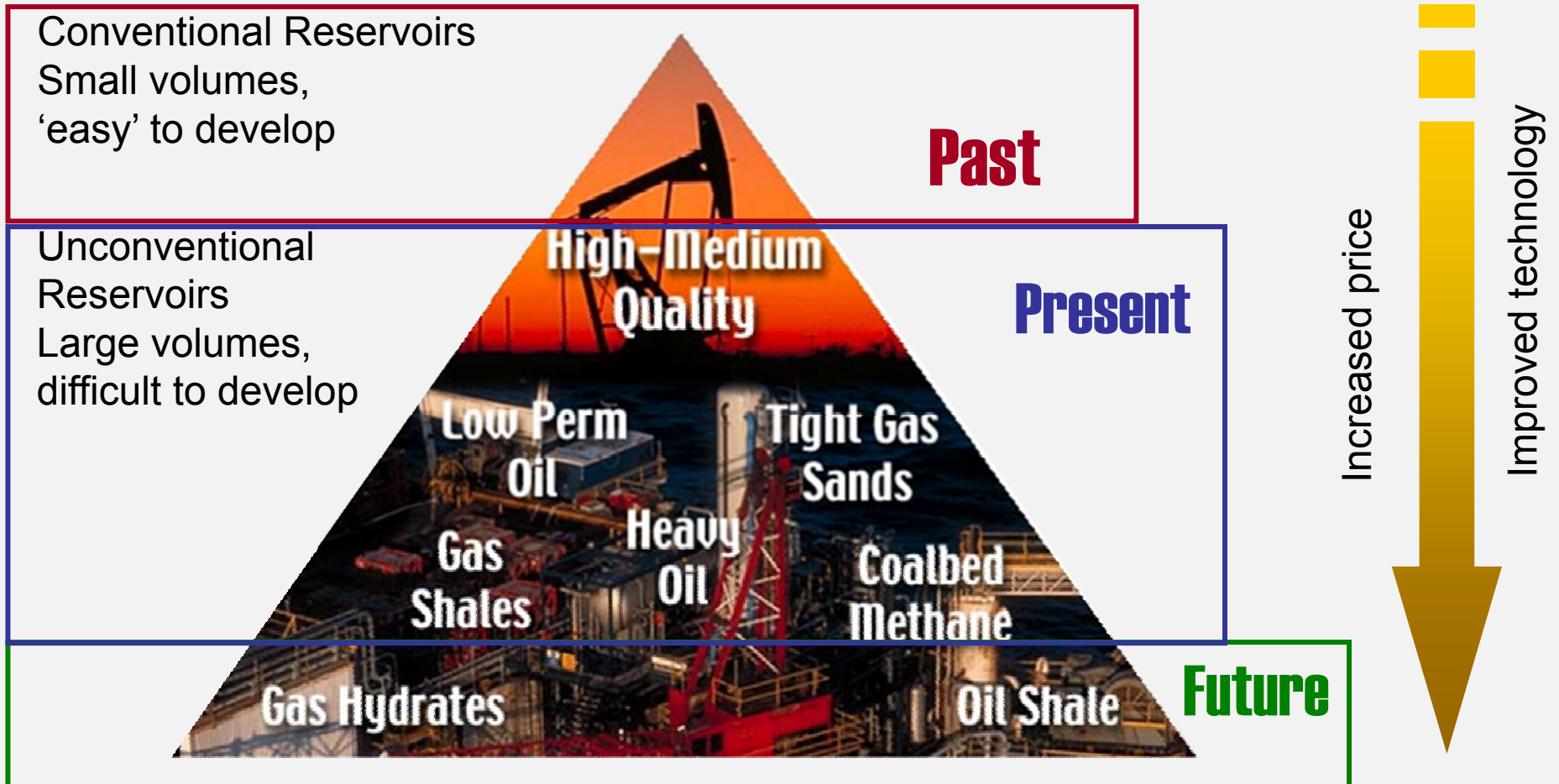


Has Unconventional Become Conventional?

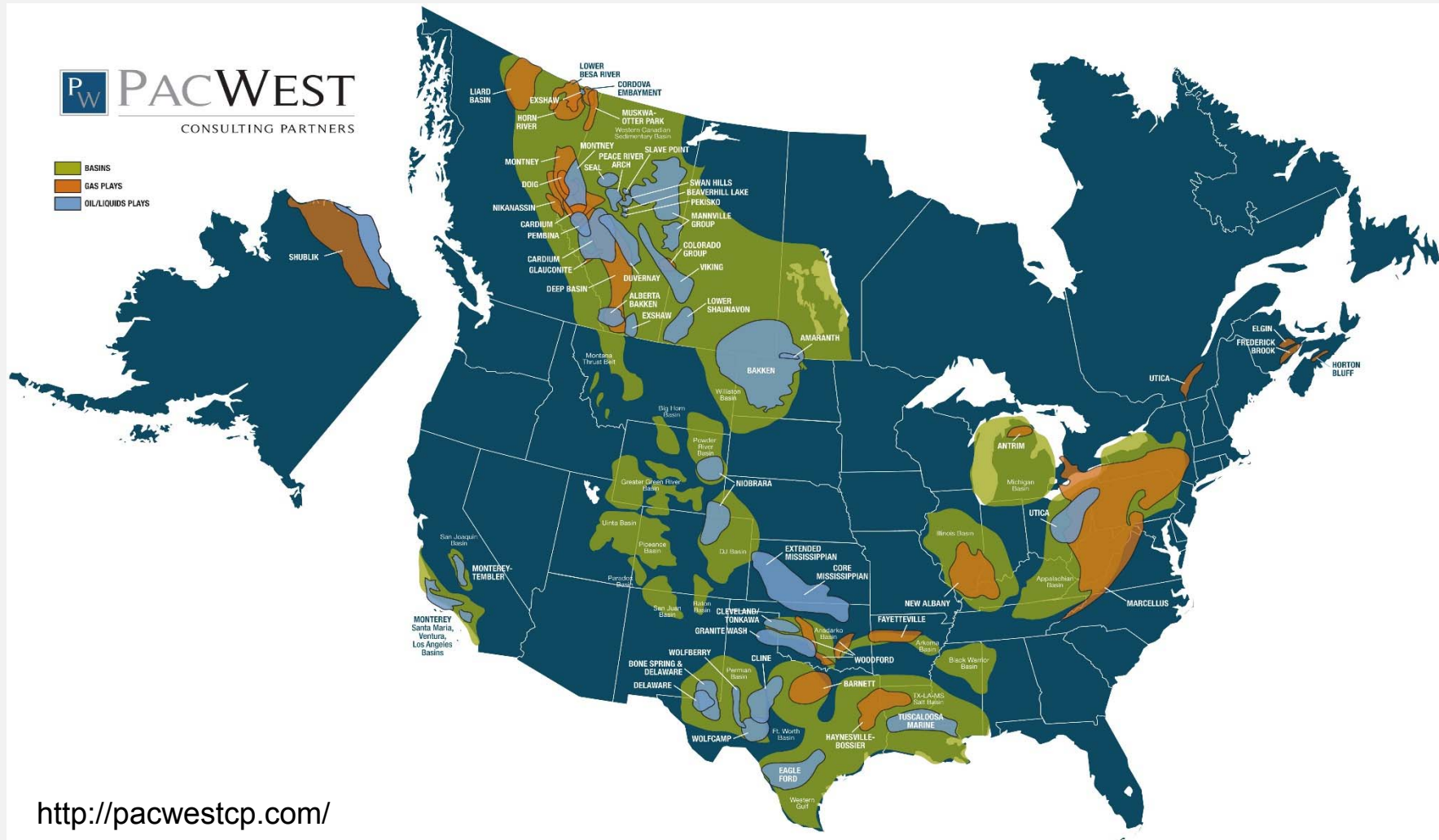
SPEE Luncheon Presentation
February 4, 2015

Dr. Christine Ehlig-Economides
University of Houston

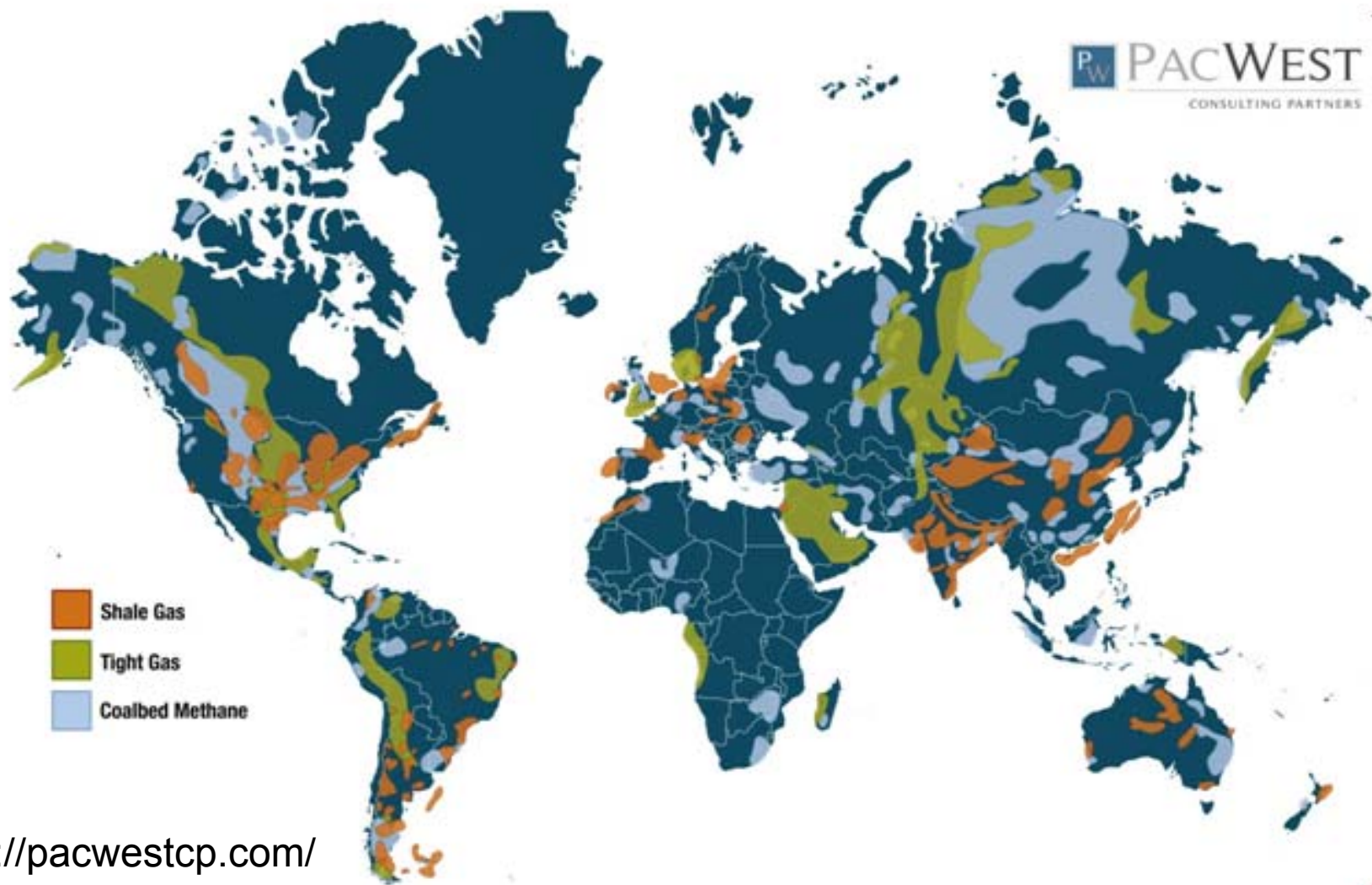
Hydrocarbon Resource Triangle



North America Shale Plays



World Unconventional Gas

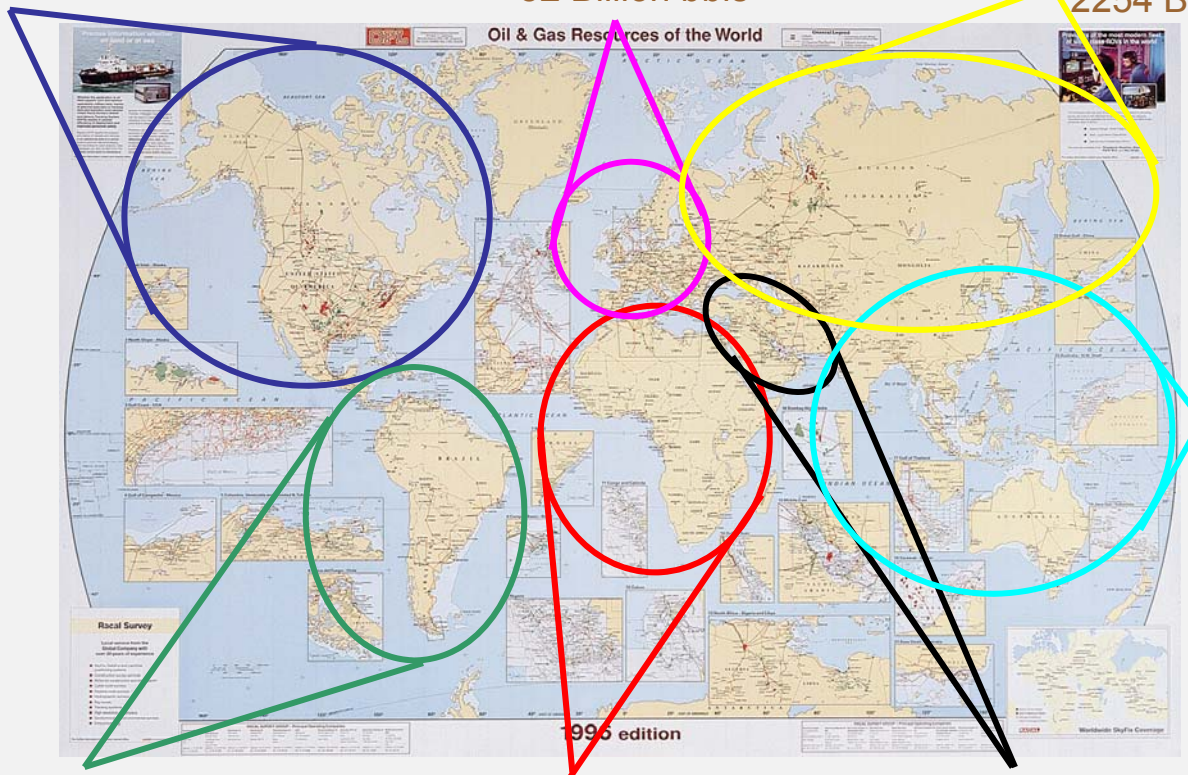


A World of Oil

North America:
15.4 MMbbls/day
50 Billion bbls
2805 billion bbls

Europe:
7 MMbbls/day
18.3 Billion bbls
52 Billion bbls

Former Soviet Union:
9.0 MMbbls/day
79 Billion bbls
2254 Billion bbls



Asia:
8 MMbbls/day
38.7 Billion bbls

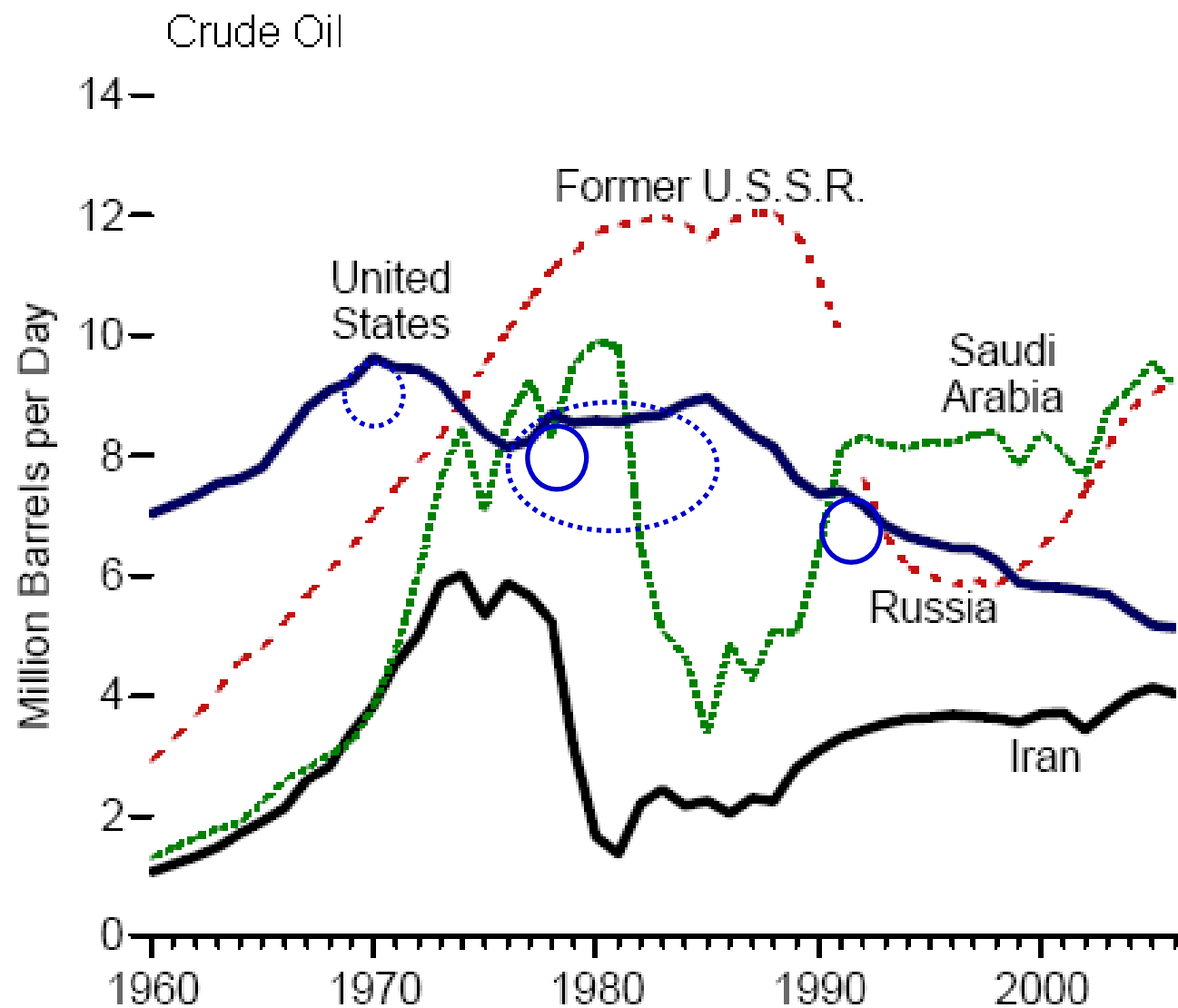
South America:
6.9 MMbbls/day
98.5 Billion bbls
2174 Billion bbls

Africa:
8.1 MMbbls/day
77.4 Billion bbls
184 Billion bbls

Middle East:
22.5 MMbbls/day
685 Billion bbls
470 Billion bbls

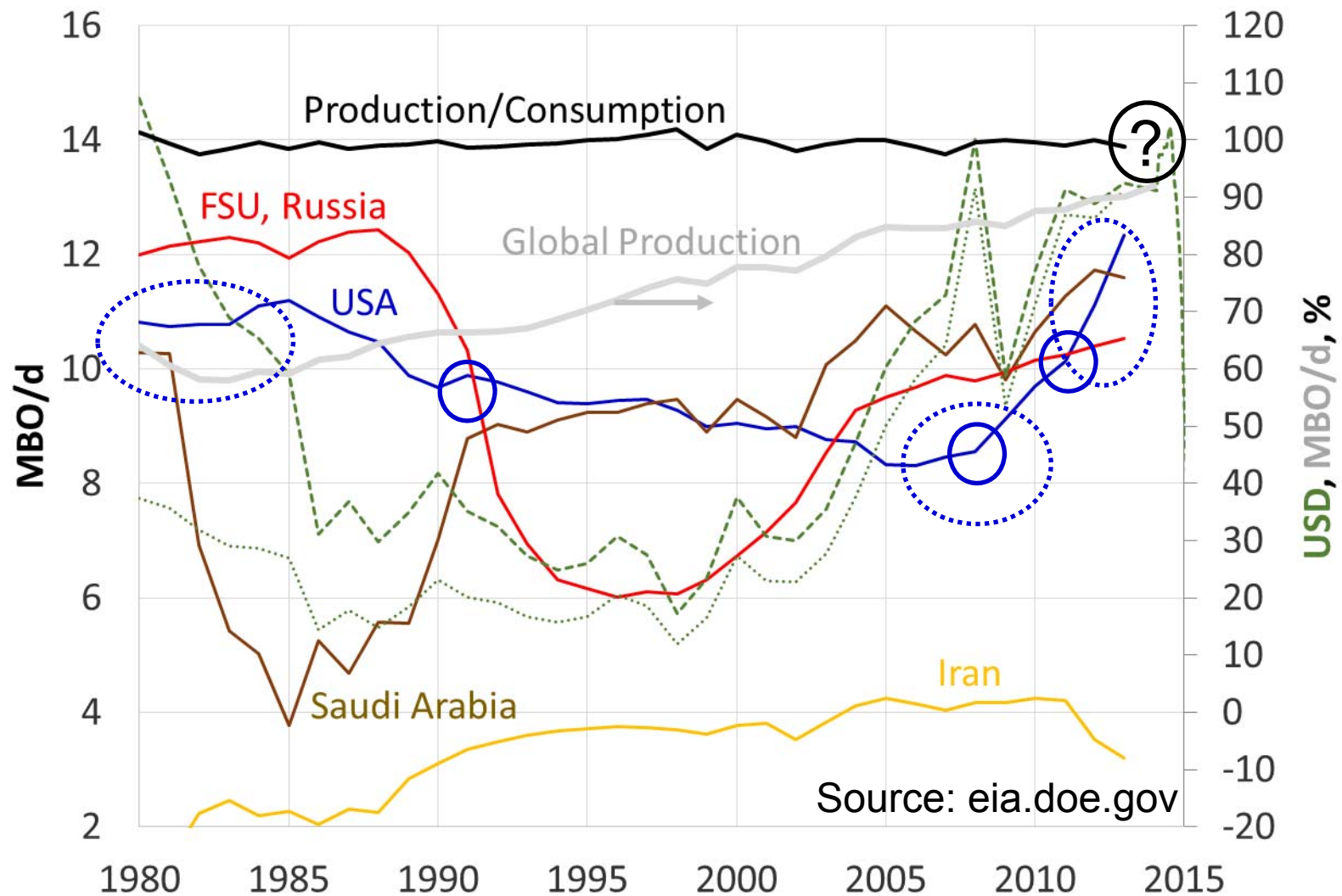
Production and Price

Top Producing Countries, 1960-2006



Source: US DOE, Energy Information Administration
Annual Energy Review 2006

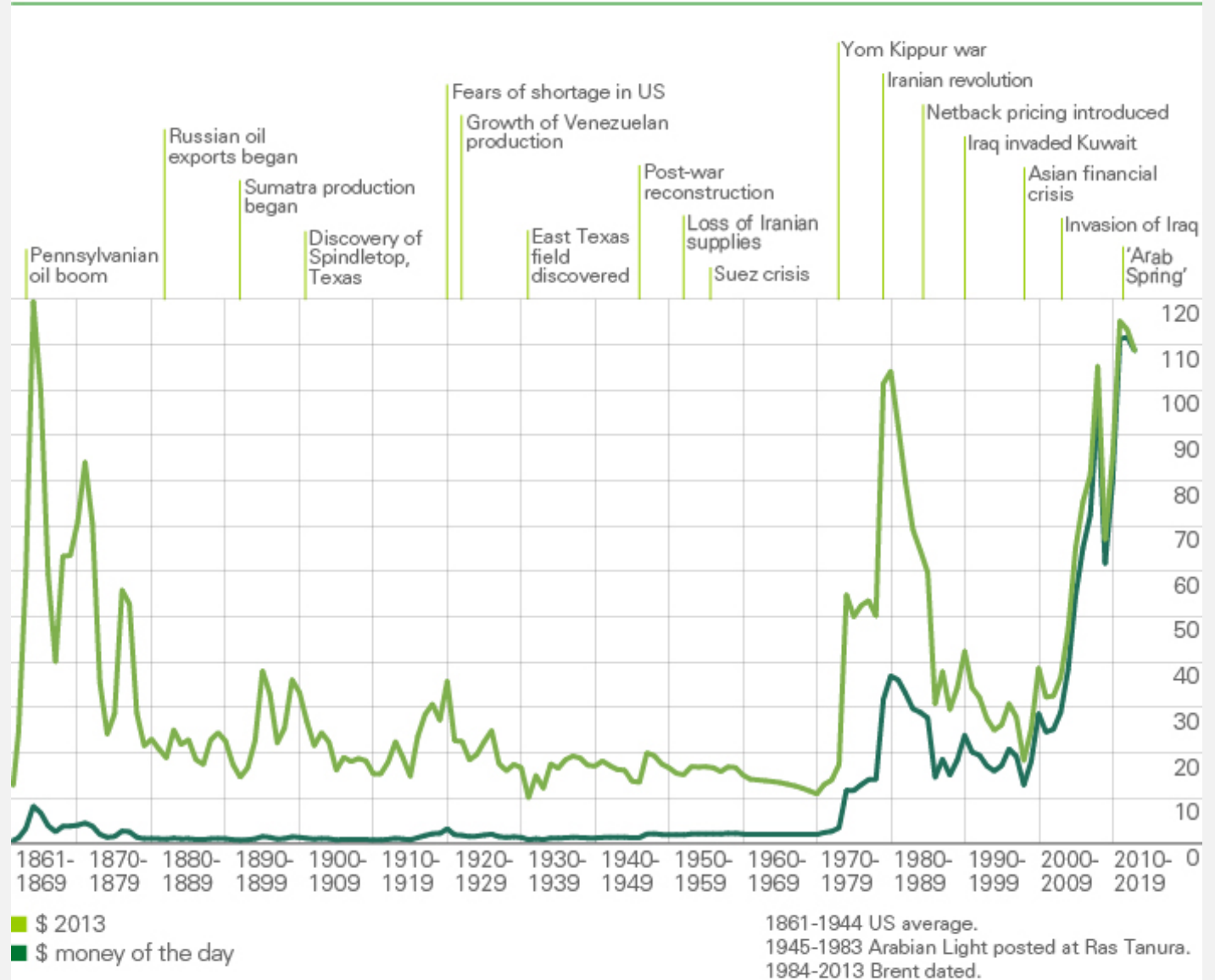
Production and Price



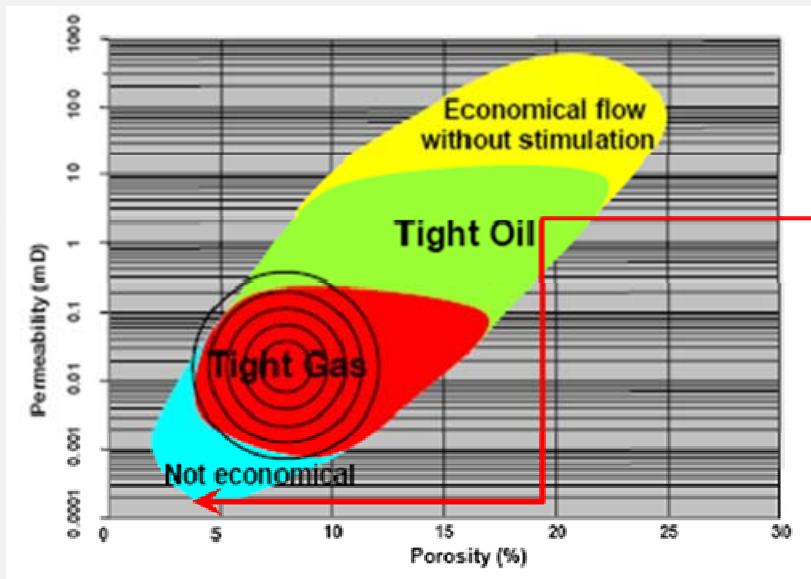
Geopolitics and Oil Price

Crude oil prices 1861–2013

US dollars per barrel
World events

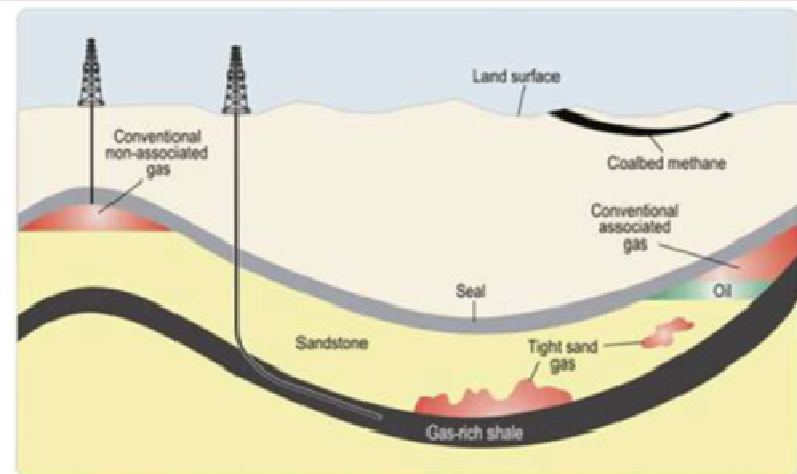


Permeability and Volume



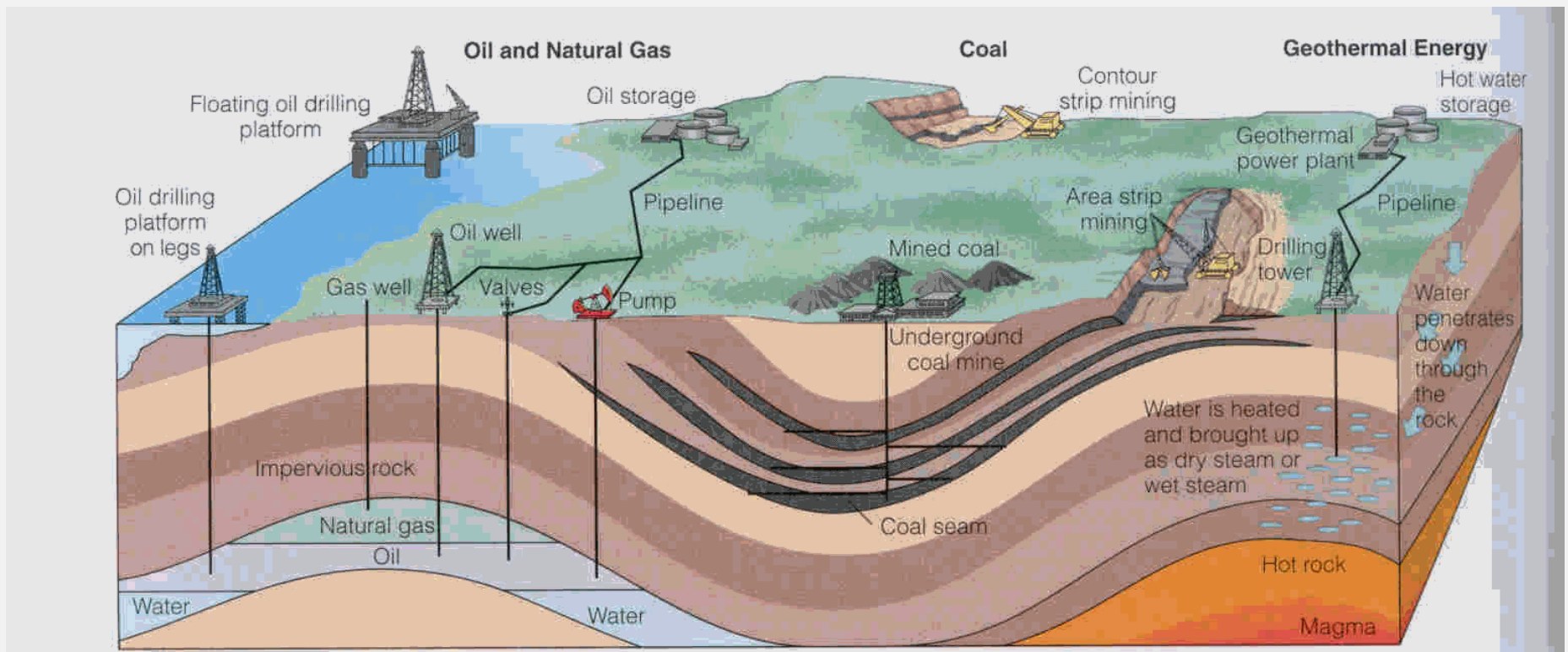
Post 2006: Shale Matrix
Permeability range

Simplified Vertical Profile Showing Unconventional Gas Reservoirs



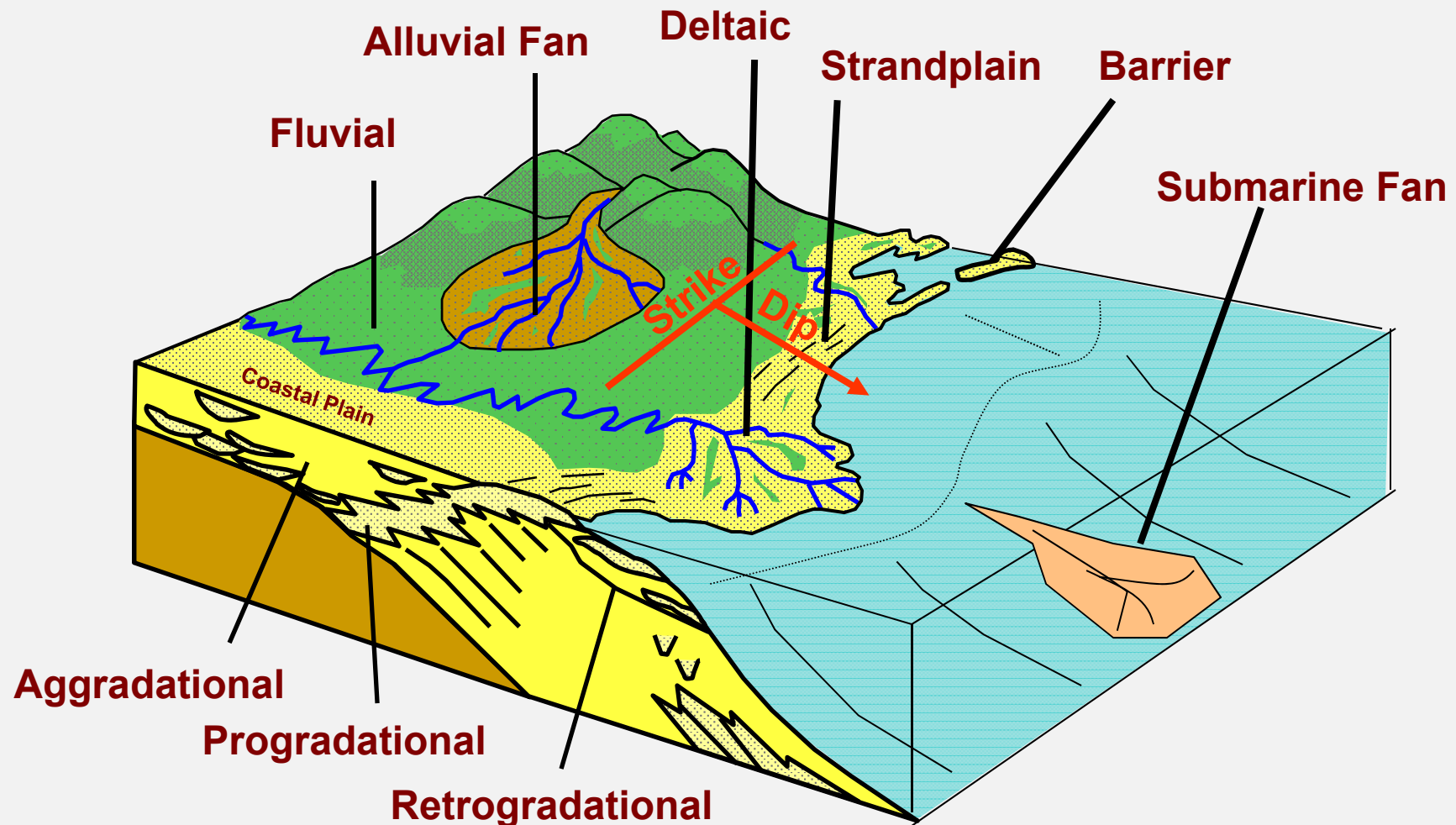
SOURCE: US Energy Information Administration (EIA).

Fossil and Geothermal Energy Sources



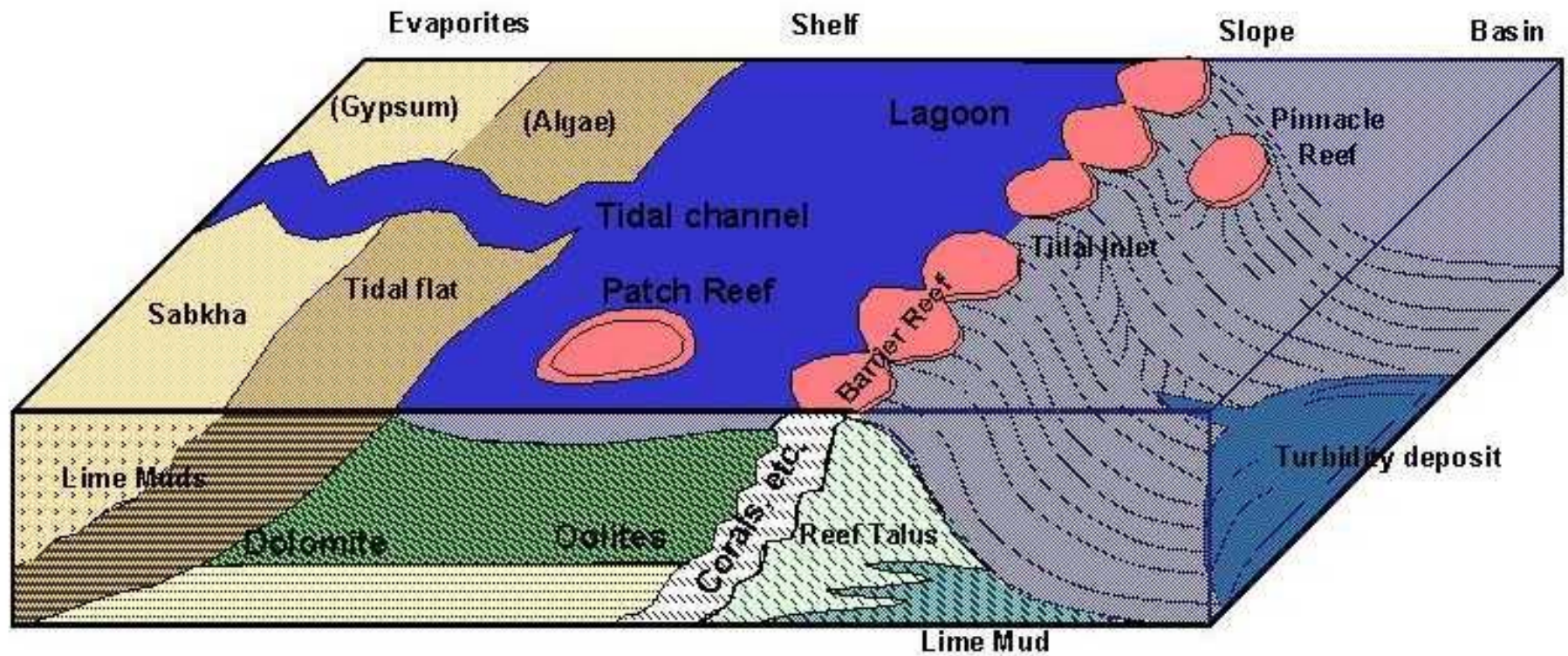
<http://geosurvey.state.co.us/energy/Coal/Pages/CoalHowdoesitform.aspx>

Clastic Depositional Systems

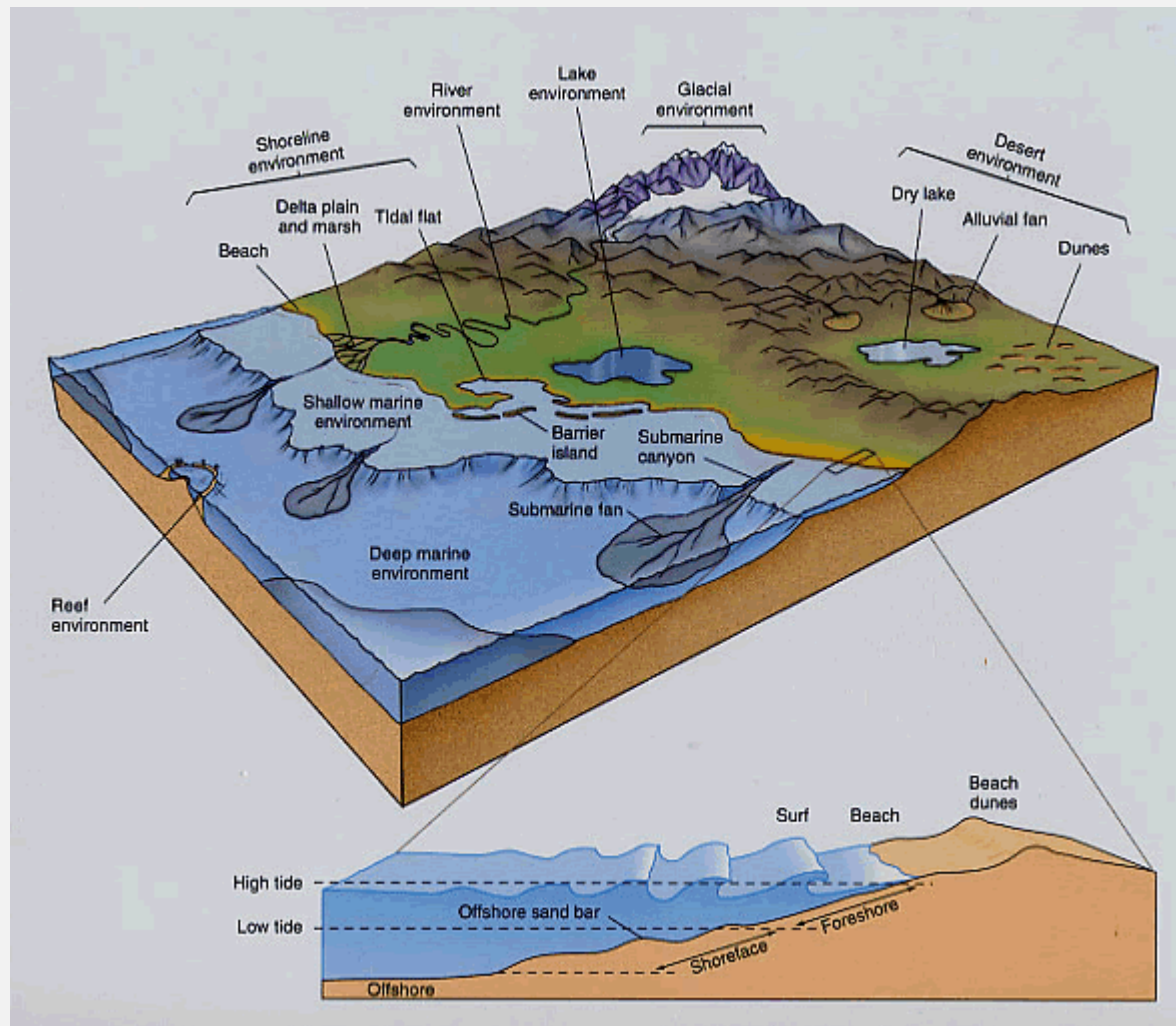


Modified from Hentz and others, 1997

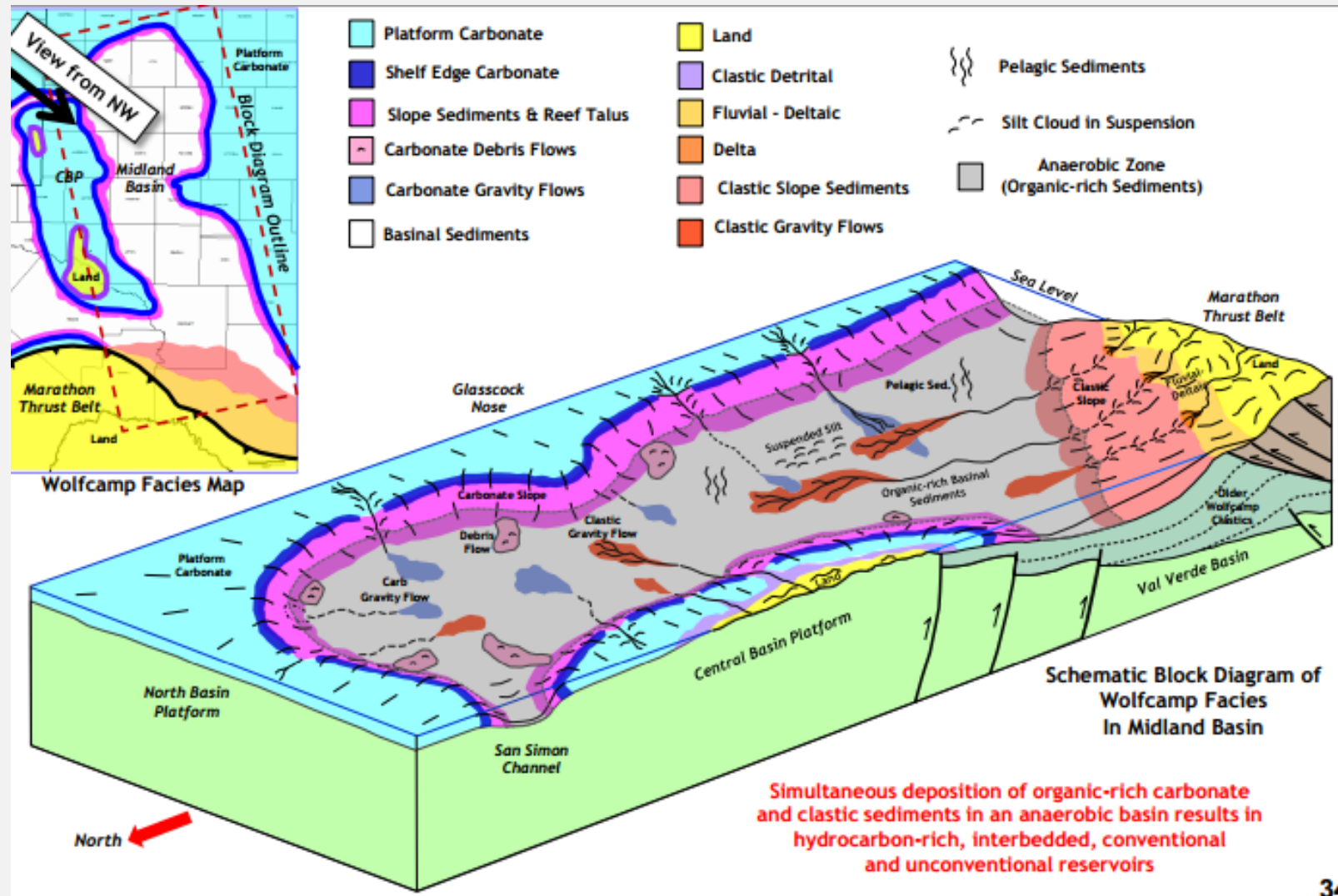
Carbonate Deposition



Shale Deposition



Wolfcamp Depositional Model

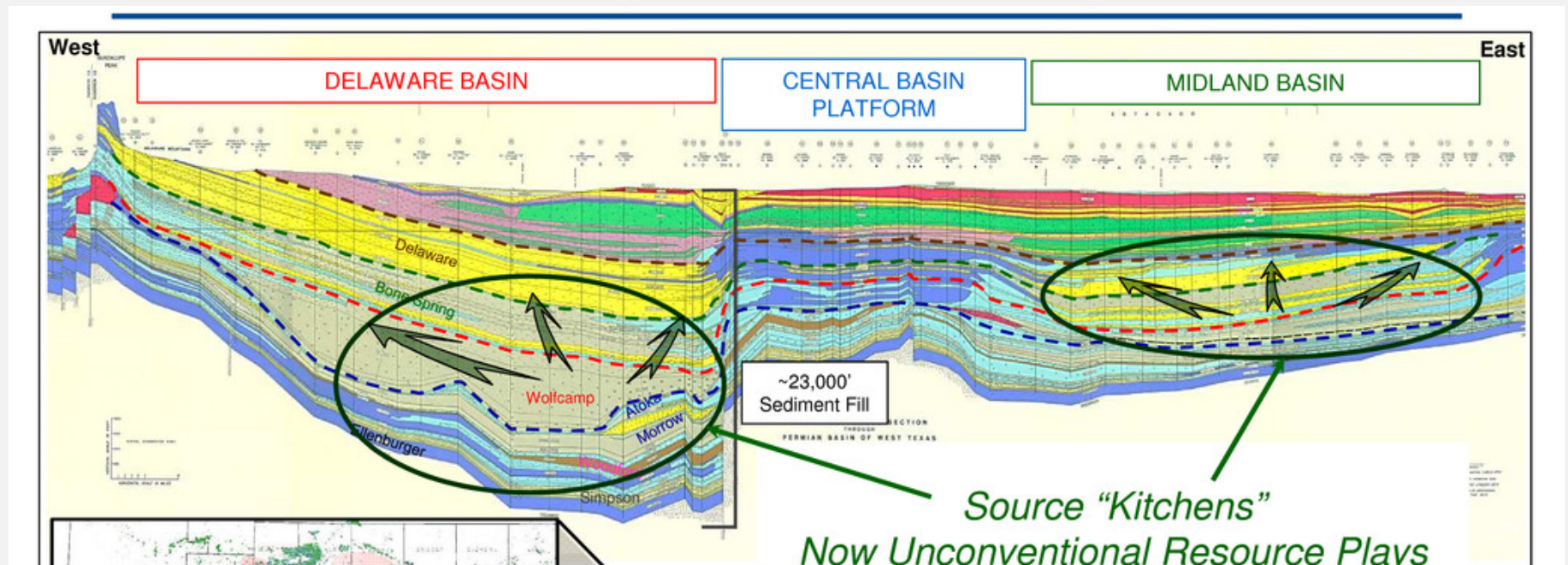


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Pioneer Natural Resources Investor Presentation

C. Ehlig-Economides – SPEE Luncheon Presentation February 4, 2015 – Has Unconventional Become Conventional?

Wolfcamp as a Source Rock

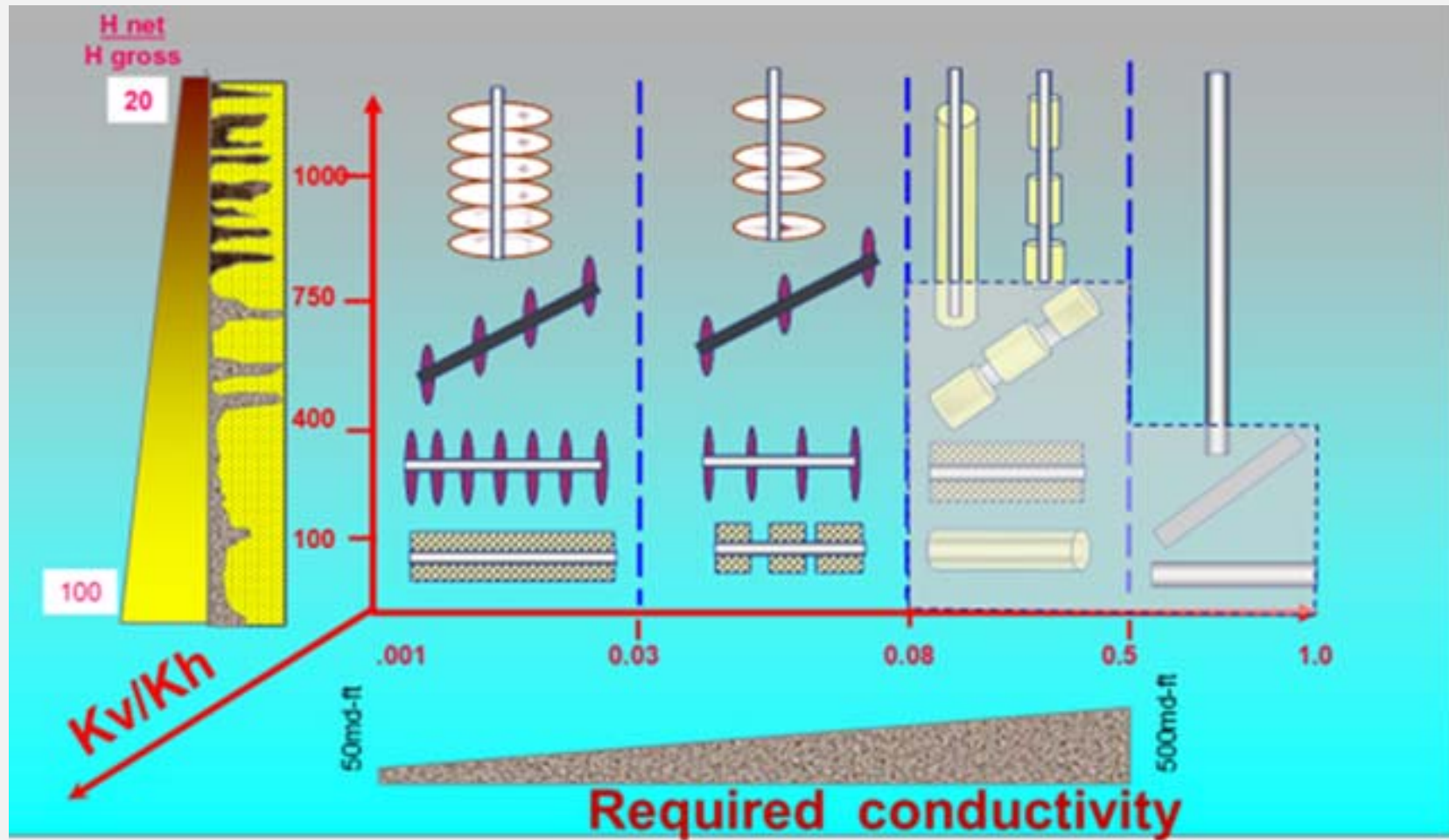


Source: <http://www.sec.gov/Archives/edgar/data/1405073/000119312513141665/d516183dex991.htm>

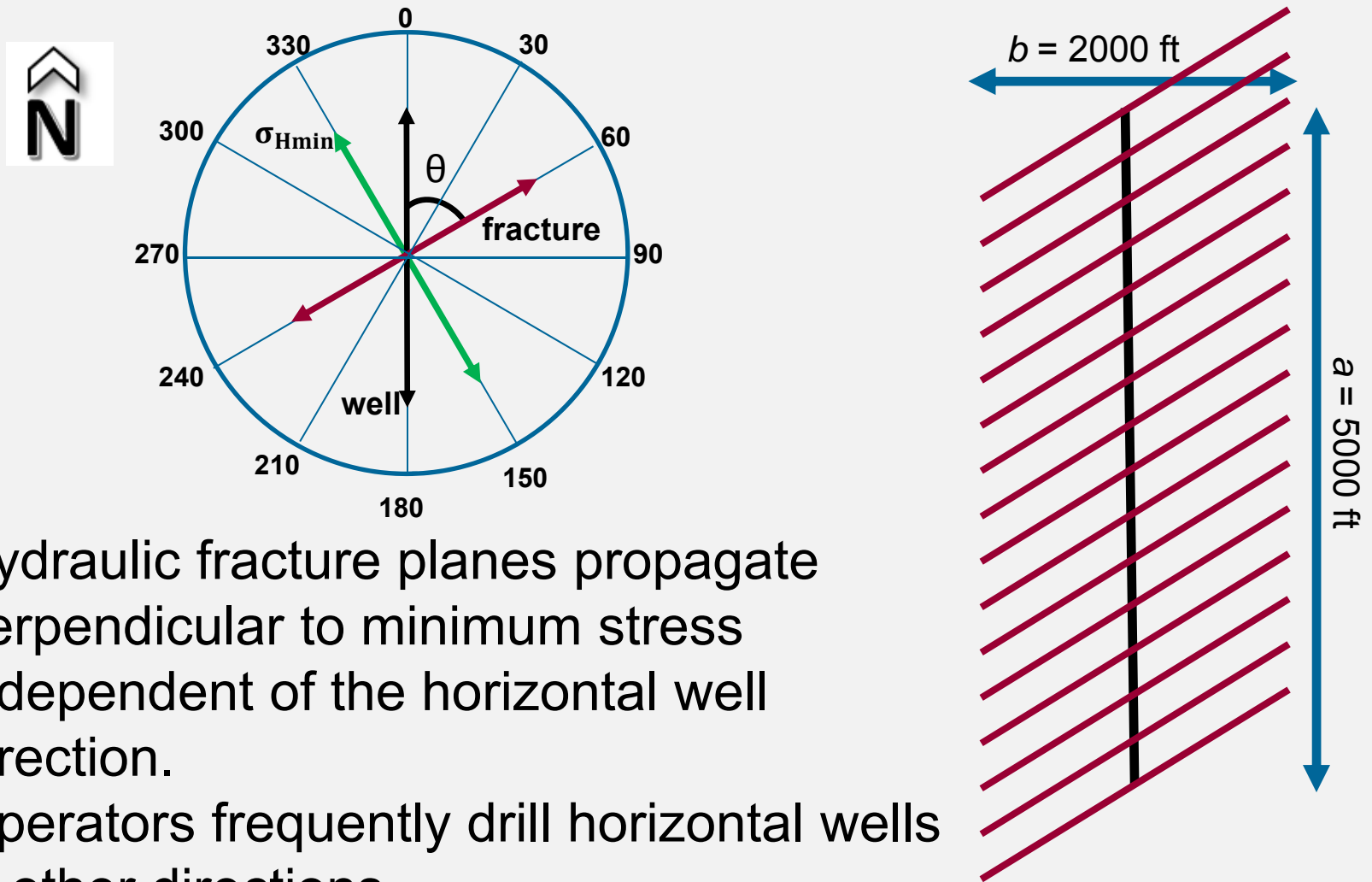
Qualitative Well Concepts

DRAINAGE VOLUME CHARACTERIZATION	WELL PATH				
	Vertical Well	Hydraulically Fractured Vertical Well	Slanted Well	Horizontal Well	Hydraulically fractured horizontal well
Thick and homogeneous, no gas cap or aquifer		Low Mobility Conventional Fracture High Mobility FRAC PACK	$k_f/k_v \geq 0.1$	$k_f/k_v \geq 0.1$	Longitudinal CH_{max} Transverse CH_{max}
Thick and homogeneous, with gas cap and/or aquifer	Gel Treatment	Small Fracture	Not Recommended: risk of premature gas or water production	Closely spaced parallel wells preferred	Not Recommended: risk of premature gas or water production
Layered		Low Mobility Conventional Fracture	$k_f/k_v \geq 0.1$ Preferred Over Vertical	Stacked parallel wells, with branch flow conformance	CH_{max}
Laminated		Hydraulic Fracture preferred Low Mobility Conventional Fracture		Not Recommended: risk of disappointing productivity/recovery due to low vertical permeability	CH_{max} CH_{min}
Naturally fractured	Prop Natural Fractures	Prop Natural Fractures		Horizontal well to normal to fractures preferred	Reopen natural fractures
Naturally fractured under waterflood	Plug Fractures Connected to injector	Water injection wells	Closely spaced short parallel wells normal to fractures	Water injection wells	Not Recommended: risk of premature water breakthrough
Structural compartment	Moderate Mobility	High Mobility FRAC PACK		Drain each with one or more wells	Maximum stress oriented by faults
Stratigraphic compartment	High Mobility FRAC PACK	High Mobility FRAC PACK		Drain each with one or more wells	Hydraulic fracturing may apply in high mobility cases
Elongated compartment		CH_{max} Low mobility	Multiple wells paths slanting from single main trunk	Single well transversing multiple channels	Single well transversing multiple channels CH_{max} Low mobility
Attic compartments	Not Preferred	Not Preferred	One single well transversing multiple beds	One well per bed drilled on strike preferred	Not Preferred

Quantitative Well Design Criteria

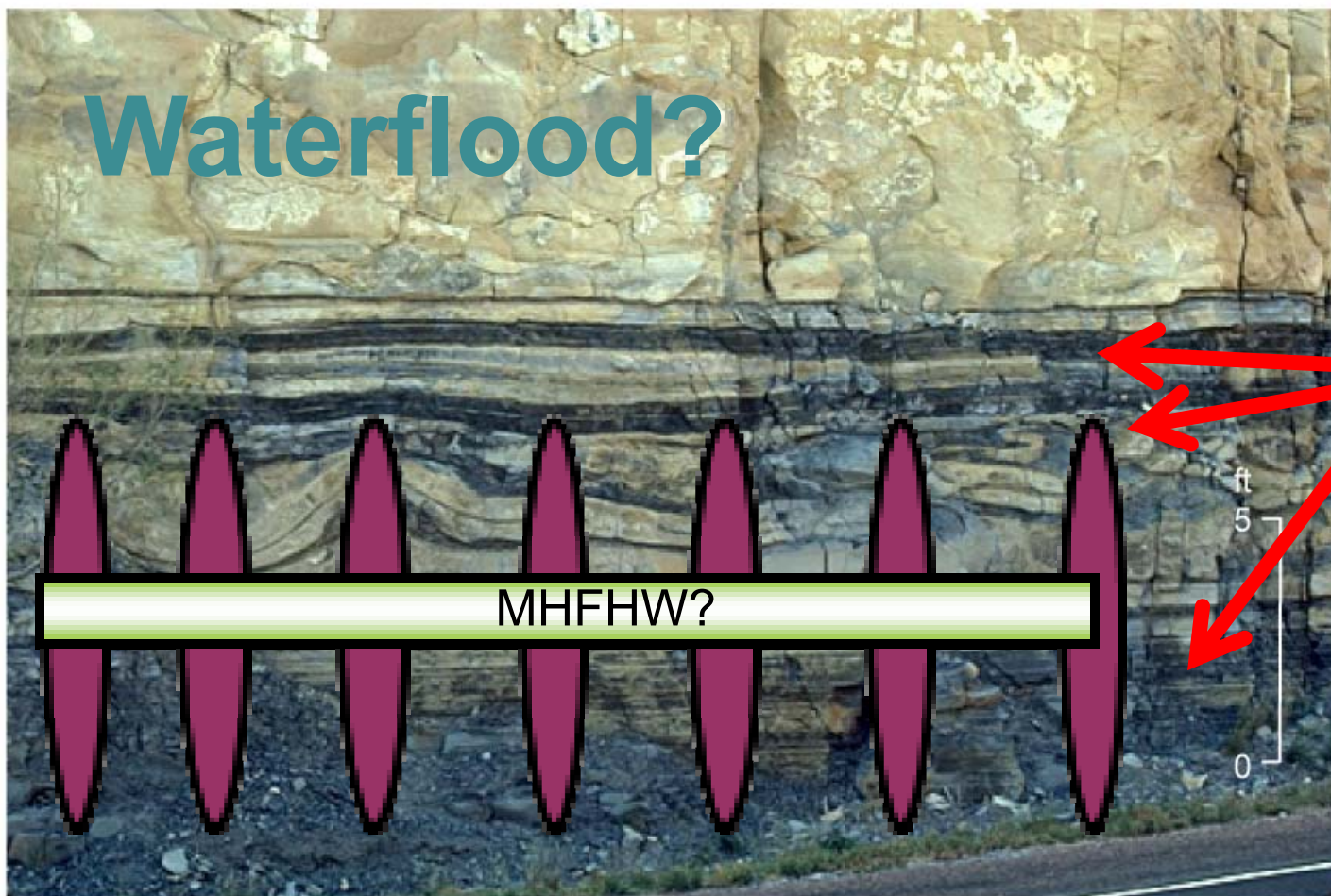


Operational Challenge



- Hydraulic fracture planes propagate perpendicular to minimum stress independent of the horizontal well direction.
- Operators frequently drill horizontal wells in other directions.

DMG Outcrop



Waterflood?

$\phi \sim 15\%$
 $S_o \sim 20\%$
 $S_w \sim 50\%$
 $k \sim 10 \text{ md}$

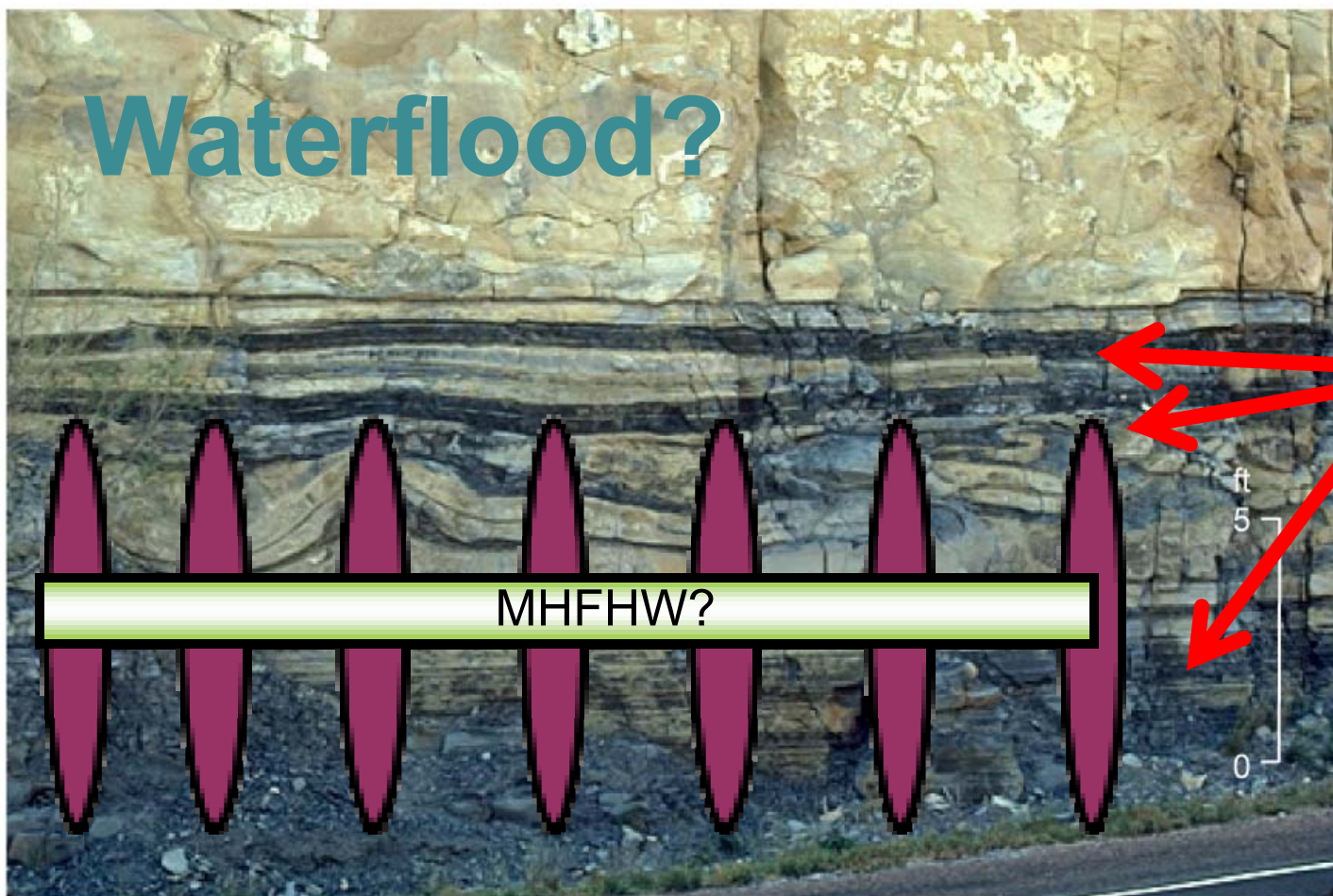
Organic-rich
siltstones

MHFHW?

$\phi \sim 5\%$
 $S_o \sim 20\%$
 $S_w \sim 60\%$
 $k \sim 0.01 \text{ md}$
TOC up to 46%

Middle Permian Basinal Siliciclastic Deposition in the Delaware Basin: The Delaware Mountain Group (Guadalupian)

DMG Outcrop



Waterflood?

$\phi \sim 15\%$
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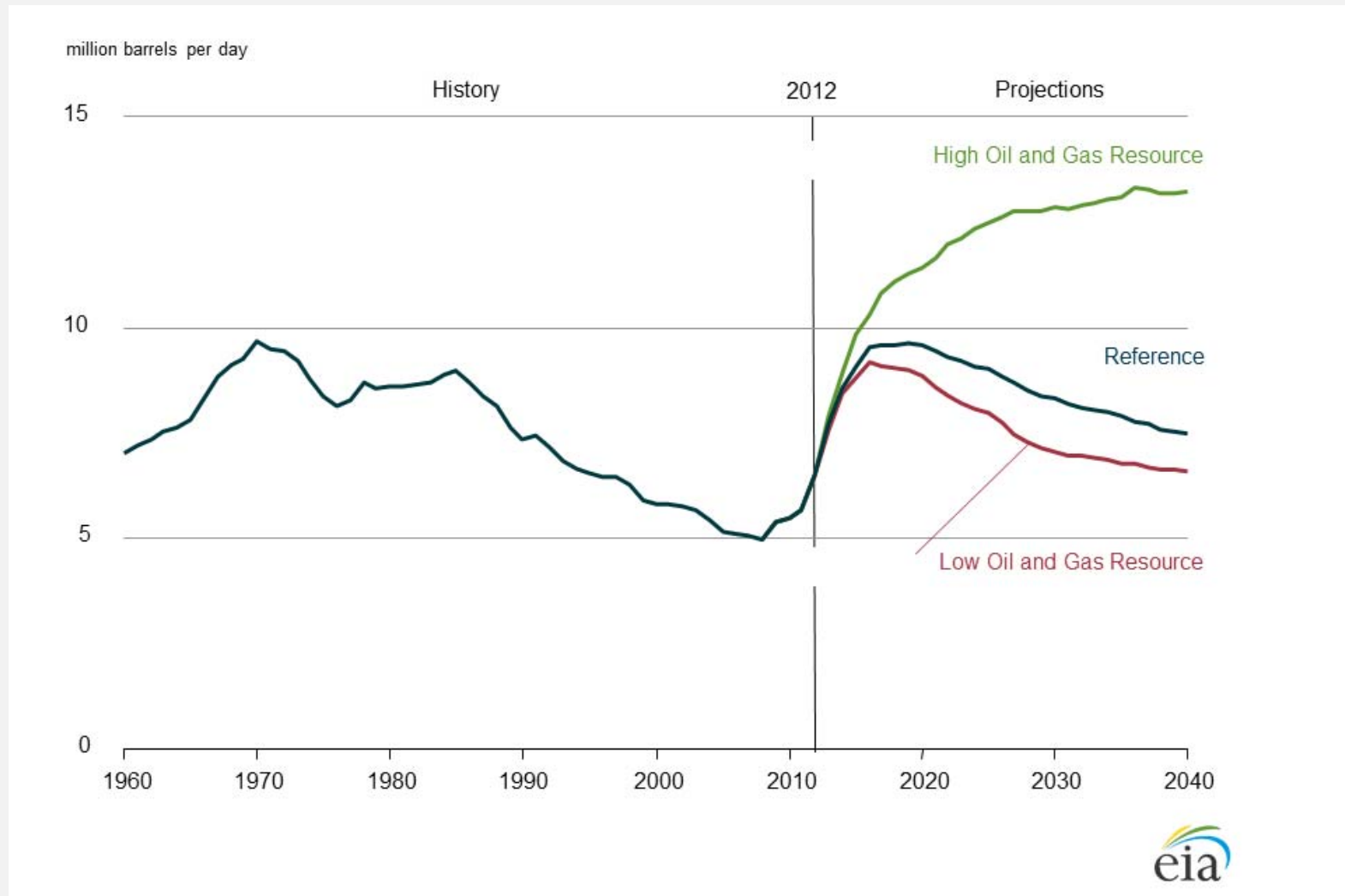
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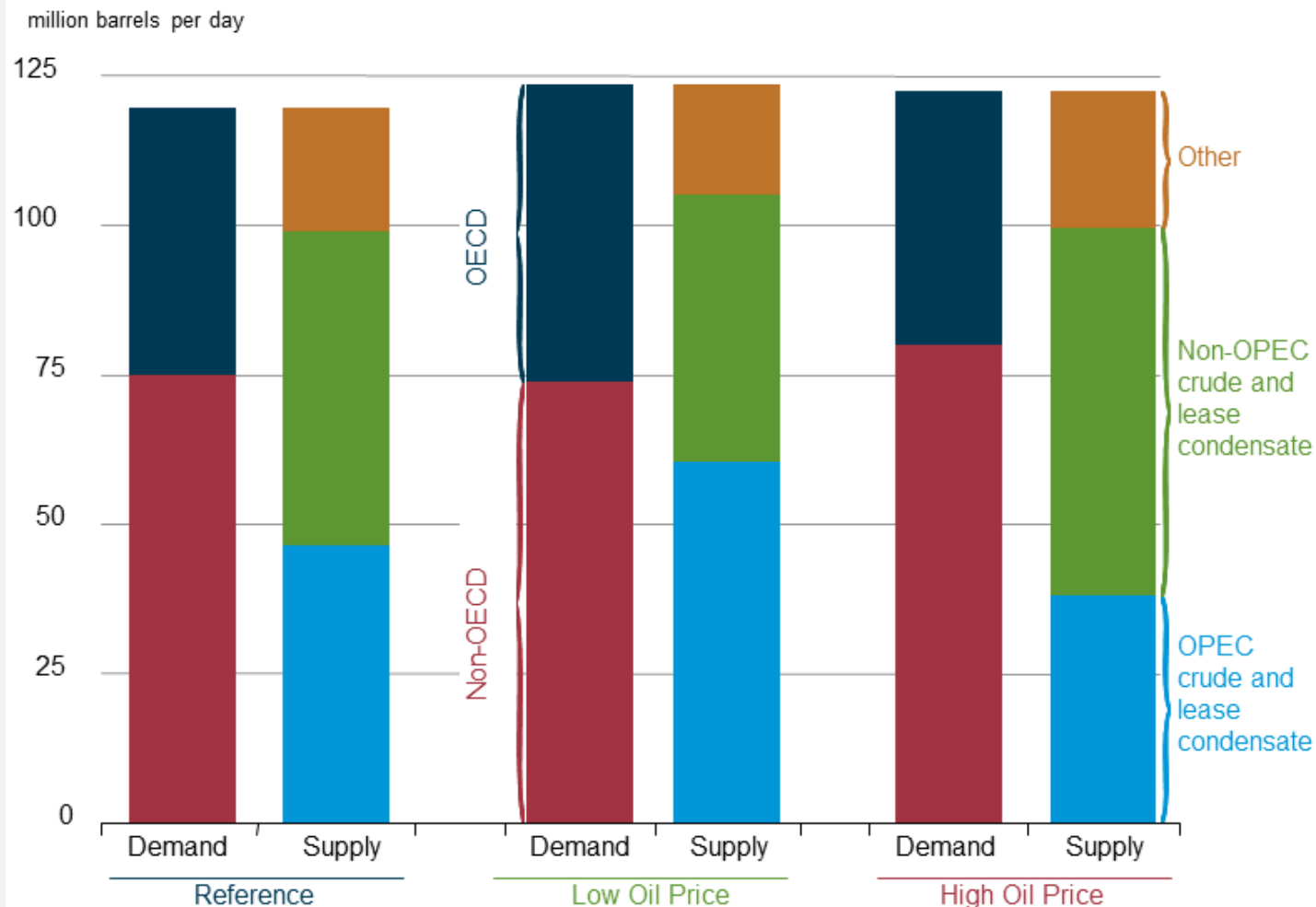
EIA US Production Forecasts



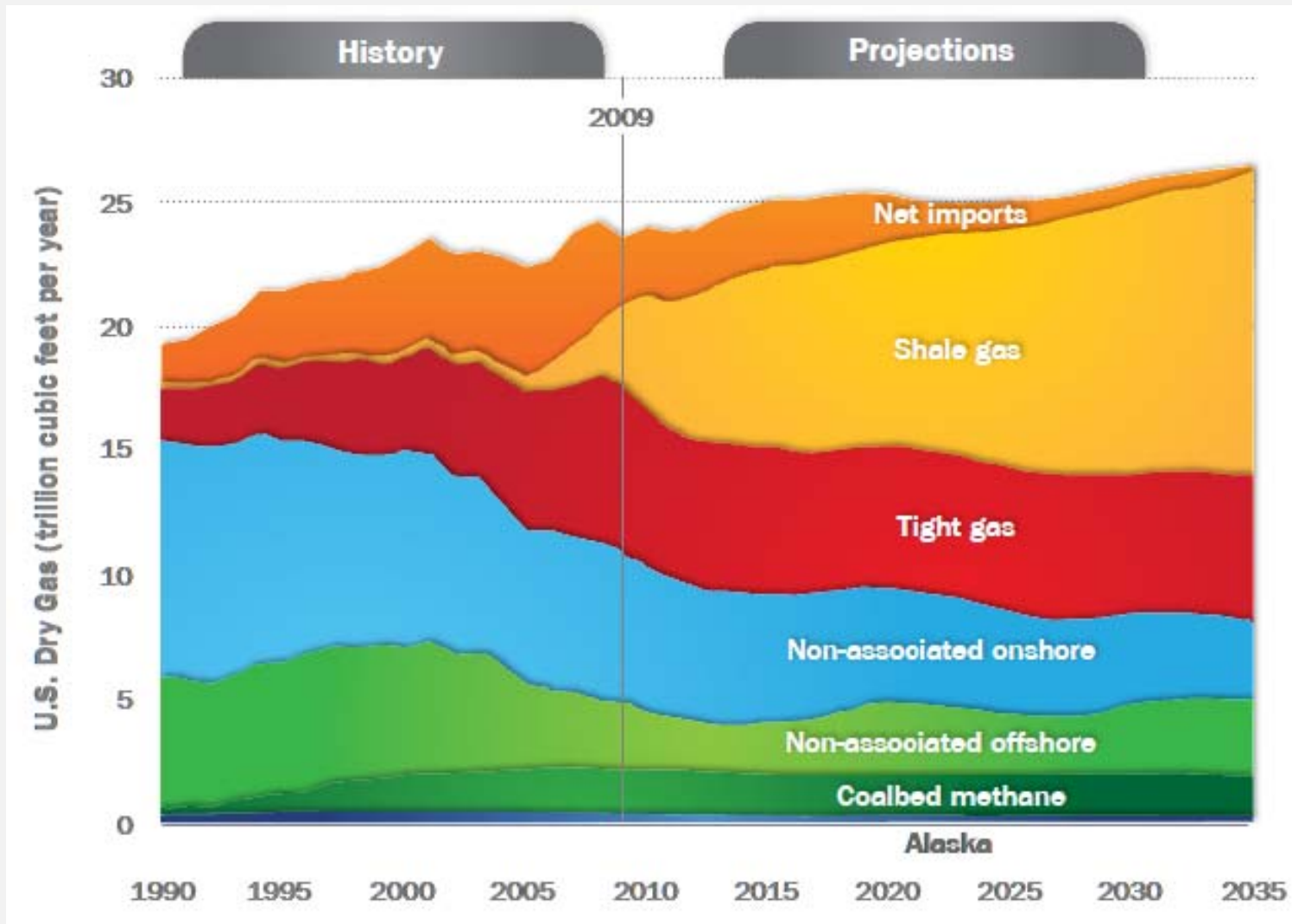
Reality Check: Oil price > \$110/STB and rising

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EIA on Oil Price Impact



Natural Gas Supply

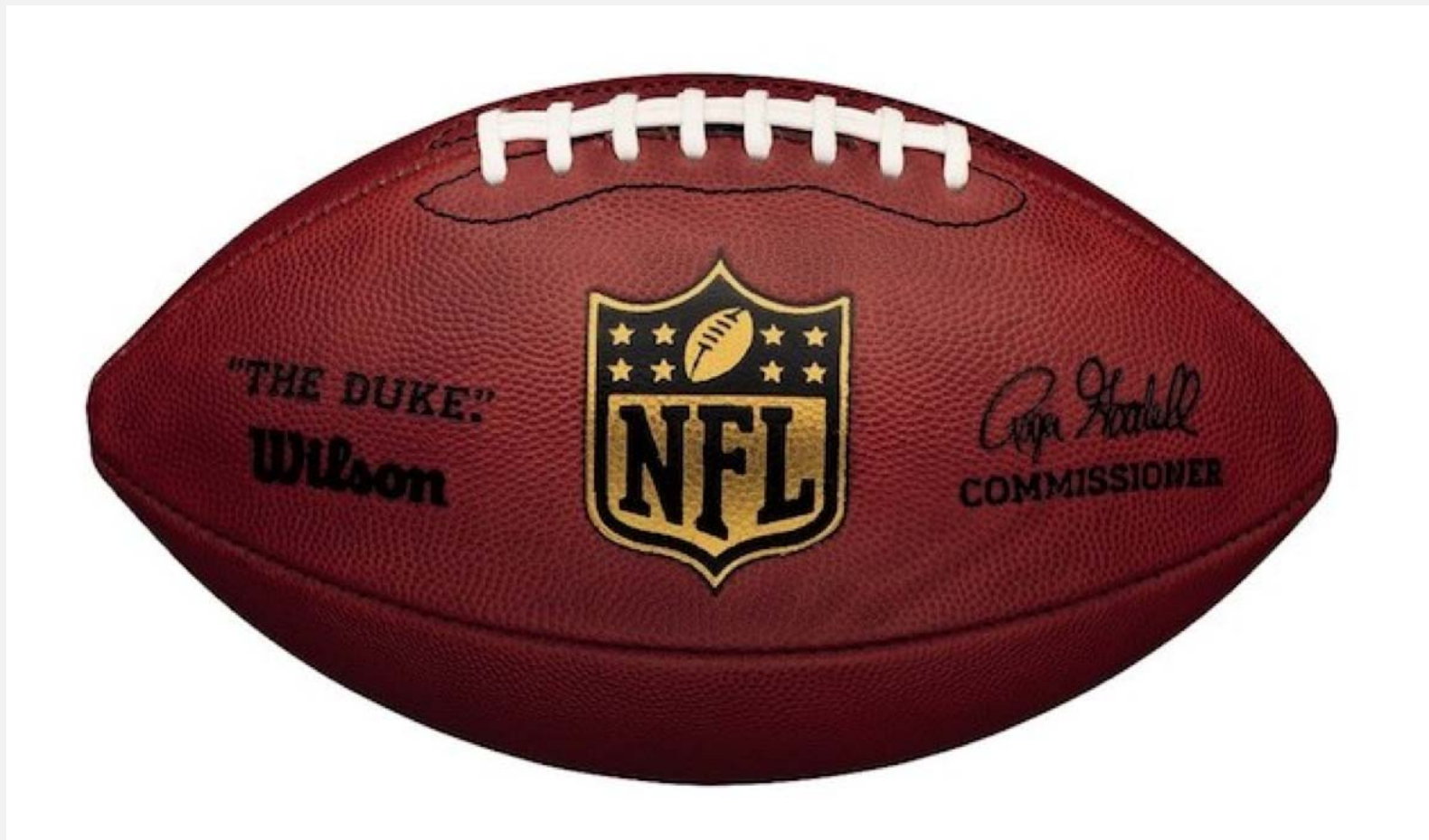


Source: DOE QTR Report 2011

Natural Gas Emerging Markets

- Electricity Generation
- Petrochemical feedstock
- Transportation
- LNG export
- Condensate export

Football Question



How much pressure will the football lose when inflated at 70 °F and in play at 35 °F?