# Unconventional Resources and Basin Evolution

# Objective

**Discuss some regional scale controls (plate to basin) on unconventional resources.**

**Illustrate with five examples (source rock, tight sand and CBM reservoirs).**

# Outline

Types of Unconventional Resources – Review

Global Screening Analysis of a Few Regional Factors

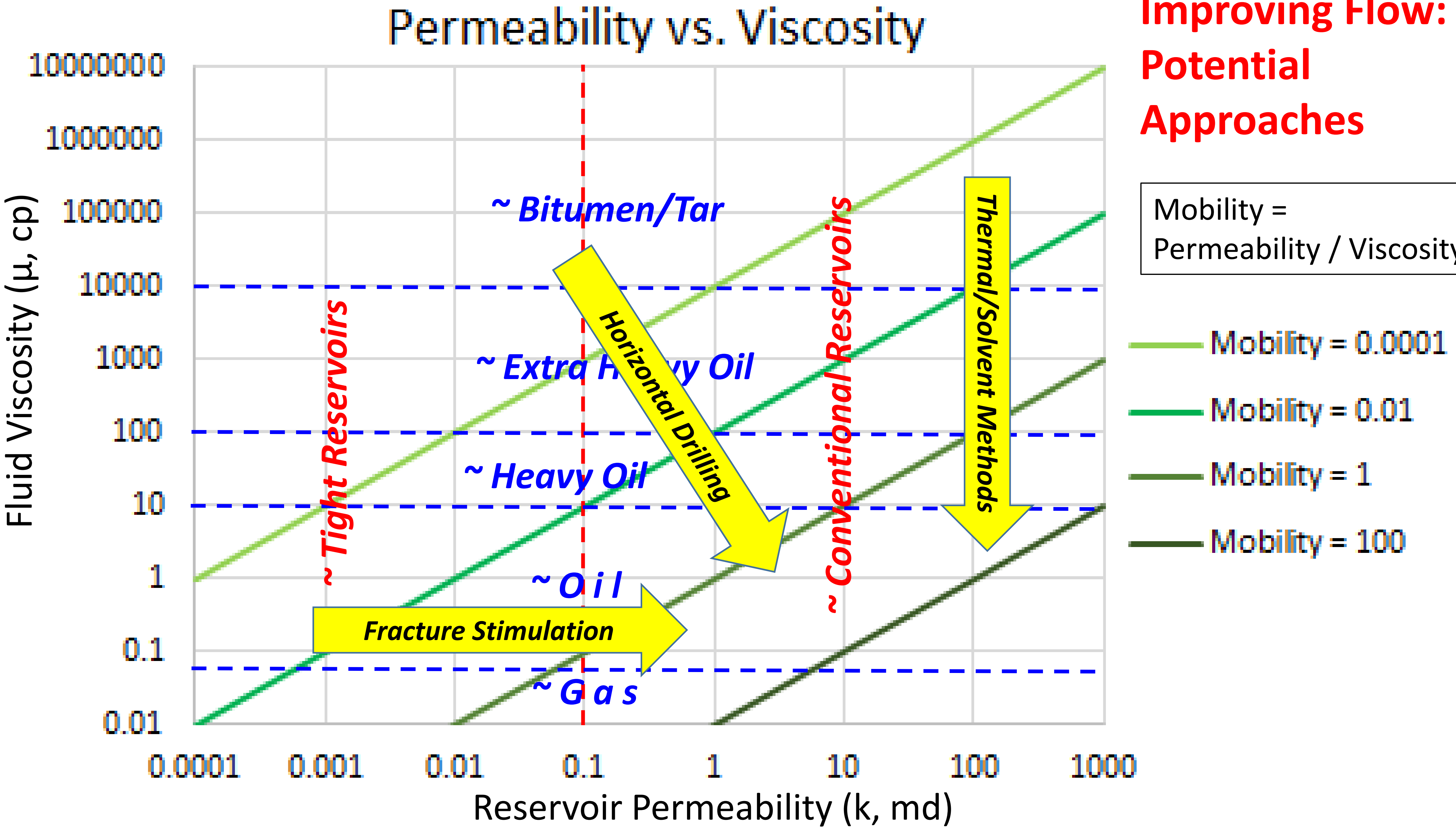
Selected Examples

- Reservoir Deposition and Characteristics
- Burial – Maturation and Diagenesis
- Uplift and Exhumation

Closing Remarks

# Unconventional Resources –

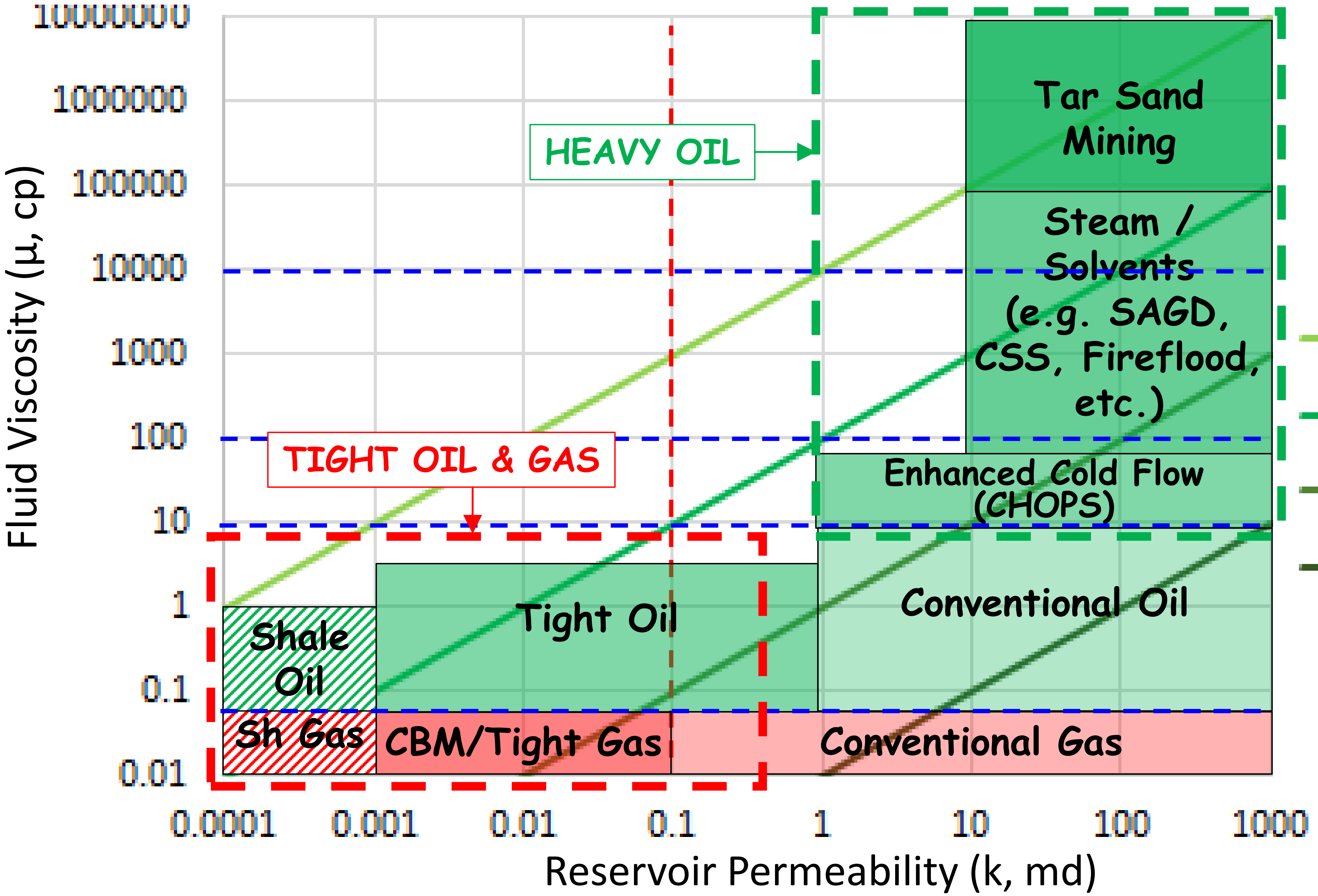
# Categories




# Improving Flow: Potential Approaches

Mobility = Permeability / Viscosity

# HC Resource Types: Permeability vs. Viscosity



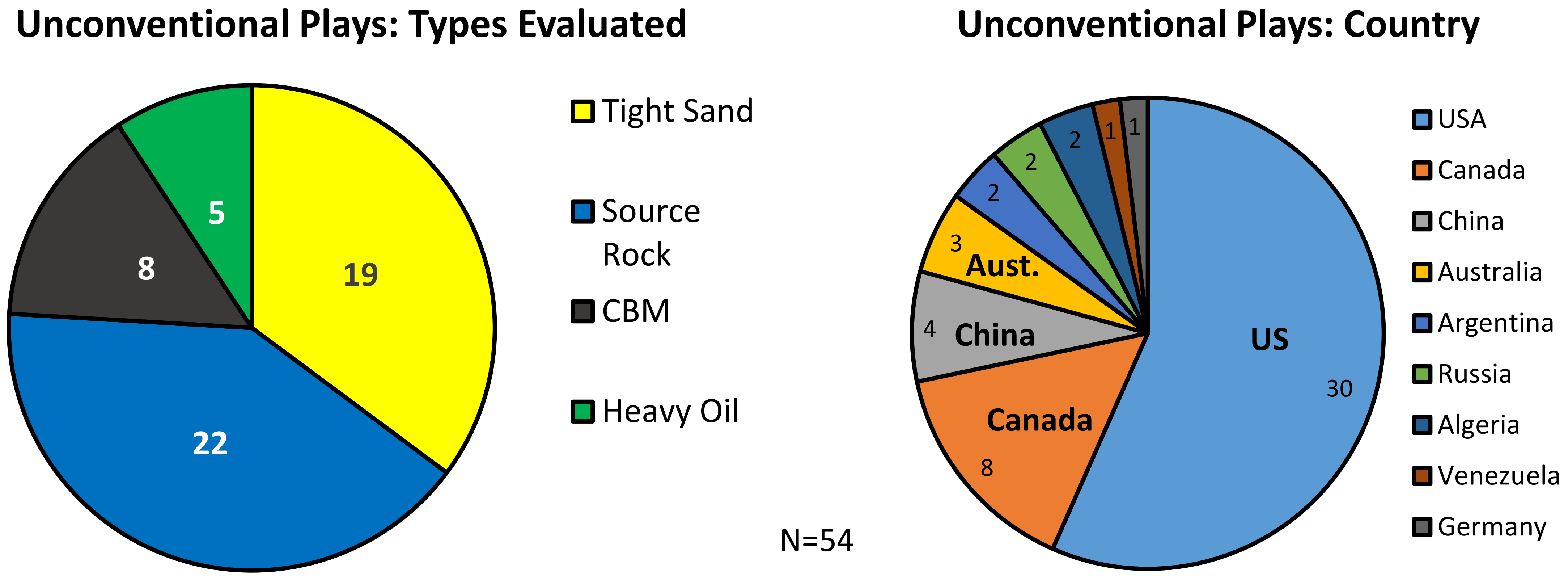

**Unconventional Types:**

Heavy Oil
Tight Sandstone/Carbonate
Source Rock ("Shale")
Coal Bed Methane

**Note** –
**In reality, there is much overlap between resource types / depletion strategies.**

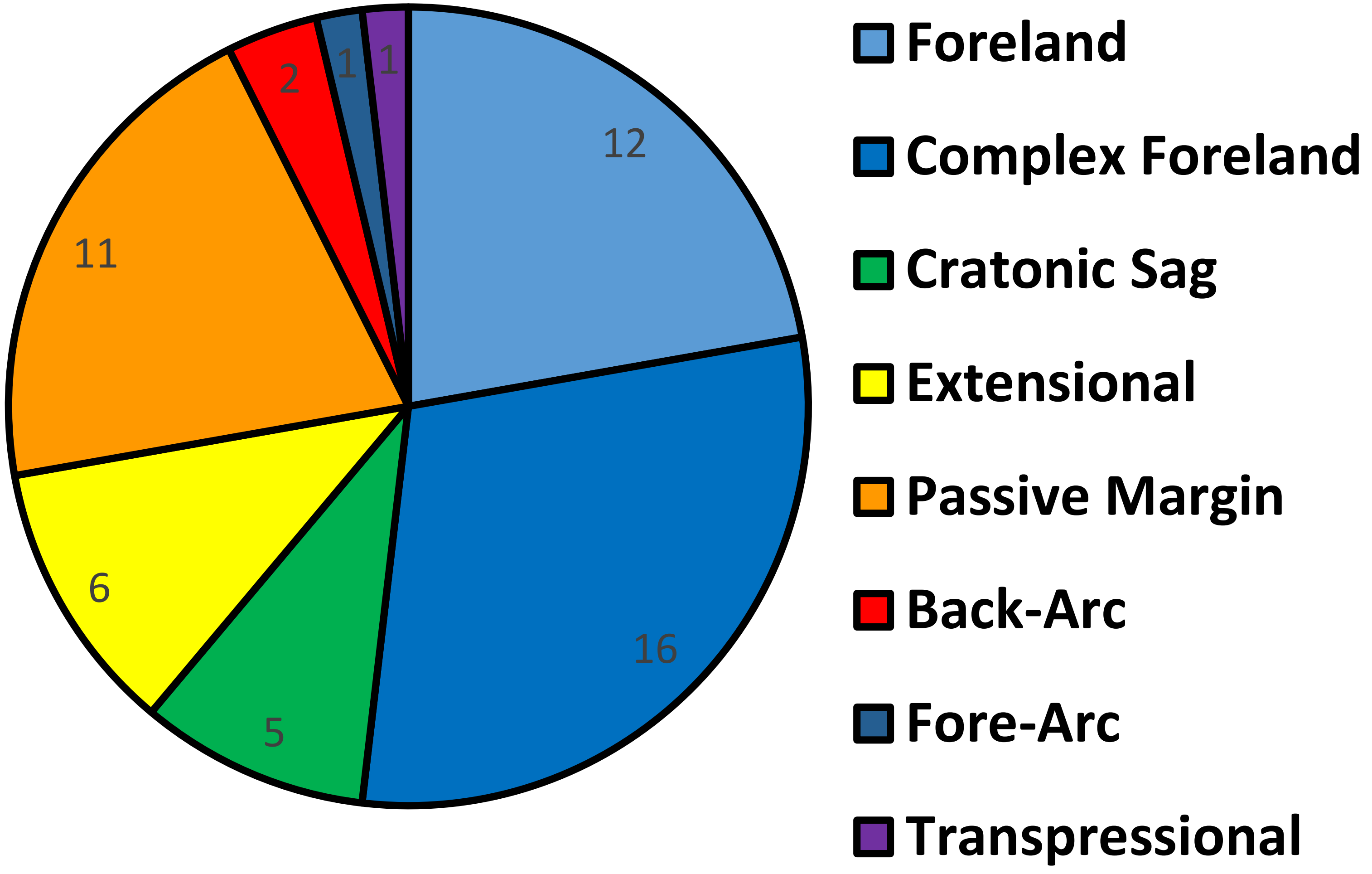
# Global Screening Analysis of Basin Factors

# Regional/Basin Controls on Unconventional Resources - Database




- **87 unconventional plays screened. 54 further analyzed based on materiality and maturity.**
- **Of these 54, 45 plays are significantly commercialized (e.g., Permian Wolfcamp); 9 are emerging with commercial promise (e.g., Nequen Vaca Muerta).**
- **Representative, but not necessarily comprehensive.**
- **Dominated by US/Canada because of commercial/infrastructure/regulatory considerations (and favorable geology).**

# Regional/Basin Controls on Unconventional Resources - Depositional Basin




Unconventional plays occur in all kinds of basins – many pathways to success.

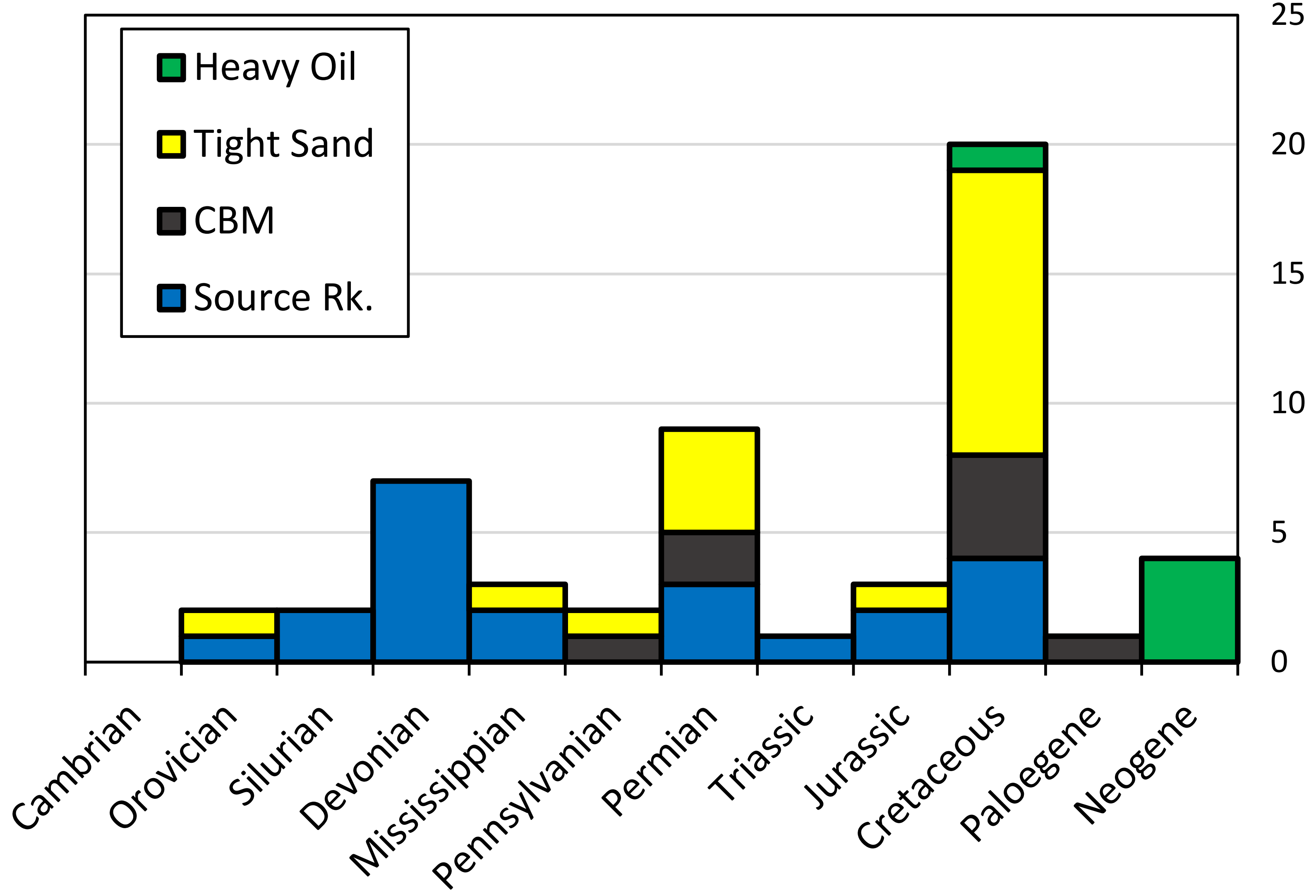
Forelands are the most important.

The prominence of forelands, in part, probably includes a bias related to commercial considerations – unconventional developments generally require an onshore setting.

But also, rapid flexural subsidence in foreland basins is often associated with thick source rocks ("shale reservoirs") and tight reservoir sandstones – discussed later.

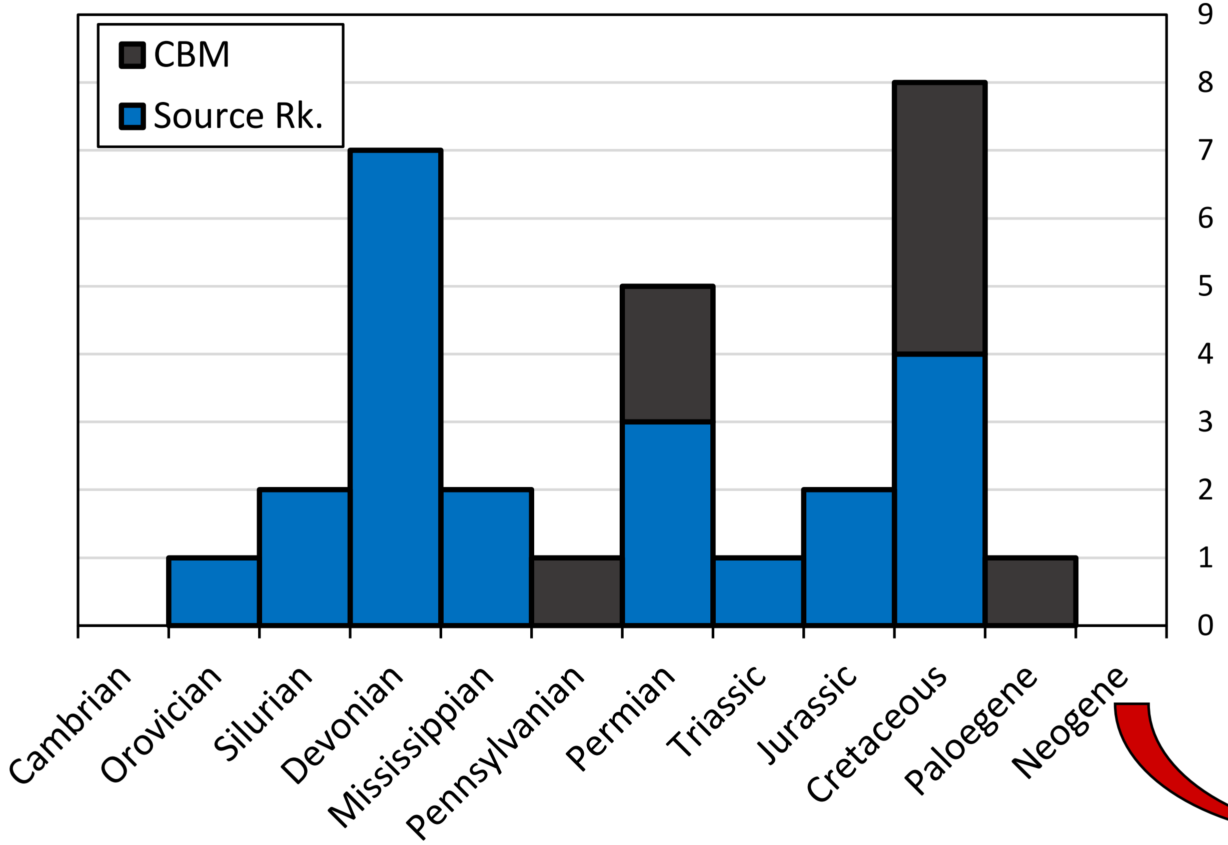
Lastly, volcanic arc association may be an additional source of nutrients.

# Regional/Basin Controls on Unconventional Resources - Reservoir Age

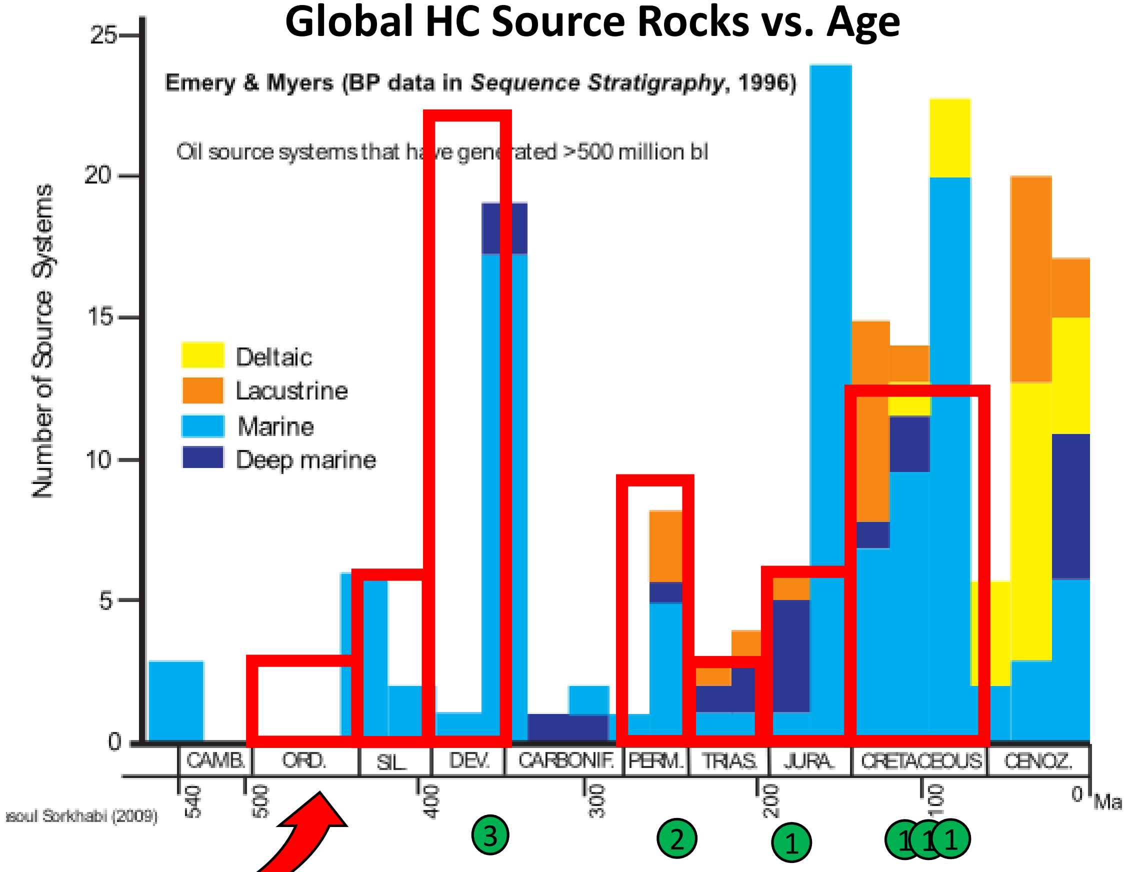


# Source Rock and CBM Plays – Age

## Source Rock and CBM Plays: Reservoir Age




## Global HC Source Rocks vs. Age

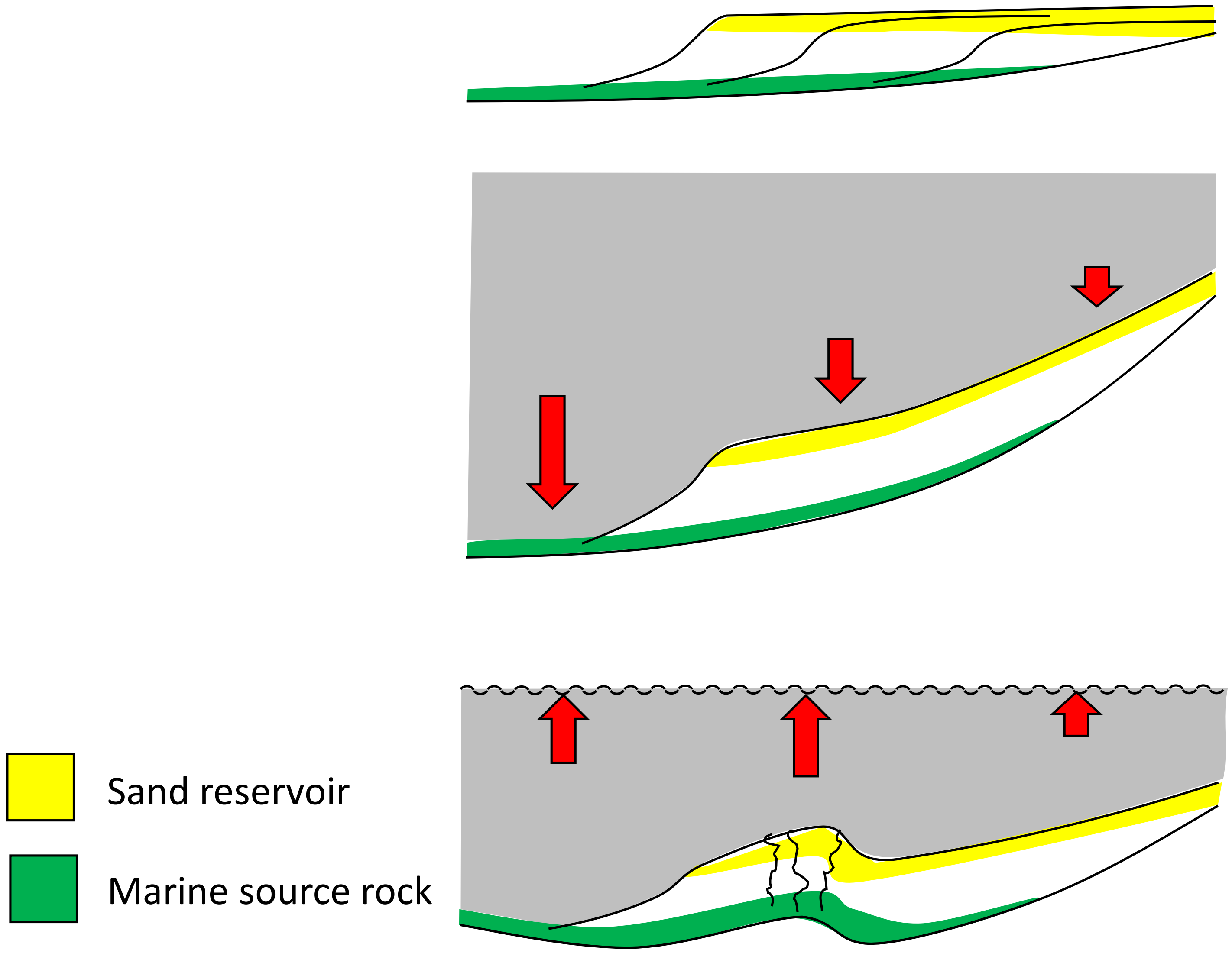



***Source Rock Reservoir Plays Only***

Oceanic Anoxic Events

1. Jenkyns (2010)
2. Brennecka (2011)
3. Algeo et al. (1994)

# Basin Evolution and Unconventional Play Elements

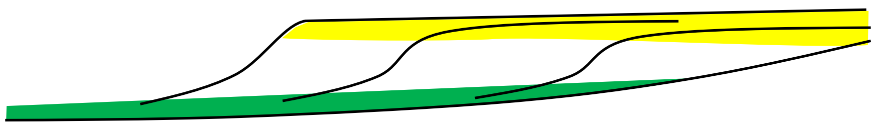



**Deposition:**
Reservoir Presence / Mineralogy
Organic Richness

**Burial:**
Reservoir Compaction/Diagenesis
Source Maturation
Pressure Development

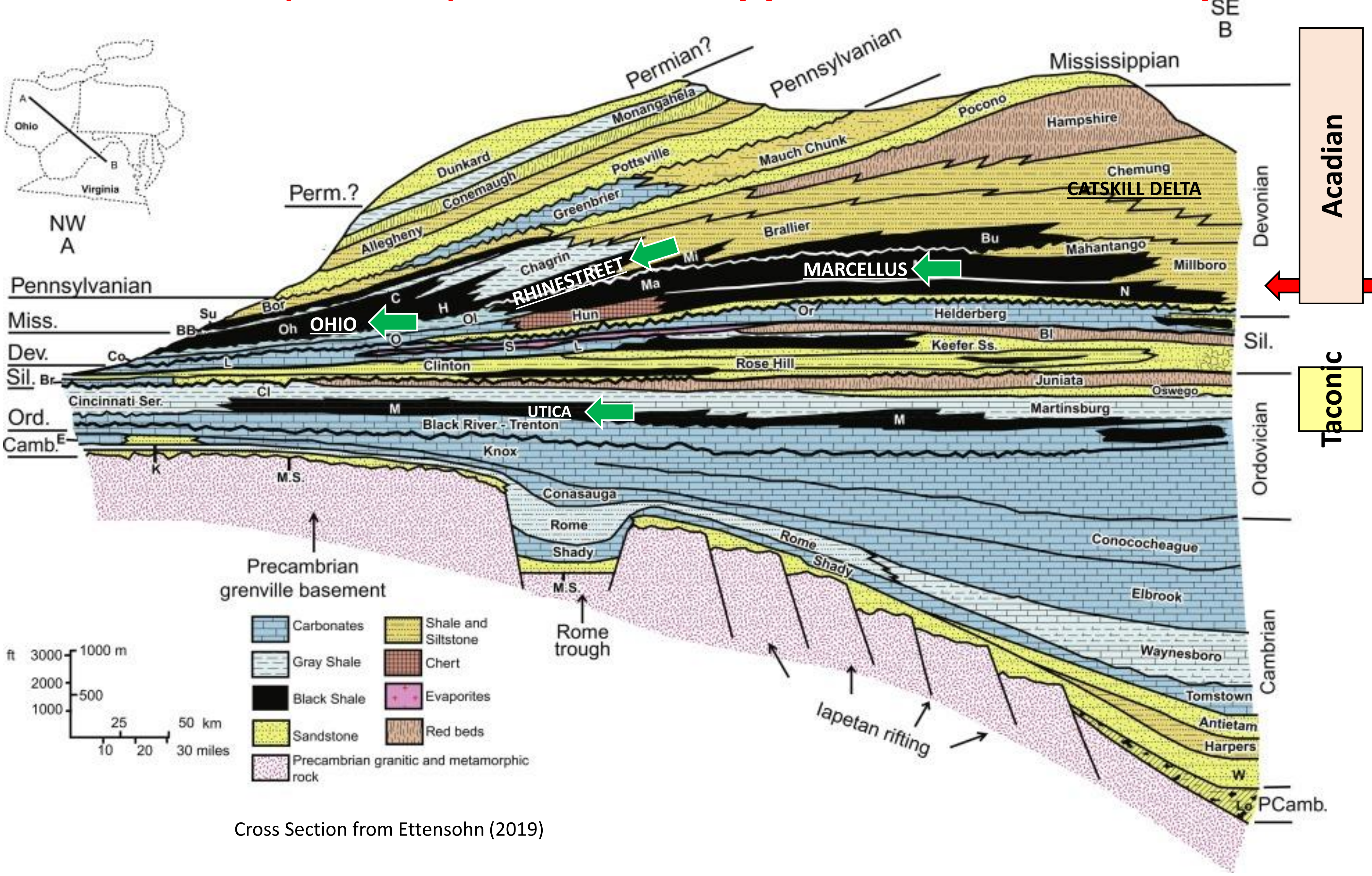
**Exhumation & Deformation:**
Folding/Faulting
Natural Fractures
Oil Biodegradation
Pressure Modification
Drilling Depth

# Reservoir Deposition / Characteristics



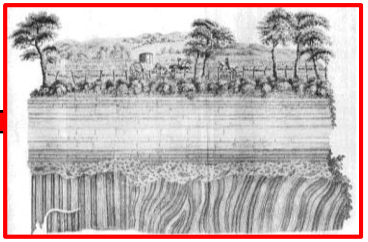
Reservoir Presence / Mineralogy
Organic Richness

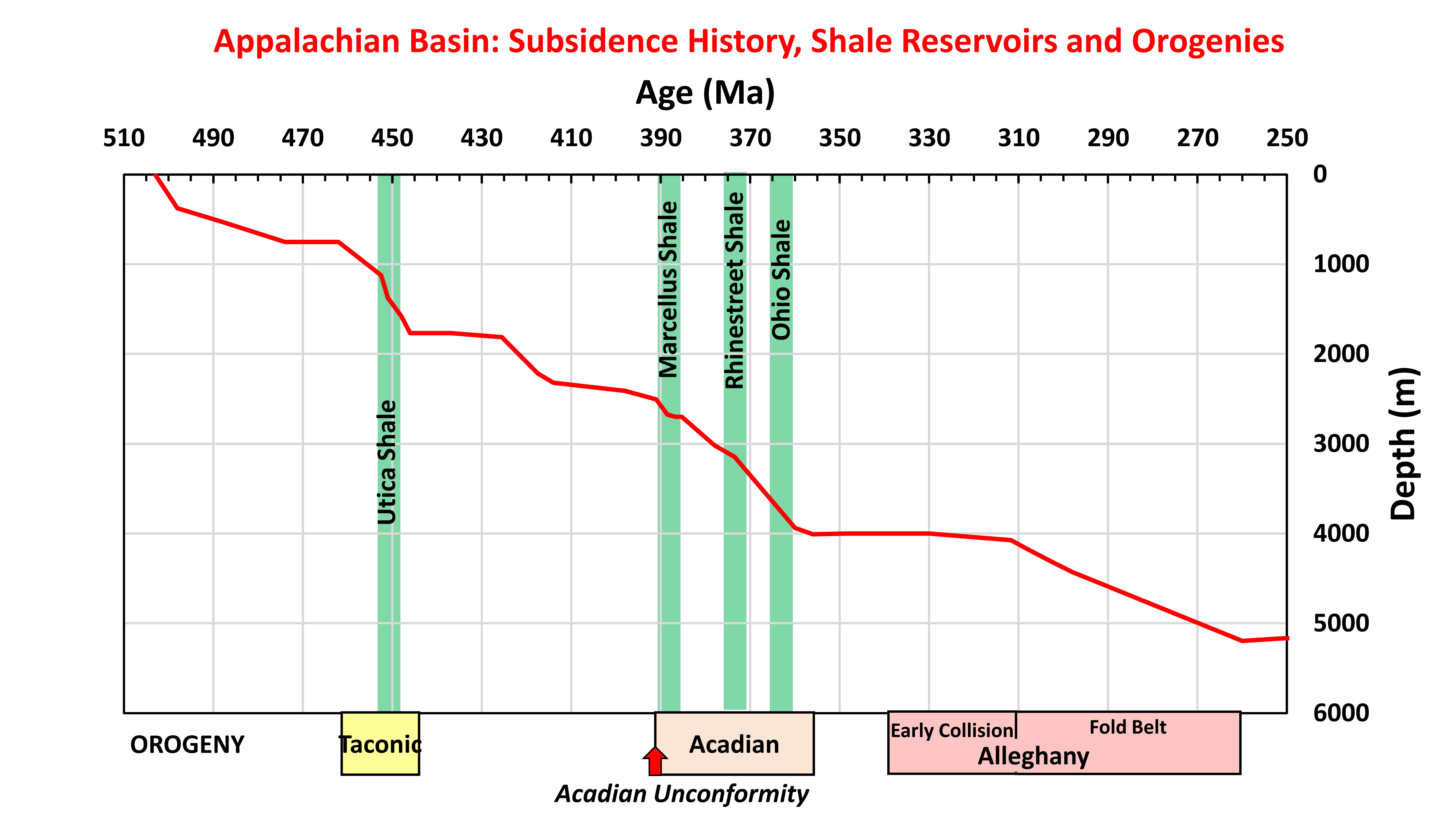
# Source Rock ("Shale") Reservoirs: Appalachian Basin Example




Cross Section from Ettensohn (2019)

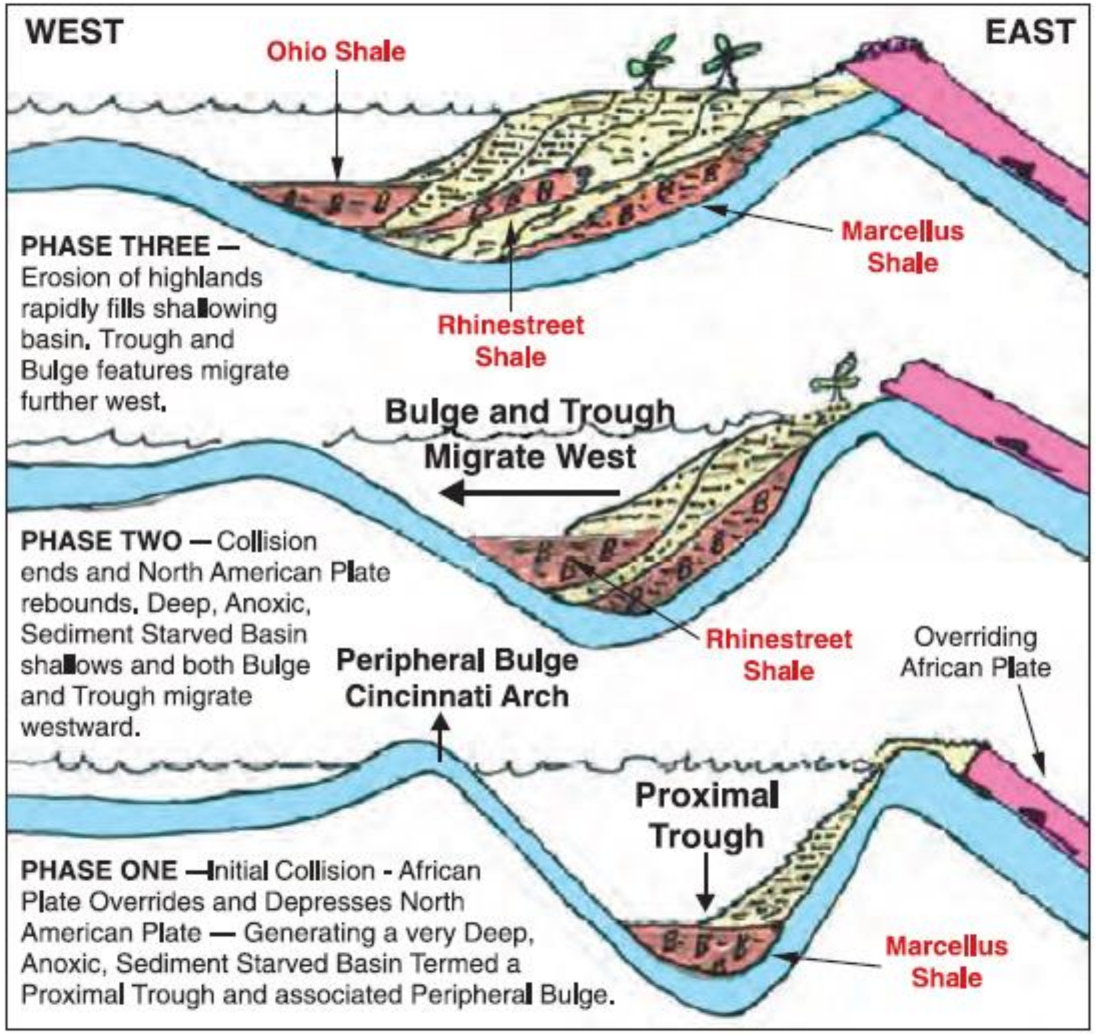
Acadian Unc. (Hutton)

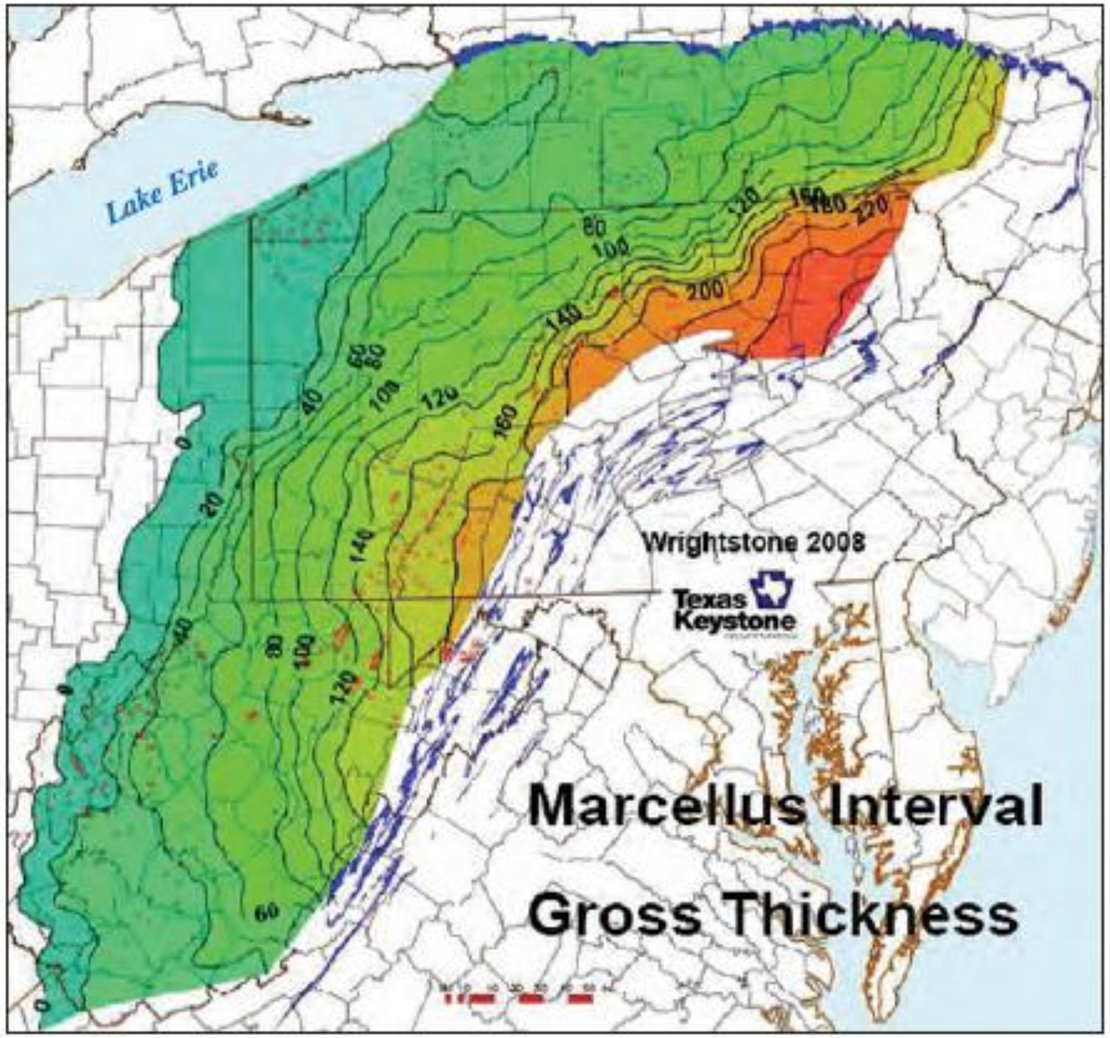




Appalachian Basin: Subsidence History, Shale Reservoirs and Orogenies
Age (Ma)
510
490
470
450
430
410
390
370
350
330
310
290
270
250
0
1000
2000
3000
4000
5000
6000
Depth (m)
Utica Shale
Marcellus Shale
Rhinestreet Shale
Ohio Shale
OROGENY
Taconic
Acadian
Early Collision
Fold Belt
Alleghany
Acadian Unconformity

# Devonian Source Rocks and Migration of Acadian Foredeep

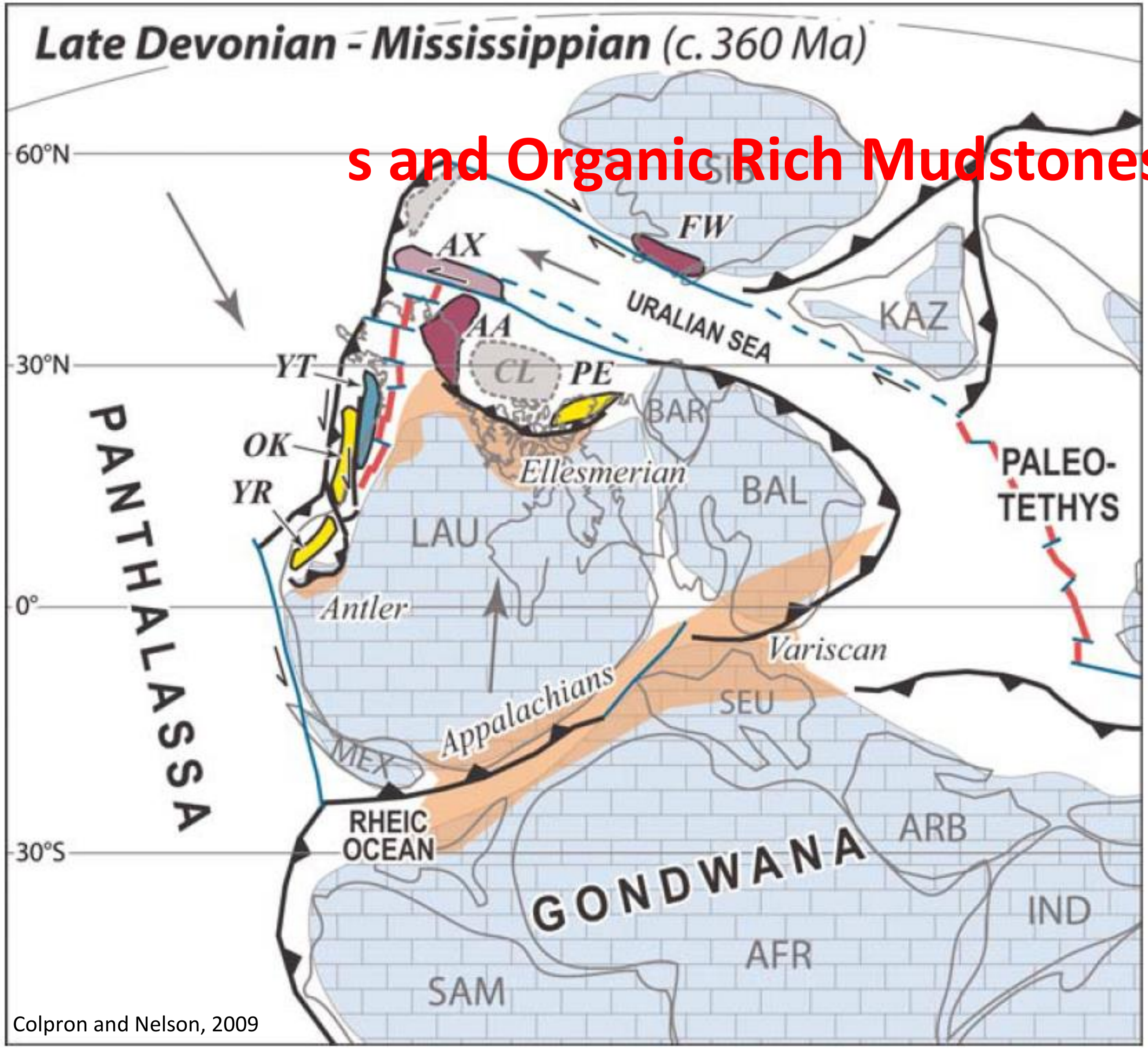


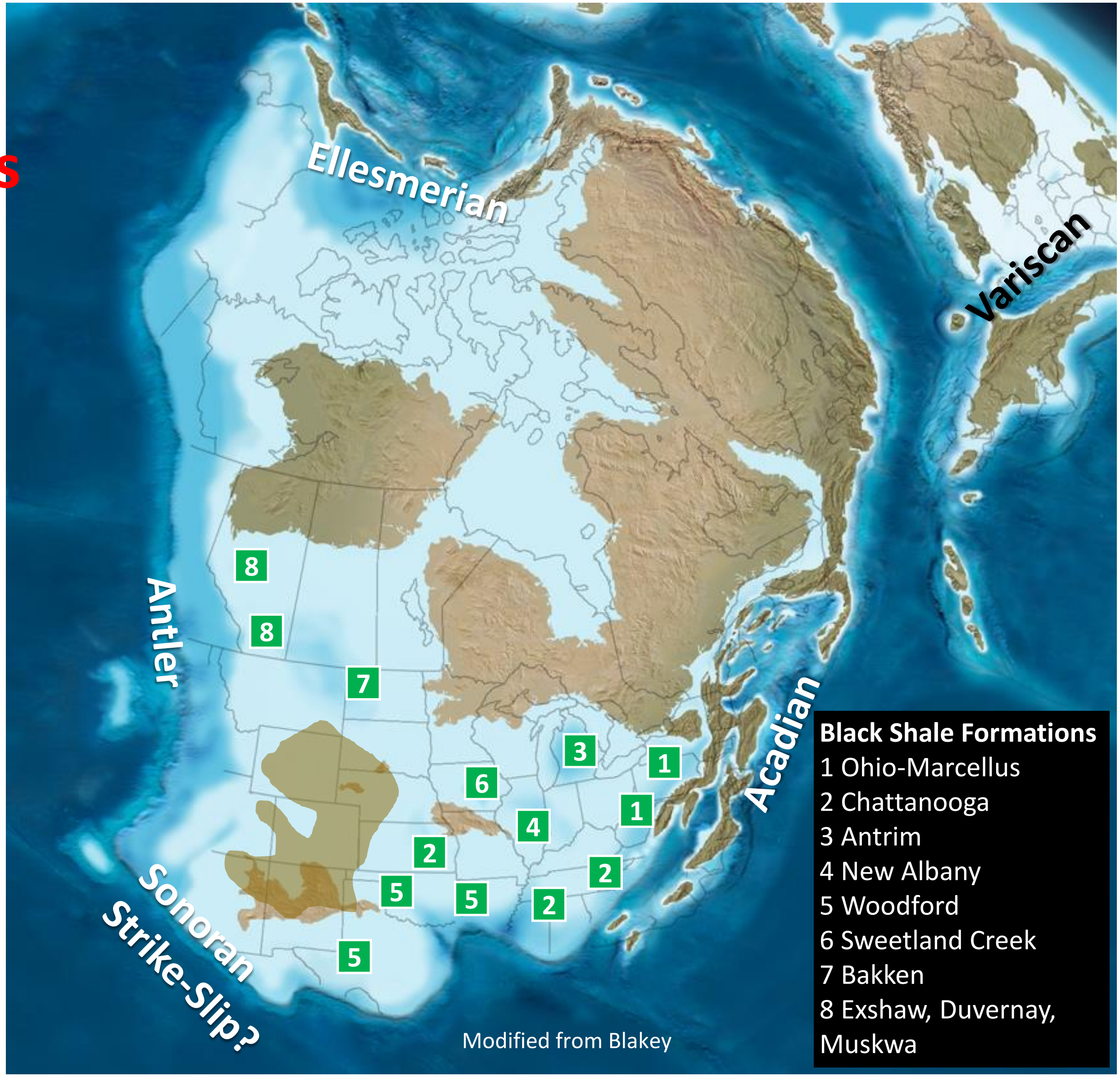




Bruner and Smosner, 2011 (DOE)

# Late Devonian Orogenie

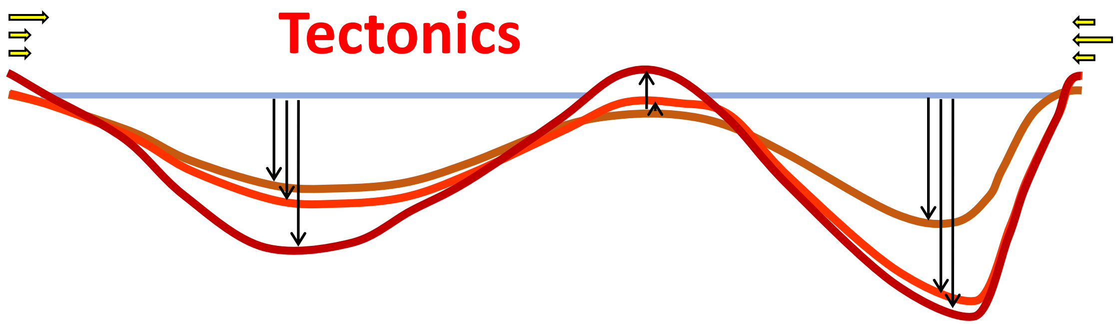
# s and Organic Rich Mudstones



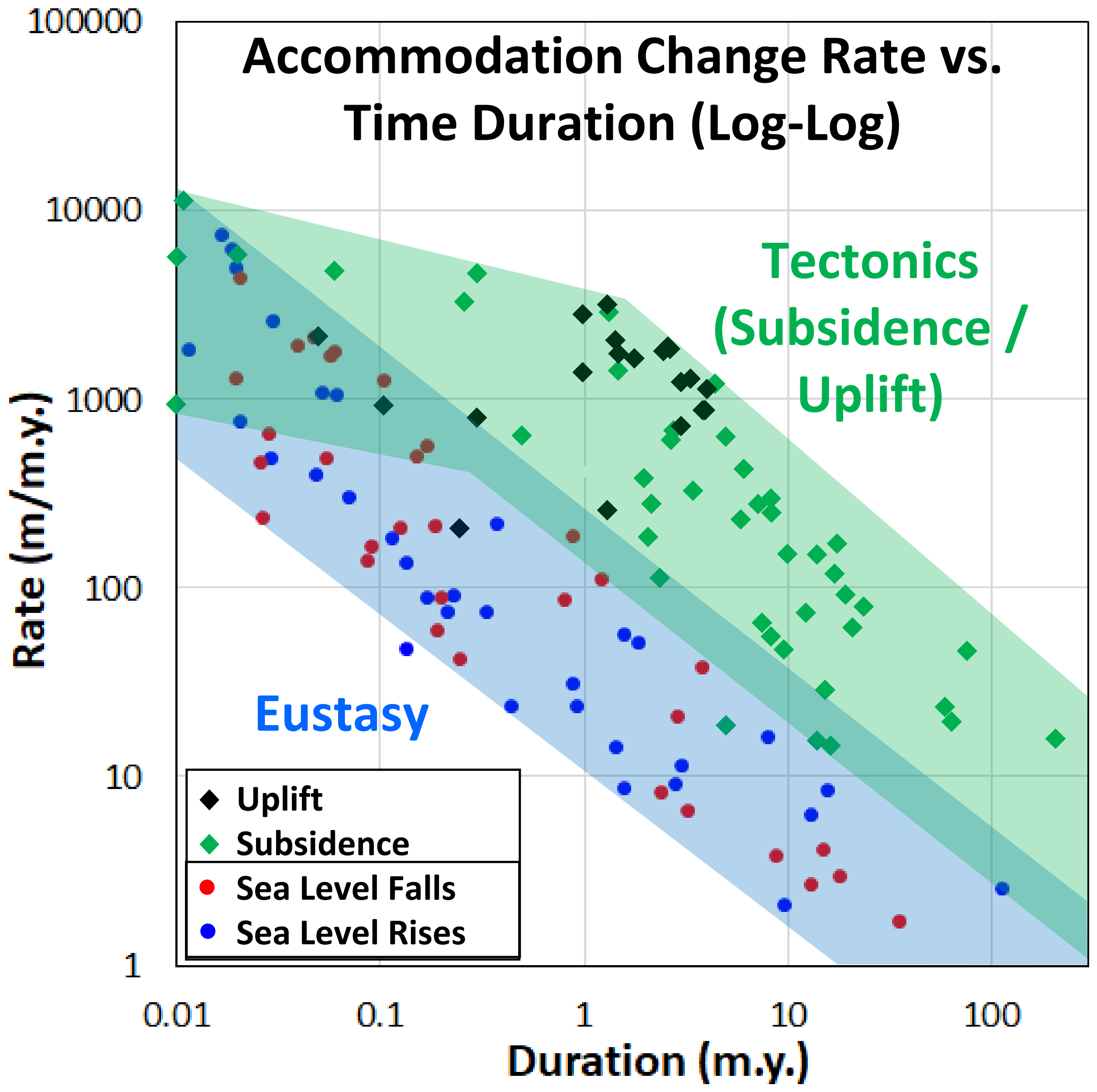



# Accommodation Controls – Eustasy vs. Tectonics

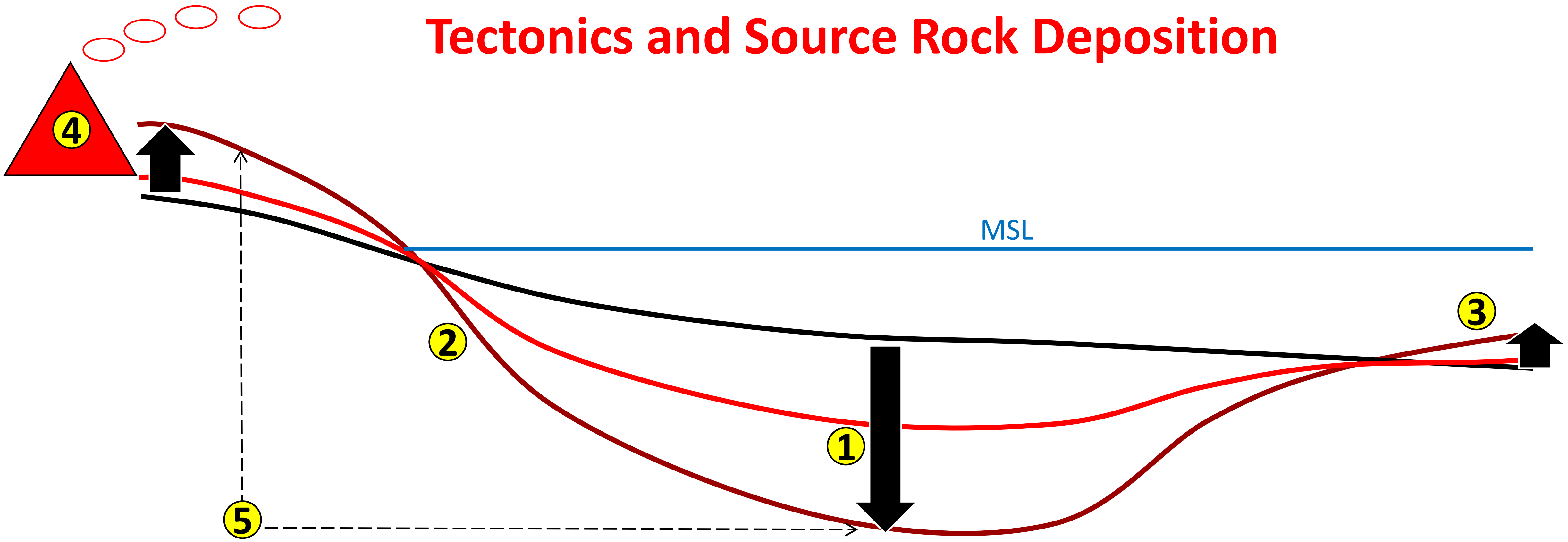

- Globally synchronous, spatially consistent.
- Rates high for durations < 0.1 m.y.
- Detailed internal reservoir architecture usually articulated at this scale.




- Temporally heterogeneous, but often correlative within a basin.
- Magnitude spatially variable and often reversed (uplift and adjacent subsidence) in same basin.
- Rates much higher than eustasy for durations > 0.5 m.y.
- General models more elusive – many “motifs”.
- Source rock and most tight sandstone reservoir intervals at this scale.

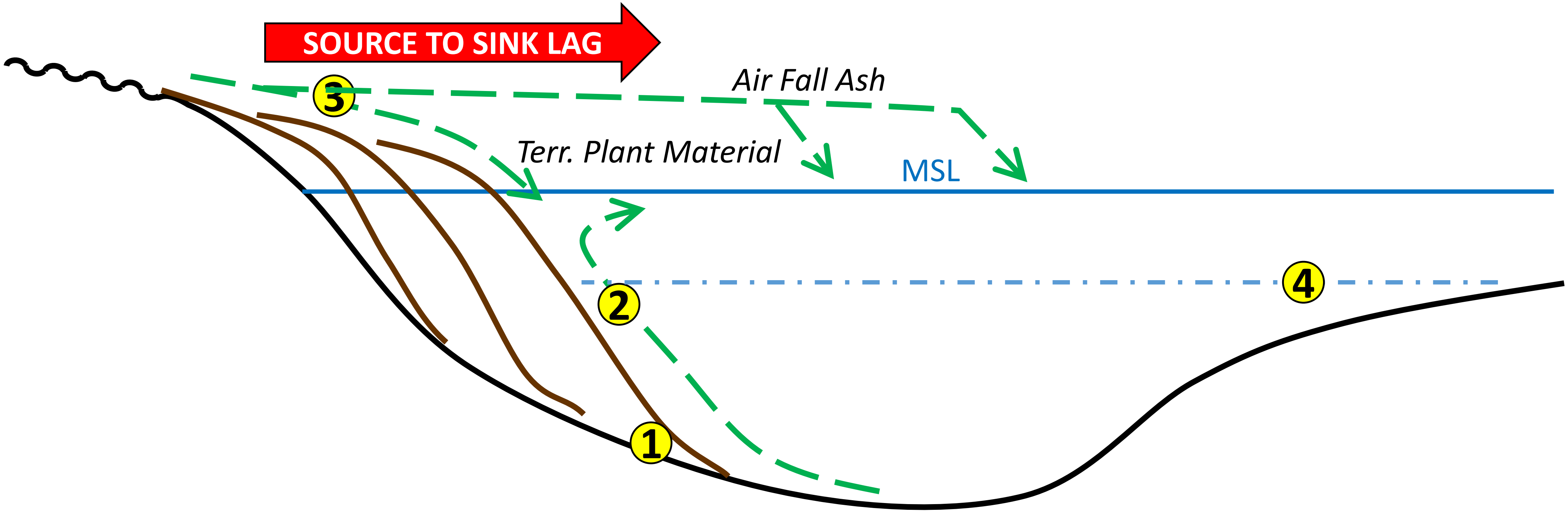


# Tectonics and Source Rock Deposition



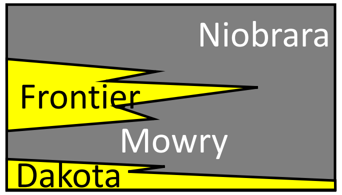

1. Increase in subsidence-related accommodation.
2. Steepening of depositional profile.
3. Differentiation / partitioning of basin.
4. Arc volcanism for retroarc foreland basins.
5. At basin-scale, $2^{nd}$ order unconformities in updip may be ~equivalent to MFS in downdip areas.

# Tectonics and Source Rock Deposition: Possible Elements




1. Condensed section driven by subsidence (concentration of organic matter).
2. Steepened profile, enhancing upwelling (organic productivity)
3. Constructional coastal plain, enhanced terrestrial productivity. Nutrient transport (land plants, volcanic ash).
4. Differentiation of basin, potential silling of water column (dysoxia/preservation)

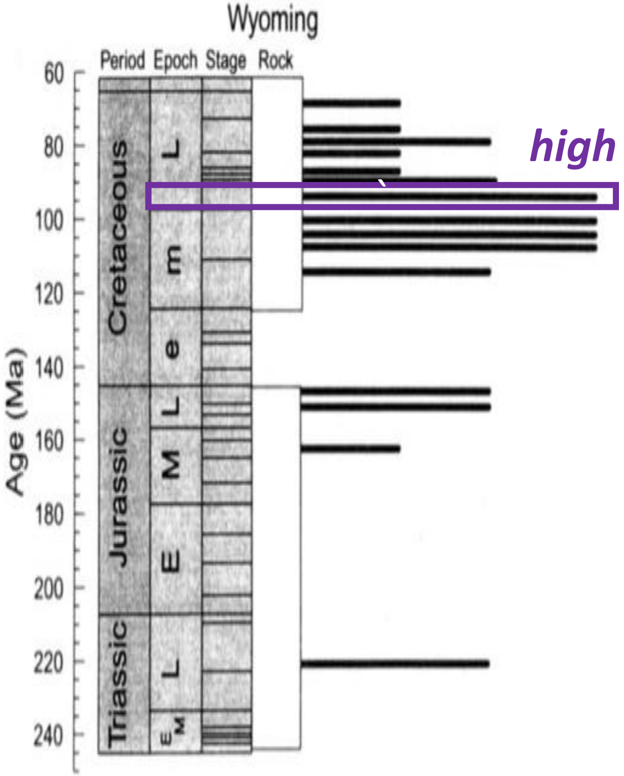
# Volcanic Ash Deposition: Inferred Distribution




Mowry-Niobrara time:

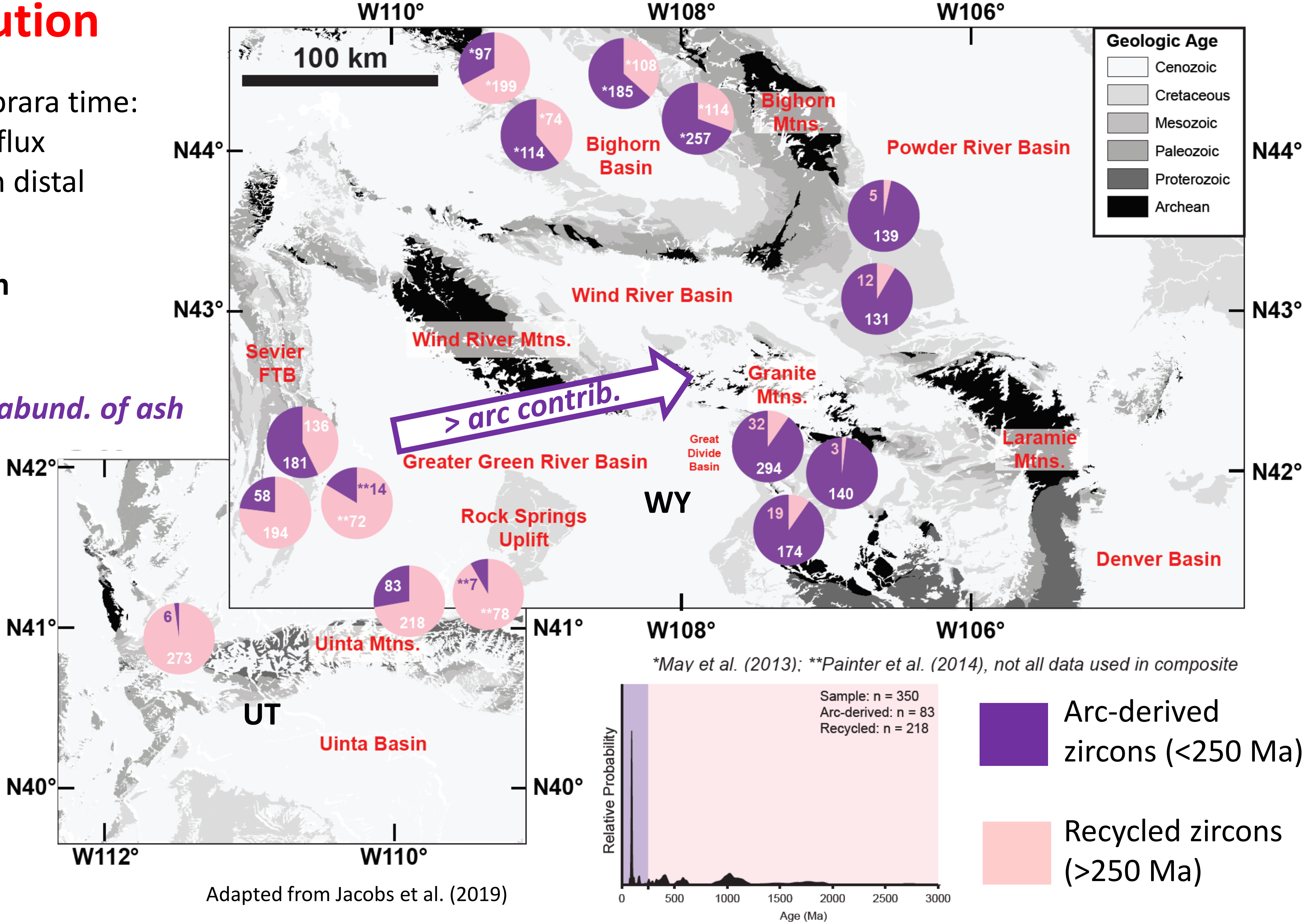
- High arc flux
- More ash distal

## Relative Abund. of Volcanic Ash




Christianson et al. (1994)

## Detrital Zircons: Frontier Fm., U. Cenomanian to L. Coniacian



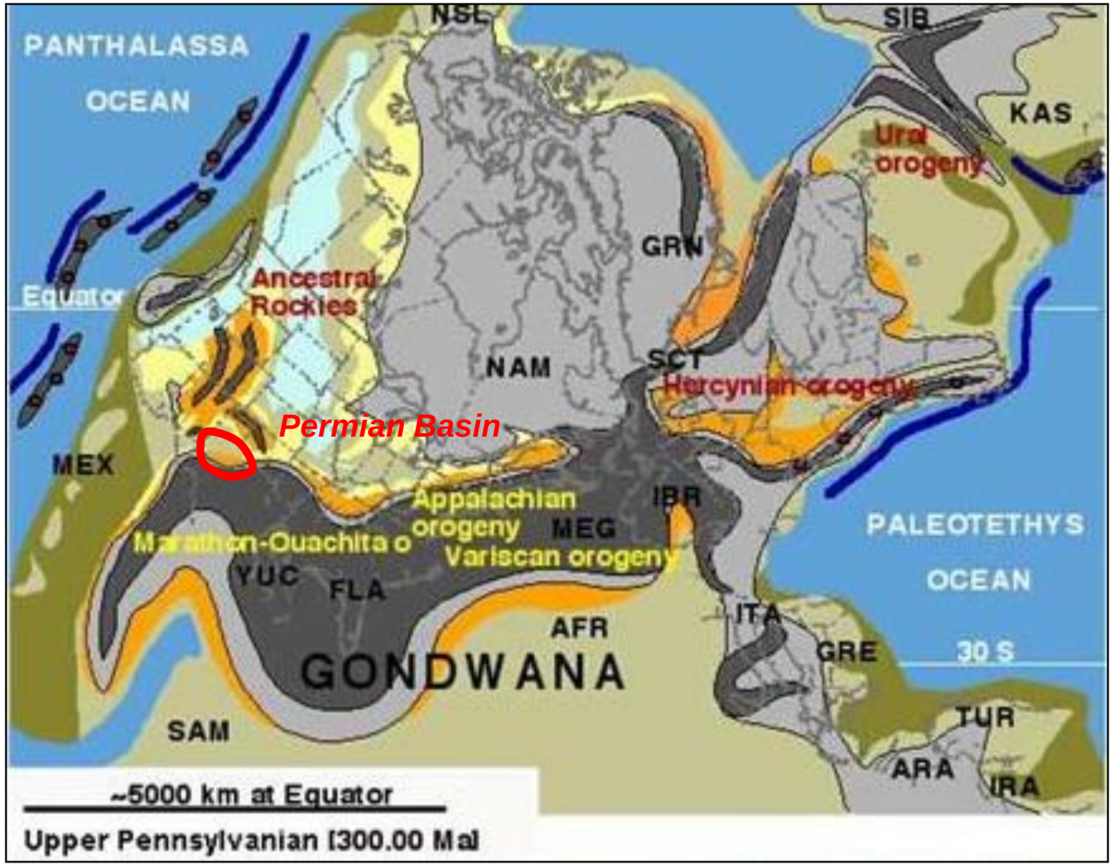

Adapted from Jacobs et al. (2019)

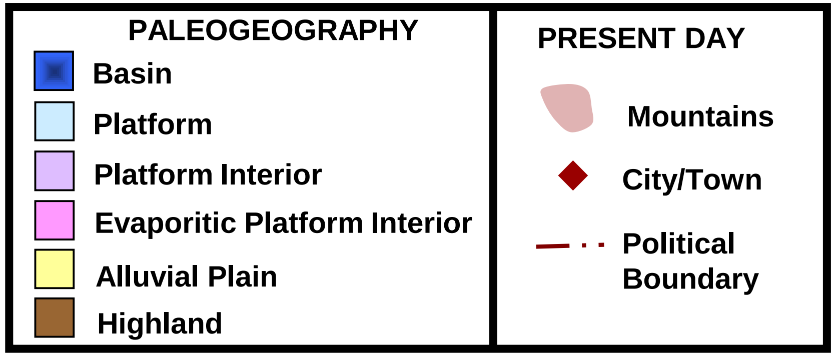
*May et al. (2013); **Painter et al. (2014), not all data used in composite

Arc-derived zircons (<250 Ma)

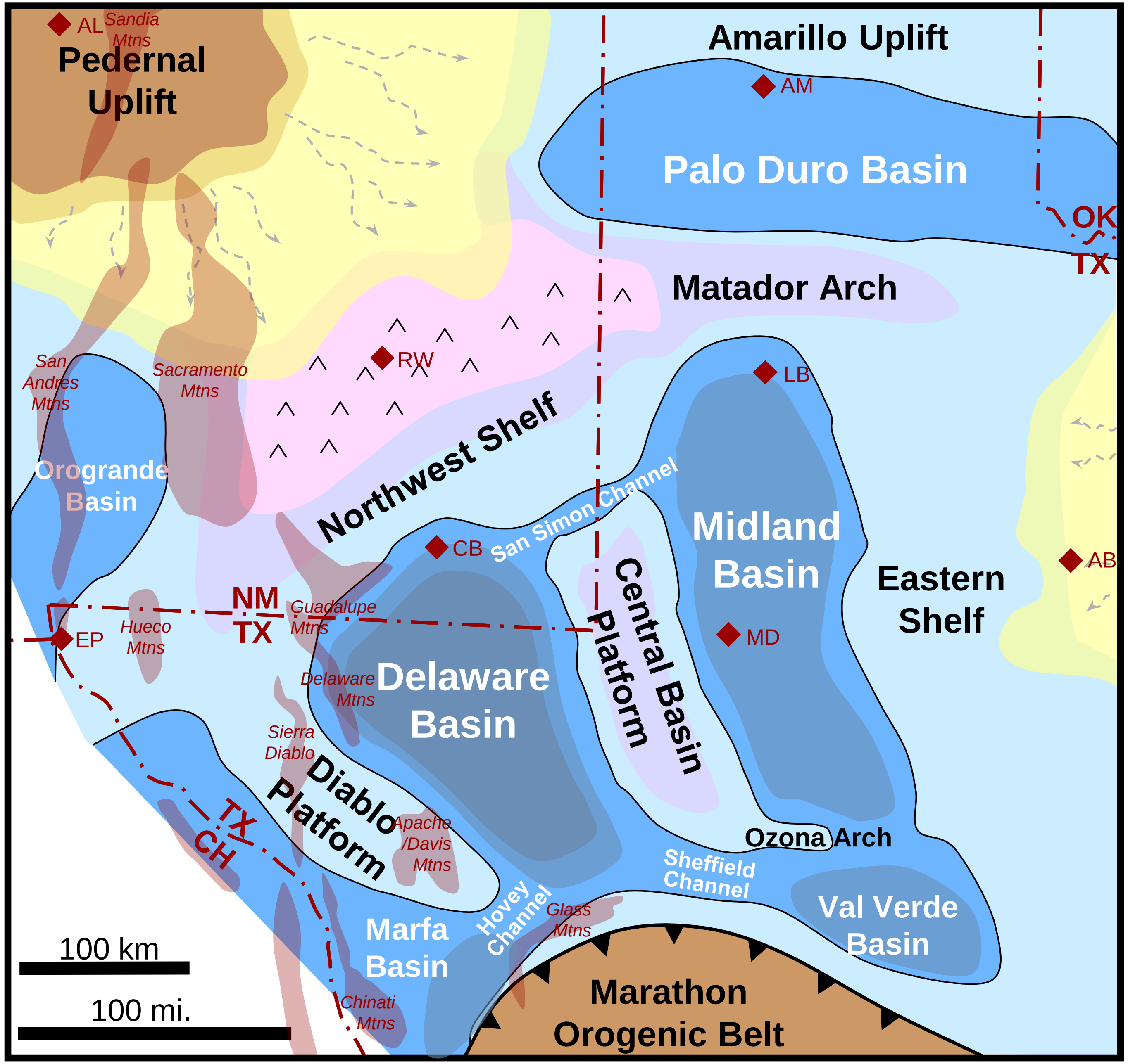
Recycled zircons (>250 Ma)

# Ancestral Rockies and Marathon/Ouachita Orogenies 300 Ma (Late Pennsylvanian)

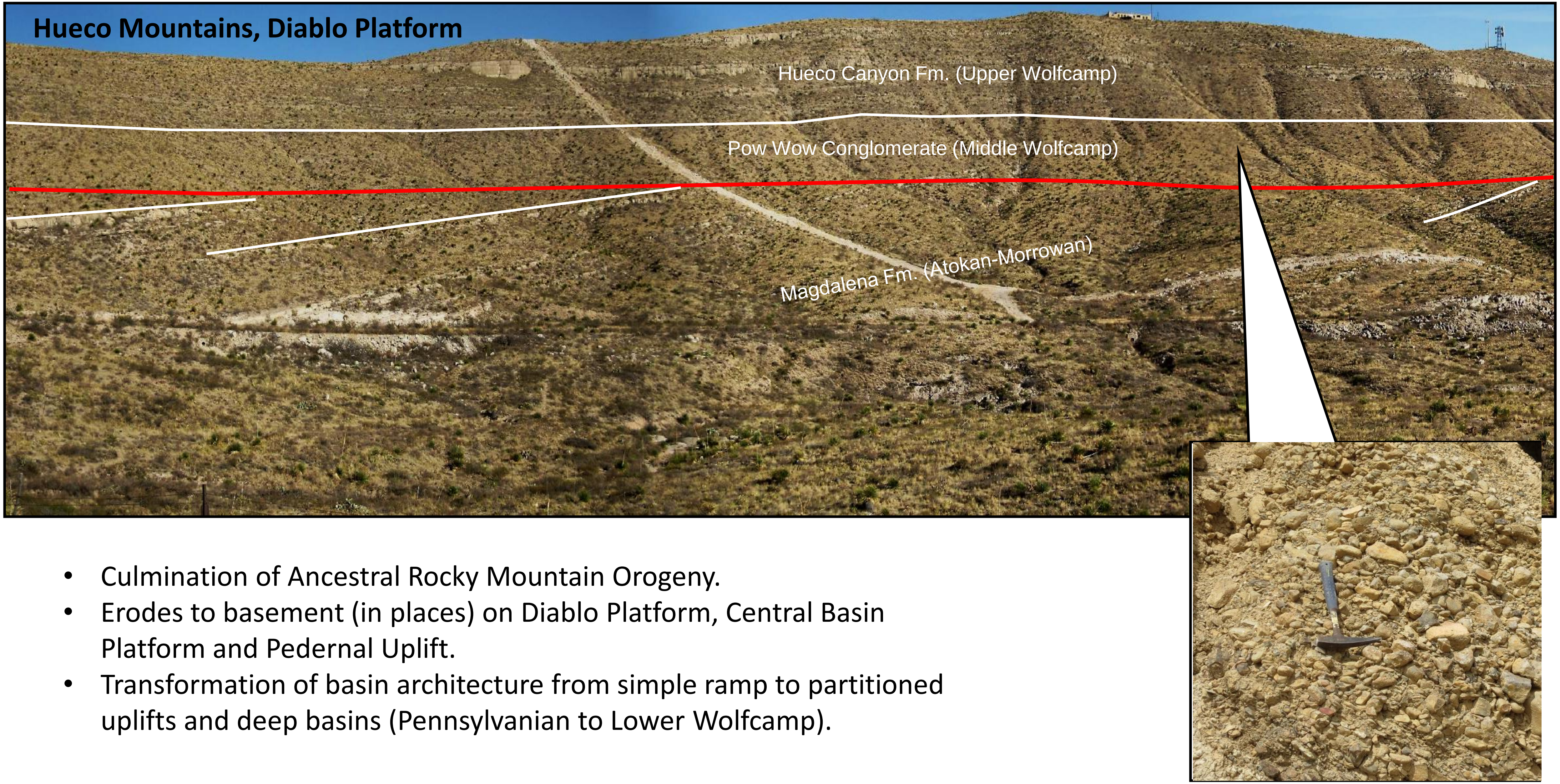



# Permian Basin Paleogeography

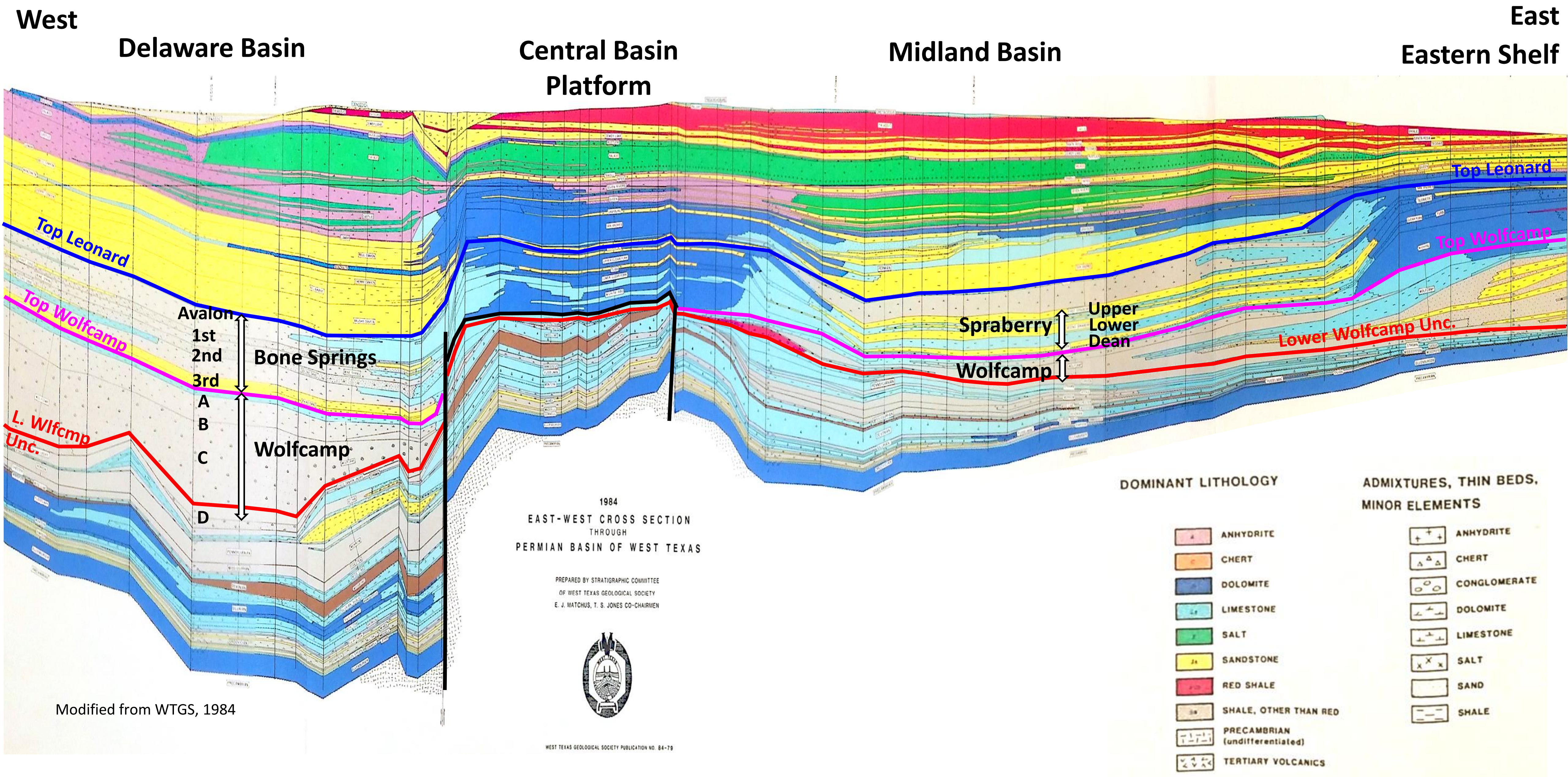


# Lower Wolfcamp Unconformity



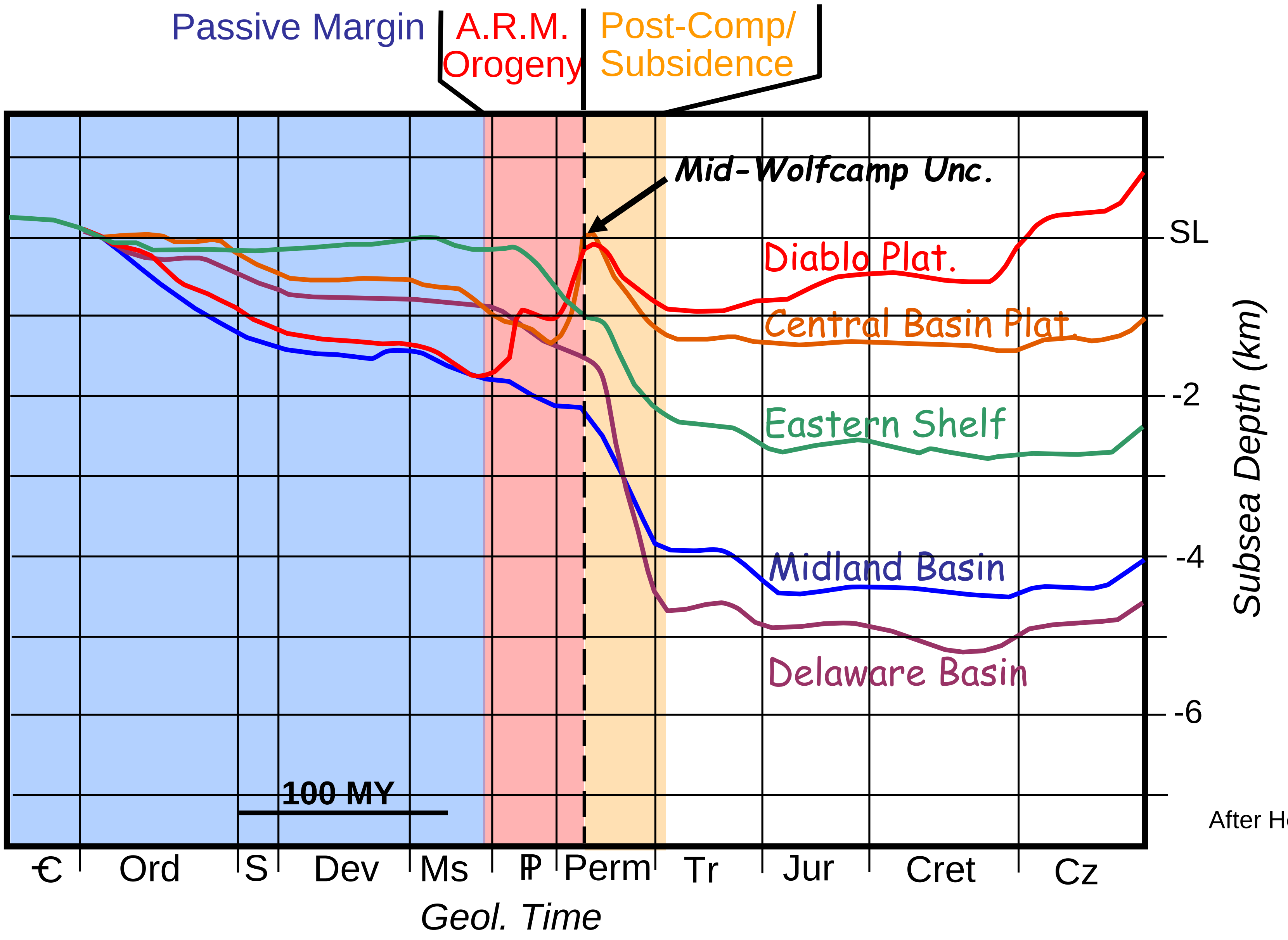

- Culmination of Ancestral Rocky Mountain Orogeny.
- Erodes to basement (in places) on Diablo Platform, Central Basin Platform and Pedernal Uplift.
- Transformation of basin architecture from simple ramp to partitioned uplifts and deep basins (Pennsylvanian to Lower Wolfcamp).

# Permian Basin: East-West Cross Section




Modified from WTGS, 1984

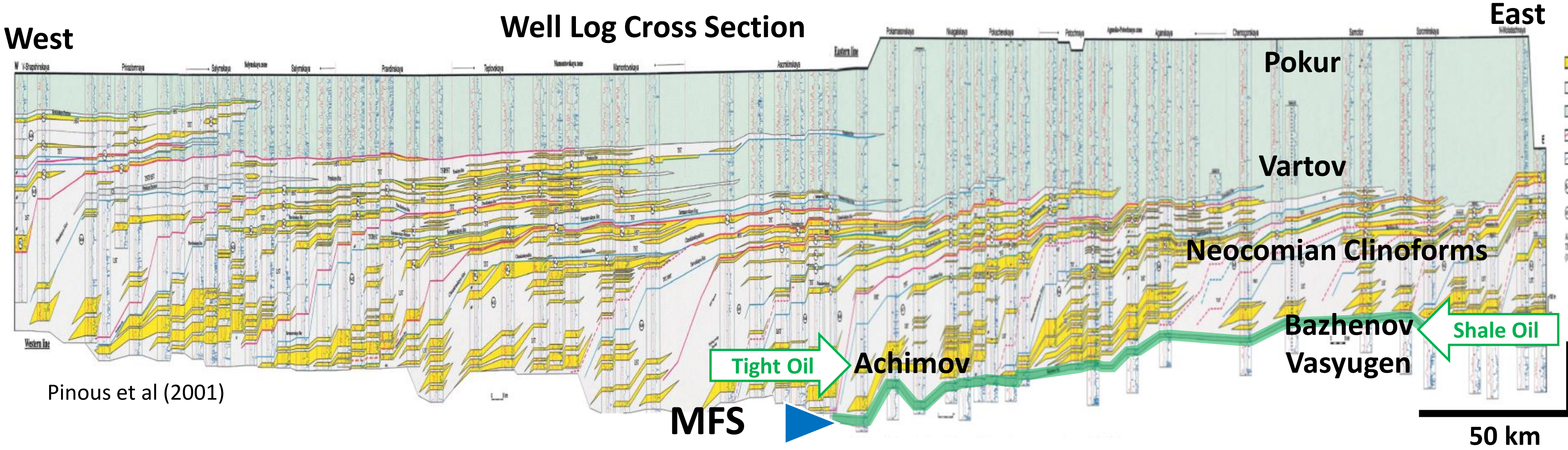
# Permian Basin: Subsidence History & Tectonic Phases

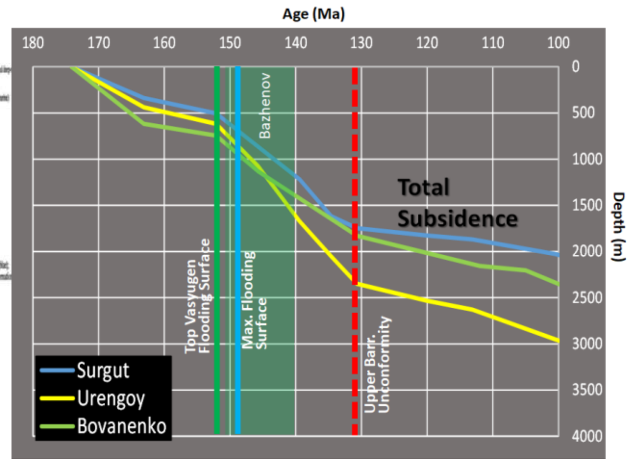



After Horak, 1985

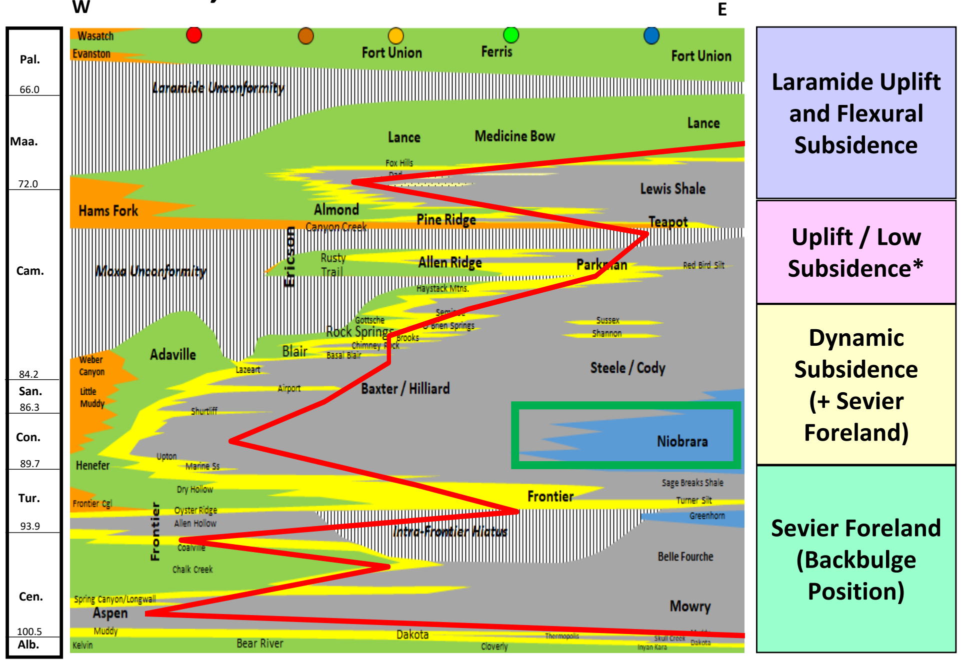
# Other Examples of Source Rock Reservoirs Associated with Tectono-Subsidence

## Bazhenov, West Siberia Basin

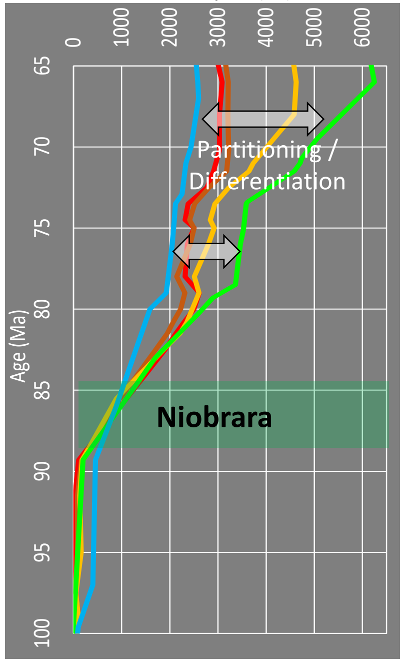


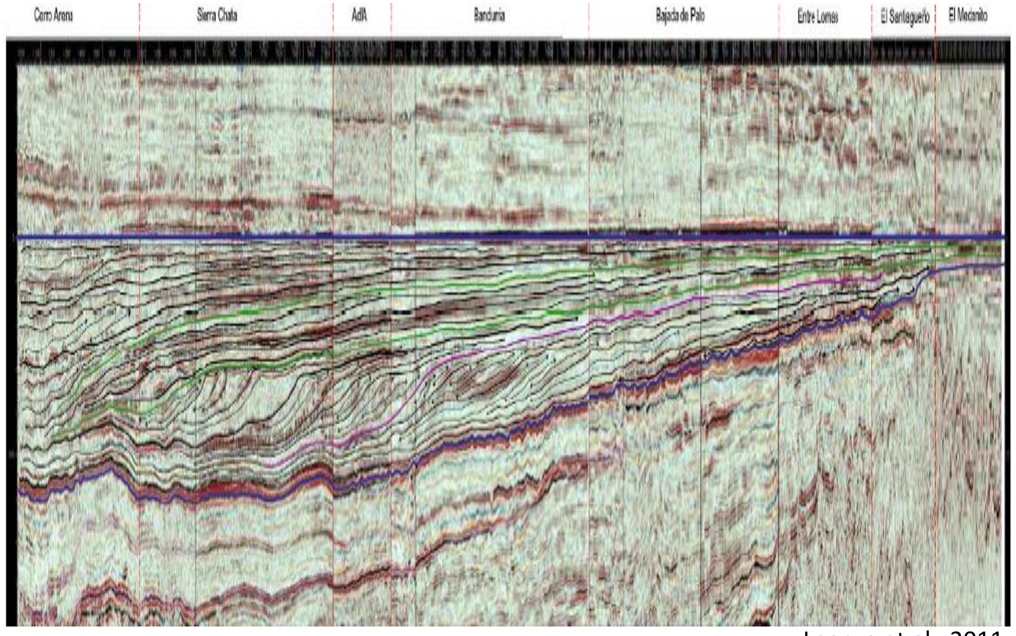

## Niobrara, Denver-Powder River Basins



Modified from Rudolph et al (2015)

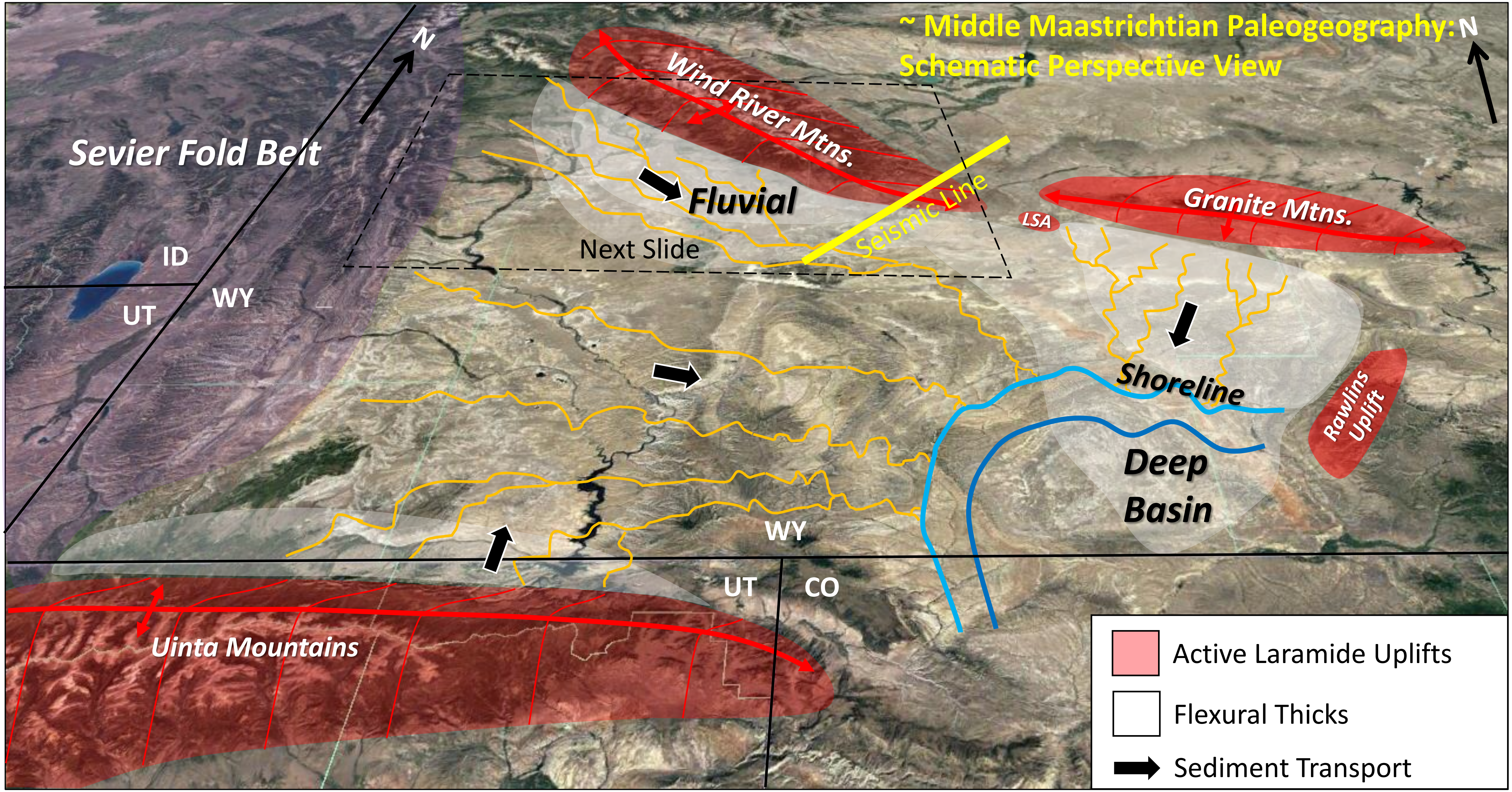



## Vaca Muerta, Neuquén Basin

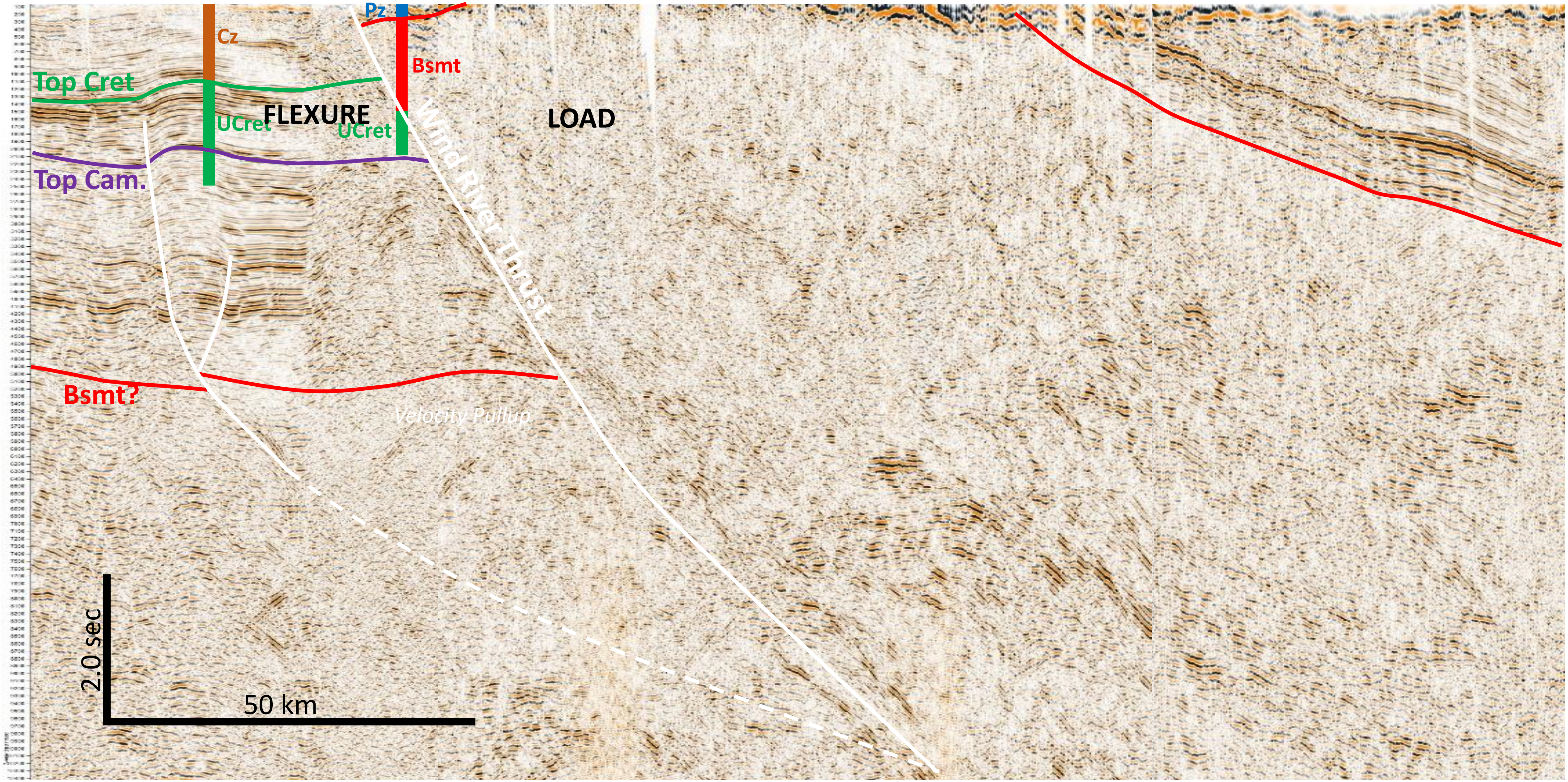


Leanza et al., 2011

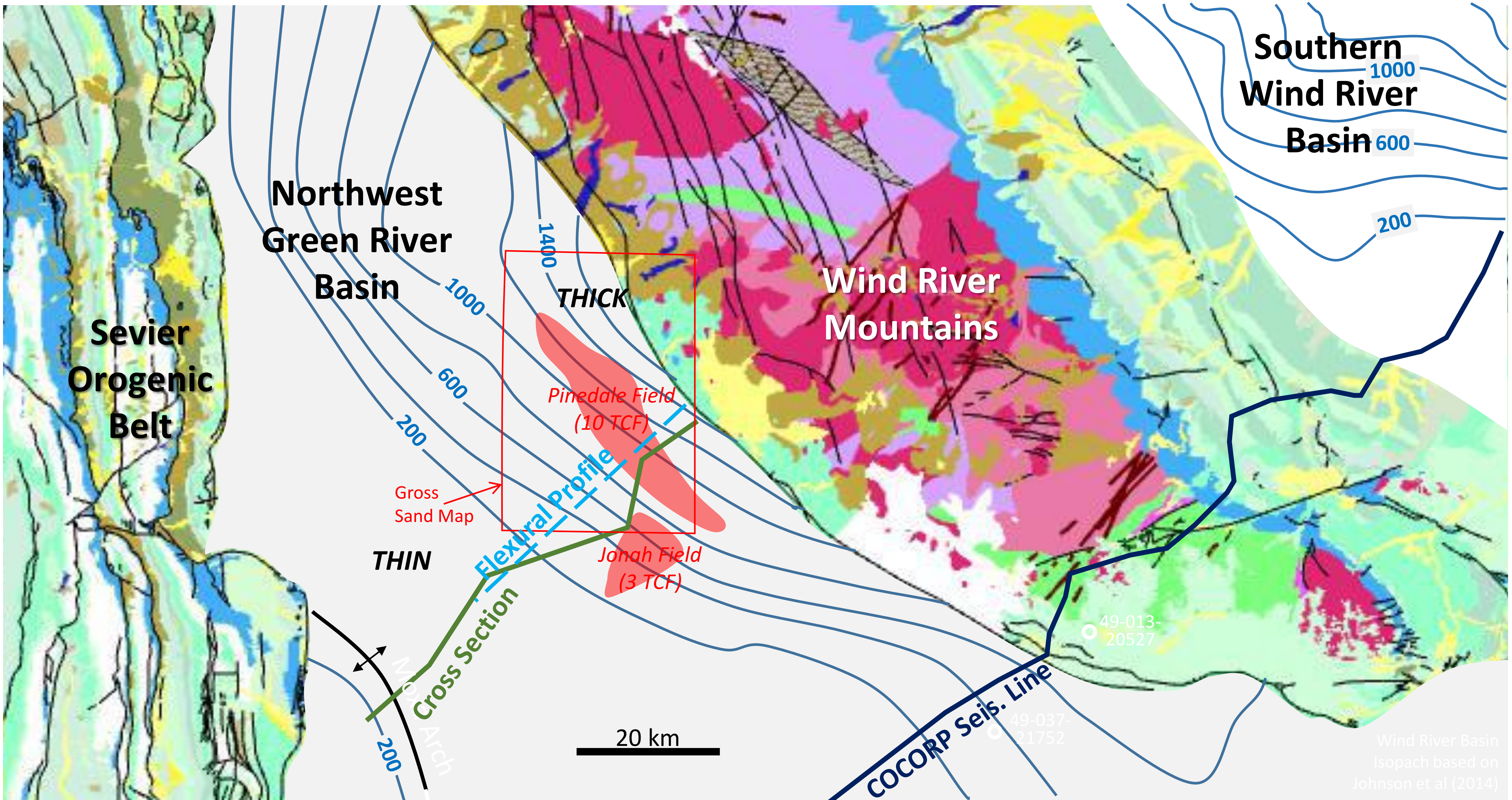
# Tight Sandstone Reservoirs: Green River Basin Example

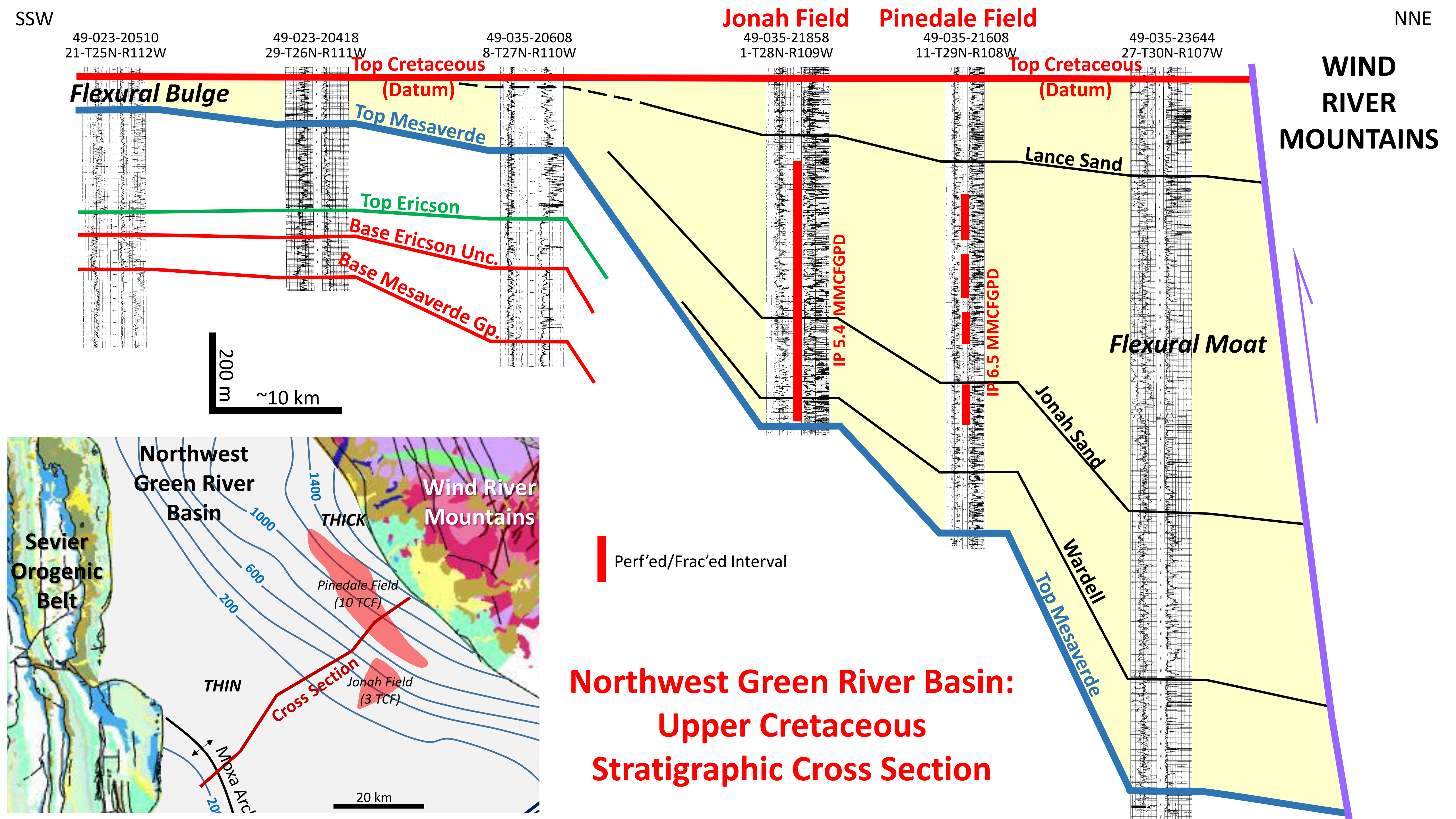


# COCORP Seismic Line



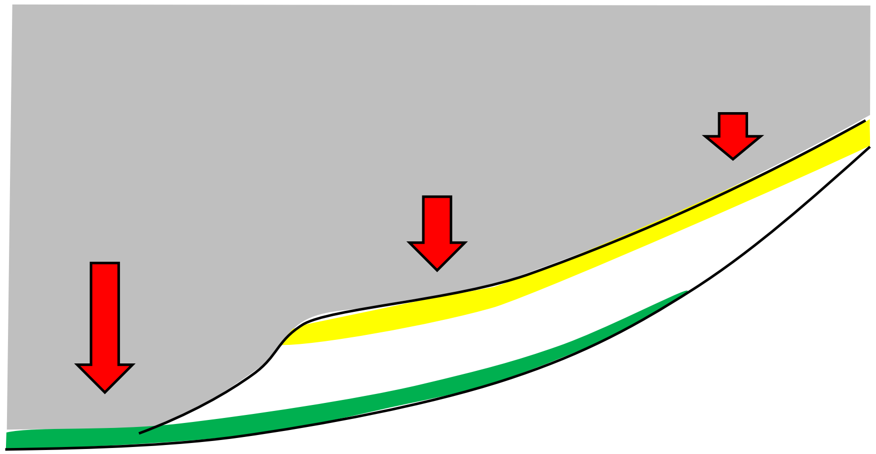
# NW Green River Basin: Surface Geology and Lance (~Maastrichtian) Isopach





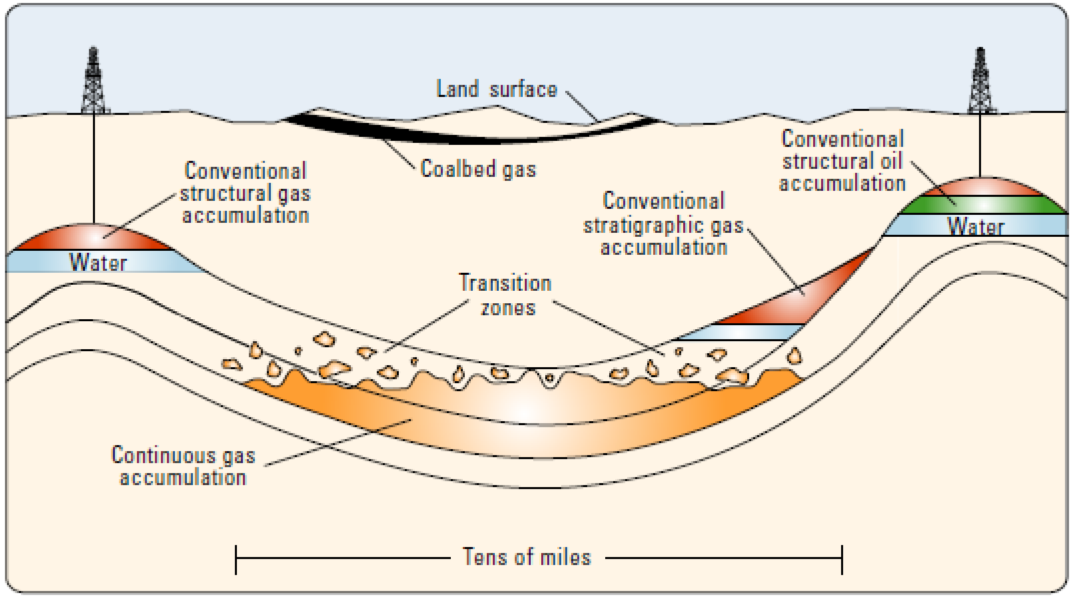
SSW
NNE
Jonah Field
Pinedale Field
49-023-20510
21-T25N-R112W
49-023-20418
29-T26N-R111W
49-035-20608
8-T27N-R110W
49-035-21858
1-T28N-R109W
49-035-21608
11-T29N-R108W
49-035-23644
27-T30N-R107W
Top Cretaceous (Datum)
Top Cretaceous (Datum)
WIND RIVER MOUNTAINS
Flexural Bulge
Top Mesaverde
Lance Sand
Top Ericson
Base Ericson Unc.
Base Mesaverde Gp.
IP 5.4 MMCFGPD
IP 6.5 MMCFGPD
Flexural Moat
200 m
~10 km
Jonah Sand
Wardell
Top Mesaverde
Perf'ed/Frac'ed Interval
Northwest Green River Basin
Sevier Orogenic Belt
Wind River Mountains
1400
1000
600
200
THICK
THIN
Pinedale Field (10 TCF)
Jonah Field (3 TCF)
Cross Section
Moxa Arch
20 km
Northwest Green River Basin:
Upper Cretaceous
Stratigraphic Cross Section

# Burial / Maturation

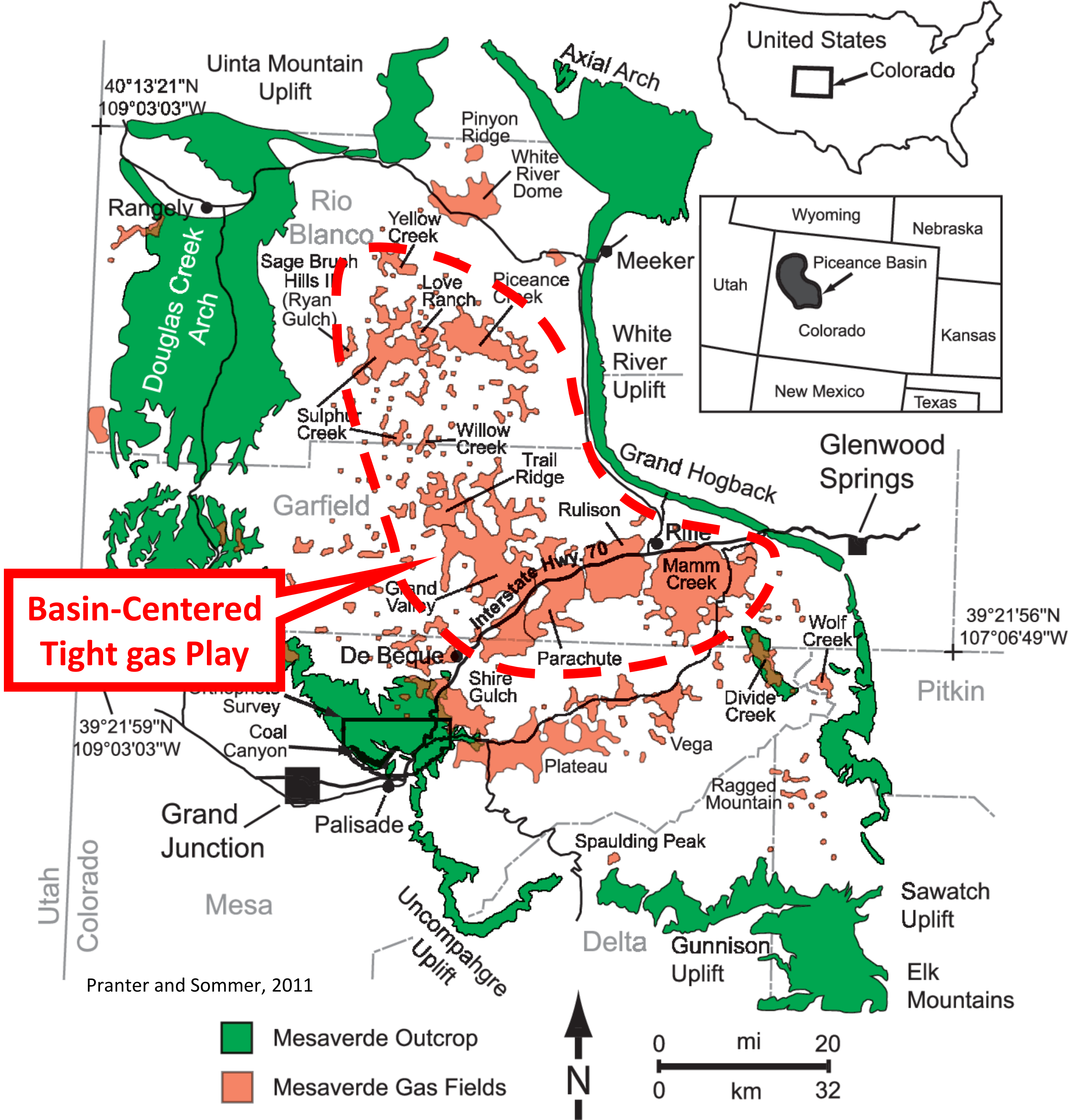


Reservoir Compaction/Diagenesis
Source Maturation
Pressure Development

# Piceance Basin: Tight Sandstone Example (gas)




USGS Assessment Team, 2002



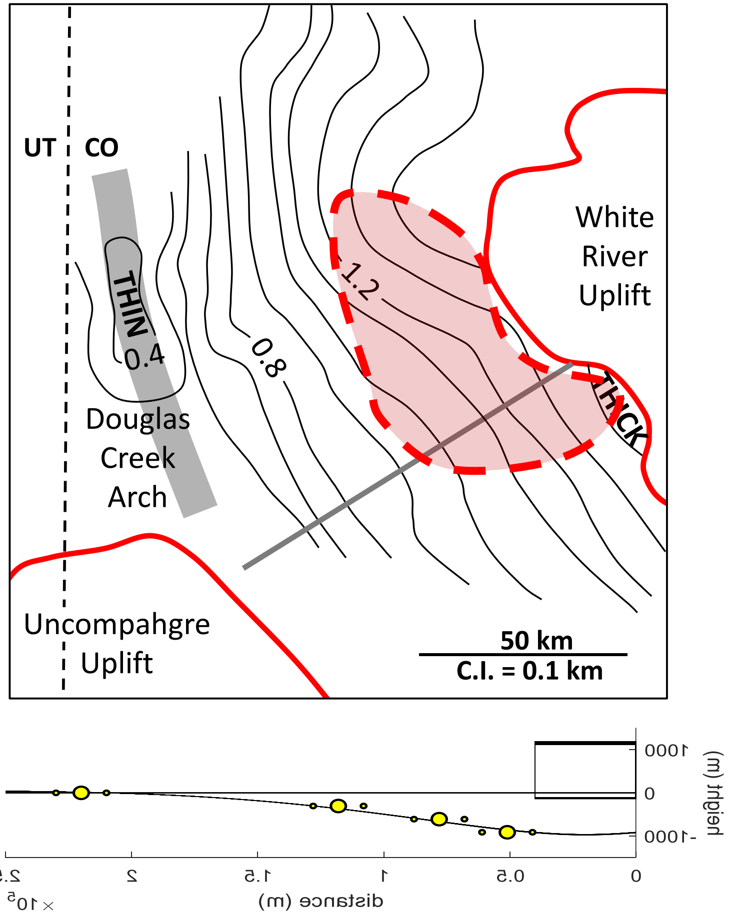

Pranter and Sommer, 2011

# Piceance Basin: Isopachs (km)

Flexural thick developed west of a major Laramide uplift (White River Mountains).
Provides space for deposition of thick non-marine reservoir interval (Upper Cretaceous).
Deposition of overburden (Paleoc.-Eoc.) that matures coaly gas sources and develops capillary seal of tight sandstones.

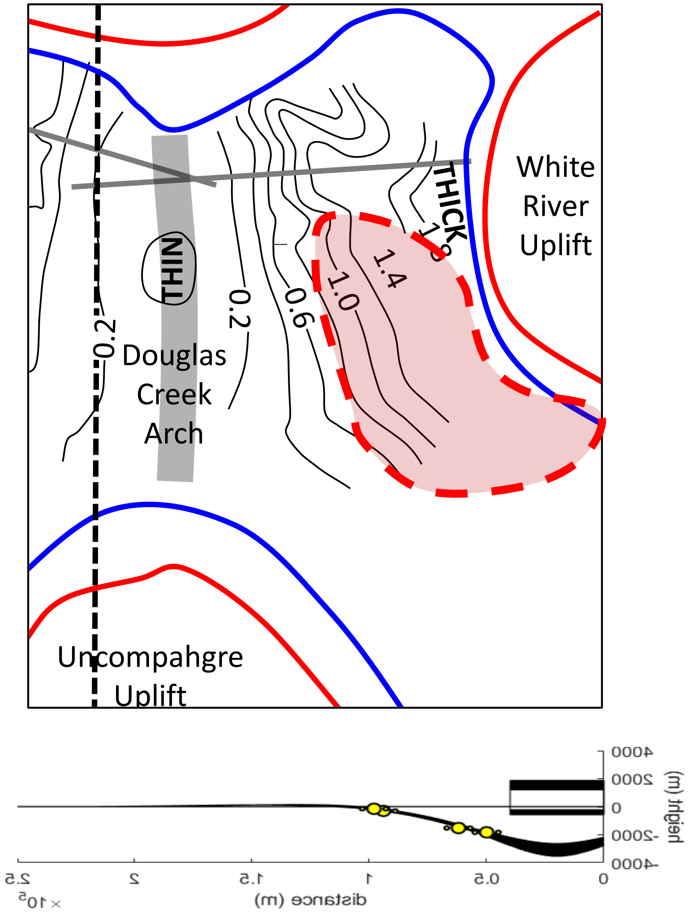
## Reservoir Deposition

Upper Campanian - Maastrichtian

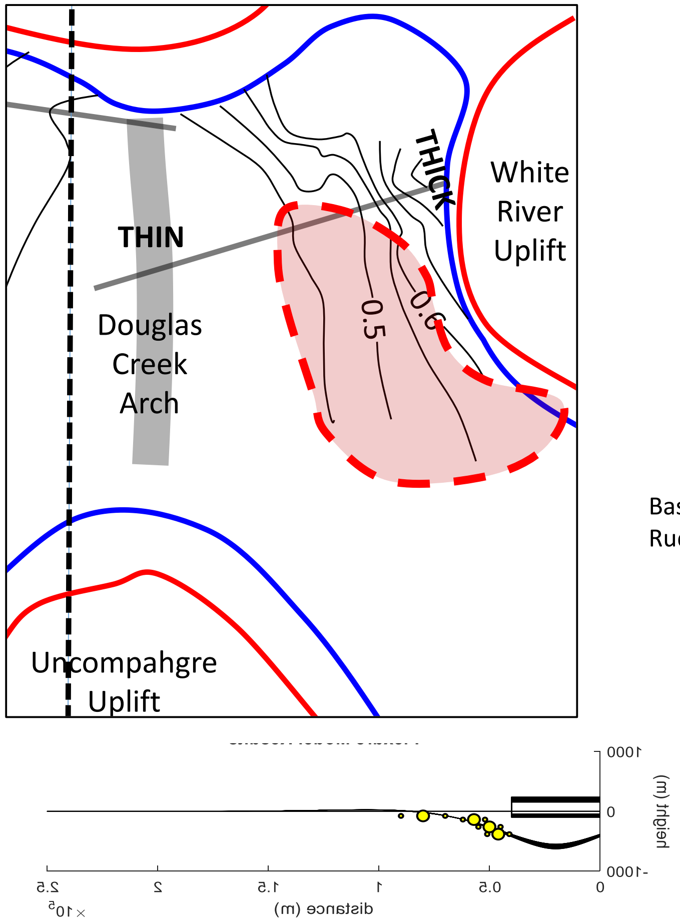


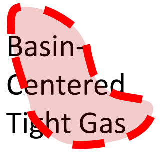

## Burial – Source Maturity and Porosity Evolution

Paleocene – Lower Eocene




Upper Eocene

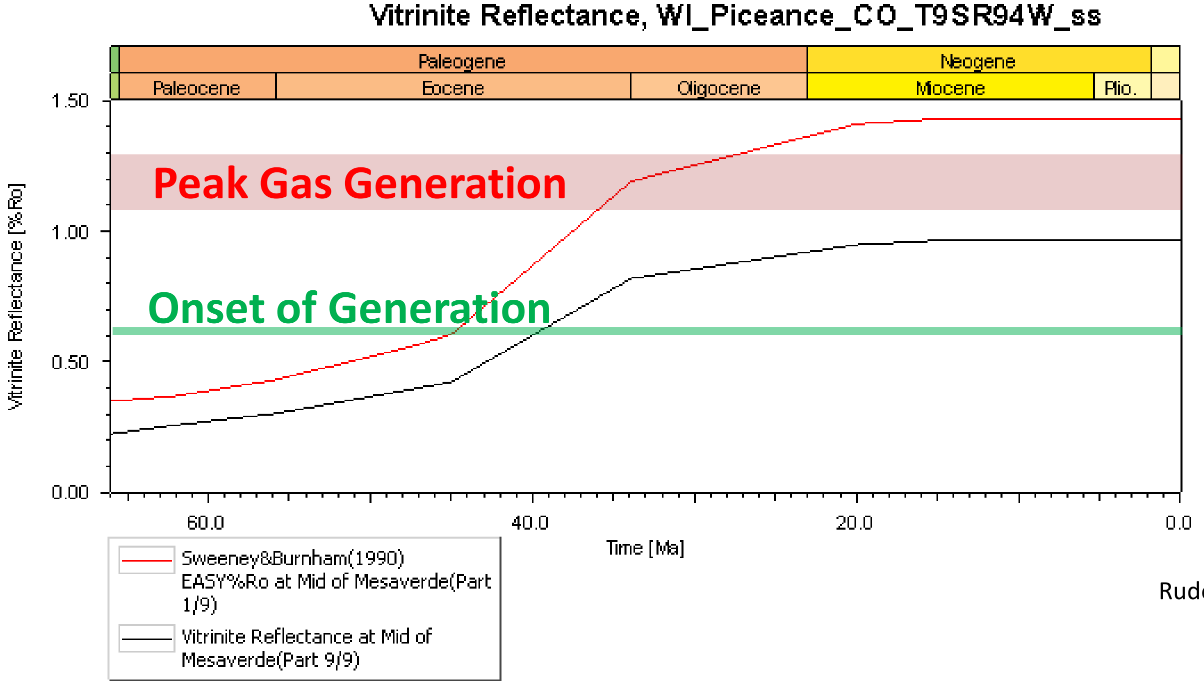



Based on Saylor and Rudolph, in prep.

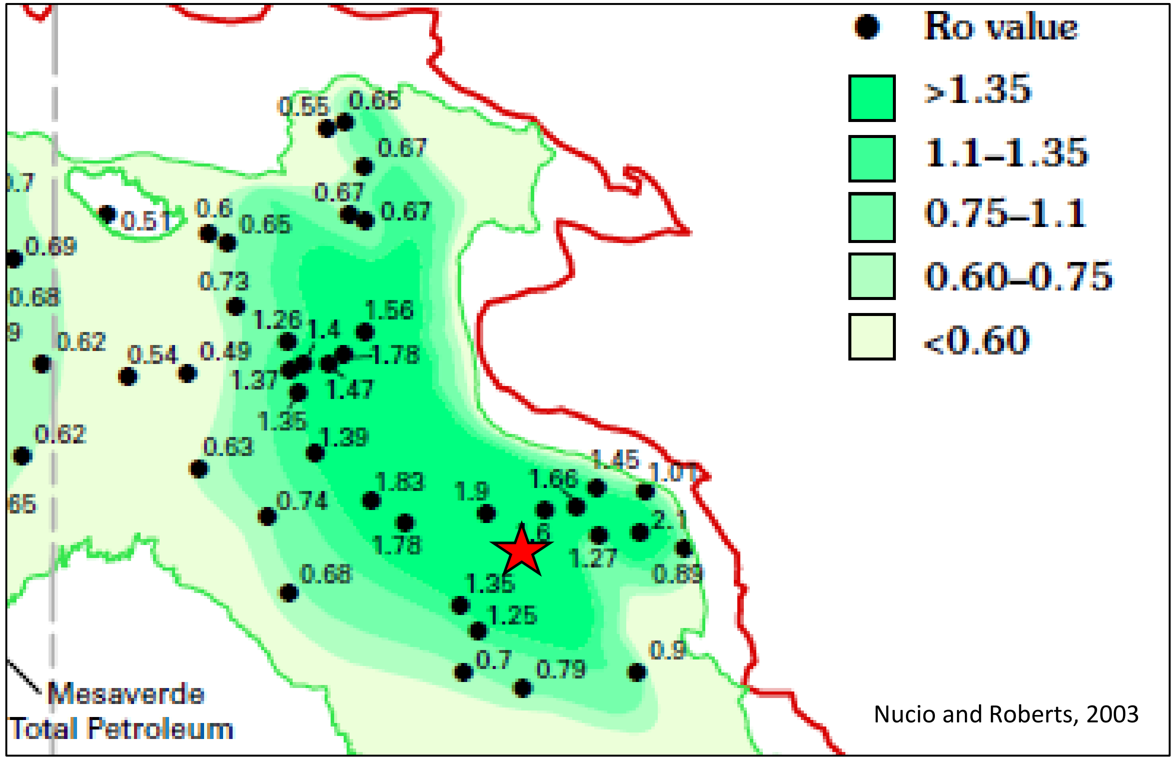
**Flexure Models**

# Piceance Basin: Mesaverde Coal Maturity (Gas Source)



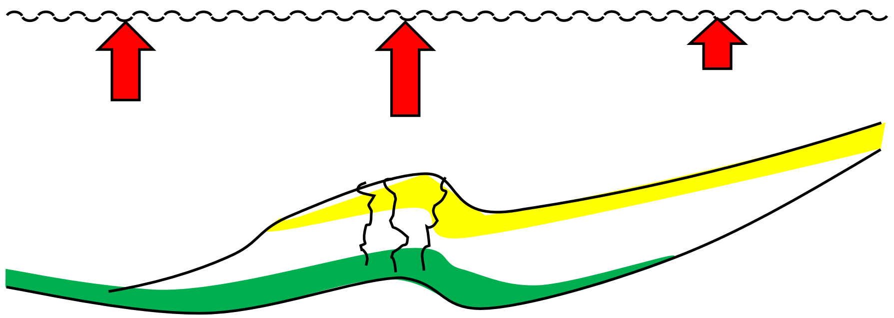

Rudolph

Vitrinite Reflectance (Ro) at base of Mesaverde Gp.



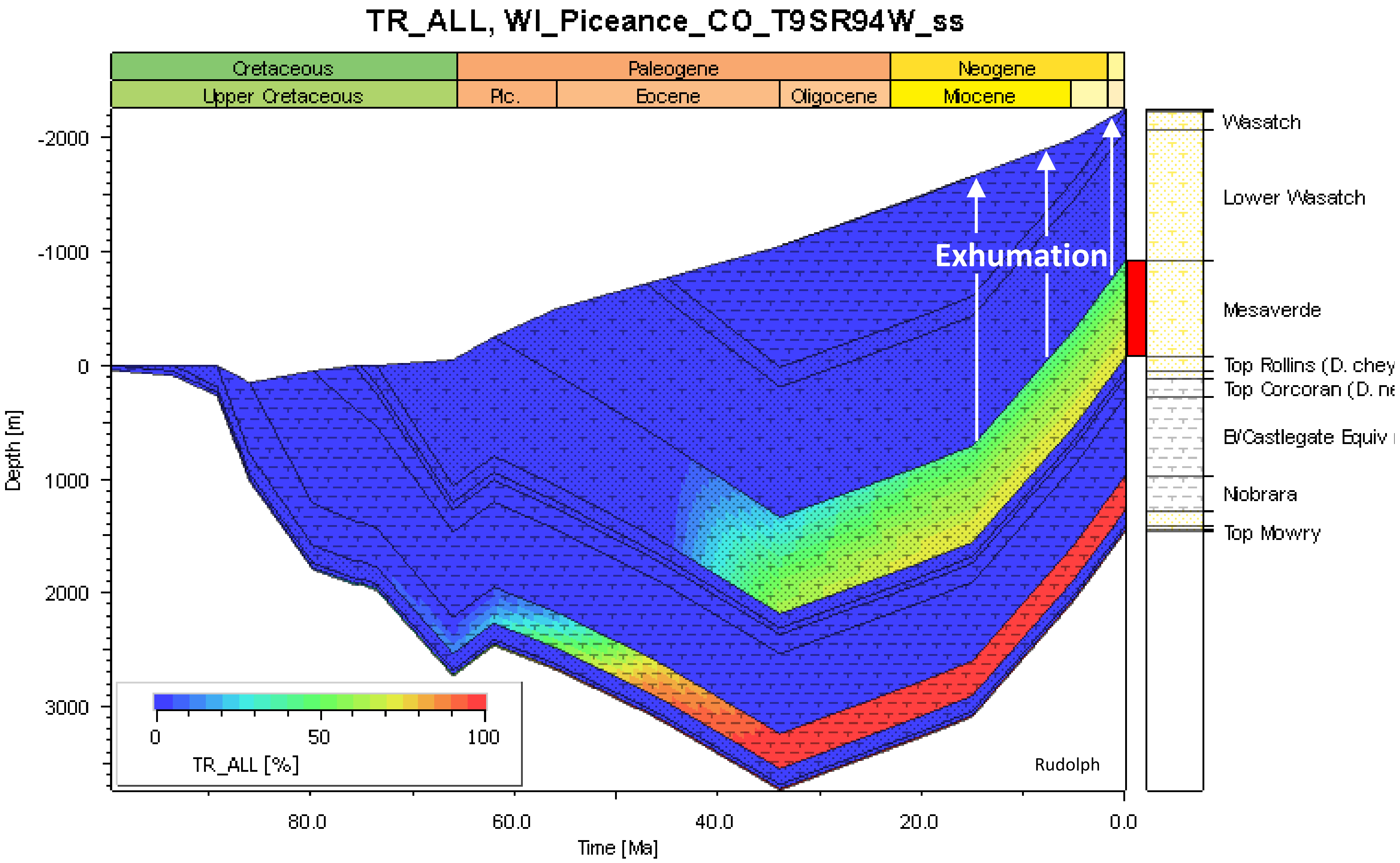

Nucio and Roberts, 2003

# Deformation and Exhumation



Oil Biodegradation
Pressure Modification
Natural Fractures
Drilling Depth

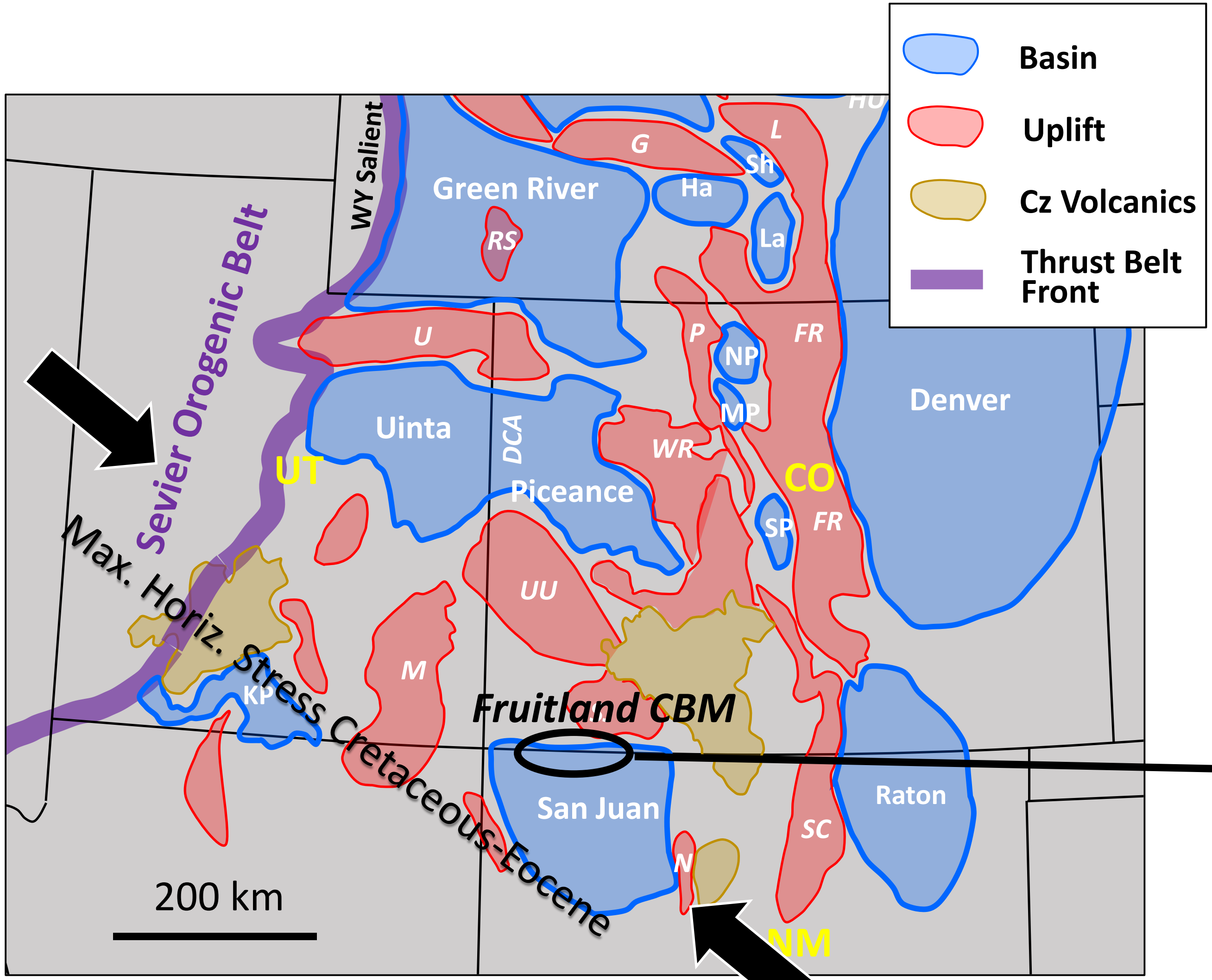
# Piceance Basin: Burial History




- Approximately 1.2 km of exhumation in Neogene.
- Related to uplift of Colorado Plateau and more widespread epeirogenic uplift of western North America.
- Potential implications of exhumation:
  - Shallower drilling targets
  - End of gas generation
  - Overpressure
  - Microfractures via unloading

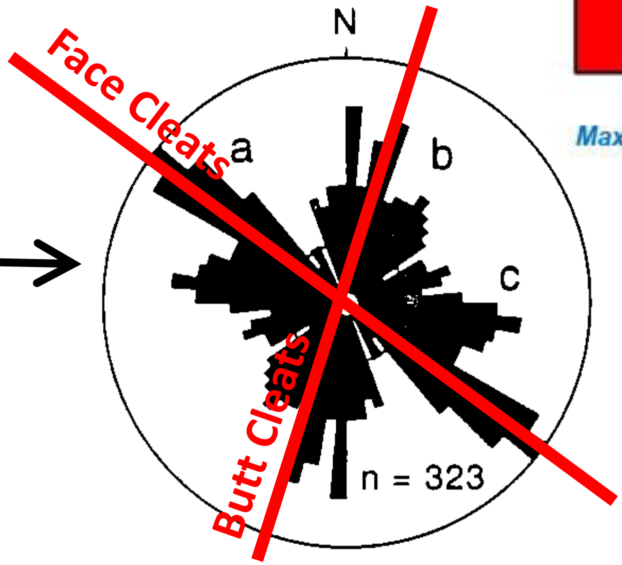
# Fracture Example: Fruitland Coal Bed Methane, San Juan Basin, NM

Paleo-Stress Direction controls cleat orientation.
Horizontal wells need to be oriented to intersect face cleats orthogonally.

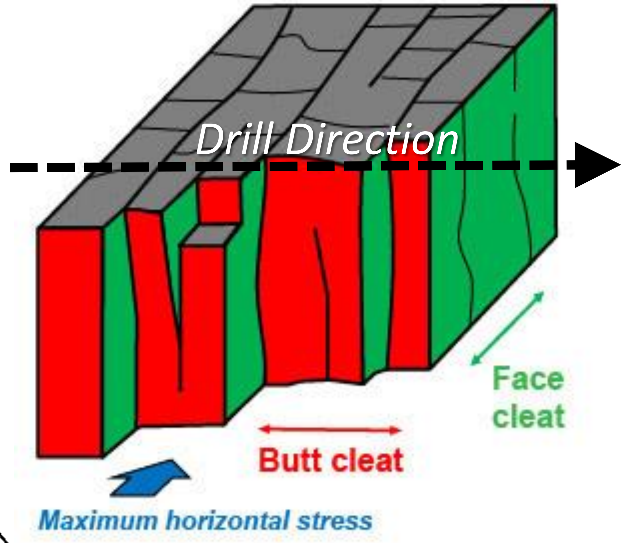



Partly based on Heller and Lui (2016)

**Fruitland Cleat Orientation, Ft. Lewis, CO**




Tremain et al. (1994)



# Research Questions of Industry Interest

Understanding the original porosity and permeability in tight unconventional reservoirs:

Quantitative and accurate estimates of organo-porosity, inter-particle, intra-particle and adsorbed gas.

Role of natural microfractures for permeability.

What is the impact of exhumation, which is common to many unconventional plays?

Under what circumstances are hydrocarbons and pressure retained?

What geologic histories lead to capillary entrapment (basin-centered gas) and can we reliably predict its occurrence?

What is the correct way to understand and model aggregate properties ("scale-up") relative to flow.

The fine-scale matters, but as it composites over ~50m frac height and 3 km lateral?

Appropriate sequence stratigraphy models at the basin-wide, 2$^{nd}$ order scale (i.e., not LST-TST-HST schema)

What is the induced <u>propped</u> fracture network and can we better predict it?

Microseismic only gives us a rough picture of the entire fracture network, most of which does not contain proppant.

Is there an environmentally more benign way to extract heavy oil, which makes up a large portion of remaining oil resources, but has a large carbon footprint.

Influence of volcanism on organic productivity.

# Closing Comments

Predicting, understanding and developing unconventional petroleum reservoirs has historically relied on empirical indicators, direct analysis/interpretation and field experimentation.

However, the same basin-scale controls that are germane to conventional resources are also relevant to unconventional resources.

While these controls are unlikely to provide important commercial insights in established unconventional plays, they should be understood and utilized in poorly-constrained ("frontier") settings.

Just as in conventional resources, there is not one (or even a few) success factors – there are many pathways to success (and even more to failure!).

So beware of purported general models, including what you have heard thus far - a consistent, integrated technical approach is more important.