Introduction to offshore installations

Constantinos Hadjistassou, PhD
Associate prof.
University of Nicosia
Web: www.carbonlab.eu

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UNIVERSITY of NICOSIA

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

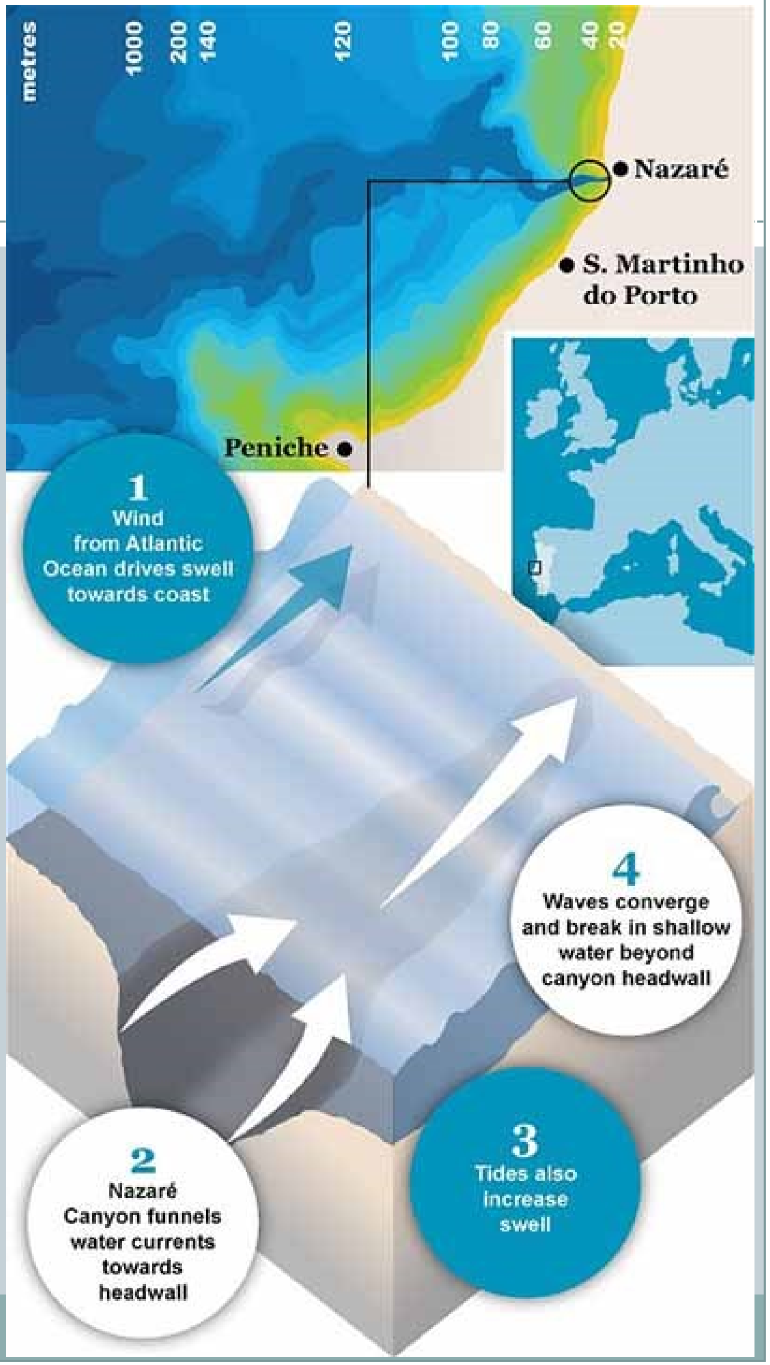
How are 100ft waves created?

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

Nazare's 100 ft waves (2)

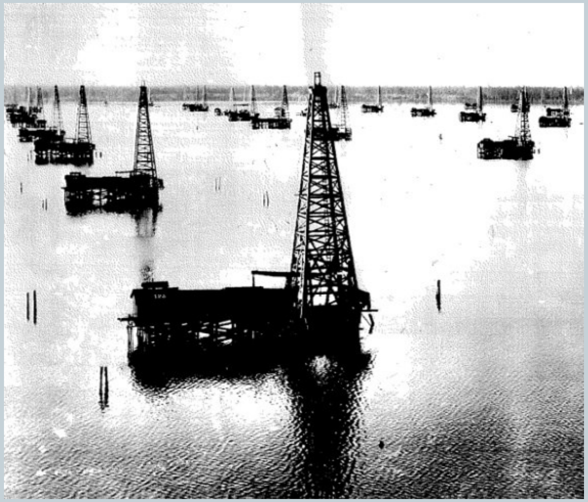
- Nazare Canyon stretches 125mi;
  3mi deepest point
- Canyon depth abruptly rises to 100-150ft
- Factors fostering huge waves:
  - Water currents
  - Winds (storms)
  - Swell
  - Abrupt drop in water depth
  - Submarine morphology

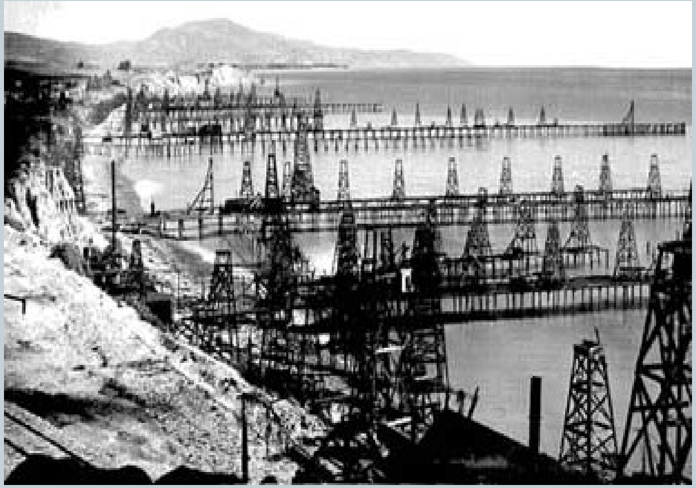
- https://bit.ly/2DRcMNQ

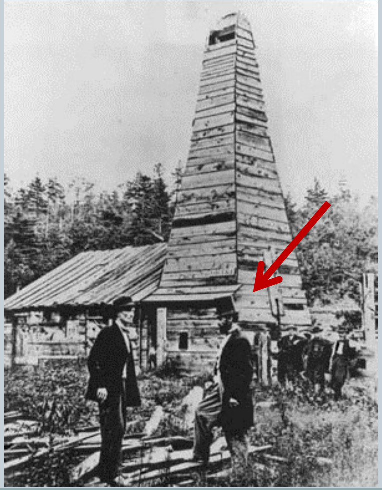


Historical milestones of offshore O&G

- 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





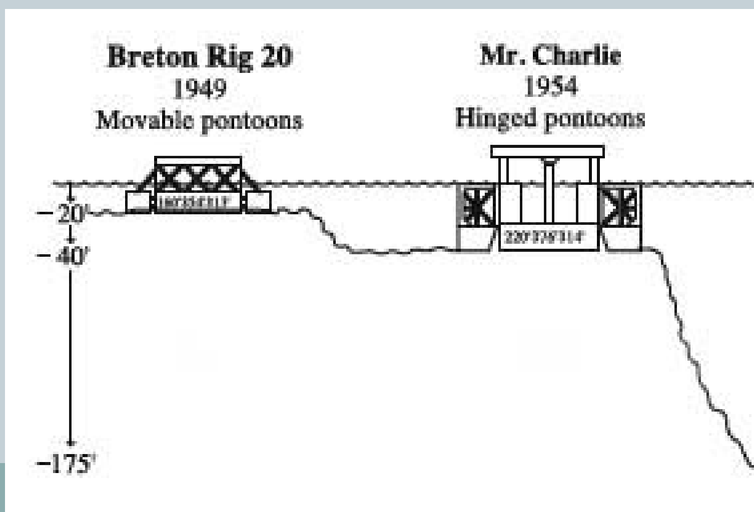


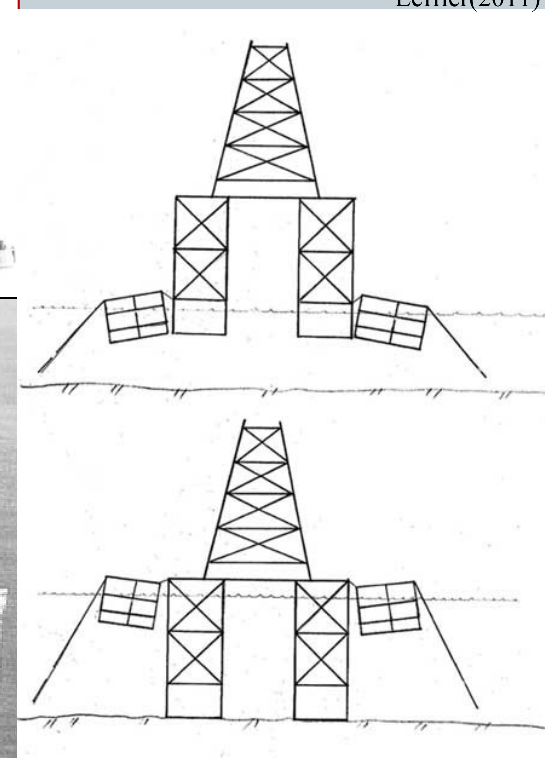
Leffler(2011)

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

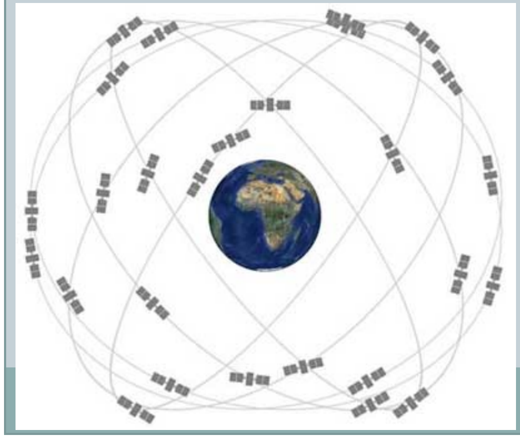
Leffler(2011)

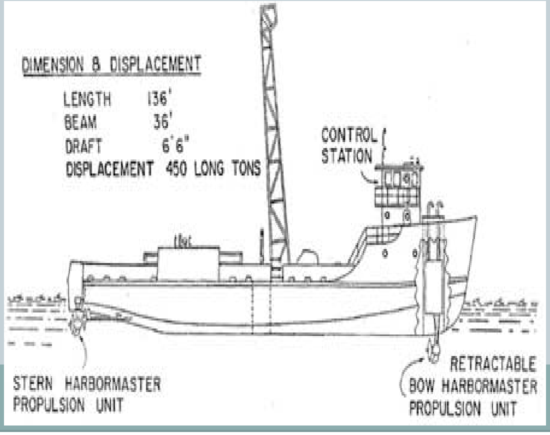


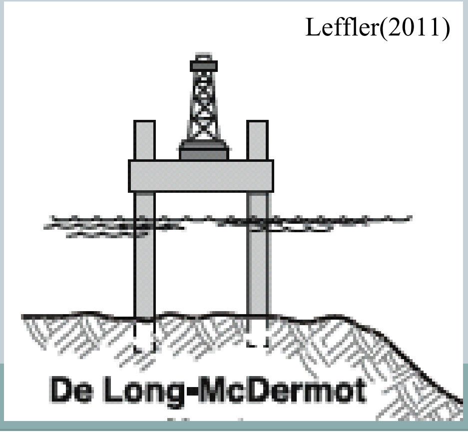


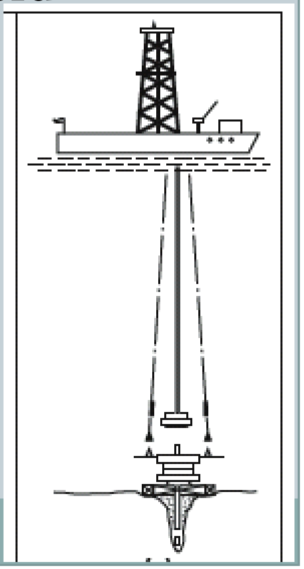
Historical milestones of offshore O&G (3)

- 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



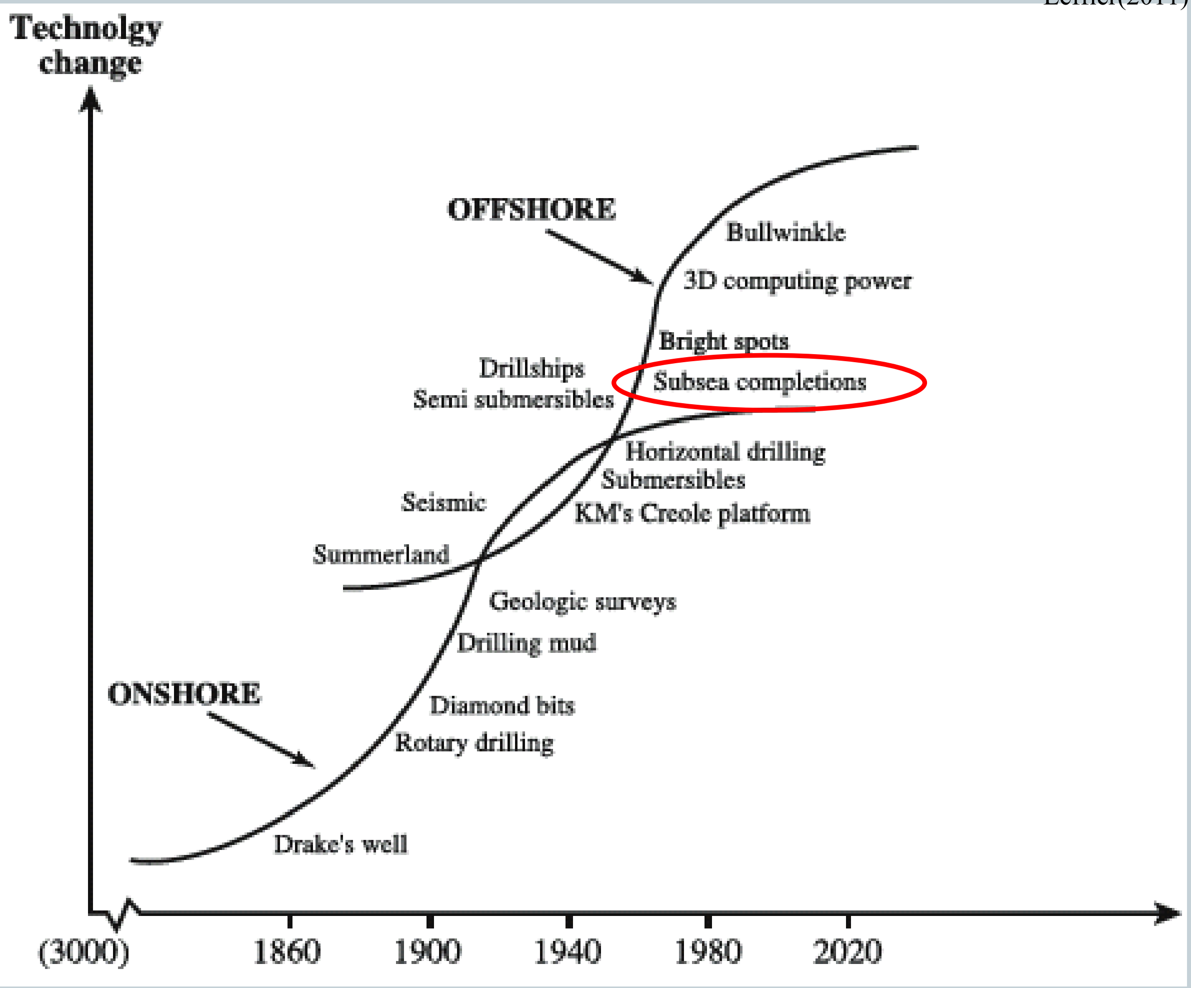






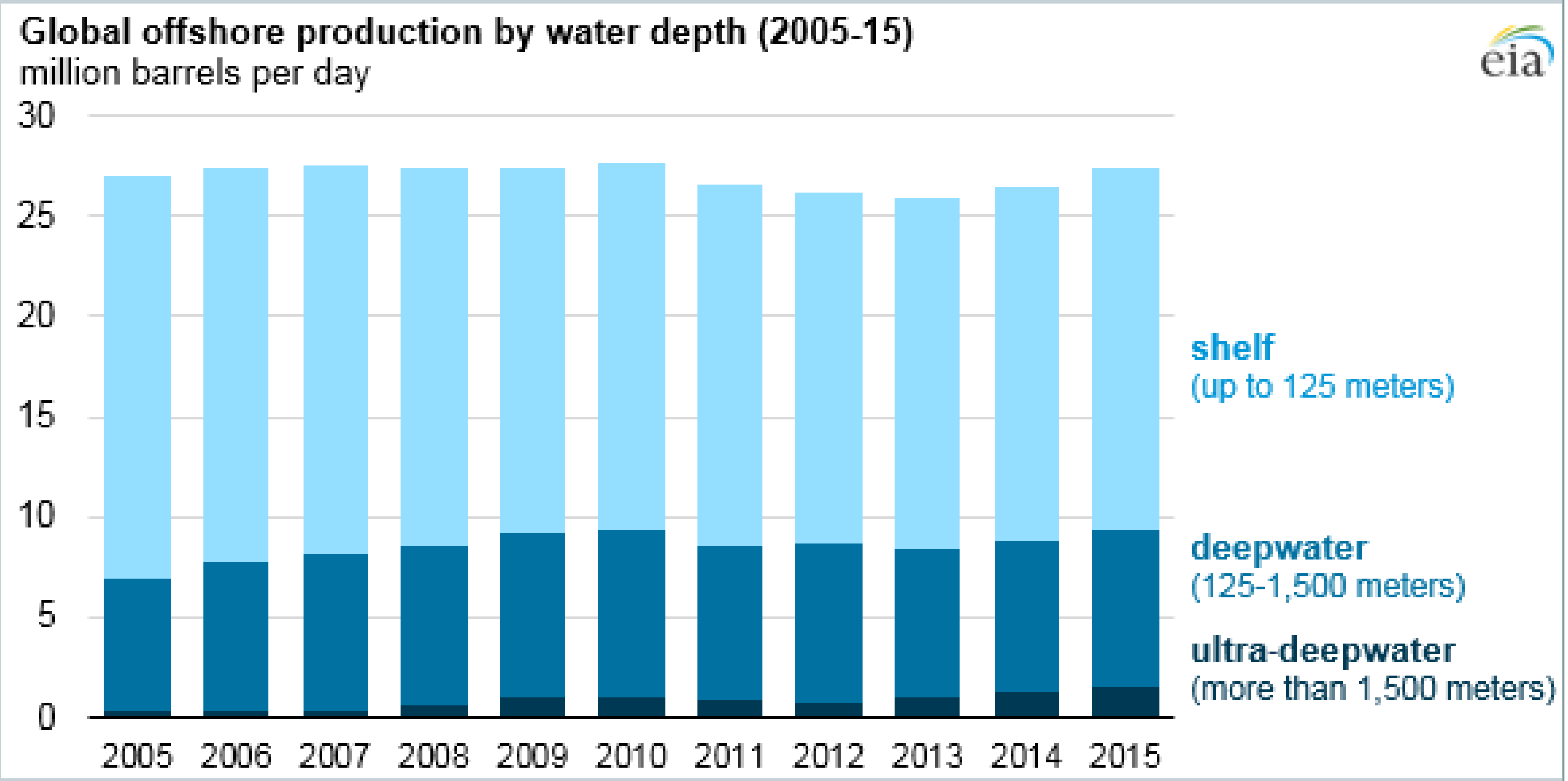
Offshore E&P

Leffler(2011)



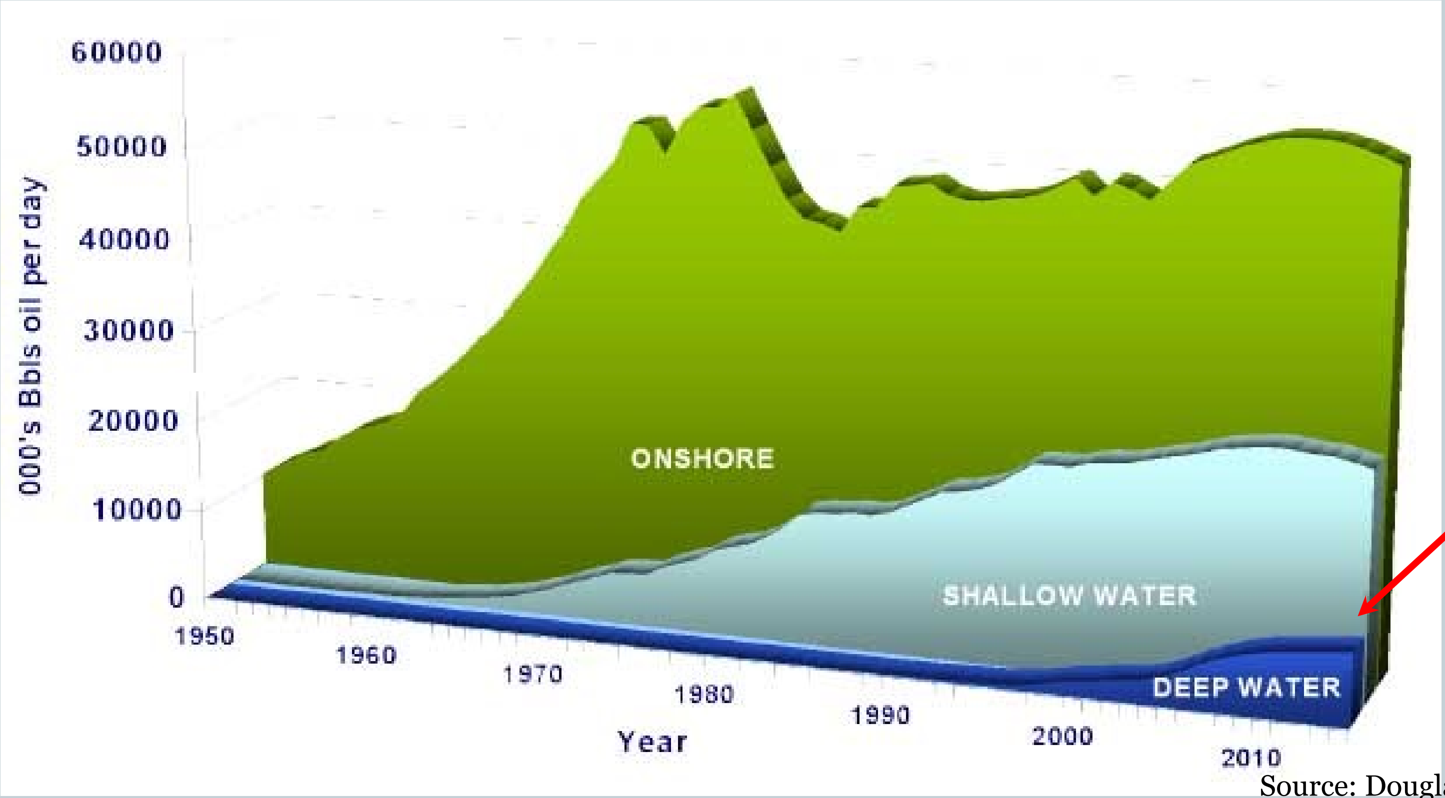
Offshore oil production

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



Offshore oil

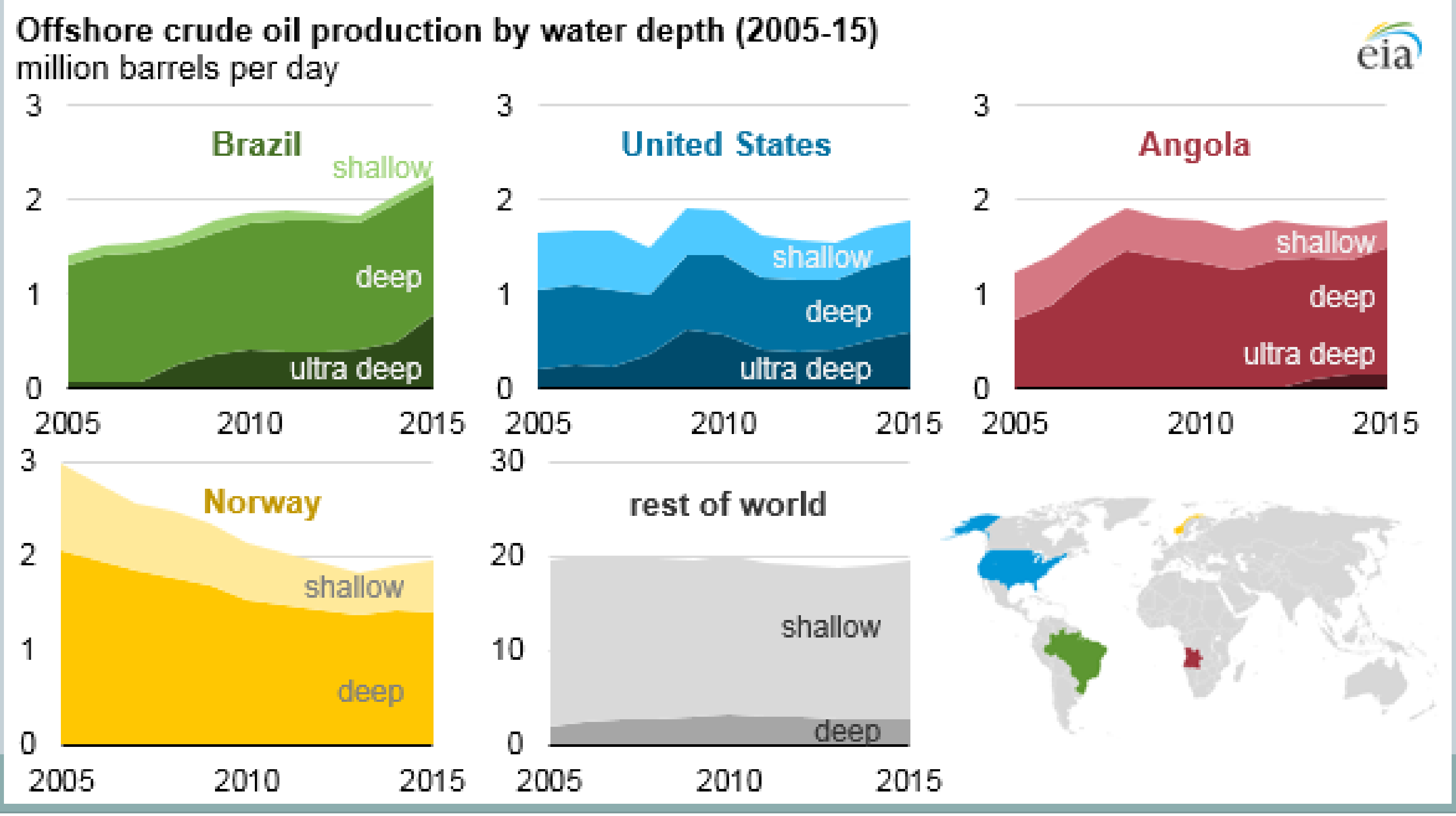
- Deepwater extraction: 3% in 2002 → 6% in 2007 → 10% in 2012
- After 2012 offshore H/C production will *probably* be the *only* growing frontier



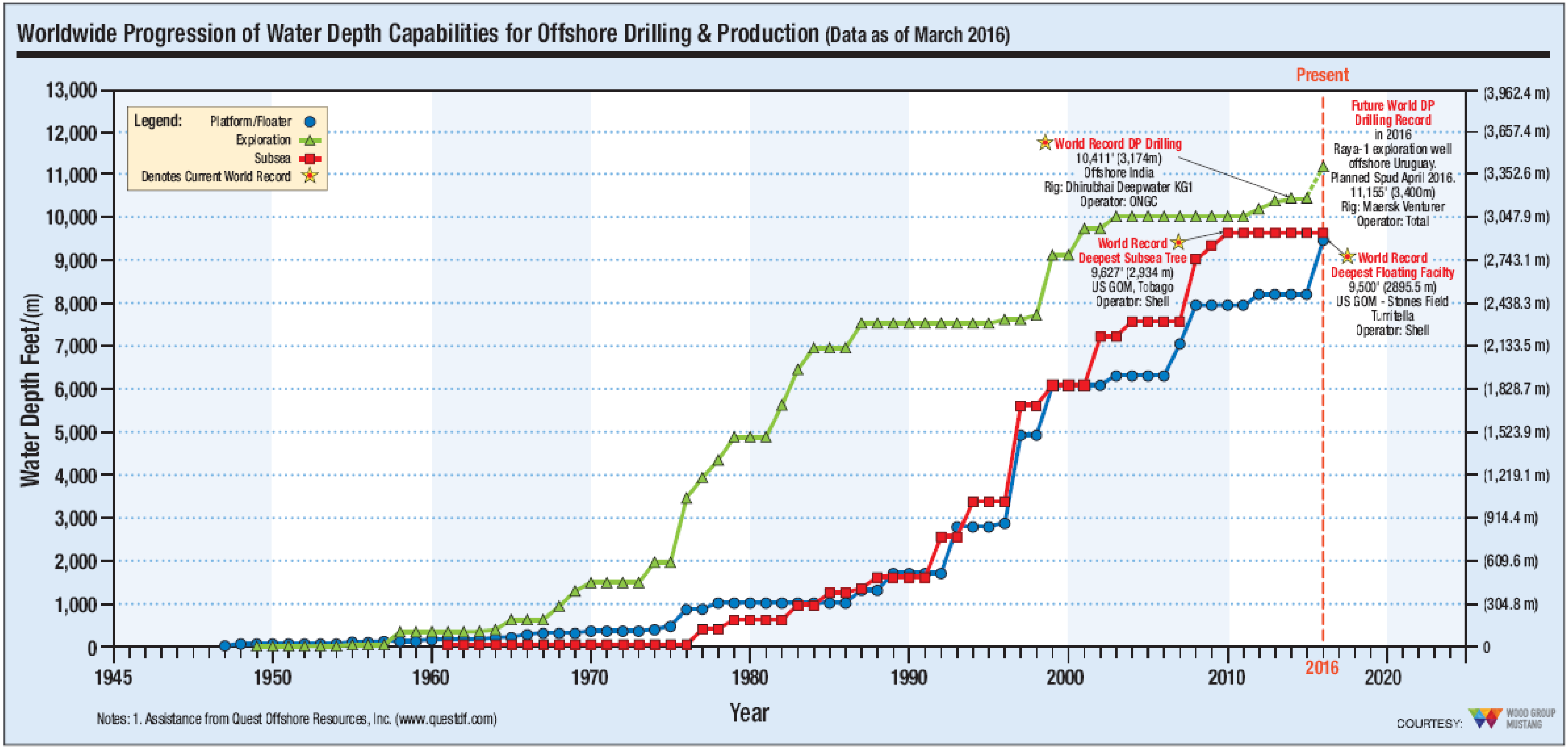
Source: Douglas Westwood

Offshore O&G production

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

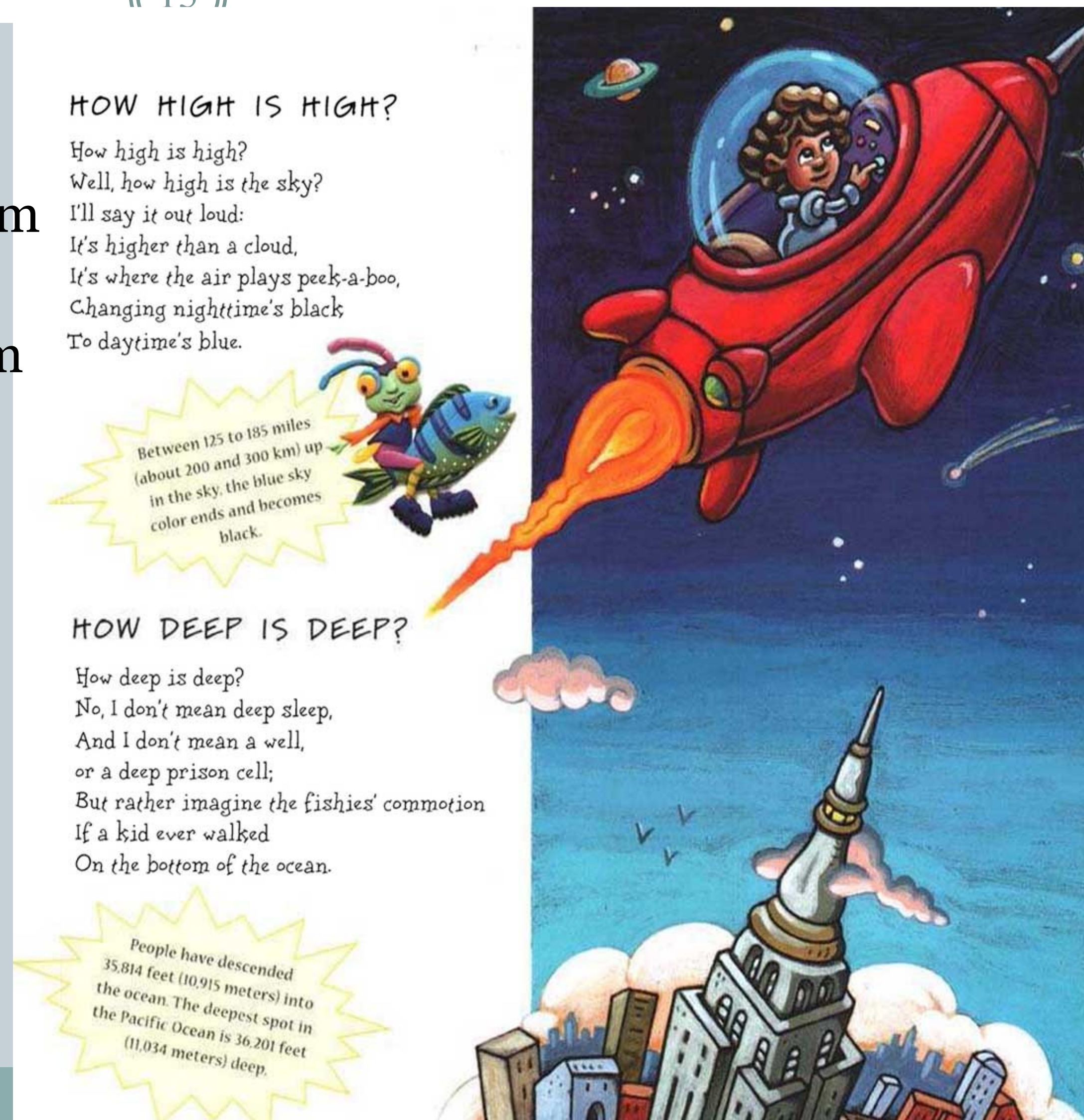


Offshore drilling & production records



Offshore: 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 deep can we drill offshore?

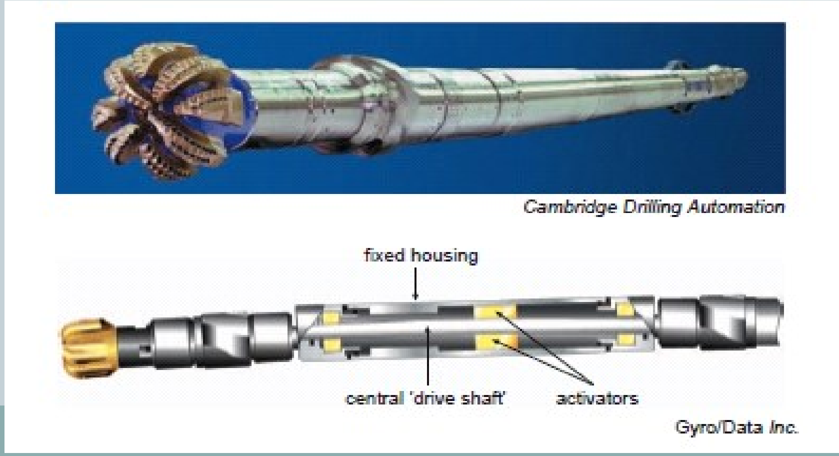
- Drilling rigs designed for ≈3,700m (12,000ft) water depth
- Operations *limited* by:
  - Variable Deck Load (drill string, drilling & completion fluids)
  - Rig hoisting capacity (*f* = (total well depth, drilling risers, ...))

- 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

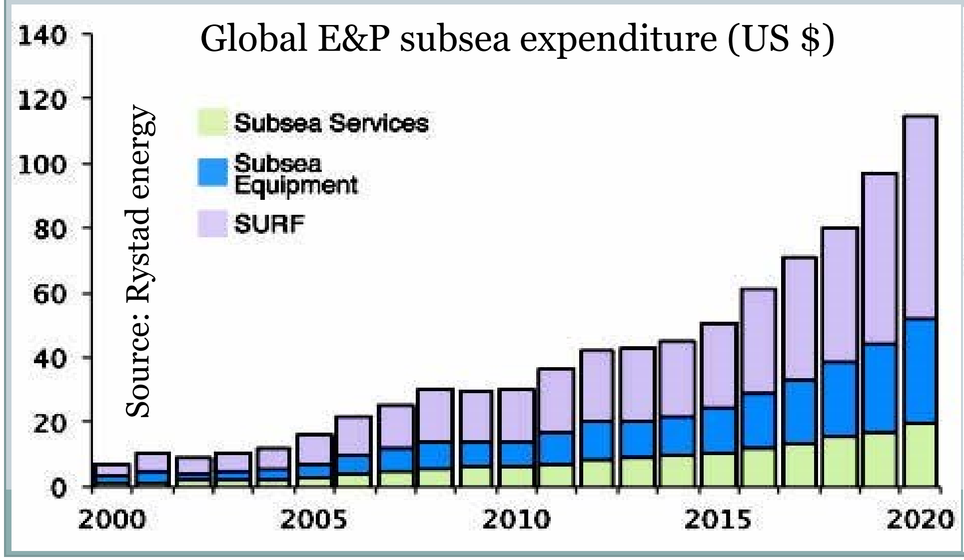
How deep can we drill offshore? (2)

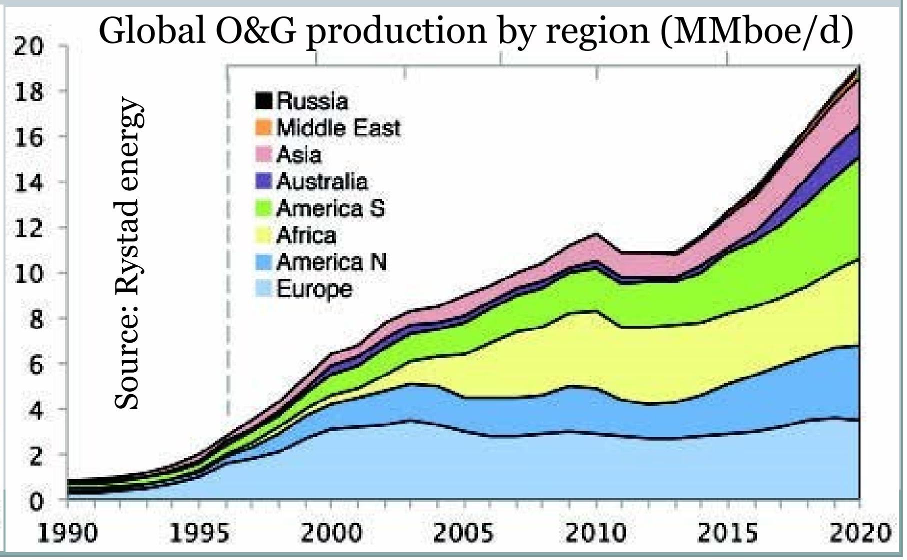
- Rotary steerable systems op. envelope = 175°C
- Flow assurance (wax & gas hydrates)
- Corrosion issues (longer risers, other equipment)
- Longer intervention times
- Other issues: sand management, cementing & perforation
- Downhole pressure & temp. gauges limit = 15 days @ 210°C
- Sealing systems to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



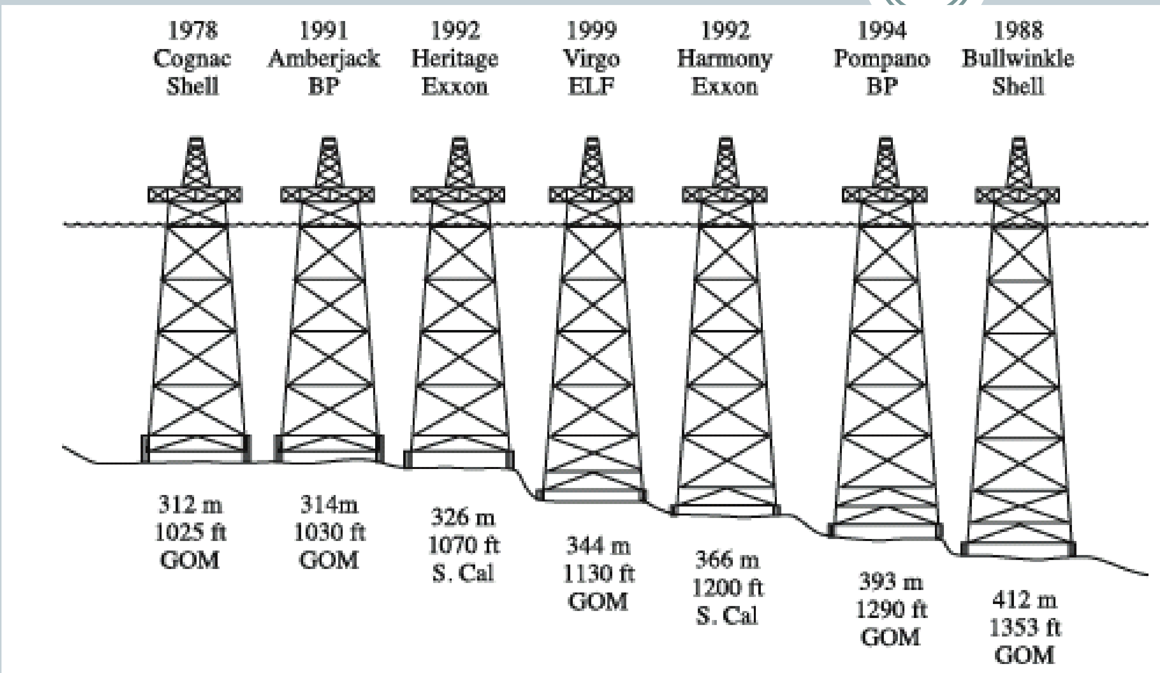
Global subsea market

- Subsea investments:
  - 2000 → \$7bn
  - 2008 → \$30bn
  - 2014 → \$45bn
  - 2020 → \$115bn (x15)
- West Africa is an emerging frontier
- Expect to see more subsea boosting & separation





Fixed platforms [to the limit]



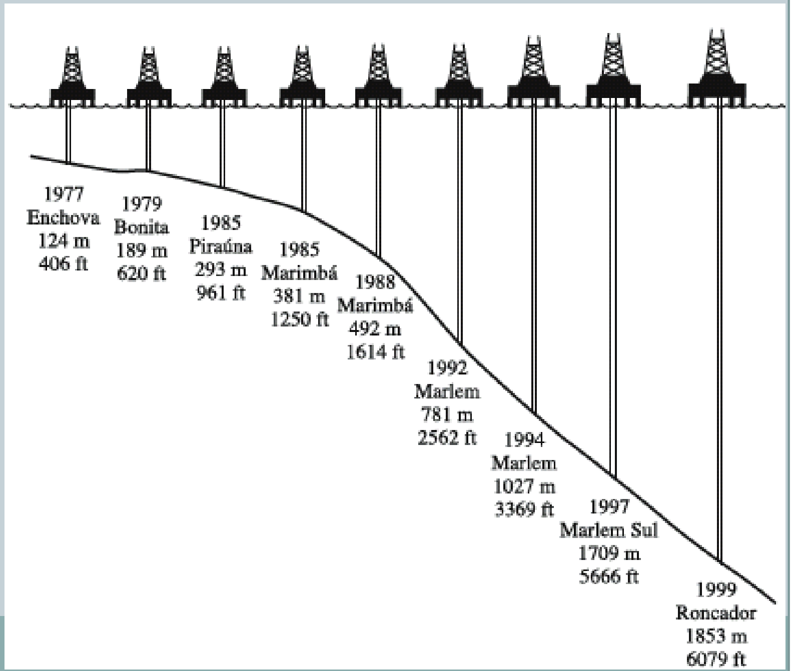
Leffler(2011)

- 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

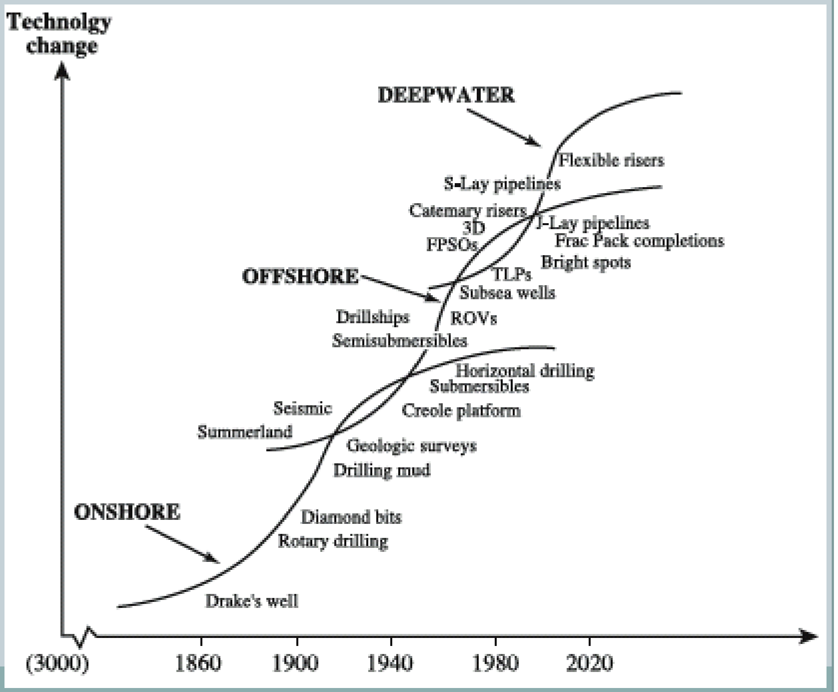
Leffler(2011)



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

Leffler(2011)

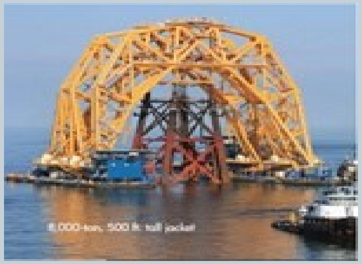


The offshore prize

- 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 hedge against risk
- Technological advances (eg, synthetic lines) & past experience
- ‘Easy’ O&G and shallow fields have been discovered (almost)
- High oil (& NG) prices and H/C demand
- Smaller environmental footprint

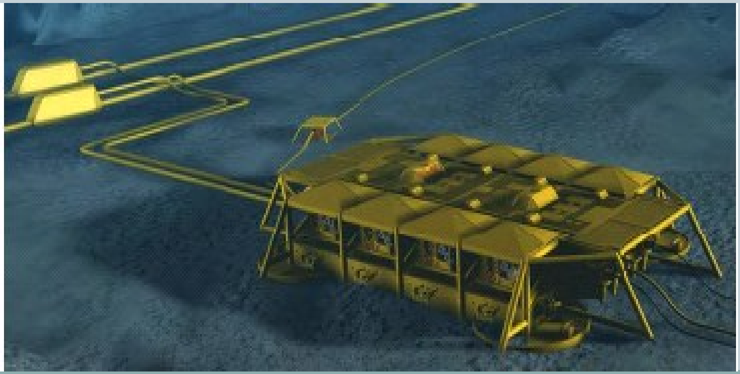


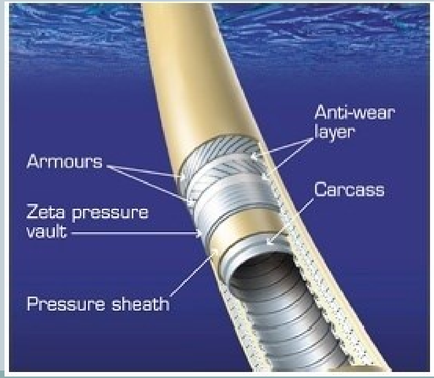




The offshore prize (2)

- 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



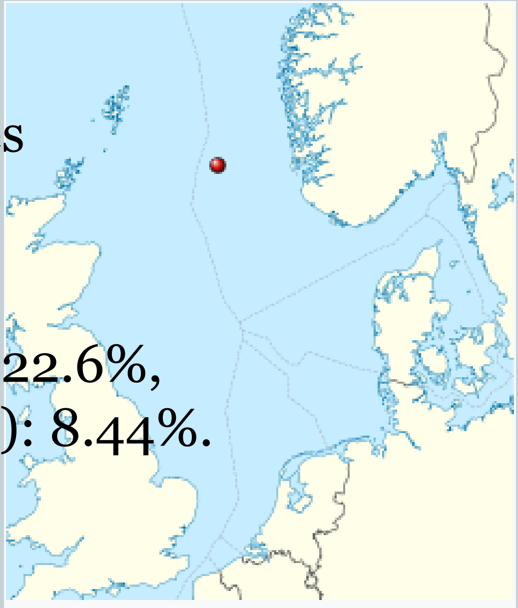


Current trends– post-2014

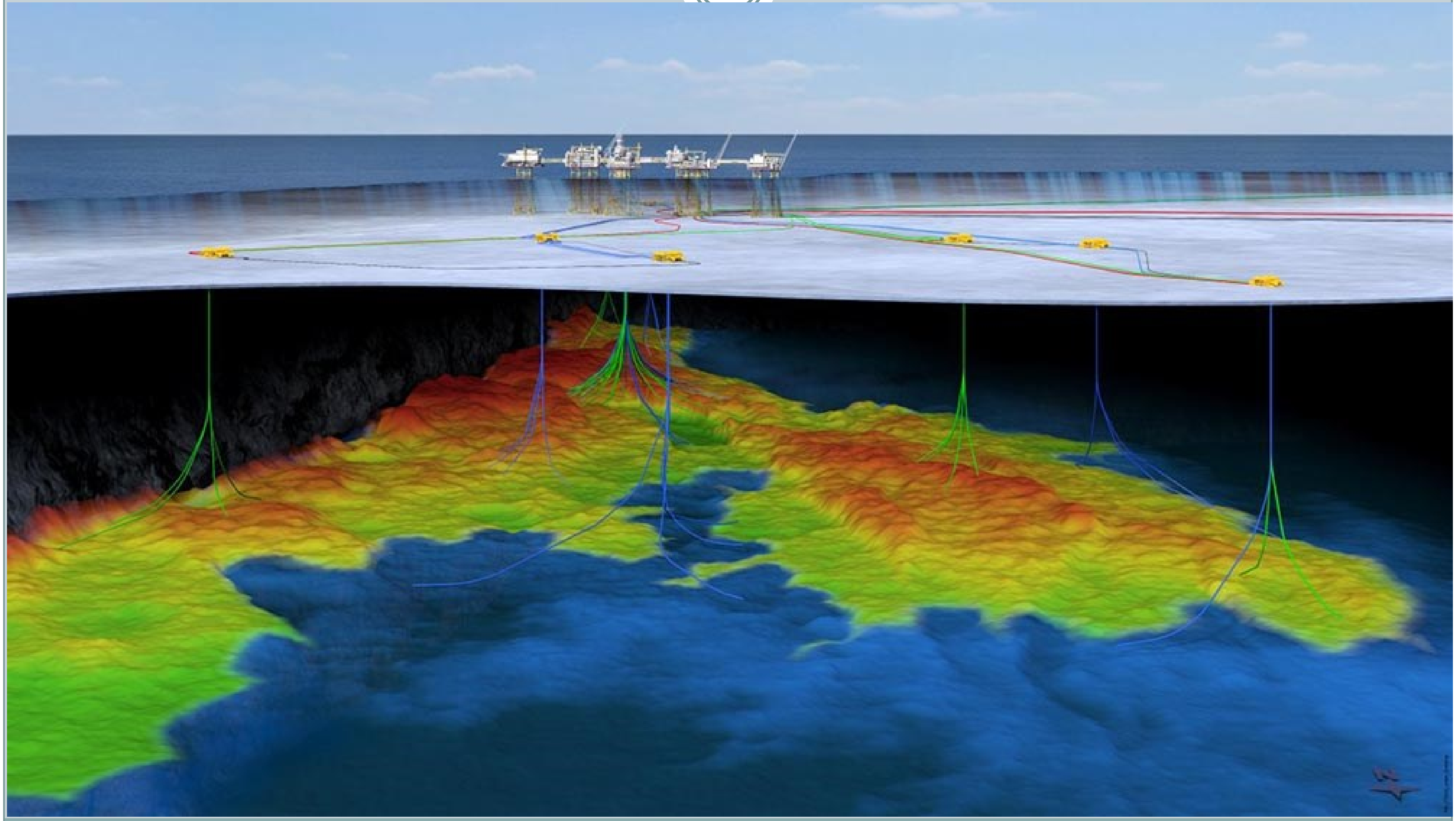
- Emphasis on brownfields
- Obsession with lowering costs
- ‘Rig clubs’ (rig pooling)
- Standardisation
- 3 weeks on & 3 weeks off
- Go after more productive assets
- Rework development plans
- Lower complexity eg 28 different shades of yellow
- Shelve, postpone or cancel expeditions eg Shell’s Arctic exploration which cost $7bn
- Case study: Johan Sverdrup; break-even costs $15/bbl

Johan Sverdrup (Norway)

- Discovered in 2010; 2-3 billion bbl (OOIP)
- Water depth: 110-120m; spans on 2 different licenses
- First oil: end 2019
- Production to peak at 660,000bbl/d
- Partners: Equinor (Statoil, 40%, operator), Lundin: 22.6%, Petoro: 17.4%, AkerBP: 11.6% and Maersk Oil (Total): 8.44%.
- Ambition for a 70% recovery
- Powered from shore
- Cost: $29bn

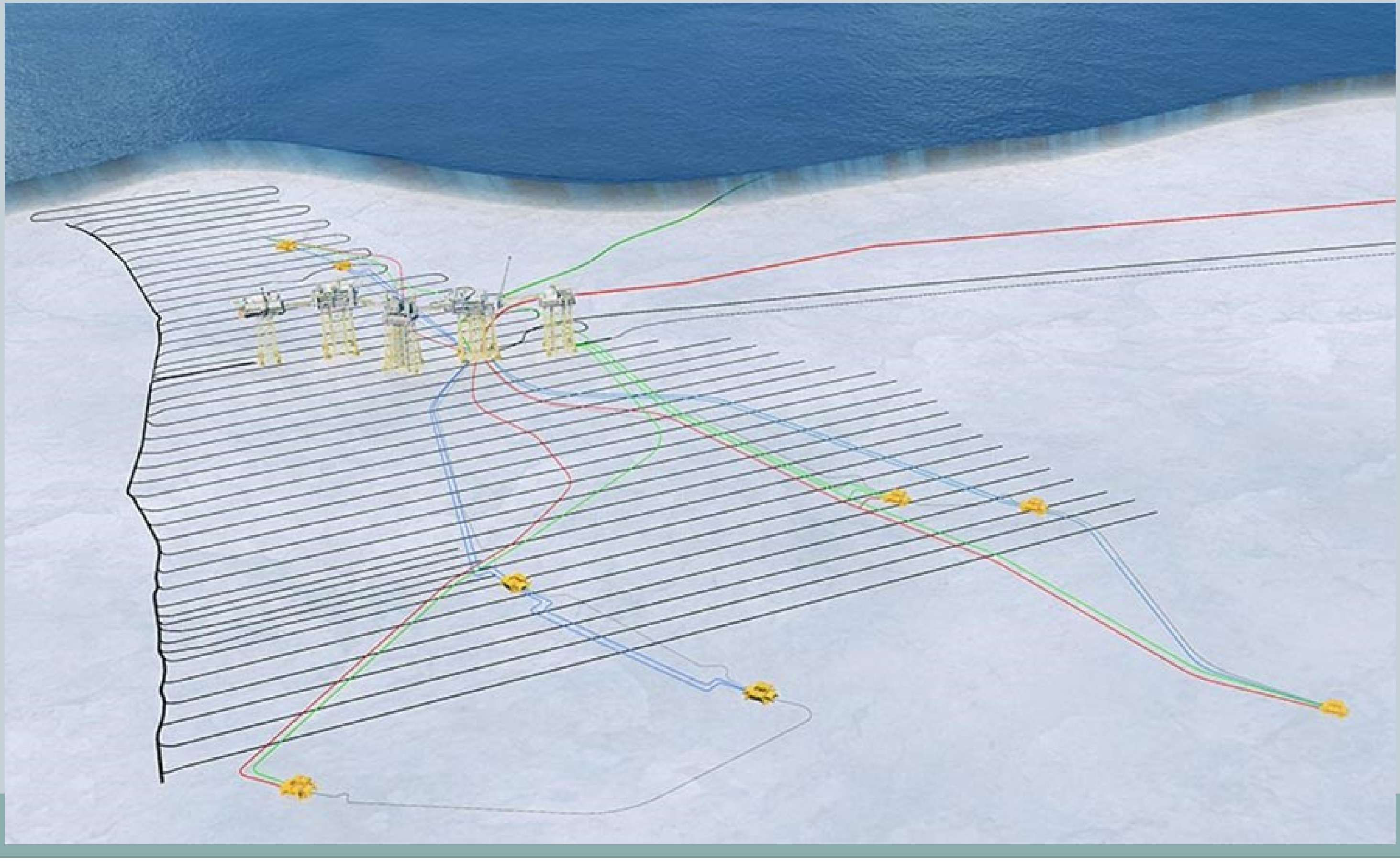


Johan Sverdrup (2)



Johan Sverdrup (3)

- Permanent reservoir monitoring (PRM); better visualization, modelling & predictive analytics; well siting, production control & injection
- Fiber optic seismic cables: 380km;>6500 acoustic sensors over 120km^2

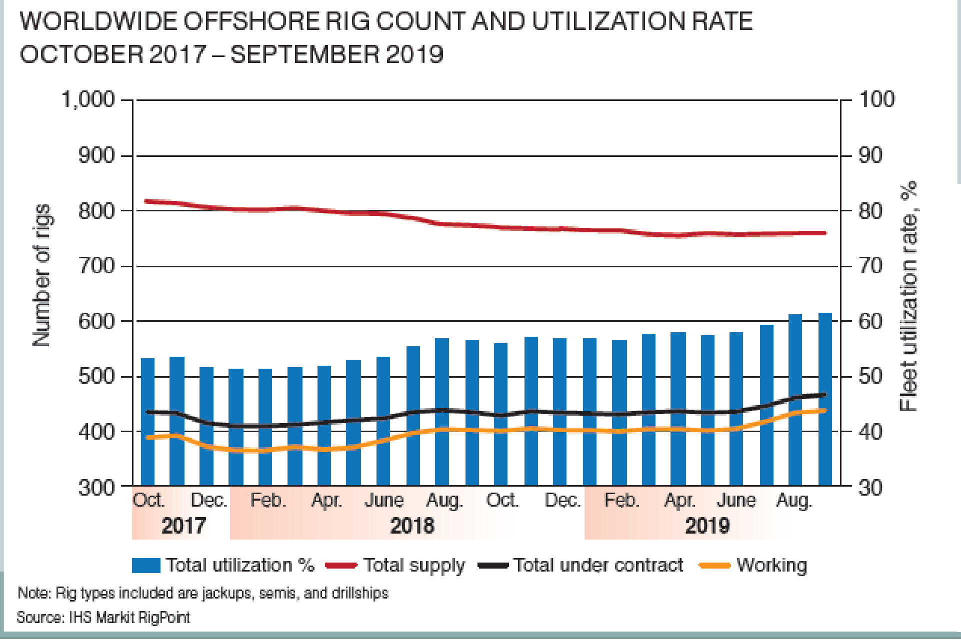


Johan Sverdrup (4)

- Videos:
  - Johan Sverdrup– the story so far
  - Johan Sverdrup pipeline installation

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 (06/2015): a) Semis $400,000/d, b) Drillships: $510k/d

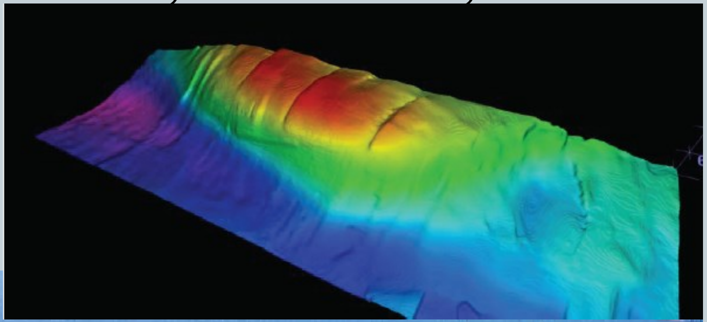


Leffler(2011)

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) exposes 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 (eg, Ekofisk)
- Flow assurance (gas hydrate formation)
- High static pressure (H_2O depth >2,000m)
- Max. diver depth >330m
- Frigid temperatures (-1 to 2°C)



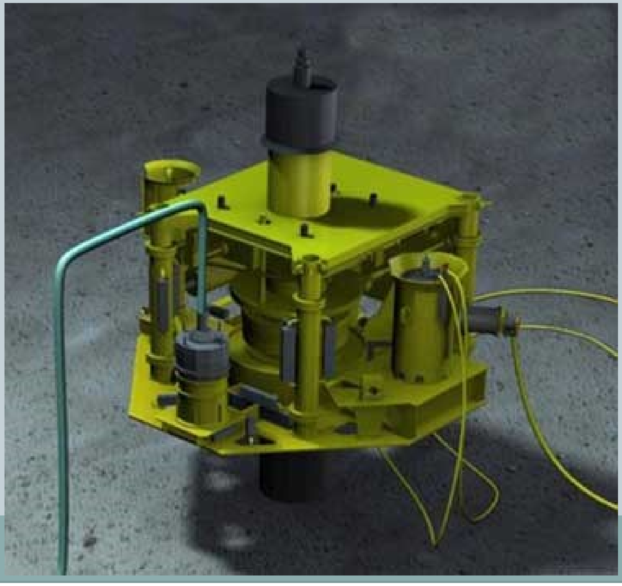
Challenges to offshore E&P (2)

- 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: 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)

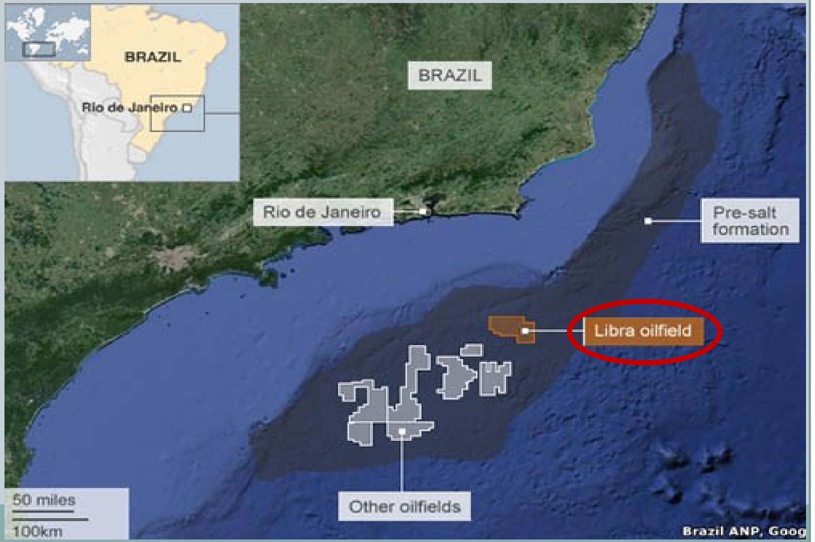
System design challenges

- Lack of human access complicates things
- Need for in-built redundancy (eg, 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
- Dropped objects (shipwrecks, airplanes, etc)



Libra oil field (Brazil)

- 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?

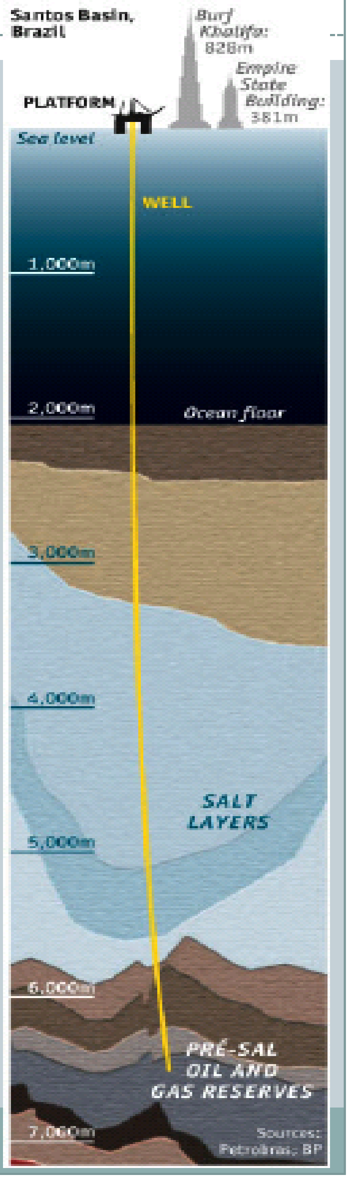


Libra (Brazil)

- 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.

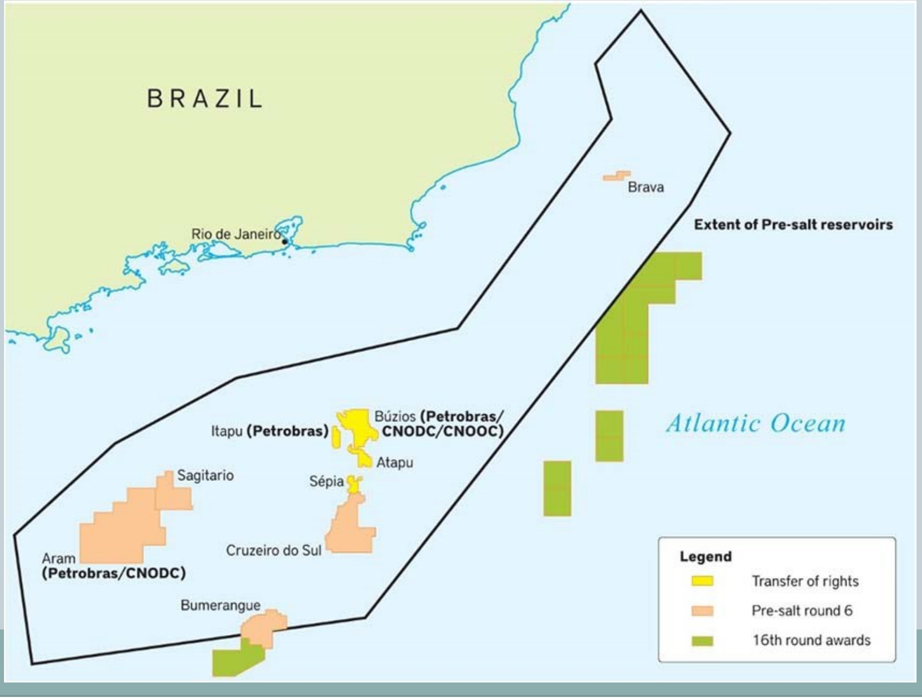
- Lesson(s):

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



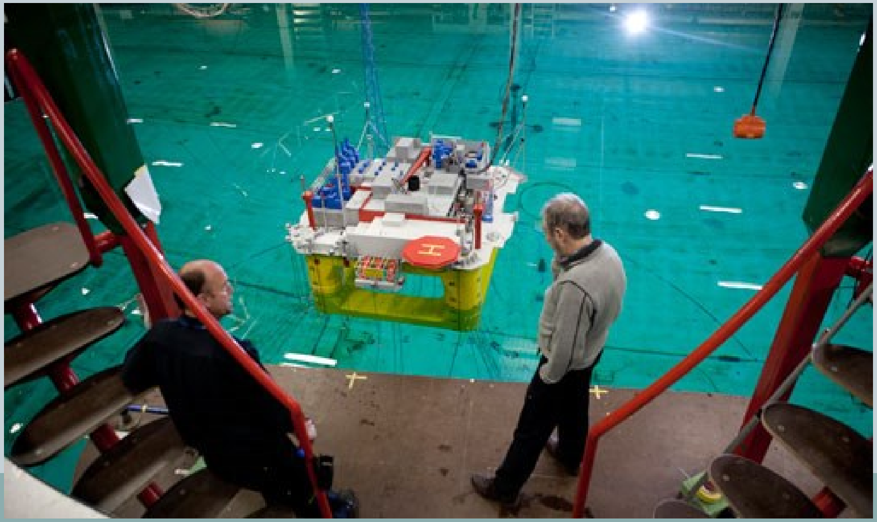
Brazil big bet backfires

- 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

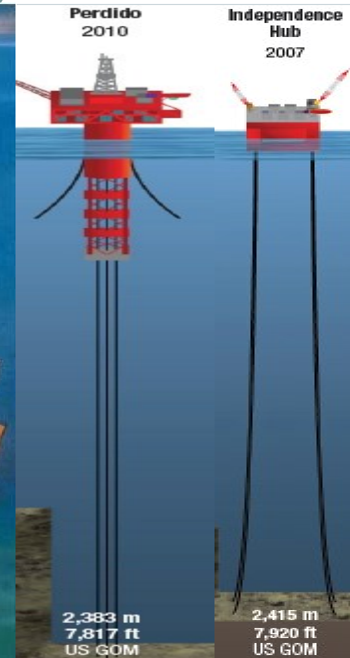


Better technologies & innovations

- Testing facilities (water tanks, risers)
- Advanced materials (eg, flexible risers)
- Virtual reality modelling
- New technologies (eg, subsea compression)
- Advances in computational power
- Sophisticated computer models (simulation tools)
- Lines (synthetic polyester lines *vs* chains & wires)
- Communications (eg, fibre optics)
- More dexterous ROVs
- Dynamic positioning (DP3)

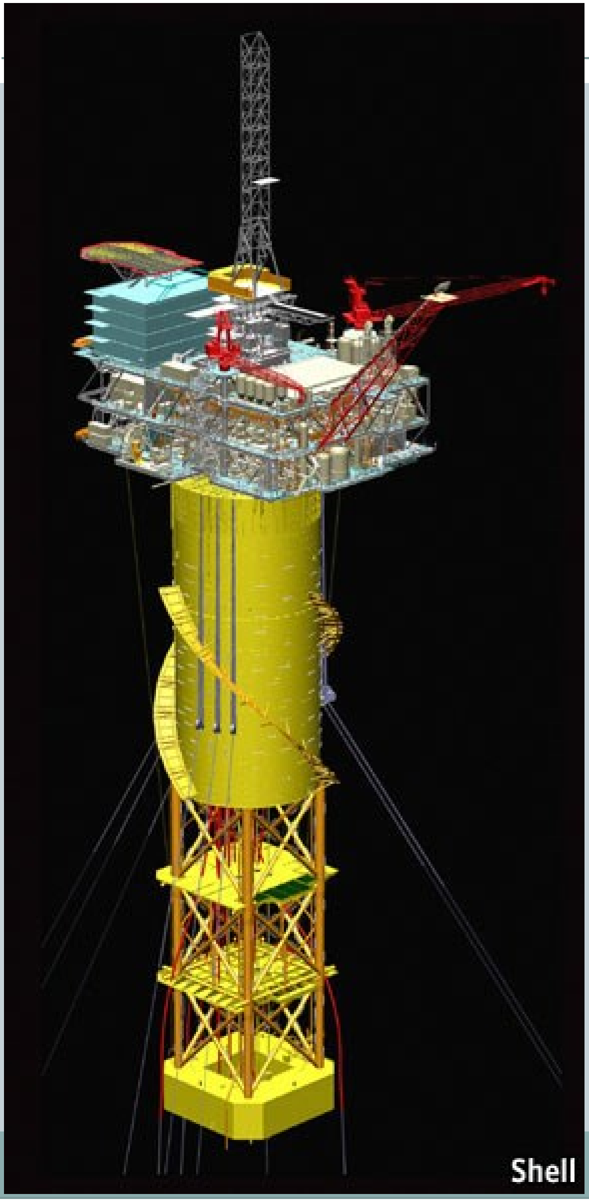


Offshore drilling & production systems



Offshore projects' requirements

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



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

Offshore

- Complex
- Time intensive
- Very costly (€100m/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)x)
- 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

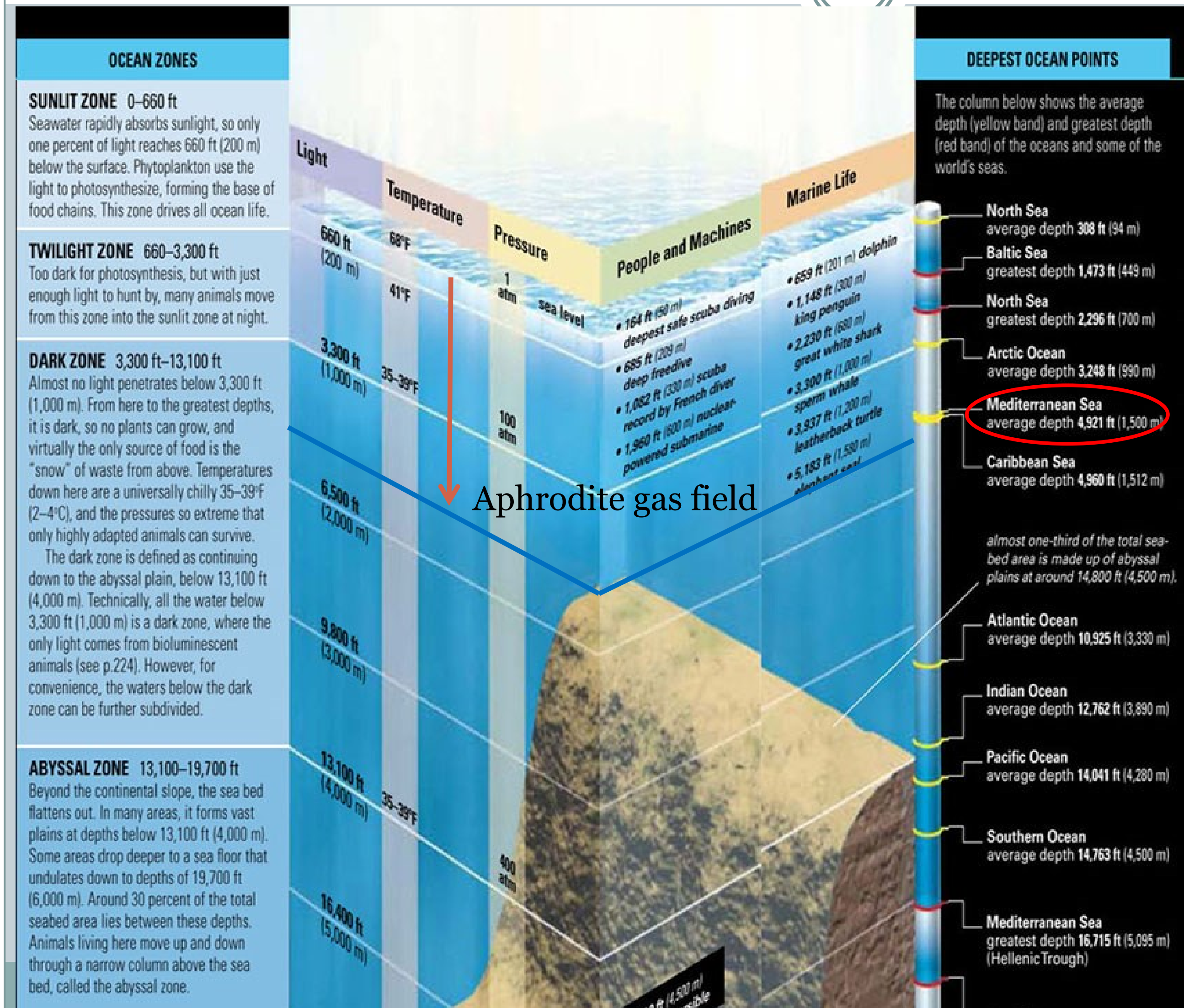
- Equipment design: diver intervention;
- No need for an ROV;
- No pipeline insulation or heating;
- Hardware installation limited by vessel size;
- Small(er) umbilicals;
- Maintenance & repair done by divers;
- Proven technologies, …

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

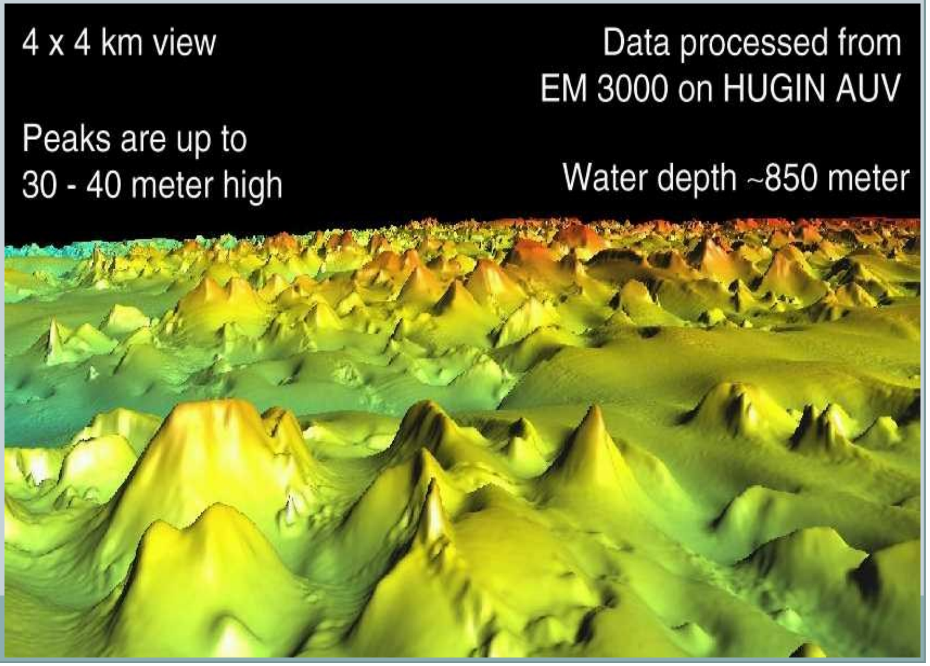


Marine environment

- Salinity
- Corrosive nature
- Pressure variation
- Sea water temperature = –1°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

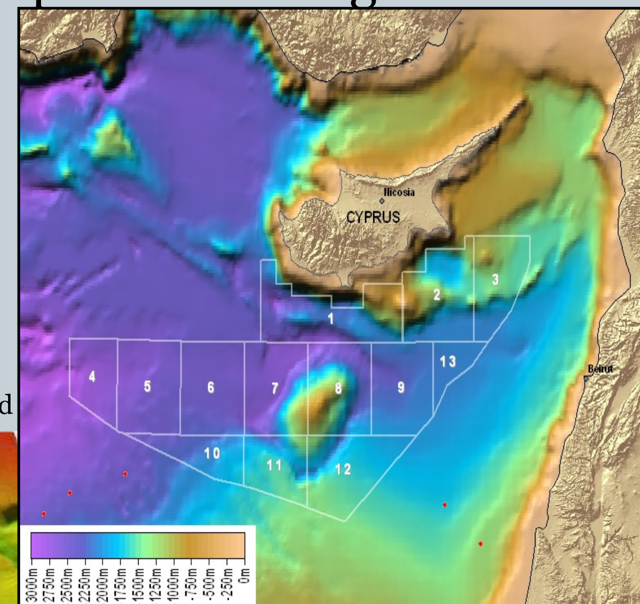
Subsea terrain survey

- 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
  - Bathymetry mapping
  - Soil investigation
- ROV visually inspects sea bottom



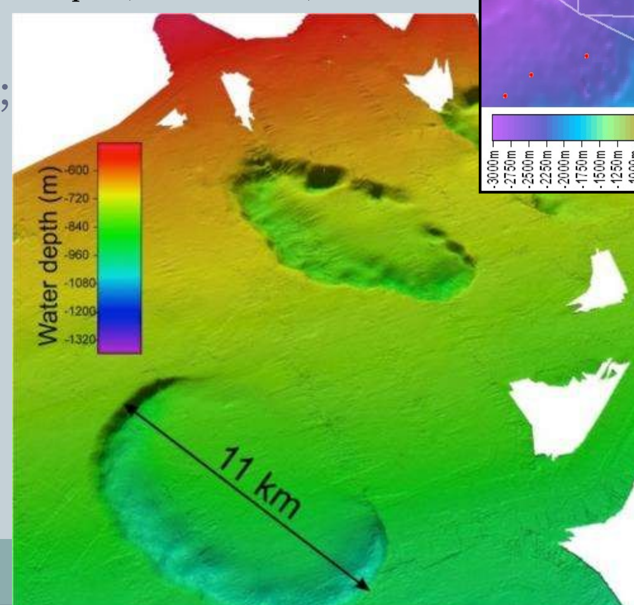
Route surveys

- 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

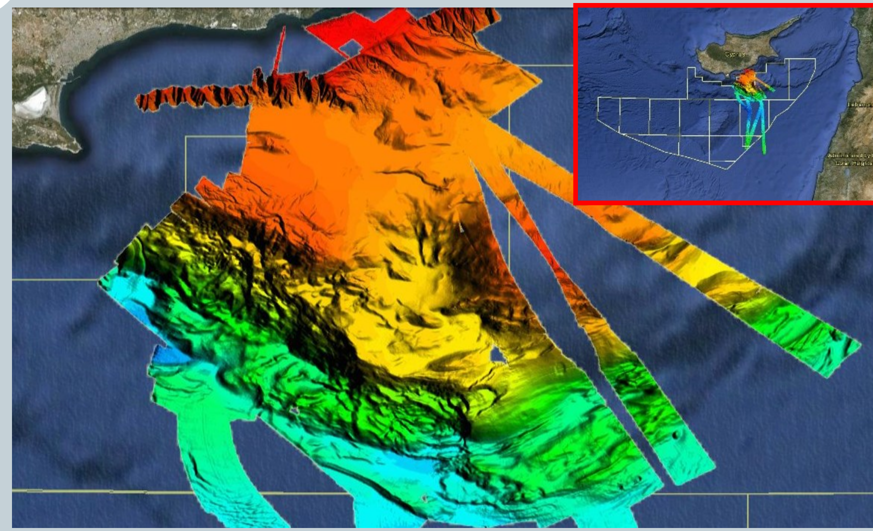


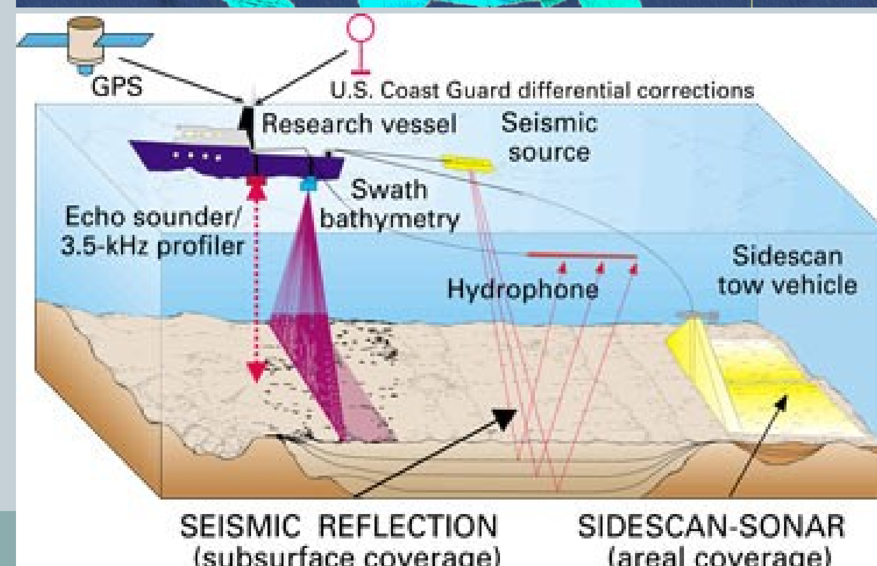
Route investigation

- 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 survey

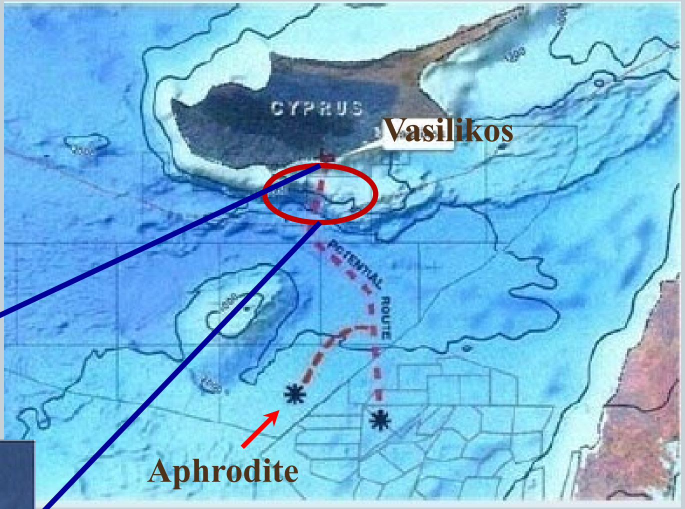
- Geotechnical investigation
  - Recovers seabed samples
  - Typical duration spans 1 year
  - Costs about $1m

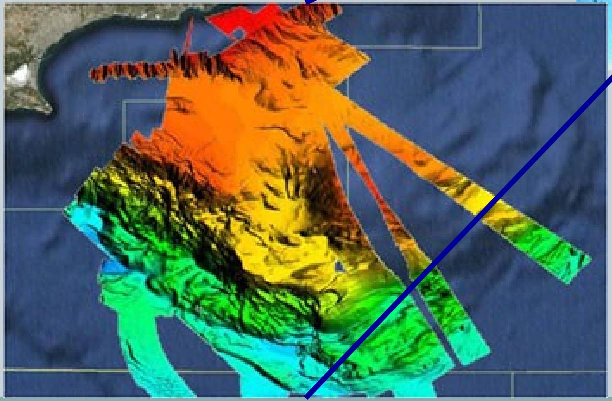




Geo-hazards

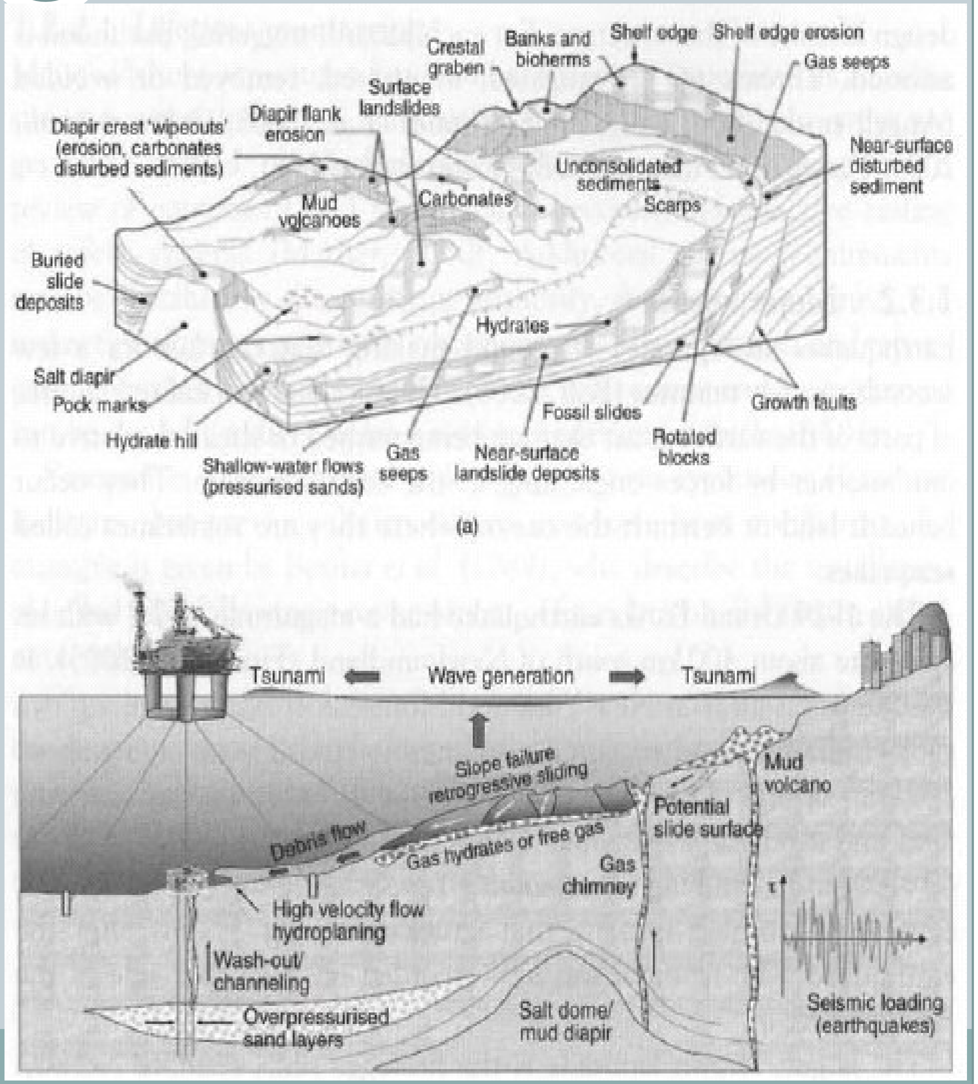
- Hazards arising from *geological* or *geotechnical features*
- Geohazards endanger the *integrity* or *serviceability* of a structure
- Typical offshore geohazards include:
  - Submarine (land)slides (eg, Storegga slide);
  - Gas seeps;
  - Mud volcanoes;
  - Debris flow;
  - Gas hydrates;
  - Shelf edge erosion;
  - Subduction zone;
  - Gas chimney;
  - Seismogenic area;
  - 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

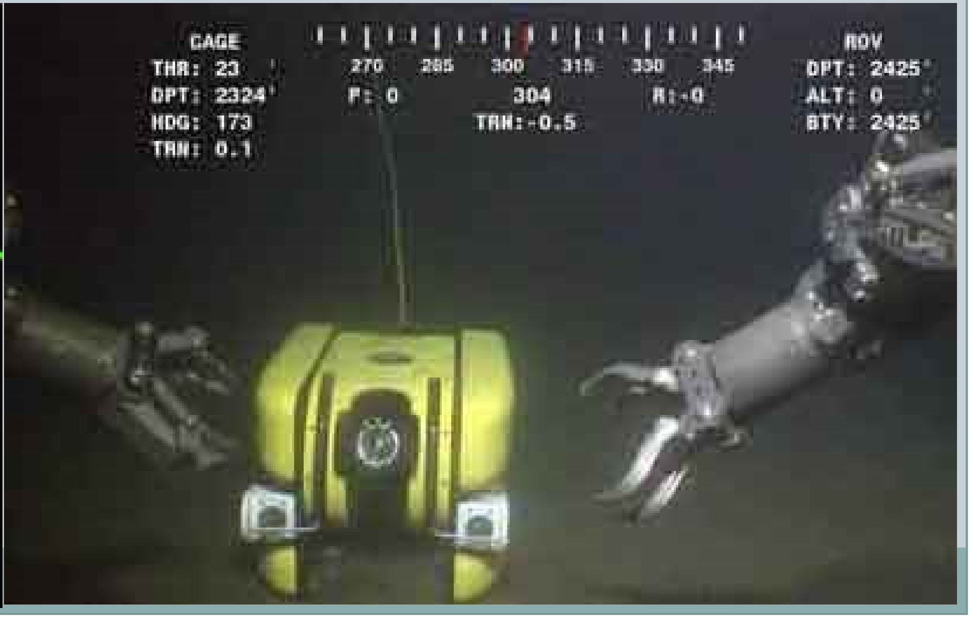
- Categories:
  - Semi-subs
  - FPSO & FPS
  - Spars

- Offshore platforms — Appr. water depth (m)

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)

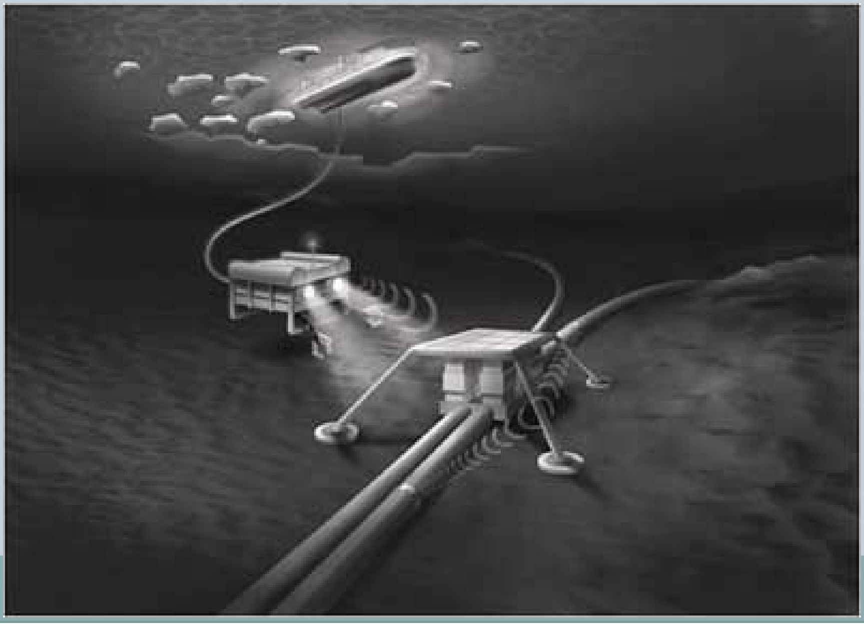
Remotely Operated [underwater] Vehicles (ROVs)

- Advances in ROVs expedited deep-water E&P (>330m)
- How do you mount a wet tree on the well head @ –2000m?
- 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



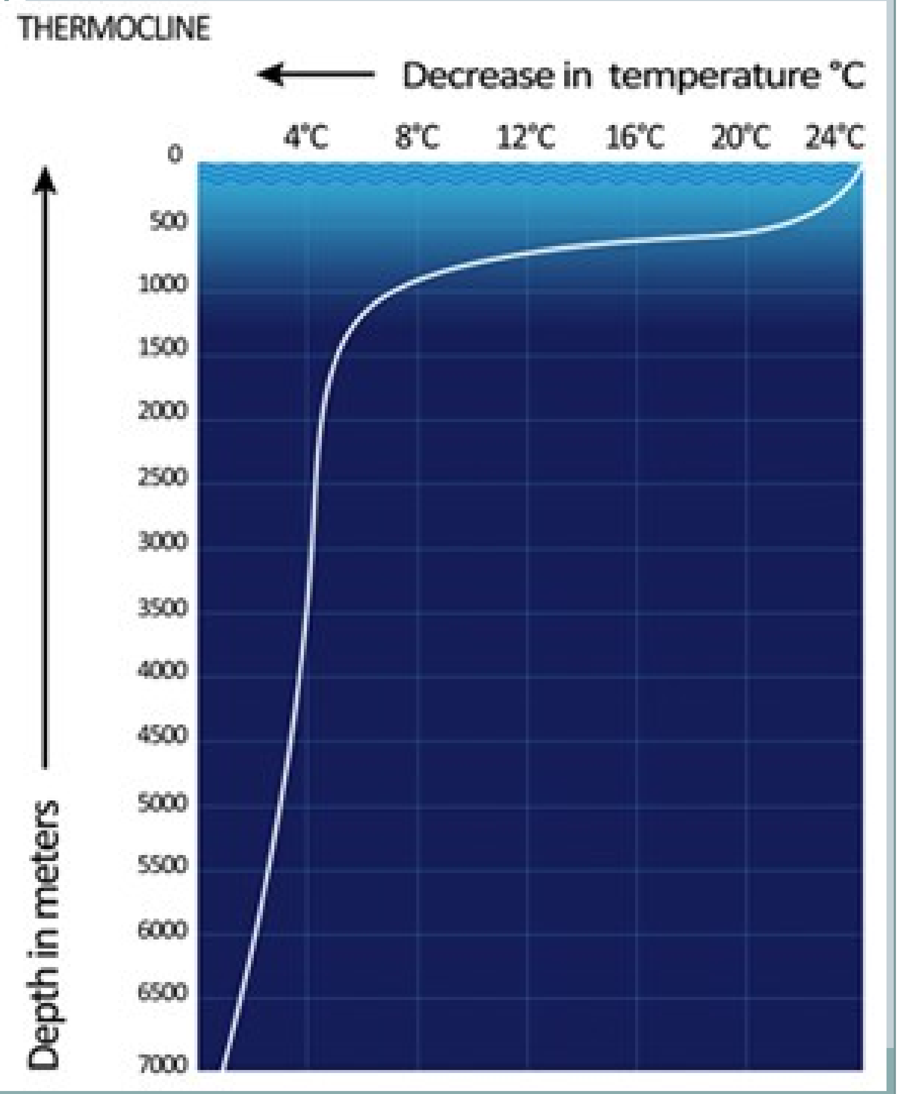
ROVs (2)

- 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



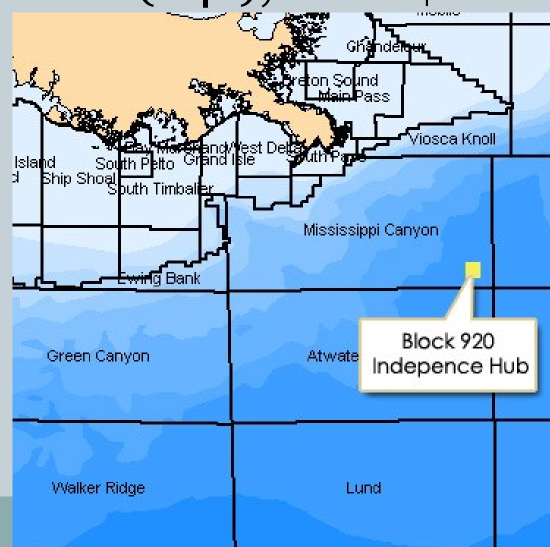
Subsea conditions

- Thermocline phonomenon: 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

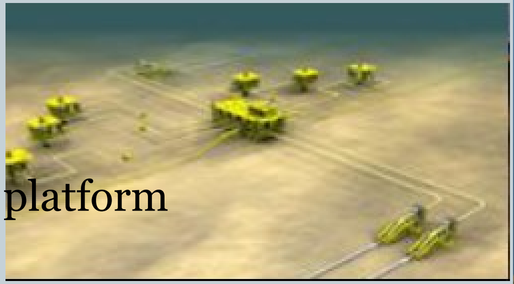


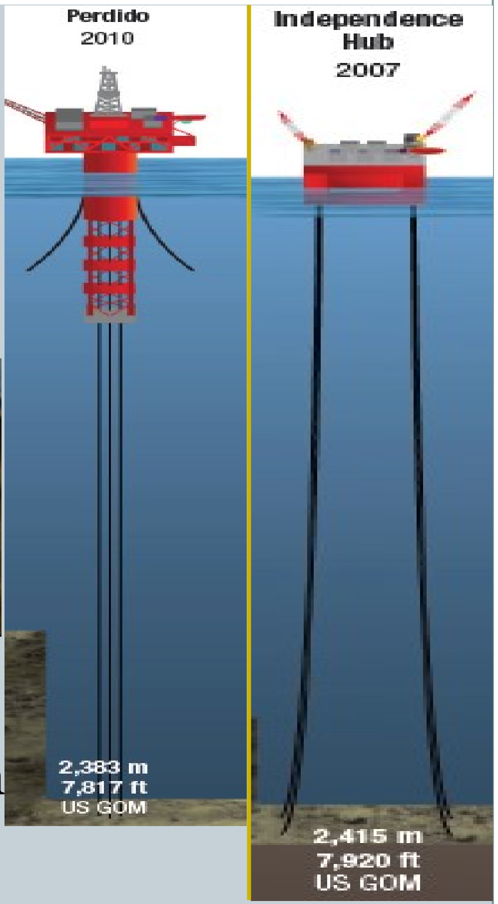
Case II: Akpo FPSO

- 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 bbo/d, 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 development





Subsea production systems

- Subsea production systems create large savings because are unmanned
- 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-2014 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 will help lower operational costs

Ultimately engineering ingenuity is perhaps the only limitation!