Some Thoughts on Rock Mechanics in the Oil and Gas Industry

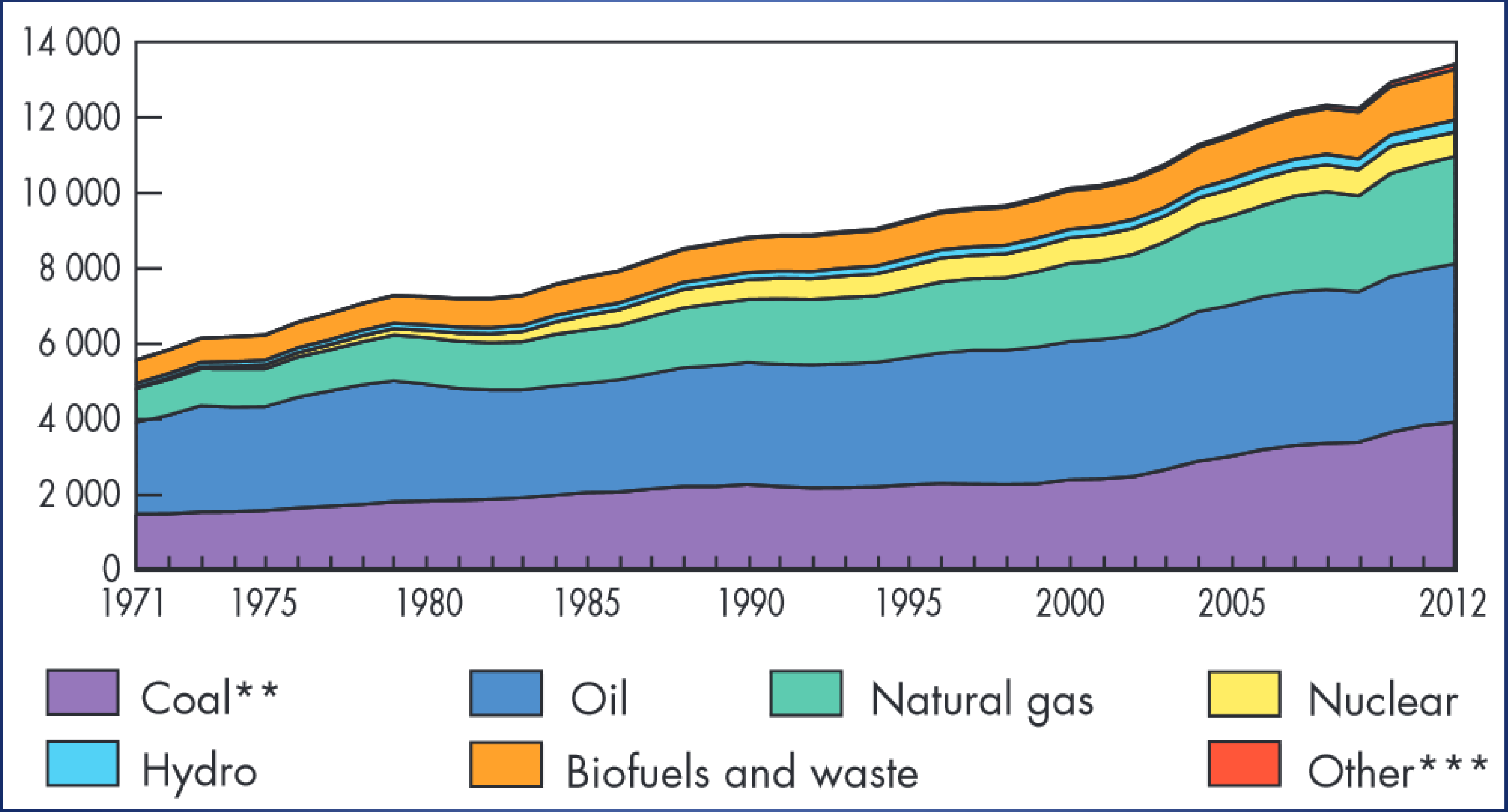
Kate Hadley Baker

BP and ExxonMobil (retired)

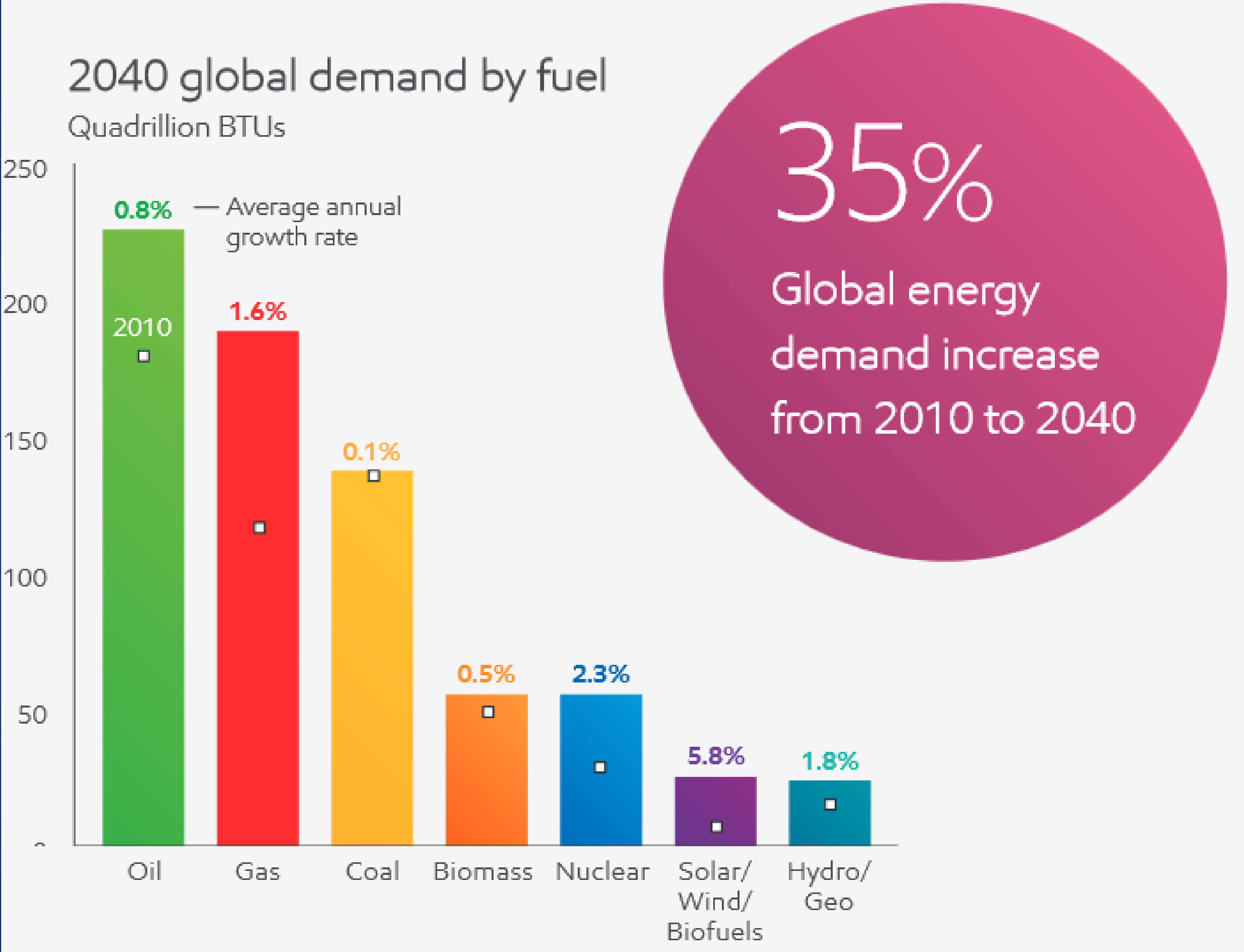
Outline

- The energy industry and oil and gas therein
- Rock mechanics in the oil and gas industry
  - Exploration
    - With a seismic rant
  - Appraisal
    - With a drilling and completions rant
  - Development/Production
    - Valhall and Wamsutter case histories
  - Abandonment
- Closing thoughts

World total primary energy supply 1971 to 2012 by fuel (Mtoe)



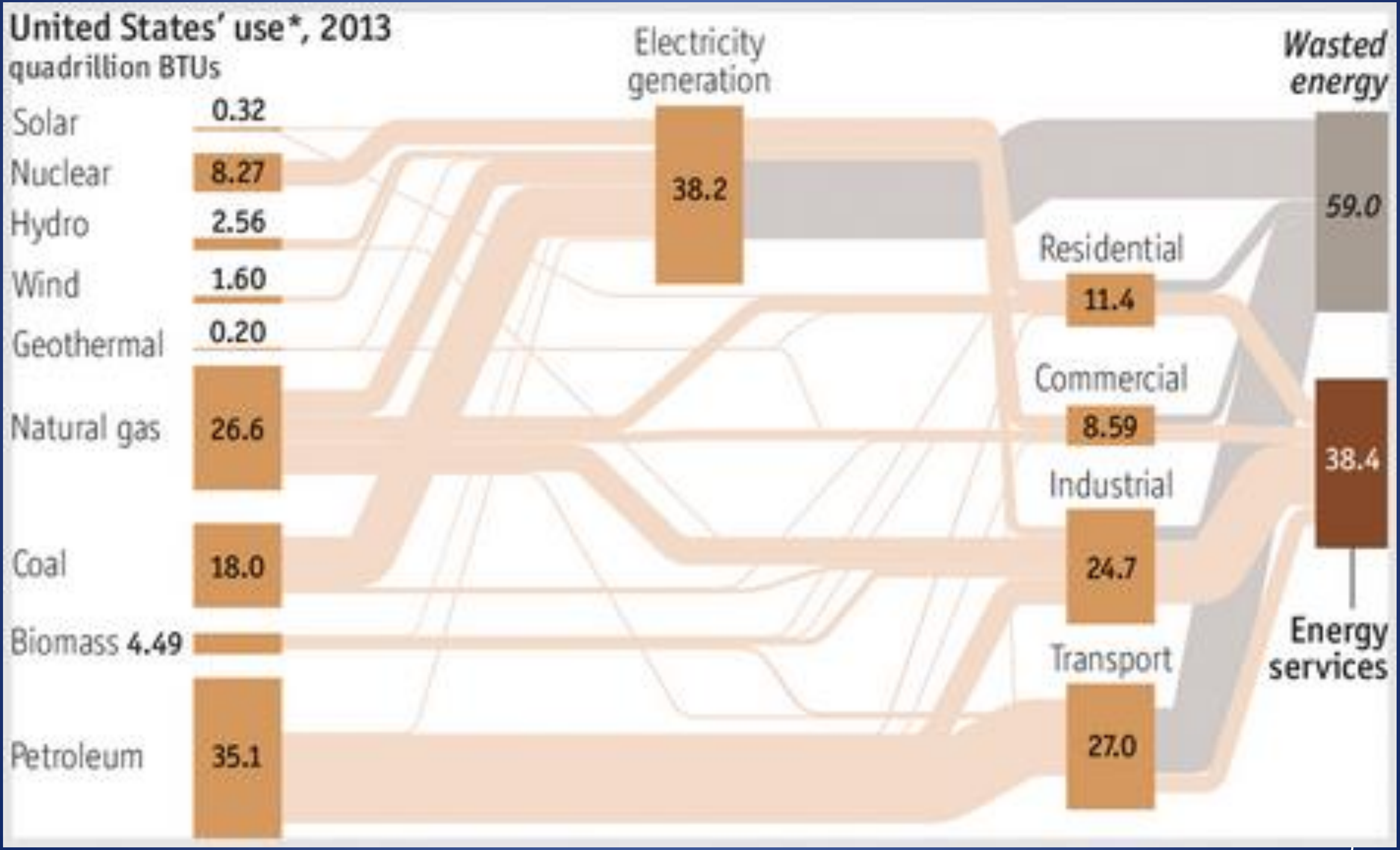
http://www.iea.org/publications/freepublications/publication/KeyWorld2014.pdf, p.7



ExxonMobil Outlook for Energy 2015, p. 57

Sources and Uses of Energy

United States' Use, 2013 quadrillion BTUs



The Economist (Jan 17 2015) Special Report "Let there be Light" p.4; original Sankey diagram from LLNL

Ahmed Abou-Sayed's View

Geomechanics -- Major impact
on Risk and Assurance in the O&G industry
--from far-field to near-wellbore scale

Paramount for Increased National Energy Supplies from Heavy oil and Shale Gas
Reserve Recovery Assurance particularly in deepwater reservoirs, tight formations
Increase O&G Reserves through precise and efficient Fracturing and stimulation Designs
Reserve Access and Recovery Management throughout Reservoir Life in Arctic Areas
Essential for Cost Management and viability during Wellbore drilling and Construction
Assurance of Total life access to reserve via mitigation of failure in the seal, casing and faults
Life Long Cost Containment through Sand and Hydrate Management
Design Basis for completions in highly faulted Reservoirs and near of Salt Bodies
Management of E&P Wastes through Injection and Assurance of Environmental compliance
Risk Management in deep HTHP Environments

Maurice Dusseault's View

Petroleum Geomechanics Areas…

- Borehole stability (+ chemistry, diffusion, wellbore hydraulics…)
- Hydraulic fracturing (+ fracture and porous media flow of fluids & slurries, filtration…)
- Reservoir compaction (+ reservoir mechanics, geological history, mineralogy…)
- Sand production (+ capillarity, hydrodynamic forces…)
- Thermally-induced casing shear (+ thermo-dynamics, fluid flow…)

1-B Examples of Vital Geomechanics Knowledge

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Rock Mechanics and Geomechanics are used Interchangeably in this talk. Is shale a rock or a soil?

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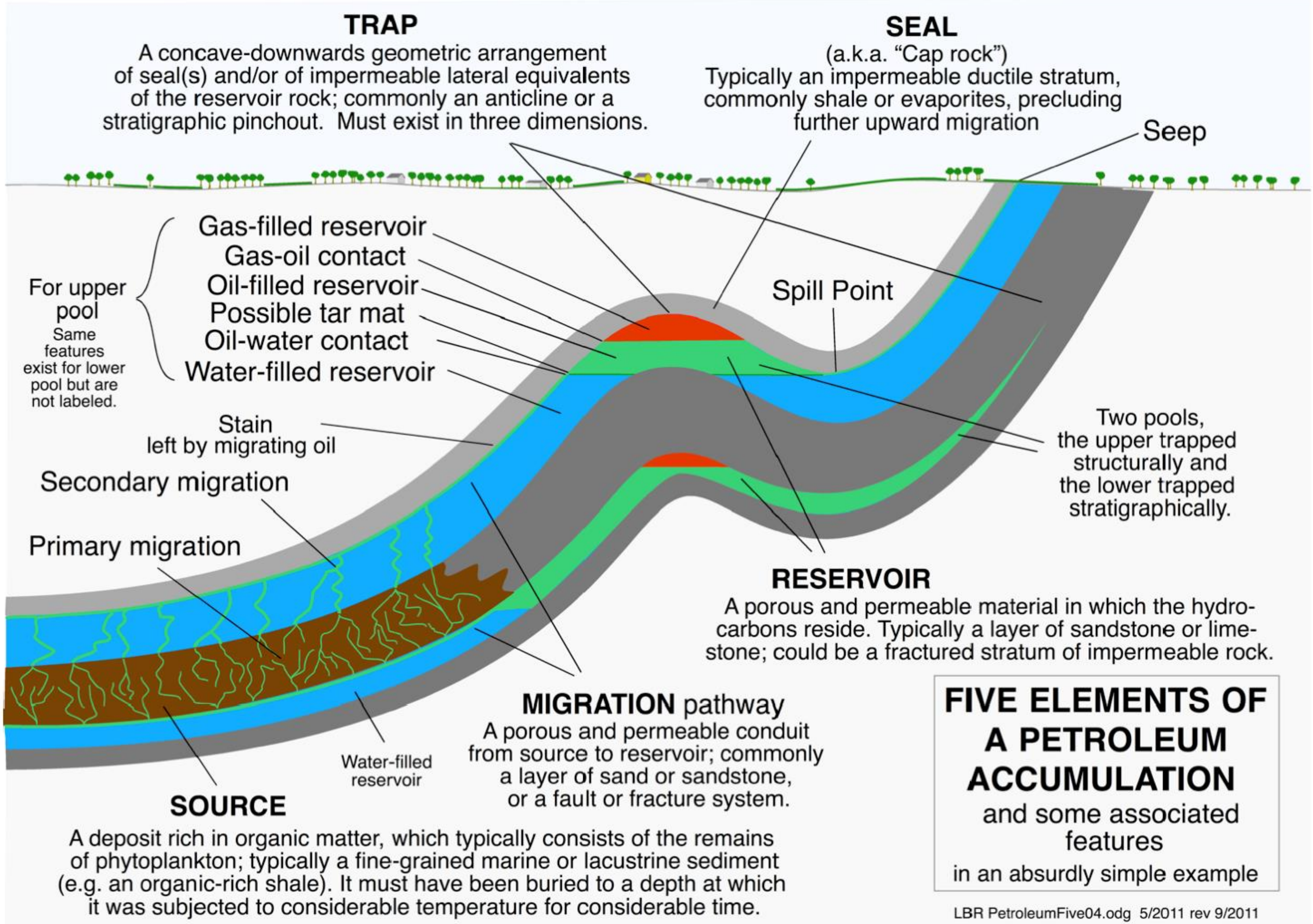
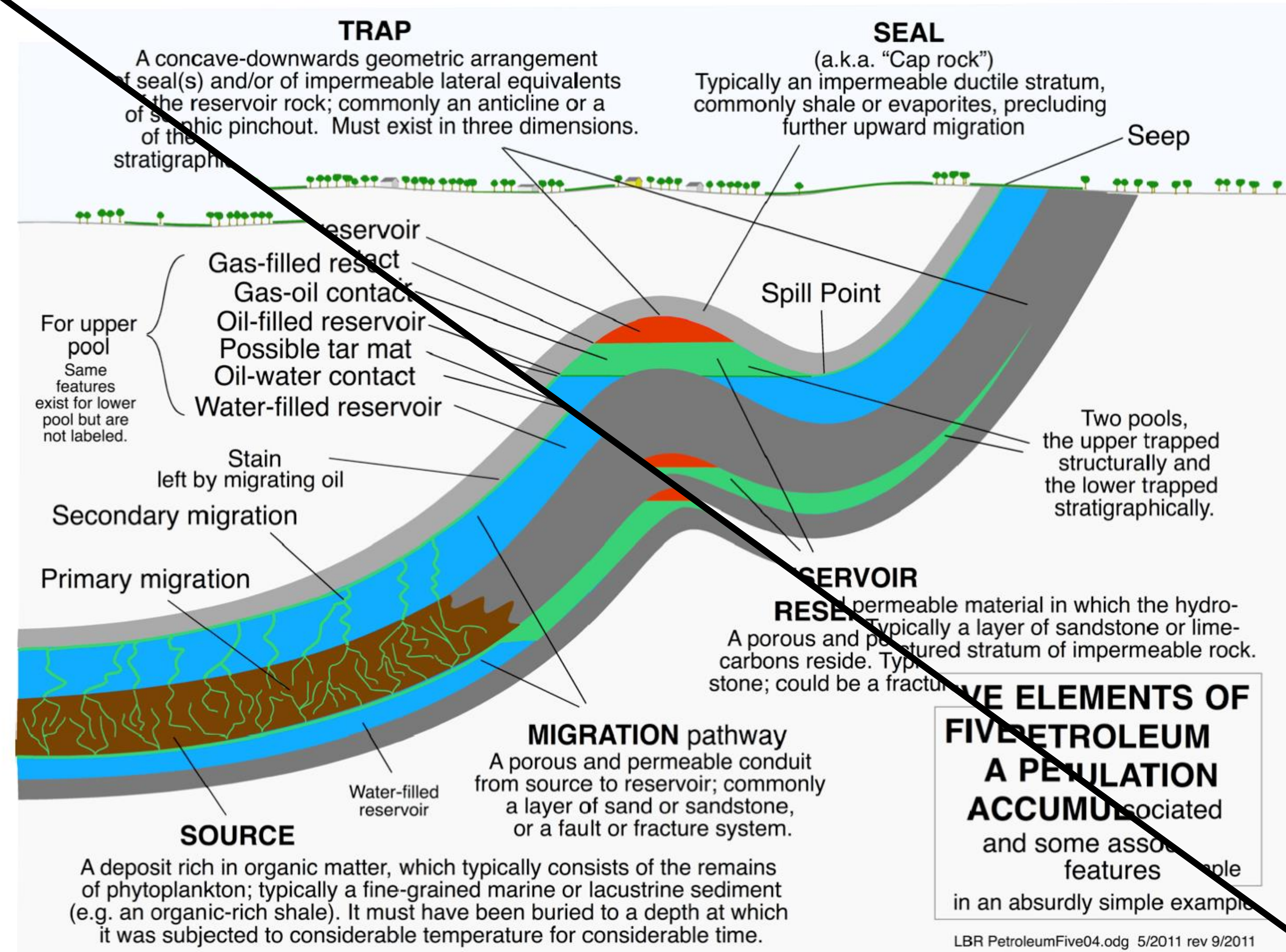

TRAP
A concave-downwards geometric arrangement of seal(s) and/or of impermeable lateral equivalents of the reservoir rock; commonly an anticline or a stratigraphic pinchout. Must exist in three dimensions.
SEAL
(a.k.a. "Cap rock")
Typically an impermeable ductile stratum, commonly shale or evaporites, precluding further upward migration
Seep
For upper pool
Same features exist for lower pool but are not labeled.
Gas-filled reservoir
Gas-oil contact
Oil-filled reservoir
Possible tar mat
Oil-water contact
Water-filled reservoir
Spill Point
Stain left by migrating oil
Secondary migration
Primary migration
Two pools, the upper trapped structurally and the lower trapped stratigraphically.
RESERVOIR
A porous and permeable material in which the hydrocarbons reside. Typically a layer of sandstone or limestone; could be a fractured stratum of impermeable rock.
MIGRATION pathway
A porous and permeable conduit from source to reservoir; commonly a layer of sand or sandstone, or a fault or fracture system.
Water-filled reservoir
SOURCE
A deposit rich in organic matter, which typically consists of the remains of phytoplankton; typically a fine-grained marine or lacustrine sediment (e.g. an organic-rich shale). It must have been buried to a depth at which it was subjected to considerable temperature for considerable time.
FIVE ELEMENTS OF A PETROLEUM ACCUMULATION
and some associated features
in an absurdly simple example
LBR PetroleumFive04.odg 5/2011 rev 9/2011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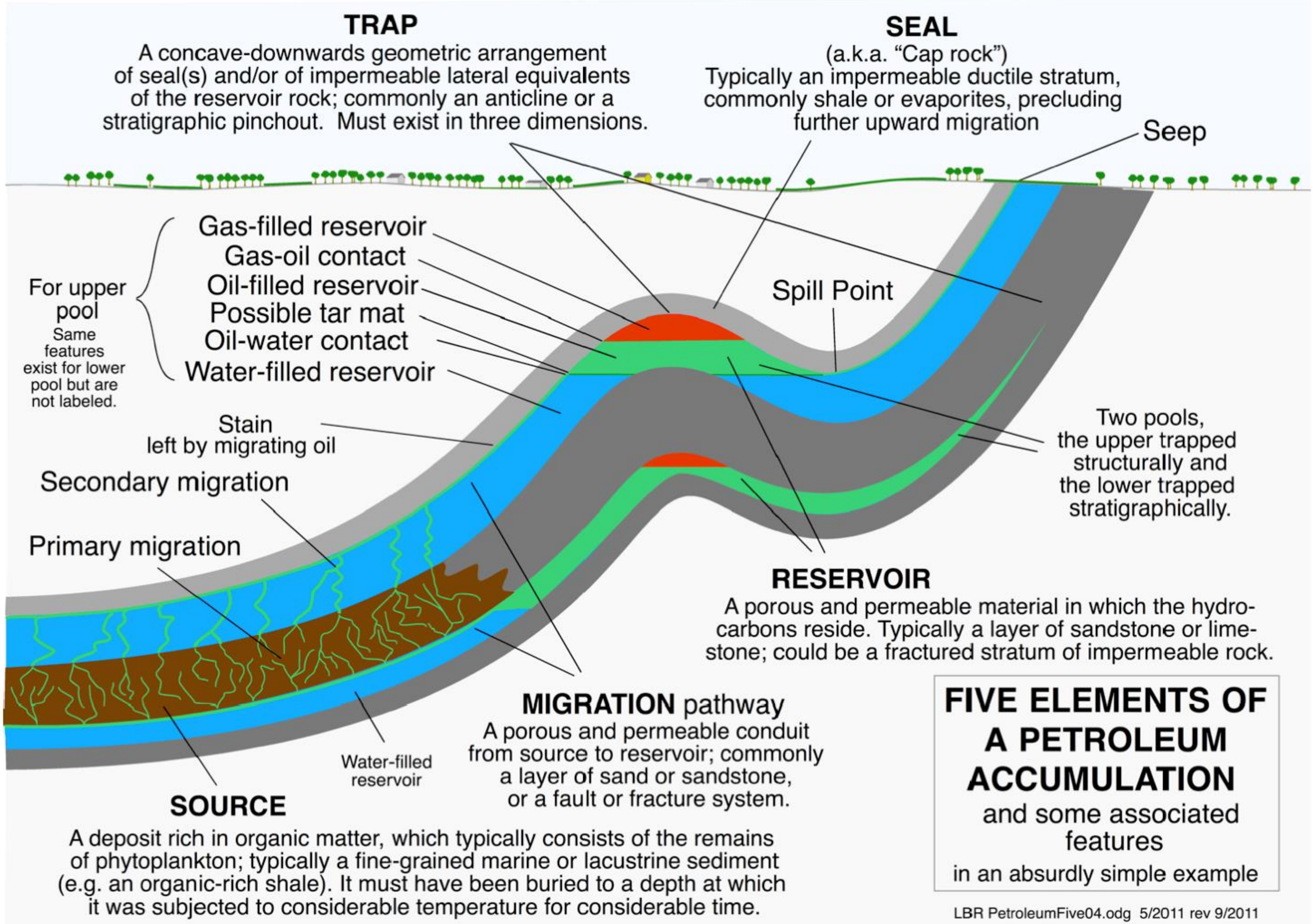
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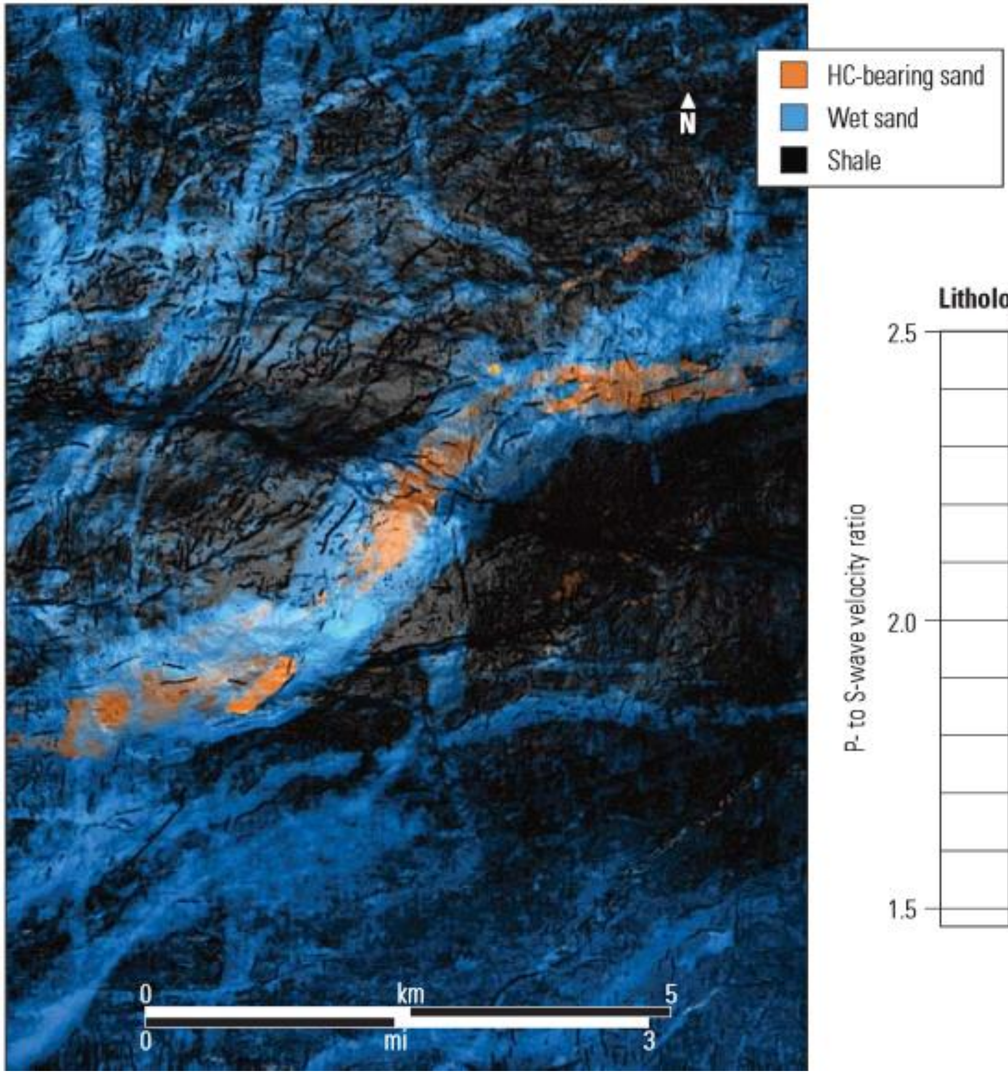
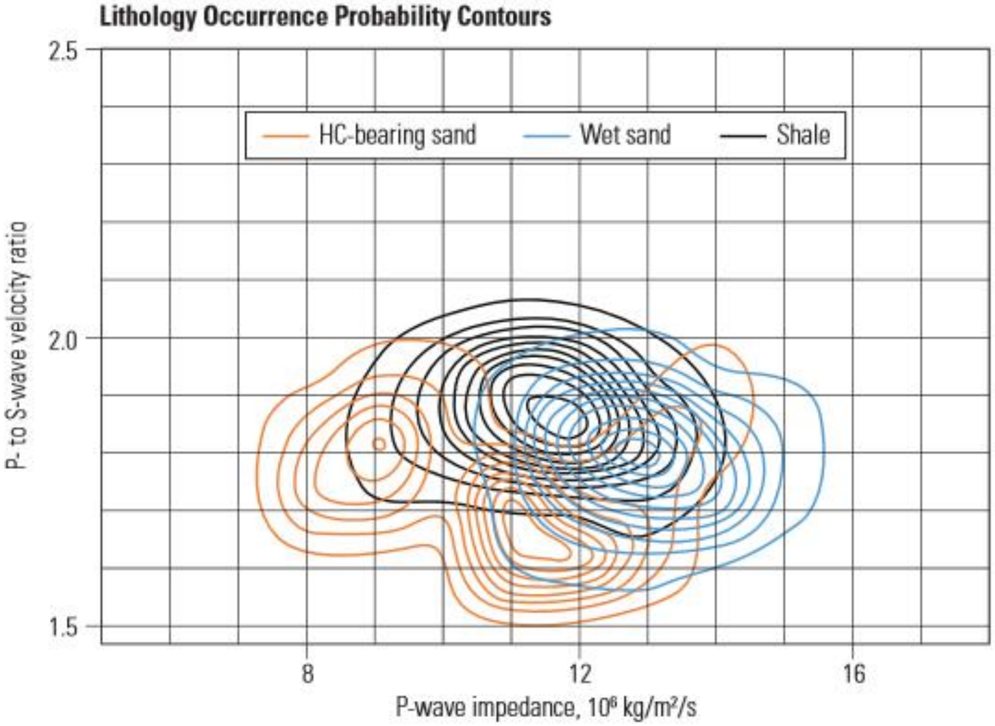
Seismic Rant





Busanello et al. (2014) *Oilfield Review*

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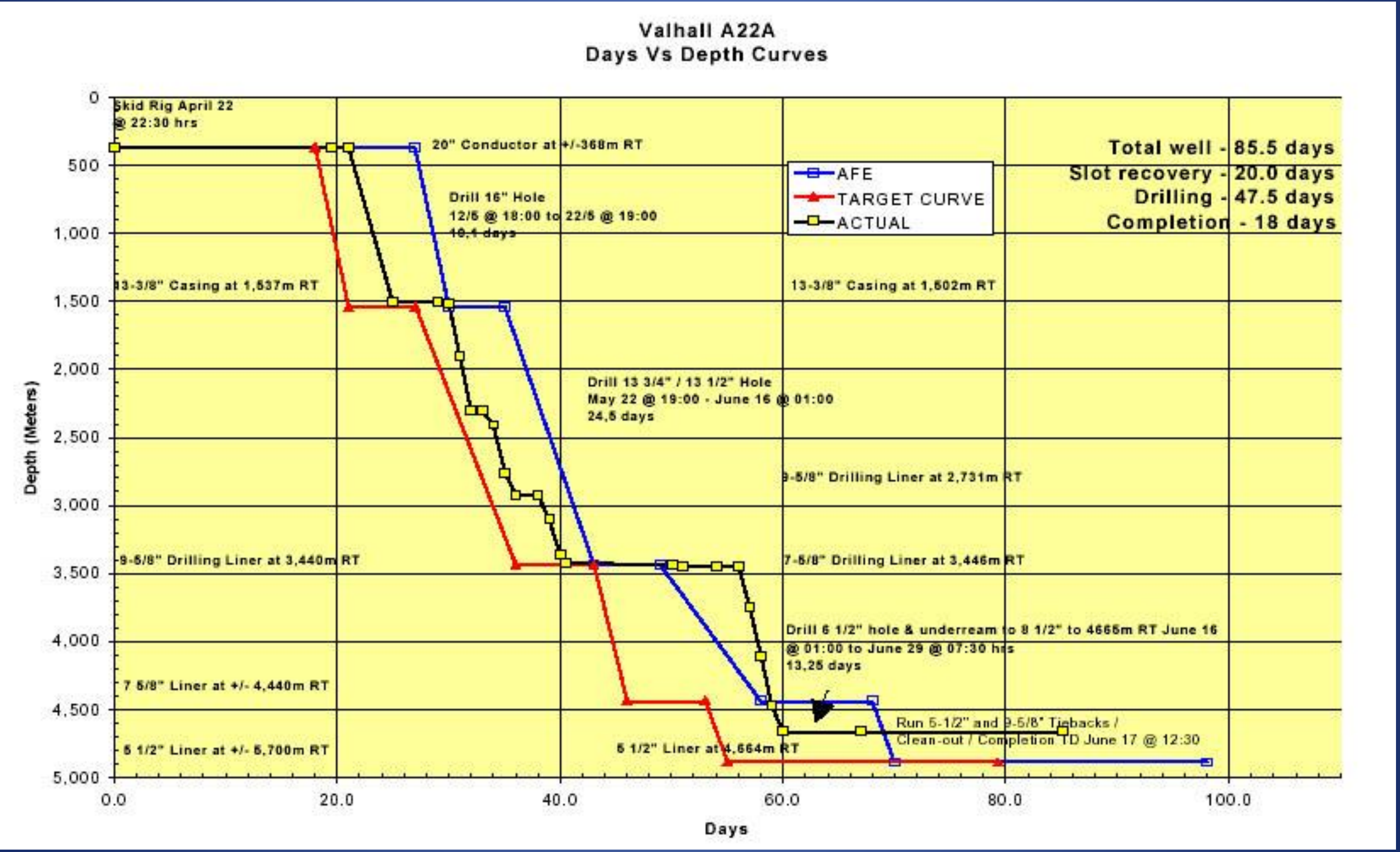
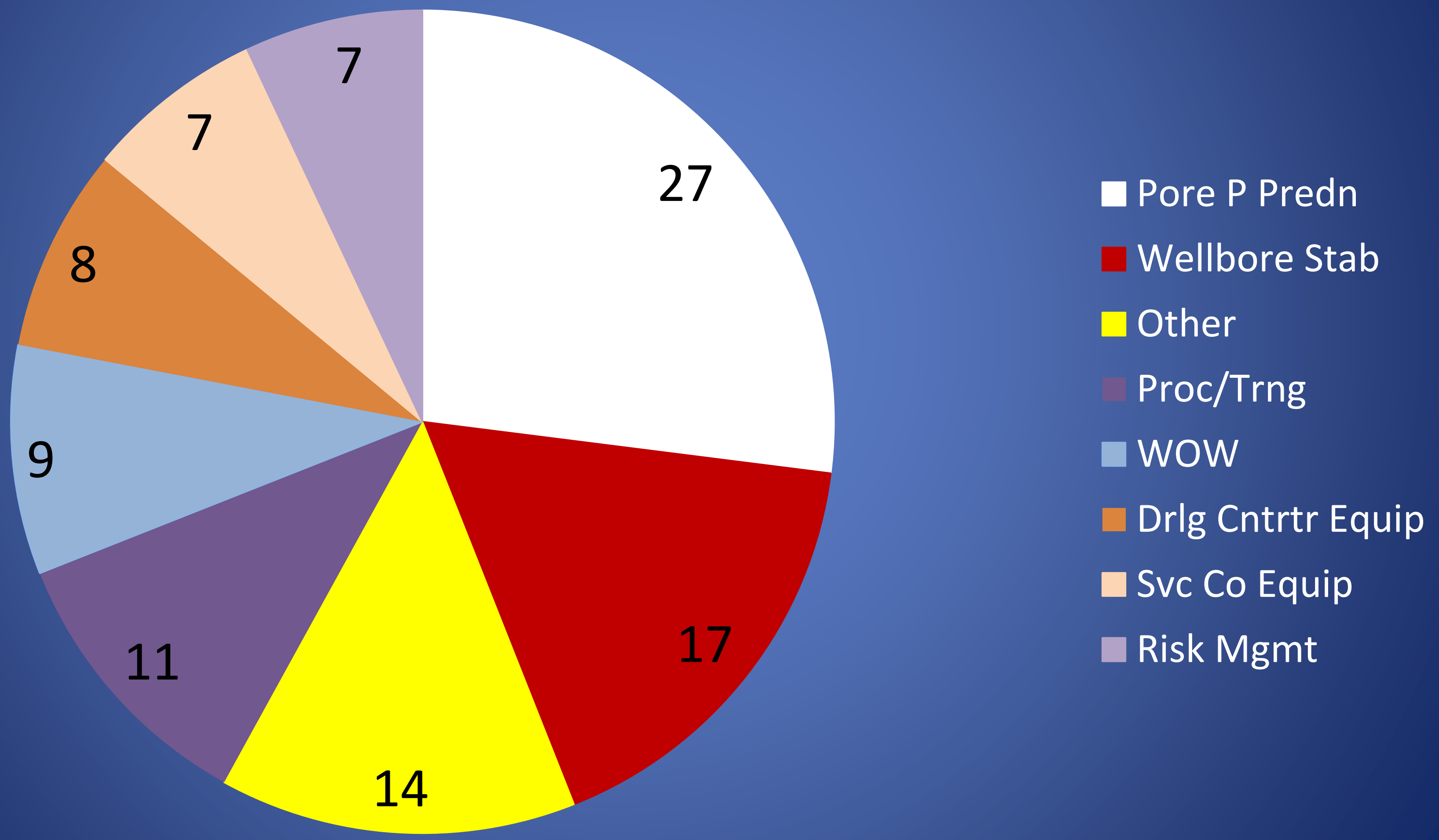
Drilling progress is measured by days vs depth



Non-productive time causes, % of lost time



Peeling the NPT onion: Documented Subsurface Conditions Causing Drilling NPT

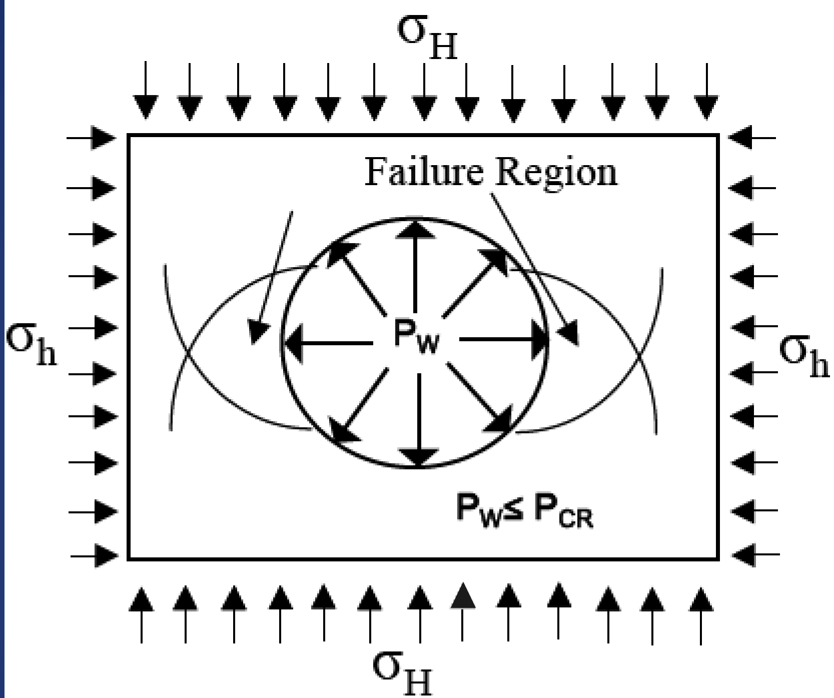
- PPFG
  - Uncertainty in variation with depth
  - Narrow PPFG windows or sharp pressure ramps
  - Production artifacts
- Geology/Geomechanics
  - Inherently troublesome formations
  - Faulted or rubblized zones
  - Large differences between σ_H and σ_h
  - Bedding at high angle to wellbore
- Shallow Hazards
  - Seabed obstructions or instability
  - Shallow subsurface hazards
- Geophysics
  - Water depth errors
  - Seismic uncertainty
- Inexperience
- Equipment Failure

Eight Root Causes of Lost Circulation

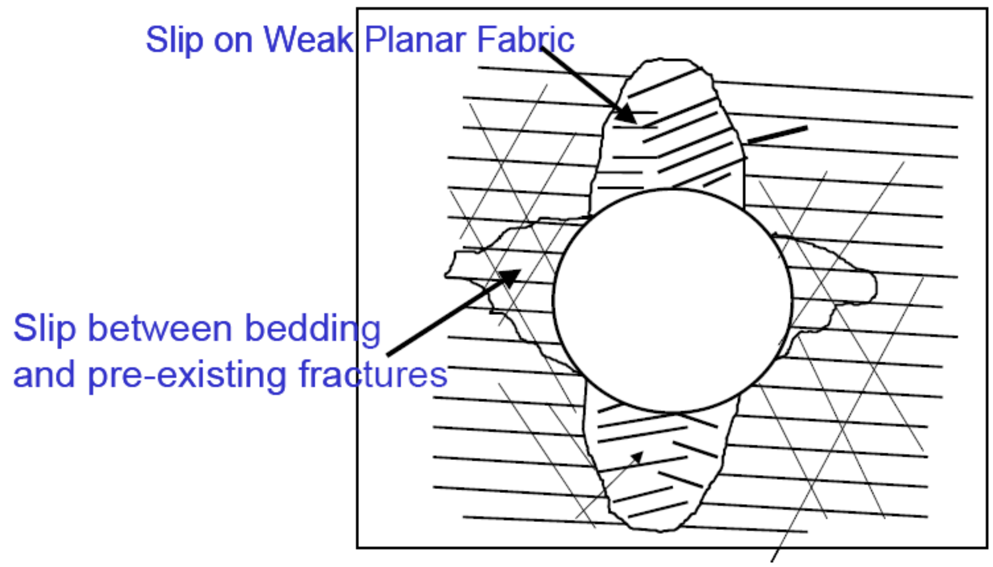
- Seepage
- Borehole breathing
- Induced axial fracture (vertical)
- Induced orthogonal fracture (horizontal)
- Natural faults and fractures
- Vugs
- Failed casing shoe
- Hole in casing

Mark Alberty, personal communication (2007)

Geology / Geomechanical Considerations in Borehole Instability



(A)



(B)

Schematic of comparative failure in an isotropic formation due to high differential stress (A) and in a formation with pre-existing planes of weakness (B)

Stress orientation controls failure orientation in (A); Rock fabric or structural grain controls failure orientation in (B)

Mody et al. (2007)
Willson et al. (2003)

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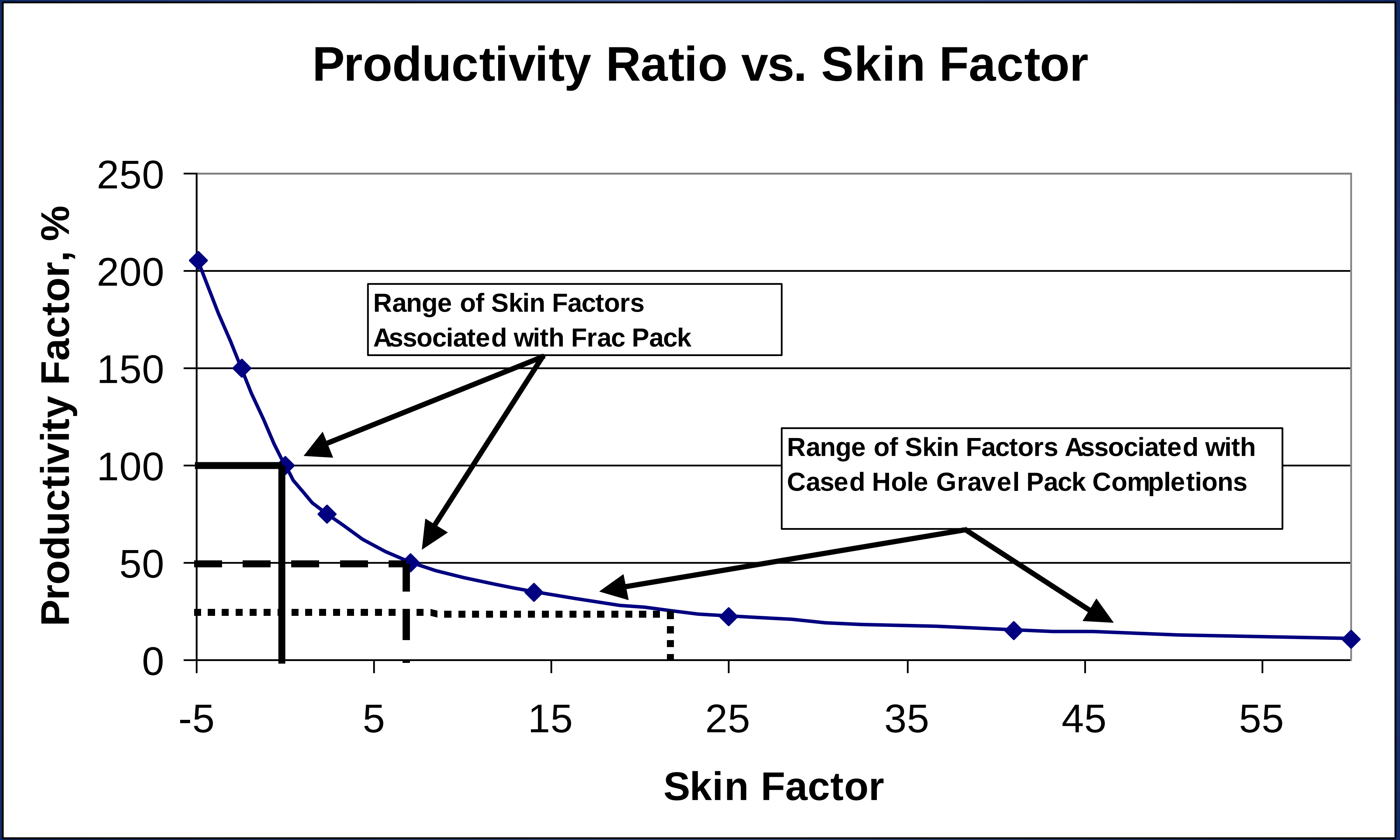

George King, personal communication (2004)

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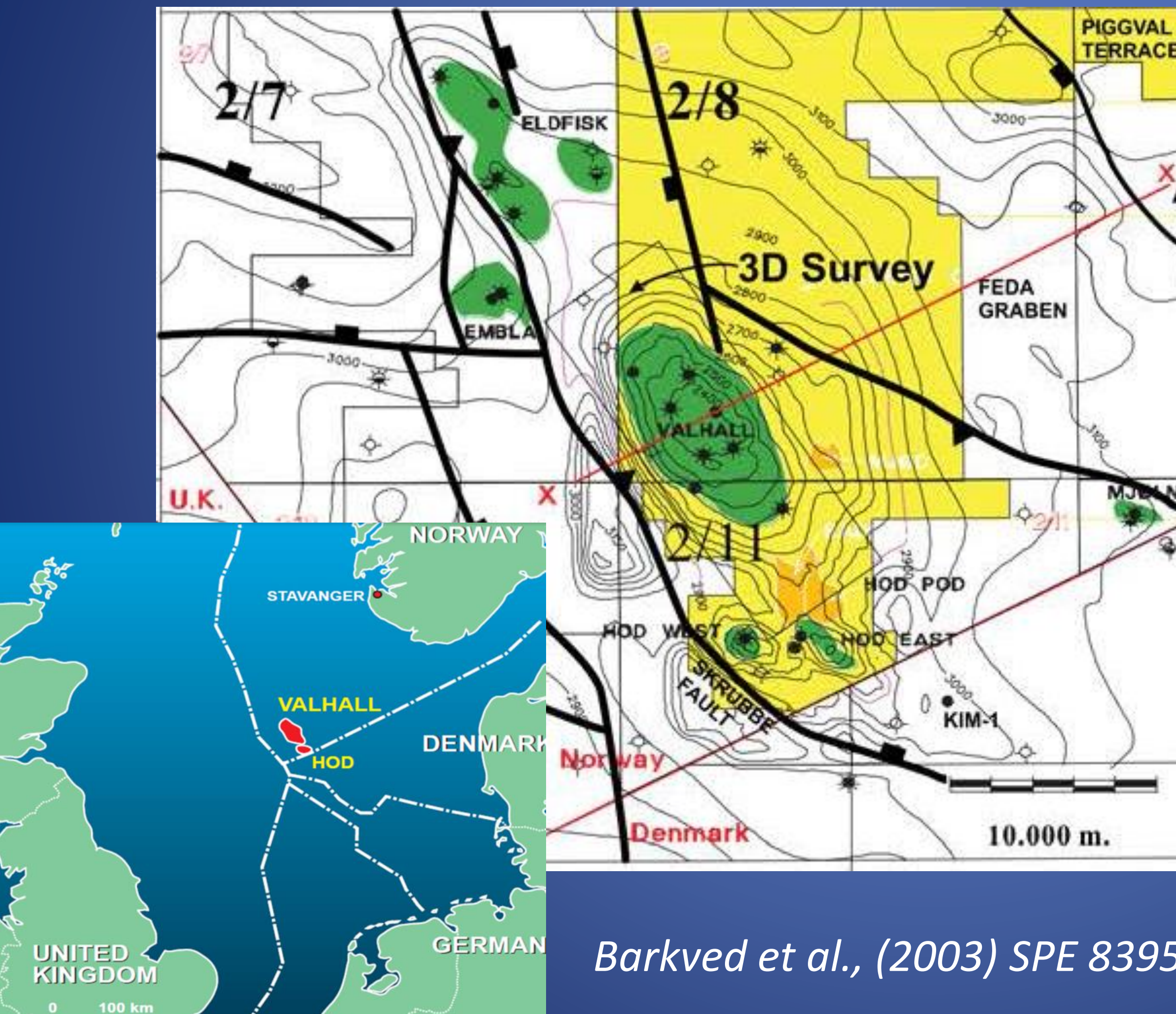
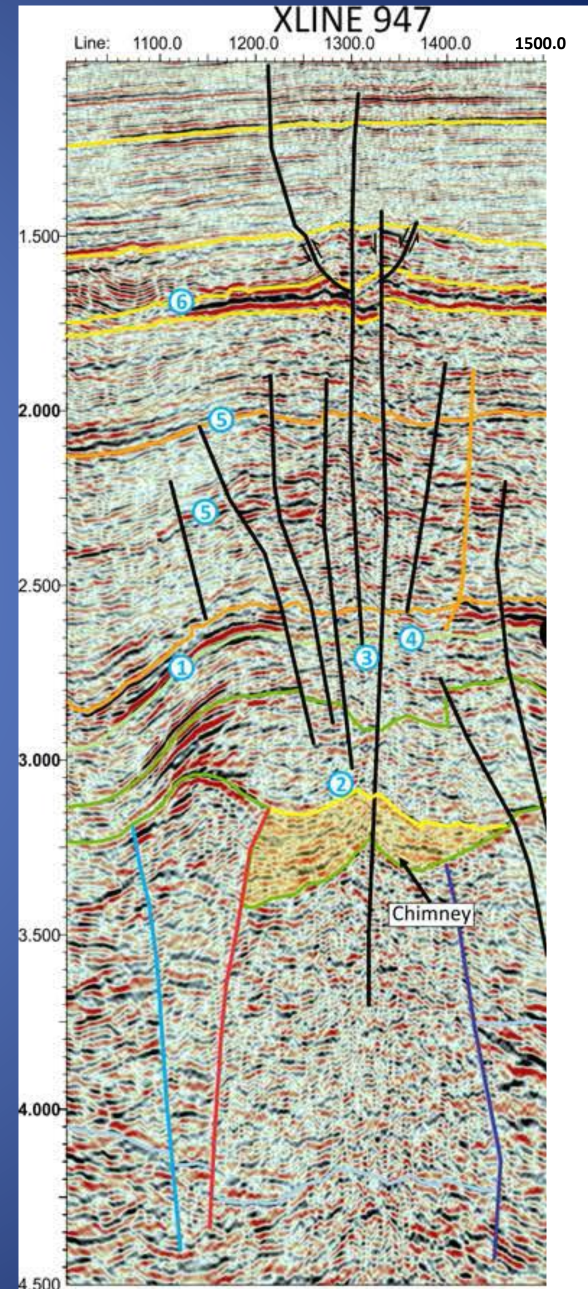
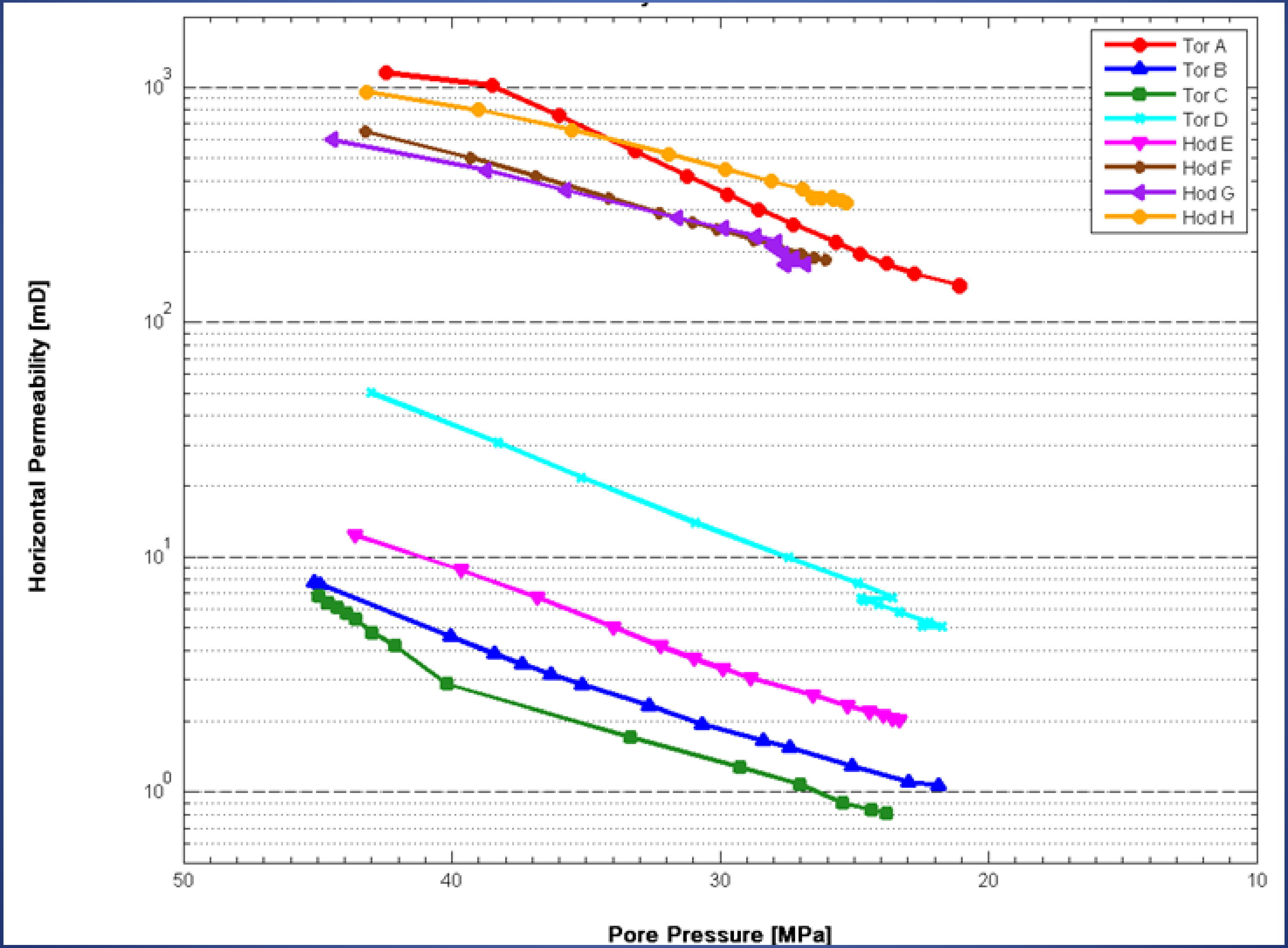
Valhall Field





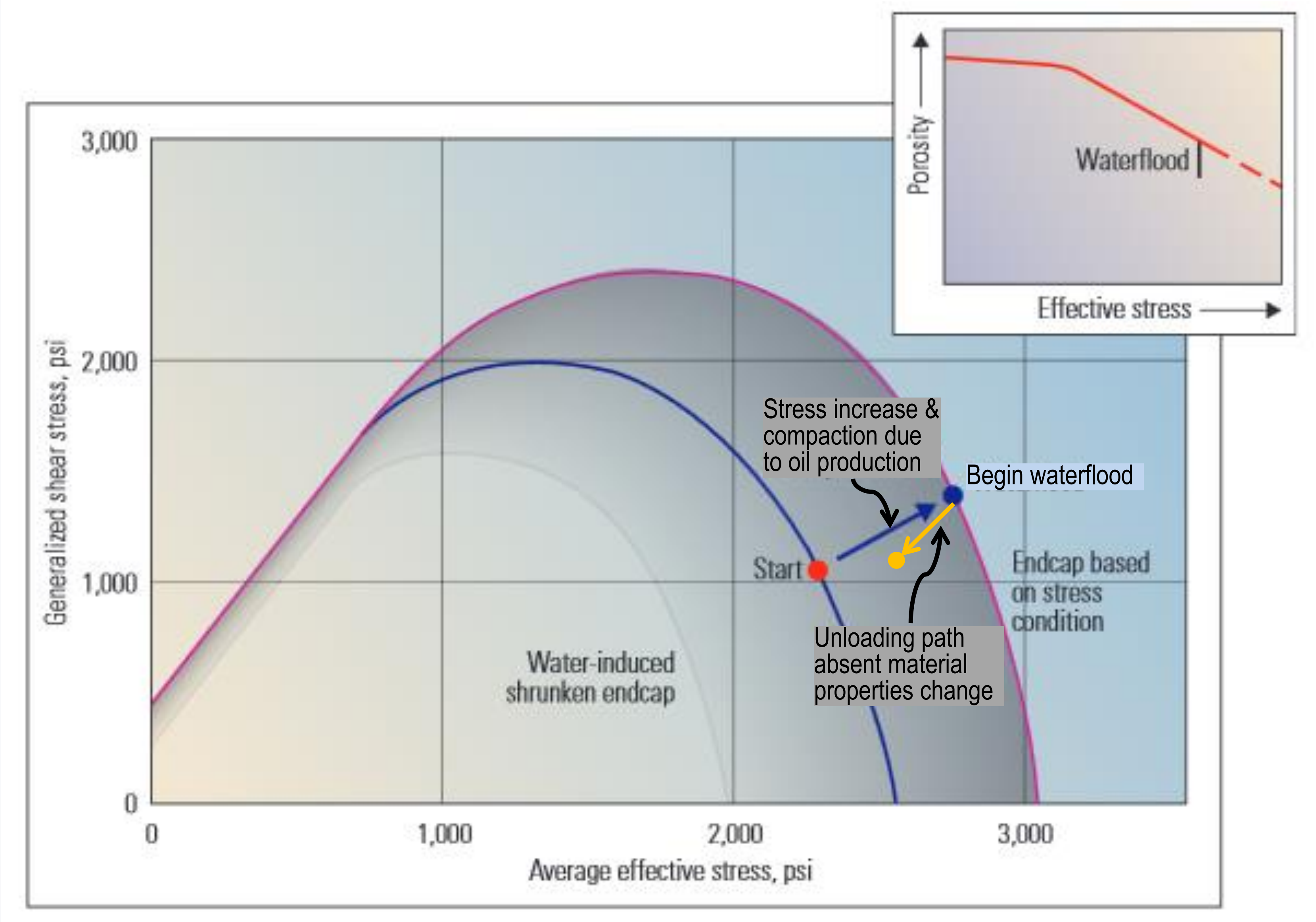
Barkved et al., (2003) SPE 83957

Valhall: Absolute Permeability Reduction Affects Production Rate



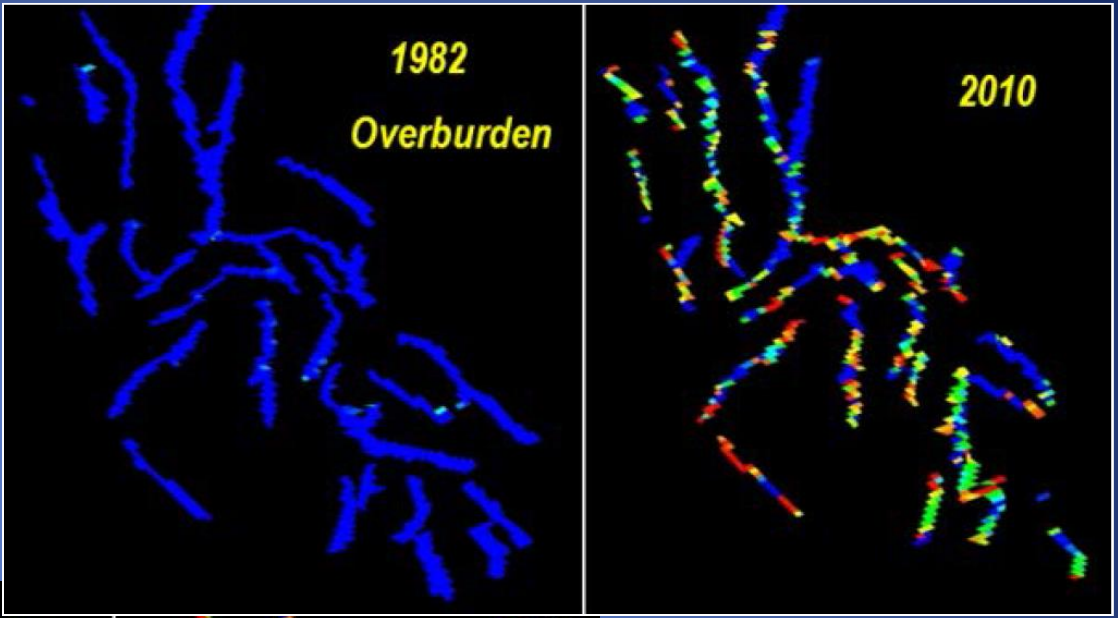
Han et al, (2013) ARMA 13-163

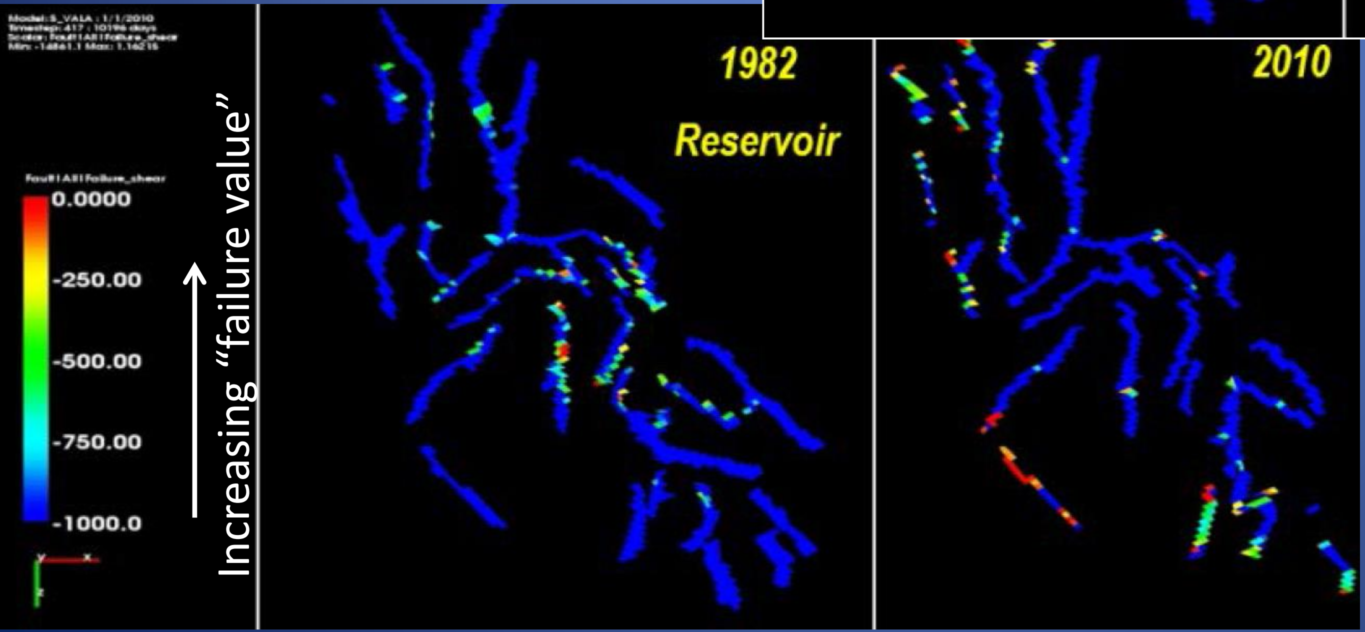
Water-induced chalk compaction



After Doornhof et al. (2006). Oilfield Review

Valhall: Fault Reactivation Complicates Drilling and Well Integrity



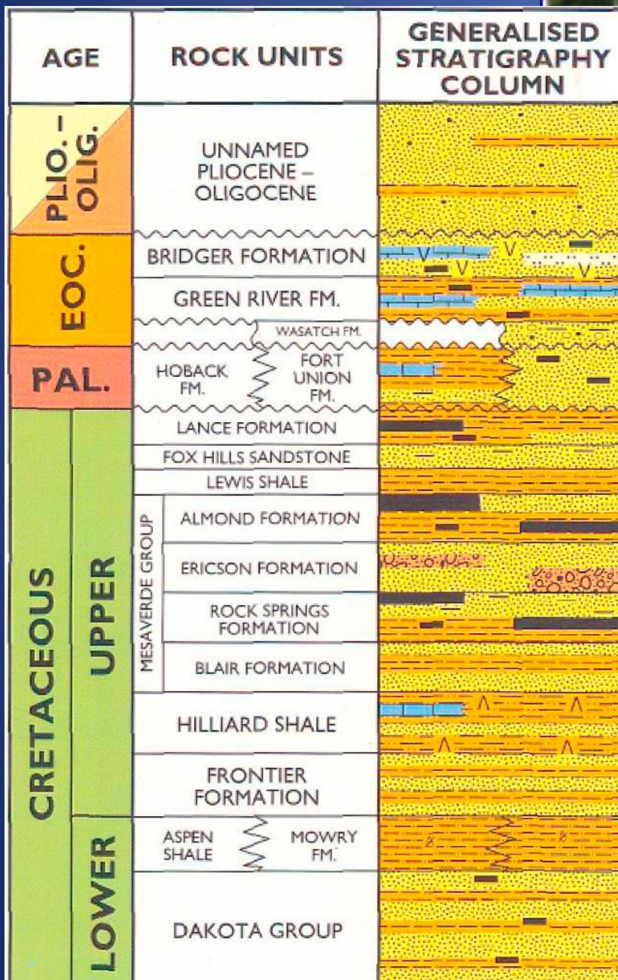


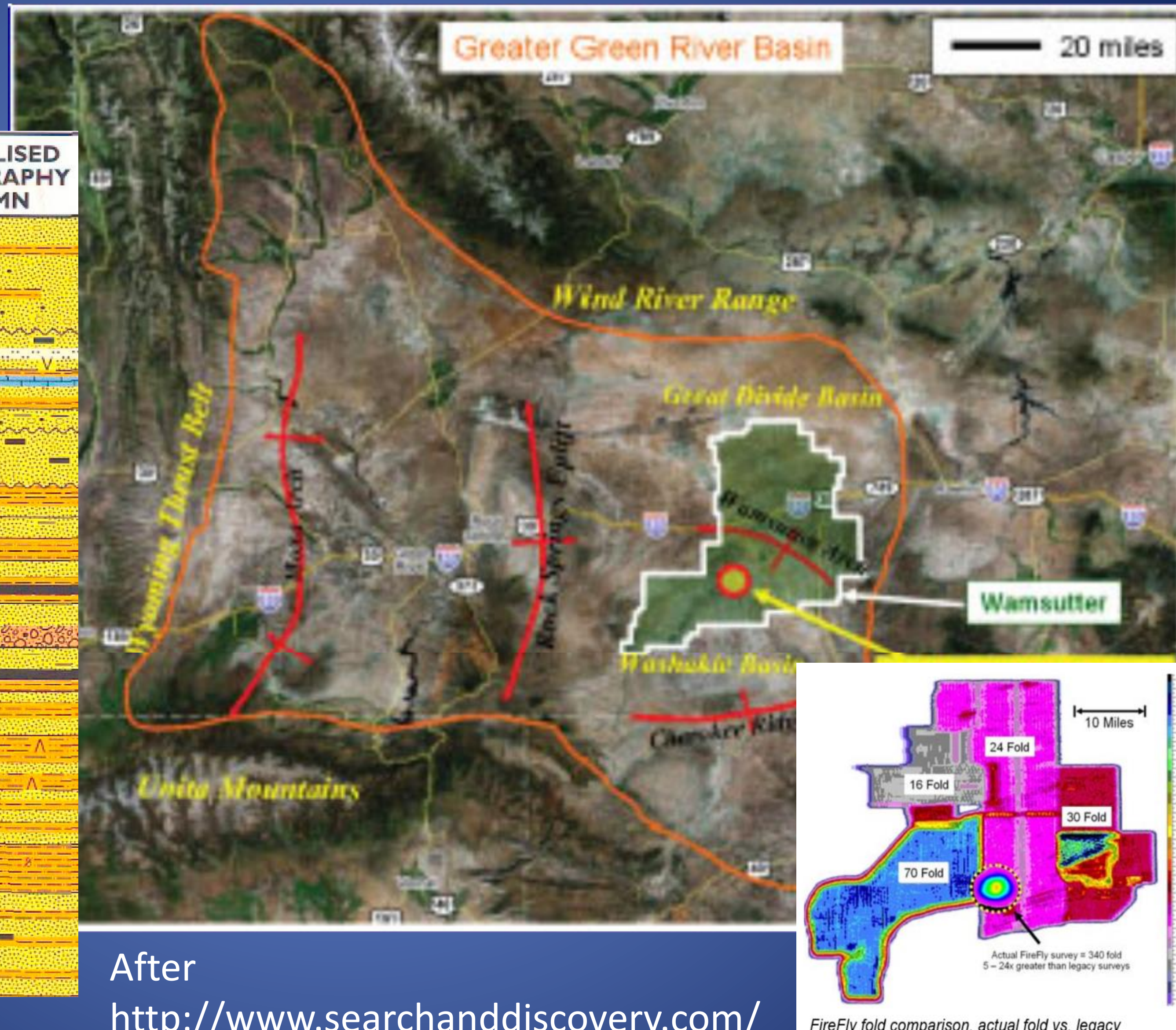
Han et al, (2013) ARMA 13-163

Valhall: Seabed Subsidence Endangers Infrastructure

Kvernstrøm et al (2012), personal communication

Wamsutter: Stratigraphy & Seismic Coverage

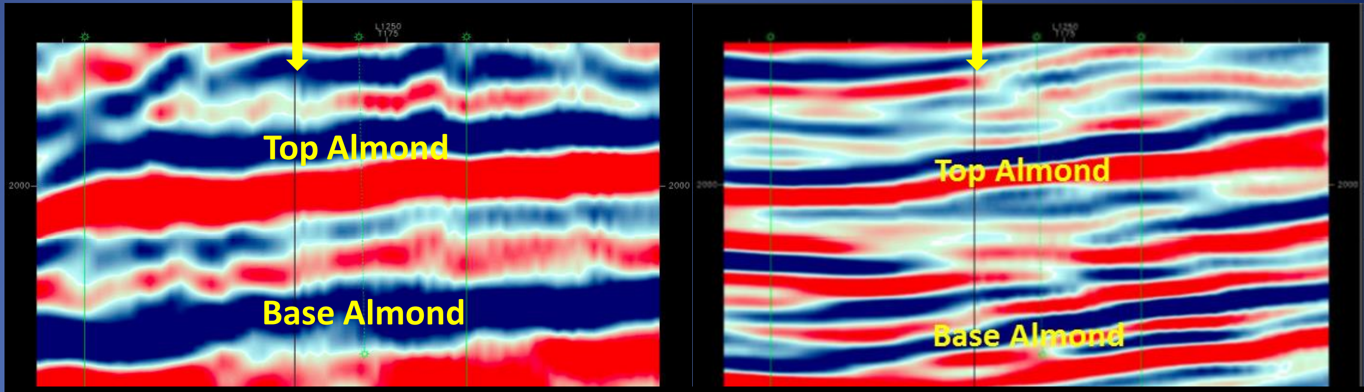




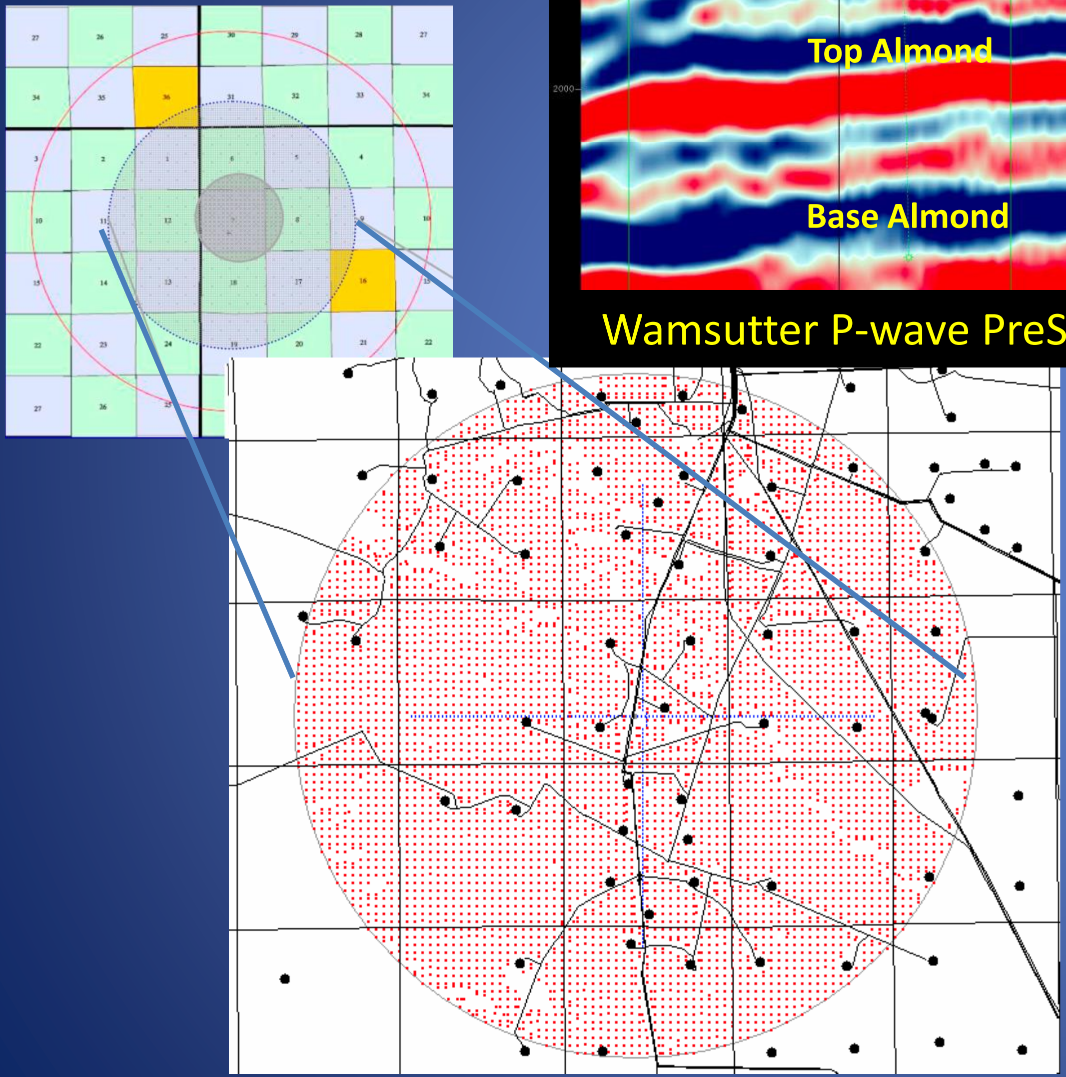
FireFly fold comparison, actual fold vs. legacy

After http://www.searchanddiscovery.com/documents/2011/110159geetan/ndx_geetan.pdf

Wamsutter Large Array VSP Survey



Wamsutter P-wave PreSTM   Wamsutter VSP Data



Shot spacing 250 ft
Receiver spacing 50 ft
Max Offset 11,000 ft

- Recover un-aliased frequencies up to 120 Hz at reservoir
- Imaging away from wellbore

Rosemarie Geetan et al. (2011) , Search and Discovery Article #110159

What to do?

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Abandonment

- Think of the Well as Part of a System
- Protect Freshwater
- Seal Zones of Light Density Fluid Influx – especially those that are or may become gas-bearing
- Seal pressure ramps

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Annual contribution of one group

- Tight formation gas completion design improvement, including the use of staged hydraulic fractures
  - Taken for granted today in O&G but most geothermal well stimulations are bullheaded from the casing shoe. Diverters have only begun to be considered seriously in the last 2 years.
- ID optimum drilling direction in a naturally fractured carbonate reservoir
- Improved wellbore stability for drill wells in an offshore oil field [Valhall]
- Identification that, owing to compaction drive, primary oil recovery in another offshore field would likely be 25-35%, not 5% as originally thought – but with potential consequences for infrastructure.