Advanced Training for CBM Geologists

Unconventional Hydrocarbons and Geological Models

Ulaanbaatar, Mongolia

16 June 2022

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Cipher Doc#: 22-423

Australian Aid

AMEP
Australia Mongolia Extractives Program

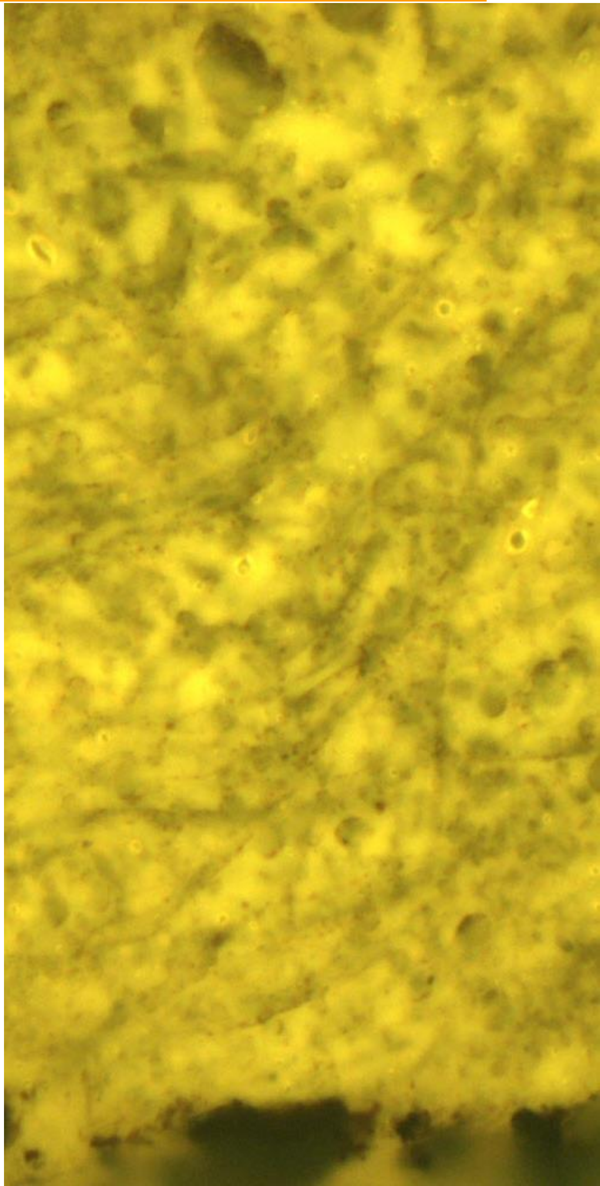
Schedule

Advanced Training for CBM Geologists			
from	**To**	**total time (hr:min)**	**Topic**
9:00	**9:15**	**0:15**	**Opening Remarks & Introduction**
9:15	10:45	1:30	Origin of Reservoir Properties: from Peat to Pores
10:45	11:00	0:15	Questions/Discussion
11:00	11:15	0:15	Coffee Break
11:15	12:45	1:30	Unconventional Hydrocarbons and Geological Models
12:45	13:00	0:15	Questions/Discussion
13:00	**14:00**	**1:00**	**LUNCH**
14:00	14:45	0:45	CBM Drilling Equipment & Methods
14:45	15:00	0:15	Questions/Discussion
15:00	16:00	1:00	Coal & Rock Review - What and How to Characterise
16:00	16:15	0:15	Questions/Discussion
16:15	16:30	0:15	Coffee Break
16:30	17:30	1:00	Measuring Gas
17:30	18:00	0:30	Critical CBM Reservoir Properties: Know where to Place Your Efforts
18:00	18:15	0:15	Questions/Discussion
18:15	**18:30**	**0:15**	***Closing Remarks***

NOTE: Times are in UB, Mongolian Times

Outline of Lecture

- **What makes a reservoir Conventional or Unconventional?**
- **Brief review of a Conventional reservoir system**
- **Unconventional Reservoir Review**
- **Focus on Coalbed Methane as Shale Gas**
- **Geological Models**



Definition: Conventional vs Unconventional Resources

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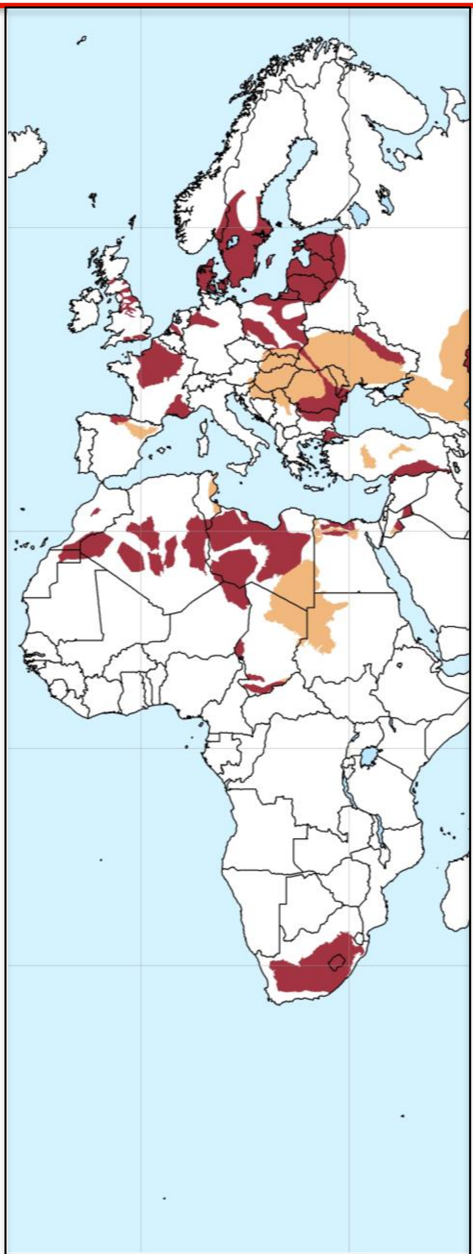
"In the past, the oil and gas industry considered gas locked in tight, impermeable shale uneconomical to produce. However, advances in ***directional well drilling*** *and* ***reservoir stimulation*** *have dramatically increased gas production from unconventional shales"* (Andrews et al., 2009).

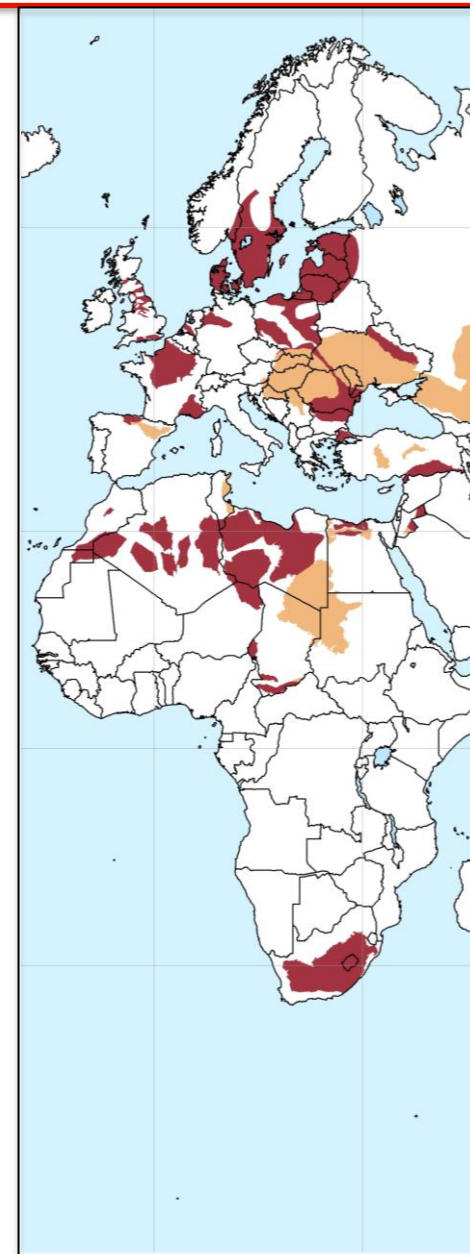
> *"When hydrocarbon resources are referred to as either conventional or unconventional, what is really being referenced is the maturity of knowledge on how to develop those reservoirs. For the last 150 yrs the oil, and later, natural gas industries have exploited high permeability reservoirs that have accumulated hydrocarbons in structural and stratigraphic traps. Now, the search for hydrocarbons includes very low permeability strata where new technologies must be employed in order to extract them at economic rates" (Moore & Friederich, 2021 (in press).*



Definition: Conventional vs Unconventional Resources

"Gas resources are commonly classified as unconventional on the basis of the geological characteristics of the source rock, the technologies required for production or some combination of the two. For example, unconventional gas is commonly defined as gas contained in rocks with a low permeability (e.g. less than 0.1 mD), but other factors such as gas saturation, rock porosity and reservoir pressure also influence the technical and economic viability of production" (McGlade et al., 2013).

"…natural gas that cannot be produced at economic flow rates nor in economic volumes unless the well is stimulated by a large hydraulic fracture treatment, a horizontal wellbore, or by using multilateral wellbores or some other technique to expose more of the reservoir to the wellbore" (Perry & Lee, 2007).



Definitions

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Although the terms shale oil[1] and tight oil are often used interchangeably in public discourse, shale formations are only a subset of all low permeability tight formations, which include sandstones and carbonates, as well as shales, as sources of tight oil production. Within the United States, the oil and natural gas industry typically refers to tight oil production rather than shale oil production, because it is a more encompassing and accurate term with respect to the geologic formations producing oil at any particular well.

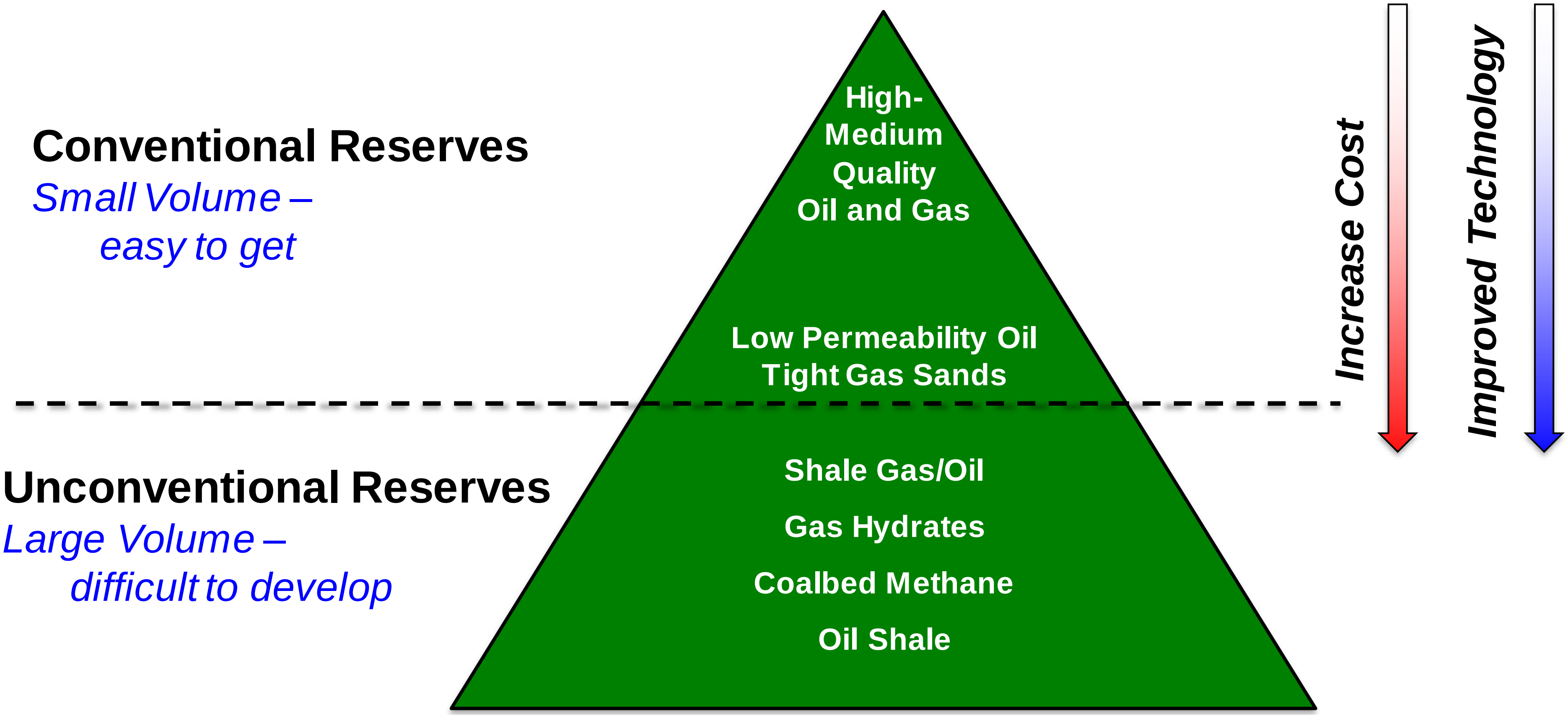
[1]This is not to be confused with oil shale, which is a sedimentary rock with solid organic content (kerogen) but no resident oil and natural gas fluids – i.e. what Canada is mining and processing

Source: US EIA, 2013

Conventional and Unconventional Resources

Conventional Reserves
Small Volume – easy to get

Unconventional Reserves
Large Volume – difficult to develop



Biggest Future Volumes of Natural Gas are Hard to Get

Source: Kristoffersen, 2010

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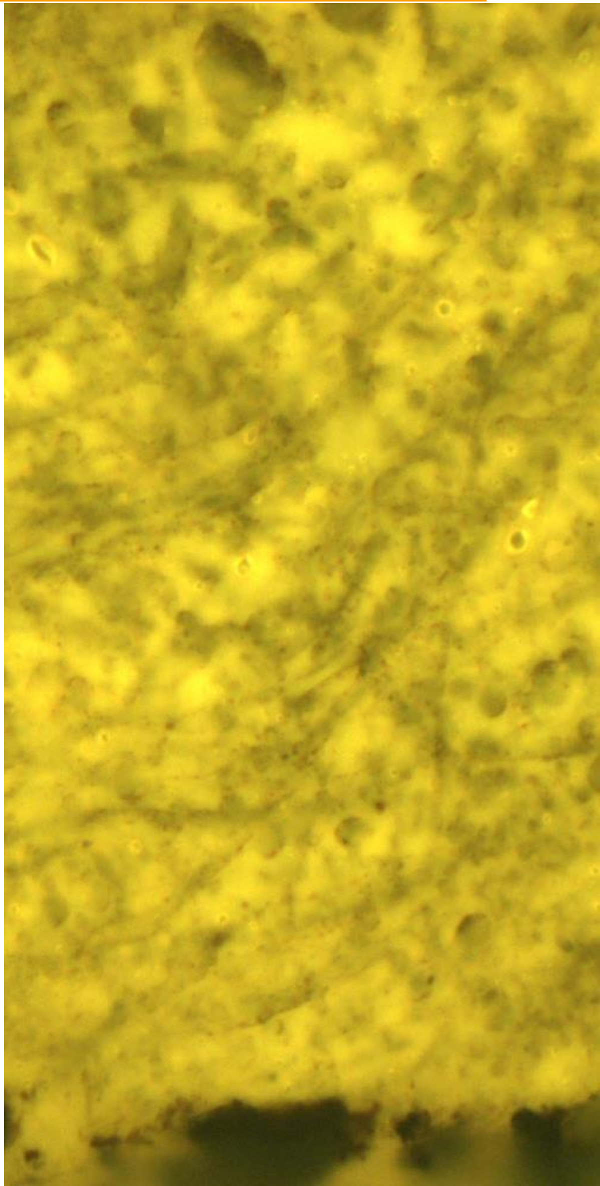
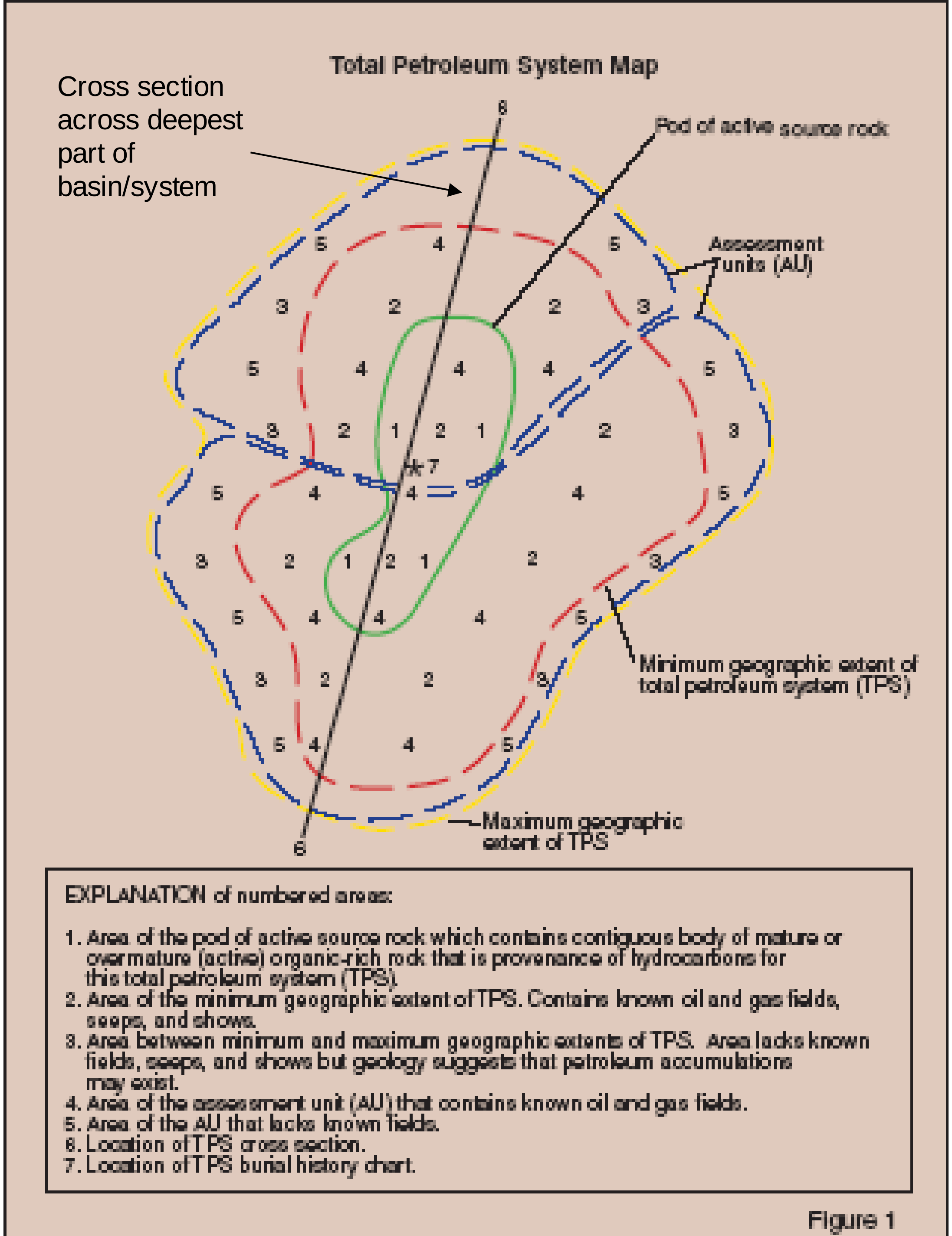




The Total Petroleum System

"the **essential elements** and **processes** as well as all genetically related hydrocarbons that occur in petroleum shows, seeps, and accumulations whose provenance is a single pod of active source rock (Magoon and Dow, 1994a)".

<u>Elements</u>

- **Source** Rock
- Reservoir Rock
- **Seal** Rock, and
- Overburden Rock

<u>Processes</u>

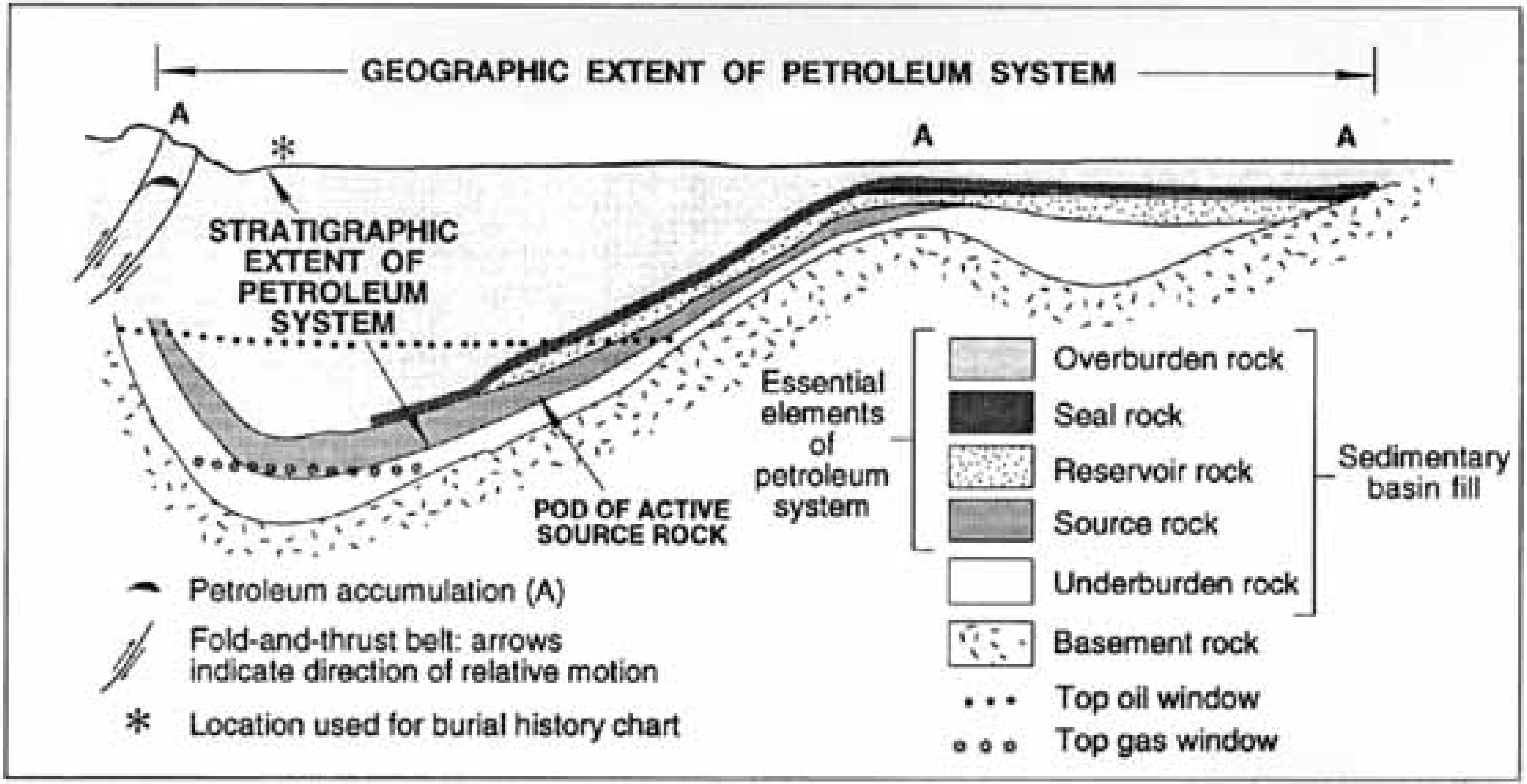
- Generation
- Migration
- Accumulation and
- **Trap** formation

"Hydrocarbon charge"

By L.B. Magoon and J.W. Schmoker, 2000 THE TOTAL PETROLEUM SYSTEM—THE NATURAL FLUID NETWORK THAT CONSTRAINS THE ASSESSMENT UNIT in U.S. Geological Survey Digital Data Series 60

http://energy.cr.usgs.gov/WEcont/chaps/PS.pdf

14 *Magoon and Dow*, **1994**



Fairway, play, etc etc etc

Source rock

•The pod of active source rock is a contiguous volume of source rock that generated and expelled petroleum at the critical moment and is the provenance for a group of genetically related petroleum shows, seeps, and accumulations in a Total Petroleum System.

•The chemically active source rock includes both the **mature and overmature** source rock. A spent source rock is overmature. The **critical moment** is the time that *best depicts the generation-migration-accumulation of hydrocarbons* in a Total Petroleum System (Magoon and Beaumont, 1999). A pod of active source rock (sometimes referred to as a **"kitchen" or "oil and gas windows")** may be active, inactive, or spent (Magoon and Dow, 1994a).

•It is identified and mapped using **thermal maturity** and **organic richness** measurements, such as **vitrinite reflectance** and results of **Rock Eval analyses** (to find out **T**otal **O**rganic **C**arbon **content (TOC)**.

Source Rock Concentrated Organic Matter (> 2 Wt% TOC)	
Humic and sapropelic components	
Sandstone	0.03%
Red shales	0.04%
Green shales	0.11-0.54%
Gray shales	1.2-3.0%
Black shales	7.0-11.0%
Limestones/Dolomites	0.2-3.2%
Calcareous shales and argillaceous limestones	4-18%
Data from Hunt, 1995	

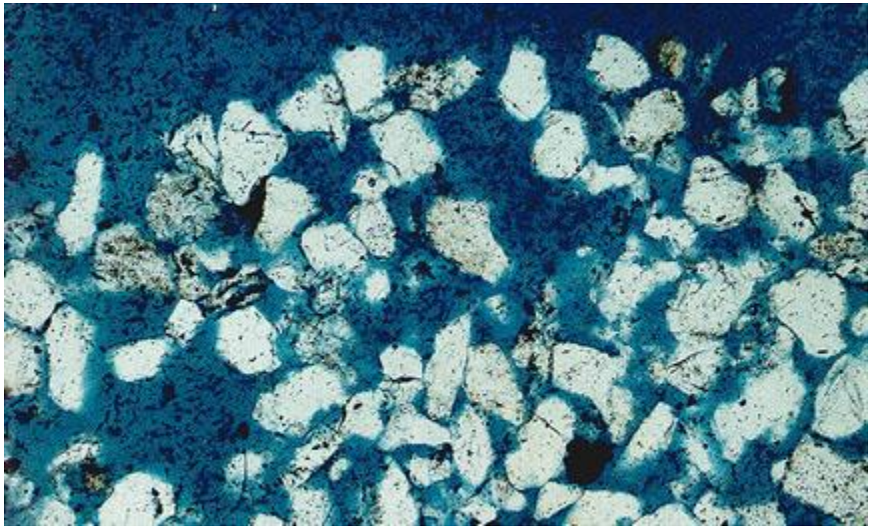
Does it matter what the composition of the organic matter is?

WHAT MAKES A GOOD RESERVOIR?

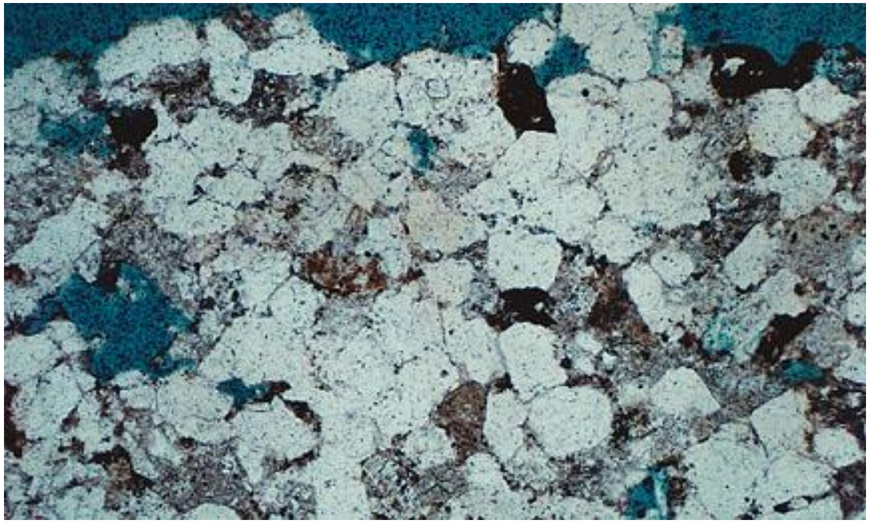
Storage Capacity (function of rock properties as well as pressure/depth)

Porous means that liquids and gas can be held and stored. The pores in rock are the spaces that occur between the individual rock particles. These spaces are created because the rock particles are irregularly shaped and so don't fit together exactly or closely together.

Permeable means that liquid can flow through. A permeable rock has pores that are connected and so allows oil and gas to flow through.



Thin section shows a conventional sandstone reservoir that has been injected with blue epoxy to highlight pore space. The pore space can be seen to be interconnected so gas is able to flow easily from the rock (porosity does not always=permeability).



Thin section of a tight gas sandstone. The pores are irregularly distributed through the reservoir and much less than the conventional reservoir. The pores are poorly connected by very narrow capillaries resulting in very low permeability. Gas flows through these rocks at generally low rates and special methods are necessary to produce this gas.

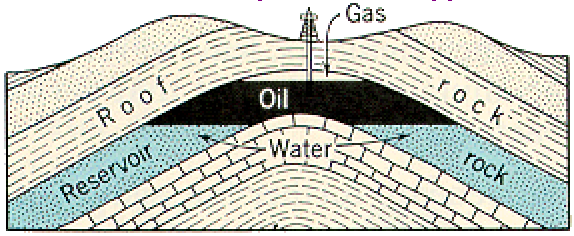
http://energy.usgs.gov/factsheets/Petroleum/reservoir.html

TRAPS AND SEALS

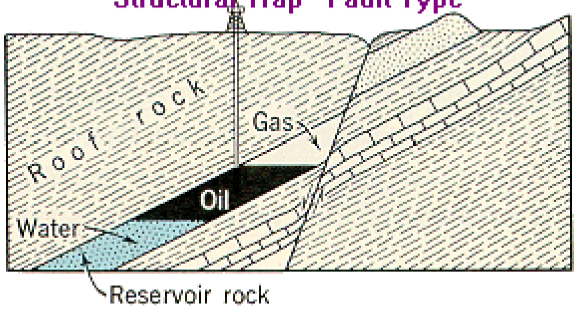
The impermeable layer is called a **seal**.

A trap can occur where rocks have been pushed or folded by the powerful forces within the Earth's crust. When this happens- this is known as an anticline trap. The impermeable rock traps the crude oil preventing it from flowing away - like an upturned bathtub.

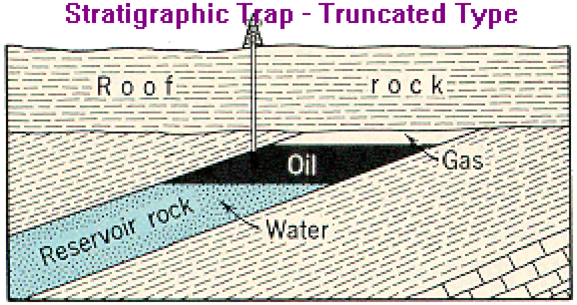
Structural Trap - Anticline Type



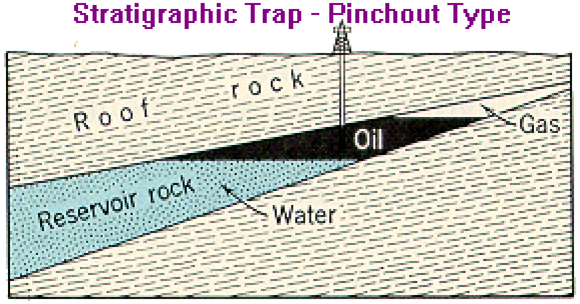
Structural Trap - Fault Type



Stratigraphic Trap - Truncated Type



Stratigraphic Trap - Pinchout Type



STRUCTURAL TRAPS

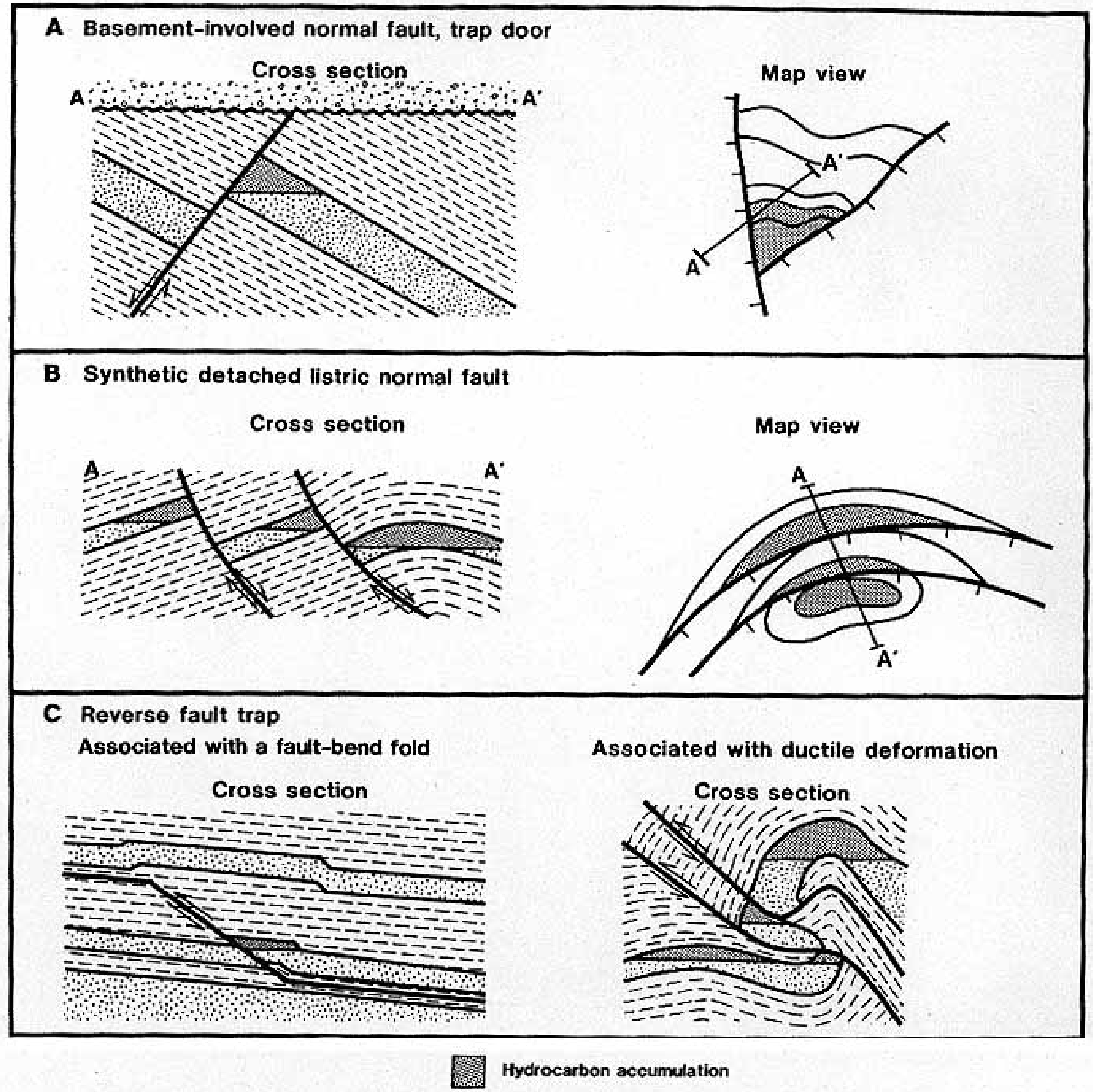


Figure 13.6. Types of traps in which faulting dominates the reservoir–seal interval. (A) Basement-involved normal fault trap and trap door. (B) Synthetic detached listric normal fault traps. (C) Two types of reverse fault traps. (D) Strike-slip fault traps.

Outline of Lecture

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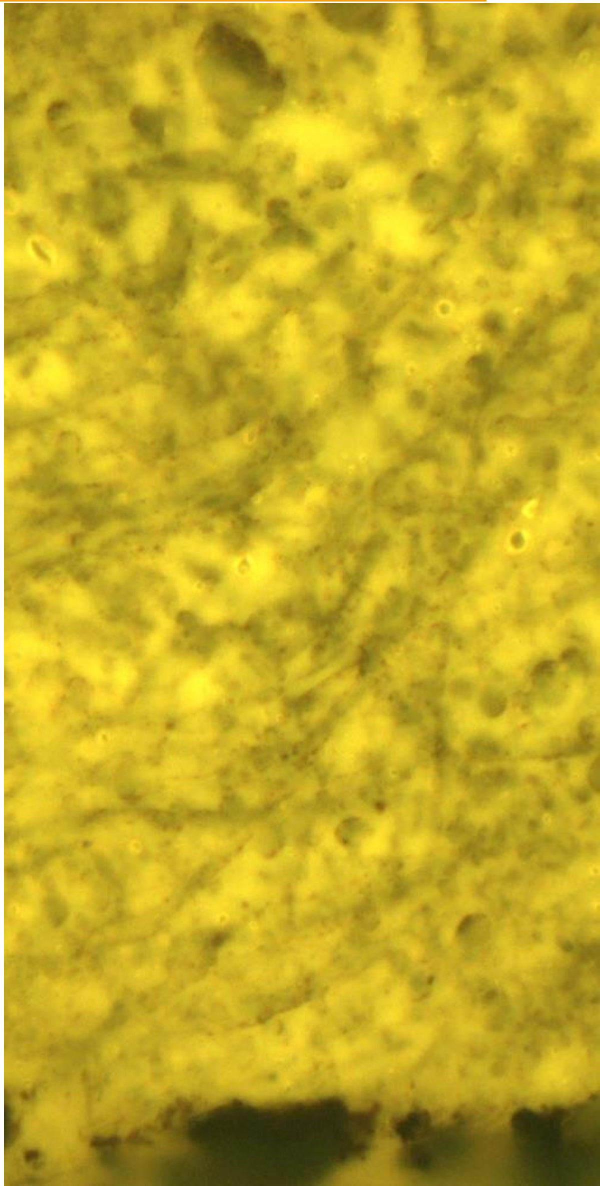

World Basins with Shale Gas and Shale Oil

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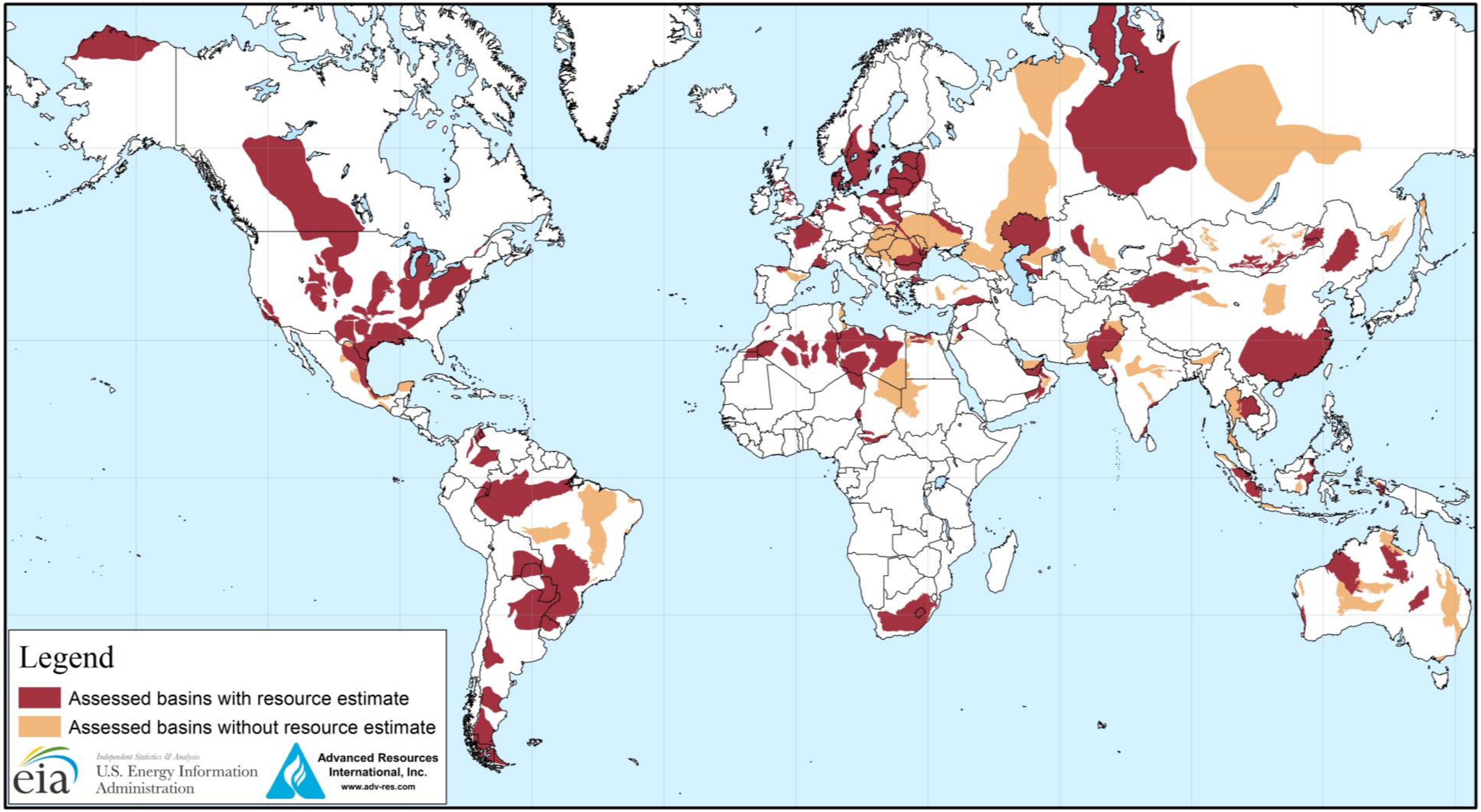

Source: US EIA, 2013

Definitions

Almost all Unconventional Require Special Treatments

- **Horizontal Well**

  - drill holes which may start out vertically but then turn horizontal and drill parallel within a single rock unit

- **Hydraulic Fracturing ('Fracs')**

  - Using water or other liquid to cause fractures in a rock layer; these fractures allow gas to flow to the well. Without these fractures the layer will have too low permeability and gas will not flow

- **Proppant**

  -sand-sized quartz or artificially produced material which is injected into the fractures of a rock layer to keep them from closing up

CBM gas flare, New Zealand
Photo by T.A. Moore 2005

Lateral/Horizontal Production Wells

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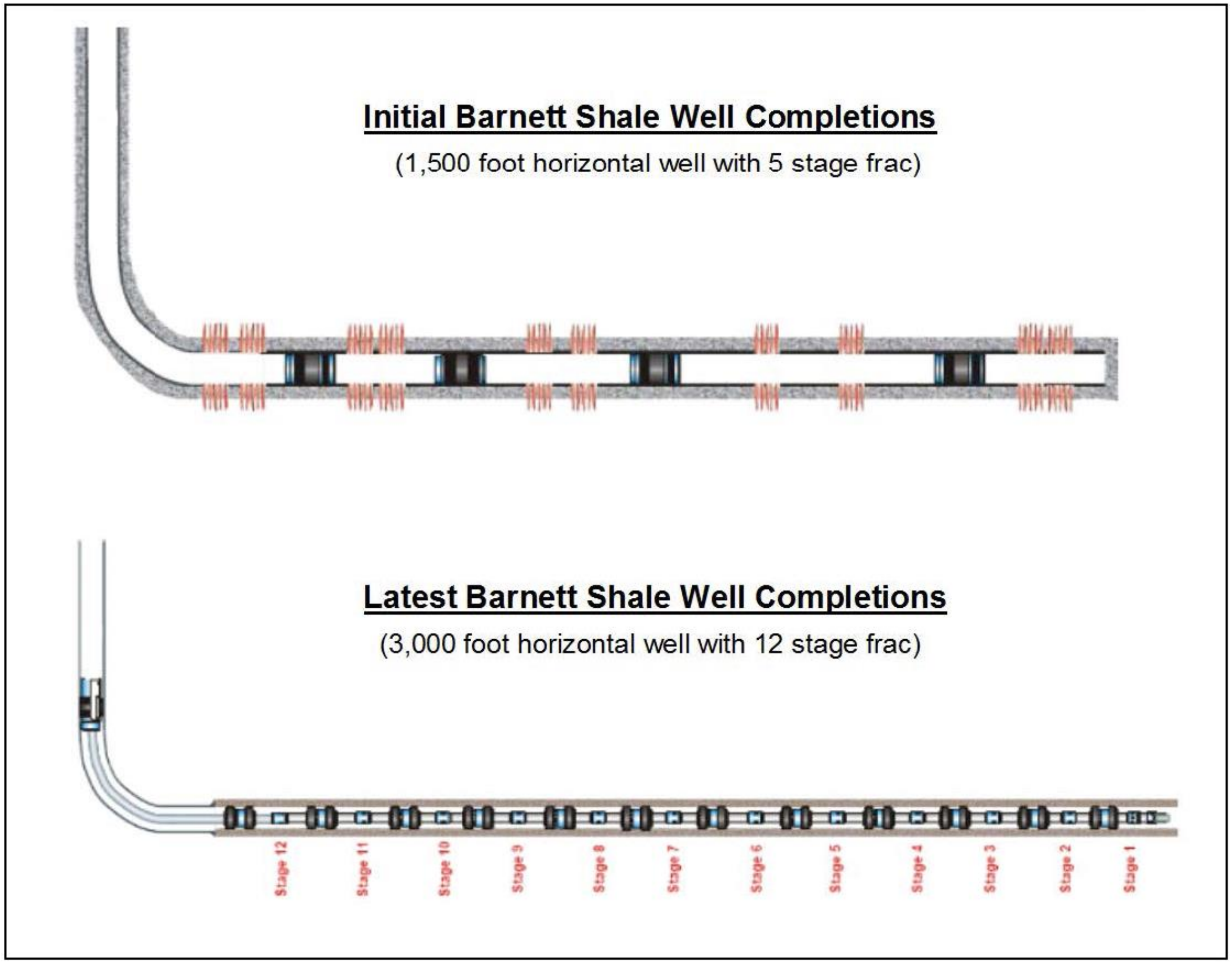
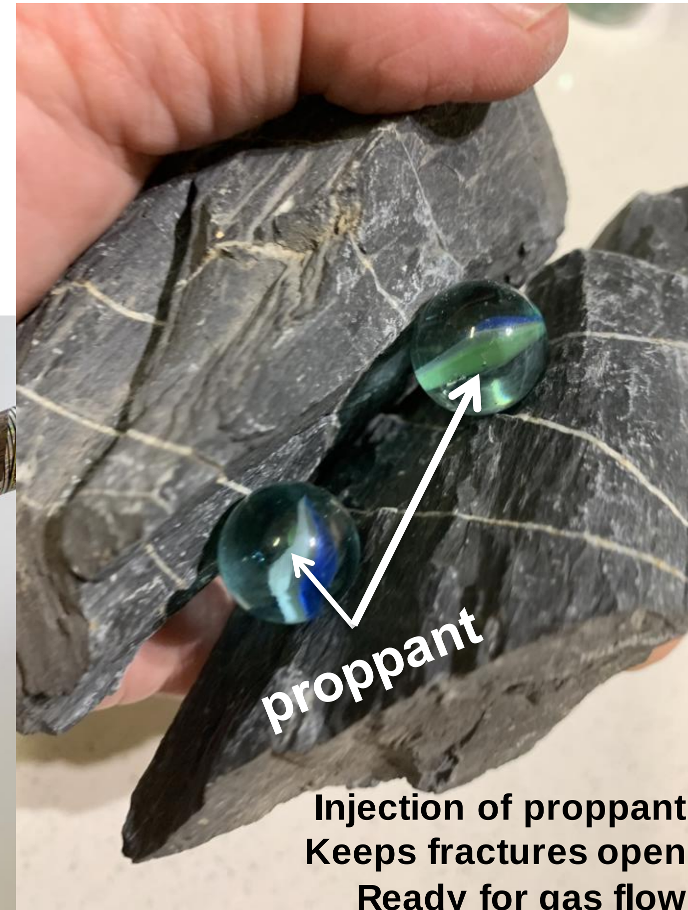
Horizontal Drilling and Fracture Stimulation



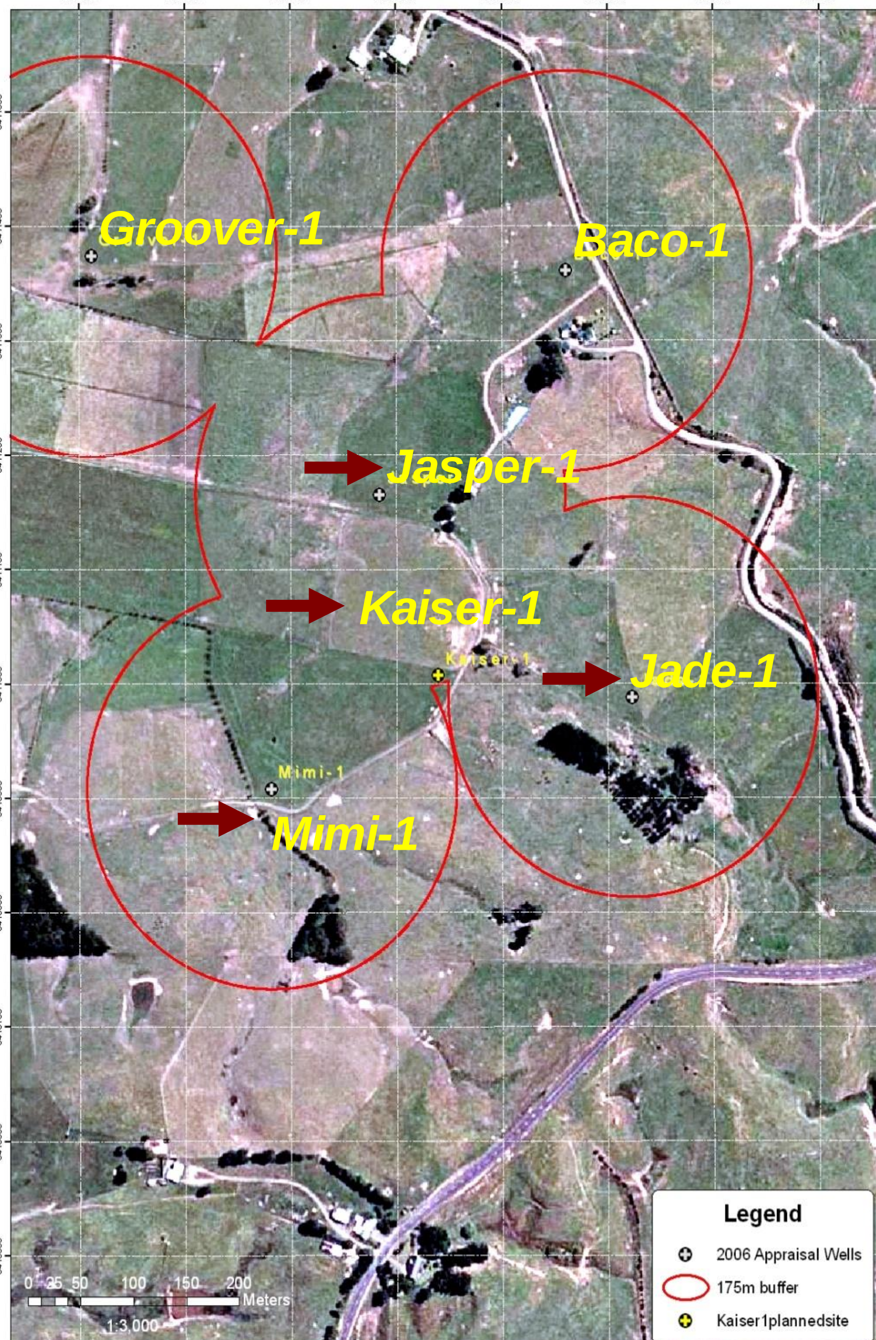
Source: US EIA, 2013

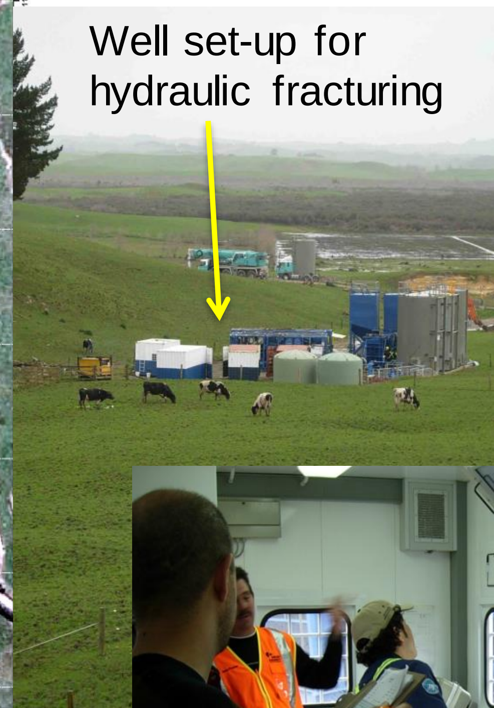
Fracture Stimulation & Proppant



Open fracture system
Allows gas to flow

CBM Fracture Stimulation





- 4 of 6 wells
- Sand proppant
- 7 days to execute
- All wells felt each frac
- Water flow:
    - 15 bbl/day pre frac
    - 220 bbl/day post frac

All photo of New Zealand; T.A. Moore 2005

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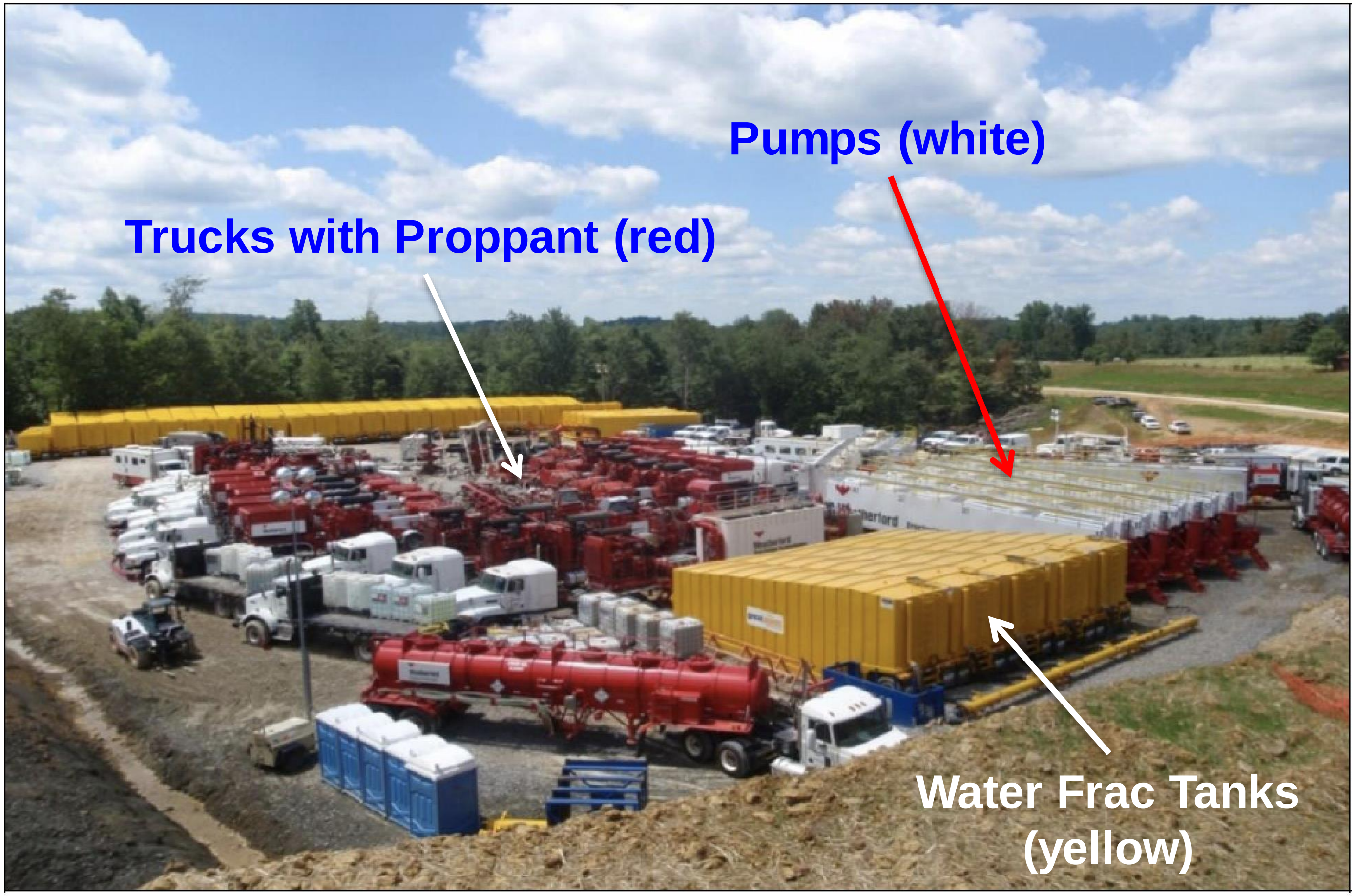
Hydradraulic Fracturing is Key to Unconventional Resources

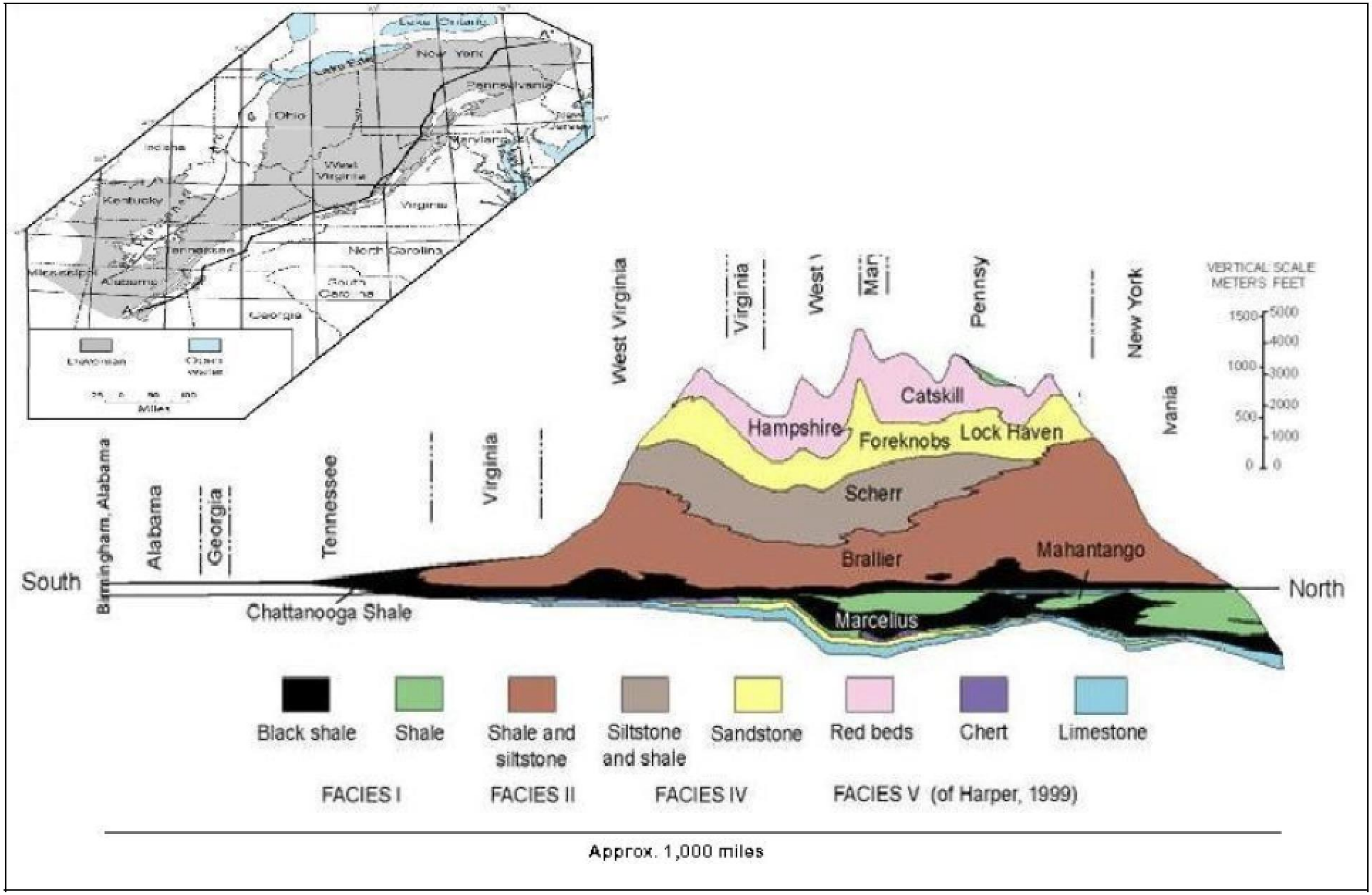
Marcellus Shale Well, West Virginia, USA



Source: Chesapeake Energy, 2008

Large Footprint for Shale Oil/Gas

Distribution of Unconventional Resources have to LARGE

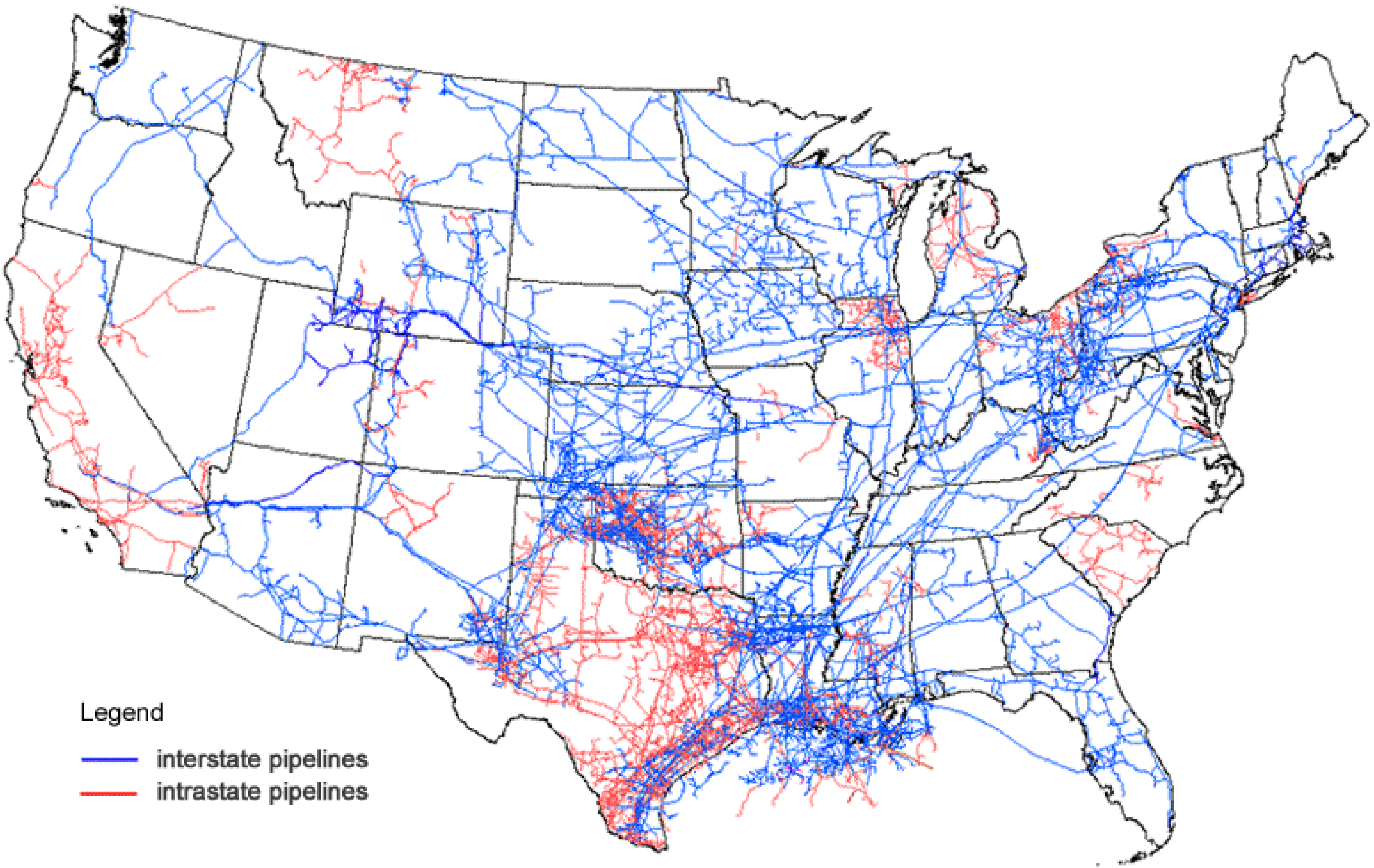


Source: Compiled from USGS Open File Report 200-1268, 2005.

Oil Shale Mining - Canada

Pipelines in the USA – *Key* to Unconventional Resources

Map of U.S. interstate and intrastate natural gas pipelines



Source: U.S. Energy Information Administration, *About U.S. Natural Gas Pipelines*

Pipelines in the USA – *Key* to Unconventional Gas Resources

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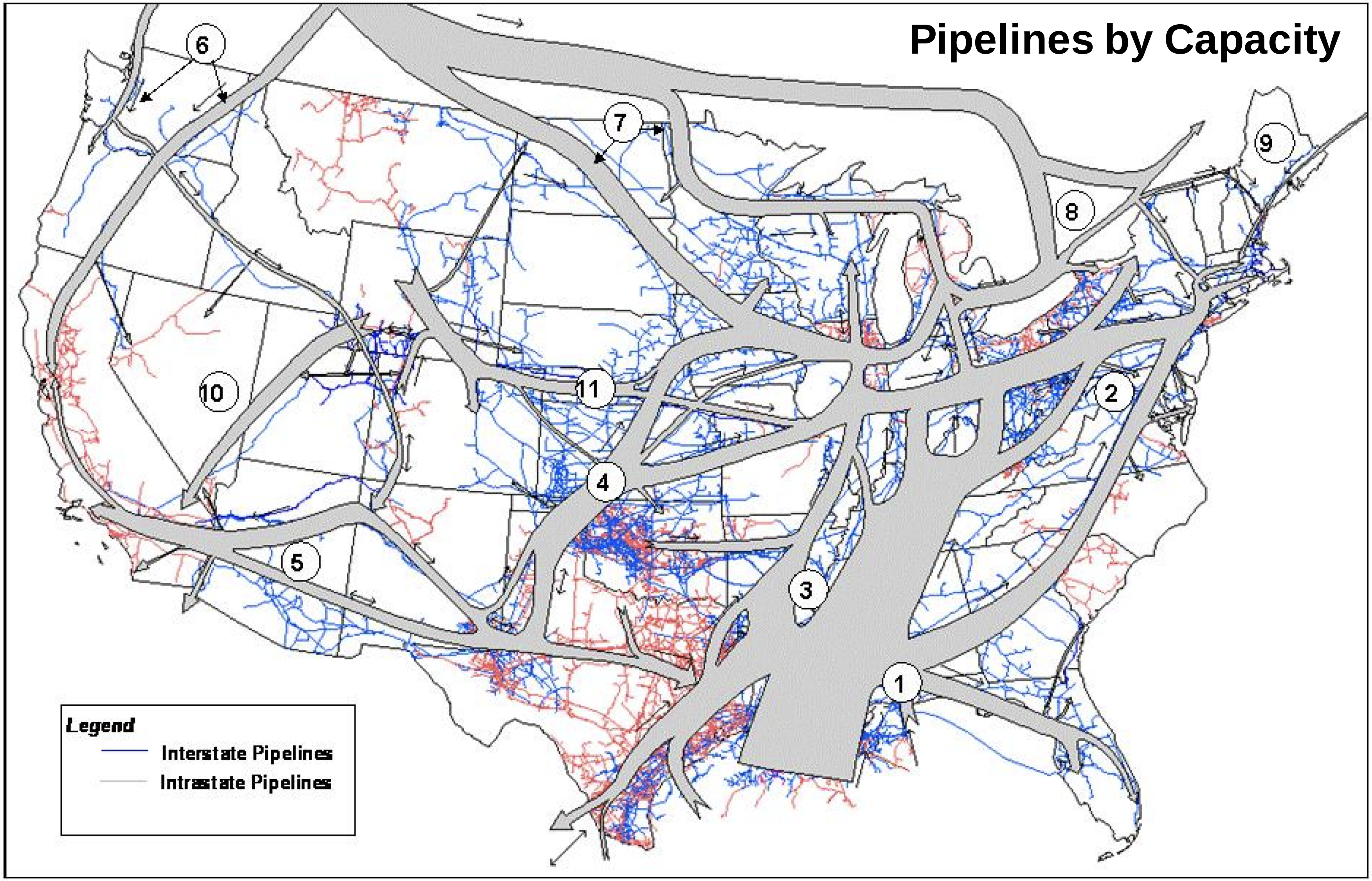
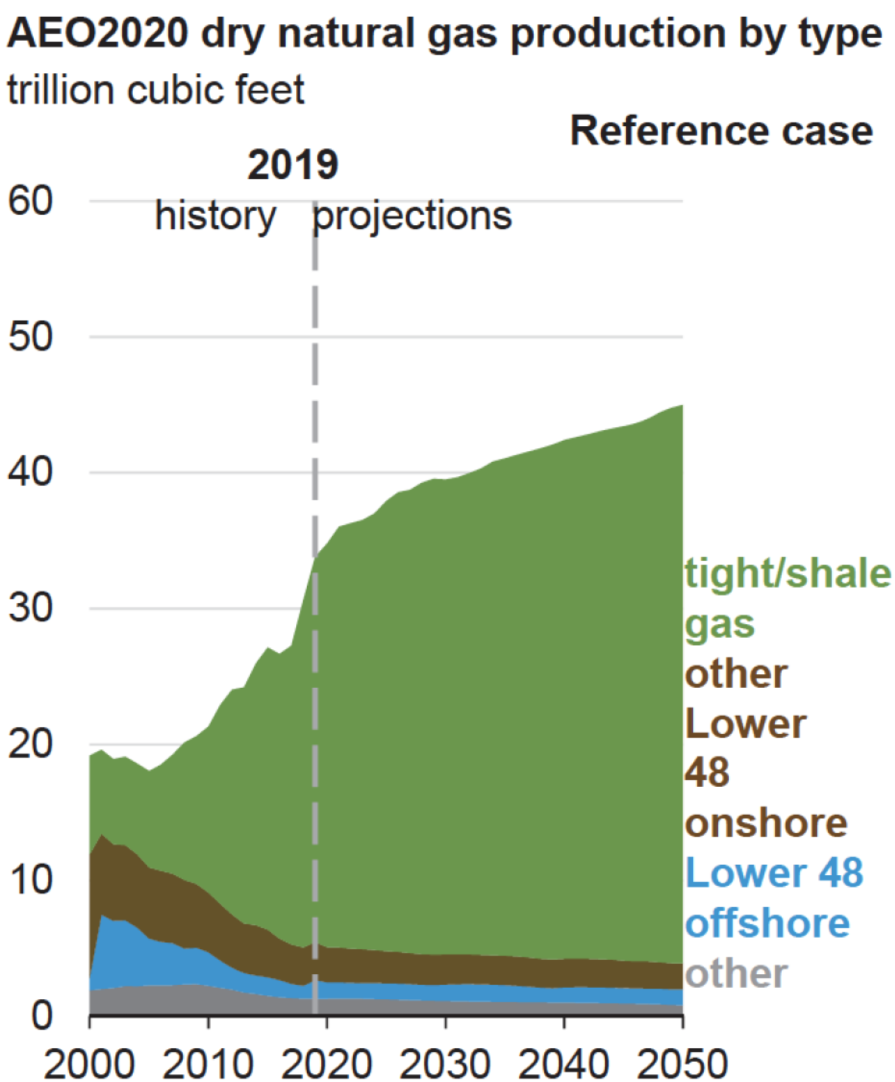


Why Are These Resources Important?

Shale Gas



Source: EIA Energy Outlook 2020

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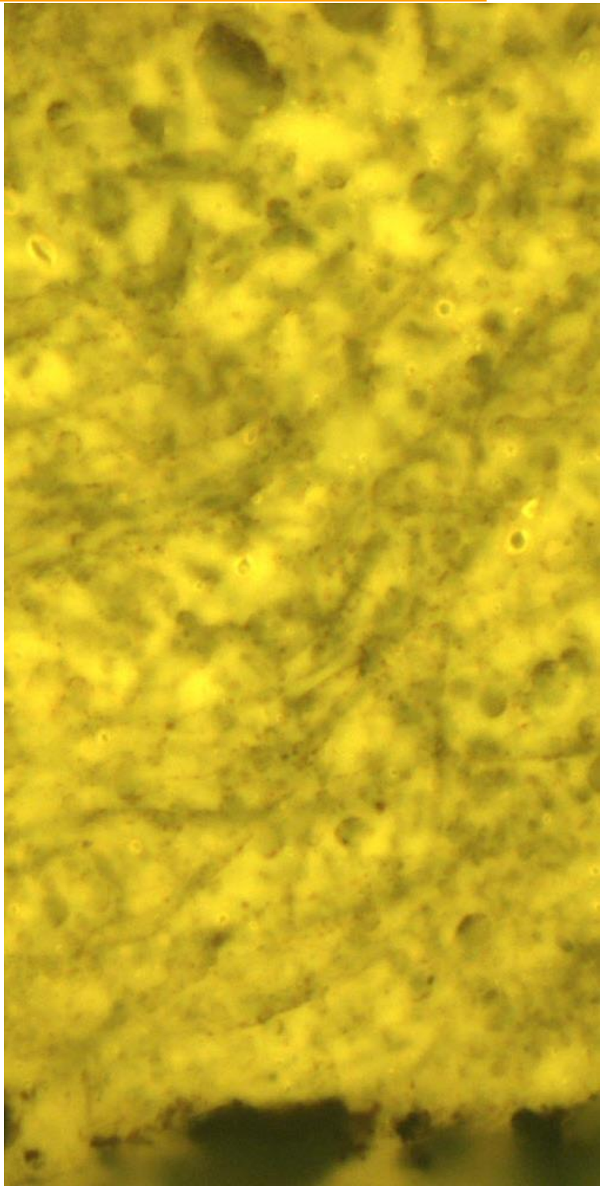


Why are both CBM & Shale Gas termed 'unconventional resources'?

Shale Gas

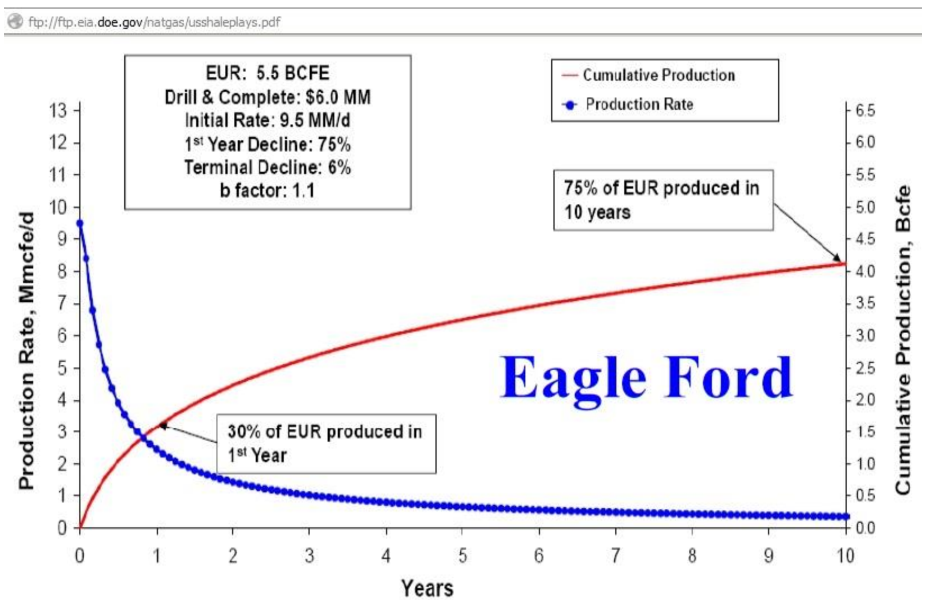
- Tight (low perm)
- Source & Reservoir
- Gas held within pores of both organic & clastic grains

Coalbed Methane

- Tight (low perm – mostly!)
- Source & Reservoir
- Gas held within pores of organic grains

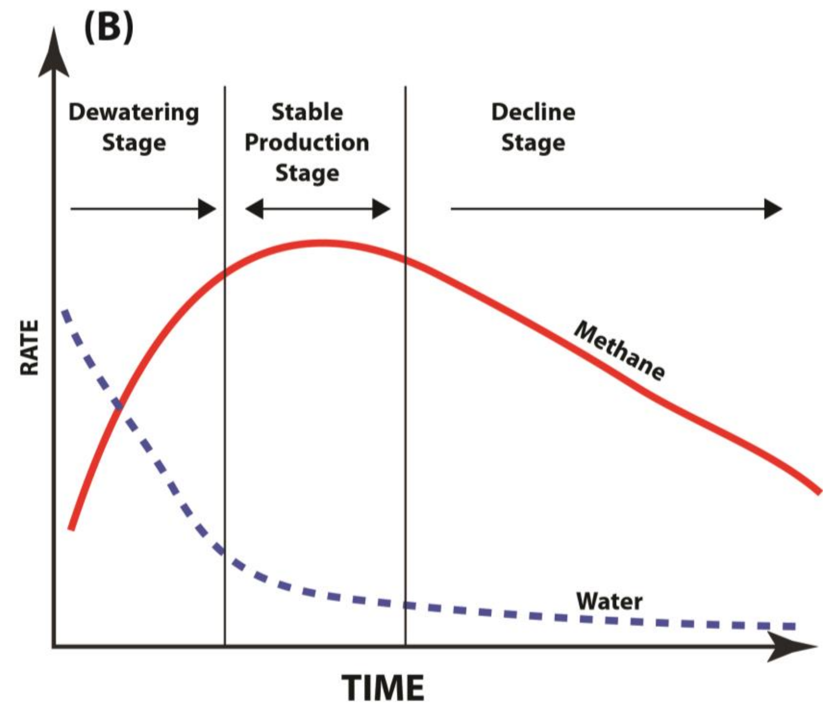
Production Profiles

Shale Gas



- Steep decline in production from first day of gas production

Coalbed Methane



- Gradual increase in gas, with dewatering, then peak, then slow decline

Definitions

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Coalbed Methane:

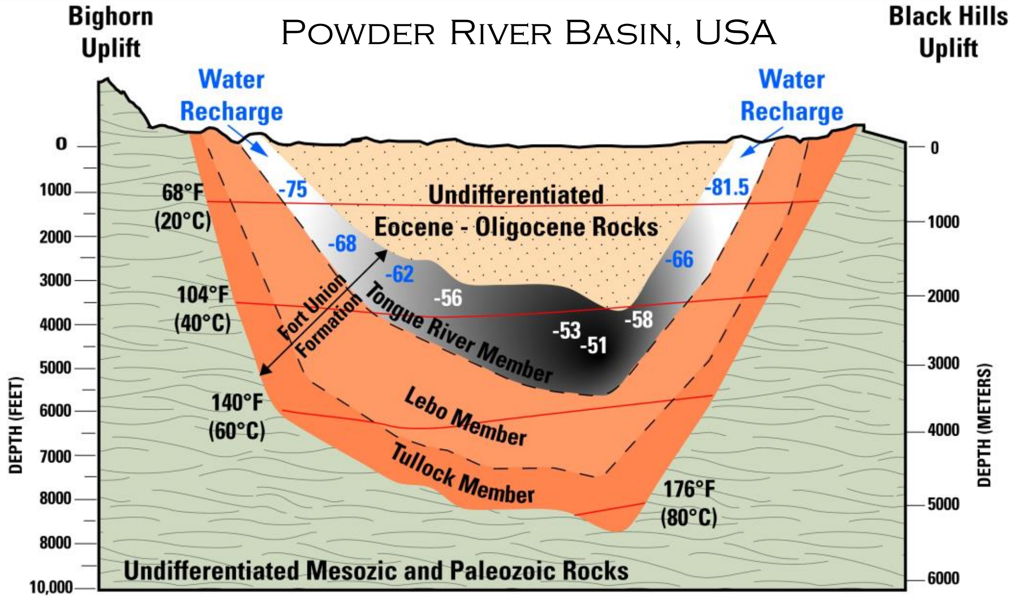
Naturally occurring methane that forms from the organic materials from the coal and is stored within the coal. Thus the coal is both the source and reservoir. The gas can be formed biogenically or thermogenically. The gas is stored primarily through adsorption on to the coal surface within micropores. CBM is always thought of as an 'unconventional petroleum system'.

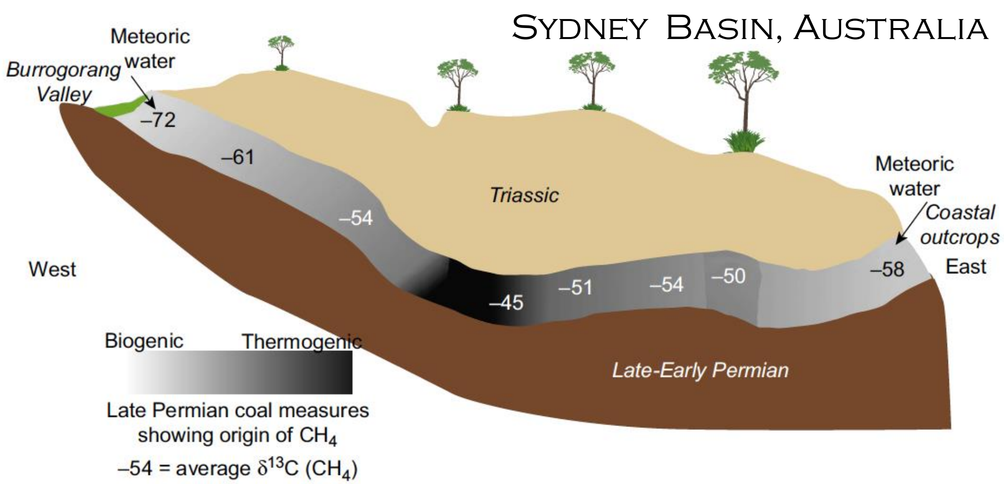
Shale Gas:

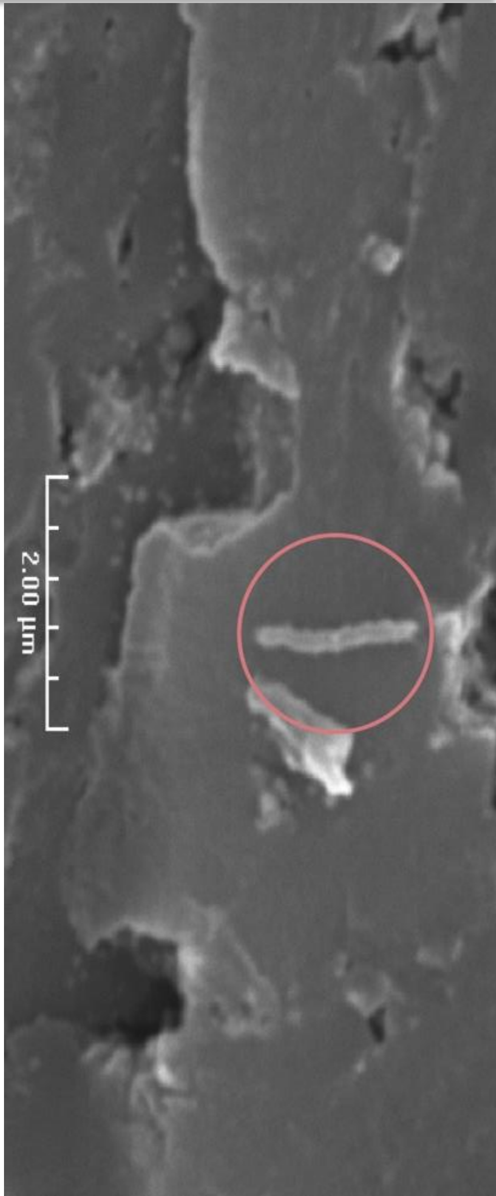
Also naturally occurring methane (commonly with some proportion of C_4H_{10}, C_2H_6, and C_3H_6) that is present in organic-rich shale and associated lithologies. The gas is thought to be primarily sourced in situ from organics but stored in both organic and inorganic porosity systems. Shale gas can be part of a petroleum system with both unconventional and conventional gas accumulations.

Definitions – Coalbed Methane

Biogenic







Modified from Flores et al. (2008); Faiz & Hendry (2006); Flores (2013)

Definitions – Coalbed Methane

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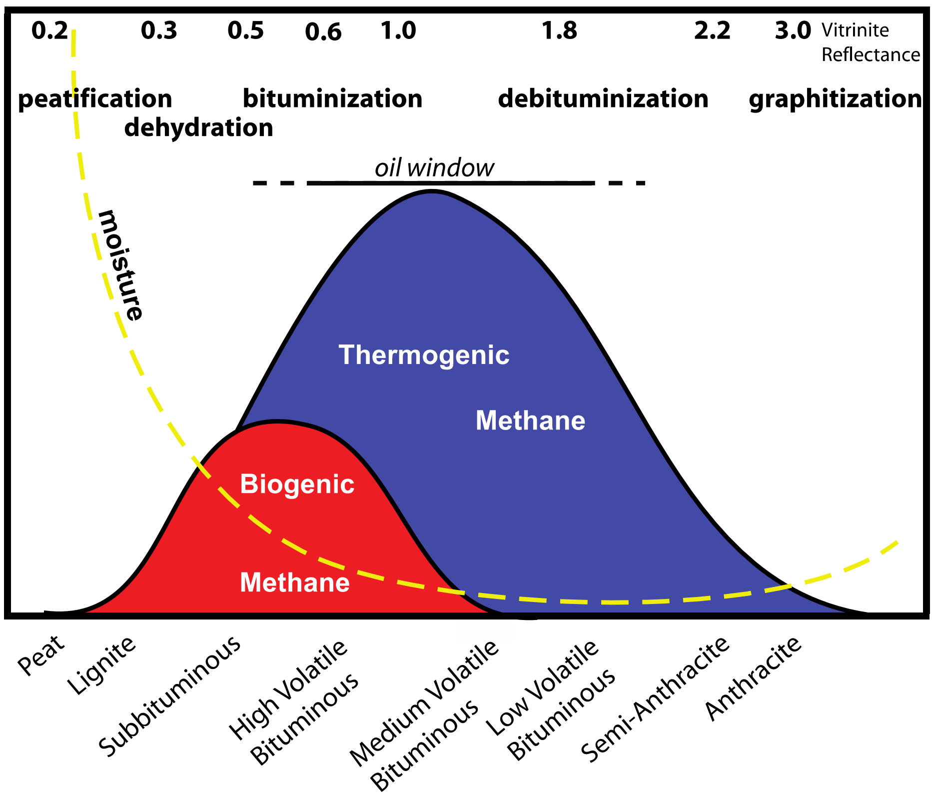
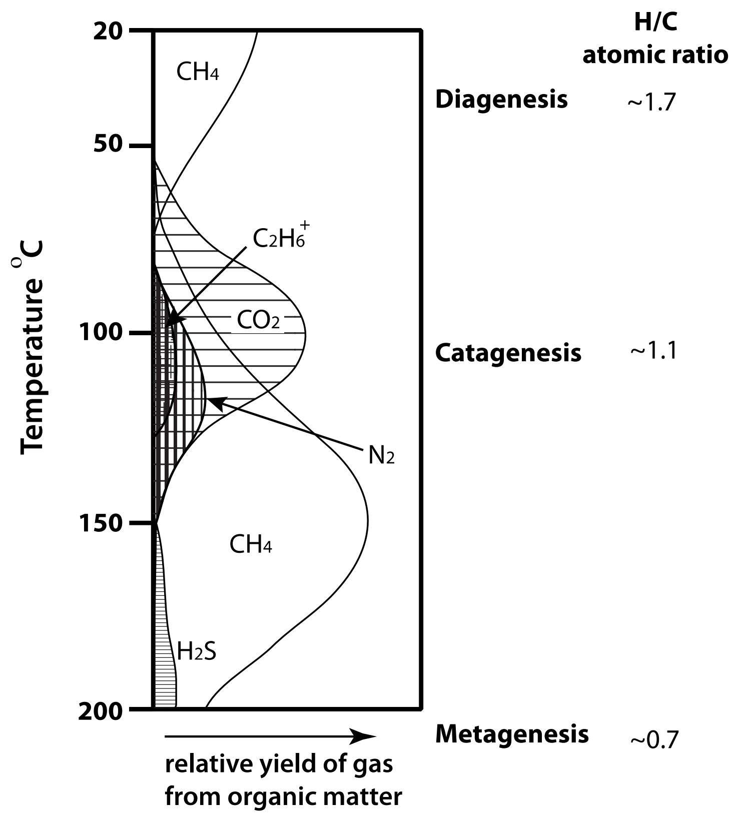
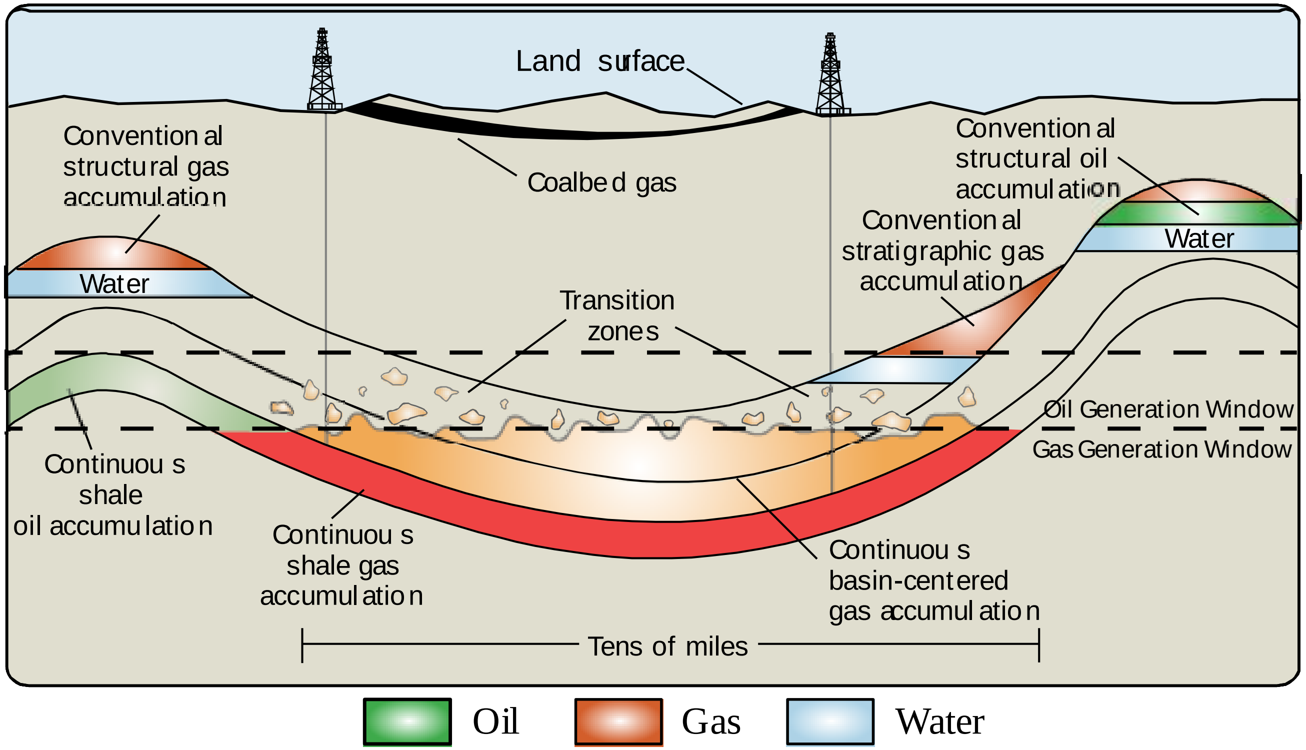
Thermogenic





modified from Hunt (1979) and Moore (2012)

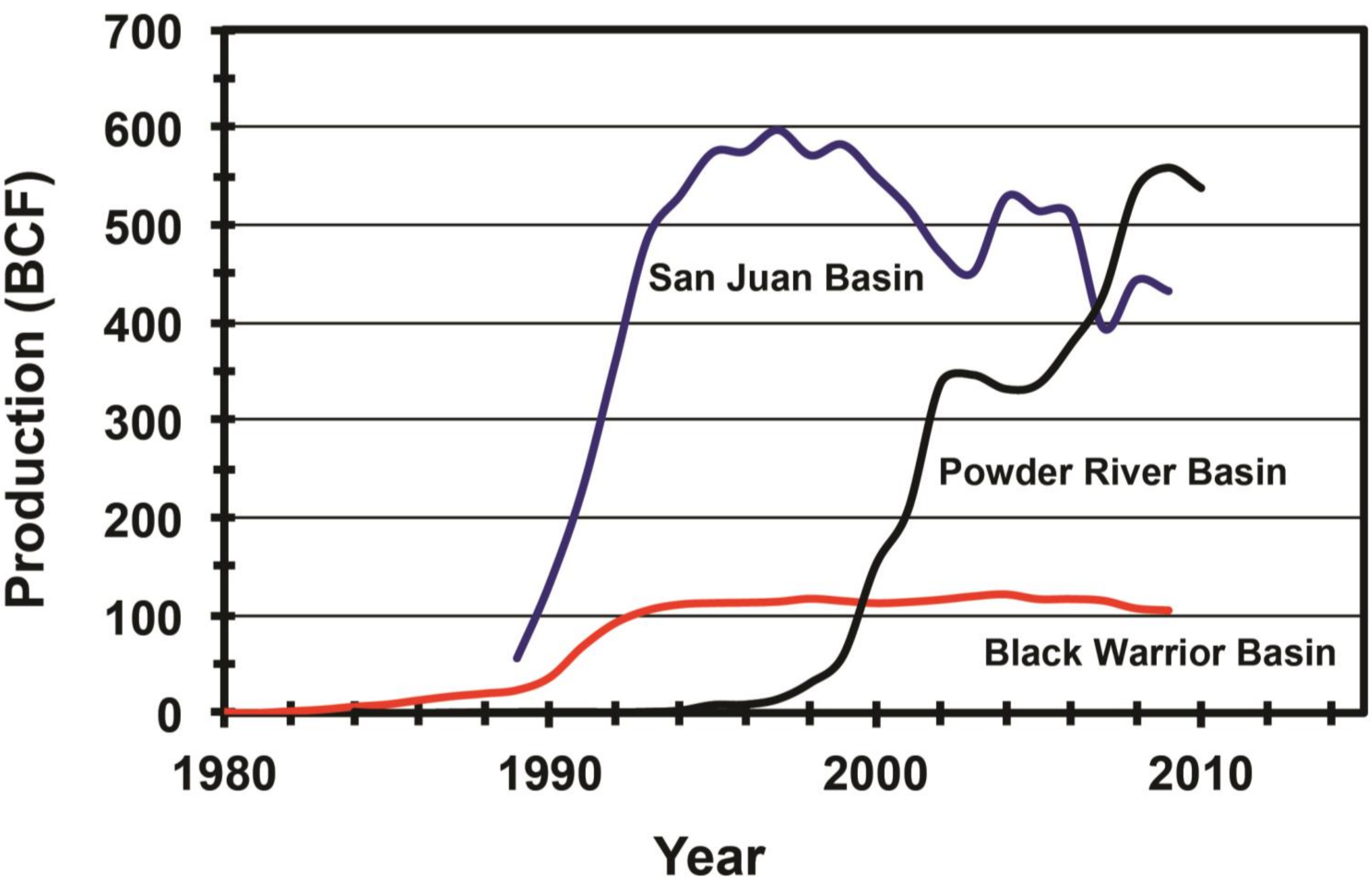
Definitions – Shale Gas



Modified from Charpentier & Ahlbrant (2003)

Why Are These Resources Important?
Coalbed Methane

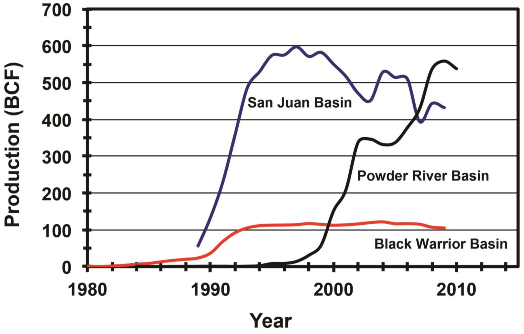
Coalbed Methane Production in the USA



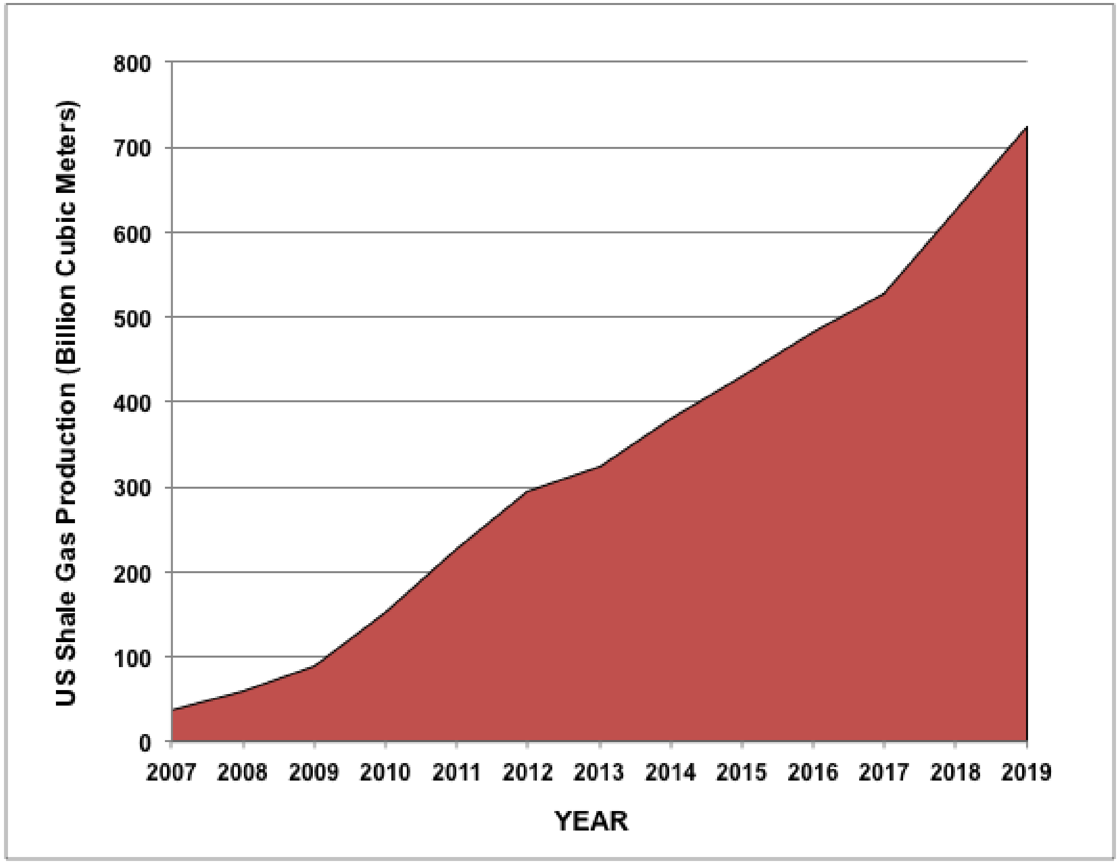
Modified from Moore

Why Are These Resources Important?
Coalbed Methane

- **Economic consequences:**
  - **Additional ‘dry’ gas supply**
  - **Relatively cheap discovered gas costs**
  - **Significant additional royalty tax for key US and Australian states**
- **Why did production come on line so fast?**
  - **Early tax incentives for exploration and development (Powder River Basin)**
  - **Government mandate on gas usage (Australia)**
  - **Clear regulatory regime, government leadership (USA & Australia)**



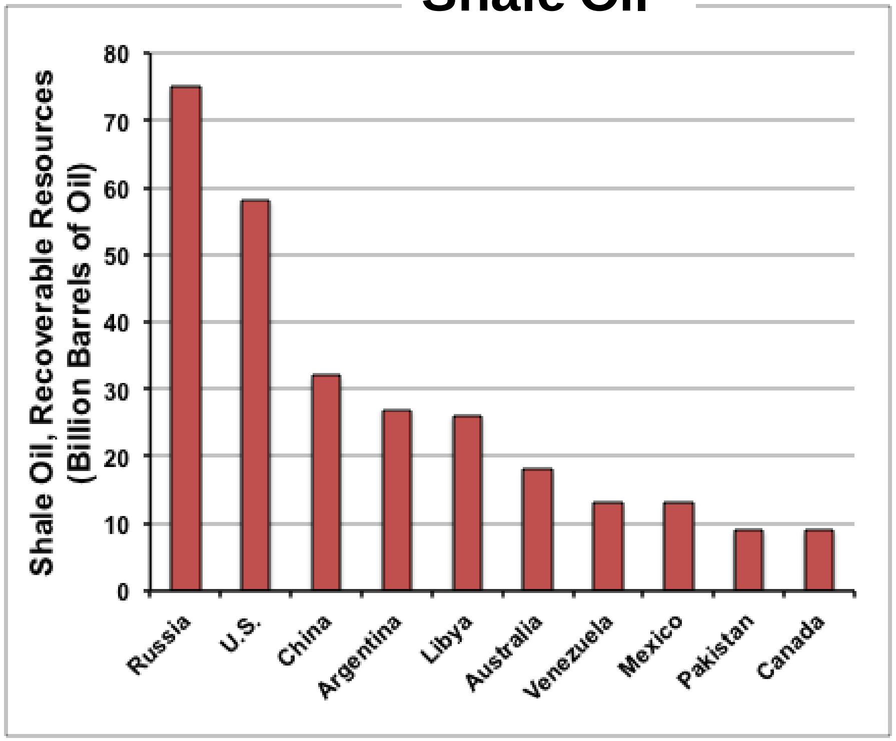
US Shale Gas Production 2007 - 2019



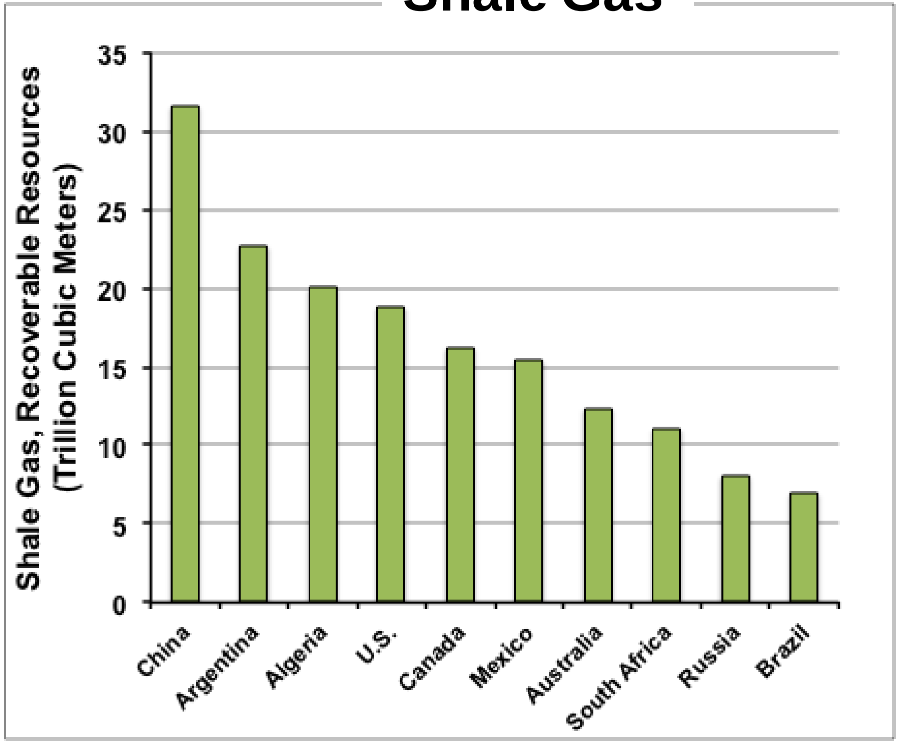
Shale Gas well, Powder River Basin, Wyoming (USA)
photo: T.A. Moore 2016

Recoverable Resources

Shale Oil



Shale Gas



Source: US EIA, 2013

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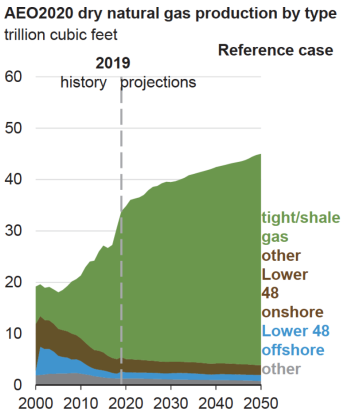
Why Are These Resources Important?
Shale Gas:

- **Economic consequences:**
  - **Decoupling of O&G market prices,**
  - **Electrical generation from coal fell,**
  - **Price of natural gas fell.**

- **Why did production come on line so fast?**
  - **Established regulatory framework & a physical infrastructure,**
  - **Private ownership,**
  - **Very competitive service industry,**
  - **Large domestic frack sand resource,**
  - **Few political obstacles.**




D. Duncan, USGS, 2010

Character of a Good Play

Coalbed Methane:

- Reservoir depths <500 m, best <400 m
- Permeability >50 mD
- Gas saturations >60%
- Coal bed thickness >10 m for low rank coals, >2 m for higher rank coals
- Low ash (<10%, ideal)
- Non-complex geology
- Area of recharge for biogenic enhancement
- Easy, inexpensive water disposal/treatment options
- Access to infrastructure/market

Character of a Good Play

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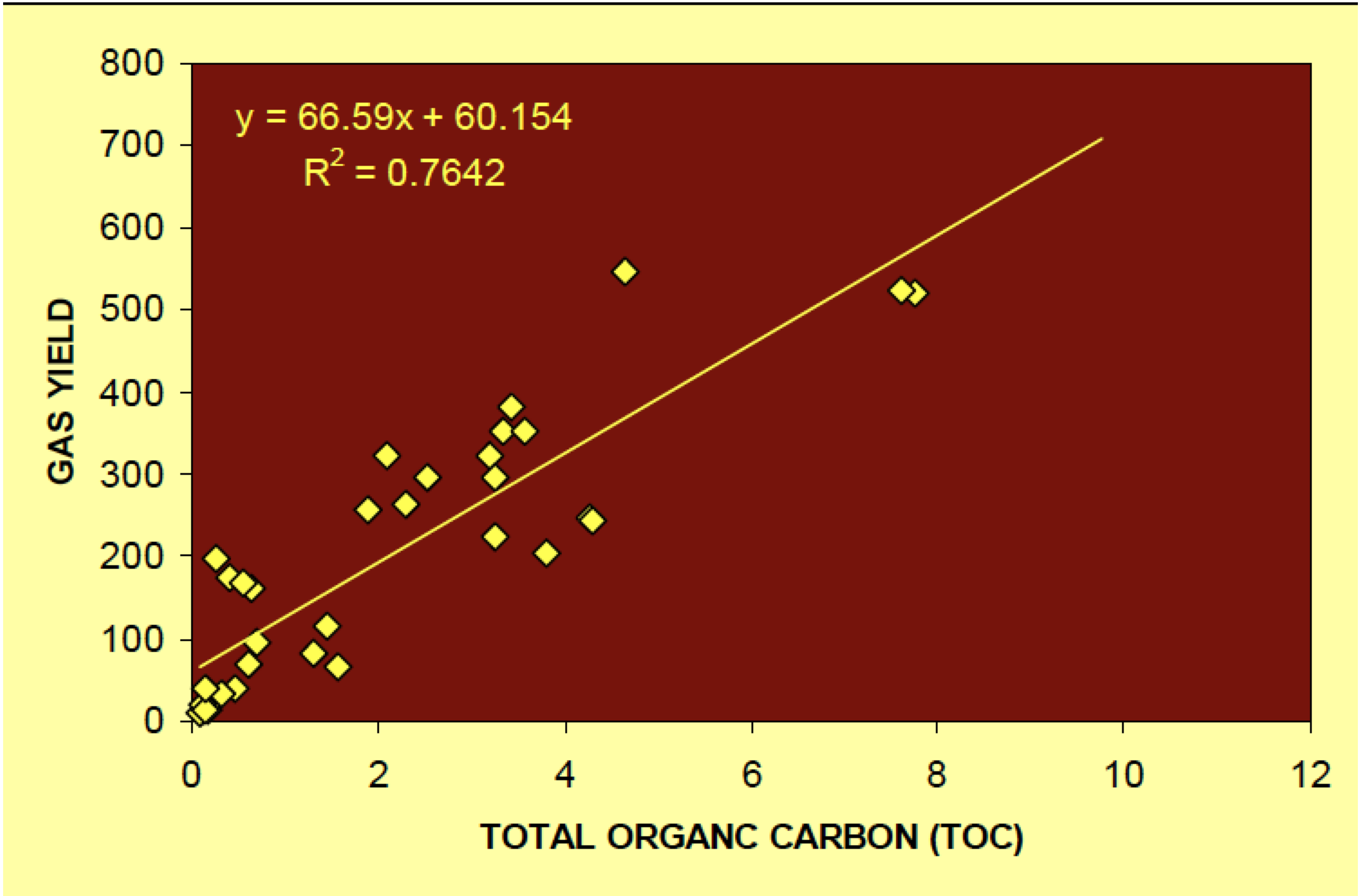
Shale Gas:

- High gas-in place content
- Permeability (> 100 nD)
- Organic richness (>2% TOC)
- Thermal maturity (>1.1 $\%R_o$, over mature oil-prone source rocks)
- Porosity (>4%)
- Water saturation (<45%)
- Oil saturation (<5%)
- Clay content and clay type (<50% clay)
- Quartz (>50%, recrystallized opaline best)
- Extensive thickness and areal extent
- Depth (>1,000 m)
- Non-complex geology

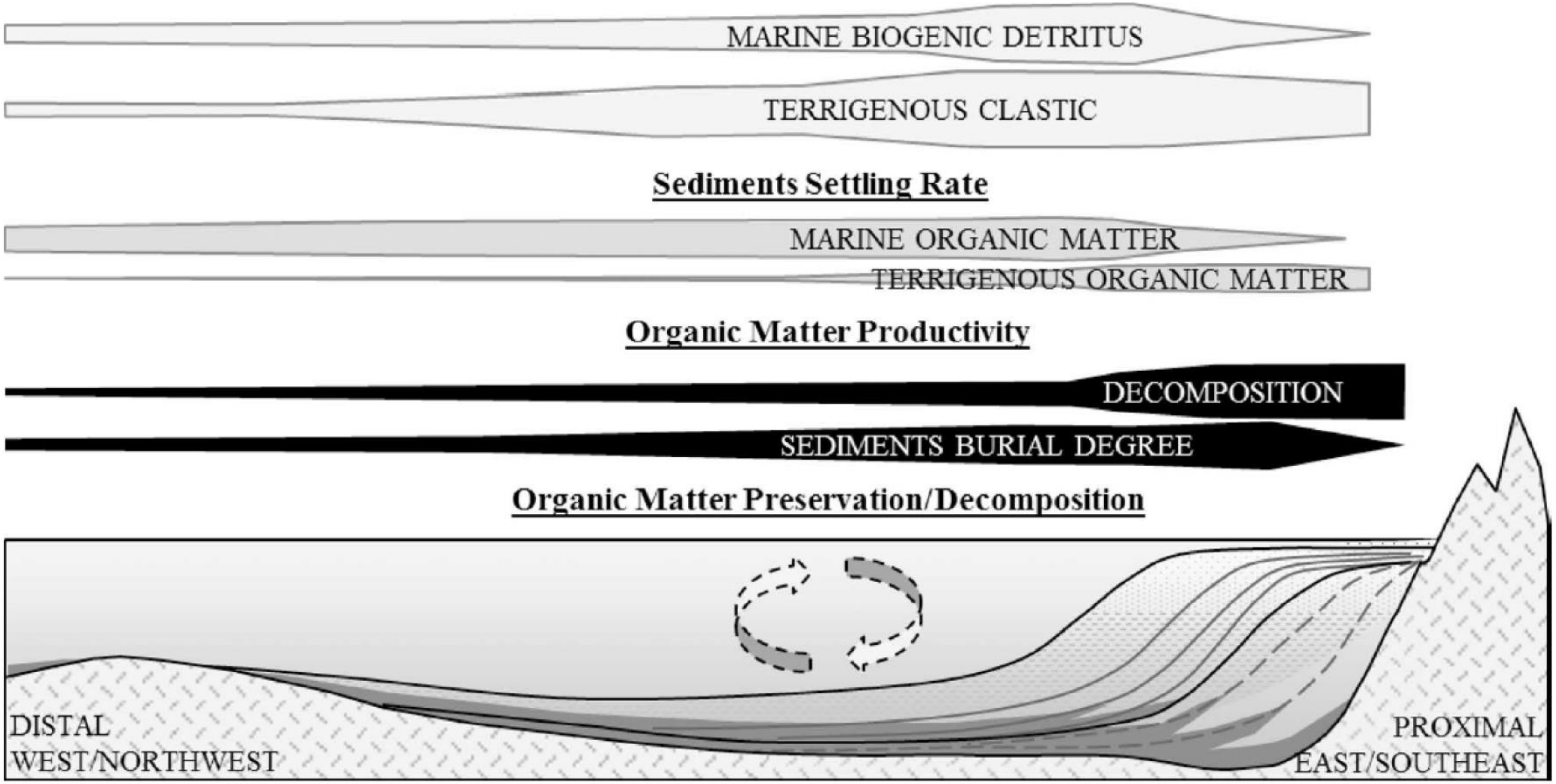
Organic Material vs. Gas Volume



Source: Jarvie, 2004

Spatial Variability of Organic Matter in a Basin

…relevant to shale gas and oil shale

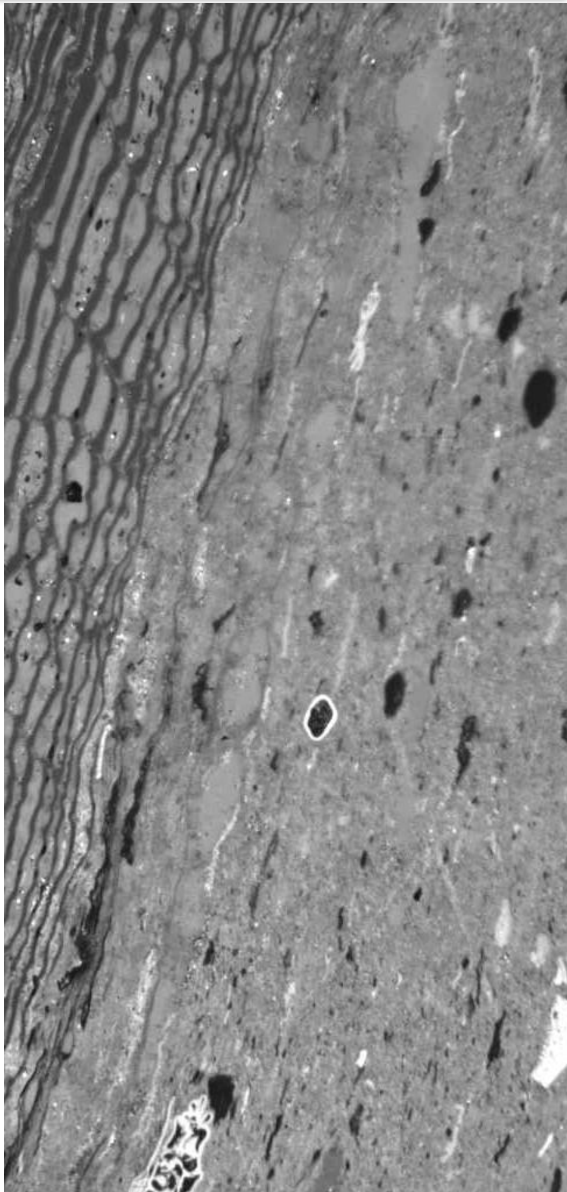


Wang & Carr, 2013

Importance of Pores: CBM

€ipher

- It's the surface area of the pores which control gas holding capacity
- Thus, its better to have smaller, more abundant pores, than fewer larger ones
- Most gas is thought to be held in the microporosity (< 2 um) … or smaller…
- The greater number of pores also increases diffusion rate of methane through the matrix
- Porosity can be either 'open' or 'closed', with the latter perhaps not contributing to recoverable gas resources.



Importance of Pores: Shale Gas

€ipher

- It's the nanoporosity (1-500 nm) in bitumen or other organic material that controls most of the gas storage in producing shale formations.
  - Although some pores are in inorganic material (e.g. clay and pyrite)
- Nanoporosity results from exsolution of gaseous hydrocarbons during thermal cracking of oil.
- Porosity can be either 'open' or 'closed', with the latter perhaps not contributing to recoverable gas resources.
- Porosity and bulk gas volumes are often related to TOC content.

Influences on Pores for Shale Gas

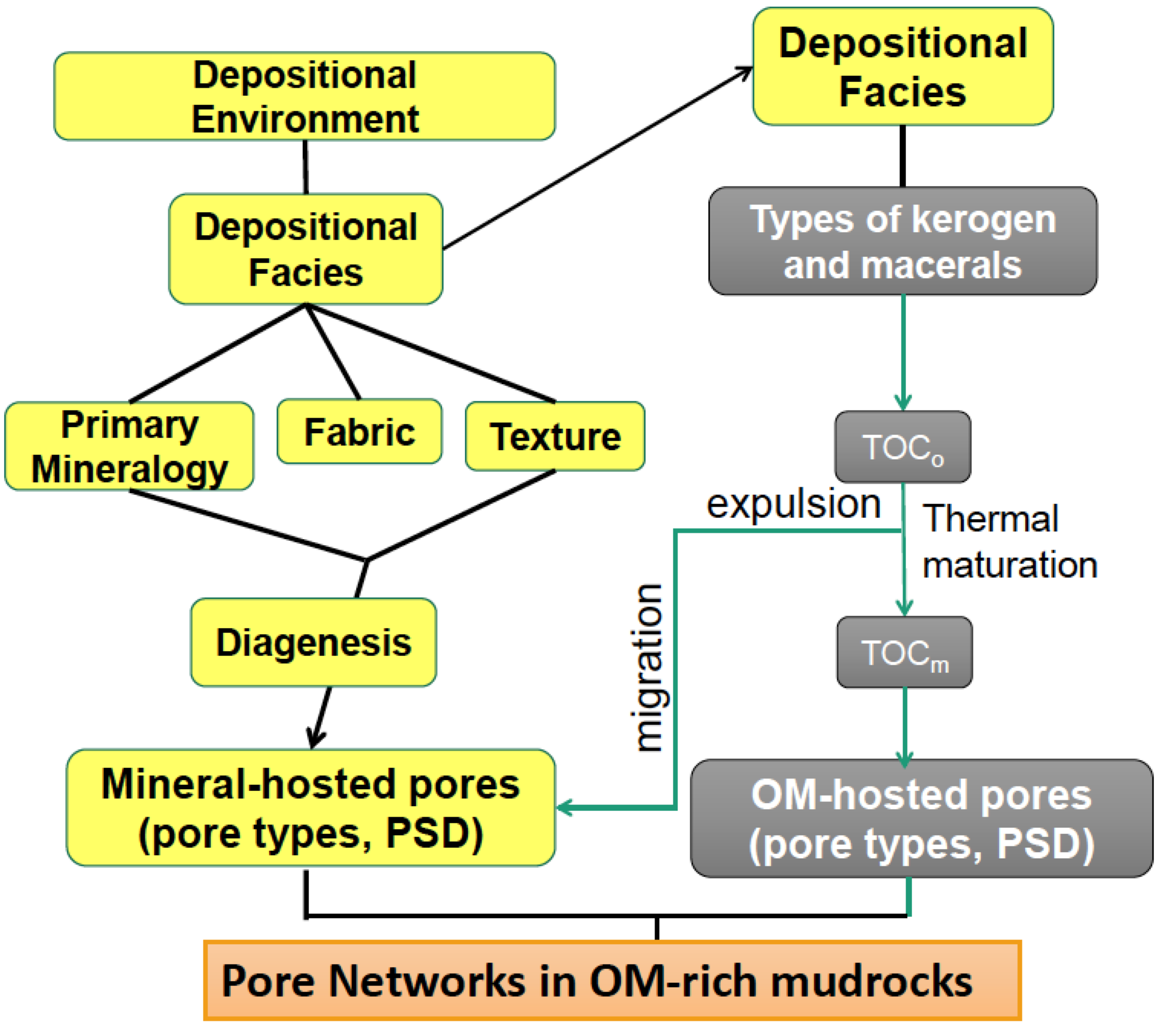
€ipher

Pore Systems in Mudrocks

1. Review past findings and present ongoing research effort.

2. Present updated concepts relative to controls on pore systems and their connectivities.

3. Discuss unresolved challenges such as upscaling and REA/REV.



Source: Ko et al., 2019

Controls on Gas Potential

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Maximum Gas Holding Capacity

Conventional Gas (Clastics)

Pore volume + Pressure (depth)

Important mechanism is: Gas Compressibility

Coalbed Methane (Organics)

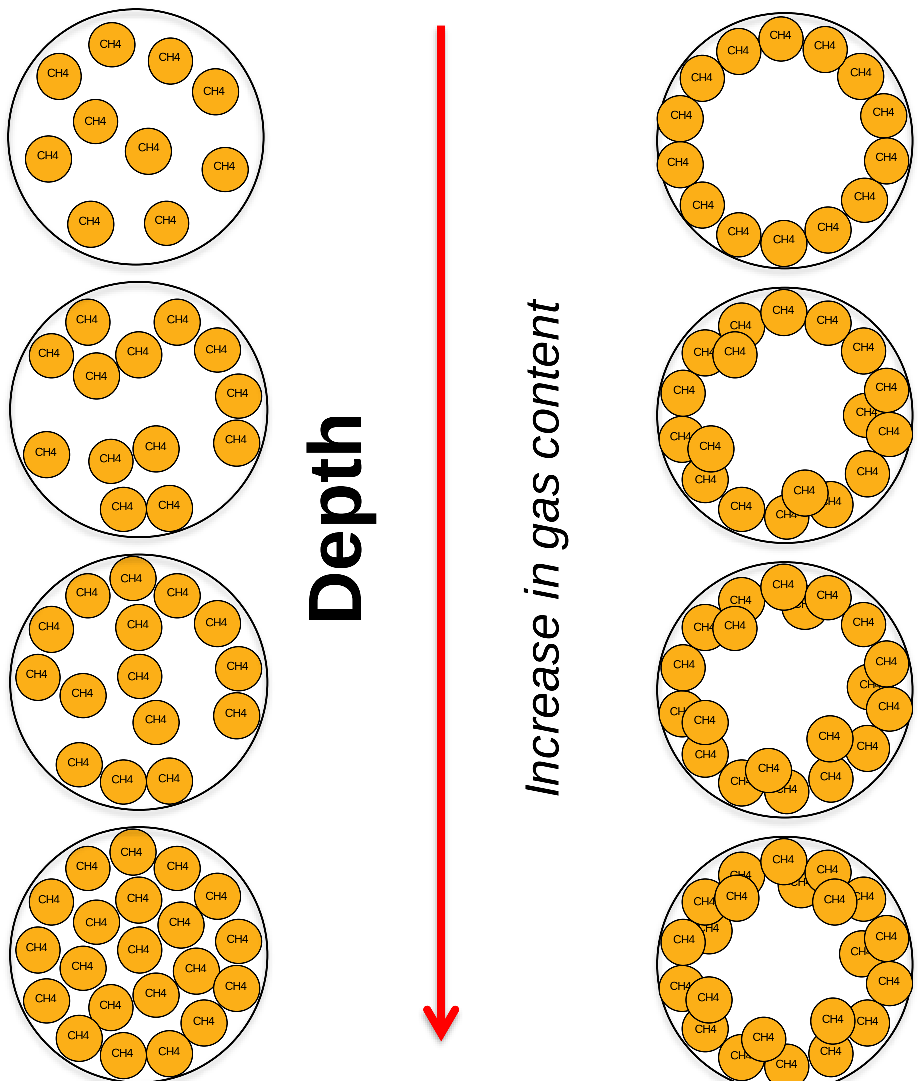
Pore surface area + Pressure (depth)

Important mechanism is: Gas Adsorption

Gas Holding Mechanism & Gas Content

Conventional

CBM

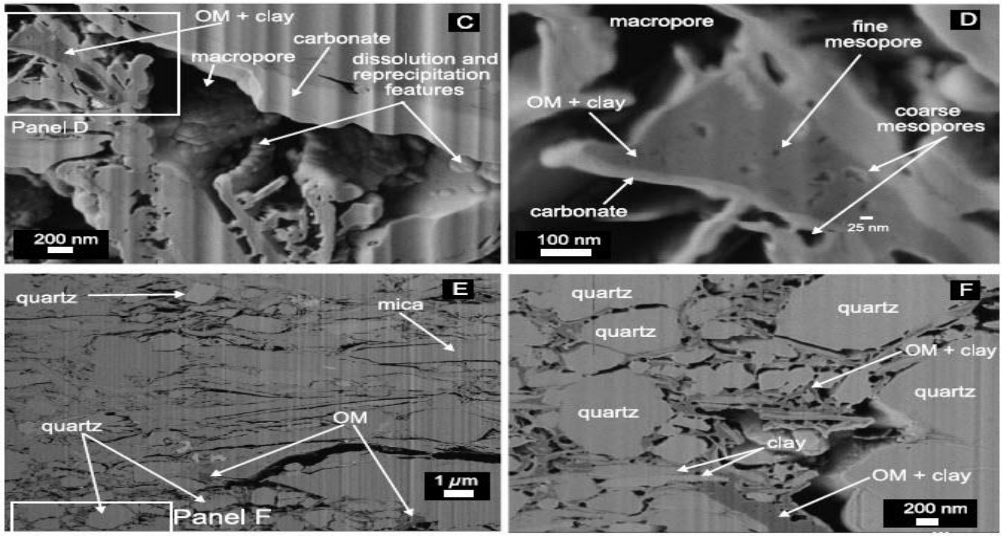


Gas Holding Mechanism in Shale

- Nevertheless, detailed understandings of hydrocarbon generation and retention processes within shale reservoirs are poorly understood.

- Methods of measuring pore volume and size, and sorptive capacity of shale using CBM and conventional reservoir analyses are of limited value in characterizing shale (Bustin et al., 2008) and must be used with care. Hybrid, multiple analyses are best.

- Generated gas can be stored as:
  - free gas in intergranular pores and natural fractures,
  - adsorbed on organic and inorganic surfaces,
  - dissolved in kerogen and bitumen.



from Curtis et al., 2012

Porosity in Shale

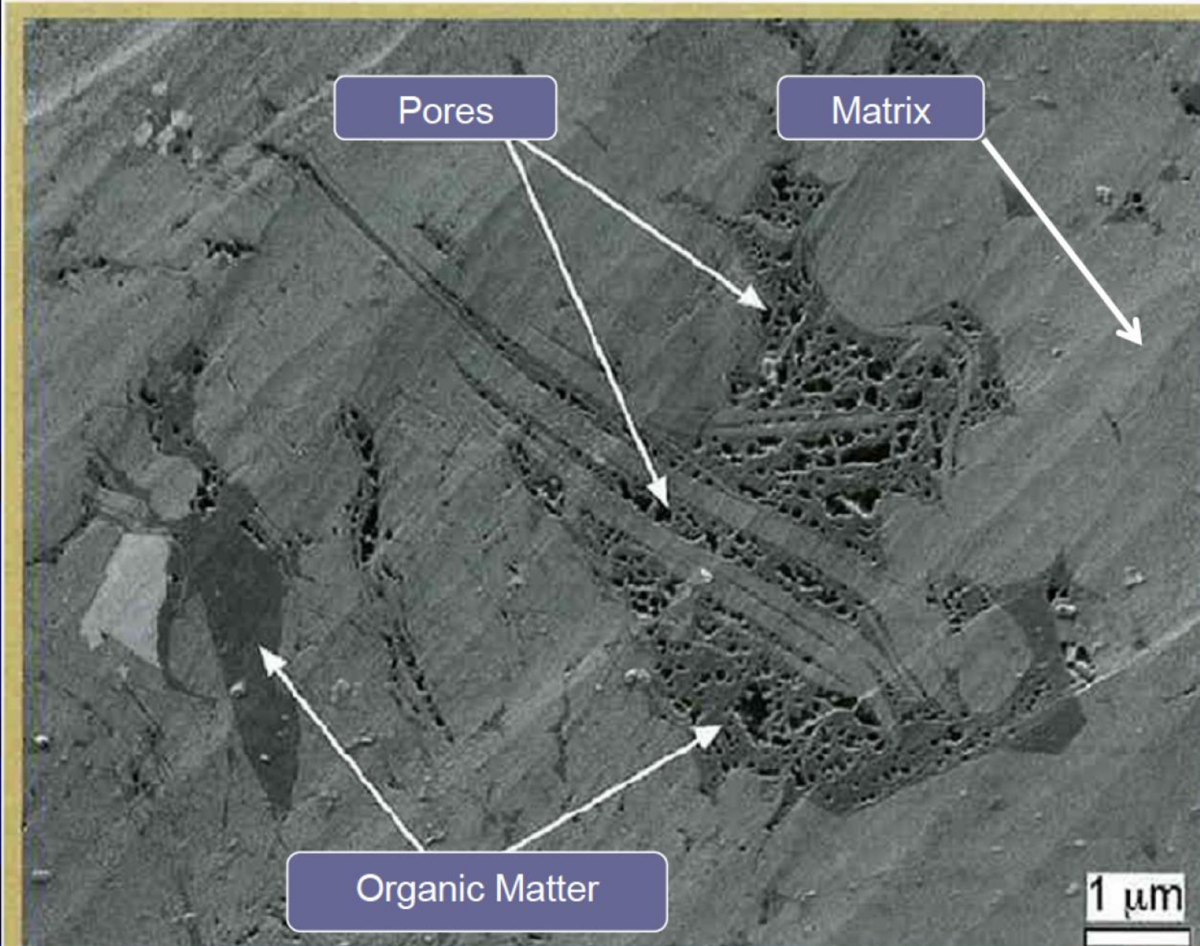
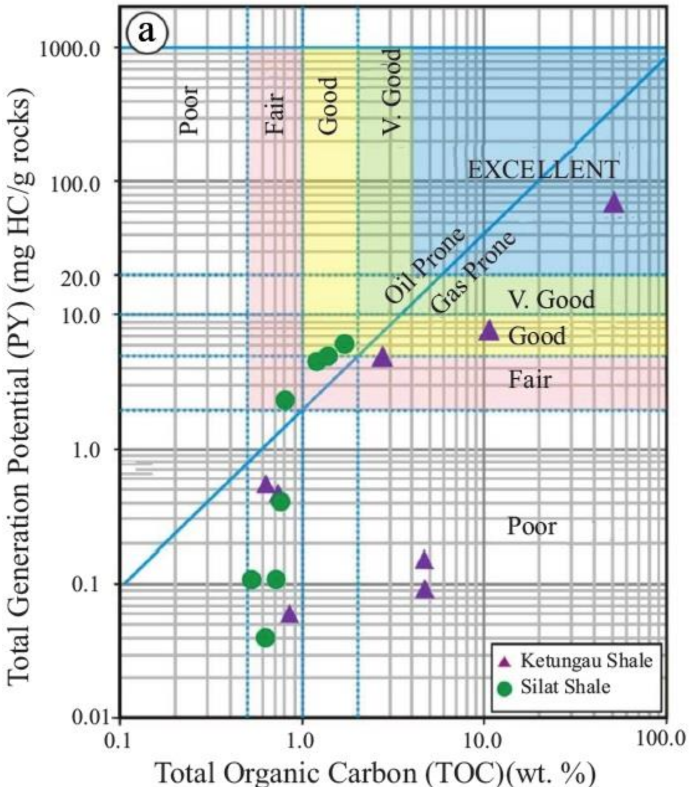


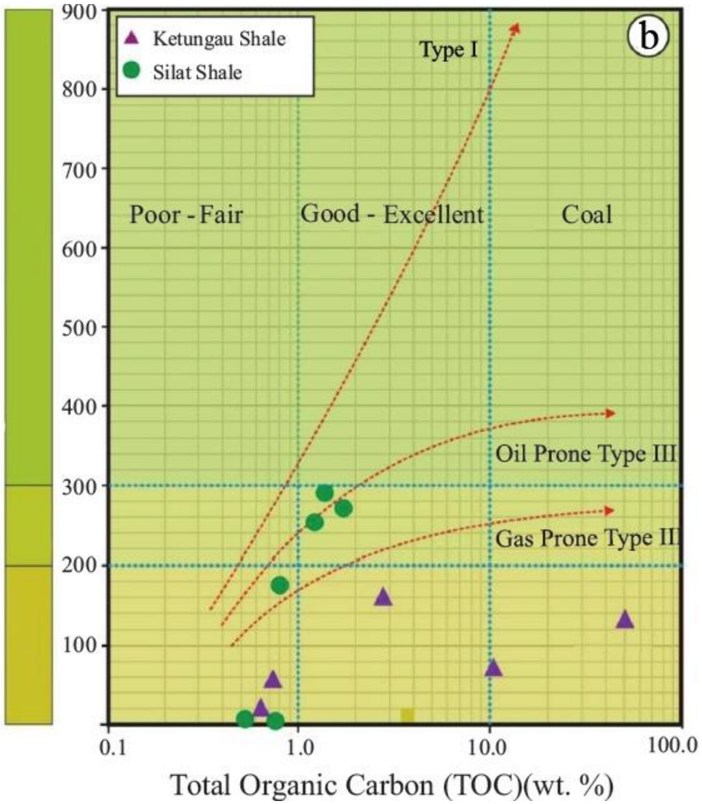
Figure 3. Field emission scanning electron photomicrograph of nanoscale pore architecture in the Barnett Formation. Image provided by R. Reed.

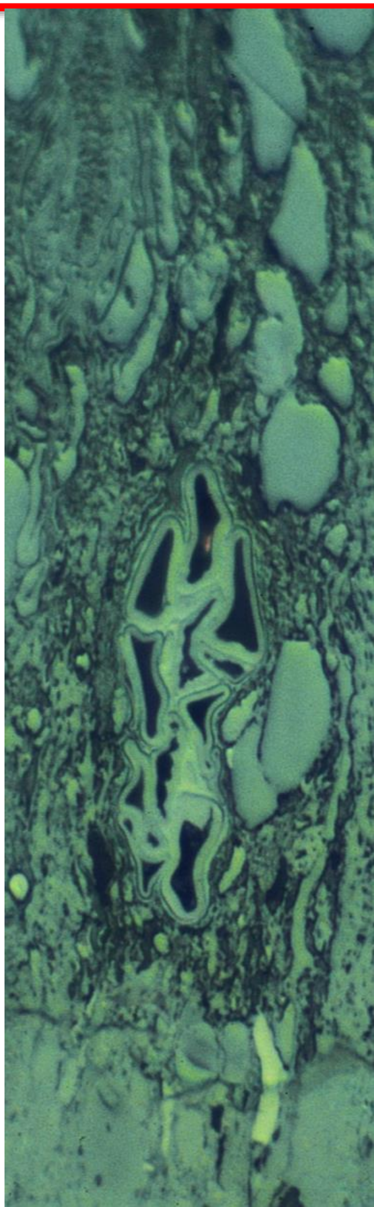
Source : Vasilache, 2010

Organics: A Moving Target!

€ipher



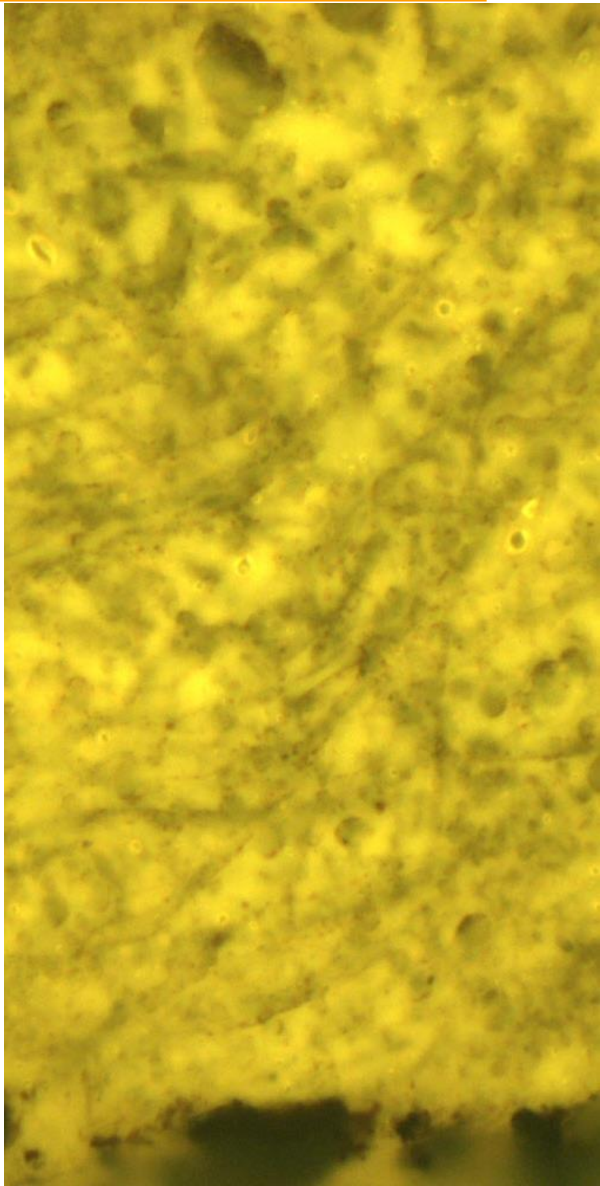




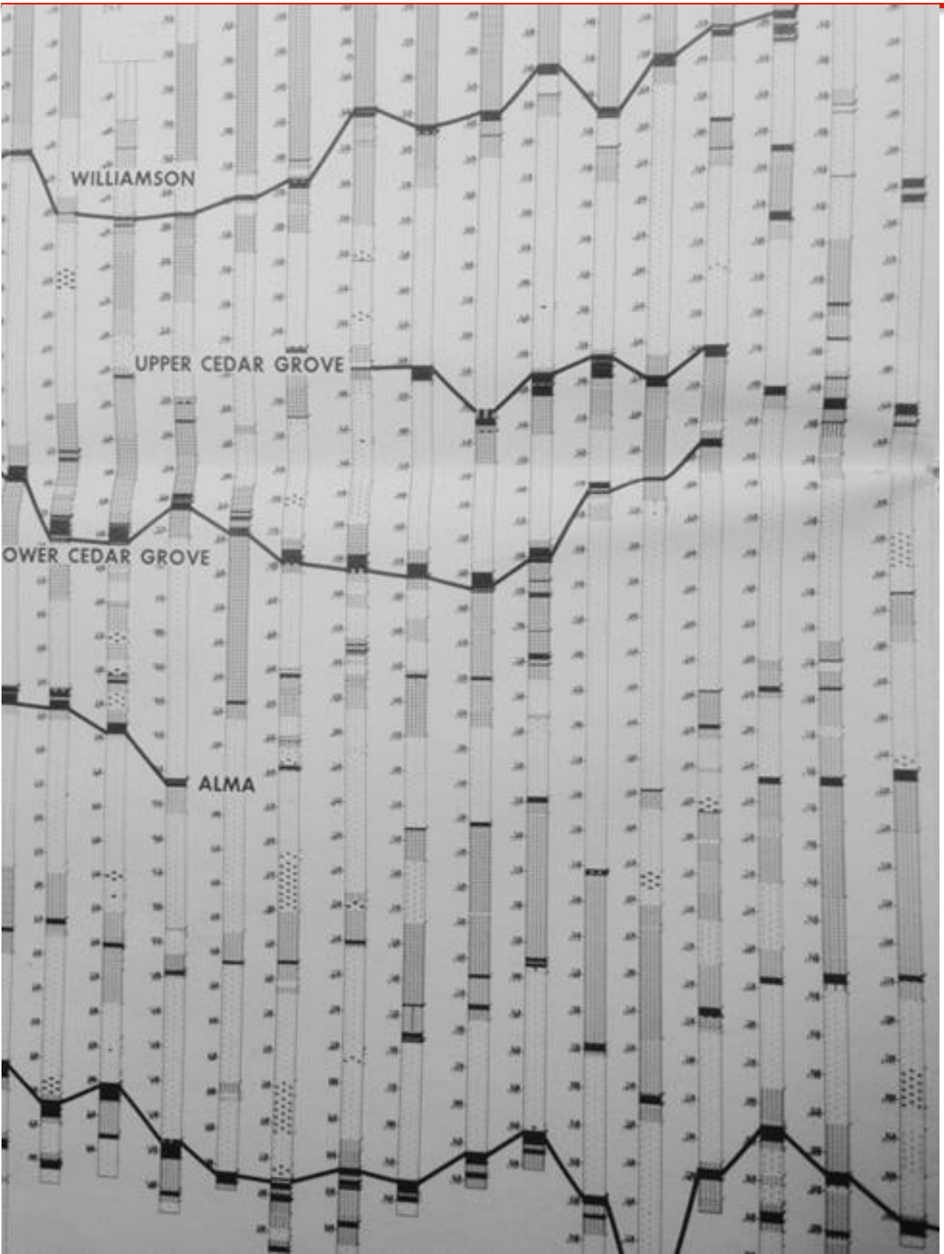
from Santy & Panggabean, 2013

Outline of Lecture

- What makes a reservoir Conventional or Unconventional?
- Brief review of a Conventional reservoir system
- Unconventional Reservoir Review
- Focus on Coalbed Methane as Shale Gas
- Geological Models



Building Models: Drill holes



Core Data: **Adds additional resolution and more confidence**

From Ferm et al., 1979

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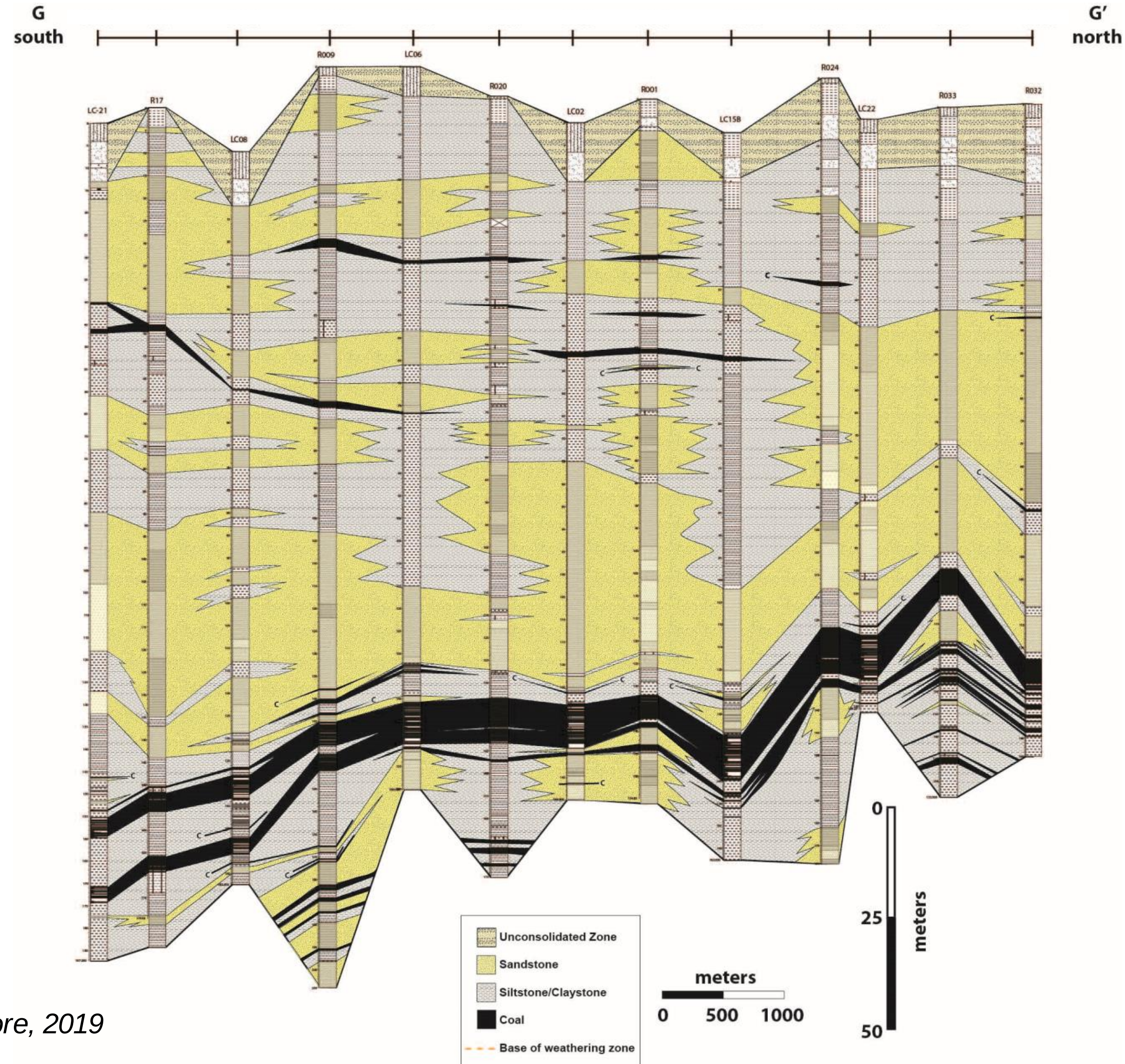
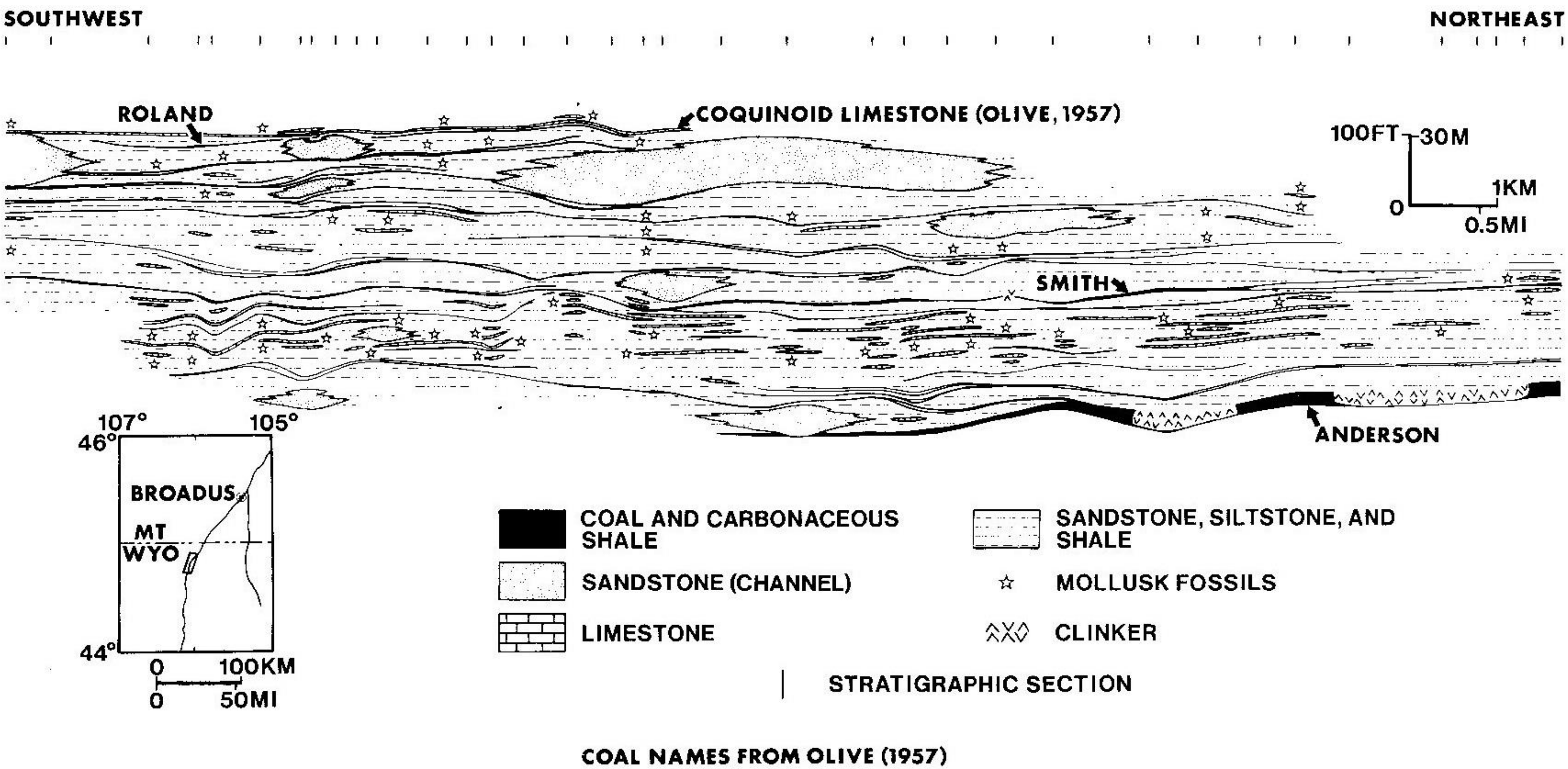
Building Models: Drill Hole Correlations



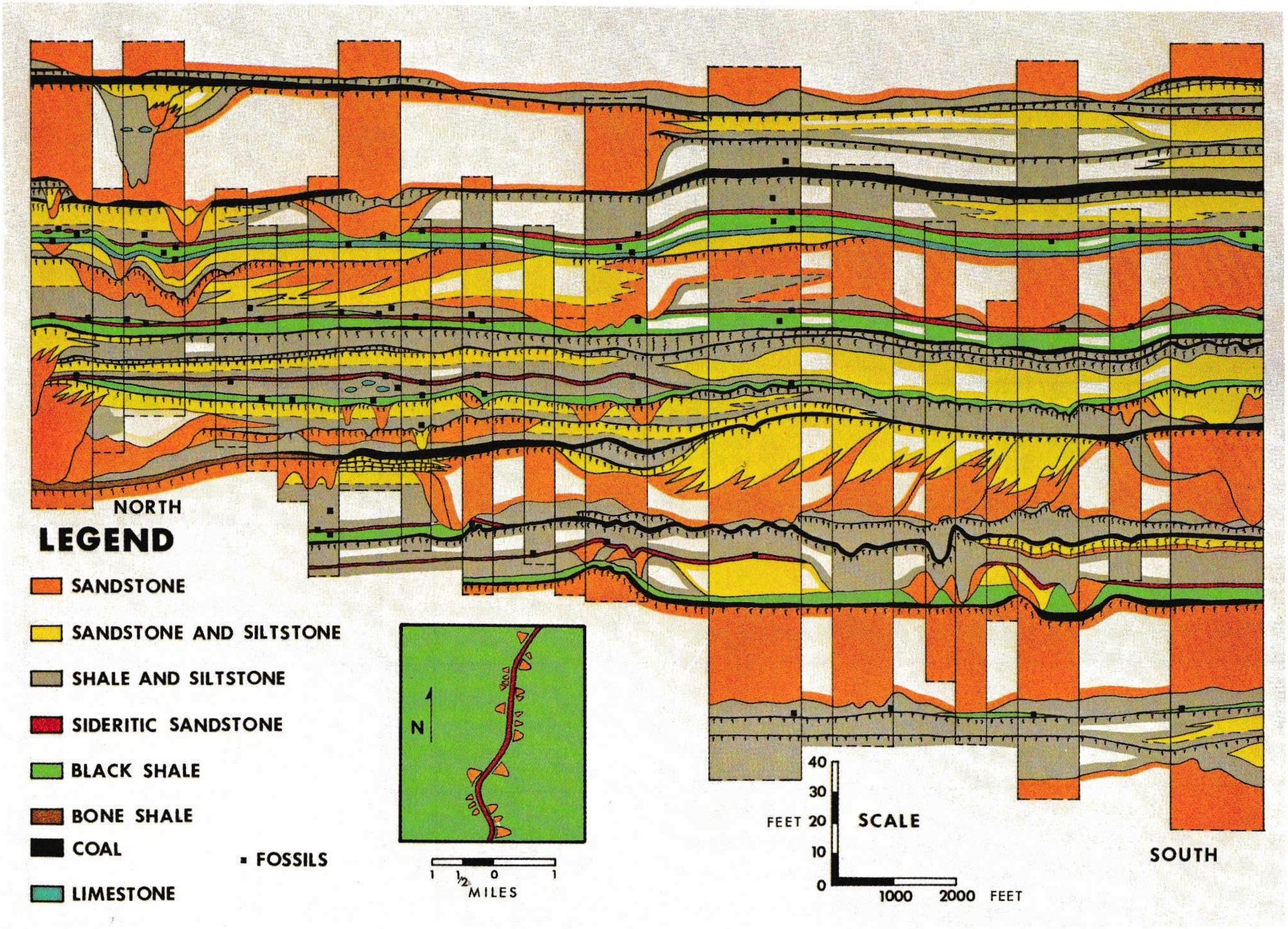
from Moore, 2019

Building Models: Measured Sections



from Flores, 1981

Building Models: Continuous Outcrops



Outcrop: The most confidence!

… but does it tell us anything about time?

From Ferm et al., 1979

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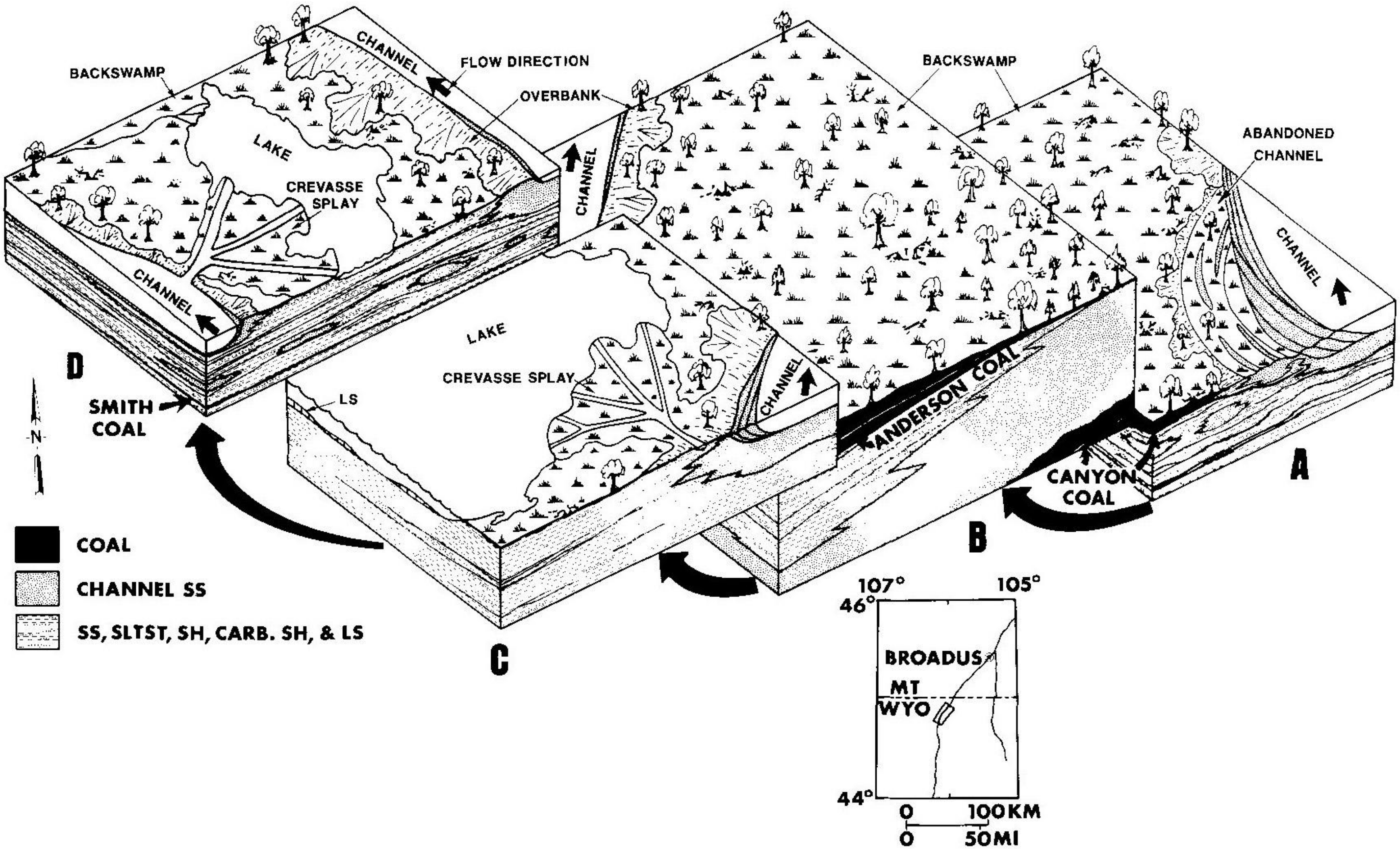
Model Building: Powder River Basin



from Flores, 1981

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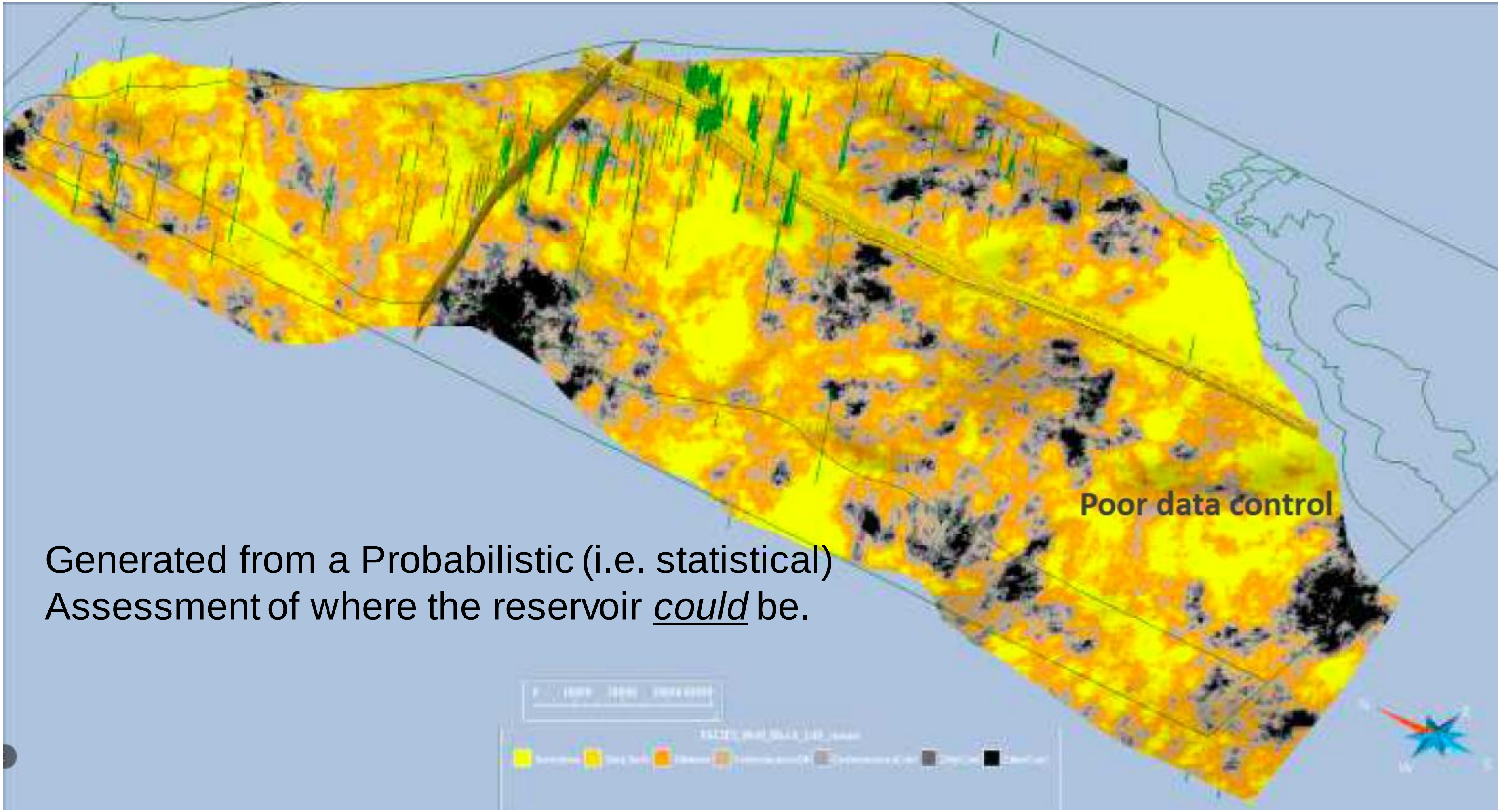
Building Models: Using Sparse Data and Extrapolating



Generated from a Probabilistic (i.e. statistical) Assessment of where the reservoir *could* be.

From Esterle et al., 2013

Computer-Based Geological Models

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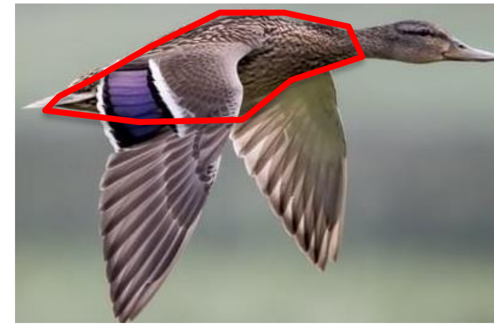
“[Geological] models are like sausages – you like them until you know what’s in them”

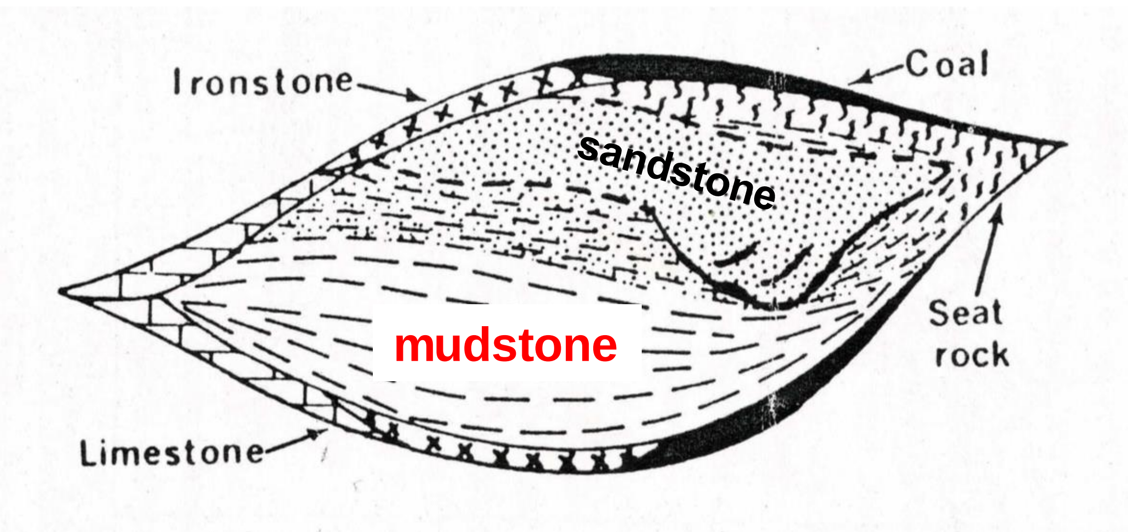
http://simpsonswiki.com/wiki/File:Springfield_Sausage_Factory.png

Dr Walter Pickel

Evolving Geological Models – Appalachian Basin



The 'Duck' Model

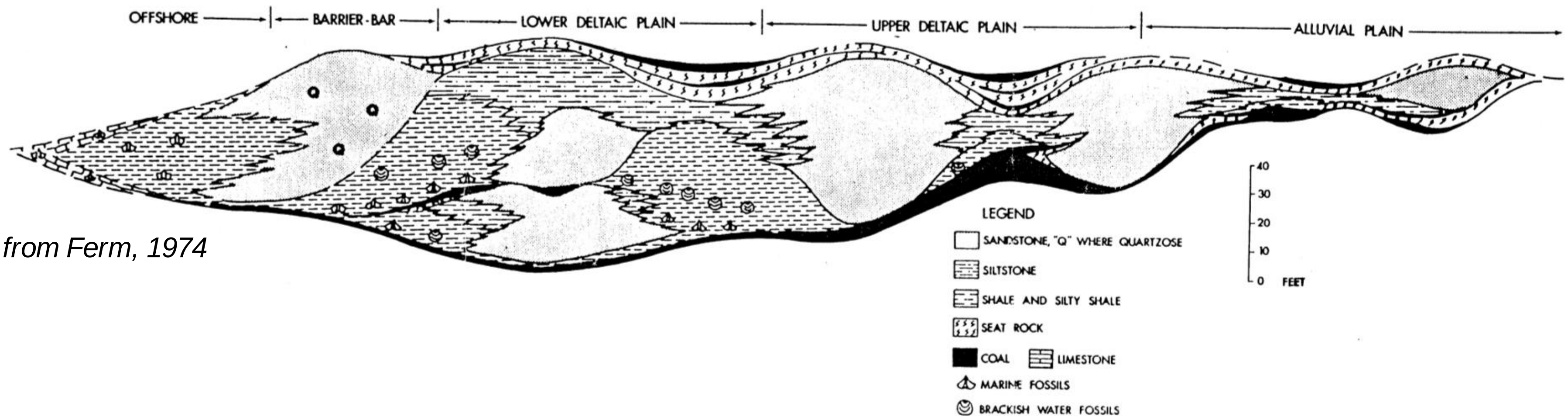


from Ferm & Williams, 1963

- **Two dimensional**
- **Predicts rock types and how they grade laterally with one another**

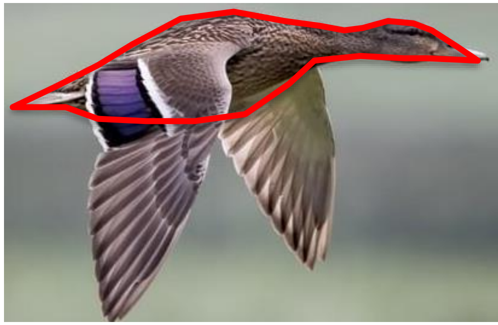
Professor John C Ferm, New Zealand
Photo: T.A. Moore, 1996

Alleghany 'Duck' Model

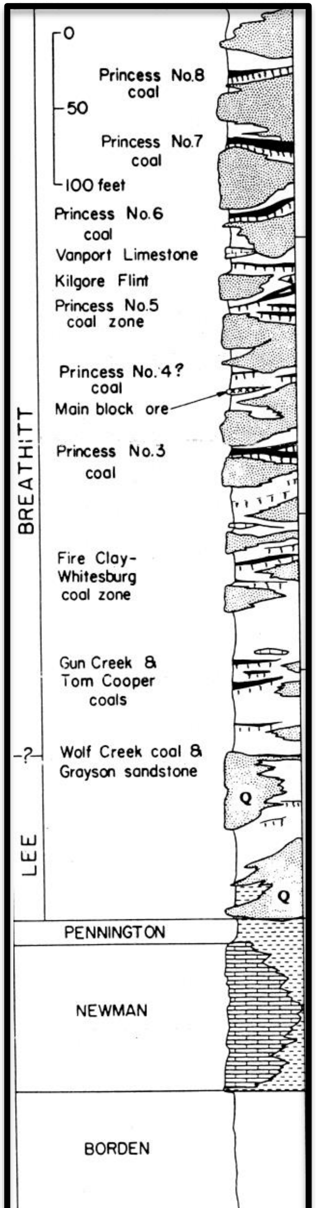


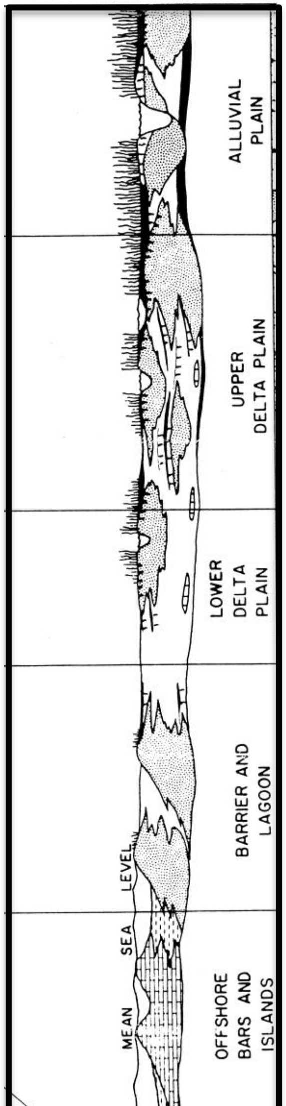
from Ferm, 1974

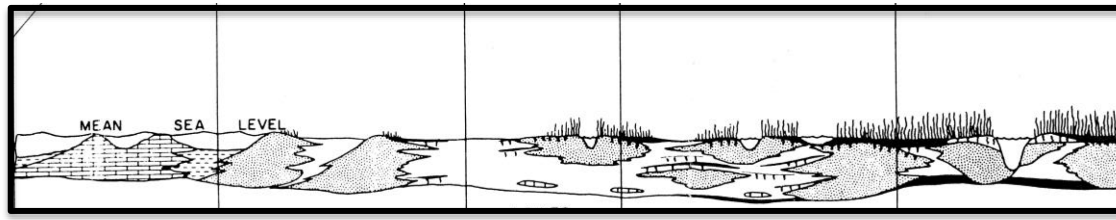
- **Two dimensional**
- **More complex than the original 'Duck' model**

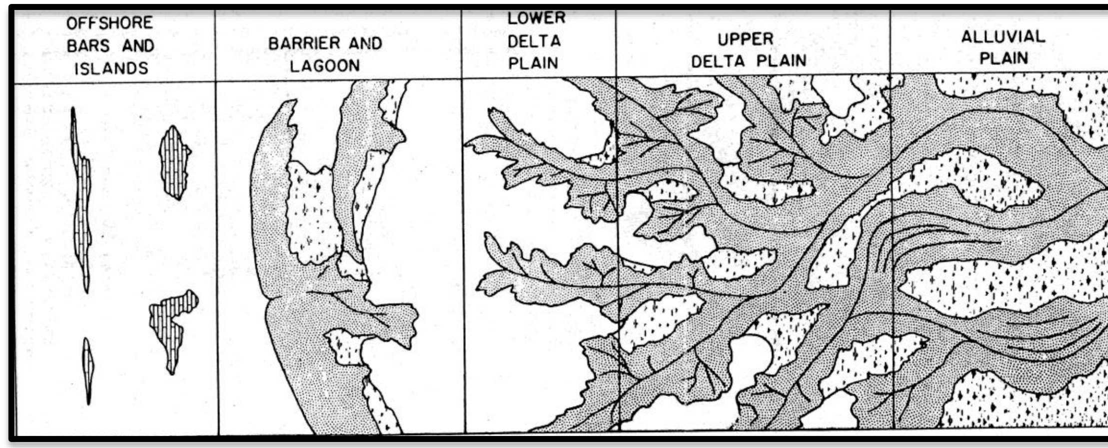


Evolving Geological Models – Appalachian Basin







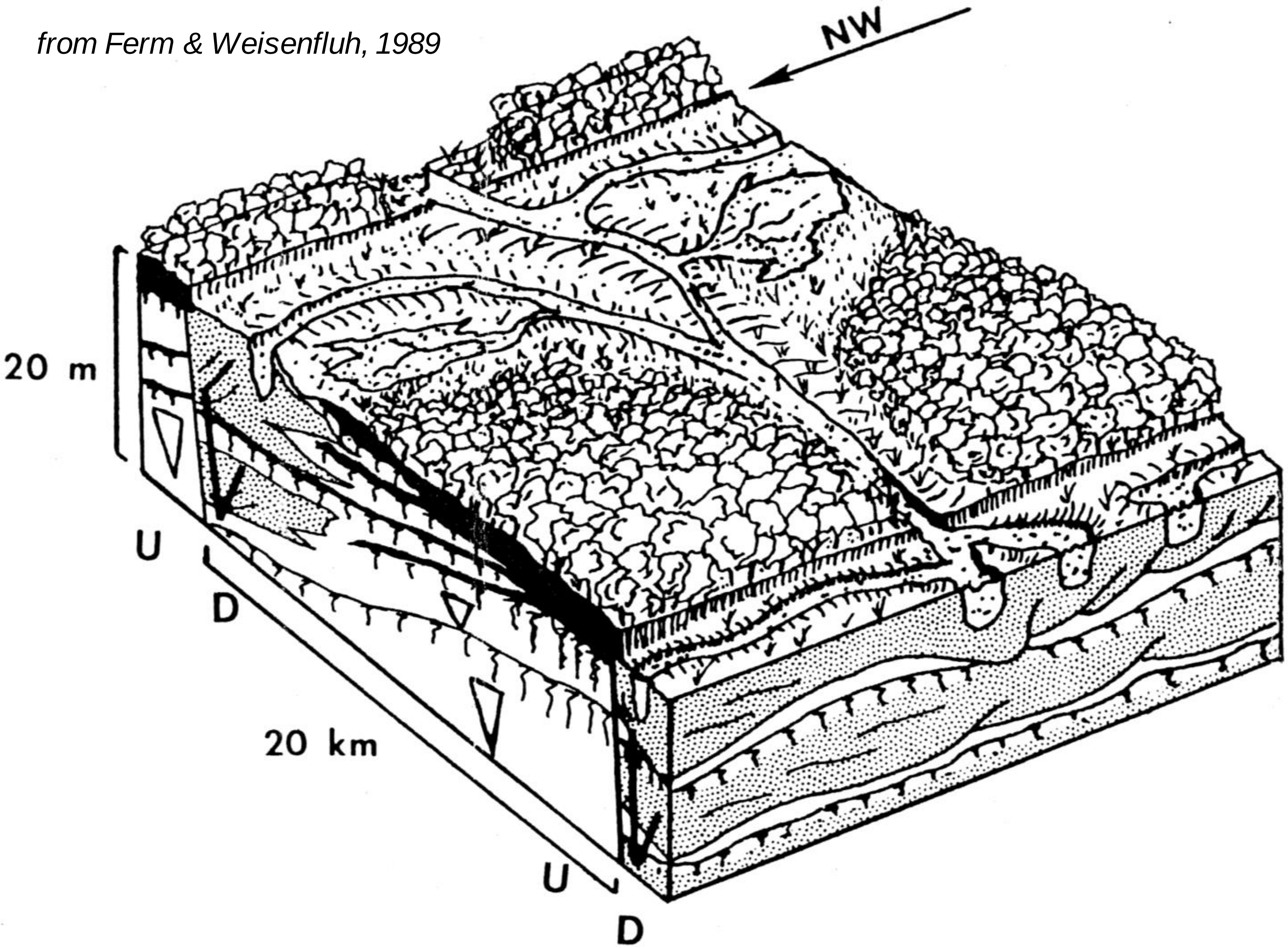


from Ferm, 1976

- Start with measured, real data
- Hypothesis as to depositional environment in 2-dimensions
- Construct a 3-dimensional model
- Using those predictive lateral changes in rock type: TEST THE HYPOTHESIS (i.e. more data)

Evolving Geological Models – Appalachian Basin

from Ferm & Weisenfluh, 1989

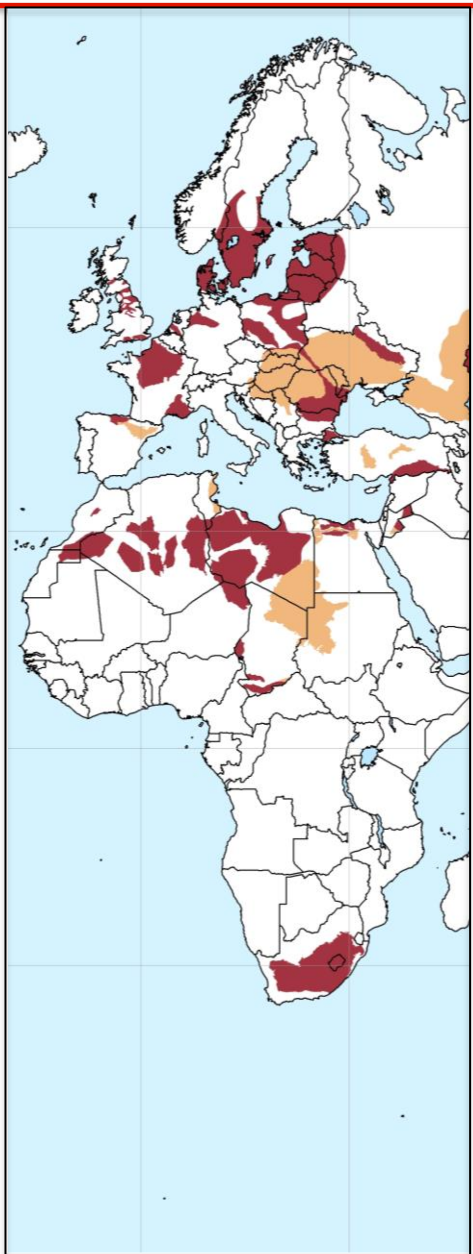


- Further model refinements in some parts of the basin
- Structural controls on sediment distribution as well as coal occurrence
- Not just depositional environment control

Geological model develop requires constant input of field data, testing, further data, more testing …and so on

SUMMARY

- Unconventional resources are low permeability and require different technology than conventional resources
- The world has huge amounts of unconventional resources, but they are harder and more expensive to exploit than conventional resources
- Fracture stimulation is key to unlocking many unconventional resources
- Coalbed methane and Shale gas are two of the many unconventional resources, both get their gas from the organics and both the source and reservoir
- Pores and porosity are key to understanding how the gas in these reservoirs are generated and stored.
- Geological models are fundamental for prediction and understanding how basins form and sediments are distributed
- Models need to be based in data, and tested, and revised with addition data
- Never "*marry*" your model! – models need to change and evolve with new data and new insight



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If you want to know more go to the Cipher website & Blog: https://www.ciphercoal.com

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