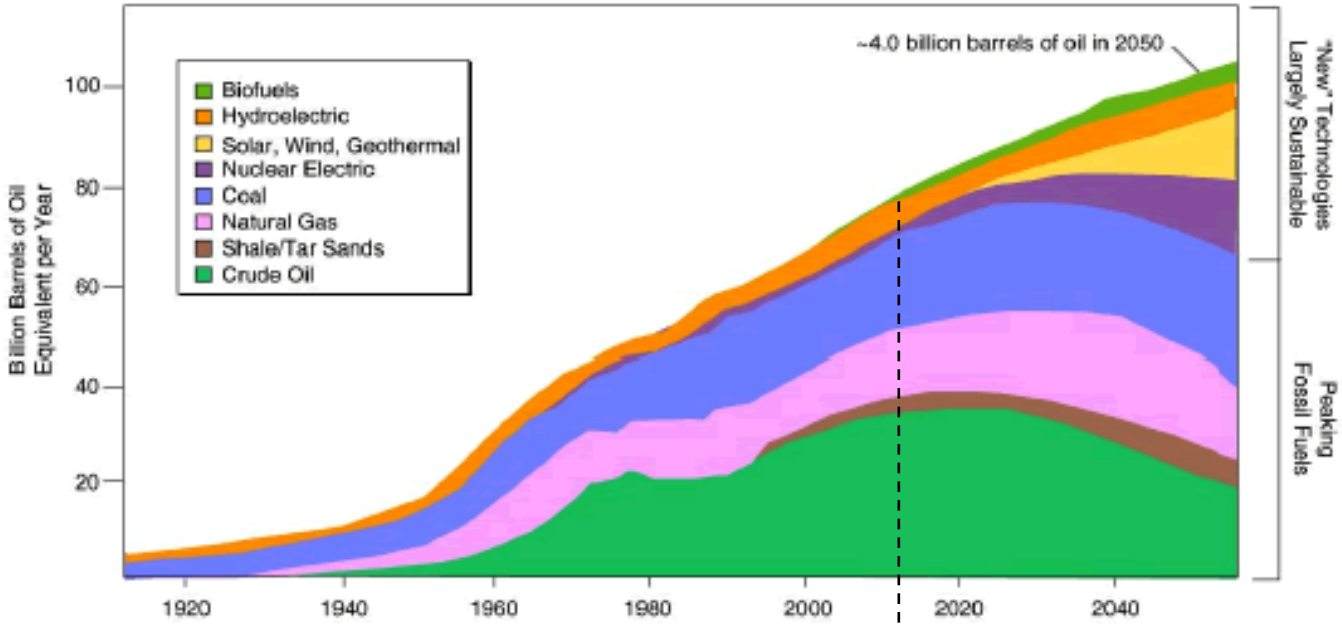
Source: seriousgamesmarket.blogspot.it/2010/09/serious-games-as-oil-drilling-3d.html

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

Hydrocarbons = by far the biggest offshore industry

because industrial society runs mainly on petroleum…

World Energy Demand – Long-Term Energy Sources



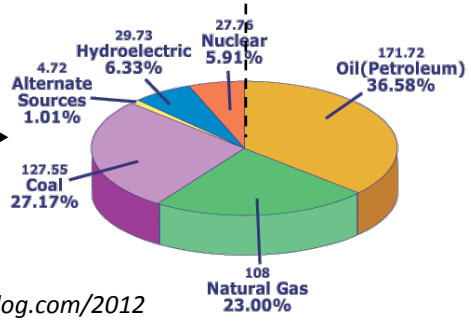
Sources: Lynn Orr, *Changing the World's Energy Systems*, Stanford University Global Climate & Energy Project (after John Edwards, American Association of Petroleum Geologists); SRI Consulting.

Fossil fuels:
majority of energy use today and for the foreseeable future (forecast to decrease as percentage)

World Energy Use 2012:

87% fossil fuels

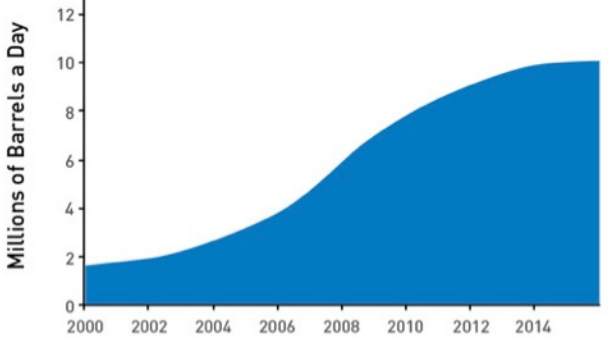
60% oil & gas



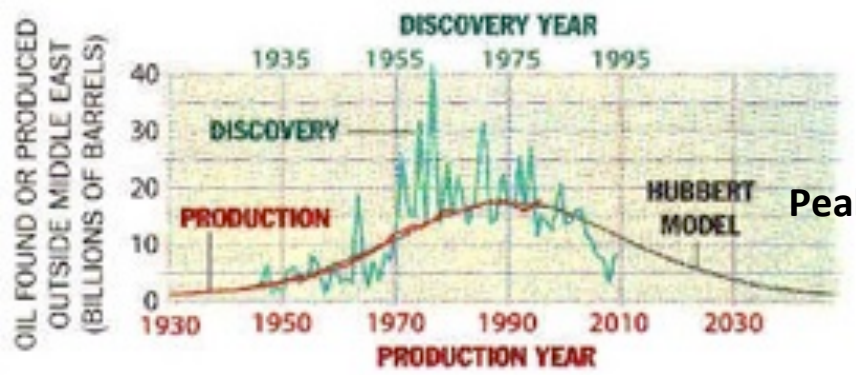
Source: triplehelixblog.com/2012

DEEPWATER PRODUCTION

Source: www.total.com

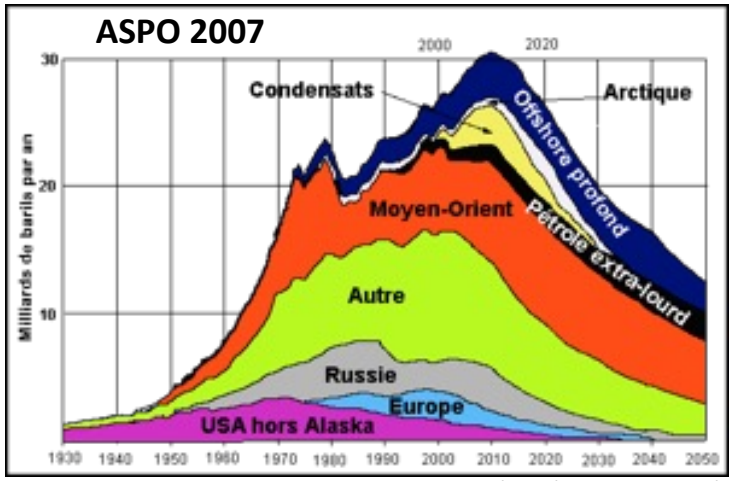


Hydrocarbons – are we at peak production?

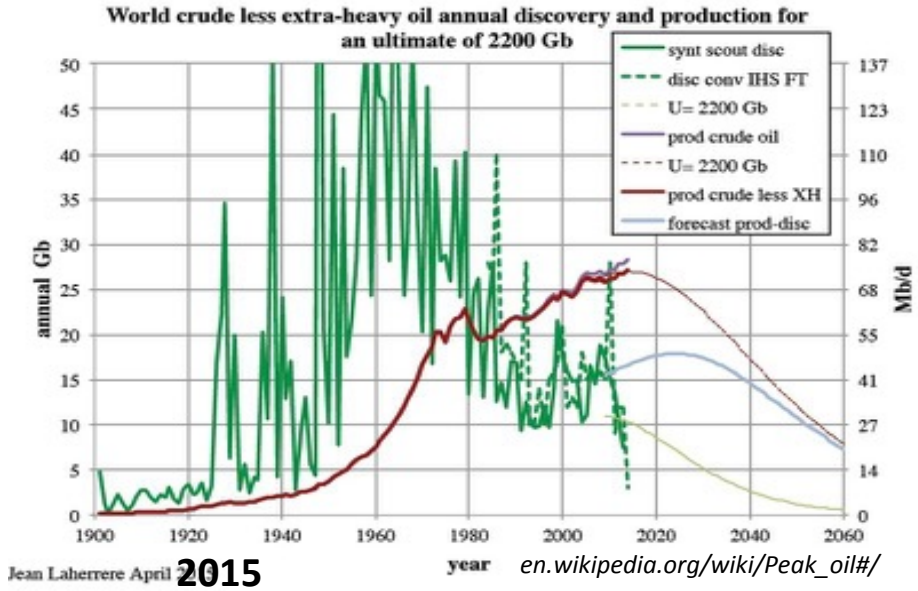


Peak Oil

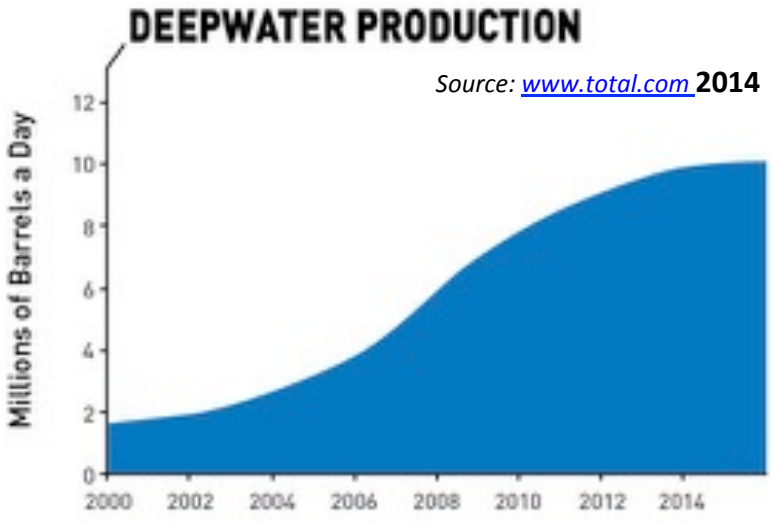
*Campbell & Laherrre **1996**, Scientific American – The End of Cheap Oil*



fr.wikipedia.org/wiki/Pic_pétrolier#/



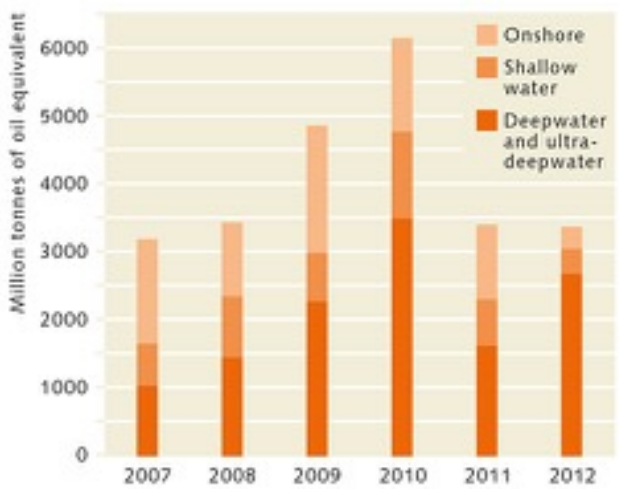
en.wikipedia.org/wiki/Peak_oil#/



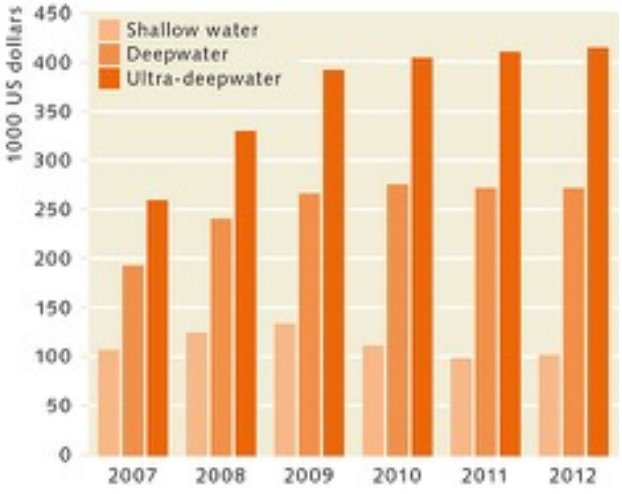
Green: discoveries peaked in the 1960s
Red: production peaking now?

Deep water production is peaking?

Global oil & gas discoveries



Costs of drilling

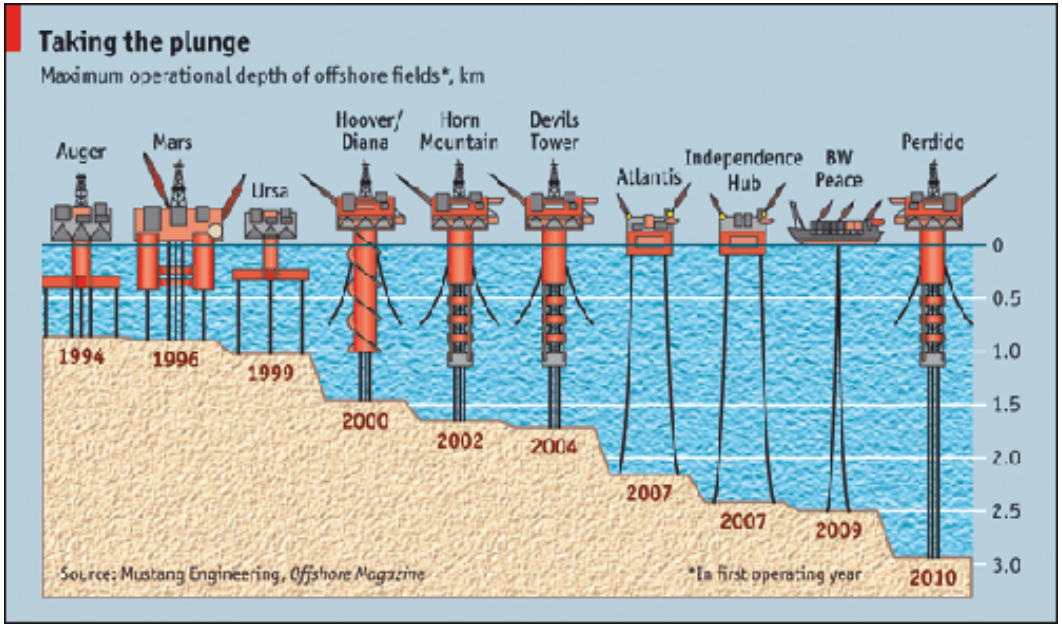


Source: World Ocean Review (http://worldoceanreview.com)

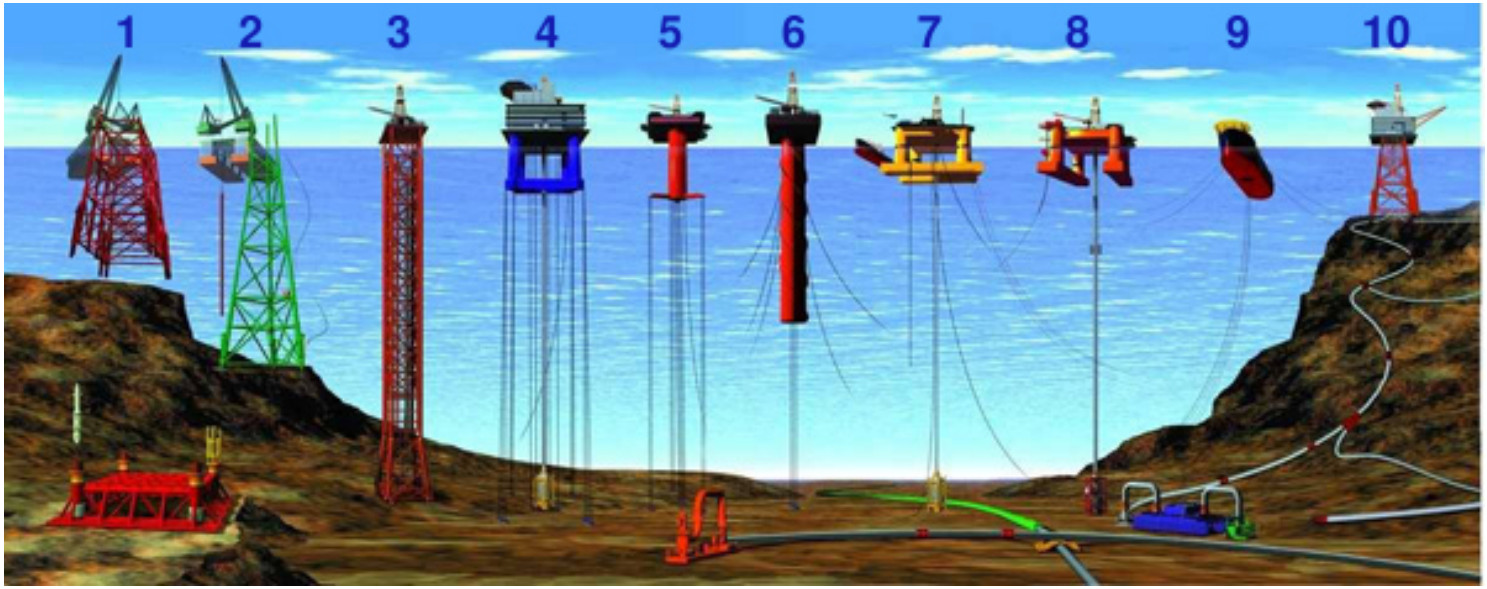
Shallow : 0-400 m
Deep : 400-1500 m
Ultradeep : >1500 m

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'



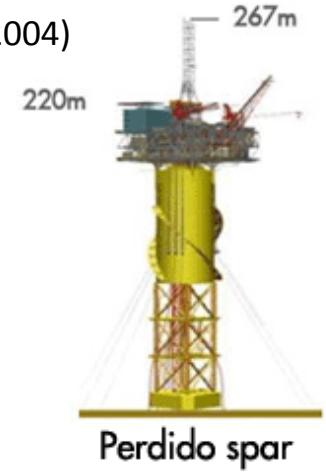
Source: www.energyandcapital.com/articles/oil-rigs-drilling-ever-deeper/



Types of Offshore Oil and Gas Structures (in 2005)

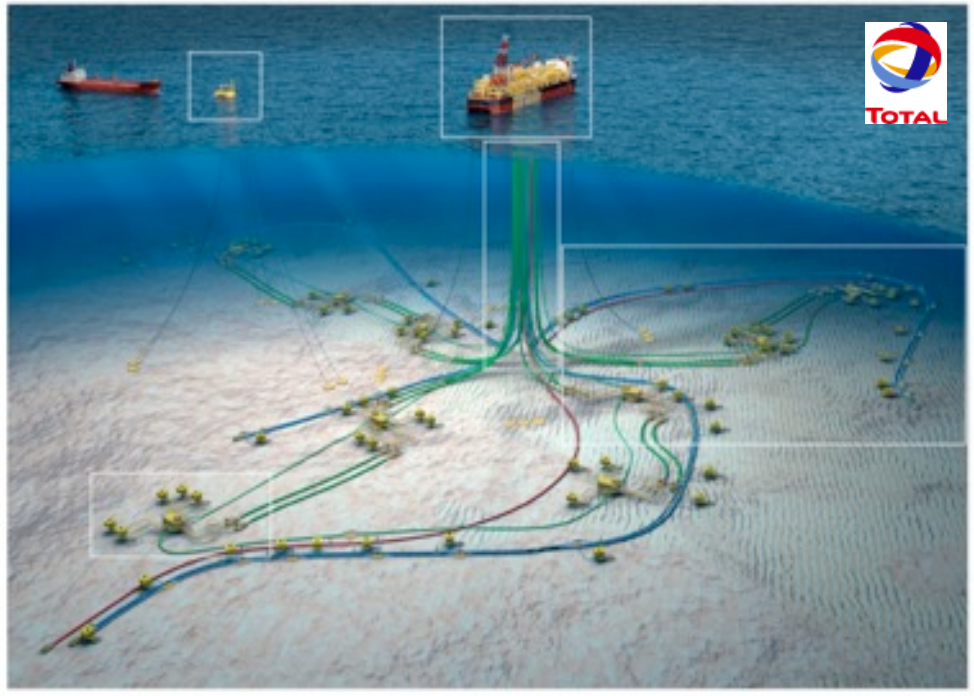
1 & 2) Conventional fixed platforms (deepest: 412 m GOM, 1991)
3) Compliant tower (deepest: 534 m GOM, 1998)
4 & 5) Vertically moored tension leg platforms (deepest: 1,425 m GOM, 2004)
6) Spar (deepest: 1,710 m GOM, 2004)
7 & 8) Semi-submersibles (deepest: 1920 m GOM 2003)
9) Floating production, storage, 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)

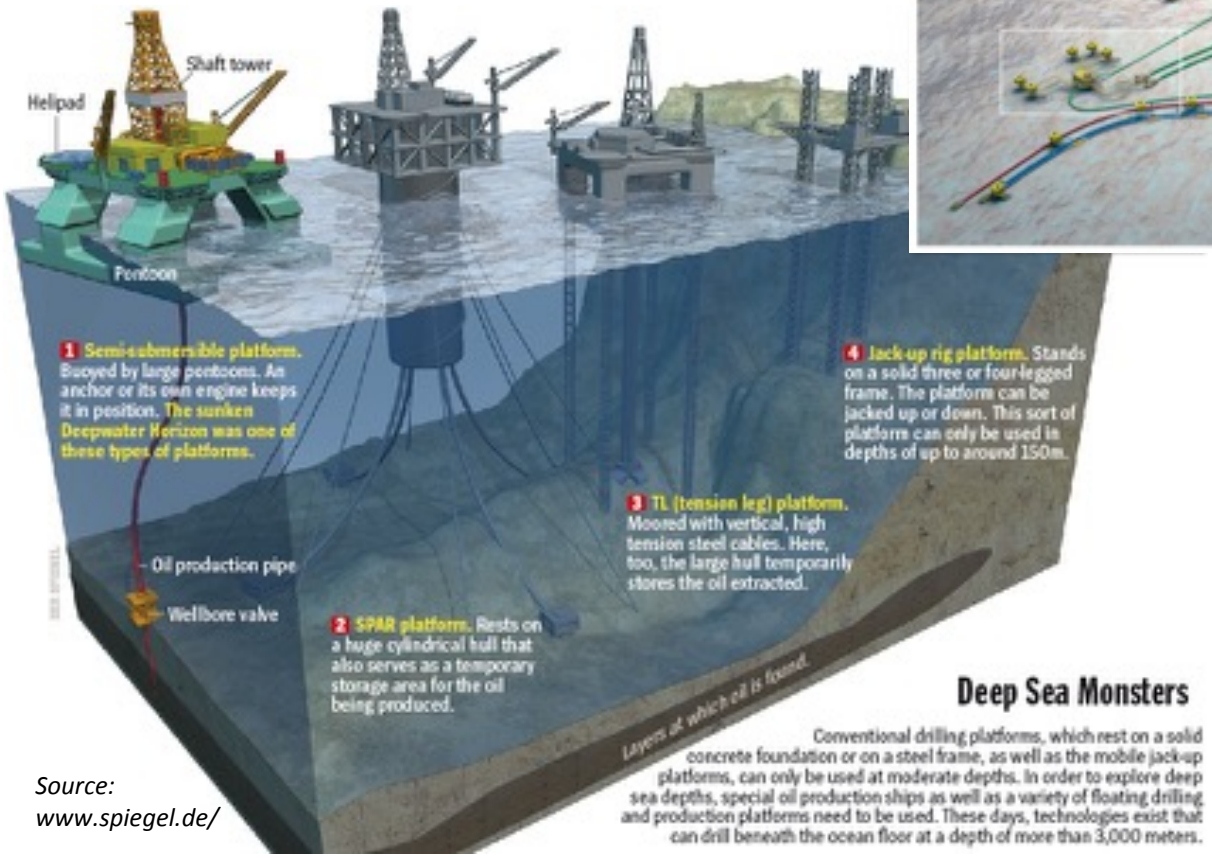
Source: http://commons.wikimedia.org/wiki/File:Types_of_offshore_oil_and_gas_structures.jpg



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/

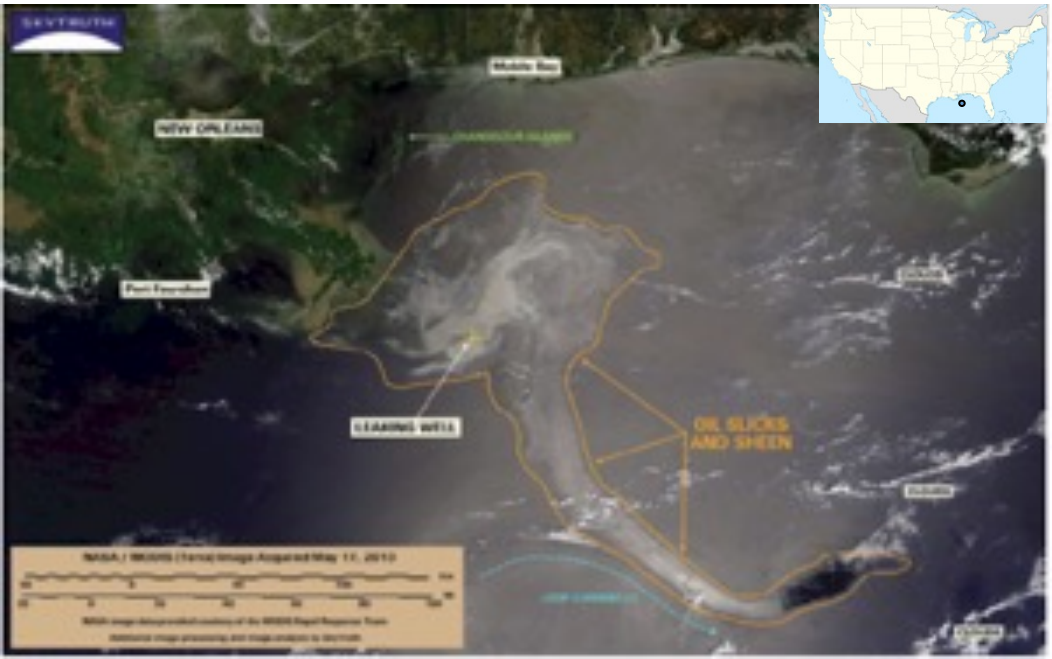
"The conquest of the deep offshore, the oil industry's latest and perhaps most extra-ordinary adventure…" (www.total.com)

And 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

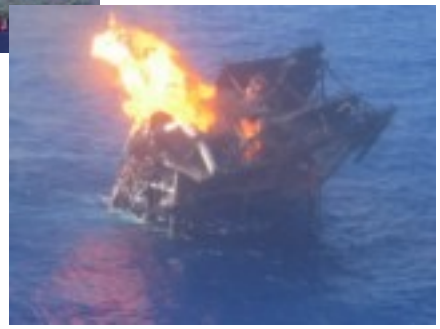


Explosion, fire, 11 deaths, massive oil spill…

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

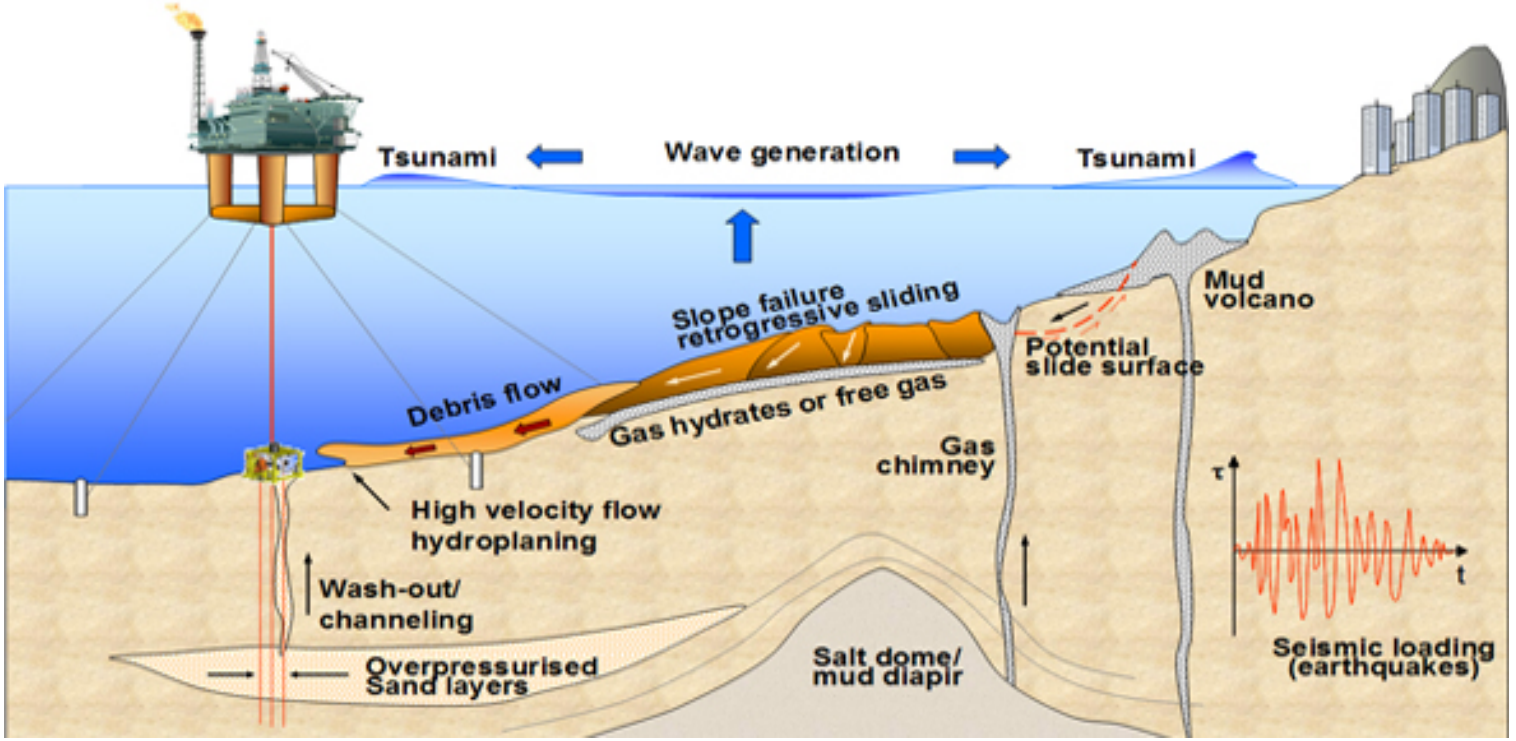
Rig: Petromar V Drillship
Date: 27 Aug 1981
Location: Off Natuna Island, South China Sea
Operator: Mobil

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

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

Site surveys & submarine geohazard assessments

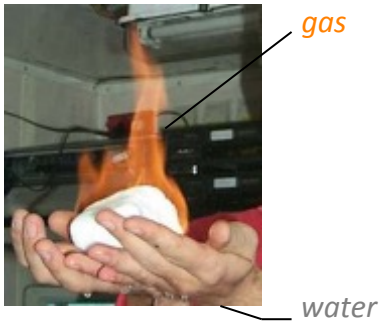
- Purpose: to try to avoid blowouts and other unwanted consequences of drilling
- Examine seabed and sub-seabed conditions at drilling sites to assess whether potential hazards exist (and take steps to avoid or address them)
- We are in the world of seabed surveying (some of the same service companies), but more concerned with geological understanding of past & future near-seabed processes
- Pore fluids are key in all processes: fluid migration and escape to seabed, their role in triggering submarine landslides, and sediment responses to seismicity.

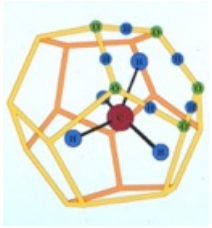


http://www.ngi.no/en/Geohazards/Content/Shortcuts/Research-and-development/to-be-filled-1/

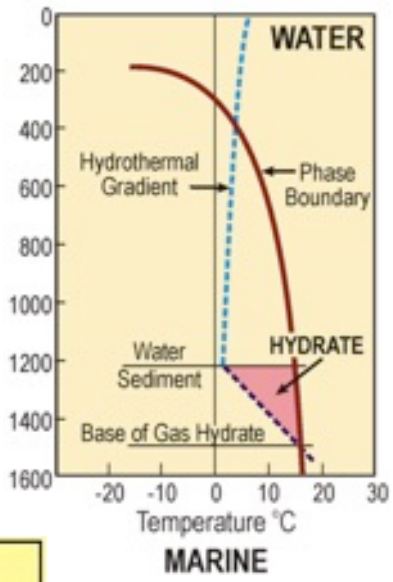
Shallow gas & methane hydrates

- Gas (bubbles and/or dissolved in water) common in near-seabed sediment
- Gas + water at high pressures and low temperatures leads to something unlikely but very interesting…



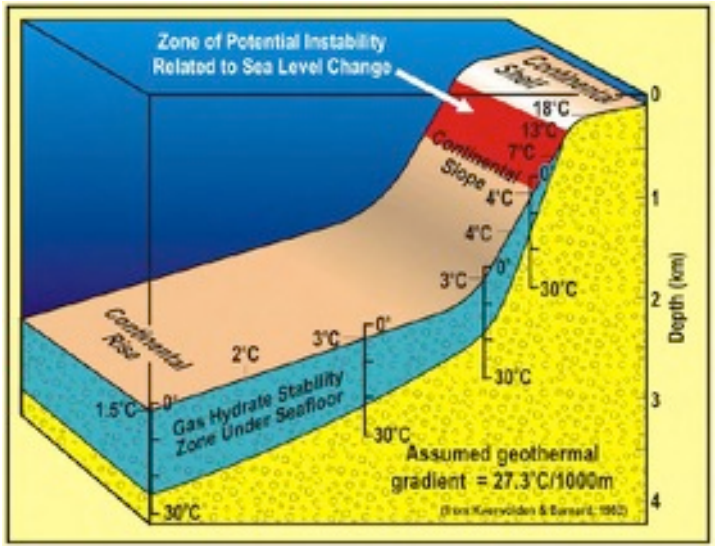


1 m³ solid yields up to 160 m³ of gas



Gas hydrates (ice that burns)

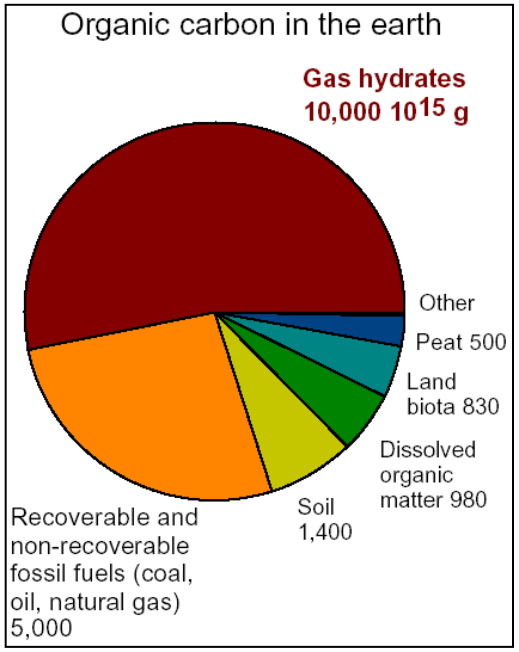
- ice-like compounds of water (molecular cages) + natural gas
- gas concentrators (mainly methane, a potent greenhouse gas)
- stable in permafrost settings on land, or in submarine settings below water depths of c. 300-1000 m
- can occur offshore on continental margins in a zone up to 1 km thick (depending on subbottom temperatures)



Fillon & Roberts (2007)

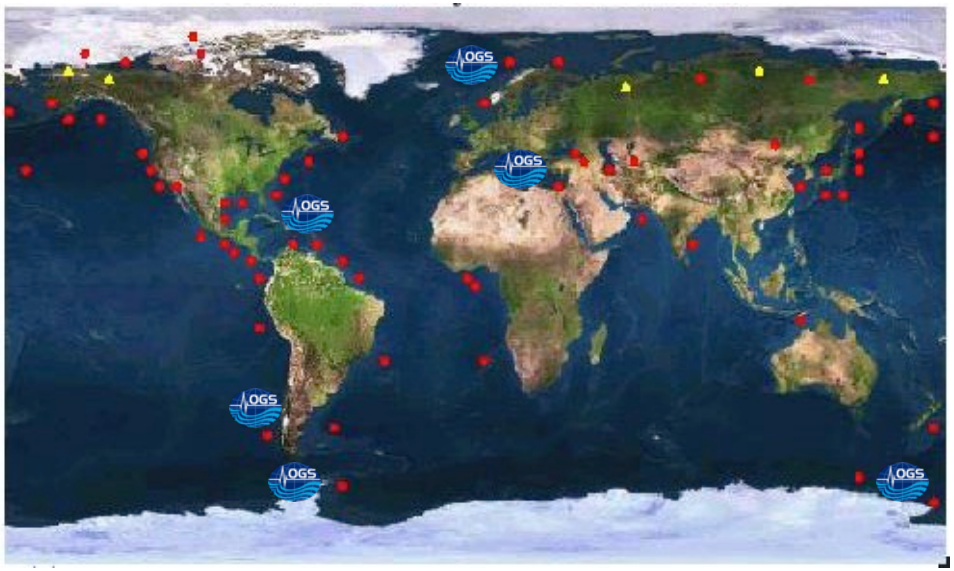
Gas hydrates – a future energy resource?

- On conservative assumptions, estimated offshore occurrences (continental margins) = the largest reserve of hydrocarbons on Earth…
- Mainly dispersed and only likely to be economic where concentrated (like most minerals)
- Efforts to exploit concentrated deposits underway in Japan, China, India, South Korea and Taiwan…



Source: Geological Survey of Canada, after Kvenvolden

GLOBAL GAS HYDRATE LOCATIONS



(▲ permafrost; ● submarine)

March 12 2013: JOGMEC (Japanese state company) announces world's first tests to extract natural gas from methane hydrate deposits are successful; commercial production planned from 2018 (www.pennenergy.com)

Career Paths for Marine Geoscientists

Academia	Offshore Industries
• Public institutions (universities, research institutes)	• Private companies (petroleum, mineral, service industries)
• Slow career progression to tenure	• Rapid intra-/inter-sector mobility
• Modest remuneration	• Bigger salaries
• 'Pure' science	• Applied science
• Intellectual freedom/satisfaction ? (understanding the Earth…)	• Satisfaction of clear objectives and the tools to reach them
• Long-term projects (years)	• Short-term problems (days-weeks)
• You take your work home	• You leave your work on your desk

Recommended Reading

Law of the Sea

- *http://www.un.org/depts/los/convention_agreements/texts/unclos/UNCLOS-TOC.htm*
- *http://en.wikipedia.org/wiki/United_Nations_Convention_on_the_Law_of_the_Sea*
- *http://en.wikipedia.org/wiki/Maritime_boundary*

Marine Resources

- World Ocean Review (*worldoceanreview.com)*