Introduction to offshore installations

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Overview

- Historical milestones of offshore O&G
- Offshore O&G exploration & production
- How deep can we drill offshore?
- The offshore prize & challenges
- Offshore mooring systems
- Geohazards & case studies
- Closing remarks

How are 100ft waves created?

- Nazare, Portugal is a renowned surfing destination
- Ever wondered how these big waves are created?

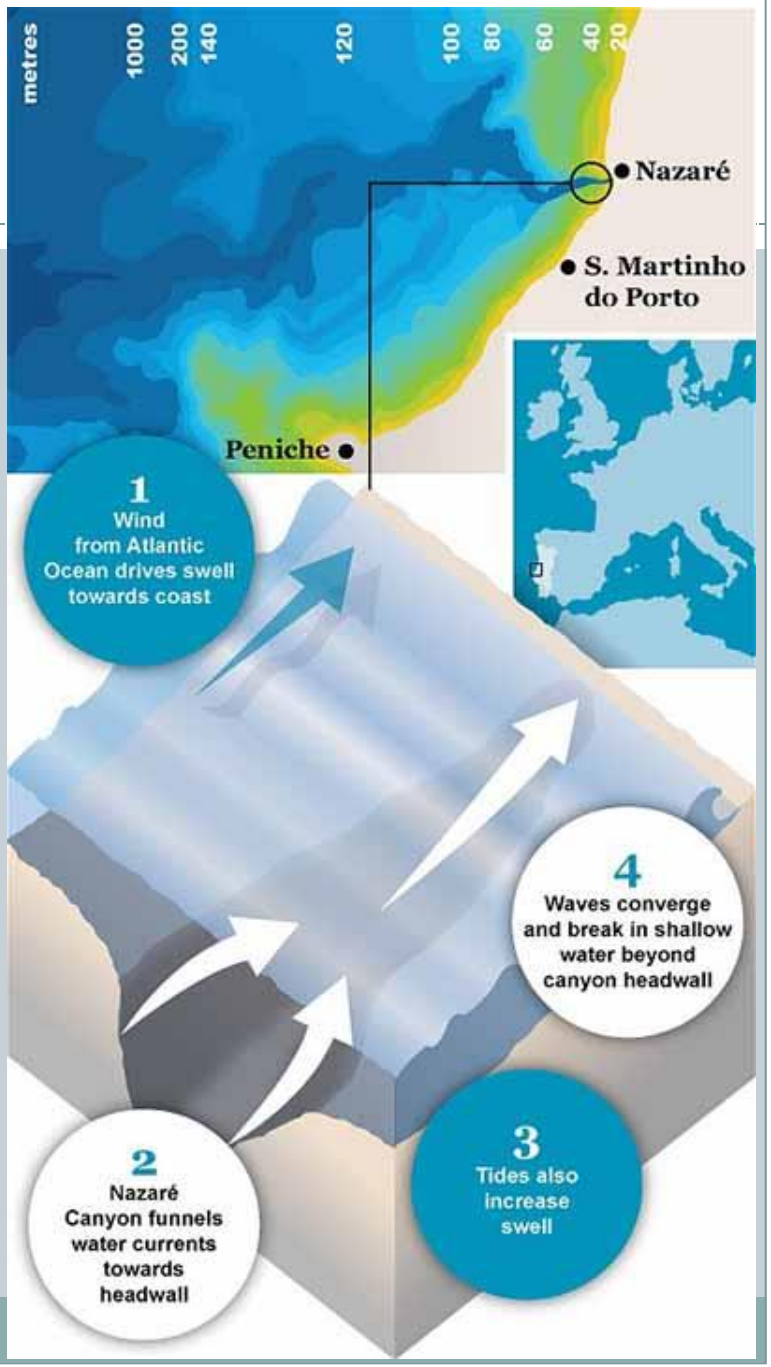




Nazare's 100ft tall waves (2)

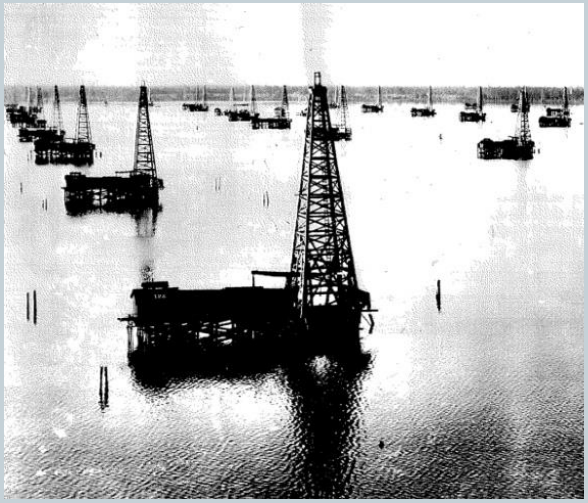
- Nazare Canyon stretches 125mi; 3mi deepest point
- Canyon depth abruptly rises to 100–150ft
- Factors fostering huge waves:
  - Water currents
  - Winds (storms)
  - Swell
  - Abrupt drop in water depth
  - Submarine morphology

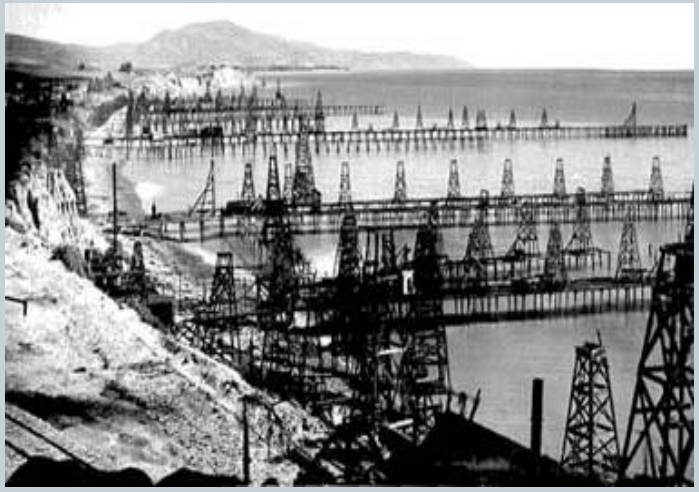
- https://bit.ly/2DRcMNQ



Historical milestones of offshore O&G

- 1859: “Colonel” Drake, drills first oil well in Pennsylvania
- 1870: John D. Rockefeller establishes Standard Oil
- 1897: First offshore E&P in California using piers
- 1910: Gulf Oil drills for oil in Lake Caddo, Texas
- 1925: Lago uses concrete pilings in Maracaibo Venezuela



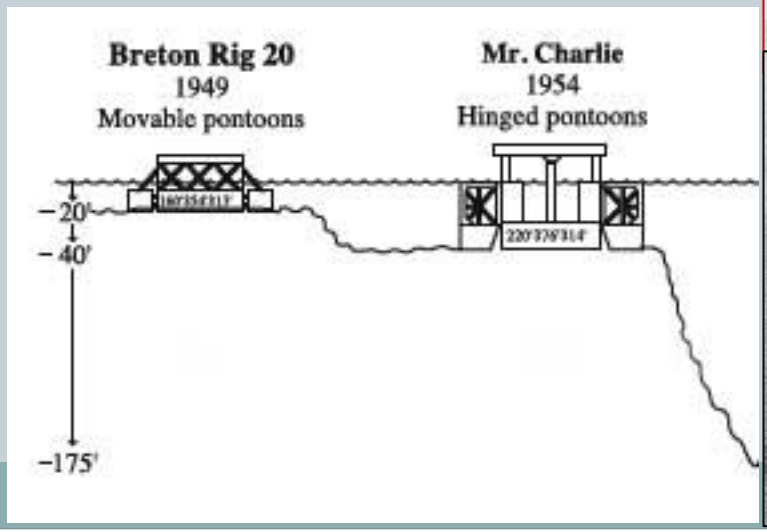




Leffler(2011)

Historical milestones of offshore O&G (2)

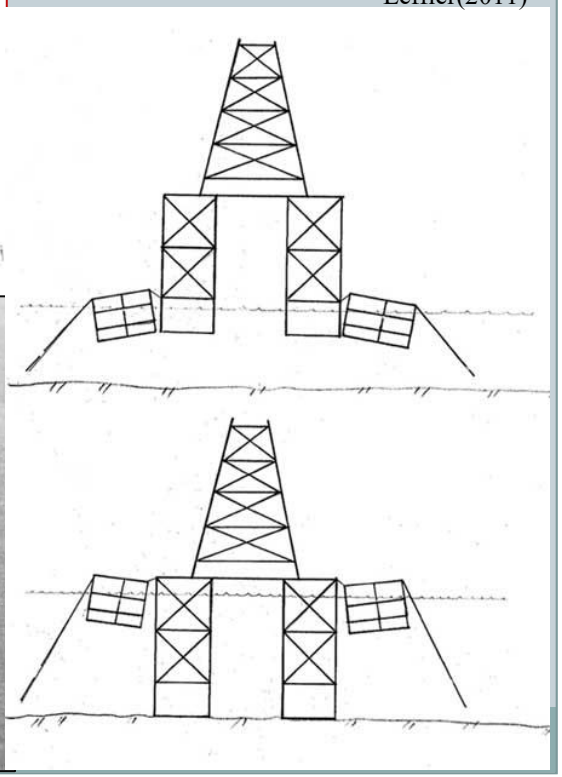
- 1933: Texas Company (Texaco) applies barge idea to Louisiana
- 1947: Superior installs 1st prefabricated platform, GOM
- 1947: Kerr-McGee Co discovers & produces oil in 4.6m water depth
- 1949: Hayward (Seaboard) builds first semi-sub (Breton rig)
- 1954: Mr Charlie resting on sea floor "attacks" stability issues





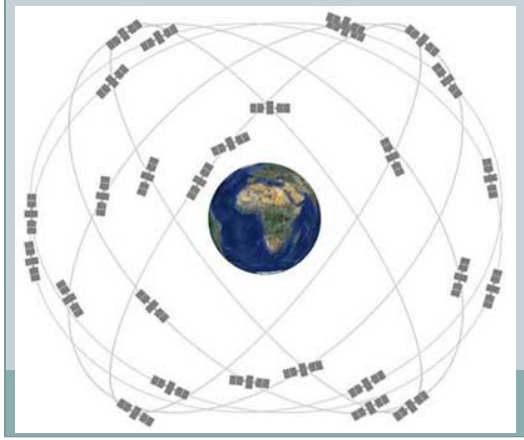


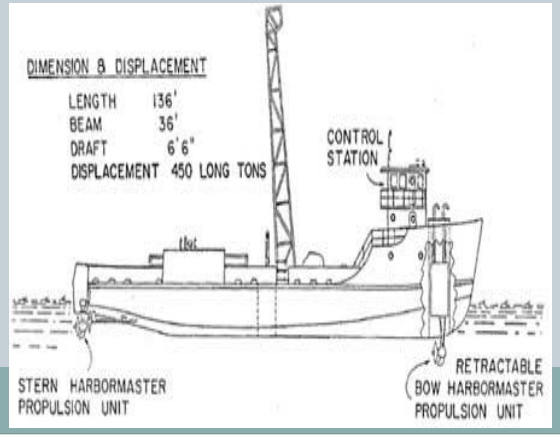
Leffler(2011)

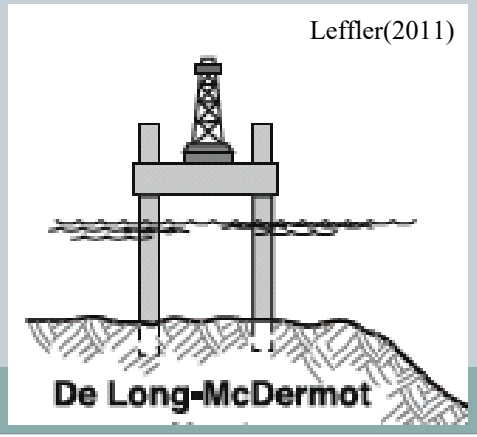


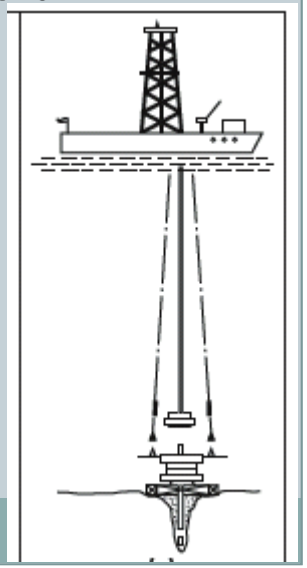
Historical milestones of offshore O&G (3)

- 1950: First jack-up installed in GOM by Magnolia Petro.
- 1953: First drill ship built by Continental, Union, Shell & Superior
- 1950s: Collipp tackles stability problem by increasing draft
- 1961: Eureka drillship uses retractable props for dynamic positioning
- 1962: Shell uses first ROV to complete an offshore well
- 1986: John Chance figured out GPS error & sold details to drillers
- 1934: Teledyne conducts offshore seismic survey for Creole field



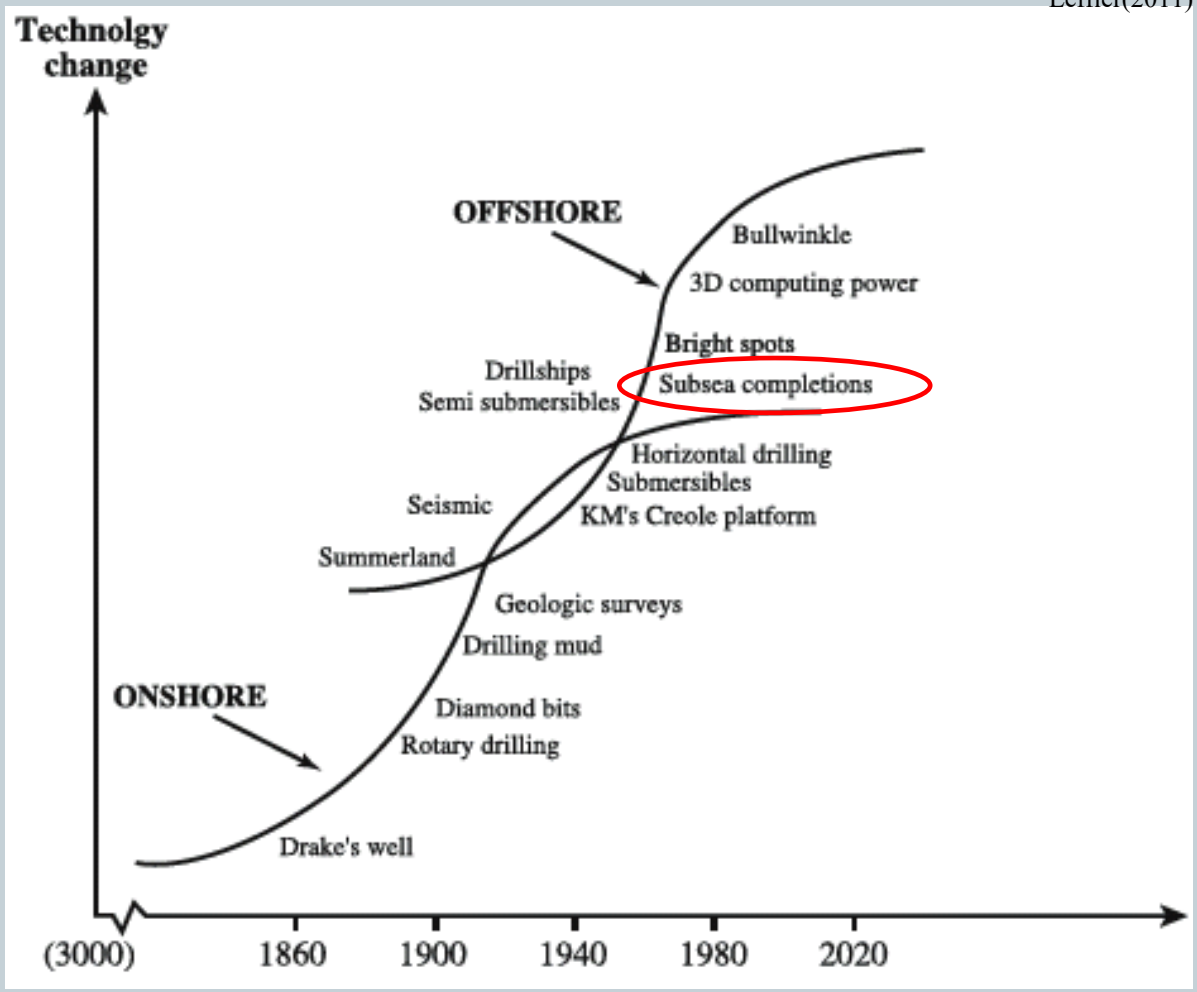






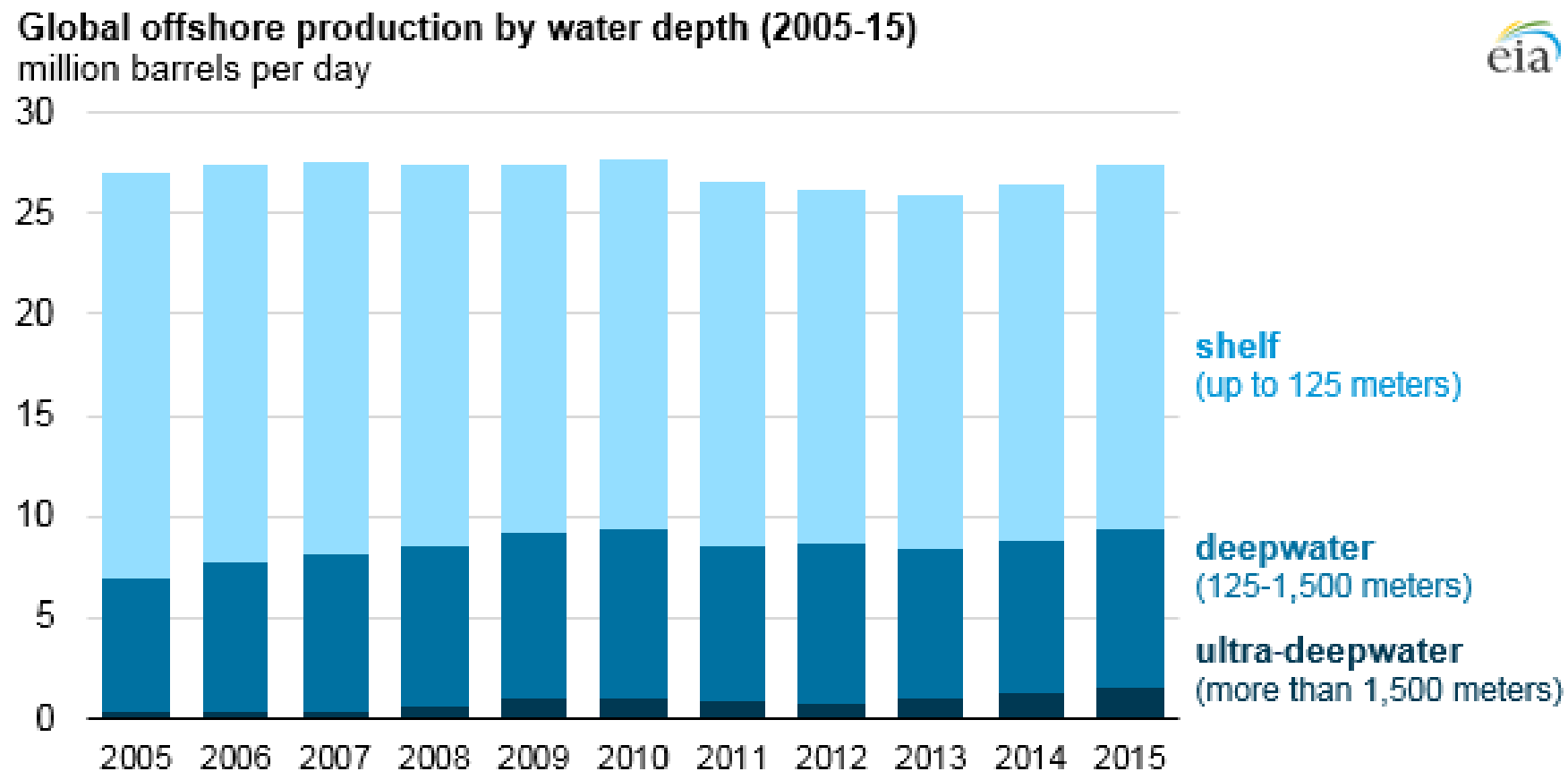
Offshore E&P

Leffler(2011)



Offshore oil production

- Offshore oil production 9.3mbp/d or ≈30% of global production



Offshore oil

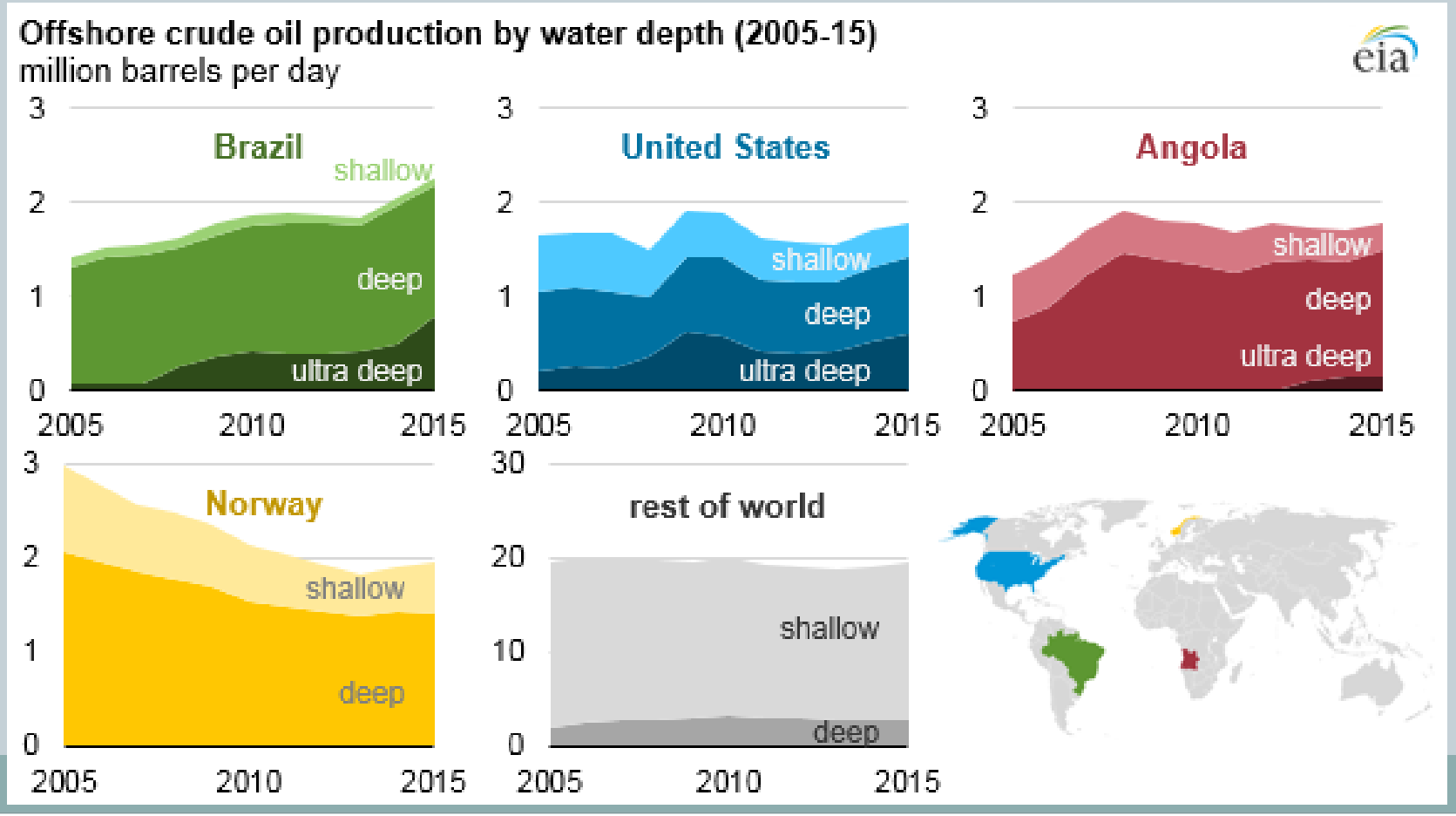
- Deepwater extraction: 3% in 2002 → 6% in 2007 → 10% in 2012
- After 2012 offshore H/C production will *probably* be the *only* growing frontier



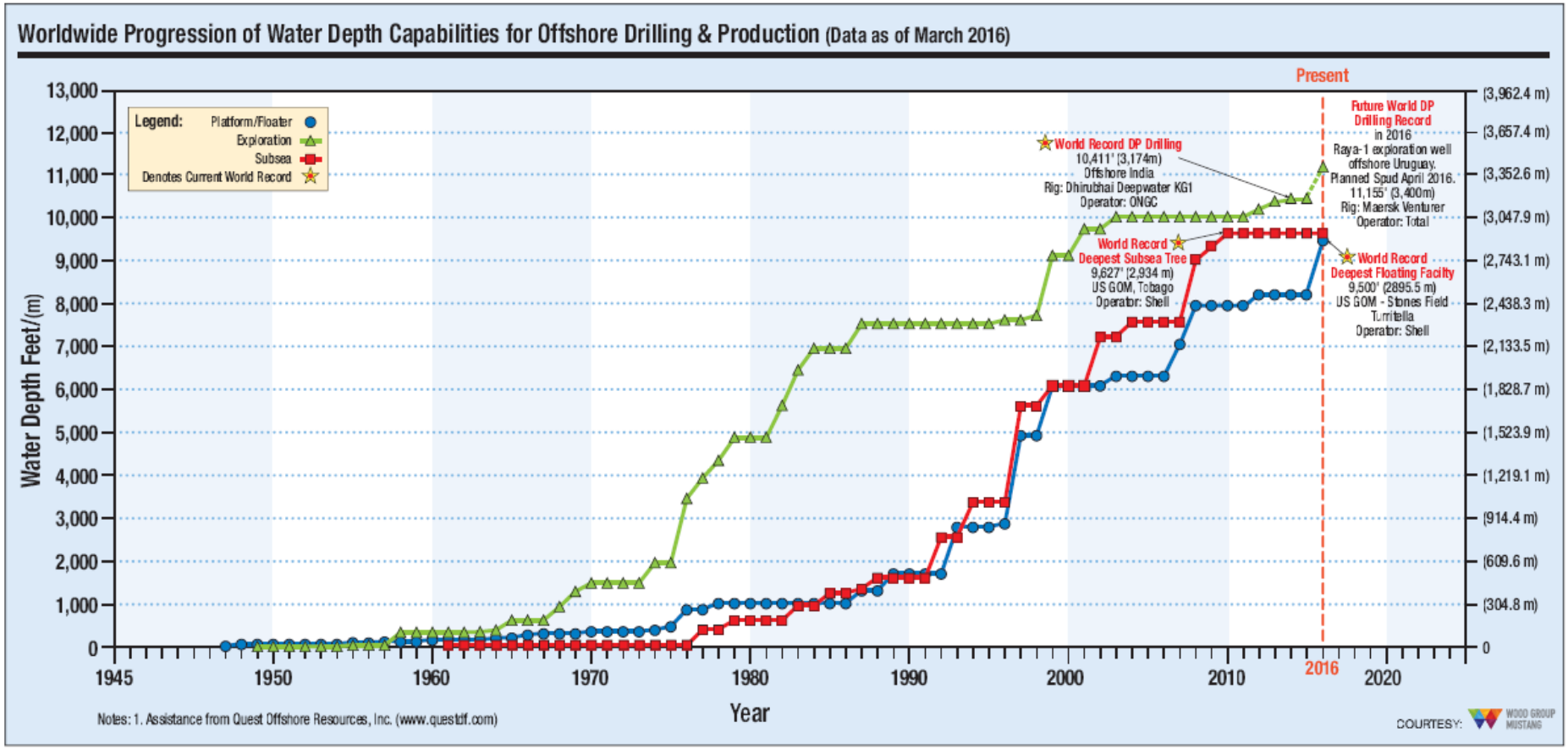
Source: Douglas Westwood

Offshore O&G production

- Despite the low-price environment offshore oil production is increasing
  How is that possible?

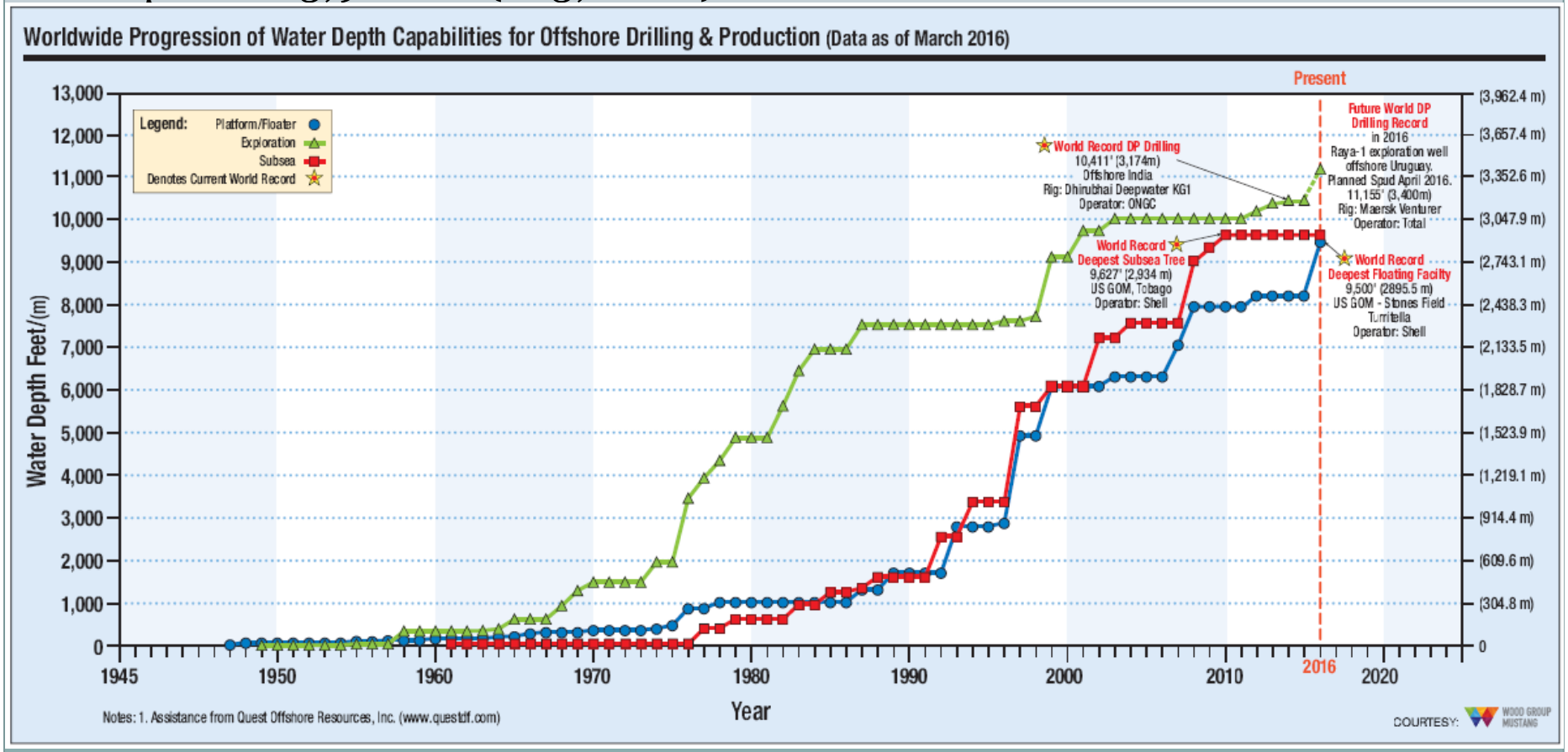


Offshore drilling & production records



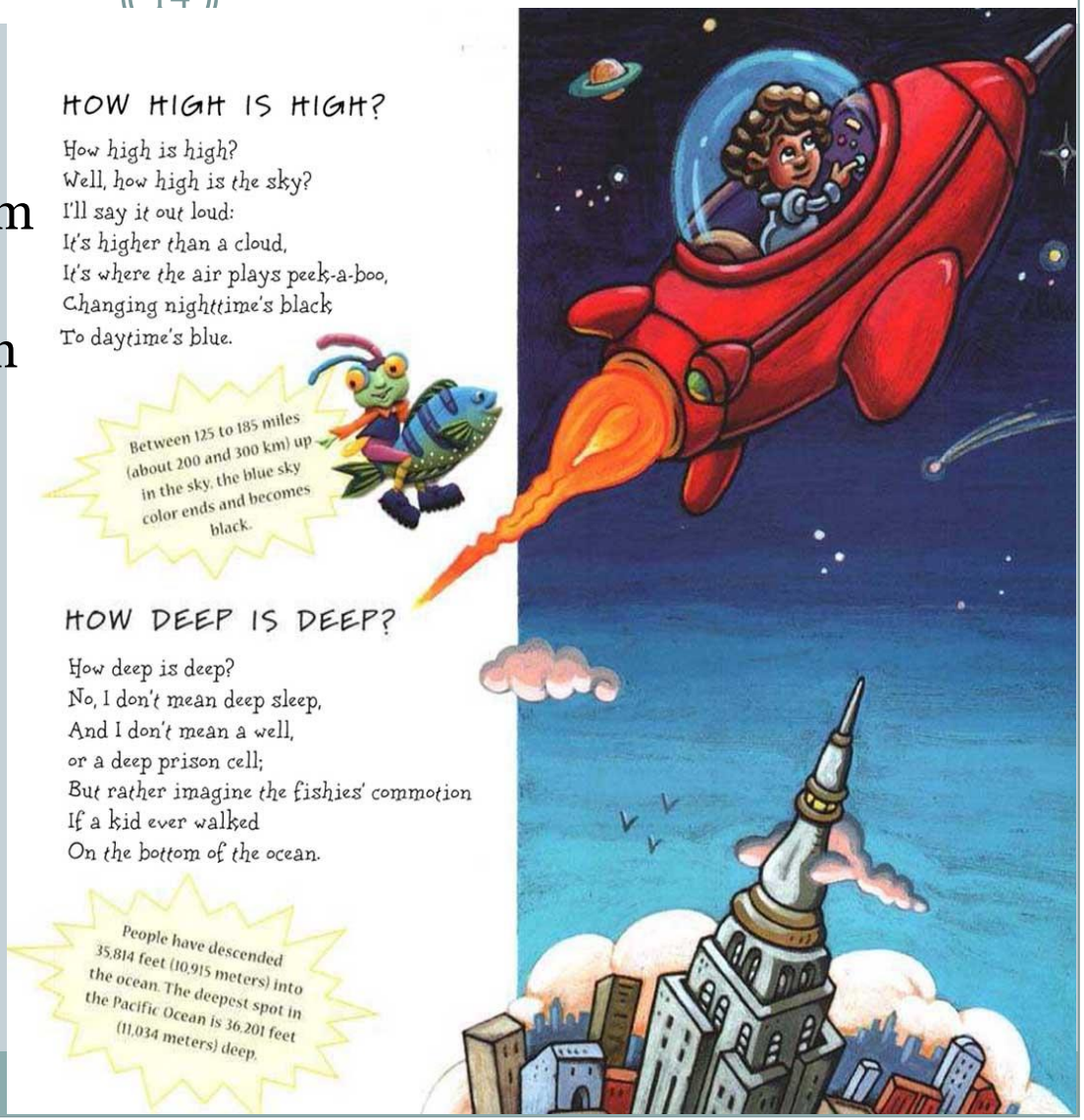
Offshore drilling & production records

- World's deepest oil well is Komodo-1, offshore Colombia, at water depth of ~3,900ms (~13,000ft)



Offshore: How deep is deep?

- Shallow-water: <200m (diver's reach)
- Deep-water: 200m to 1500m (656ft to 5,000ft)
- Ultra-deep waters: >1,500m (<5,000ft)



HOW HIGH IS HIGH?

How high is high?
Well, how high is the sky?
I'll say it out loud:
It's higher than a cloud,
It's where the air plays peek-a-boo,
Changing nighttime's black
To daytime's blue.

Between 125 to 185 miles (about 200 and 300 km) up in the sky, the blue sky color ends and becomes black.

HOW DEEP IS DEEP?

How deep is deep?
No, I don't mean deep sleep,
And I don't mean a well,
or a deep prison cell;
But rather imagine the fishies' commotion
If a kid ever walked
On the bottom of the ocean.

People have descended 35,814 feet (10,915 meters) into the ocean. The deepest spot in the Pacific Ocean is 36,201 feet (11,034 meters) deep.

How deep can we drill offshore?

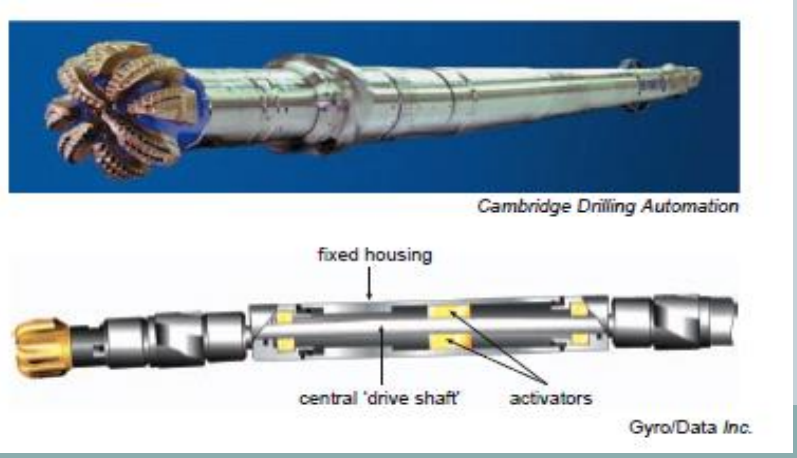
- Drilling rigs designed for ≈3,700m (12,000ft) water depth
- Operations *limited* by:
  - Variable Deck Load (drill string, drilling & completion fluids)
  - Rig hoisting capacity (*f* = total well depth, drilling risers, …)
- Increased water depth risks include:
  - Longer drilling and production risers prone to fatigue & failure
  - Augmented hydrostatic pressure
  - Increased overall drill length, drill string span, well casing, …
  - Extended operational durations
- Formation evaluation tools are a concern:
  - Fluid sampling & pressure measurements done in a single trip
  - Longer logging cables needed
  - Logging-while-drilling (LWD) tools subject to shocks & vibrations



How deep can we drill offshore? (2)



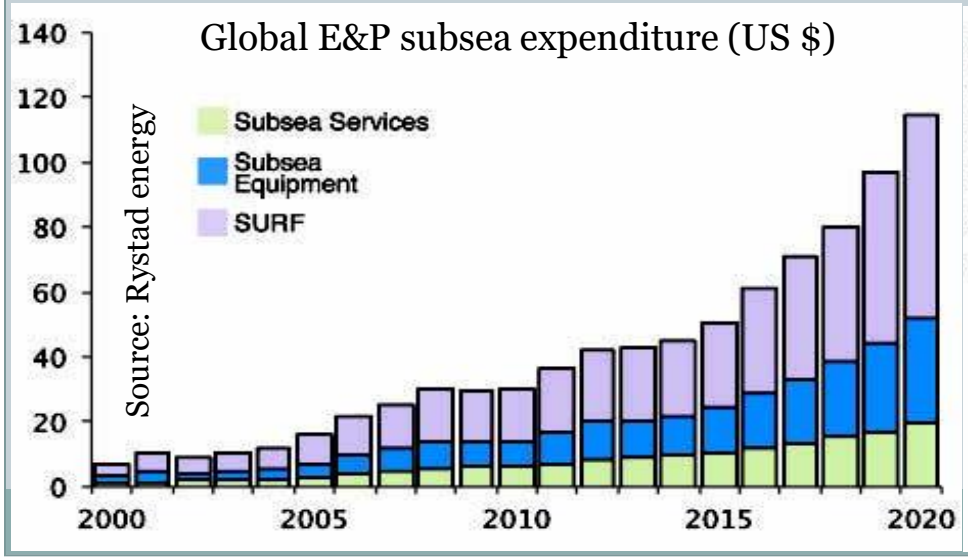
- Rotary steerable systems op. envelope = 175°C
- Flow assurance (wax & gas hydrates)
- Corrosion issues (longer risers, other equipment)
- Longer intervention times
- Other issues: sand management, cementing & perforation
- Downhole pressure & temp. gauges limit = 15 days @ 210°C
- Sealing systems to withstand higher pressures (& temps)

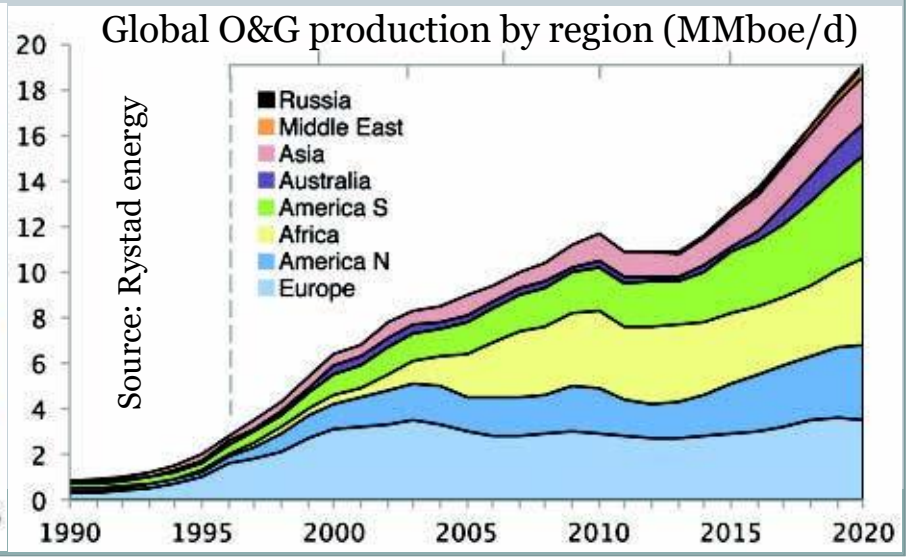




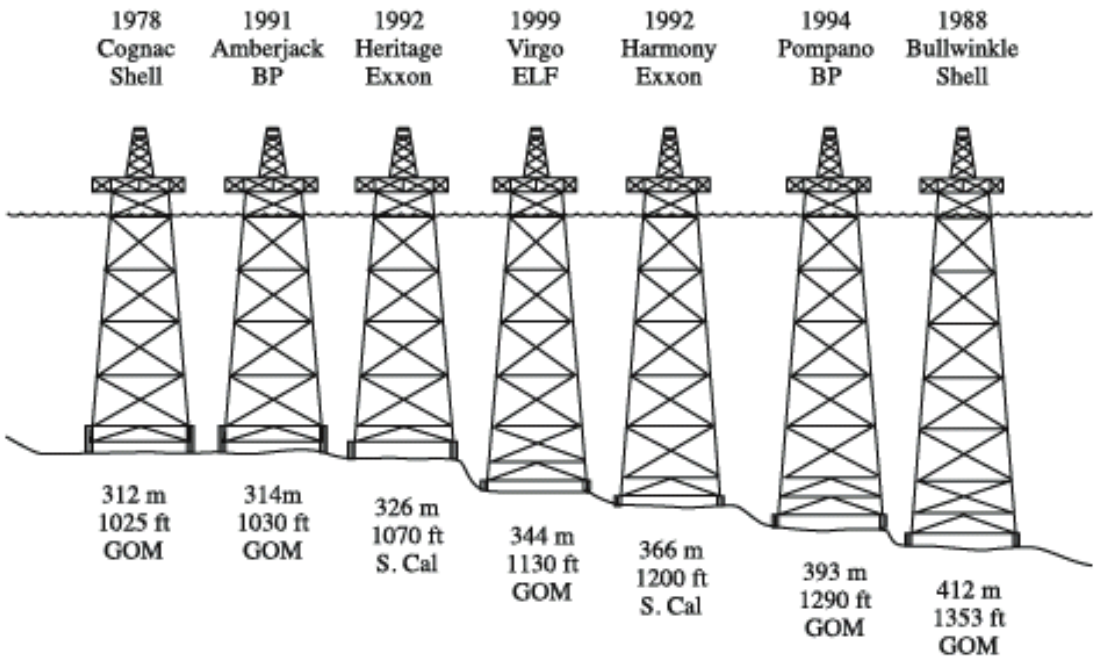
Global subsea market

- Offshore/subsea investments:
  - 2000 → $7bn
  - 2008 → $30bn
  - 2014 → $45bn
  - 2025 → $300bn
- West Africa is an emerging frontier
- Expect to see more subsea boosting & separation





Fixed platforms [to the limit]



Leffler(2011)



- 1963 → 1,000 platforms
- 1996 → 4,000 -||-
- 2000 → 6,000 -||-

Venturing in ultra-deep waters

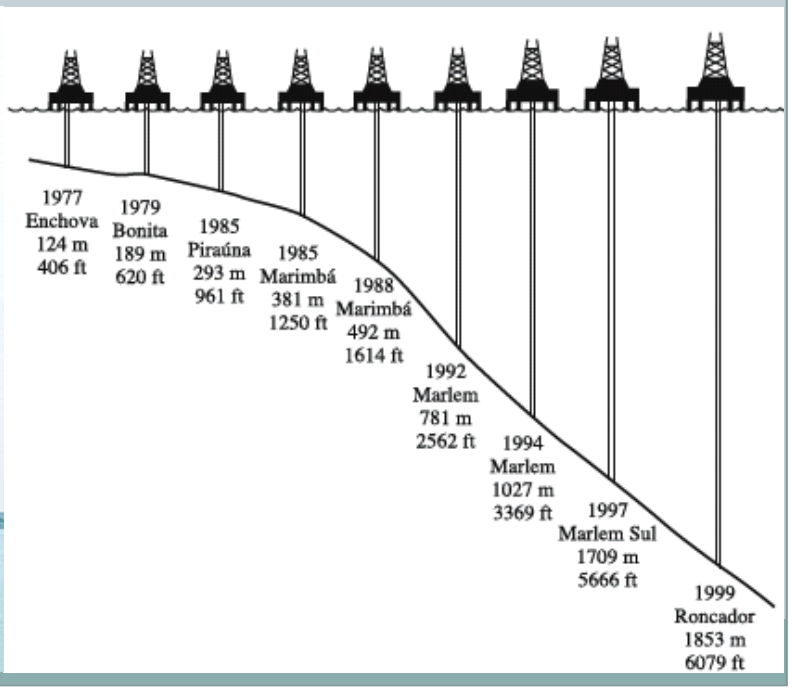
- Petrobras' spate of oil discoveries in Campos basin
- FPS & subsea wells used instead of fixed leg platforms
- Shortened development times & no pipelines, sped first oil
- FPSOs established as reliable oil production systems
- Prosperity FPSO: 220,000 bopd & storage capacity of 2MM of oil

Leffler(2011)



Prosperity cost $1.6billion.

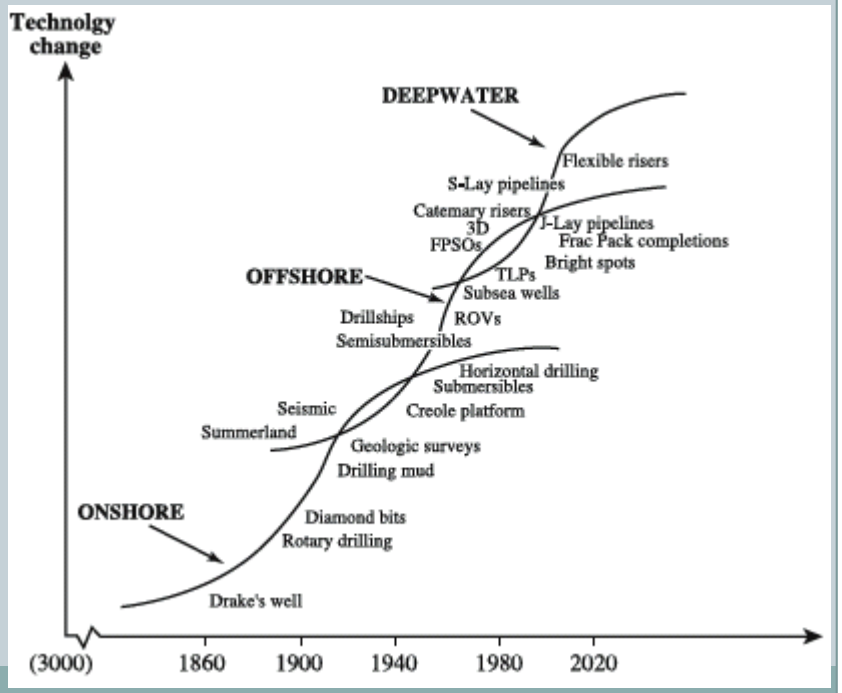
- **~400 MMscf/day** gas processing capacity,
- **250,000 barrels/day** water injection capacity
- **Payara development** (of which Prosperity is a key component) cost about **$9 billion.**



Venturing in ultra-deep waters (2)

- Shell goes after elephant O&G fields in GOM:
  - Substantial 3D seismic acquisition → lowered risk of dry wells
  - Boosted well production profile (7k bbl/d) → fewer wells, lower cost
  - Pre-drilled wells with semi-subs expedited first oil
- ≈30% of petro-infrastructure costs relate to production operations:
  - Flow assurance
  - Transmission of H/Cs from wells to processing plants, refineries & tankers
- Offshore O&G processing to be proved
- Natural gas requires expensive infrastructure for liquefaction
- Most frequently, natural gas is sent to shore by export pipelines

Leffler(2011)



The offshore prize

- Costs are prohibitively expensive & stakes are high. Why go offshore?
- Fewer wells that operate at a higher productivity
- Lack of access to onshore plays (NOCs possess the rights)
- 3D seismic acquisition lower risks
- Technological advances (e.g., synthetic lines) & previous experience
- 'Easy' O&G and shallow fields have been discovered (almost)
- High oil (& NG) prices and H/C demand
- Smaller environmental footprint
- Easier licensing than onshore
- Not easy to harass by environmentalists, terrorists, guerillas

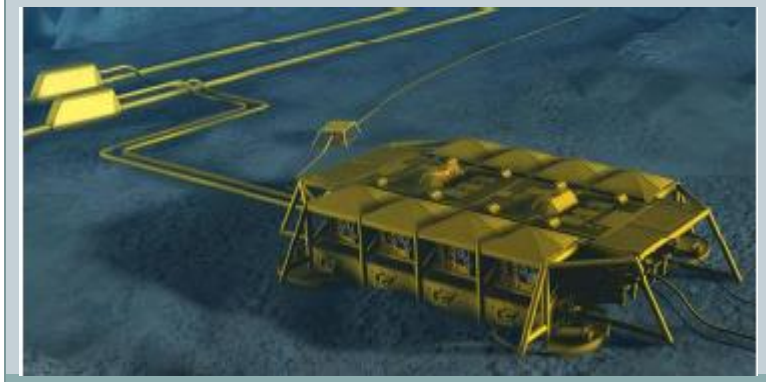






The offshore prize (2)

- Learning curve – repeatability & standardisation:
  - 1992: $.95/boe → 2005: $.4/boe
- Concurrent engineering from design to decommissioning
- Innovations – flexible pipes, ROVs, cranes, DP, seismic acquisition, …
- Subsea templates help lower costs (& environ. footprint)
- Consolidate fluids thru fewer flowlines
- Commence production & then drill additional wells







Current trends– post-2014

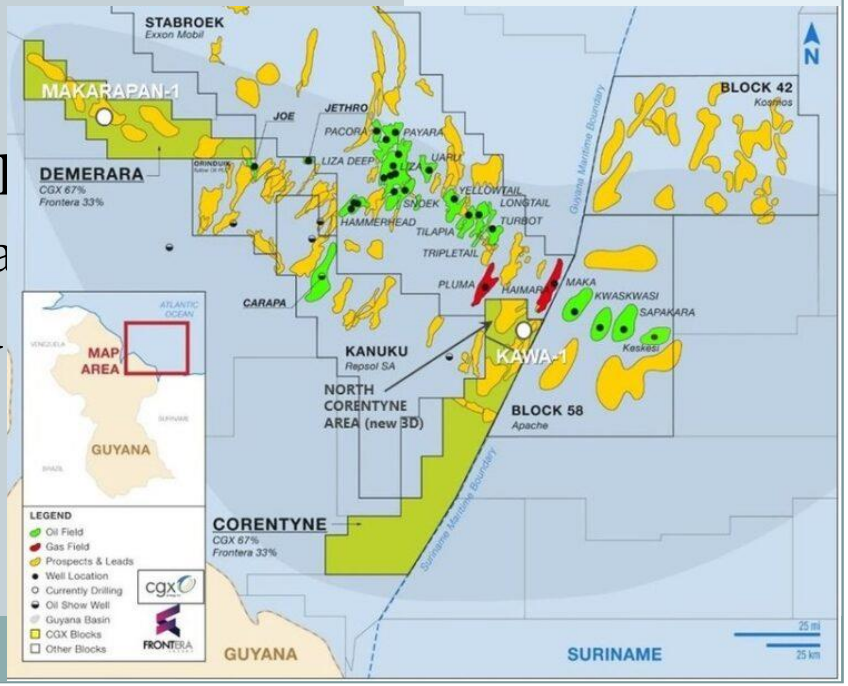


- Emphasis on brownfields
- Obsession with lowering costs
- 'Rig clubs' (rig pooling)
- Standardisation
- 3 weeks on & 3 weeks off
- Go after more productive assets
- Rework development plans
- Lower complexity e.g., 28 different shades of yellow
- Shelve, postponed or cancelled expeditions e.g., Shell's Arctic exploration which cost $7bn
- Case studies: 1) Johan Sverdrup; break-even costs $15/bbl
  2) Offshore Guyana oil discoveries

The Guyana offshore oil bounty

- 2015: ExxonMobil-CNOOC-Hess discover oil offshore
- Reserves: 11 billion barrels of oil.
- Largest addition in reserves since 1970s
- 30 discoveries by Exxon consortium alone
- From 0 to 650,000bbl/d (2026)
- Valuable sweet light crude oil
- Break-even price: $23–$35/bbl
- 30% lower carbon footprint v other bbl
- Profits split 50:50;Consortium:Guyana
- Windfall to exceed $100bn for Guyana
- Resource curse is a major concern







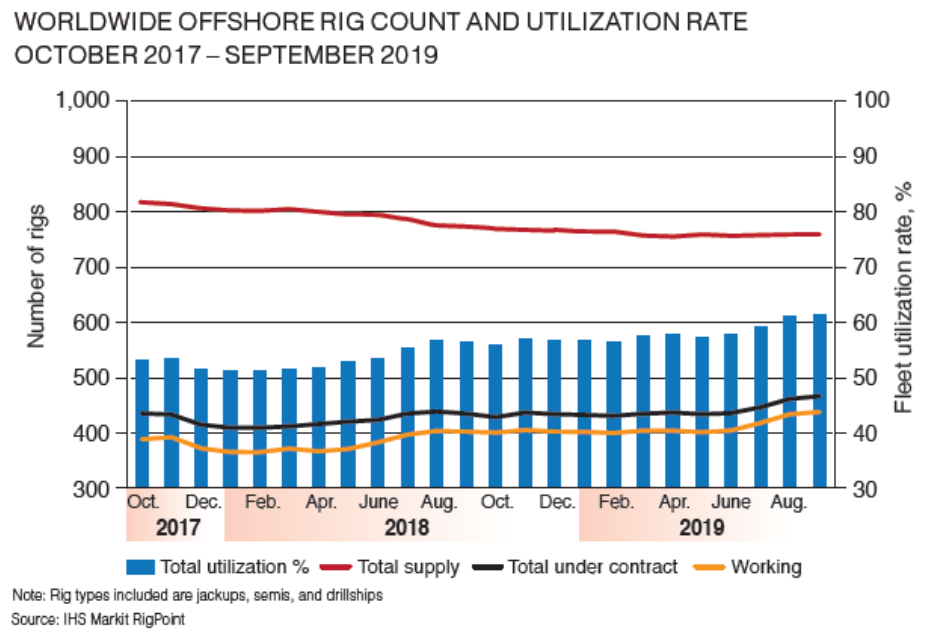


Guyana's offshore oil boom

- Guyana's oil boom.mp4
- Guyana & Suriname-hottest exploration area on the planet.mp4

Offshore drilling rigs

- Floating drilling rigs are divided into:
  - Semi-submersibles (semis)
  - Drillships
- Variable Deck Load (VDL) = drillstring, BOP, fuel, potable water, cement, …
- Average rates (2025): Semis $350-500k/d, Drillships: $550-750k/d



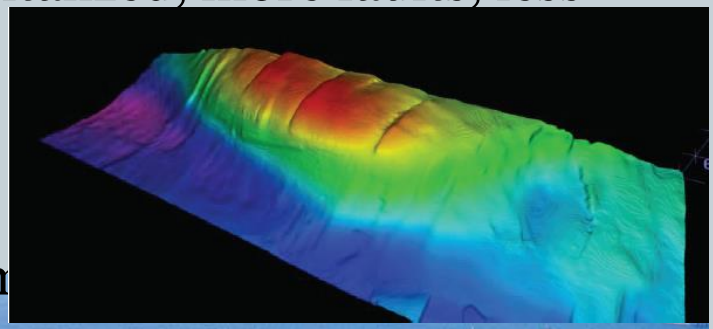
Leffler(2011)

Generation	Era	Water Depth	Variable Deck Load
I	1960s	600 ft	–
II	Early 1970s	2,000 ft	2,000 T.
III	Early 1980s	3,000 ft	3,000 T.
IV	1990s	4,000 ft	5,000 T.
V	Early 2000s	7,500 ft	7,000 T.
VI	2010s	10,000 ft	8,000 T.

Challenges to offshore E&P

- Abnormal (reservoir) geo-pressures & temps
- Eddies (Loop Current, GOM) expose risers to undue stress & vibration
- Excessive geological faulting btw 330m–750m below sea bottom
- Gas pockets jeopardise drilling
- Deepwater reservoirs are more compartmentalized, more faults, less homogeneous sediments & less continuity
- Subsidence of sea floor (e.g., Ekofisk)
- Flow assurance (gas hydrate formation)
- High h/static pressure (H_2O depth >2,000m
- Max. diver depth <330m
- Frigid temperatures (–1 to 2°C)
- Ekofik jacking (10,500 tonnes): 1987

https://www.youtube.com/watch?v=siUpnltiTc8





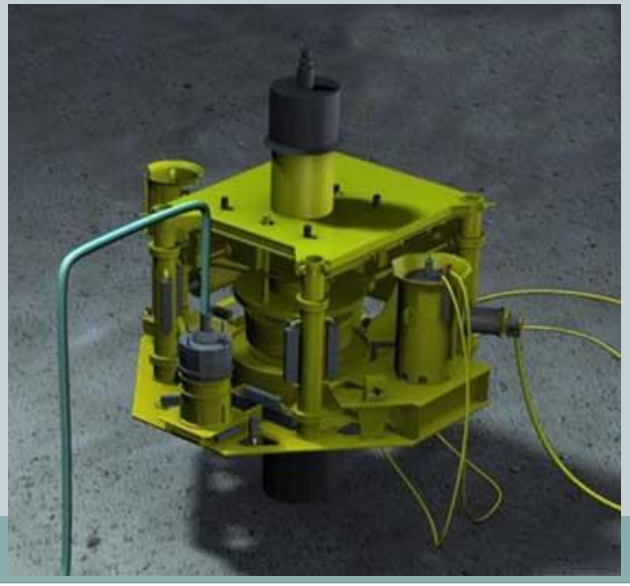
Challenges to offshore E&P (2)

- Harsh environment (wave loads, corrosion, static pressure)
- Geohazards, sour fluids
- Lack for access for equipment installation, maintenance & repair
- Often longer E&P time frames
  - Morphology of seabed– subduction zones
  - Unstable/soft seabed?
  - Seismogenic area
- Soft deepwater sediments
- Metocean conditions: wind, waves, currents, tides, ice loads, etc.
  - North Sea: wind speed: 200km/hr, waves: 30m
  - GOM: Hurricane season: 240km/hr, waves: 25m
  - West Africa: 120km/hr, waves: 8m

"Though we walked on the moon three decades ago, we'll probably never walk on the deep seafloor." Kuznig R. (2001)

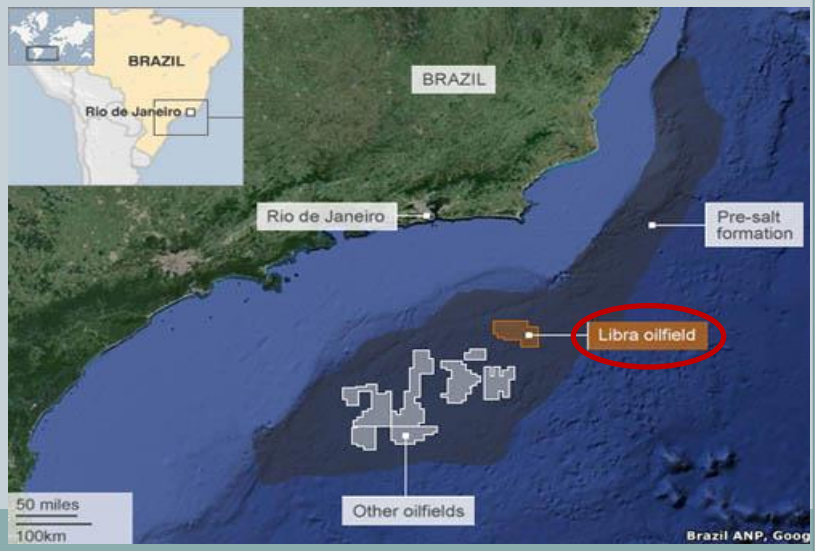
System design challenges

- Lack of human access complicates things
- Need for in-built redundancy (e.g., data retrieval)
- Ease of installation, retrieval & replacement
- Corrosion protection
- Thermal shock management
- Provisions for ROV intervention & ROV friendly design
- Safety standards
- Stringent environmental regulations
- Economic considerations
- Reliability issues
- Rigorous testing
- Electronics & materials' challenges
- Immersed in water (waterproofing)
- Dropped objects (shipwrecks, airplanes, etc.)



Libra oil field (Brazil) case study

- 2010: Offshore Rio de Janeiro (Santos basin)
- Super-giant: 8–12 bn barrels, water depth: 2,000m
- Bidding process for production rights: 21 Oct., 2013
- Anticipated interest: 40 companies, 6 consortia
- Expected investment: $200bn spanning 35 years
- Future production: 1.4 MMbp/d
- Operator: Petrobras
- Consortium: provides the funding
- Results?



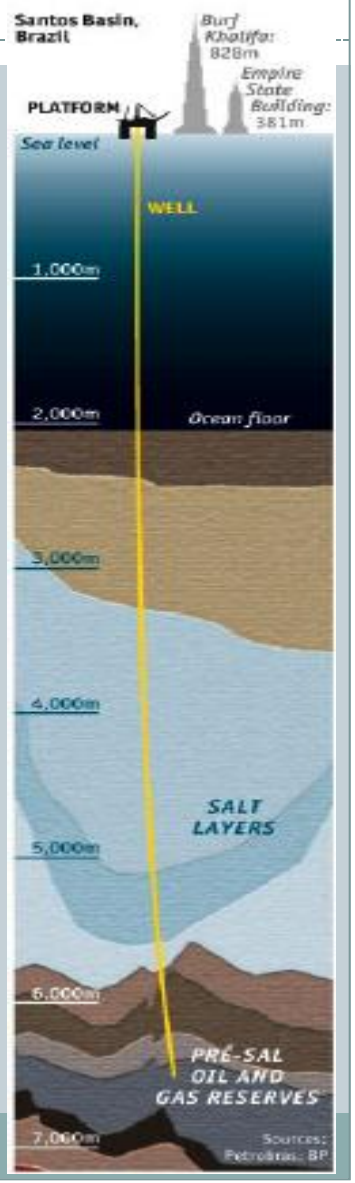
Libra (Brazil) case study

- 1 consortium applied: Shell, Total, CNOOC, CNPC
- Potential earnings: $1 trilling (30 years)
- Of 40 firms, only 11 expressed interest & 9 took part
- Results: mixed success.

- Lesson(s):

  The licensing framework is extremely important but so is offshore E&P *knowhow* and financial standing!

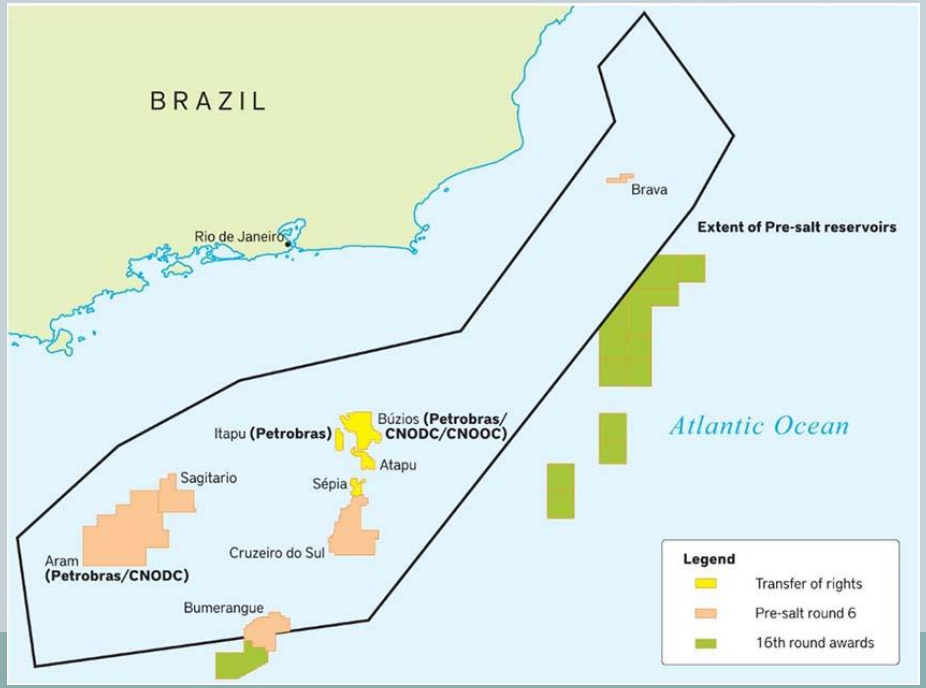




Brazil big bet backfires

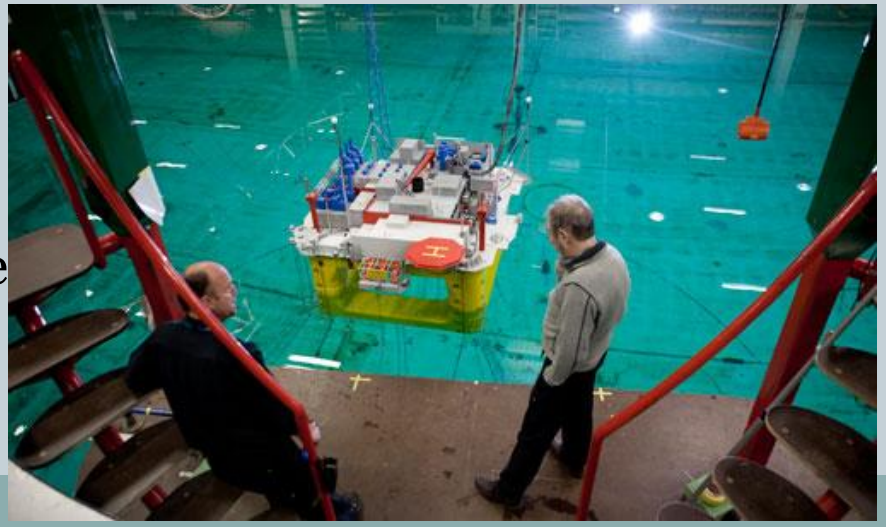
- 6/11/2019: Brazil auctioned 4 offshore blocks
- Expectation to catapult production from 3 to 7mbpd by 2030
- Upfront fees: $26bn, instead earned $17bn
- Discoveries: Buzios, Itapu, Sepia & Atapu
- Only Petrobras, CNOOC, CNDOC bid
- Chinese to hold a 5% share





Better technologies & innovations

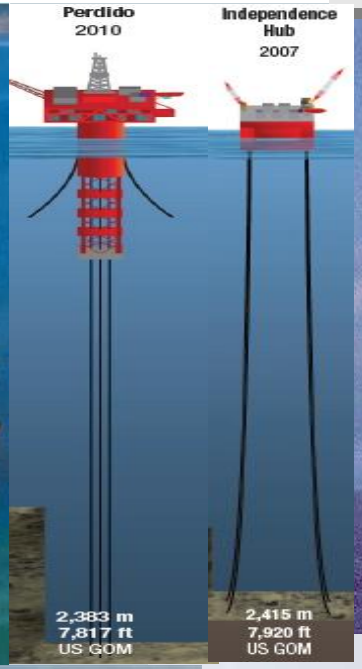
- Testing facilities (water tanks, materials tests)
- Advanced materials (e.g., flexible risers)
- Virtual reality modelling
- New technologies (e.g., subsea compression, AI tools)
- Advances in computational power
- Sophisticated computer models (simulation tools)
- Lines: synthetic polyester lines *vs* chains & wires
- Communications, e.g., fibre optics
- More dexterous ROVs
- Dynamic positioning (DP3)
- Artificial intelligence tools for wave prediction & structural behaviour



Offshore drilling & production systems









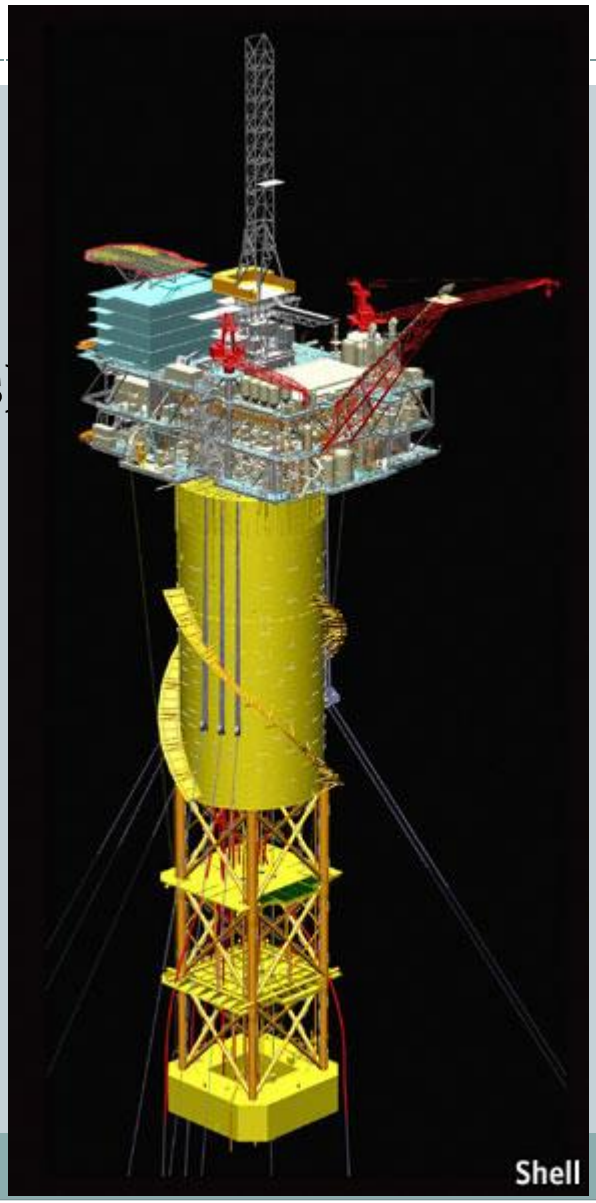






Offshore projects' requirements

- Water depth, total drilling depth
- Riser sizes, pressure levels, …
- BOP specs
- Hook load capacity (8th gen vessels:1,540 tonnes)
- Health & safety issues
- Gov't & EU regulations
- Reservoir characteristics & location
- Risk investment targets
- Host Gov't expectations
- Environmental considerations
- Time frames and ambitions
- Knowledge transfer, etc.



Onshore (shallow waters) *vs.* Offshore E&P

Offshore

- Complex
- Time intensive
- Very costly (€45m/well)
- Intervention done using ROVs
- Dedicated know-how is necessary
- Weight and space restrictions
- Floating facilities, stability issues
- Fewer suppliers (FMC, Aker Slts, Cameron, Vetco Grey, Drill-Quip; ABB, Siemens, Prysmian)
- No utilities offshore. All light, H_2O, power & living quarters, etc. have to be installed

Onshore (& shallow waters)

- Less complex
- Less time demanding
- Less costly (~(1/10)×)
- Simplified well intervention
- Easier to find knowhow & suppliers
- No weight and space limitations
- Stable foundations
- Numerous suppliers
- (1) Platform has to be installed above sea level before drilling & process facilities can be placed onshore.
- (2) Solid foundations alleviate stability issues

Shallow- *vs* deep-water developments

Shallow-water

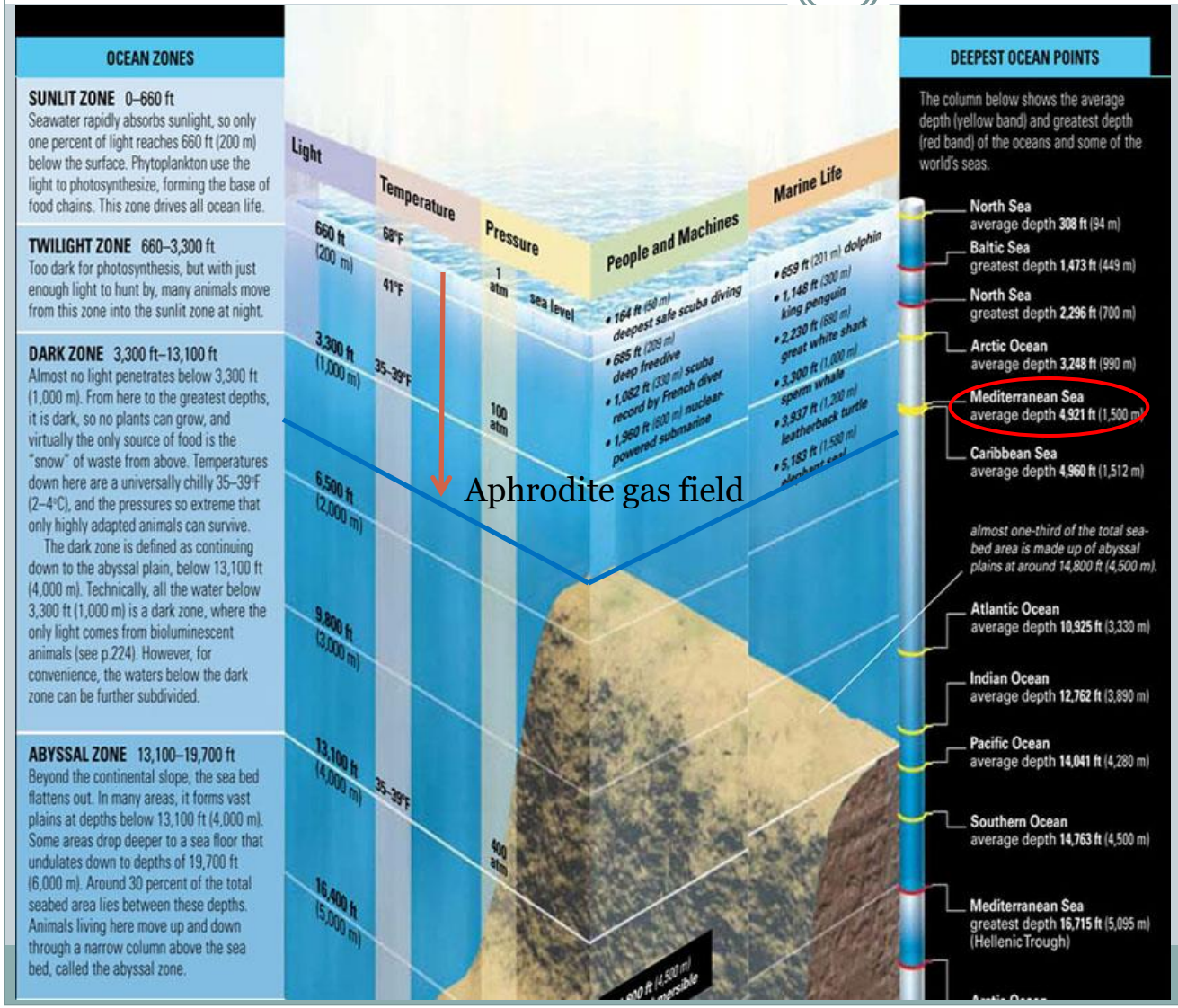
- Equipment design: diver intervention;
- No need for an ROV;
- No pipeline insulation or heating;
- Hardware installation limited by vessel size;
- Small(er) umbilicals;
- Maintenance & repair done by divers;
- Proven technologies, …

Deep-water

- Equipment design diver-less intervention;
- ROVs are indispensible;
- Pipeline insulation may be needed;
- Water depth complicates equipment installation;
- Larger diameter, longer & more expensive umbilicals;
- Maintenance & repair done remotely;
- Material limitations, …

Ocean environment

Ocean environment









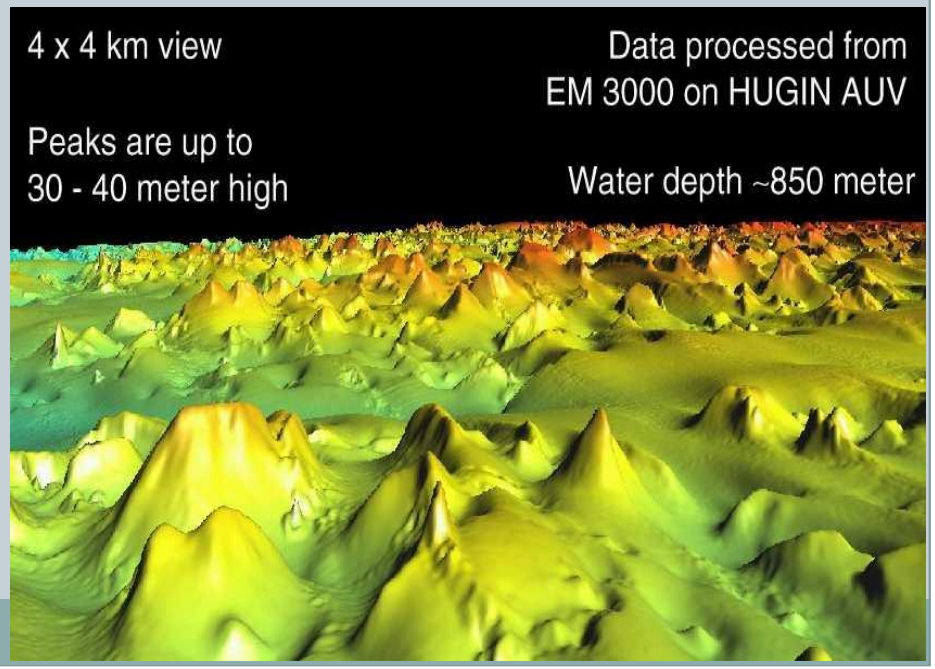
Marine environment

- Salinity
- Corrosive nature
- Pressure variation
- Sea water temperature = –2°C to ~2°C
- Geohazards
- Oxygen levels
- Sea motions (& loads)
- Cold temp. can form hydrates or paraffins which can occlude flowlines and/or pipeline & equipment



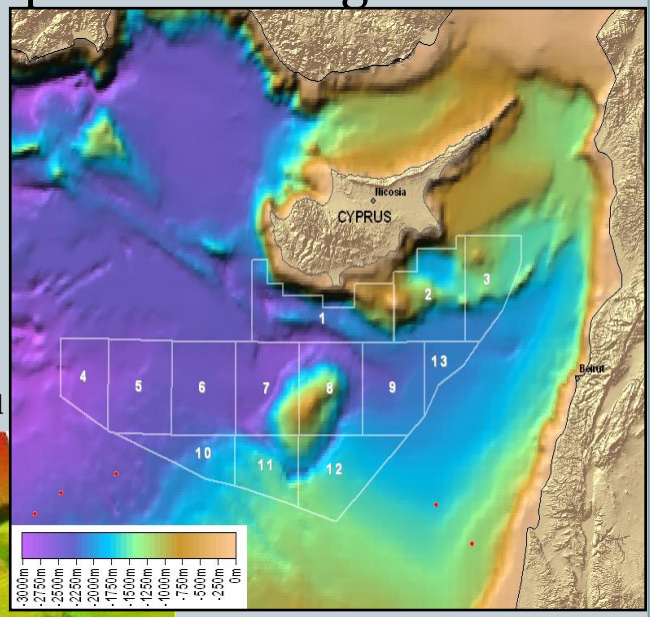
Subsea terrain survey

- Identify potential:
  - Man-made hazards
  - Geo-hazards
  - Engineering & physical constraints
  - Impact of biological communities on hardware
- Sea bottom survey conducted by depth-finding sonar
- Field development encompasses:
  - Geophysical survey
  - Geotechnical survey
  - Bathymetric mapping
  - Soil investigation
- ROV visually inspects sea bottom



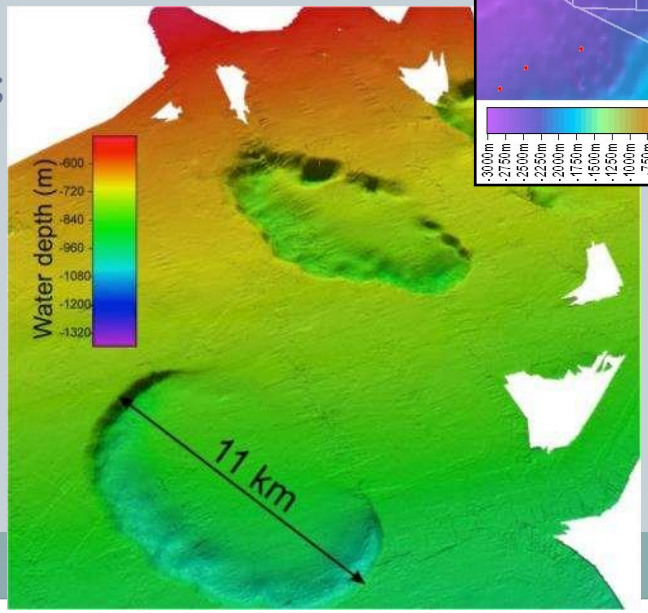
Route surveys

- Bathymetric mapping helps determine water depth & seabed gradients
- Corridor ranges btw 8–10km wide
- 1 geotechnical borehole at km points (KP)
- Other tests comprise:
  - Sea floor thermal conductivity;
  - Bacteriological tests;
  - Geochemical tests;
  - Geotechnical tests.



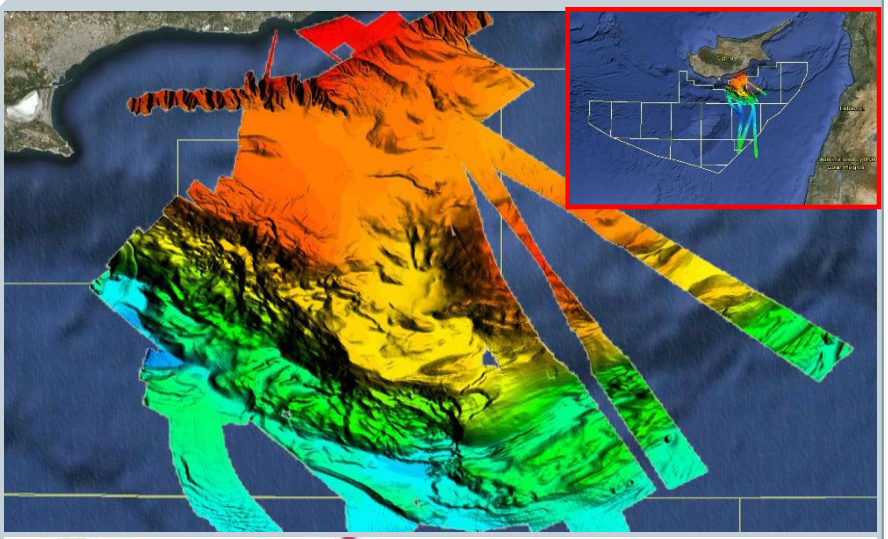
Bathymetric map, East Med

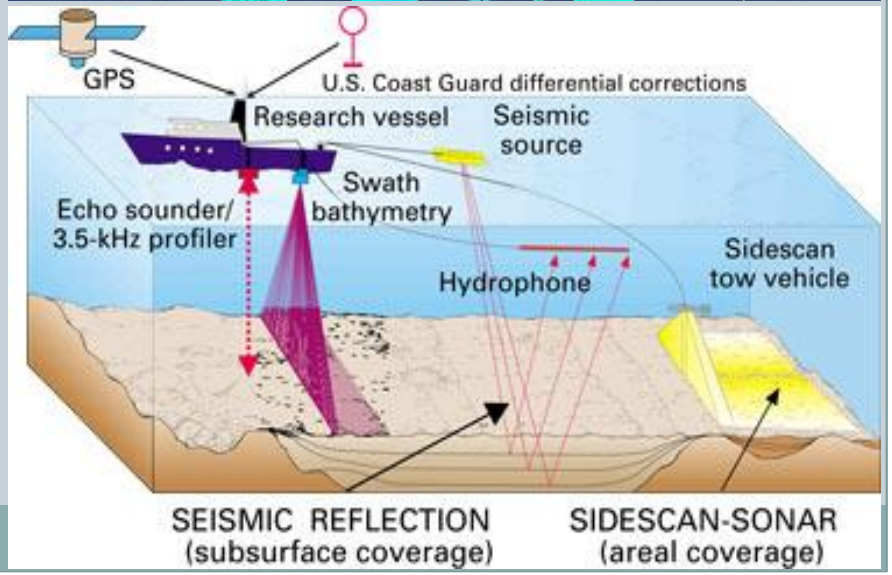
Sea pock, Chatham Rise, New Zealand



Route investigation

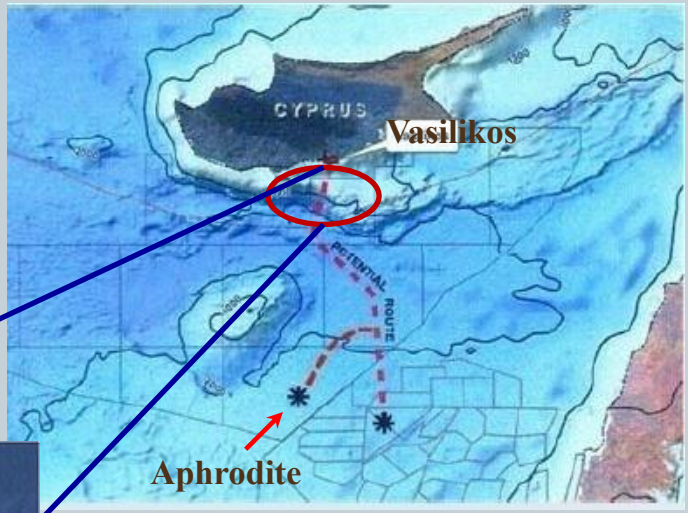
- Desk study to collect:
  - Approximate bathymetric data
  - Regional geology
  - Potential geohazards
  - Seabed obstacles & other features
  - Local met-ocean data
- Geophysical investigation:
  - Bathymetry (echo sounding)
  - Sea-floor mapping (side-scan sonar)
  - 3D seismic surveys
- Geotechnical investigation
  - Recovers seabed samples
  - Typical duration spans 1 year
  - Costs about $2m

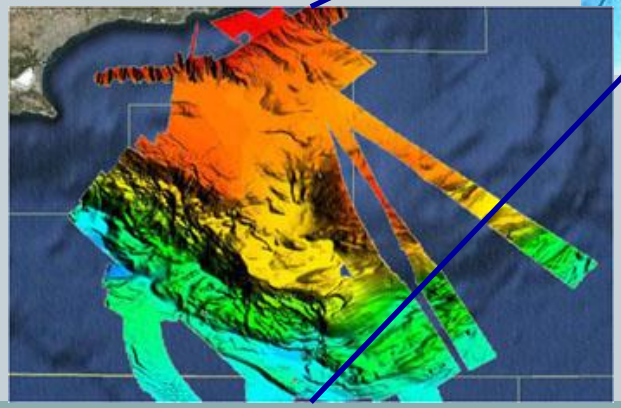




Geo-hazards

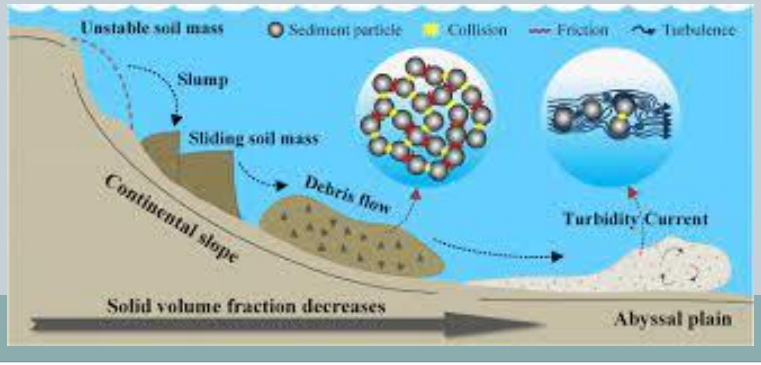
- Hazards arising from *geological* or *geotechnical features*
- Geohazards endanger the *integrity* or *serviceability* of a structure
- Typical offshore geohazards include:
  - Submarine (land)slides (e.g., Storegga slide);
  - Gas seeps;
  - Mud volcanoes;
  - Debris flow;
  - Gas hydrates;
  - Shelf edge erosion;
  - Subduction zone;
  - Gas chimney;
  - Seismogenic zones;
  - High velocity flow;
- Remove, monitor or avoid threats

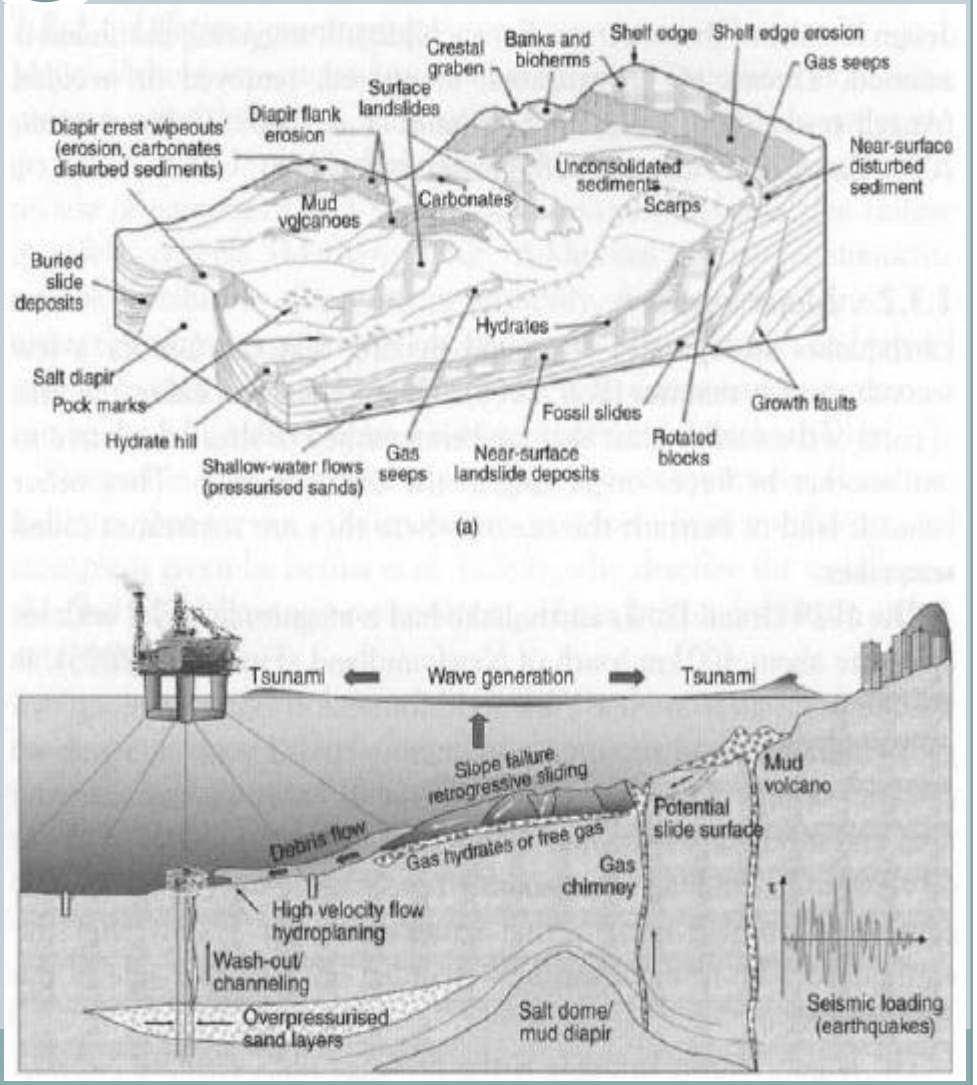




Typical geohazards

- A seismic episode can trigger a turbidity current
- Platforms are designed to withstand the forces from turbidity currents





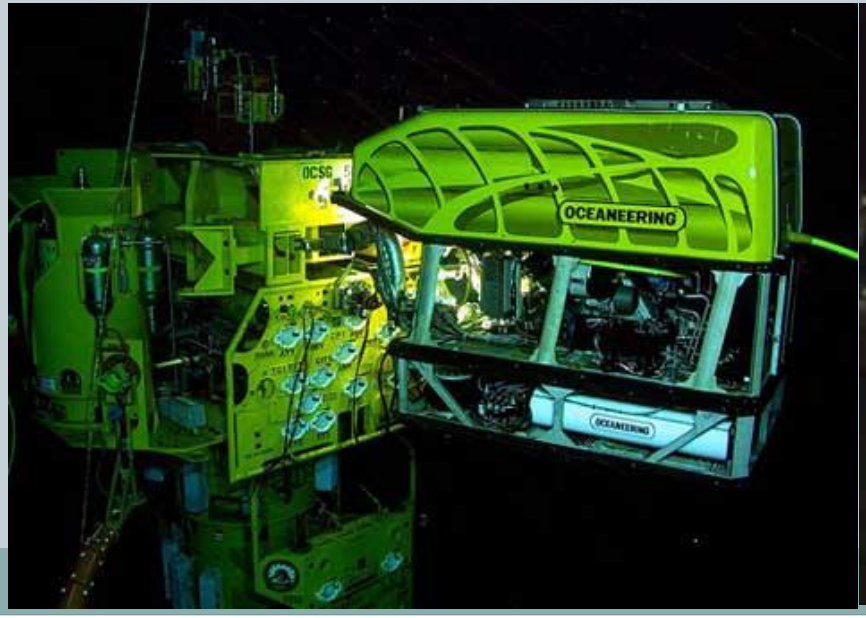
Offshore rigs & limitations

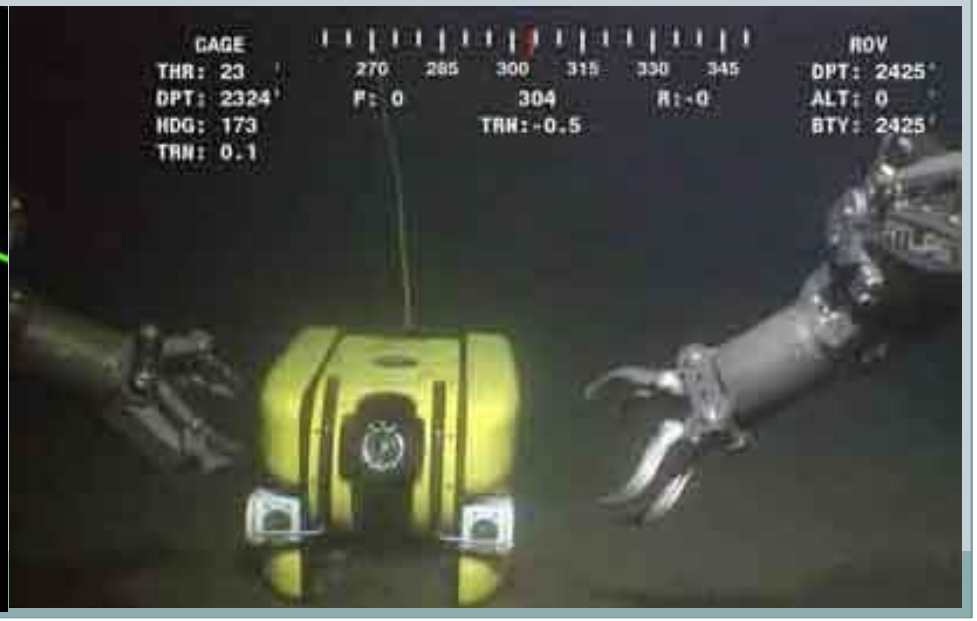
- Categories:
  - Semi-subs
  - FPSO & FPS
  - Spars

Offshore platforms	Appr. water depth (m)
Steel jacket (fixed) platforms	≤ 500
Compliant towers	330 to 1,000
Gravity-based platforms	330
Tension leg platforms (TLPs)	1,530
Spars (Classic, truss, cell)	no limit (yet)
FPS (incl. FPSO, FDPSO, FLNG, FLPG)	no limit (yet)
Subsea development	no limit (yet)

Remotely Operated [underwater] Vehicles (ROVs)

- Advances in ROVs expedited deep-water E&P (>330m)
- How do you mount a wet tree on the well head @ 2,000m water depth?
- Nearly all deepwater rigs have a [subcontracted] ROV
- ROVs are tethered using a buoyant line or a load-bearing umbilical
- Equipped with manipulator arms, sonar, camera, lights, hydraulics, …
- Floating pack offers buoyancy using syntactic foam





ROVs (2)

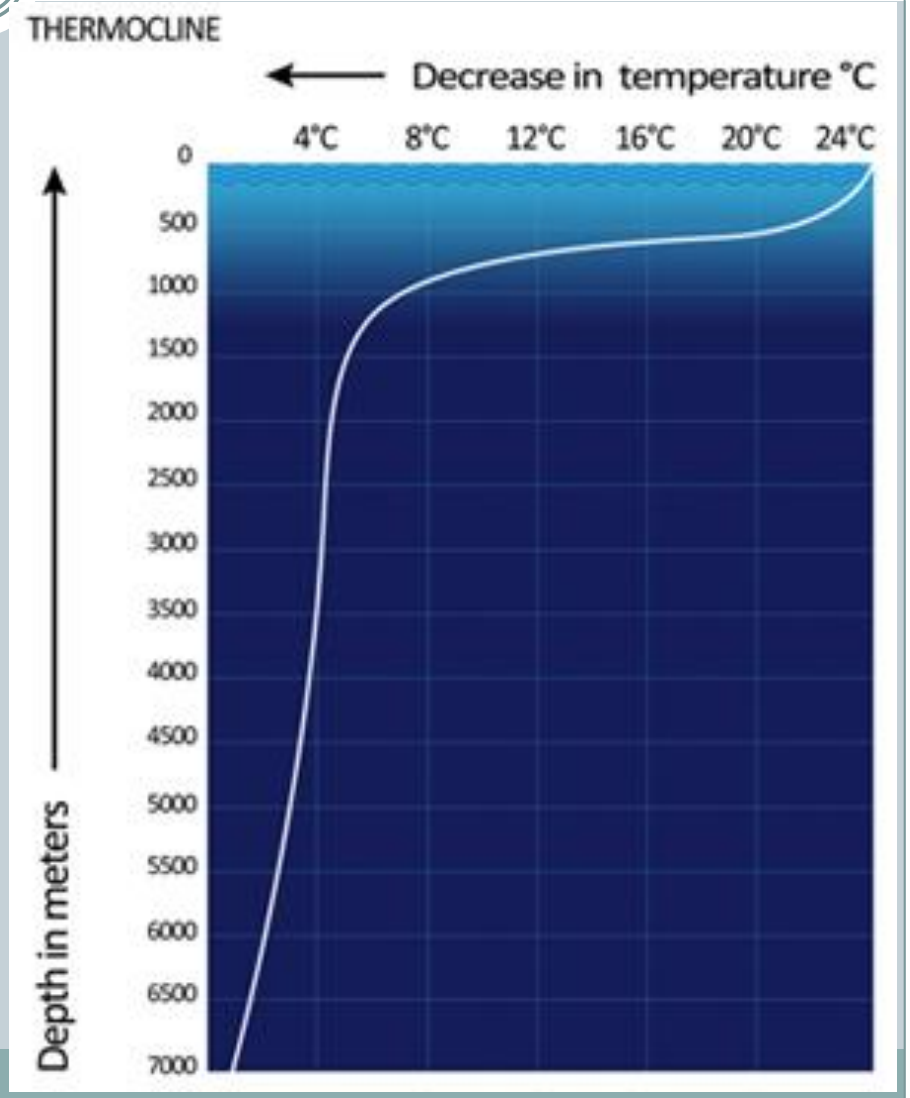
- ROVs divided into: (i) *inspection* & (ii) *work-class*
- Propulsion realised via electric or hydraulic thrusters
- Most ROVs deployed in a cage connected to 1km tether & transponder
- *Inspection* type check pipeline thickness & 'listen' to sand particles
- *Work-class* equipped with cable cutter, wrenches, awl, pincer, etc.
- Manipulators have a *7 degree of movement* like human hand





Subsea conditions

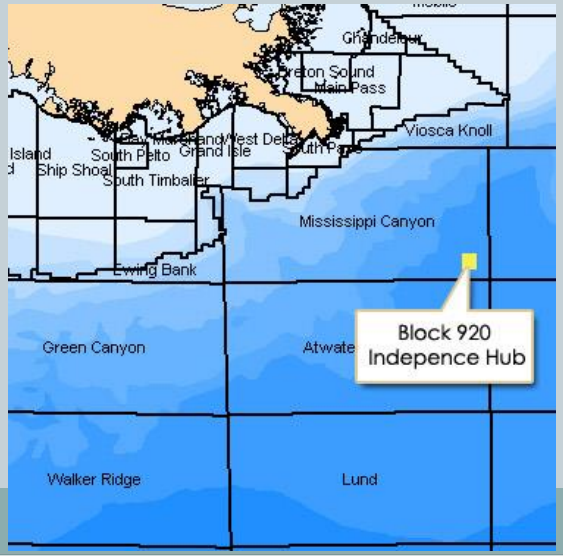
- Thermocline phenomenon: temp. varies more rapidly with H_2O depth
- Sea water freezing temp. @ –2.3°C
- Mediterranean seabed temp.: 13°C @ 2,500m



Case I: Independence Hub (GOM)

- Natural gas offshore development
- Completion date: 07/2007
- Field water depths: 2,350 m to 2,750m
- Estimated cost: $2bn
- Production: 28.3 MMcm/d
- Semi-sub platform cost: $≈420m
- Export pipeline length: 140 km (24”), cost: $280m







Case II: Akpo FPSO

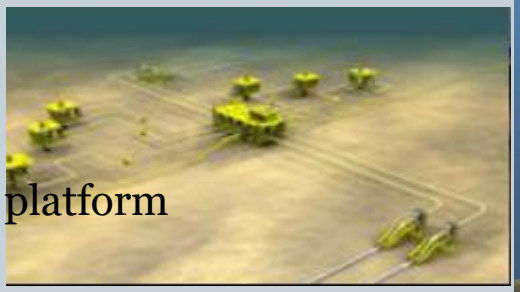
- Offshore Nigeria: Usan development
- Production: Feb., 2012 (Operator Total SA)
- Consists of 42 wells (23 producing, 19 water & gas injectors)
- Akpo FPSO costs: $1.6bn; 320m by 61m
- FPSO can process 180,000 bbld, 5MMcm/d
- Development costs: ~$4bn
- Storage capacity: 2MMbbl

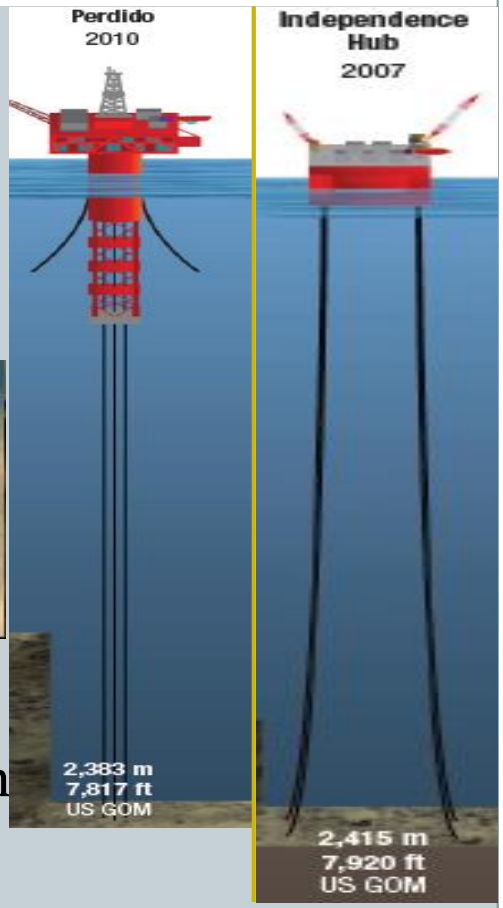




Concepts for the Aphrodite gas field

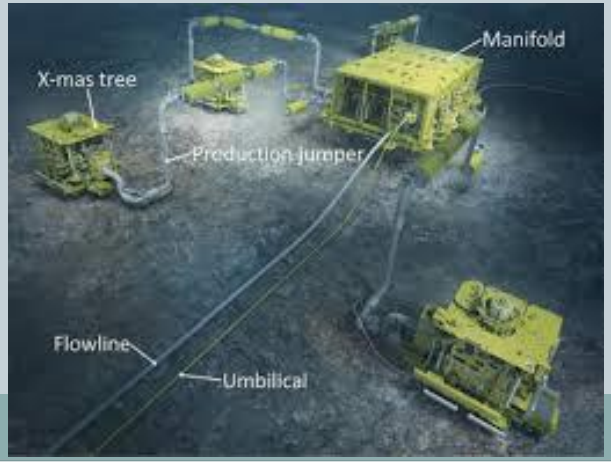
- Subsea architecture– Dry or wet wells
  - Floater: spar-based or semi-submersible
- Flowlines – manifolds – umbilicals
- Hydraulic & electrical power & control, communications
- Flexible marine risers
- Costs:
  - Independence Hub: $2bn — $420m platform
- Development costs: $3.5+$2bn
- State revenue: $9.5bn
- Cyprus gas needs alone do not justify the developmen





Subsea production systems

- Subsea production systems create large savings because are unattended
- High OPEX for:
  - Well servicing
  - Subsea intervention
  - Mobilise expensive & specialised vessels & crew
  - Reliability lowers OPEX
- 1982: First subsea manifold installed offshore brazil
- Later, Petrobras installed first electric subsea pump
- 2010: sea floor separation & water reinjection.



Closing remarks

- Post-2020, offshore H/C prod will continue as a growing frontier
- Offshore developments pose numerous formidable challenges
- Understanding these risks & problems is vital
- Need to mitigate geohazards
- Innovations are central to pushing the E&P boundaries
- New tools, techniques, and instruments will be needed
- Handful of majors, IOCs, OFS & quasi-NOCs will lead the way
- Environmental matters will assume more importance
- Reliability poised to help lower operational costs

Ultimately engineering ingenuity is perhaps the only limitation!