



Defining the Core of Shale Plays

Lessons from Cutting-Edge Research and Practical Experience

Neil McMahon, PhD, Kimmeridge Energy, Thornton House, Wimbledon, London, neil.mcmahon@kimmeridgeenergy.com

Marlan Downey, Roxanna Associates, 952 Echo Lane, Suite 364, Houston, TX 77024, USA, marlandowney@mindspring.com

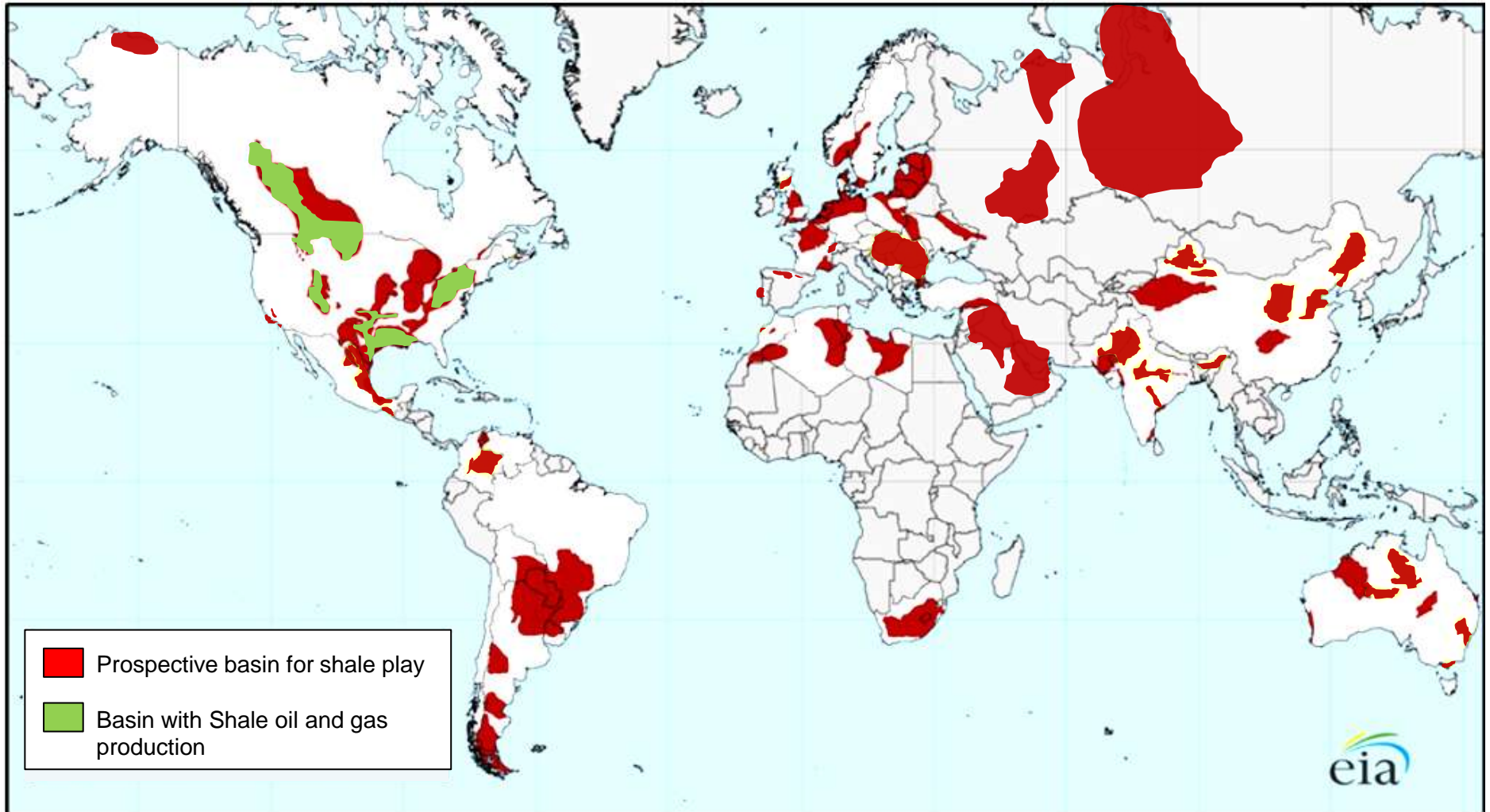
Alex Inkster, CFA, Kimmeridge Energy, Thornton House, Wimbledon, London, alex.inkster@kimmeridgeenergy.com

Agenda

- Defining the Global Opportunity Set
- Defining the Core of Shale Plays

Defining the Global Opportunity Set

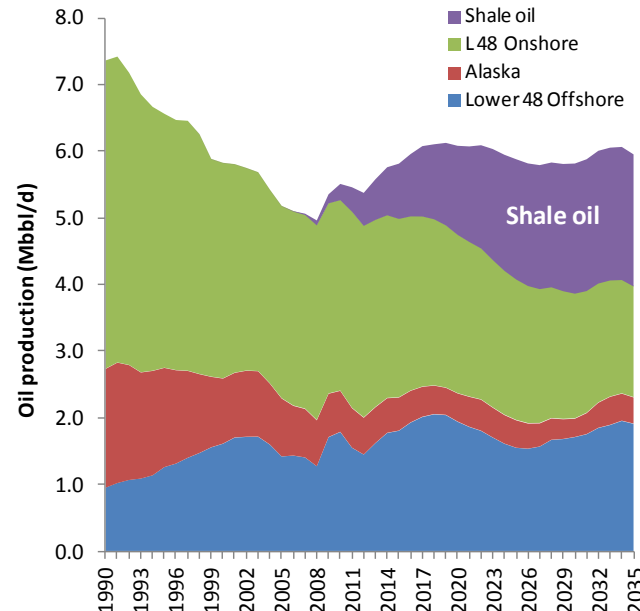
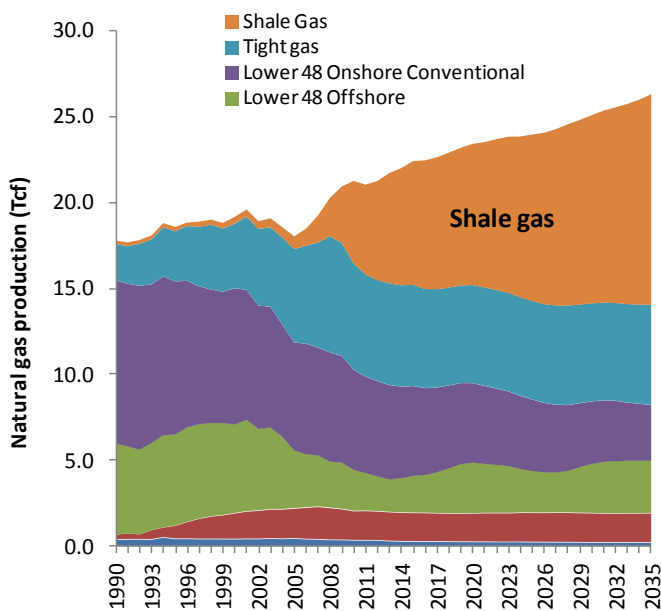
Our research suggests that estimated in-place unconventional resources for onshore basins may be >20 trillion boe



Source: Kimmeridge Energy, USGS, Advanced Resources International and Energy Information Administration (EIA)

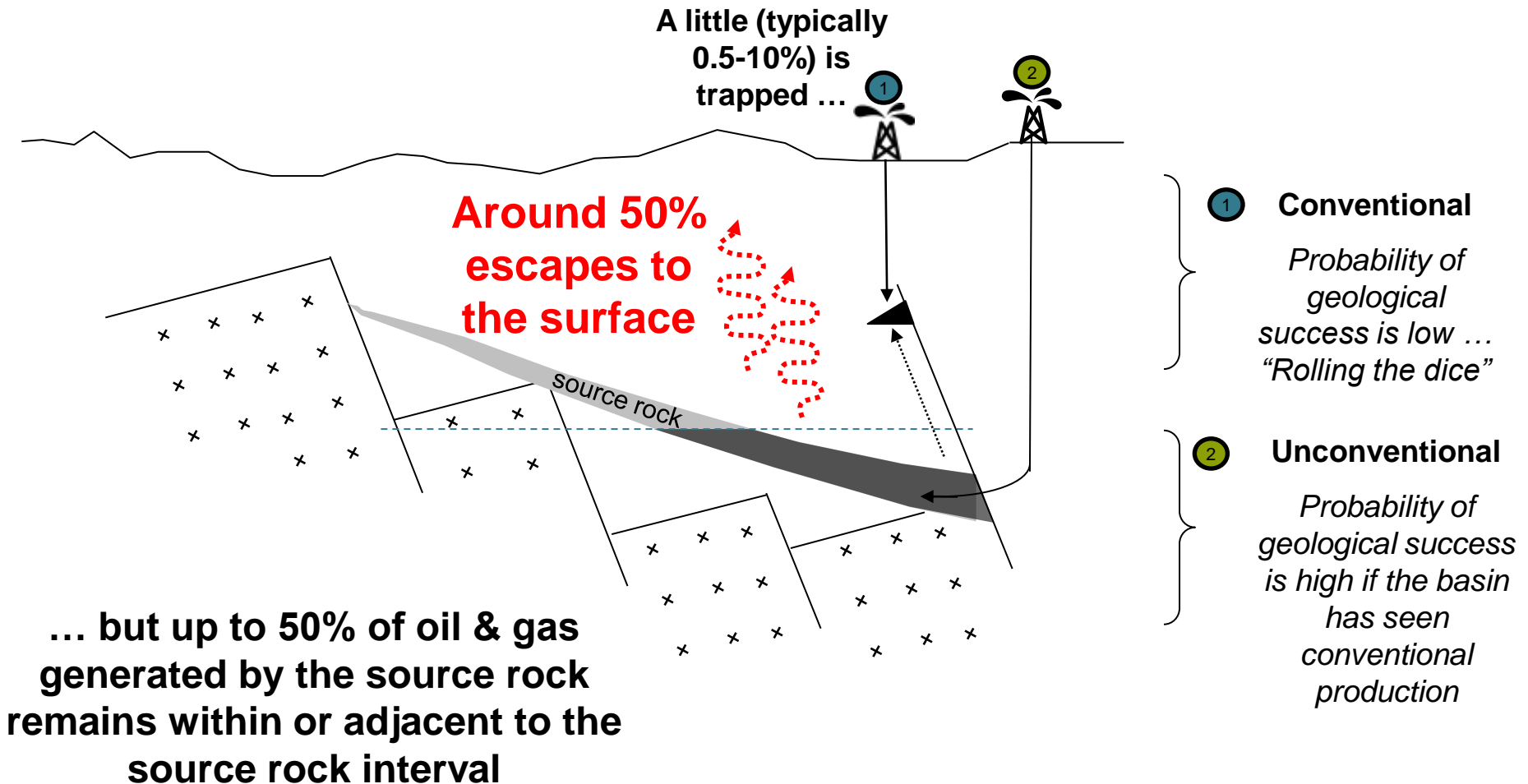
Only N. America Unconventional Potential Has Been Accurately Modelled

- Global oil and gas industry undergoing a “renaissance” in onshore exploration and production, exemplified by rapidly growing production of shale gas and oil in the US
- This has resulted from advancement of drilling technology, which has enabled us to produce oil and gas from increasingly low porosity and low permeability rocks
- Opportunity set in the US is large and conditions right to foster growth in shale production



Source: EIA, Kimmeridge Energy estimates

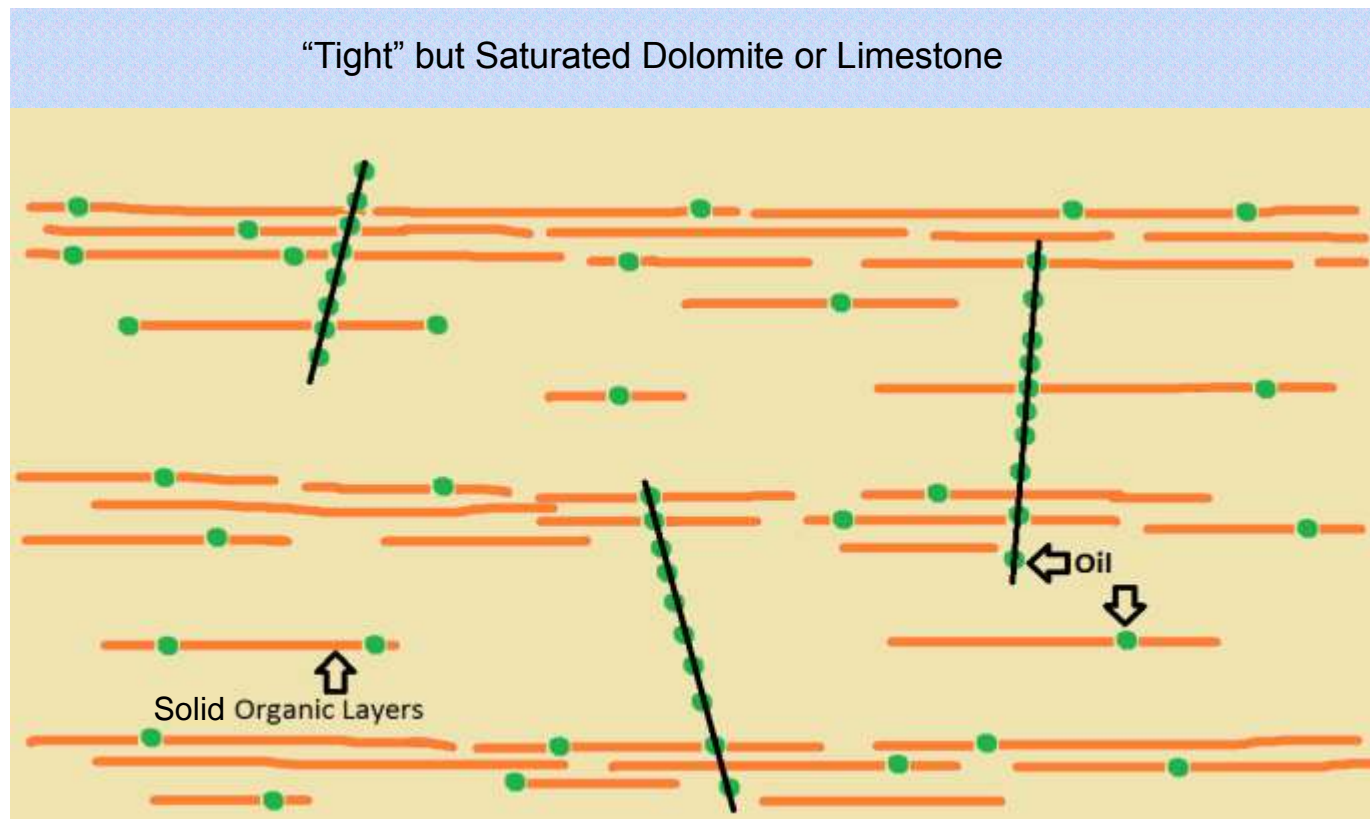
The Relationship Between Conventional and Unconventional



The key risk to unconventional exploration is not so much finding the oil and gas, it is understanding if it can be produced at commercial rates

Schematic of Oil Generation Within a Source Rock

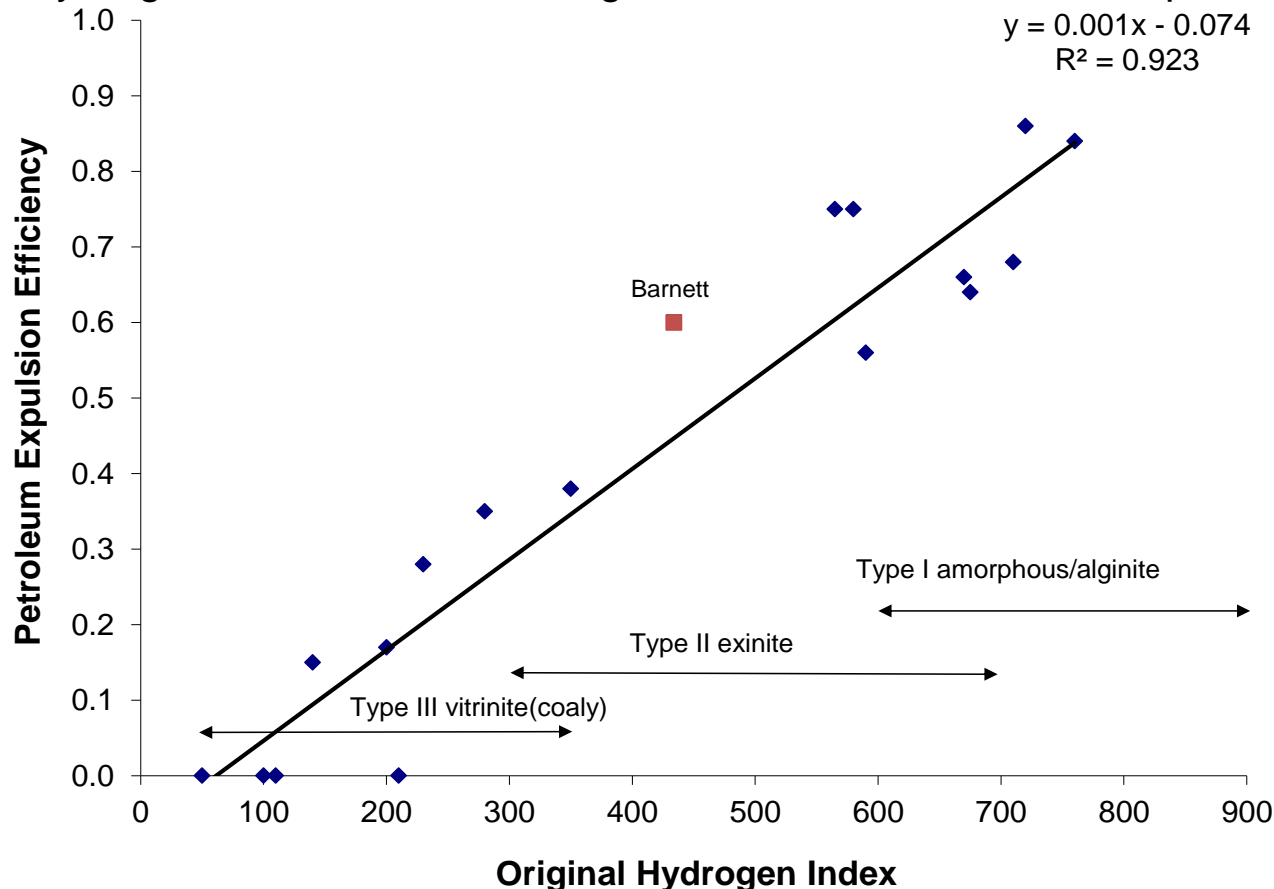
- Oil and gas are generated in-situ within the source rock, and the volume expansion from kerogen to oil & gas creates microfractures, which aid in expulsion into surrounding strata and provide storage for oil & gas
- A significant proportion of generated hydrocarbons can remain in or adjacent to the source rock



Source: Modified after Downey et al. (2011)

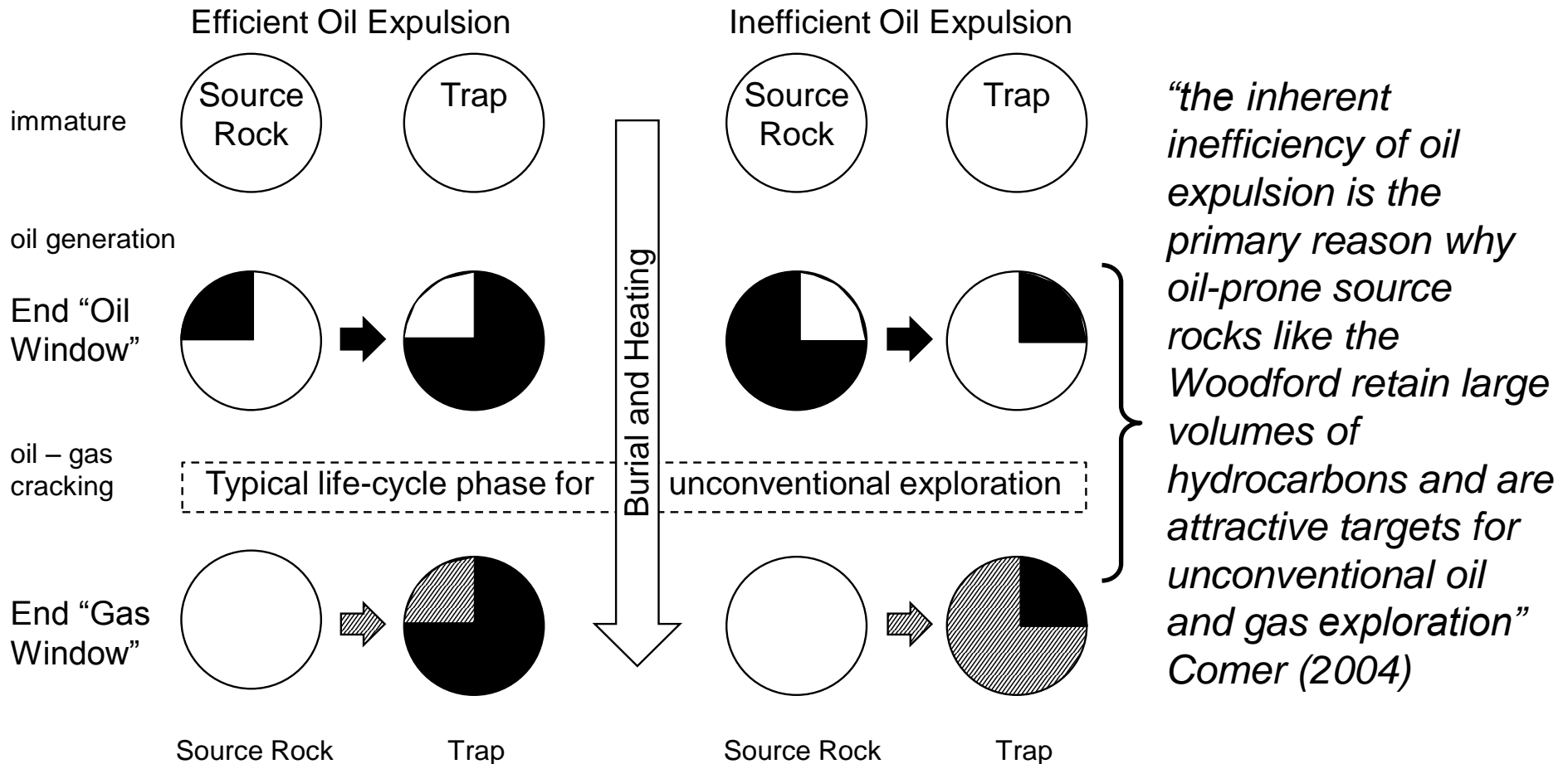
Expulsion Efficiency of Source Rocks

- No industry standard model to explain expulsion efficiency ... various models proposed that don't match empirical observations
- Pepper (1993) proposed model of expulsion efficiency related to source rock type, as measured by original hydrogen index – shows strong correlation with observed expulsion efficiency



Source: Modified after Pepper (1993)

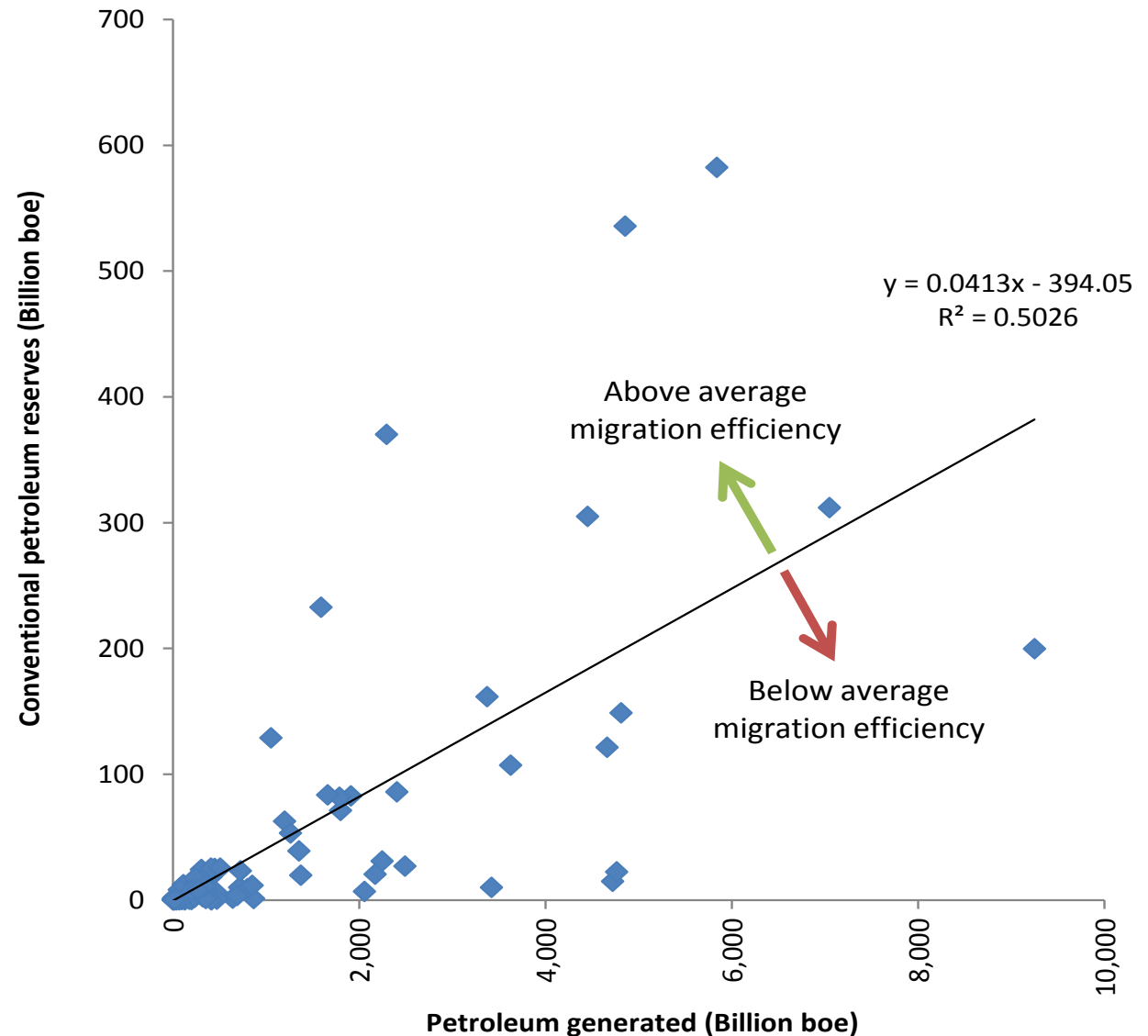
Life-cycle of a Petroleum System – Importance of Expulsion



Source: Pepper (1993)

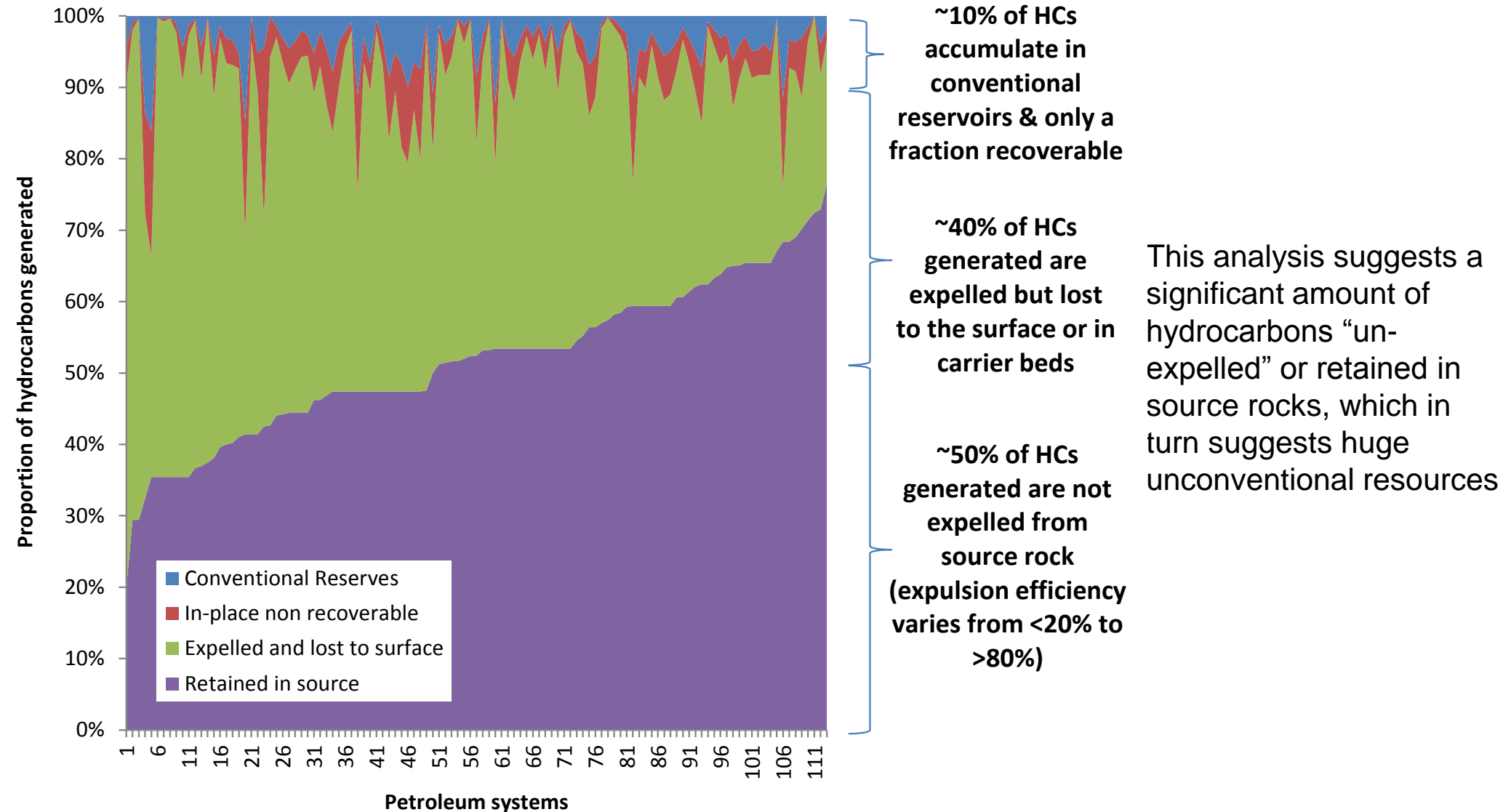
Modelling Petroleum Systems to Find Unconventional Opportunities

- We have built mass balance estimates for >100 global petroleum systems
- There is a correlation between the volume of petroleum generated and the conventional petroleum reserves that exist in a basin
- However, conventional reserves are usually less than 10% of petroleum generated in the system



Source: Kimmeridge Energy estimates

Using Mass Balance Estimates to Model & Screen Petroleum Systems



Source: Kimmeridge Energy estimates

Estimated In-Place Unconventional Resources of Largest US Basins

Shale play(s)	Total Oil & Gas Generated (Bboe)	Total Conventional Petroleum Endowment (Bboe)	Estimated In-Place Unconventional Resource (Bboe)
North Slope Alaska shales	2,247	30.9	876
Utica	2,058	6.8	613
Permian Basin shales	1,803	71.0	517
Bakken	416	0.1	276
Marcellus	853	11.6	166
Barnett	729	23.0	162
Eagle Ford	870	1.1	143
Haynesville/Bossier	473	0.5	99
Monterey (California)	263	15	93

Source: Kimmeridge Energy estimates

Estimated In-Place Unconventional Resources of Largest Global Basins

Shale play(s)	Total Oil & Gas Generated (Bboe)	Total Conventional Petroleum Endowment (Bboe)	Estimated In-Place Unconventional Resource (Bboe)
Bazhenov shale (West Siberia)	9,250	200	3,290
Western Canada shales	7,051	312	1,672
Qusaiba (Arabian Peninsula)	5,839	582	1,544
Tarim Basin shales (China)	4,812	149	1,481
Jurassic & Cretaceous shales (West Siberia)	4,454	305	1,401
Querecual (Orinoco Oil Belt)	4,857	536	1,284
Junggar Basin shale (China)	4,722	15	1,159
Neuquen Basin shales (Argentina & Chile)	3,424	10	986
Sichuan Basin shales (China)	4,767	22	929

Source: Kimmeridge Energy estimates

Summary: Defining the Global Opportunity Set

- Using our global dataset of petroleum system mass balance calculations, we estimate that typically around 50% of hydrocarbons generated remain within the source rock
- A significant amount is often trapped in closely associated lithofacies
- Combined, the source rock and adjacent strata typically present the largest continuous accumulation of hydrocarbons in a given basin
- Basins that have seen significant production of oil & gas from conventional fields are often the best places to look for new unconventional plays, as we can be 100% sure that at least one prolific source rock exists
- Our estimates for recoverable unconventional resources in the largest global onshore basins show a potentially enormous prize that could **equate to or exceed** the amount of oil and gas discovered in onshore conventional fields

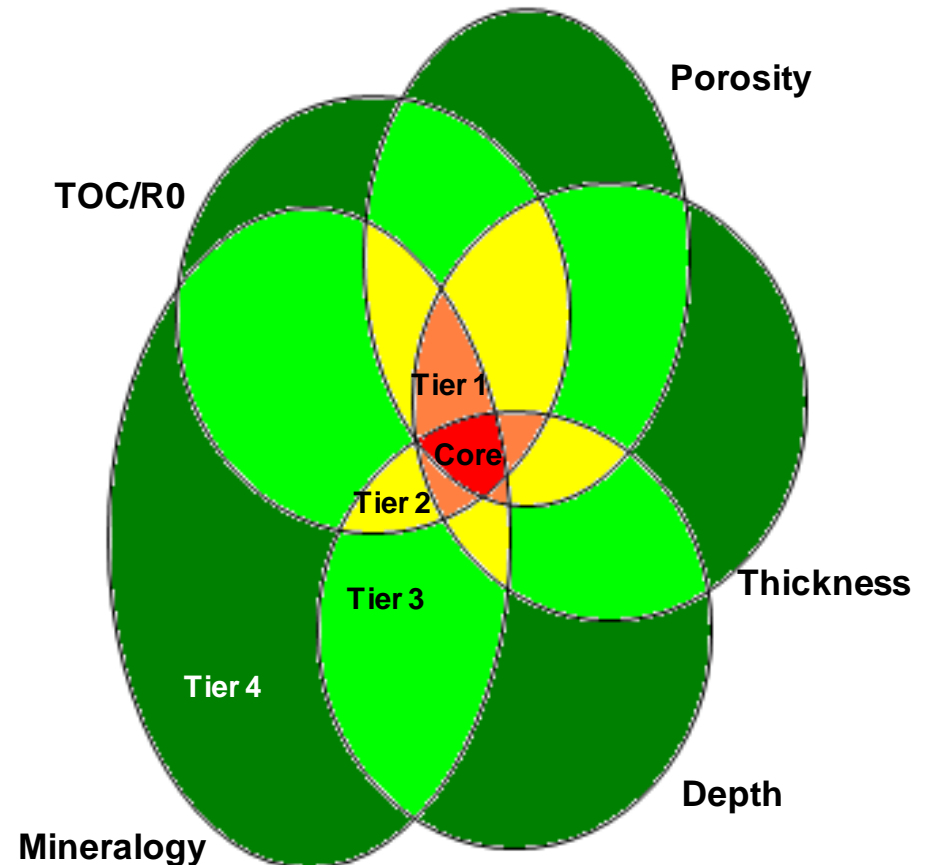
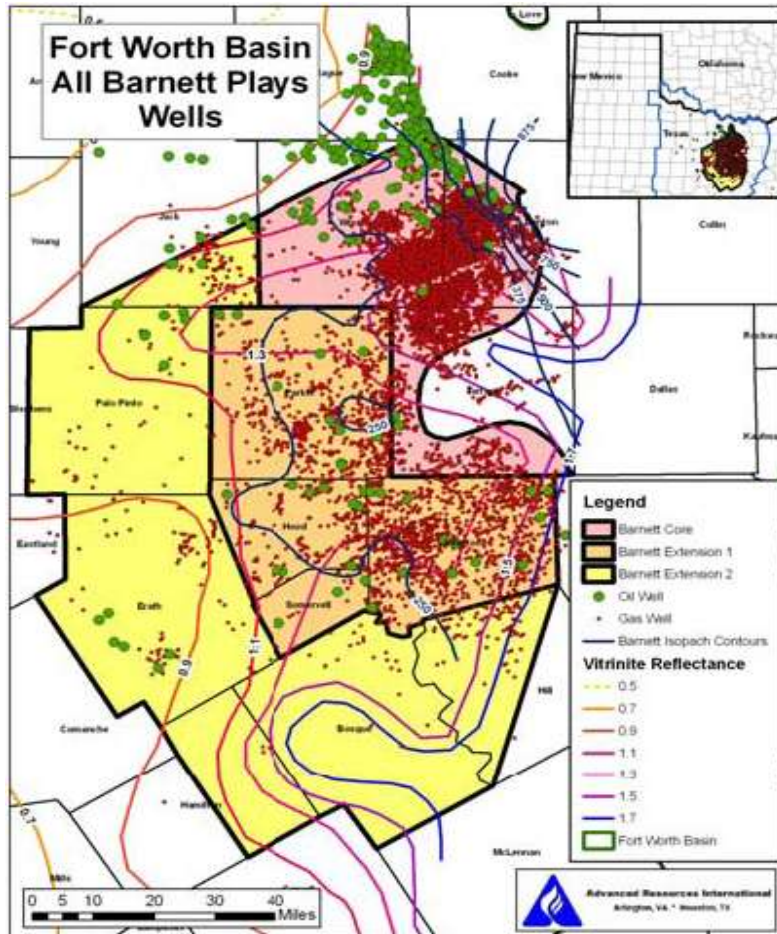
Agenda

- Defining the Global Opportunity Set

- Defining the Core of Shale Plays

Once You Know Where to Look – You Need to Define the Core

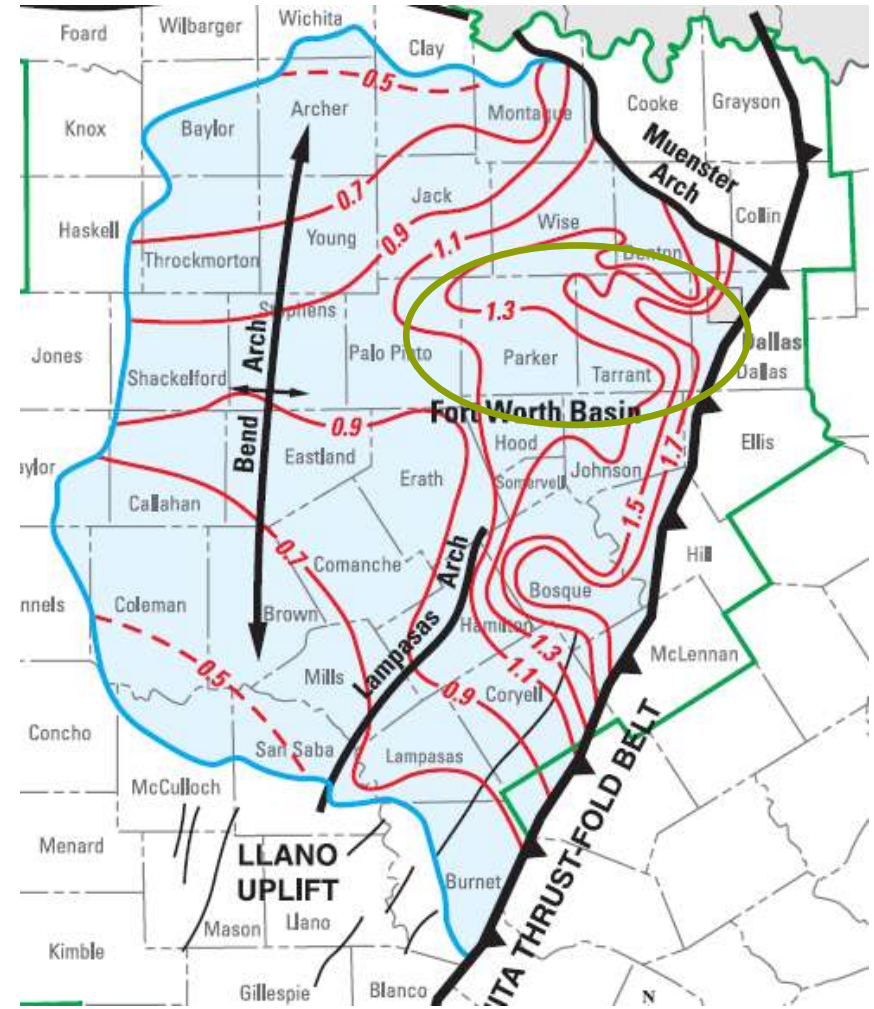
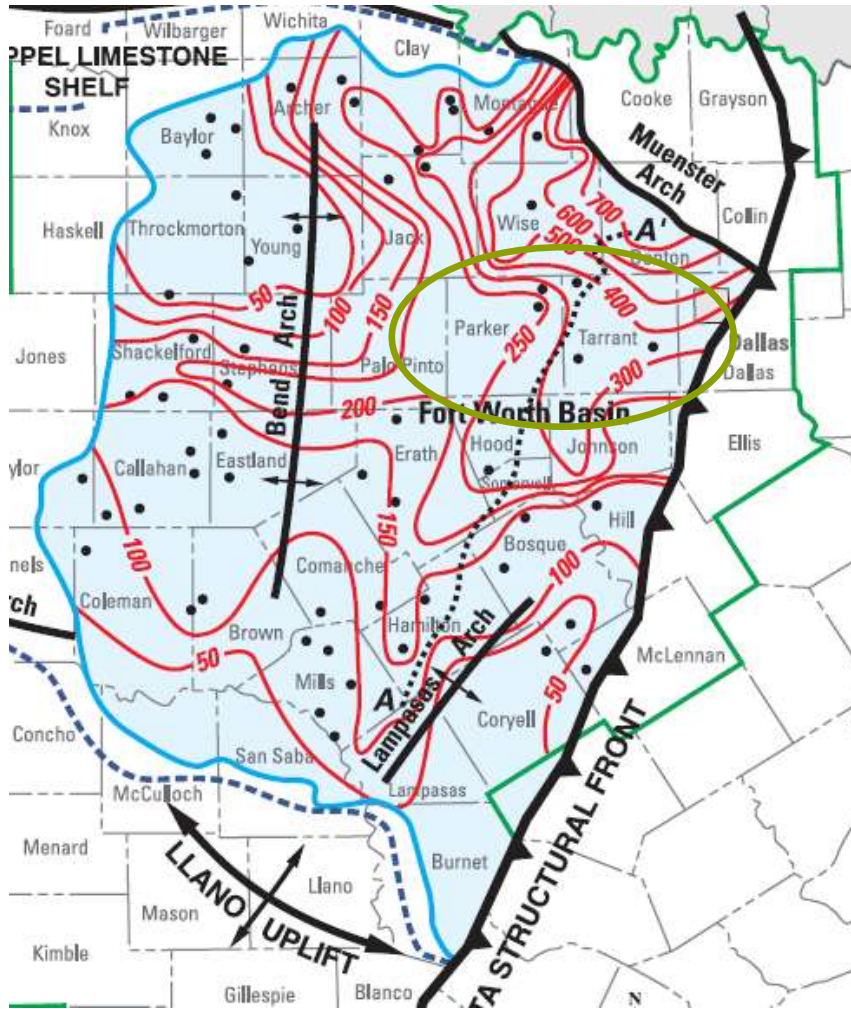
- Defining the core of a shale play post-development drilling is relatively easy – it is a statistical exercise based on mapping Initial Production rates for standardized completions e.g. Barnett
- Defining the core pre-drill is much harder – shale plays tend to be gradational in nature, so defining the core relies on mapping optimal convergence of various technical attributes



But Do You Want a Thicker, Richer, More Mature Source Rock?

- Thickness 300-500 ft in Tarrant vs. 200-250 ft in Parker ... Higher GIP and EUR

- Higher maturity in Tarrant than Parker ... more dry gas generated (Higher GIP, IP and EUR)



Screening Methods and Important Indicators

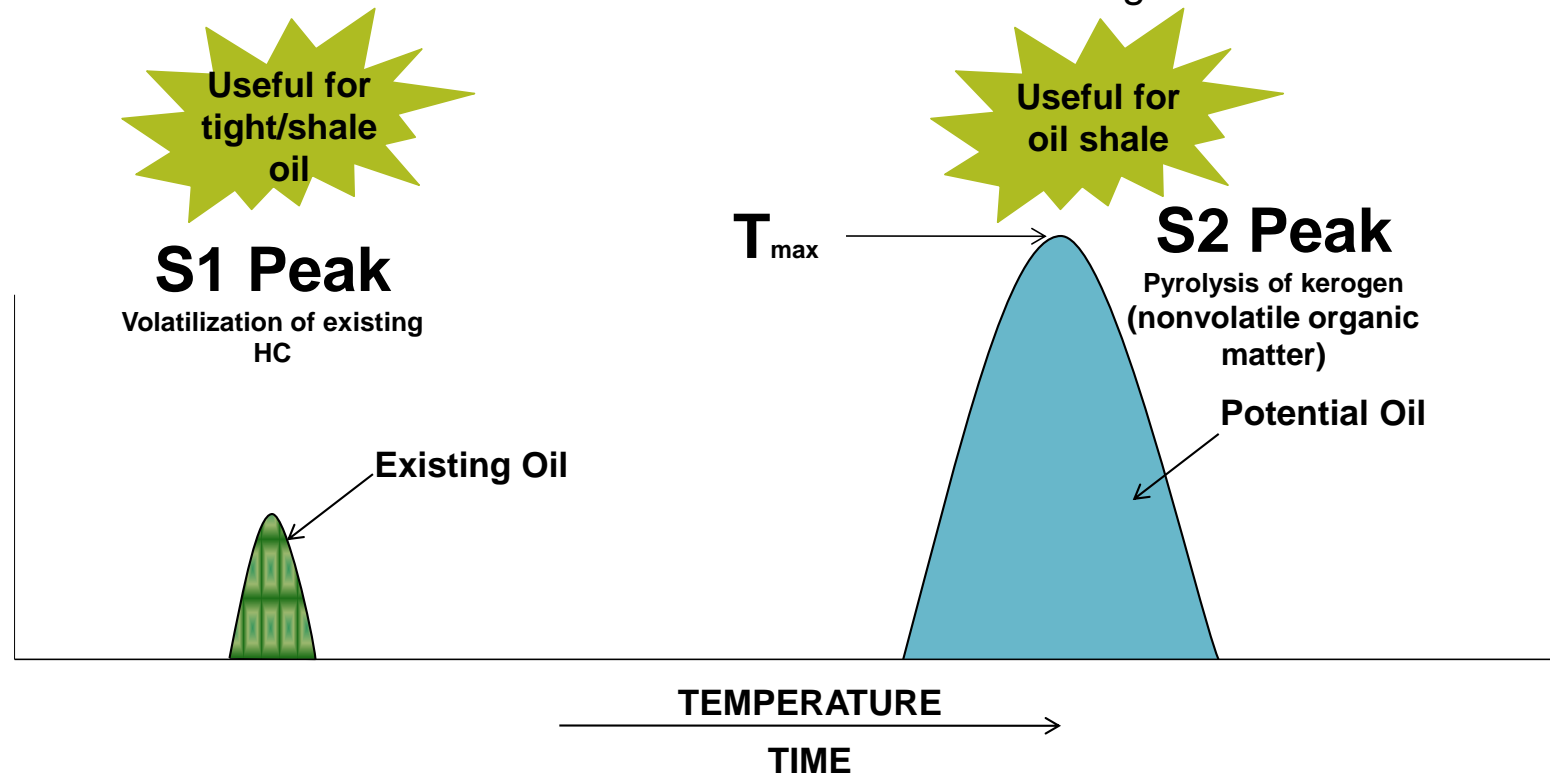
- Shale plays lend themselves to statistical screening, due to their large areal extent and large amount of historic data, which enables significant “desktop” de-risking
- Key parameters to screen are:
 - Kerogen type (types II or II/III)
 - TOC (>2%)*
 - S1**
 - Thickness (>50ft for fracture completion)
 - Maturity (Ro 0.55-2.5%)***)
 - Mineralogy (low clay, high quartz/carbonate)
 - Por/Perm (Por >3%; Perm >10 nD)
 - Pressure (>0.433 psi/ft)
 - Natural fractures (helps OIP/GIP and flow rates)
 - Bounding rocks (increase HC retention & pressure)
- Indicators such as the Saturation Indicator (SI) are useful for estimating oil saturation in shales
- **BUT**, SI must be used with caution, as it is only useful if you know the rock type and type of organic matter that makes up TOC. According to Jarvie, organic-rich rocks retain upwards of 50-80 mg HC/g TOC, which is adsorbed oil and thus **hard to produce**.

Depends on rock type and % convertible carbon **Depends on whether oil or gas play *Depends on kerogen type*

Rock Eval S1 Can Be Used to Estimate Oil In Place in Shales

- S1 represents the free hydrocarbons in a rock

- S2 represents the amount of hydrocarbons generated through thermal cracking of nonvolatile organic matter



Simplified equation for calculating shale OIP:

$$\text{OIP per 640 acre/ft} = 4965.36 \times (\rho_{Av}) (S1_{Av})(\rho_{oil})$$

Where:

ρ_{Av} = Average bulk density (g/cc)

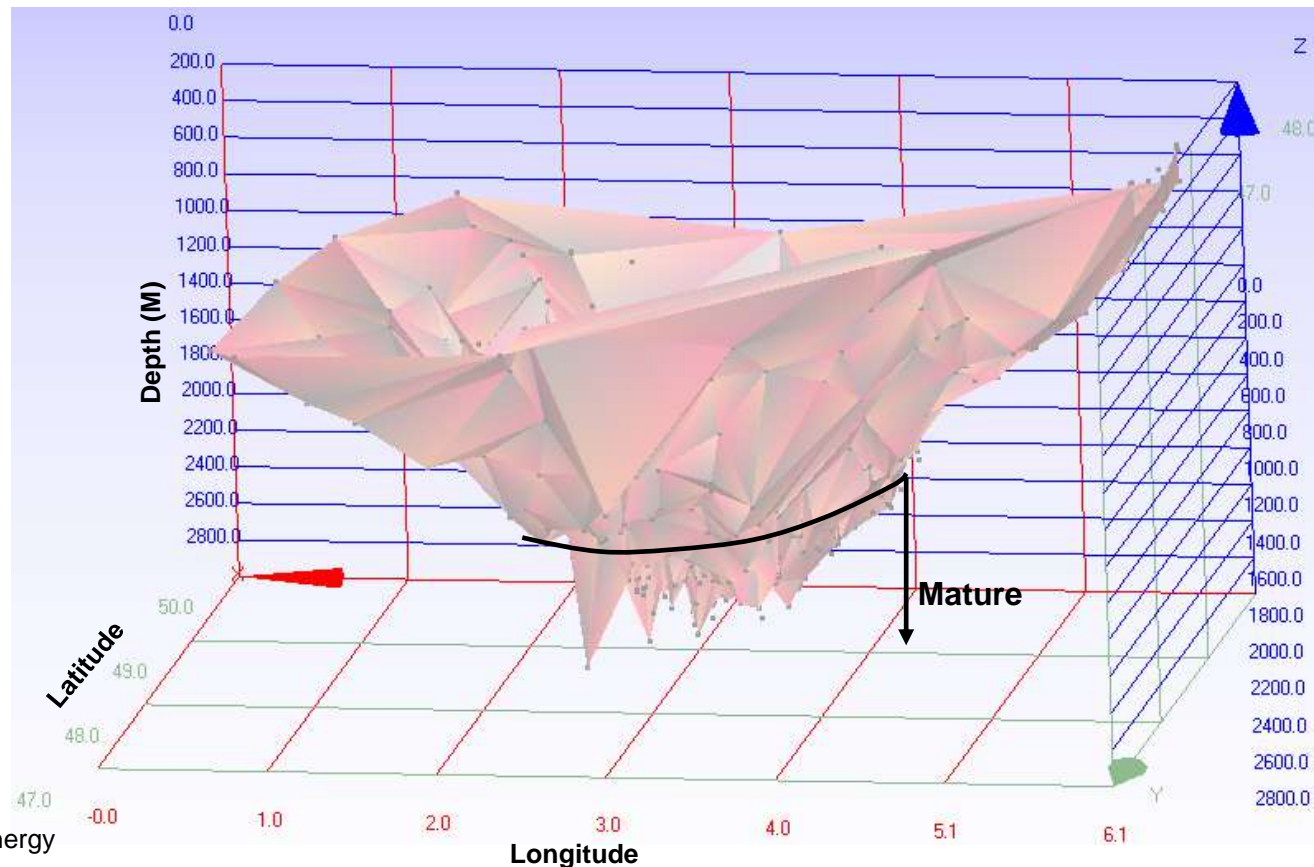
$S1_{Av}$ = Average S1 (mg/g)

ρ_{oil} = Density of oil (g/cc)

Source: Downey et al. (2011)

Worked Example – The Paris Basin Liassic Shale

- Paris Basin Liassic shale oil play is first international Bakken analogue. By mapping depth of Toarcian in 3D, we can visualize Paris Basin as relatively undisturbed intracratonic basin
- The Toarcian Schistes Carton source rock is mature at depths $>1800\text{m}$, with maximum burial reaching $\sim 2700\text{m}$ at the basin depocentre

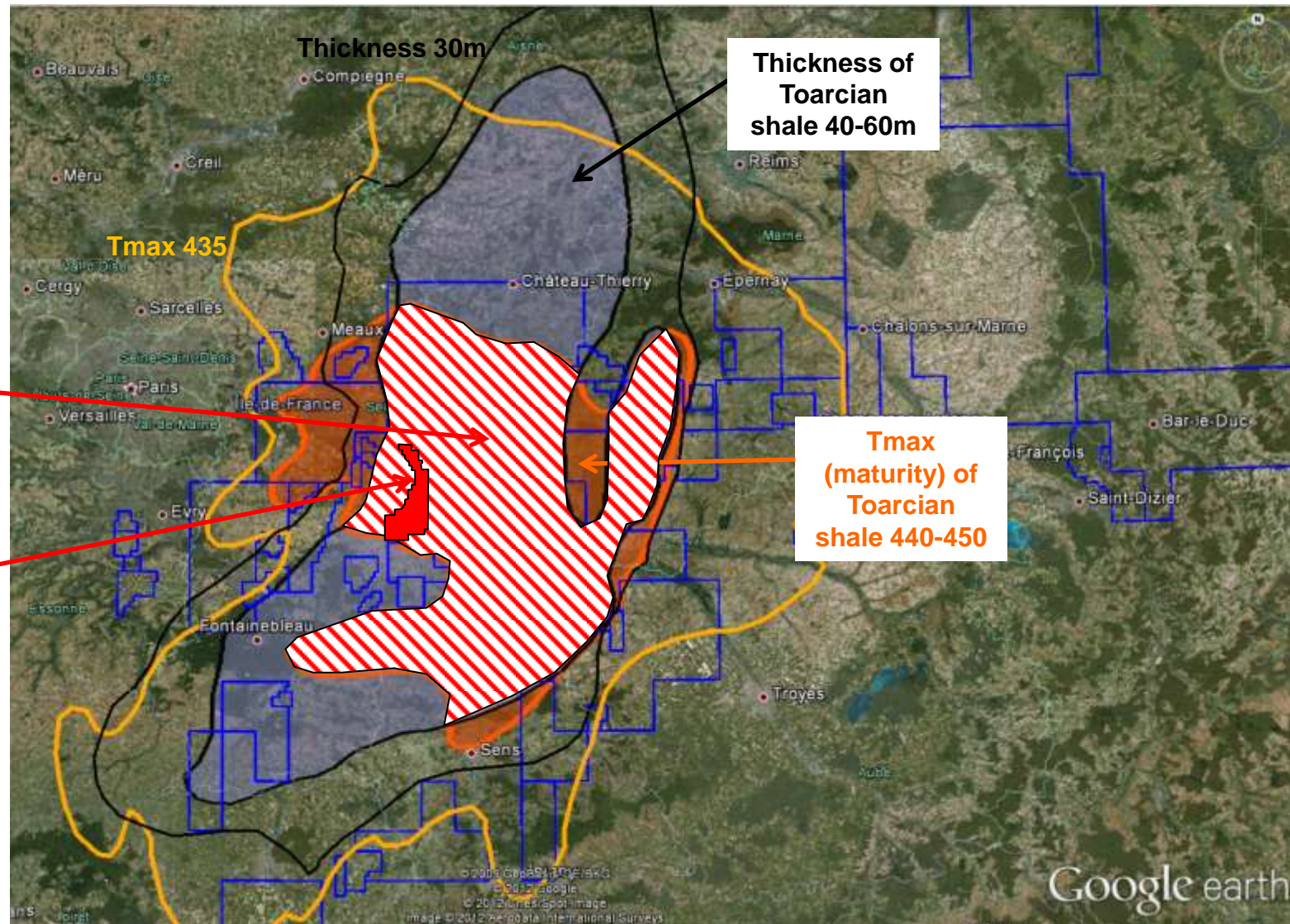


Source: IHS and Kimmeridge Energy

Schematic of Schistes Carton Maturity & Thickness vs. Acreage Blocks

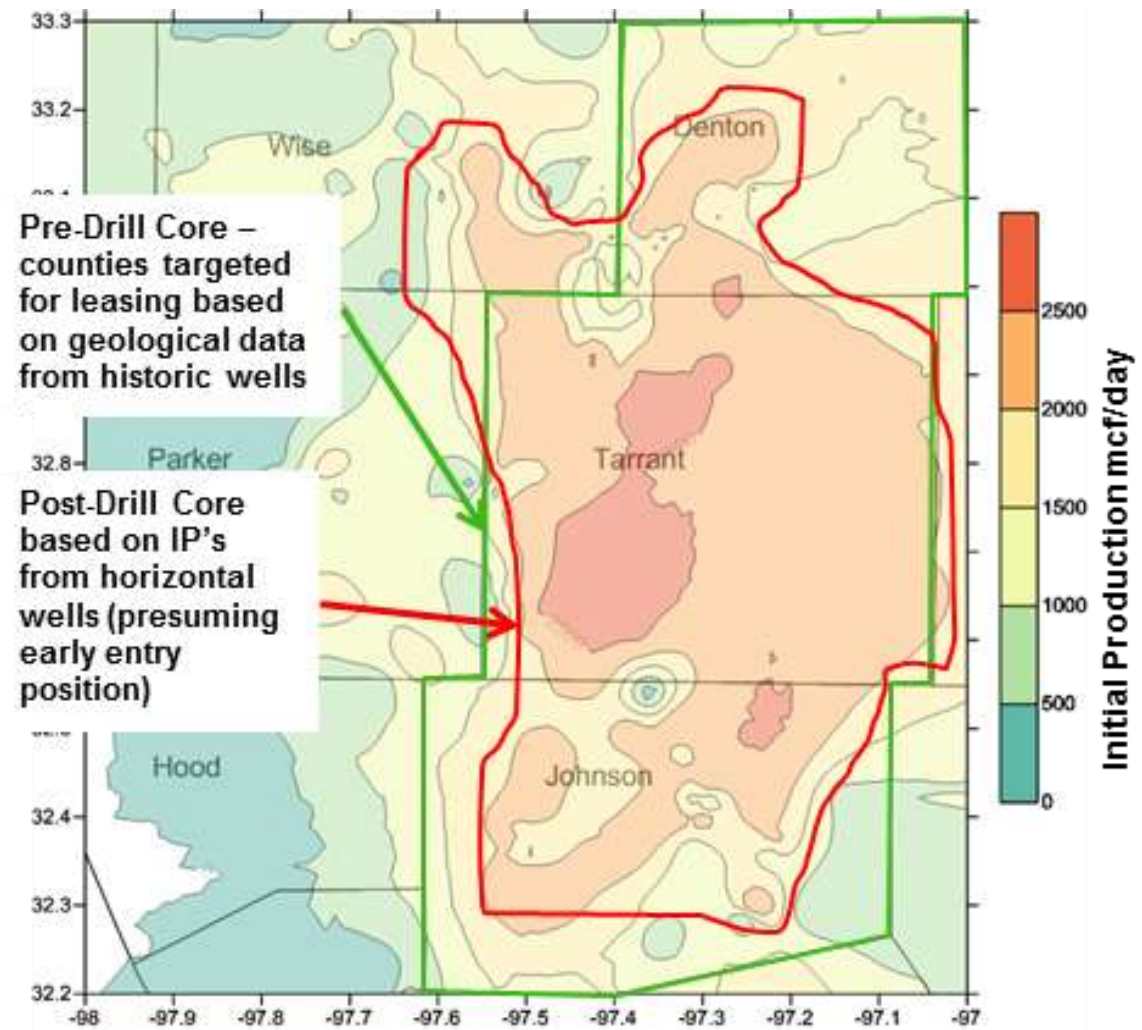
The pre-drill core of the play is expected to be in the depocentre of the Paris Basin, where the Toarcian Schistes Carton is thickest and most mature ...

This area has already seen production from the Liassic shale from 2 modern vertical wells drilled by Vermillion in its Champotran licence block



Defining the Core Post Drilling

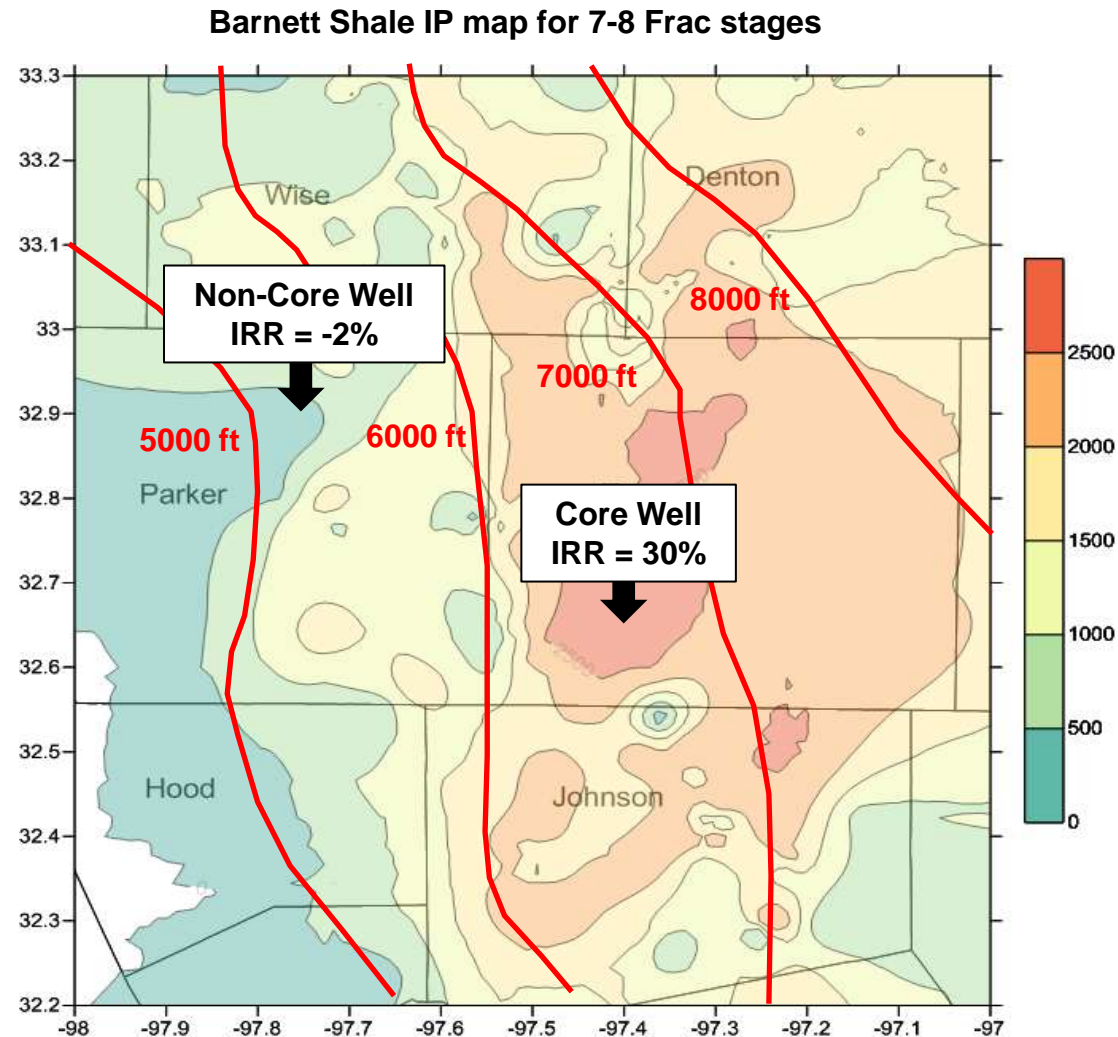
- We have developed a proprietary North American frac database with over 10,000 completions.
- Using this, we compared pre-drill core counties targeted for leasing in the Barnett, with the post-drill core of the play based on Initial Production (IP) rates for horizontal wells



Source: Kimmeridge Energy

Economics for Core vs. Non-Core Wells (Barnett Example)

- Our analysis shows that economics for Barnett shale wells in the core (Tarrant Co.) vs. non-core (Parker Co.) can diverge materially
- An example using 2 dummy wells in the Barnett, based on standardised completions, shows a strong return (IRR) for the core well, but potentially a negative return for the non-core well *



* This assumes constant inputs, such as a royalty rate of 16.67% and gas price of \$5/mcf, and the only difference being well costs and performance (IPs and EURs)

Summary and Q&A

- The global unconventional opportunity set is vast. We believe that over time unconventional resources in shales could provide as much, if not more, oil and gas than conventional reservoirs
- Companies that hope to succeed in unconventional exploration need sound technical understanding of these plays ... especially geochemistry, which is scarce in the industry
- Defining the core of a shale play pre-drill is crucial for economics, as returns can diverge materially between the core and fringe of a play, making it crucial to lease early
- The core of a new play is likely to occur where there is an optimal convergence of factors such as Thickness, Maturity, Por/Perm, Depth, TOC, etc ... this needs to be proven through drilling
- Companies hoping to succeed in unconventional exploration need to have the requisite technical expertise to define the core pre-drill

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