Offshore geo-hazards to keep in mind during prospecting and exploration activities of the Jan Mayen Micro-Continent area.

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Hydrocarbon exploration in deep water, offshore environmental considerations and geo-hazards

- **Environmental parameters**
  - Reservoir depth (drilling depth, drill path & position)
  - Water depth
  - Sea currents, weather & wave heights
  - Sea & surface temperature
  - Sea ice
  - Distance to shore
  - Wild life

- **Deep water geo-hazards**
  - Complex & unstable sea beds
  - Active & changing foundations
  - Shallow geo-pressure
  - Drilling hazards
  - Deep sea environmental issues

- **Known hazards in O&G drilling and production operations process**

- **Knowing preventive measures beforehand – contingency planning**
  - Define possible environmental, geo- or technical hazards
  - Risk assessment and mitigation is essential
  - Detailed contingency planning

Environmental impact parameters comparison

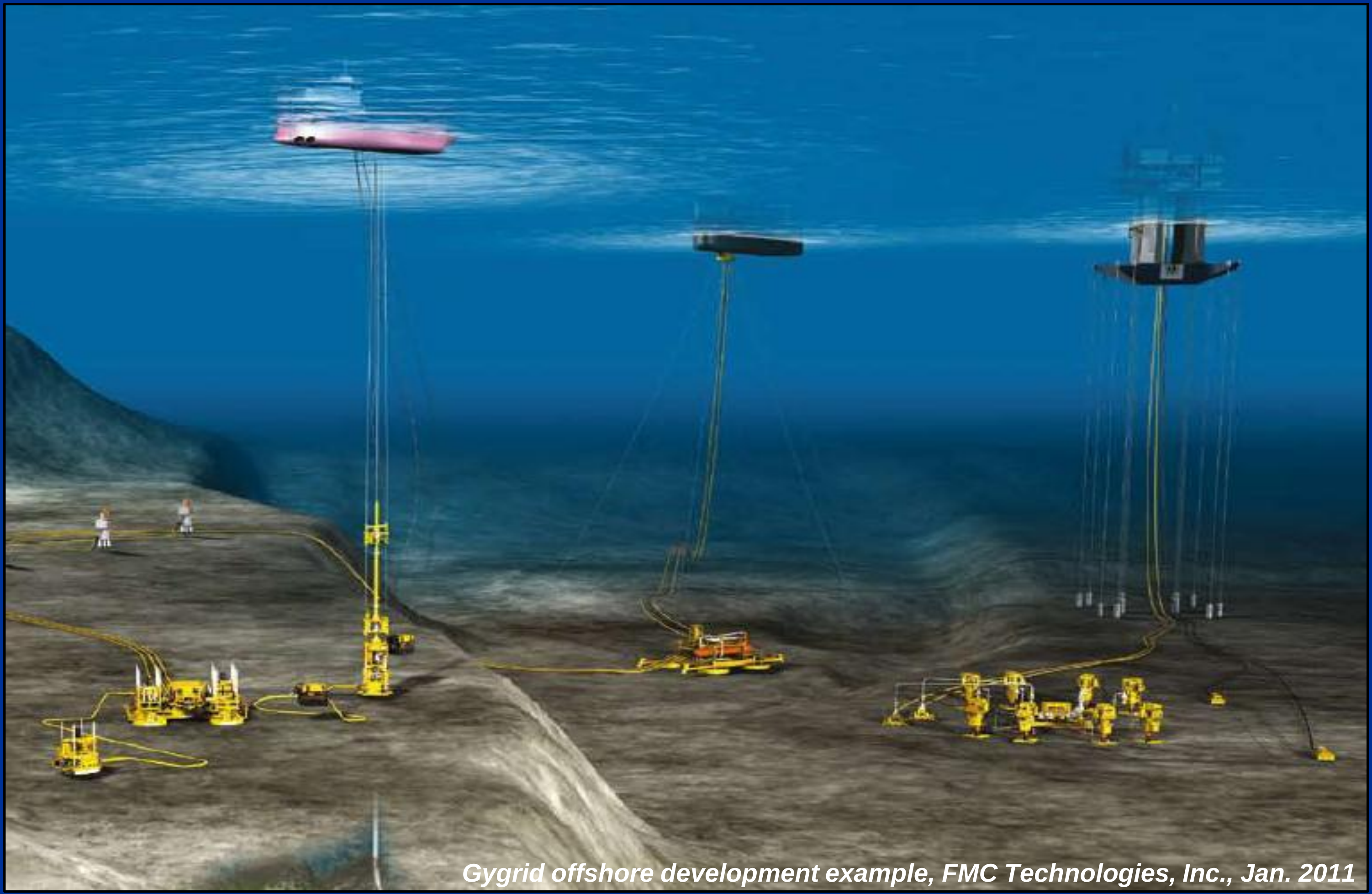
Criteria	Dreki Area	North-Western Europe	Gulf of Mexico	Offshore Brazil	Offshore Western Africa
Reservoir depth (m)	3 000 – 3 500	1 400 – 5 500	700 – 10 000	2 000 – 4 000	2 000 – 4 000
Water Depth(m)	1 000 – 2 000	10 – 2 000	0 – 3 000	0 – 3 000	0 – 3 000
Minimum sea bed temperature (C)	-1	-1	4	4	4
Maximum sea currents (m/s)	~1,0	~1,0	6-8 Lube currents	~1,0	~1,0
Minimum surface temperature (C)	-2 (-15)	~-10	Not relevant	Not relevant	Not relevant
Sea ice	Occasional pack ice	Not relevant	Not relevant	Not relevant	Not relevant
100-year wave height, Hs (m)	12	15-18	15	8	4
Wind speed design criteria (m/s)	36	36	40(54)	20	20
Distance to shore (km)	200 - 400	0 - 300	0 - 300	0 - 300	0 - 300
Gas off-take	No regional market & infrastructure	Regional market & infrastructure	Regional market & infrastructure	Regional market & infrastructure	No regional market & limited infrastructure

Jan Egil Arneberg, BayernGas, Norge, Iceland Exploration Conference, 2008

Environment impact parameters
Main conclusions from the SEA (Strategic Environment Assessment)

- Water depths 1000m to 2000 m in 80% of the area
- Great variability in biomass and consequently in habitats
- The area is important feeding ground for pelagic fish, especially herring, and possibly for whales
- On-site current measurements needed (collected 2007-2008)
- Need for registration and mapping of delicate habitats of benthic species (started in 2008)
- No information on demersal fish in the area (investigated in 2009)

Deep sea drilling and operations example

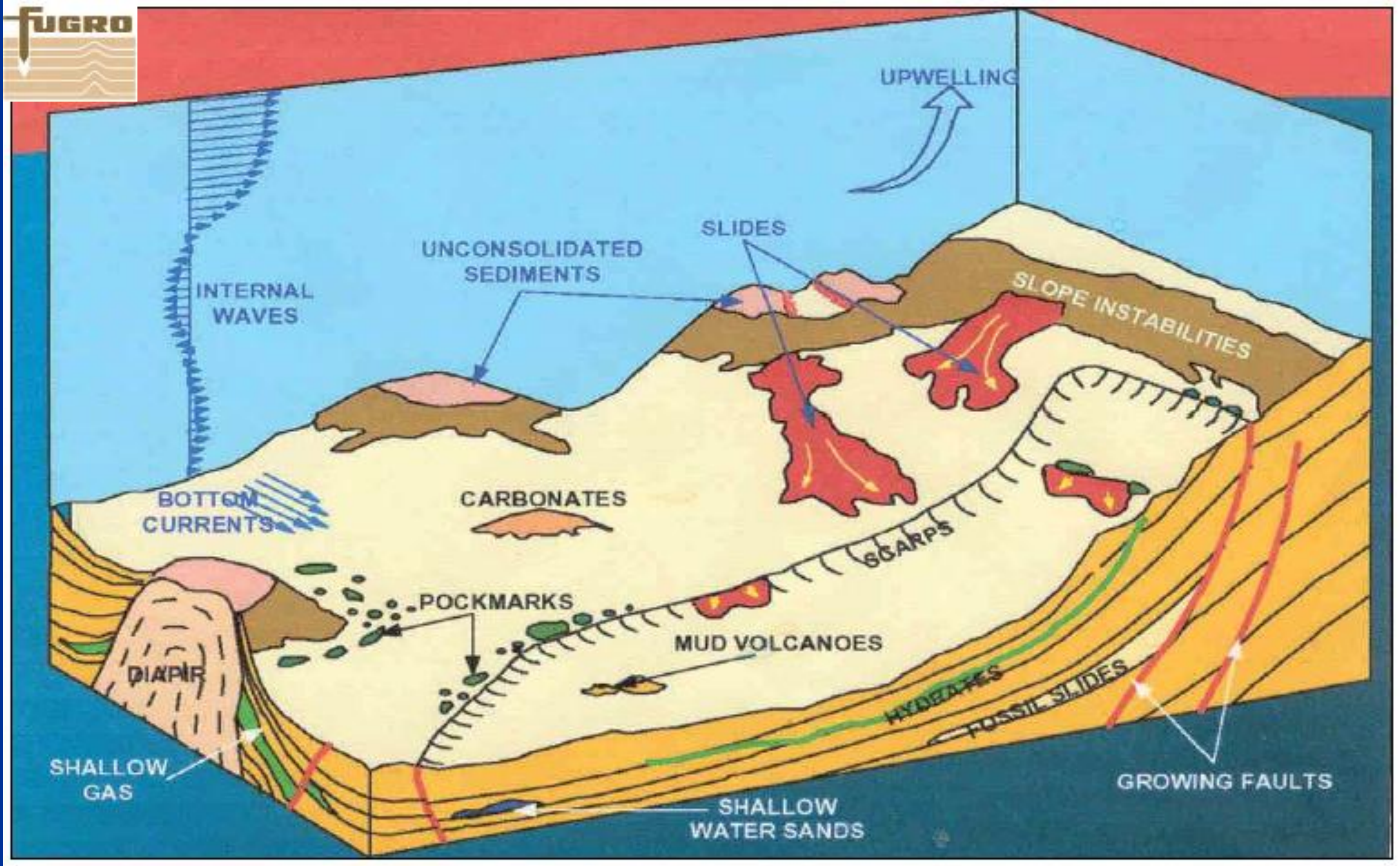


Deep Water Geo-Hazards

- **Complex & unstable sea beds**
  - Soft, thick and high fluid content sediments at sea floor
  - Rugged, steep and sloping topography that can lead to failure with sediment flows and turbidites
  - Rapid sedimentation and erosional processes
- **Active & changing foundations**
  - Continuous and active faulting can lead to foundation instability
  - Salt tectonics and sea floor deformations
  - Steep fault scarps and extreme topography
- **Shallow geo-pressure**
  - Shallow water flows
  - Weakened sea bed and sub-sea bed foundation
  - Mud volcanoes, diapirs, fluid vents
- **Drilling hazards**
  - Shallow gas
  - Gas hydrates
  - Shallow water flow
- **Deep sea environmental issues**
  - Deep sea currents
  - Oscillating deep sea currents

Reference: modified after Kelvin Chow, Fugro, 2006

Possible Environmental and Geo-Hazards to consider



Steve Wardlaw and Richard Salisbury, Fugro GeoConsulting, Geophyics and Geohazards – Defining Subsea Engineering Risk, March 2010

Deep Water Geo-Hazards – Applicability for the Jan Mayen Ridge

➢ Complex & unstable sea beds

- Soft, thick and high fluid content sediments at sea floor
- Rugged, steep and sloping topography that can lead to failure with sediment flows and turbidites
- Rapid sedimentation and erosional processes – possible gravitational failure on steep slopes of the JMR

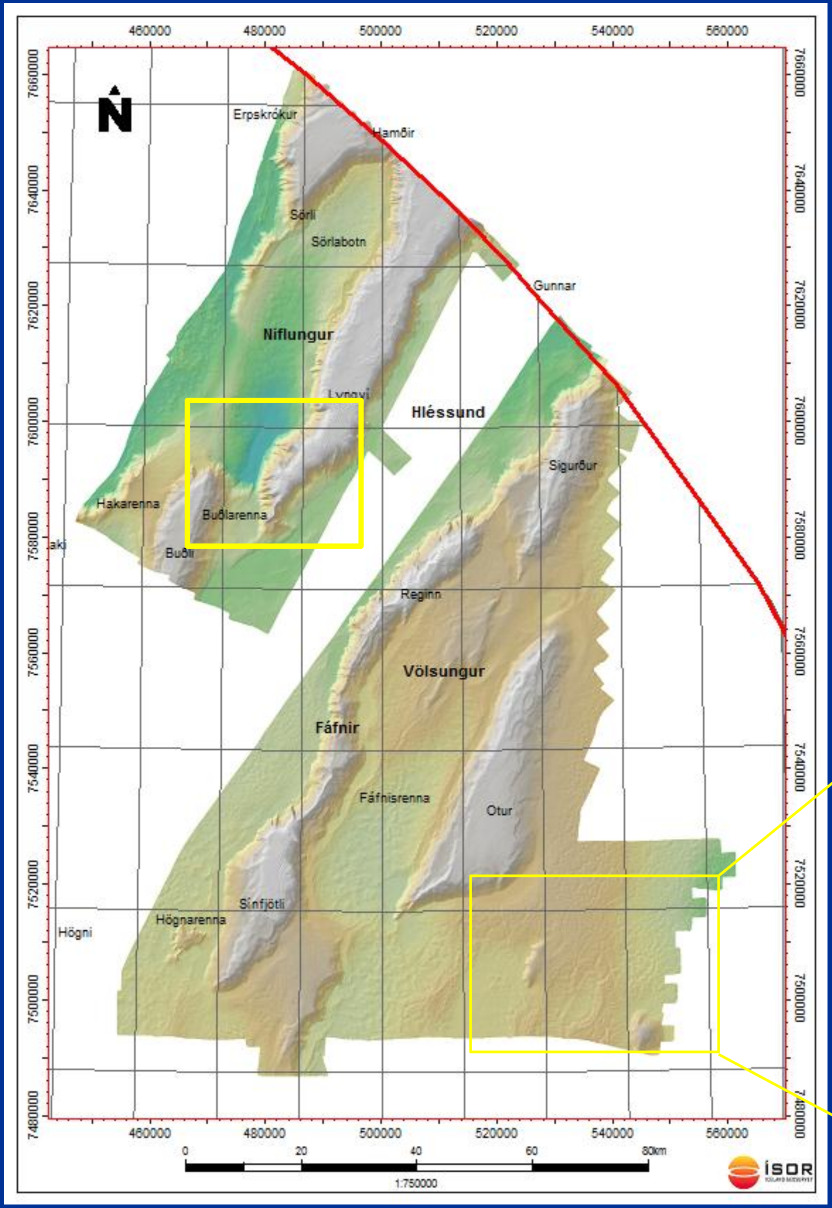
➢ Active & changing foundations

- Continuous and active faulting can lead to foundation instability
- Salt tectonics and sea floor deformations
- Steep fault scarps and extreme topography
- Earth quakes

Reference: modified after Kelvin Chow, Fugro, 2006

Minding Topography

Multi-beam Survey 2008
Marine Research Institute & NEA

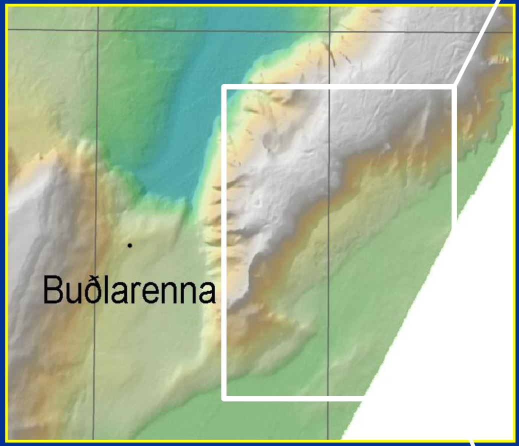


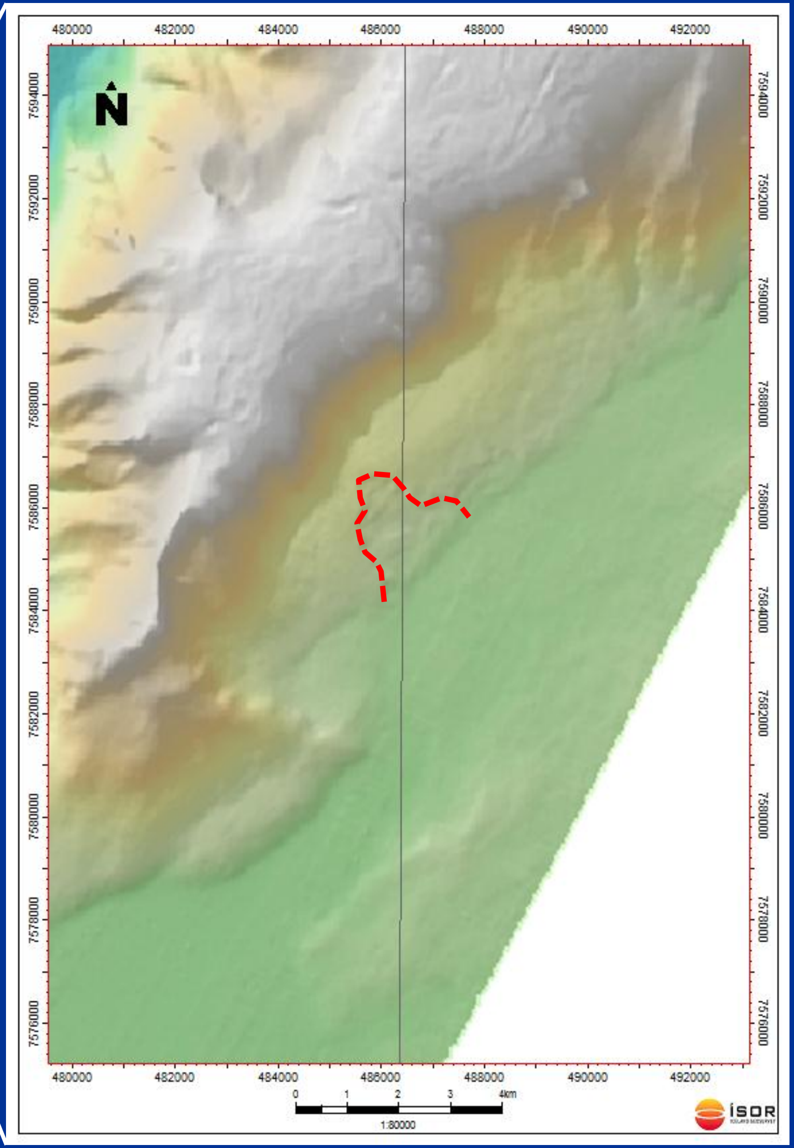
Possibly polygonal fault pattern related to de-watering of clay rich soft sediments.

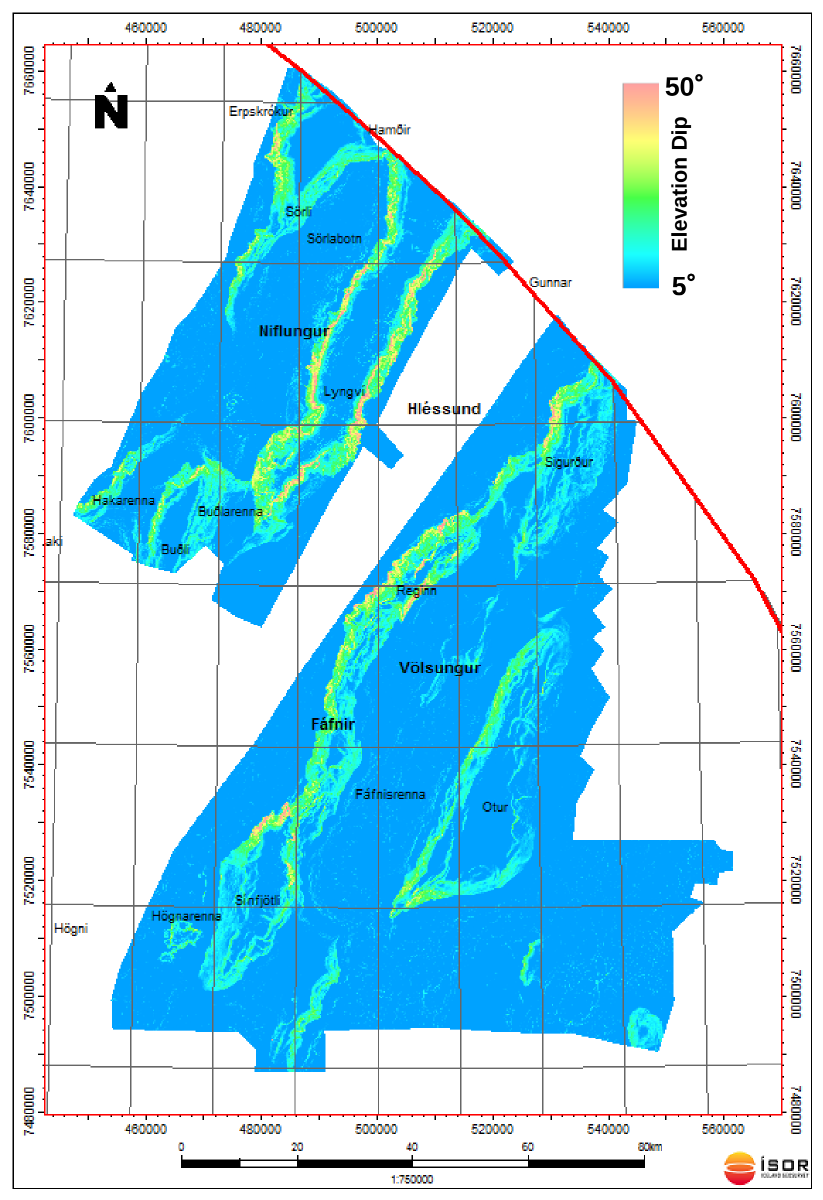
Minding Topography

Multi-beam Survey 2008
Marine Research Institute & NEA

Sediment slide example







Minding Topography

Identifying steep slope areas

Modified Multi-beam Survey 2008
Marine Research Institute & NEA

Deep Water Geo-Hazards – Applicability for the Jan Mayen Ridge

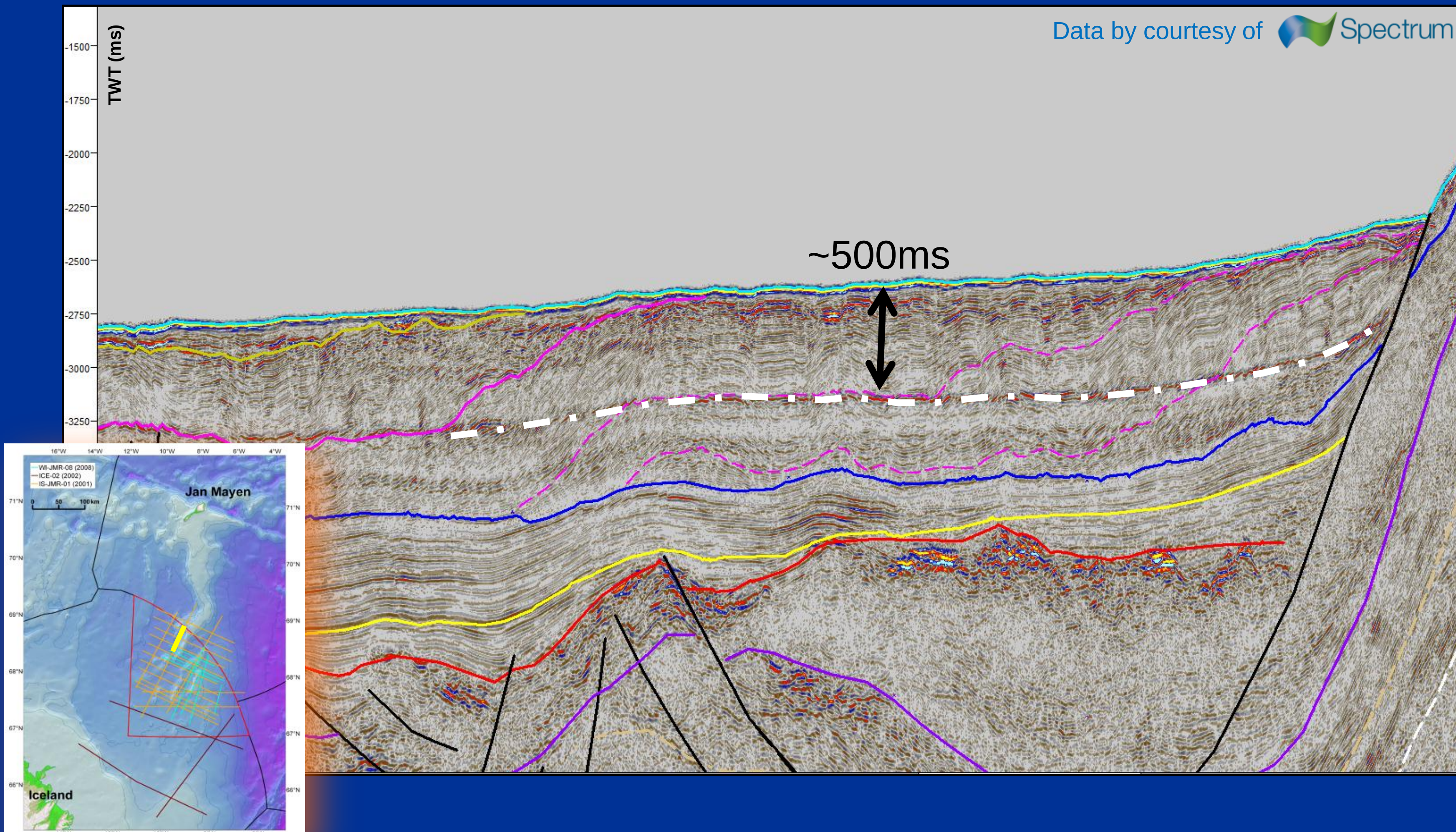
- **Shallow geo-pressure**
  - Shallow water flows ?
  - Weakened sea bed and sub-sea bed foundation
  - Mud volcanoes ?, diapirs, fluid vents

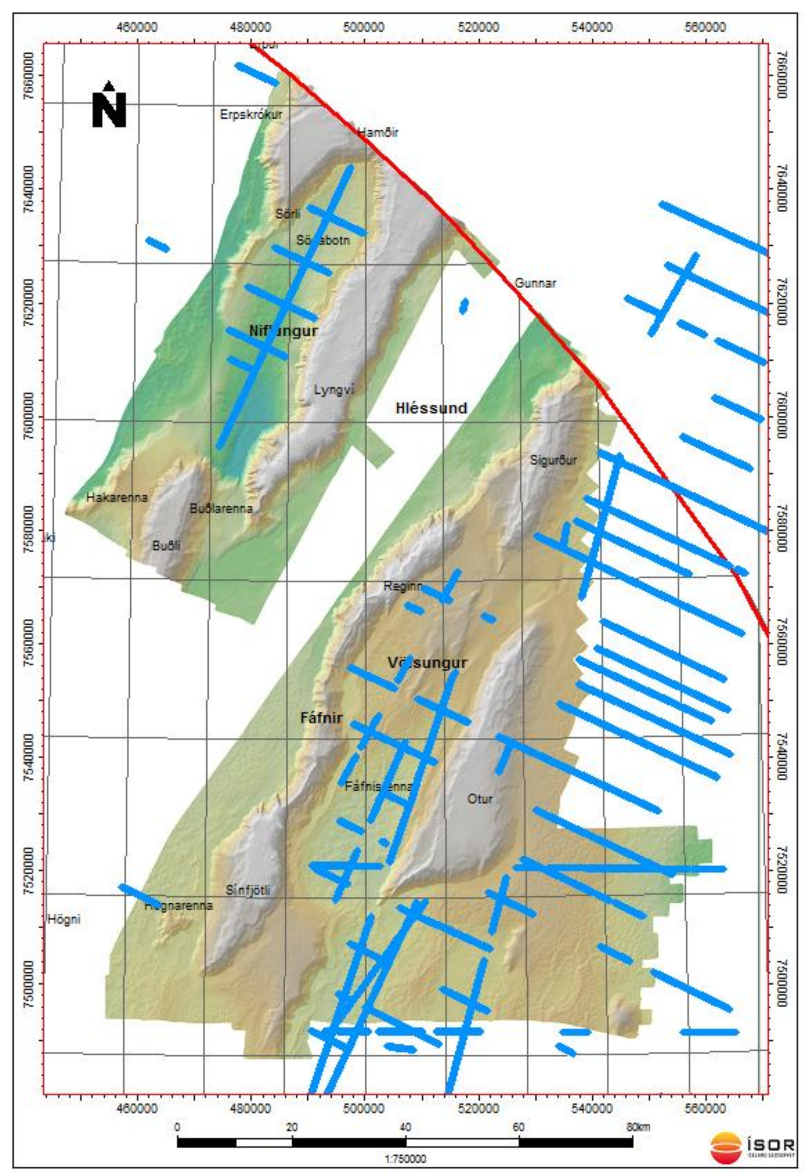
- **Drilling hazards**
  - Shallow gas – possible
  - Gas hydrates – possible
  - Shallow water flow ?

Reference: modified after Kelvin Chow, Fugro, 2006

Possible indications of Gas Hydrates: Bottom Simulating Reflector (BSR) or diagenetic effects?

SSW NNE





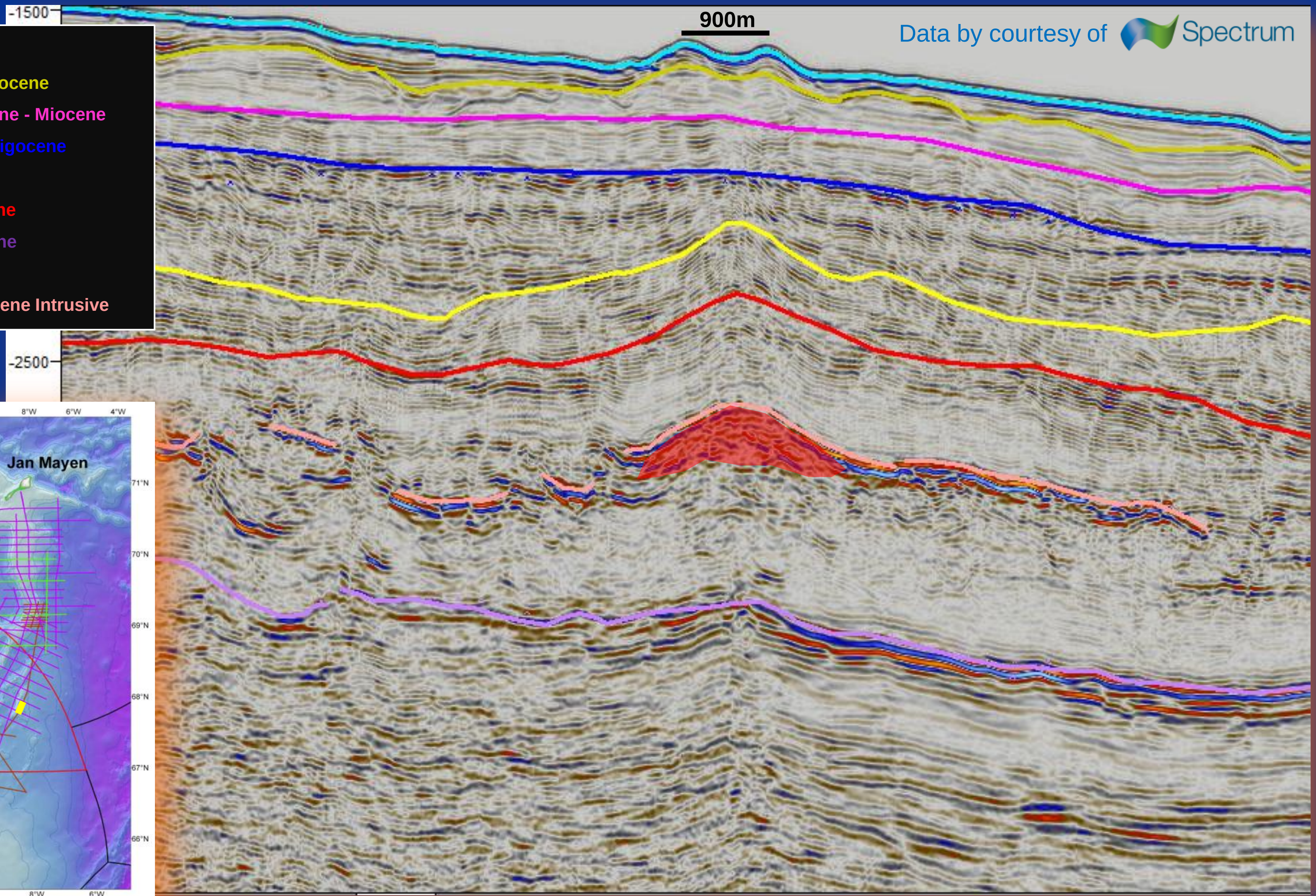
Possible indications of Gas Hydrates: Bottom Simulating Reflector (BSR) or diagenetic effects?

Potential BSR mapped over the Dreki area of the JMMC

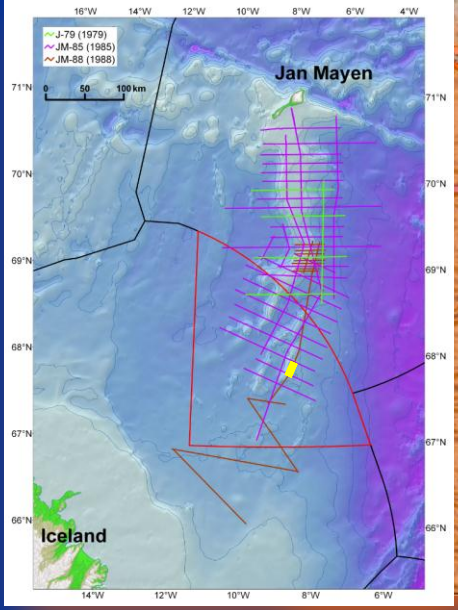
Fluid vent example – Southeastern JMR

SSW

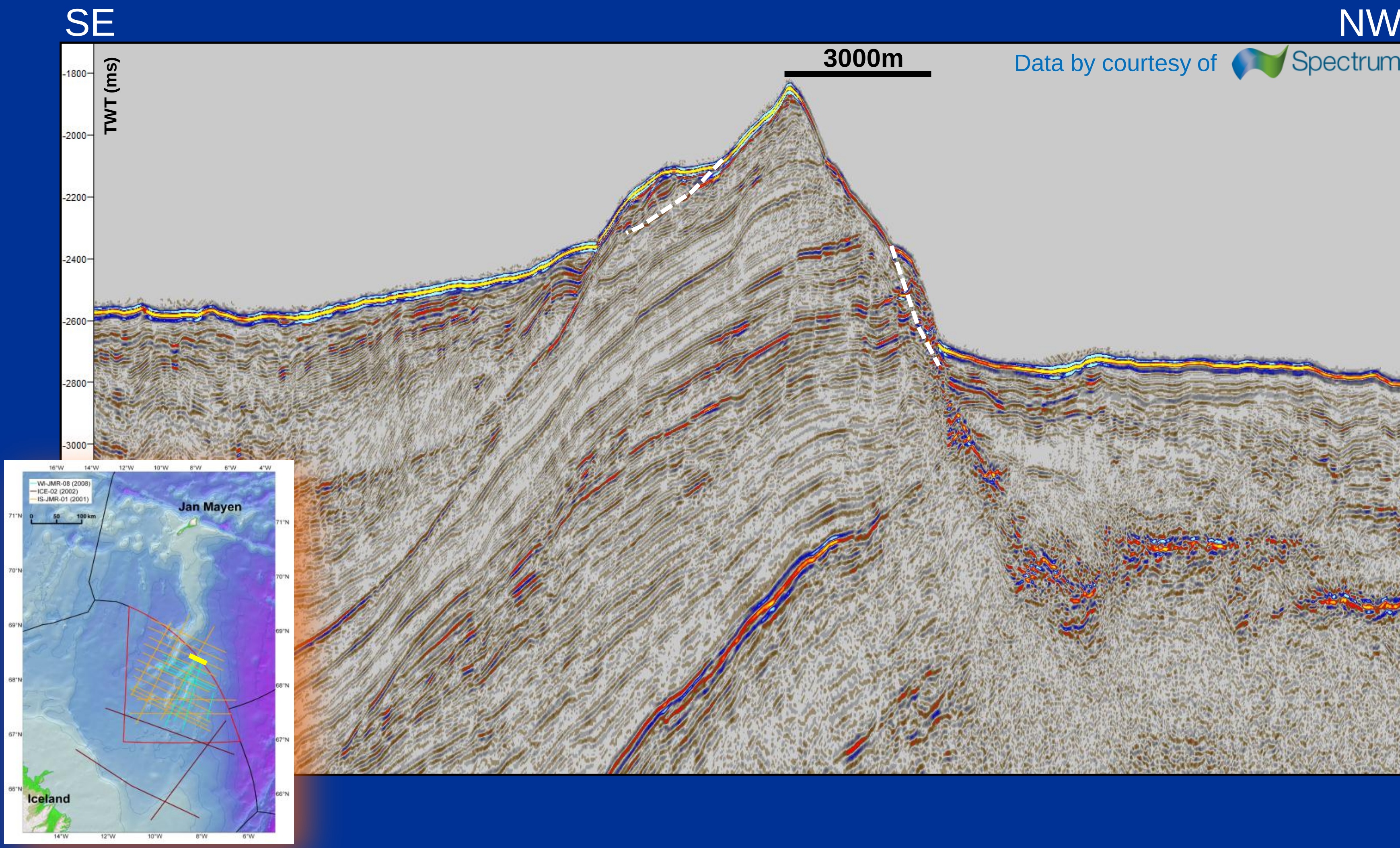
NNE



- Seabed
- Pleistocene - Pliocene
- UC Late Oligocene - Miocene
- UC Base Late Oligocene
- Top Eocene
- UC Middle Eocene
- UC Top Paleocene
- Eocene – Oligocene Intrusive



Steep slopes and gravitational failure example - JMR

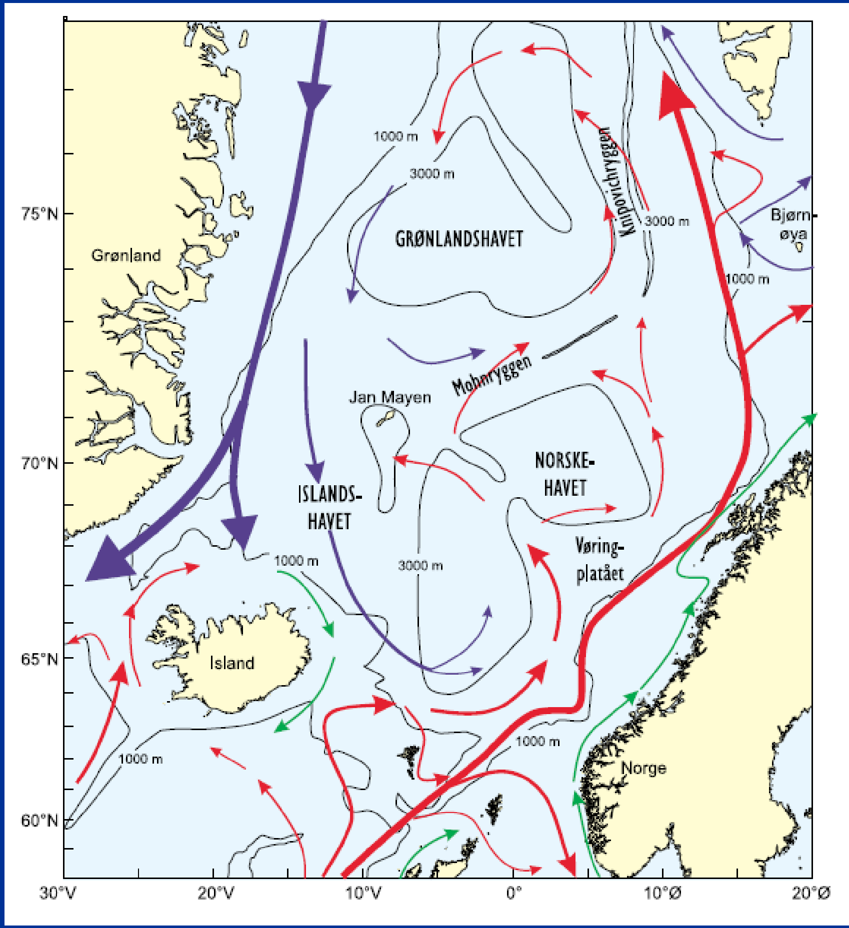


➢ Deep sea environmental issues

- Deep sea bottom currents – weak flow
- Oscillating deep sea currents – local seasonal variations

- Measurements conducted by taking ADCP profiles from a ship and by an anchored mooring
- Weak flow of bottom current velocity in the area on the order of 5 cm/s
- Seasonal variation between upper current and bottom flows

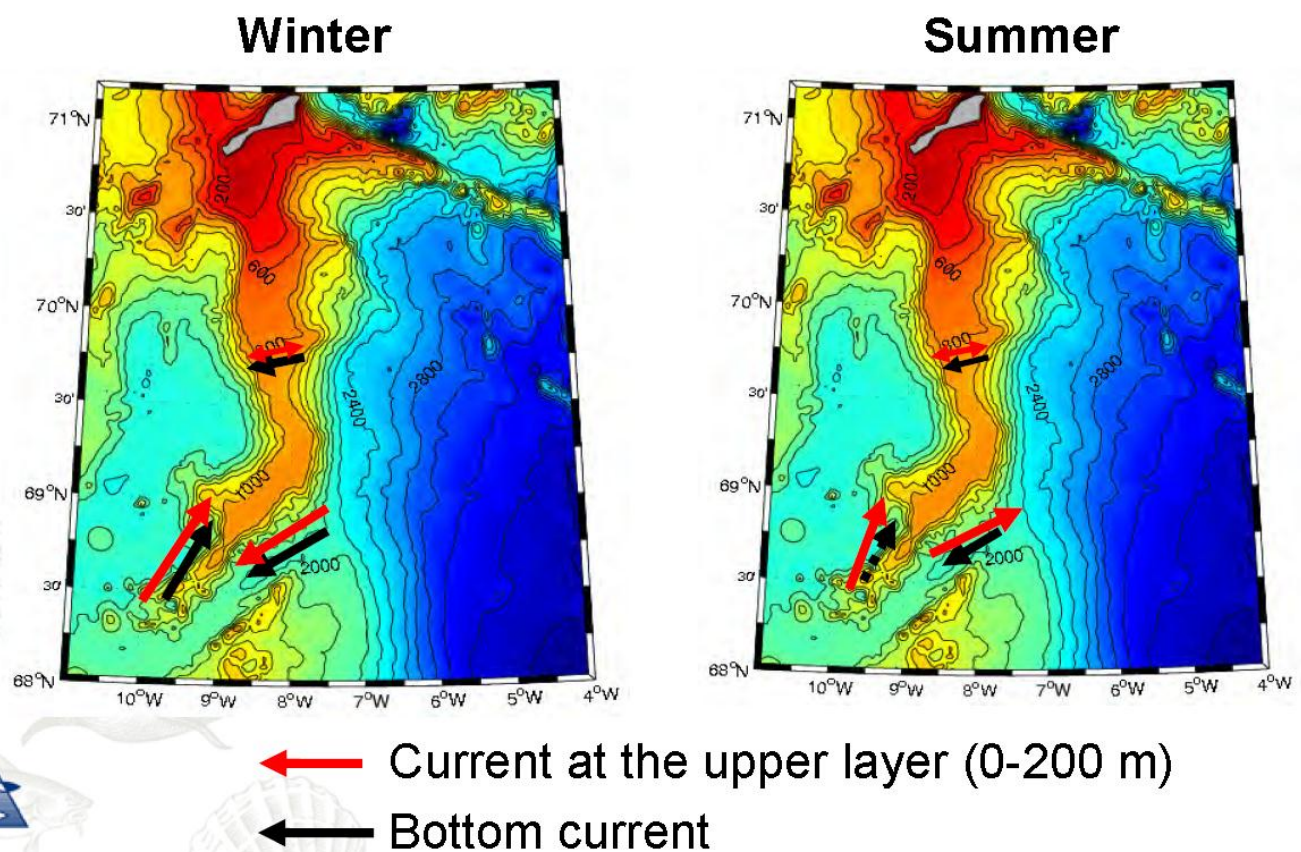
Surface currents in the North-Atlantic



Marine Research Institute, 2007

Kjell Arne Mork et al, 2011

Mean current field (schematic)



Curtesy of Steingrimur Jónsson, University of Akureyri

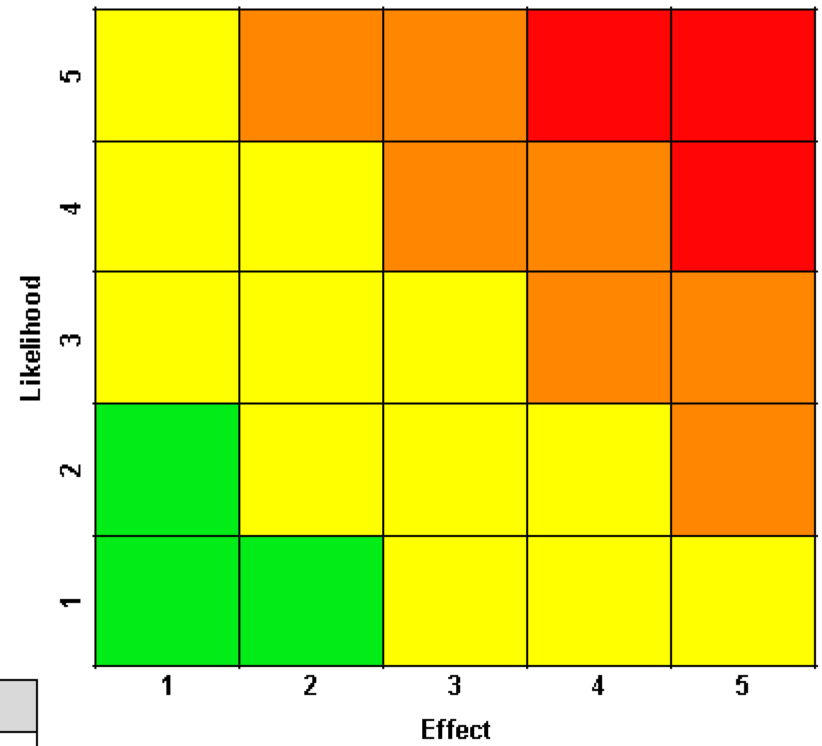
Necessity to specifying Risk – Risk Matrix Example

Scale	Likelihood	Probability of occurrence
5	Highly possible	>1 in 3
4	Possible	1 in 10 to 1 in 3
3	Unlikely	1 in 100 to 1 in 10
2	Very unlikely	1 in $10^{\text{[illegible]}}$
1	Negligible	<1 in $10^{\text{[illegible]}}$

multiplied by

Scale	Effect	Impact as % of total project cost or time
5	Extremely high	>100 %
4	Very high	10 % - 100 %
3	High	4% - 10 %
2	Low	1 % - 4 %
1	Very low	<1 %

Degree of Risk	Risk Level	Action suggested
17-25	Intolerable	Project should not proceed unless hazard can be shown to be absent
10-16	Substantial	Project should not proceed unless risk can be avoided, transferred or mitigated
3-9	Significant	Further investigation to refine assessment; mitigate through relocation or re-design
1-2	Insignificant	Accept and manage



Steve Wardlaw and Richard Salisbury, Fugro GeoConsulting, Geophyics and Geohazards – Defining Subsea Engineering Risk, March 2010

Summary

- **Need to be realistic: Accidents during the offshore oil and gas development do happen - but they need to be avoided as far as planning, technology and operations are concerned.**

- **Safety and environmental regulations have to be followed !**

- **Not to follow short cuts due to time or financial pressure – this has played a role in the events leading up to most recorded incidents of disaster and pollution.**

- **Most typical causes of accidents include:**
  - Equipment failure
  - Personnel mistakes
  - Extreme natural impacts (seismic activity, ice fields, hurricanes, etc.)

- **Main hazards are connected with:**
  - Spills and blowouts of oil, condensate, gas, and other chemical substances
  - Environmental consequences can be severe near shore, in shallow waters or areas with slow water circulation.

Thank you very much for your attention !