Session IV:

What changes have occurred in materials, designs, practices, fabrication, manufacturing, and technology between 1980 and today to make OTEC feasible to pursue on a commercial scale?

Summary of Improvements Since 1980s

- **Materials:**
  - **New materials**
    - **e.g., composites, synthetics**
  - **Higher Strength**
  - **More reliable**
  - **Lower cost**

Summary of Improvements Since 1980s

- **Design:**
  - Vastly improved computing capability
  - New analytical methods
  - Vastly improved modeling methods
- **Fabrication:**
  - Improved extrusion methods
  - Welding advances
  - Aluminum brazing advances
  - Coatings improvements
  - Advances in QC

Summary of Improvements Since 1980s

- **Manufacturing:**
  - **Automation vastly improved**
  - **Improved tooling**
- **Sensor Development:**
  - **In situ health and Status Monitoring methods**

Summary of Improvements Since 1980s

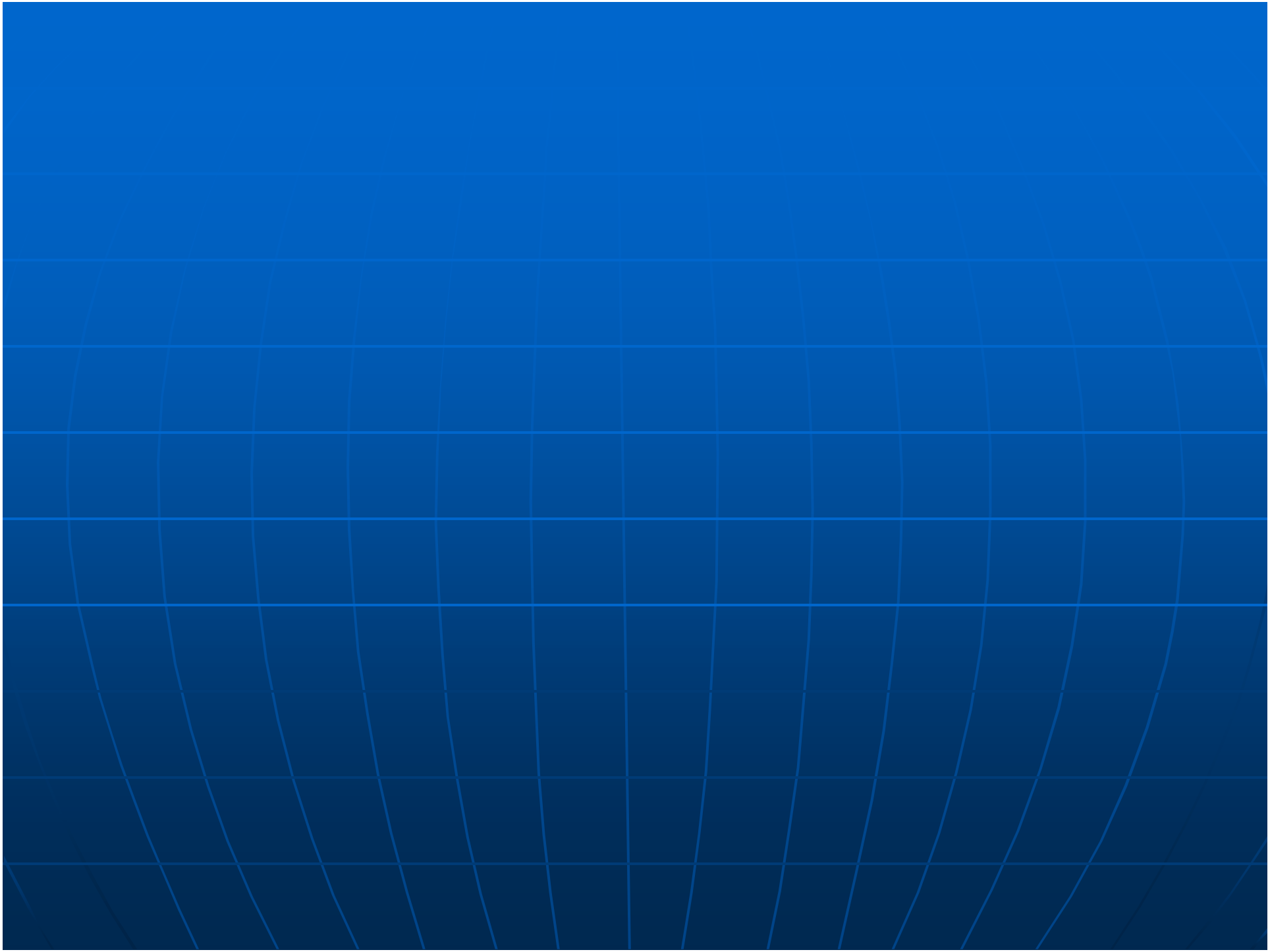
- **MET OCEAN:**
  - **Real Time Data**
    - **Satellite technology**
    - **Ocean observing network**
  - **Weather prediction modeling**
- **Development of Deepwater Oil and Gas Industry**

Summary of Improvements Since 1980s

- **New Bathymetric and Geopositioning Techniques**
- **Codes / Standards Development**
  - **e.g., deepwater industry**
- **Cable Design and Construction Vastly Improved**

Advances in Cold Water Pipe

	Then	Now	Benefit
Materials	**E-glass / Vinylester Steel, concrete**	**1. R-glass / vinyl ester Carbon fiber composite** **2. E-glass / vinylester**	**1. Higher fatigue strength; better reliability and lower cost** **2. Still viable, additional validation has been done**
Designs	**Syntactic foam core sandwich**	**1. Hollow pultruded core sandwich and other proprietary designs** **2. Syntactic foam core sandwich**	**1. Much lower cost, less labor intensive and greater consistency** **2. Still viable, additional validation has been done**
Practices		**Off-shore industry experience**	**Lower cost and better reliability, more design flexibility**



Advances in Cold Water Pipe

	Then	Now	Benefit
Fabrication	Filament winding	VARTM process	In-situ, continuous pipe
Technology		Computational tool development Improved structural monitoring (cameras, sensors, robotic devices)	Higher precision, lower testing cost More reliability, less labor, less risk

Summary:

Due to advances in computational capability, composite materials, fabrication methods, and the vast experience of the offshore industry, there is a high level of confidence that we can construct and maintain a reliable, cost efficient cold water pipe.

Advances in Heat Exchangers

- Materials
  - Titanium cost effectiveness (aerospace and automobile industries)
  - Titanium: developing improved processes (power plant condenser)
  - Thermally enhanced plastics
  - Aluminum: alloying improved (aerospace industry)
  - Aluminum: more choices
- Designs
  - Potential new HX designs
  - Plastic or foam HX new emerging techniques (improving efficiency in processing industry)
  - Surface enhancements
  - Improved heat transfer coeff. without incurring pressure drop penalty

Advances in Heat Exchangers

- Practices/Performance
  - Materials
    - High speed/low cost capability of computing
    - Improved analytical and design modeling techniques
  - Fabrication
    - Extrusions have improved
    - Aluminum brazing technology (cryogenic, LNG)
    - Improved welding techniques (for sea water applications; petro industry, LNG, oil, ships, power plant condensers)
    - Improved instrumentation/quality control
    - Improved coating processes

Advances in Heat Exchangers

- Manufacturing
  - Improved capability/tooling (petro industry, LNG)
  - Capacity for larger HX
  - greater automation
- Technology/Cycle Development
  - Open cycle performance validation
  - Hybrid cycle design
  - Direct contact condensers operational (geothermal application)
  - Flash evaporators demonstrated
  - Mixed working fluid cycle developed (demonstrated in geothermal)

Advances in Platform Mooring

- Moorings
  - Materials, design, fabrication have advanced to enable moorings to 10k feet, far exceeding the 1k foot limit of 1980, required OTEC mooring depth is 3k + feet
  - Comprehensive codes and standards now exist for deep water moorings
- Infrastructure
  - Industry has developed which routinely designs and installs mooring systems in depth up to 10k feet

Advances in Platform Moorings

- Positioning
  - In 1980 positioning of surface and subsurface assets was inadequate for deep water, far from shores for placements. Present technology is sufficient to meet OTEC requirements.
  - Satellite positioning and shipboard dynamic positioning allows positioning of surface assets within 1 meter anywhere on the planet, efficiently installed anchor systems
  - Underwater acoustic system has advanced accuracy of placement of underwater assets

Advances in Platform Moorings

- Materials
  - Synthetic Mooring lines have increased mooring depths to greater than 10k feet today
  - High strength to weight ratio, neutrally buoyant materials such as polyester, kevlar, spectra, etc
  - High strength steel for use in mooring wire and chain

Advances in Platform Mooring

- Anchors
  - General advances in anchor technology have led to increased capacities in wide ranged bottom types
- Installation and Operation
  - Dynamically positioned installation vessels are commonly available
  - Under water equipment advances allow safe and effective installation, inspection, maintenance, and recovery in deep water
- Design Analysis Tools
- Advances in software enable deep water moorings to be accurately modeled and analyzed
  - Validated by field installations in deep water
  - Allows optimization of the system
  - Broad range of commercially available, industry verified software

Advances in Platform Pipe Interface

- Established deep water industry
  - Industrial base
  - Code
  - Standards
  - Control Technologies (handling)
  - Better understood
- Improvement in Composites
  - Materials
  - Processes

Advances in Platform Pipe Interface

- Improved analytical capabilities and capacity
- Environmental awareness
- Improved Sensor technology
- Development of underwater tools
- Underwater construction techniques
- Deep dynamic cables
- Survey Technology
- Improved engineering process
  - Configuration management

Advances in Platform

- **1980**
  1. Required offshore OTEC depth of 3000ft is considered technically challenging for offshore oil industry
  2. Floating production systems were at infant technology
  3. Limited software was available and data was not validated
  4. Limited ability to predict impact of extreme weather
  5. Platforms were designed to very conservative standards due to uncertainties in extreme storm conditions and calculation accuracy

- **Today**
  1. Floating production platforms at 3000ft considered routine from a technical standpoint
  2. There are about 200 floating production systems
  3. Computer software and experimental facilities for design are in use and have been validated
  4. Meteorological/ oceanographic data gathering capability is more sophisticated
  5. Improved tools and oceanographic data allows design of more cost effective platforms

Advances in Pumps and Turbines

- Pumps and Turbines have been ready for 30 years
- No revolutionary breakthrough in pump/turbine; all advances evolutionary
- Electronics starting to be introduced into pumps/turbines to monitor health and status; most advances will be in outage management/condition based management
- Move toward a sustainable system that can function without external hydrocarbon inputs
- Seaborne environment (roll, pitch, yaw) has proven out turbine machinery over worse or equivalent situations.
- Petroleum industry has 30 years of additional experience working in increasingly harsh environments and much has been learned about operations, methods and materials.
- OTEC-style plant in India that produces Freshwater – more expensive than traditional desalinization methods, however operational and works.
- Many attempts since 1980; 250 kW open cycle at NELHA, 1996-2000 50 kW Hx Testing (NEHLA), 2005 Diego Garcia Feasibility Study, 2006 0TEC Study Makai SBIR, 2007-2008 10 MW Pilot Plant Design by Lockheed Martin.

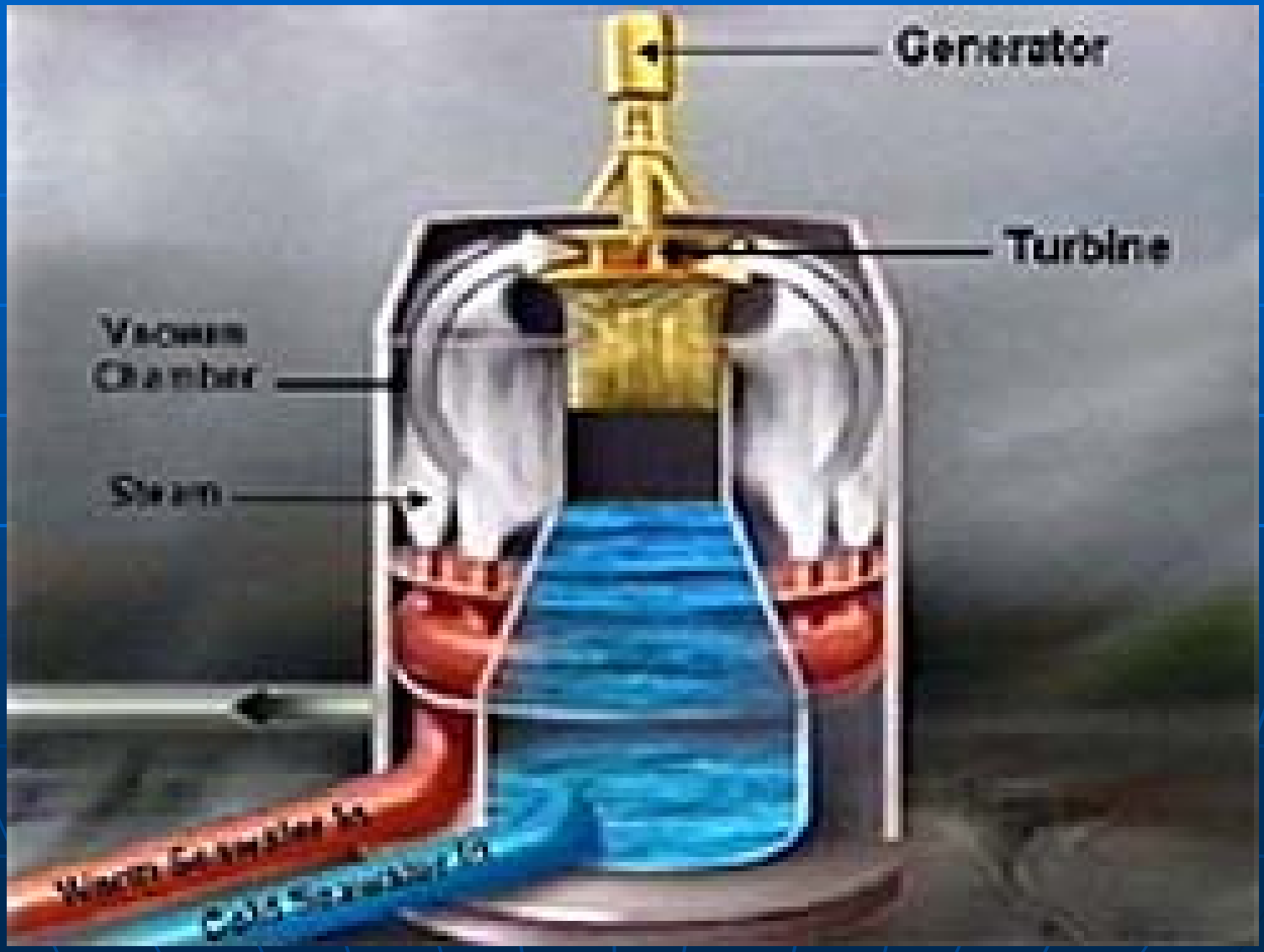
Advances in Power Cable

- Today: 10 sea crossing AC cables from 90 kV-to500 kV
- 20 DC cables up to 500 kV
- Majority have occurred in last 10 years
- Availability of remote resources and interconnection of grids
  - US: east coast NY/NJ
  - From Canada to NJ
- Dynamics cables: technology driven by offshore wind farming
  - Off shore oil drilling
  - Common connection by 13.6kV up to 50 kV
  - Connection at platform are standard and routine, sock rigid connection run through tube, secured at top
  - Length, width, diameter are function of cable
  - Swivel joint done on top side like fixed connection
- Offshore wind floating platforms
  - Individual cables to shore

OTEC Then

OTEC Then

OTEC Now


Generator
Turbine
Vacuum
Chamber
Steam

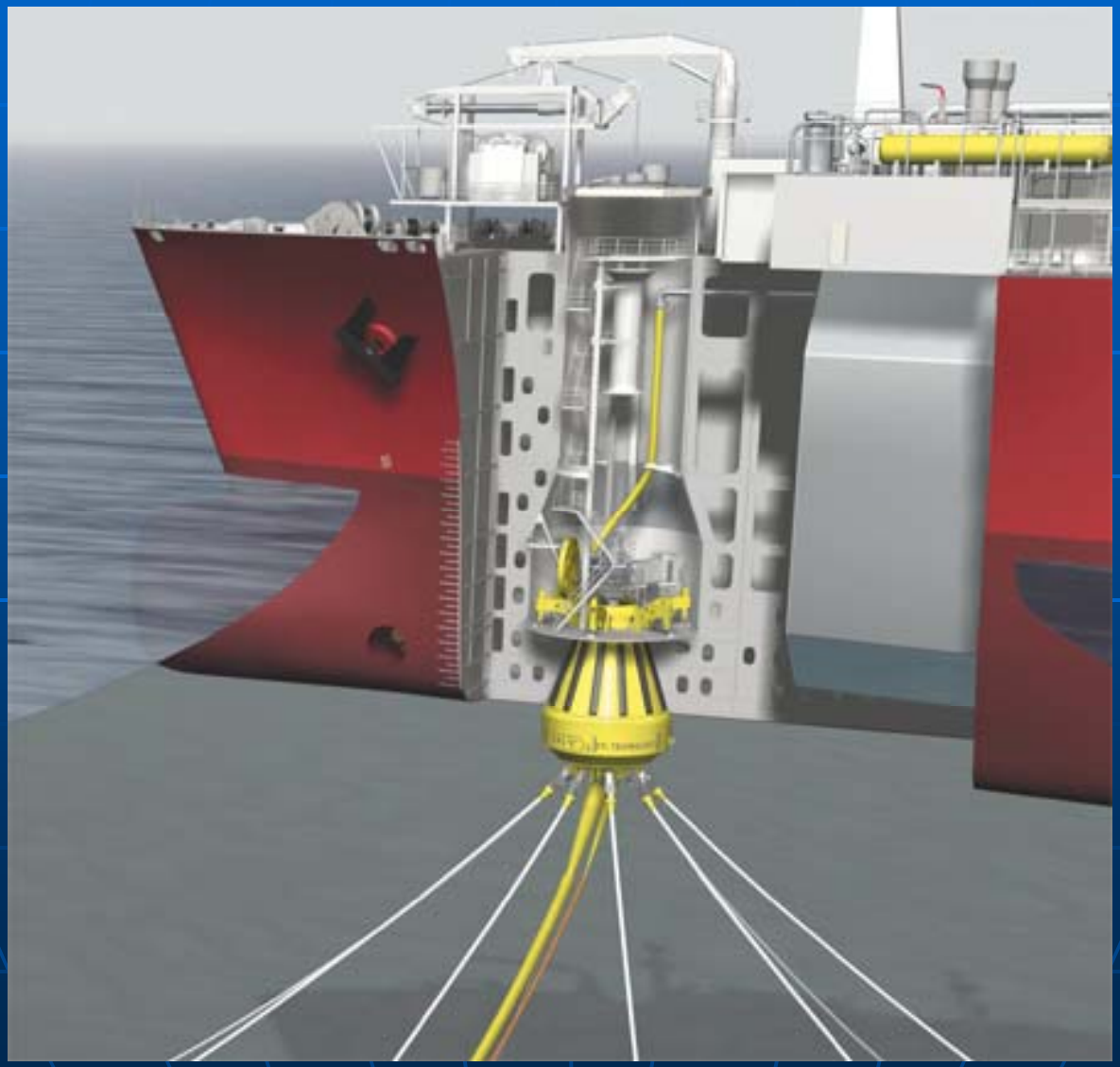

modus
CS1

Heavy Lift

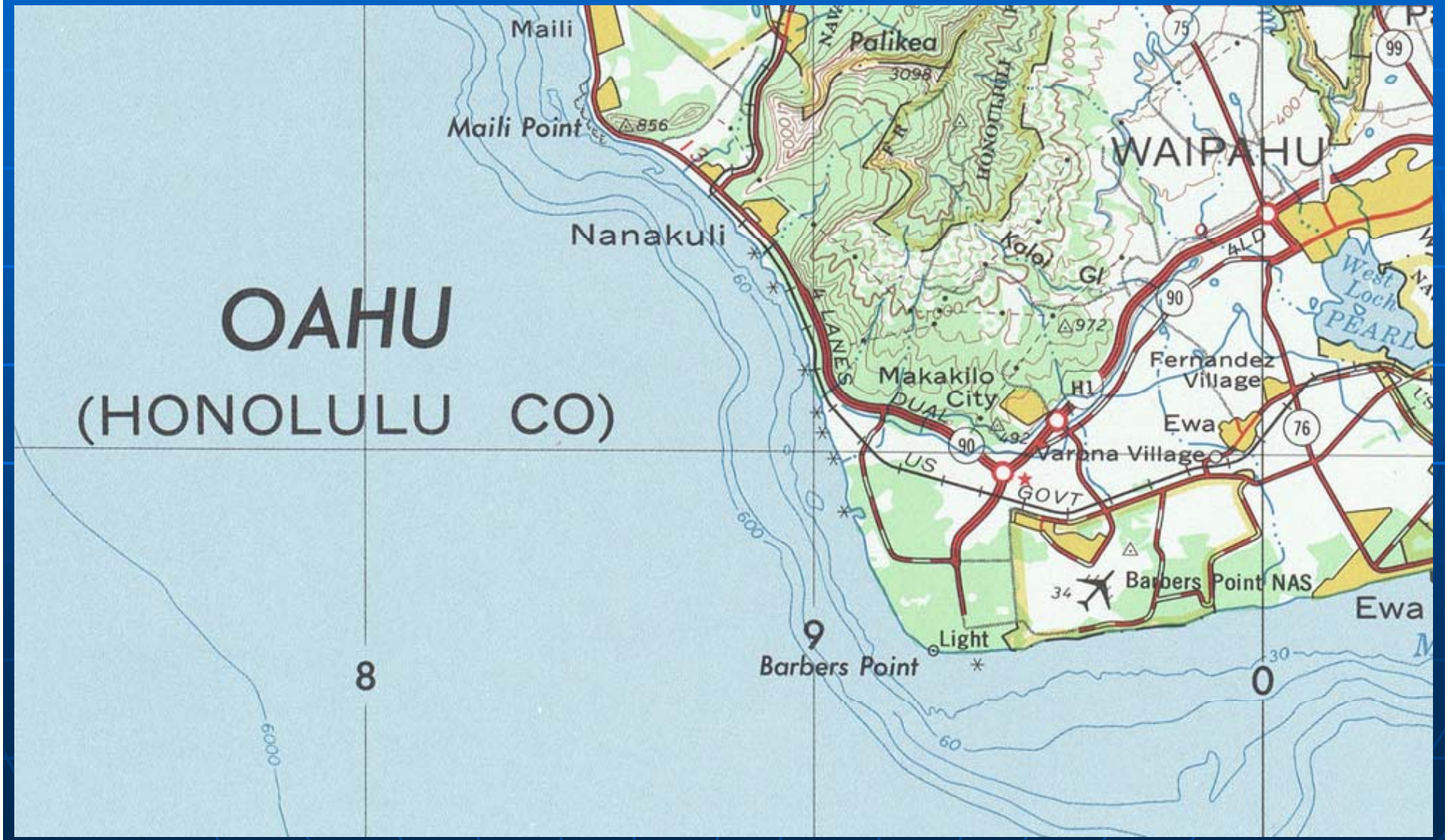
Spar

Spar

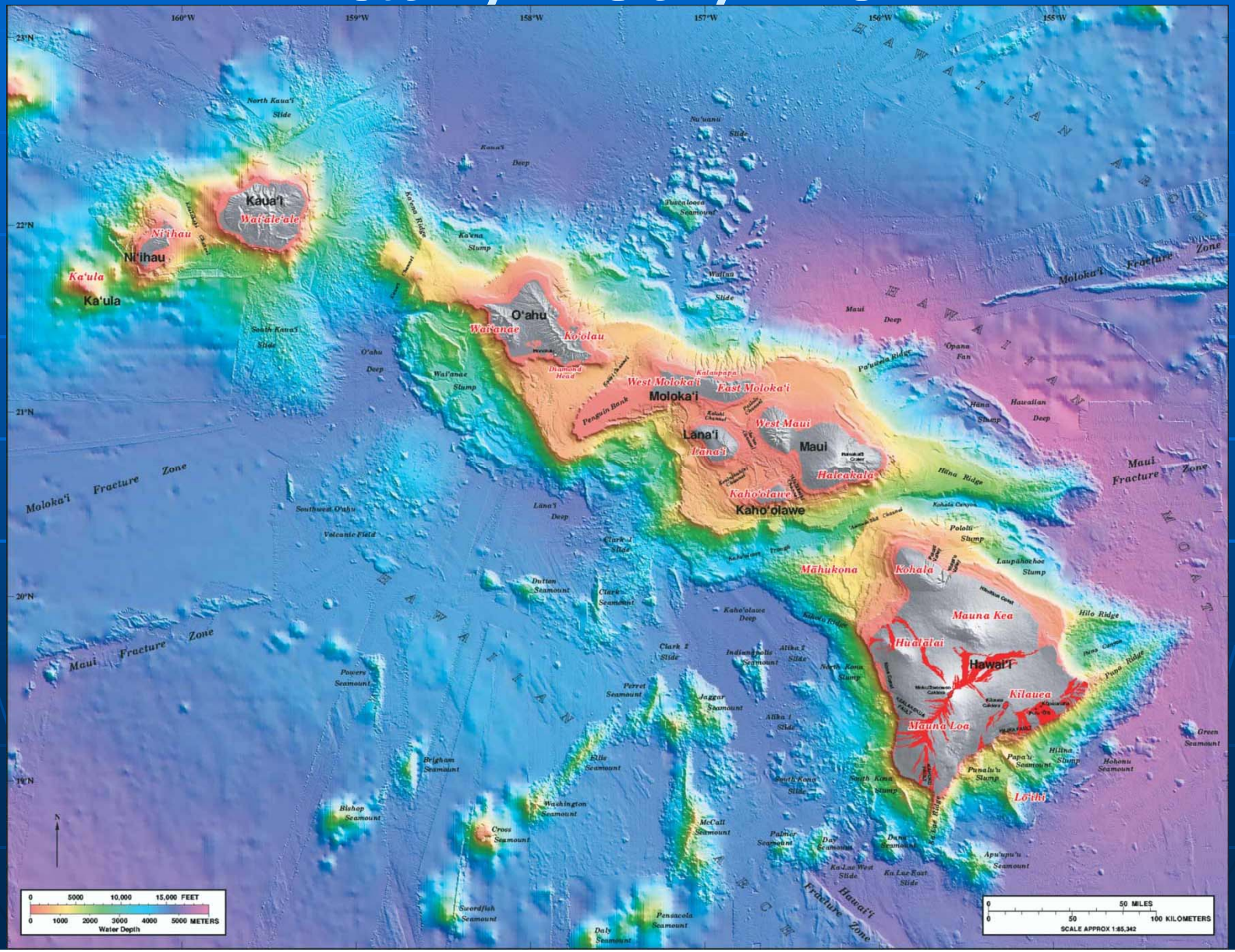
FPSO



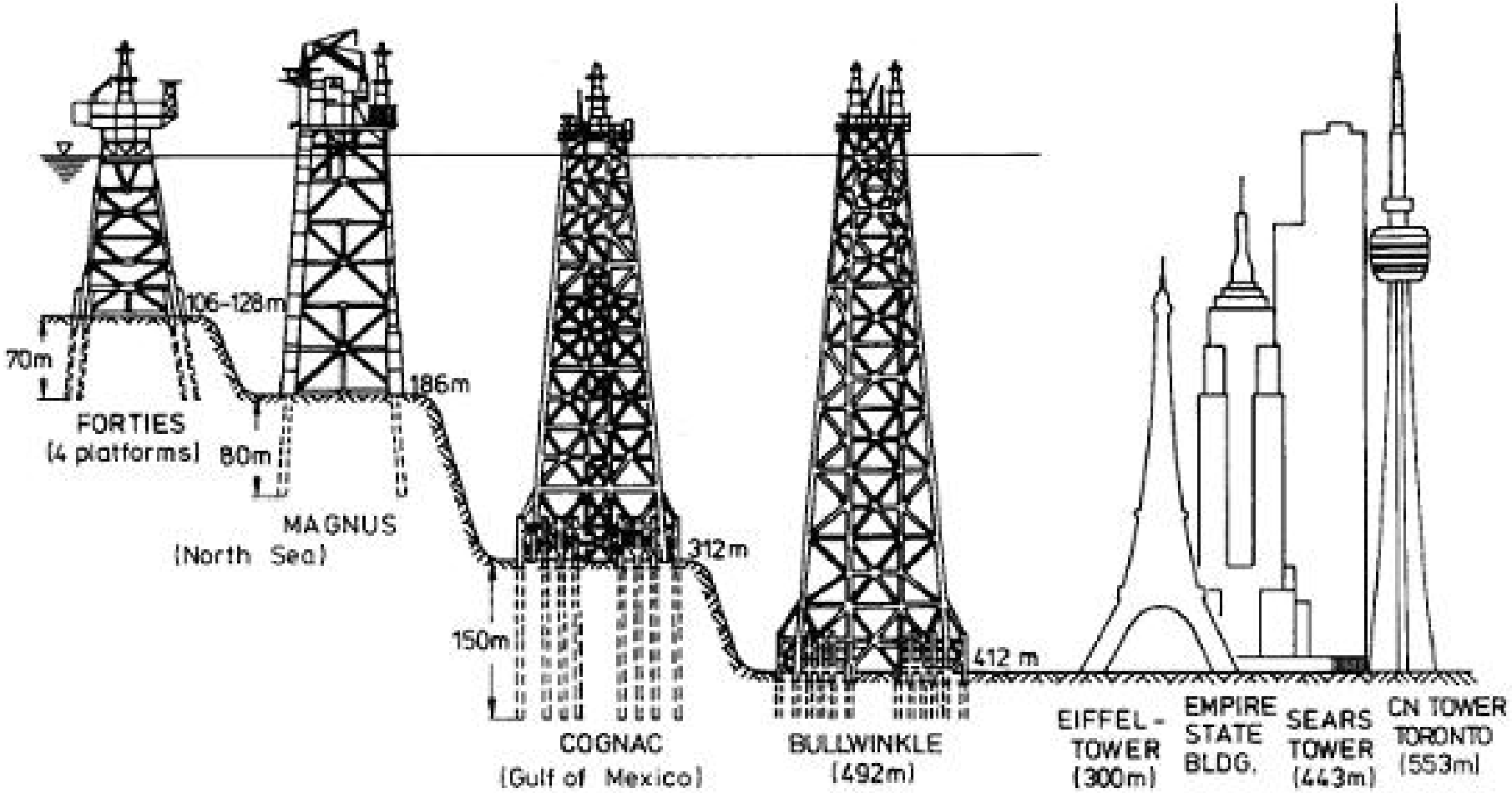
Bathymetry Then



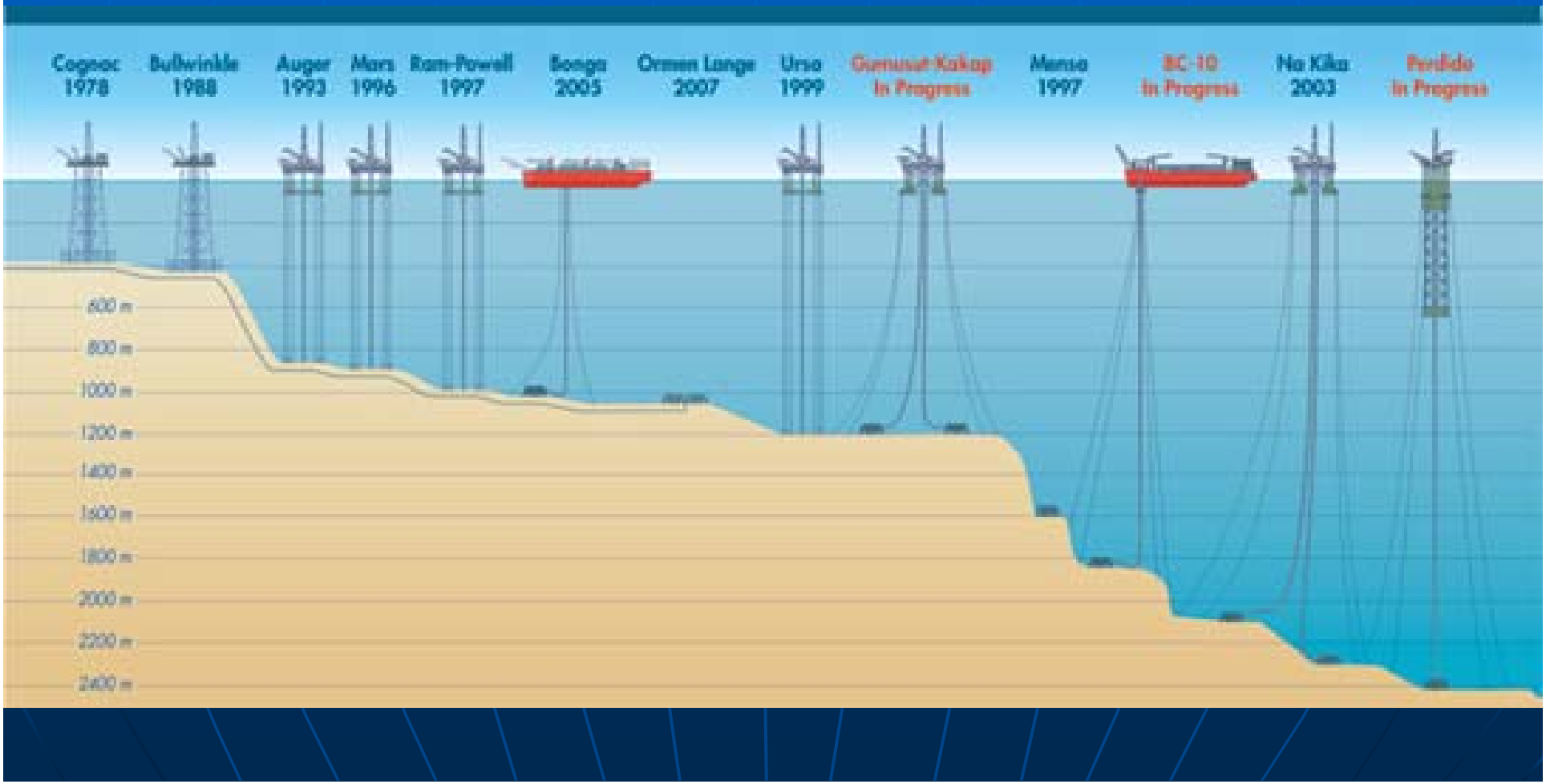
Bathymetry Now



Platforms Then



Platforms Now



Glomar Explorer Gimbal