// The Geology of Shale Gas and Tight Oil Resources in the United States

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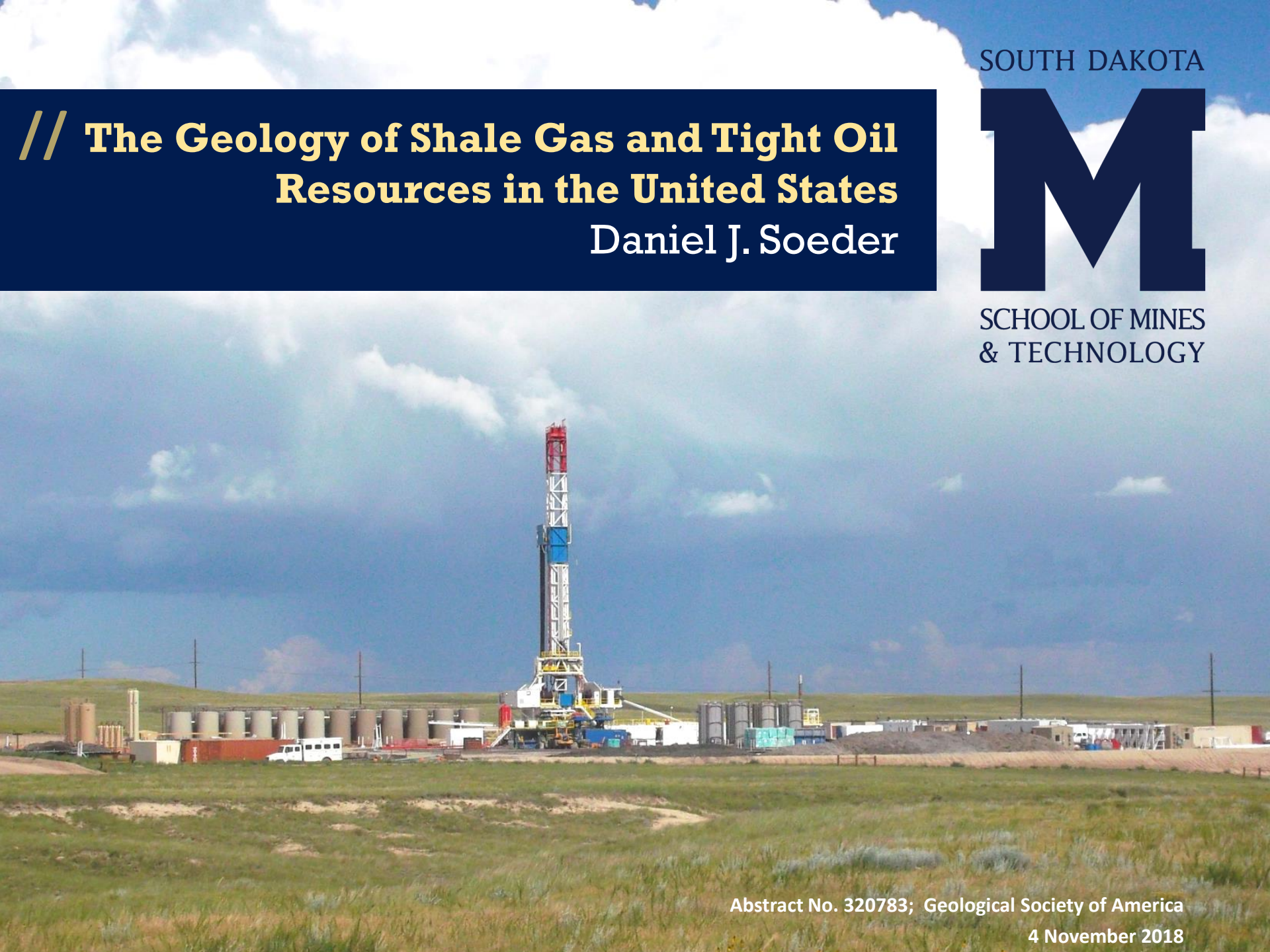
SOUTH DAKOTA SCHOOL OF MINES & TECHNOLOGY



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THE GEOLOGY OF SHALE GAS AND TIGHT OIL RESOURCES IN THE UNITED STATES

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Over the past decade, unconventional resources have dominated U.S. oil and gas production, making the United States the world's top producer of both natural gas and oil. Most U.S. production comes from ten plays: 1) The Barnett Shale is a Middle to Late Mississippian siliceous shale and limestone in the Fort Worth Basin that produces dry gas at depth and natural gas liquids (NGL) in shallower regions. 2) The Fayetteville Shale is a Late Mississippian black shale and limestone in the Arkoma Basin of Arkansas that is a dry gas producer. 3) The Late Jurassic Haynesville Shale consists of black shale with interbedded sandstones and redbeds in the Texas-Louisiana border region and produces dry gas. 4) The Woodford Shale is a Late Devonian to Early Mississippian shale that occurs in the Anadarko Basin of Oklahoma and produces NGL and dry gas. 5) The Middle Devonian Marcellus Shale extends across the Appalachian Basin from West Virginia to New York, where it primarily produces dry gas and some NGL. 6) The Bakken Formation in the Williston Basin of North Dakota, Montana and Saskatchewan consists of a Late Devonian basal black shale overlain by a limestone member, which is in turn overlain by an Early Mississippian black shale. Oil production is from the middle limestone member and an underlying limestone called the Three Forks. 7) The Late Cretaceous Niobrara Formation is a chalk and shale deposited in the Western Interior Seaway that reaches intermediate depths in the Denver and Powder River basins where it produces NGLs, and dry gas in the deepest part of the Denver Basin at the Wattenberg Field. 8) The Utica Shale is a Middle Ordovician shale above the Trenton Limestone that produces dry gas throughout the Appalachian Basin and abundant NGL in southeastern Ohio. 9) The Late Cretaceous Eagle Ford Shale consists of clay shales interbedded with limestones along the southern Texas Gulf Coast, and produces oil inland, NGL toward the coast, and dry gas at the greatest depths. 10) The Permian Basin of Texas contains six formations that form a large, stacked, unconventional play producing NGL and oil. These are the Early Permian Spraberry, Wolfcamp, Bone Spring, Glorieta, and Yeso formations, and the Middle Permian Delaware Mountain Group. Understanding the geologic factors that affect the behavior of shales can help to improve predictability of resource recovery.

(Dan.Soeder@sdsmt.edu)

// Shale Gas Origins

In the United States

Photos: public archives

Fall 1973 to Spring 1974: "Energy Crisis"

- October: Yom Kippur war – U.S. supported Israel
- OPEC Arab states embargoed oil exports to U.S.
- Price of gasoline quadrupled ($0.40-$1.60)
- Gasoline was in short supply, nearly rationed

U.S. Department of Energy established in 1977 to fund domestic energy R&D projects.

- Eastern gas shales project (EGSP) 1976-92
- Western tight gas sands
- Coalbed methane
- Geopressured aquifers/ultra-deep gas

EGSP focus: 1) define the resource, 2) develop the engineering, 3) transfer the technology

A second energy crisis in 1979 following the Iranian revolution further heightened the need.

Soeder, D.J., 2012, Shale gas development in the United States, Chapter 1 in Advances in Natural Gas Technology, Edited by Hamid A. Al-Megren, ISBN 978-953-51-0507-7, InTech Open Access, Rijeka, Croatia, April 11, 2012; DOI: 10.5772/2324, 542 pages

// Shale Gas Origins

In the United States

U.S. shale gas has a history of small-scale production going back to the 19th Century.

Engineering/economic challenges of EGSP

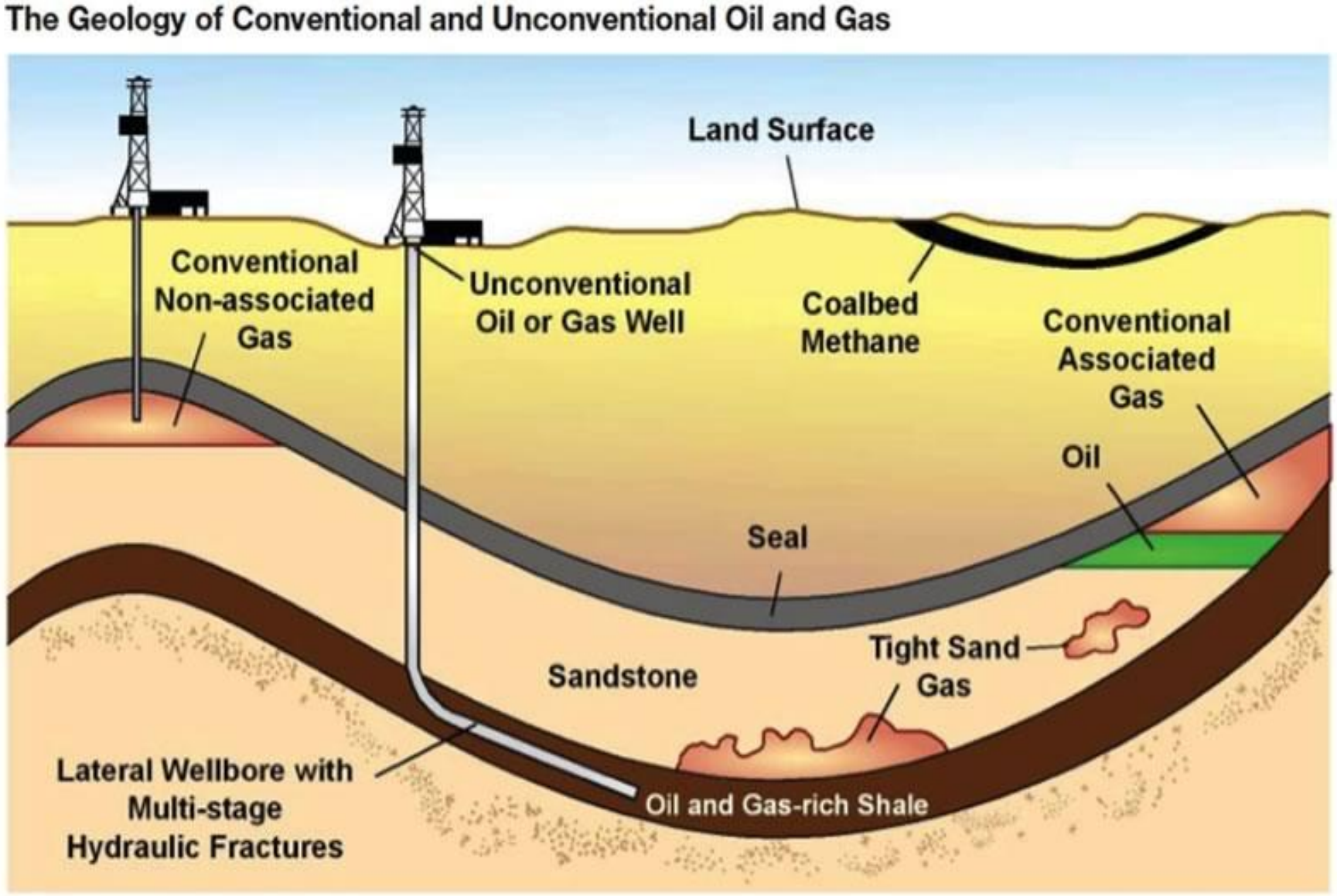
- Oversimplified concept of black shales + fractures = gas. Some shales produced gas and others did not.
- EGSP conceptual model was the Big Sandy Field in Kentucky, which is unique.
- Stimulation treatments were hit or miss for unknown reasons.

Mitchell Energy continued experimenting with drilling and completion techniques on the Barnett Shale in Texas post-EGSP, driving shale revolution.

- Mitchell success on the Barnett in 1997.
- Southwestern success on Fayetteville in 2004.
- Chesapeake developed the Haynesville in 2005.
- Range Resources success on Marcellus 2007.

Schrider, L. A. and Wise, R.L., 1980, Potential new sources of natural gas: *Journal of Petroleum Technology*, April 1980, p. 703-716. Photos at right by Dan Soeder.

// Conventional vs. Unconventional



// Shale Gas Development

Ten Major Plays

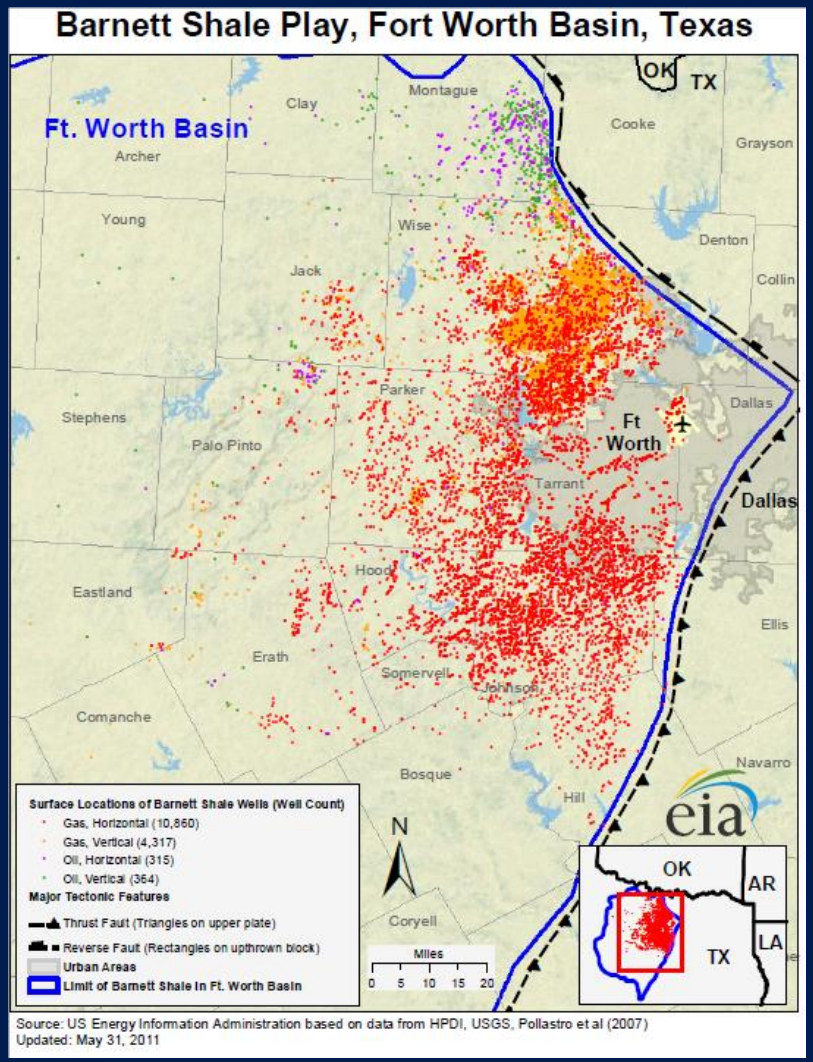
		Summary of U.S. Shale Plays					
Formation	**Age**	**Basins & Location**	**Primary Developer**	**Year**	**Depth**	**Production**	**Core Areas**
Barnett Shale	Mid to Late Miss	Fort Worth, TX	Mitchell Energy	1997	0 - 8k ft	gas, NGL	Newark East Field; NW of Ft. Worth
Fayetteville Shale	Late Miss	Arkoma, AR	Southwest Energy	2004	0 - 6k ft	dry gas	North-central Arkansas
Haynesville-Bossier	Late Jurassic	Arkla, TX-LA	Chesapeake Energy	2005	10k - 13k ft	dry gas	Lufkin, TX to Shreveport, LA
Marcellus Shale	Mid Devonian	Appalachian, WV, PA	Range Resources	2007	0 - 9k ft	gas, NGL	SW PA & NW WV; NE PA
Bakken Formation	Late Devonian to Early Miss	Williston, ND, MT, SK	EOG Resources	2006 - 2009	4k - 11k ft	oil, gas	NW North Dakota, E. Montana, Canada.
Woodford Shale	Late Devonian	Anadarko, Ardmore, OK	Newfield Exploration	2005	4k - 25k ft	oil, NGL, dry gas	central & southern Oklahoma
Niobrara Formation	Late Cretaceous	Denver; Powder River, CO, WY	Whiting Petroleum	2008	0 - 11k ft	NGL, dry gas	E. Colorado, E. Wyoming
Eagle Ford Shale	Late Cretaceous	TX Gulf Coast	Petrohawk Energy	2008	0 - 20k ft	oil, NGL, gas	southern Texas
Spraberry, Wolfcamp, Bone Spring, Glorieta, Yeso, and Delaware formations.	Mid to Late Permian	Permian, TX-NM	Multiple	2009	~1k - 25k ft	oil, NGL, gas	West Texas, SE New Mexico
Utica/Point Pleasant	Mid Ordovician	Appalachian, OH	Multiple	2011	0 - 15k ft	gas, NGL	southeast Ohio

// Shale Resources – North America

2011

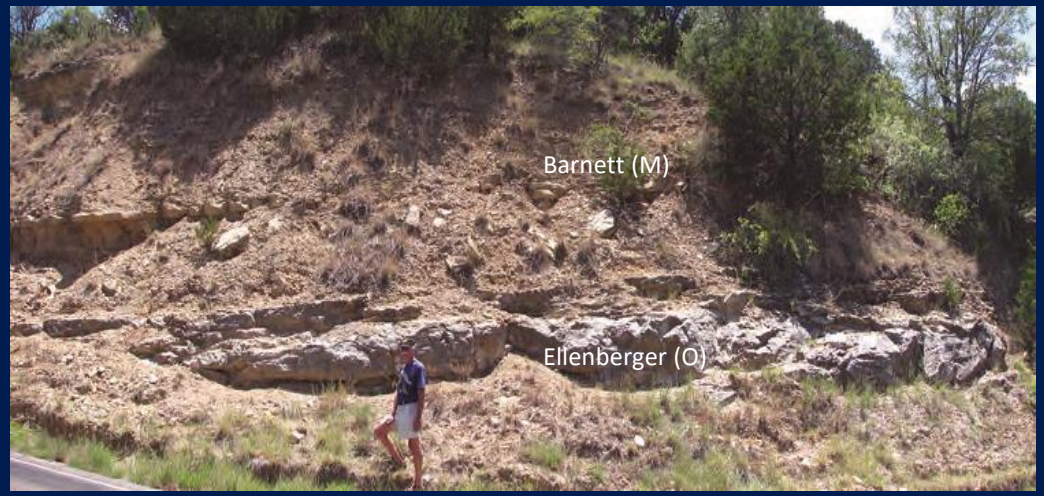
Source: U.S. Energy Information Administration based on data from various published studies. Canada and Mexico plays from ARI.
Updated: May 9, 2011

// 1. Barnett Shale
Fort Worth Basin



- Middle to Late Mississippian siliceous black shale and limestone.
- In 1997 Mitchell Energy successfully applied horizontal drilling (5,000 ft) and staged hydraulic fracturing (10).
- Basin is deeper to the northeast and shallower south on the Llano uplift.
- Shale produces dry gas at depth and NGL in shallower regions.

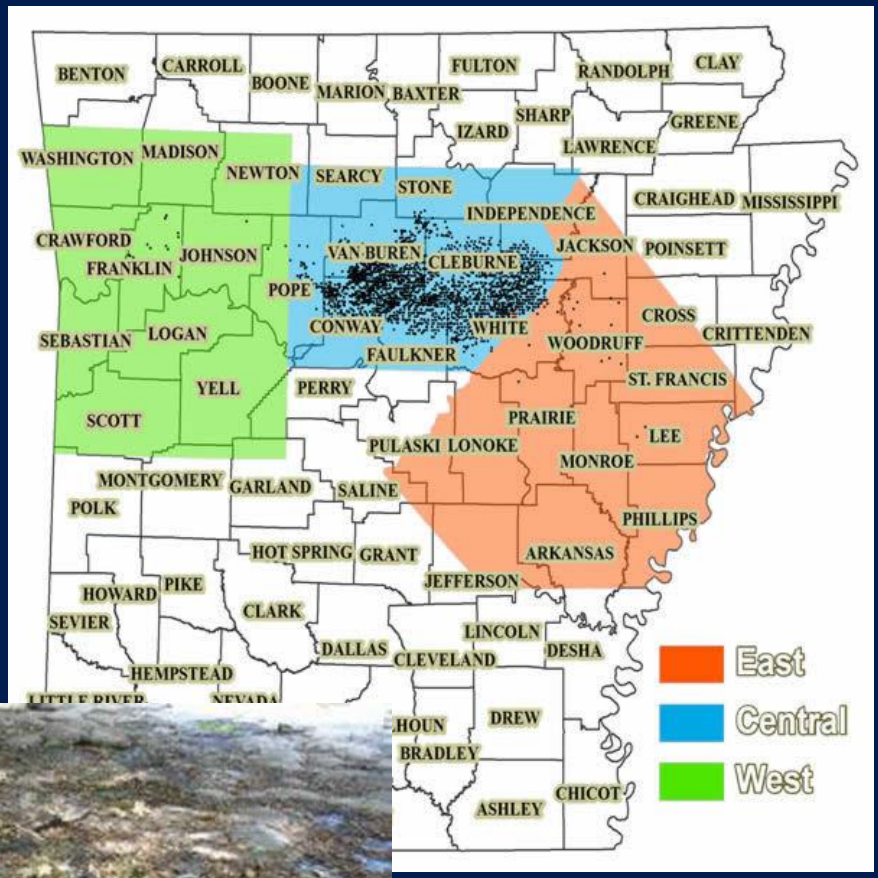
Photo from Bruner & Smosna, 2011

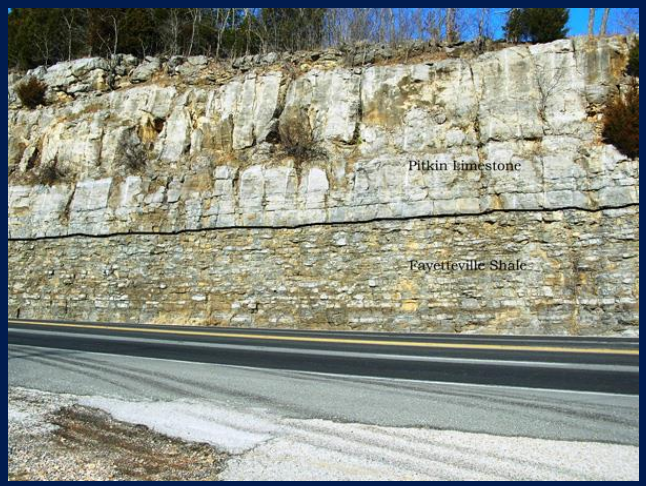


// 2. Fayetteville Shale

Arkoma Basin

- Late Mississippian fissile black shale and interbedded dark limestone, similar to Barnett.
- Developed in 2004 by Southwestern Energy using Mitchell's techniques from the Barnett.
- Main production in north central Arkansas.
- Thermally mature; dry gas producer.





Map and photos from Arkansas Geological Survey

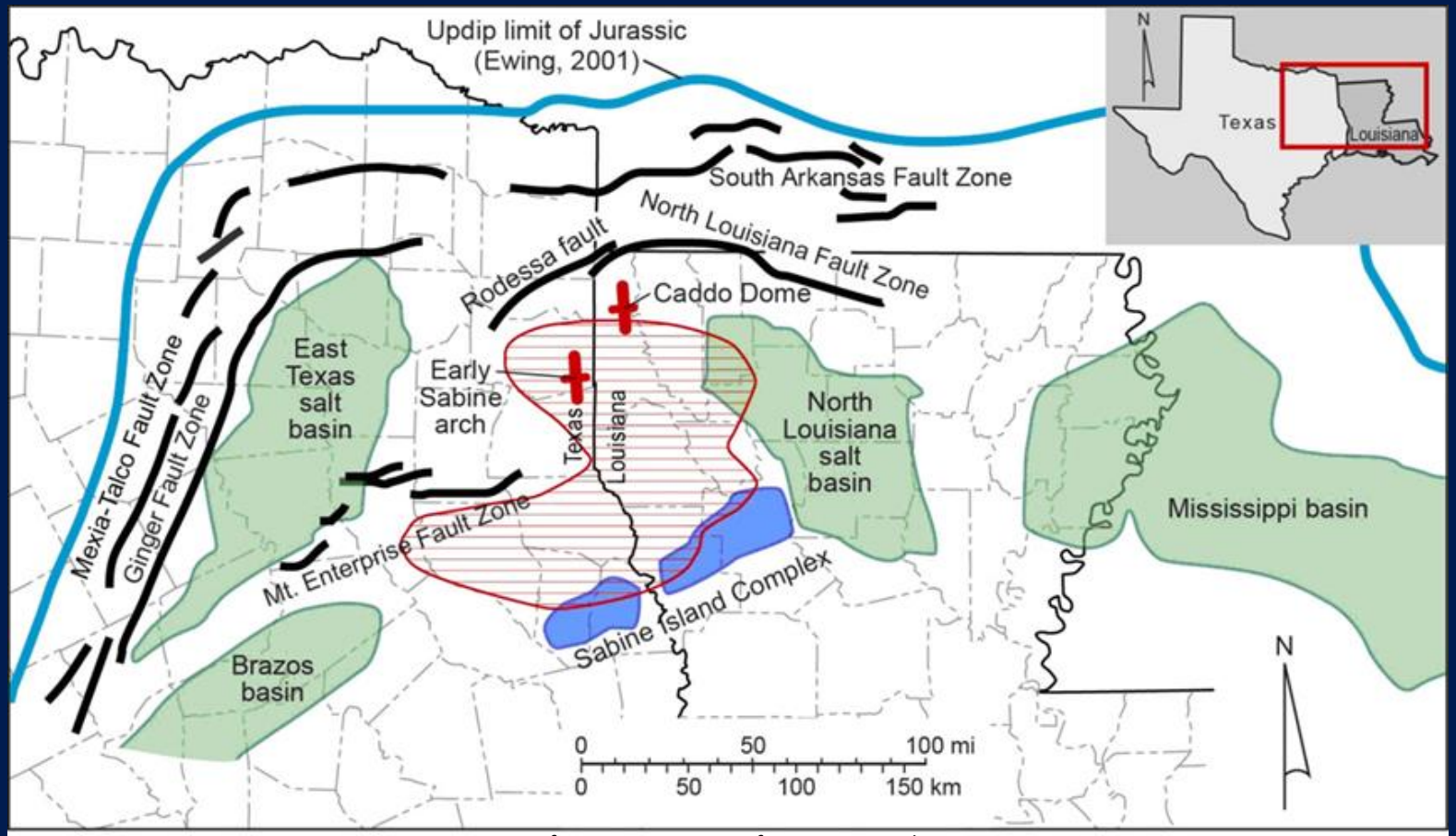
Upper contact with Pitkin LS

Concretion zone near base

// 3. Haynesville-Bossier Shale

Arkla Basin

- Late Jurassic marine black shale with interbedded sandstones and redbeds.
- Located 3-4 km subsurface (no outcrop) in the Texas-Louisiana border region.
- Thermally mature, produces dry gas; developed by Chesapeake in 2004.



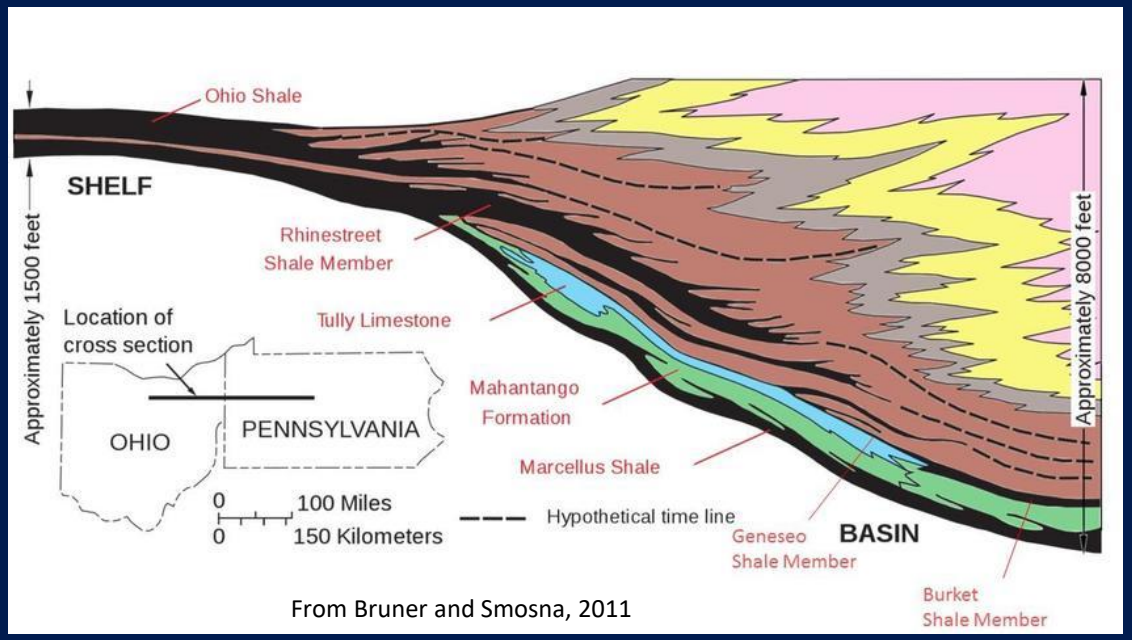
Map from Texas Bureau of Economic Geology

QAd7851

// 4. Marcellus Shale
Appalachian Basin

- Middle Devonian black, siliceous shale, middle carbonate, upper clay shale.
- Depth varies across basin; production primarily dry gas; some NGL near Ohio.
- Range Resources was the primary developer.
- Late Devonian shales were main target of EGSP; only a few cores reached Marcellus.

Photos by Dan Soeder: Oatka Creek (U) Seneca Quarry (L)



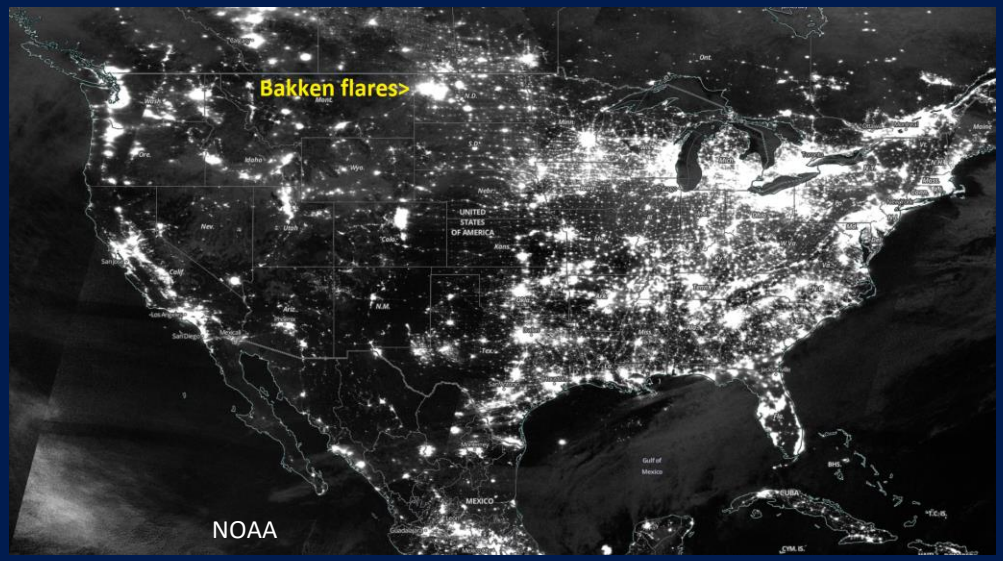
From Bruner and Smosna, 2011

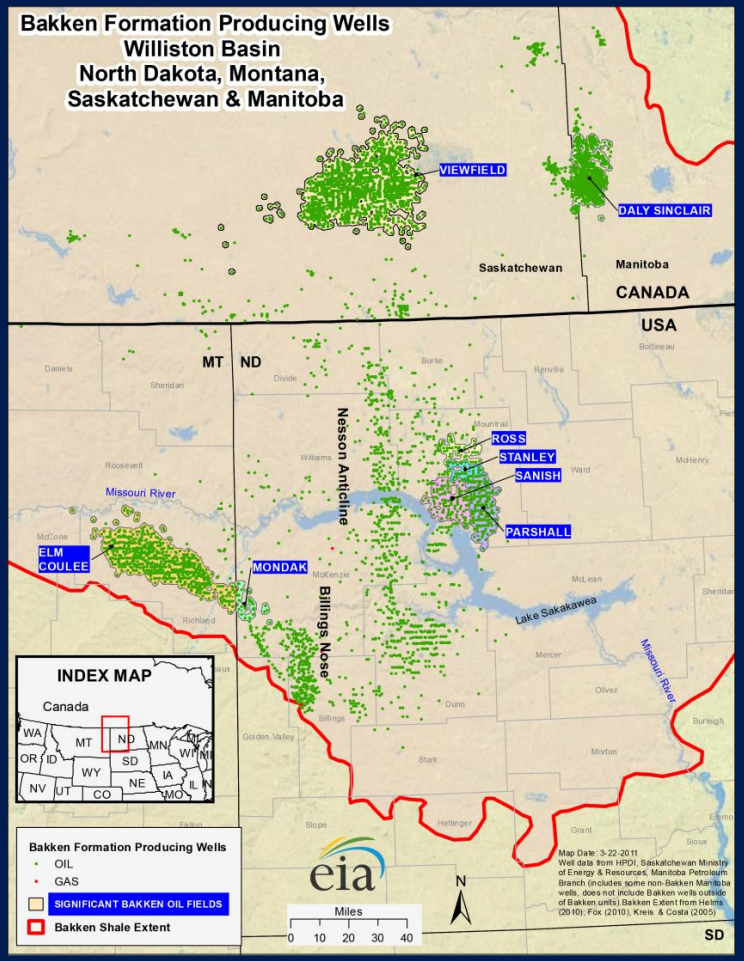
// 5. Bakken Formation

Williston Basin

- Late Devonian to Early Mississippian black shale sandwich on limestone and sandstone.
- Conventional production since 1953.
- Completely subsurface; type section is in the H.O. Bakken No. 1 well, Williams Co., ND.
- Bakken and underlying Three Forks primarily produce light oil and associated gas.
- Developed in 2006 by EOG at Parshall.

Upper and middle Bakken; NDGS photos





// 6. Woodford Shale

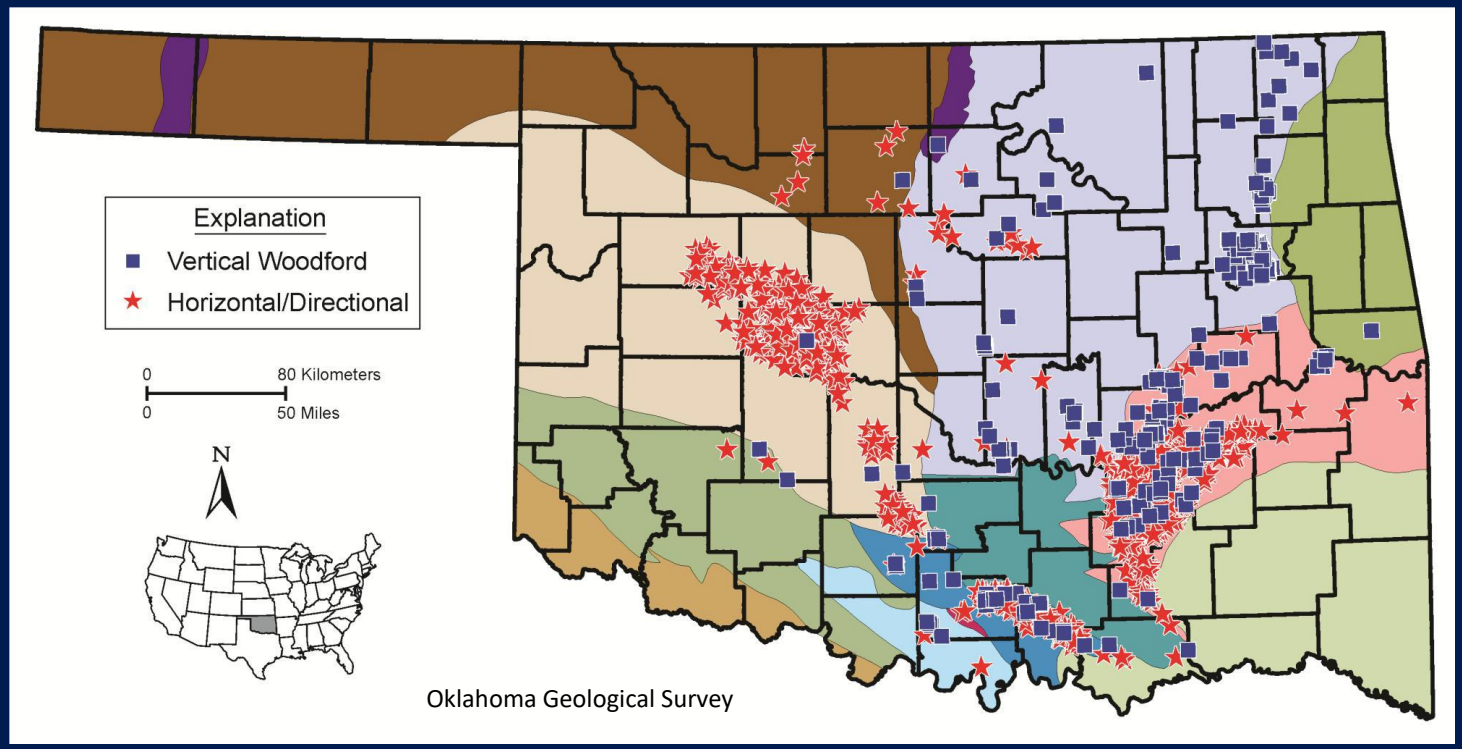
Anadarko Basin

- Late Devonian to Early Mississippian black, bituminous, cherty, fissile shale.
- Depth varies across basin; shale produces NGL shallow/dry gas deep.
- SCOOP/STACK are main plays.
- Newfield was primary developer.

Bitumen-filled fractures in Woodford (OK Minerals)

South Central Oklahoma Oil Province

Sooner Trend Anadarko: Canadian and Kingfisher counties

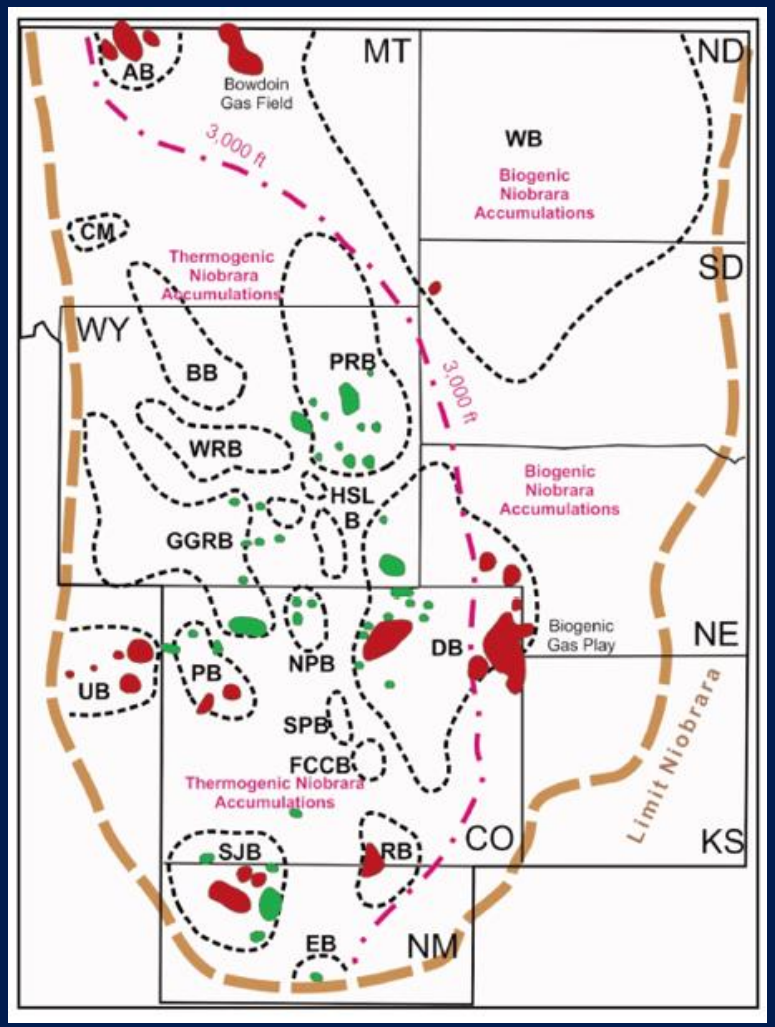


Oklahoma Geological Survey

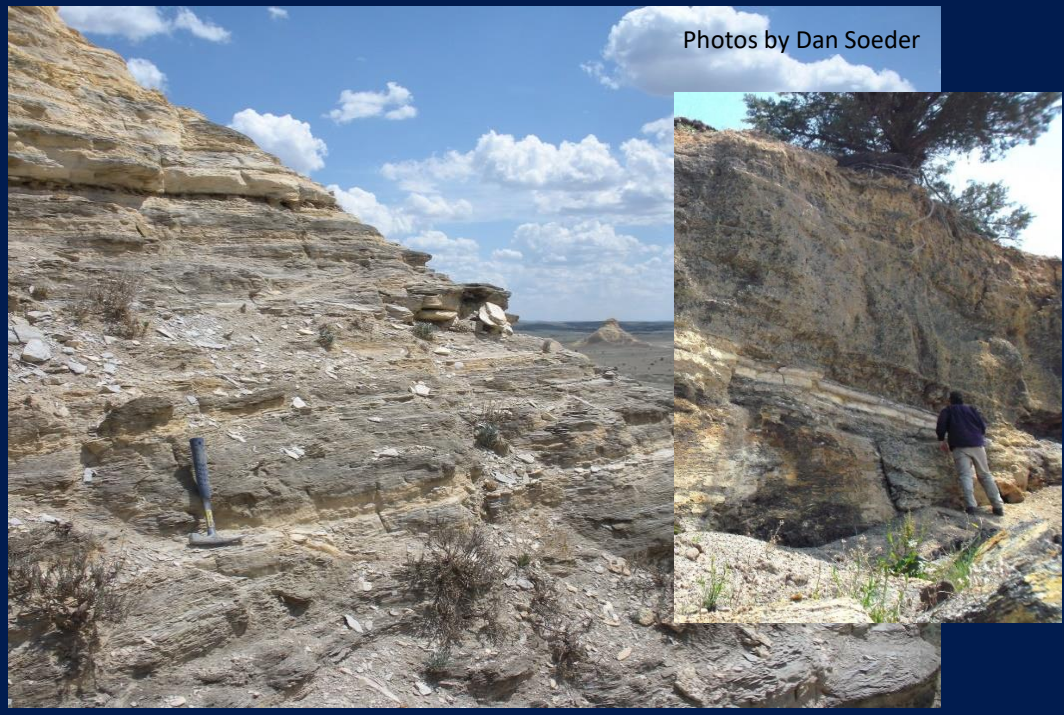
// 7. Niobrara Formation

Denver-Julesburg Basin

- Late Cretaceous chalk and calcareous shale in the Western Interior Seaway.
  - Overlain by the organic-rich Pierre Shale.
  - Mostly shallow, but thermally mature in deep structural basins.
  - Developed by Whiting in eastern Colo.
  - Makes part of stacked play in the PRB.



Map from Sonnenberg, 2011



Photos by Dan Soeder

// 8. Eagle Ford Shale

Texas Gulf Coast

- Late Cretaceous calcareous shale on Gulf Coast from East Texas into Mexico.
- Located below the Austin Chalk and above the Buda Limestone and Woodbine.
- Varies in depth from outcrops to 14,000 feet toward the Gulf of Mexico.
- Produces oil and NGL shallow/dry gas deep; Petrohawk was primary developer.

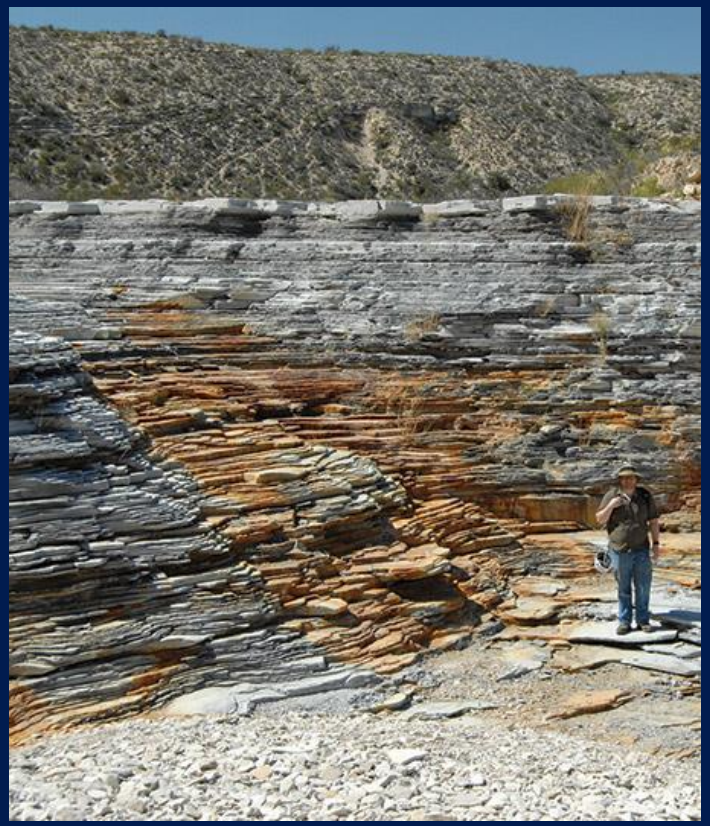
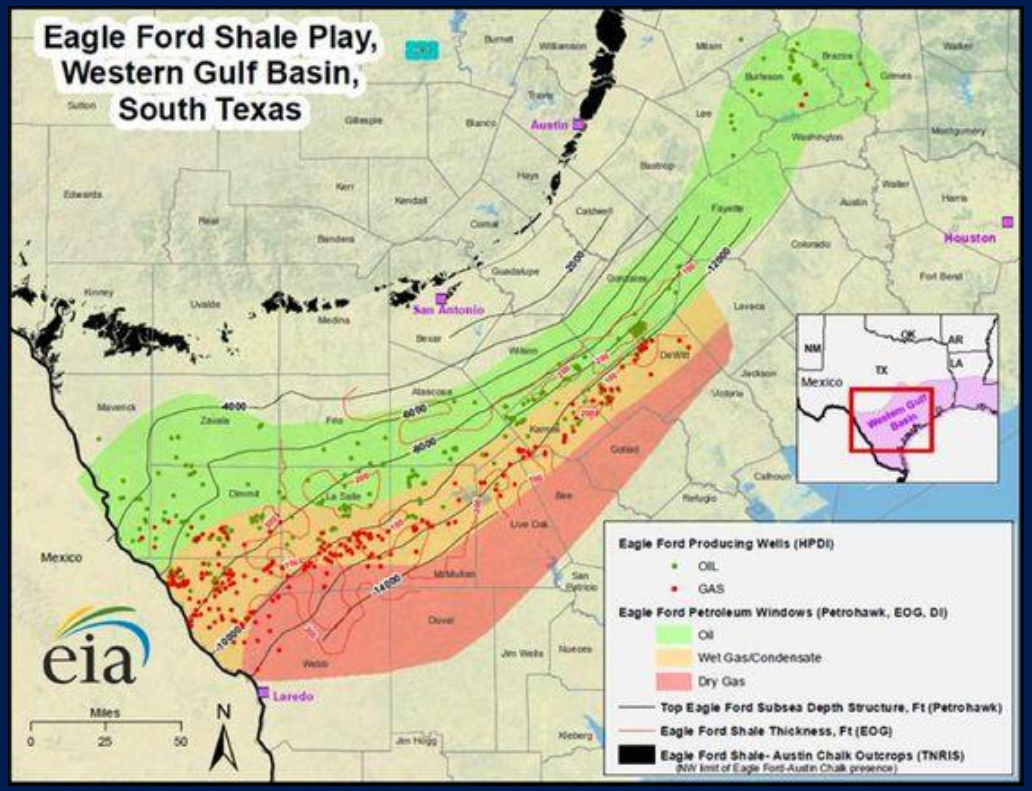


Photo from AAPG

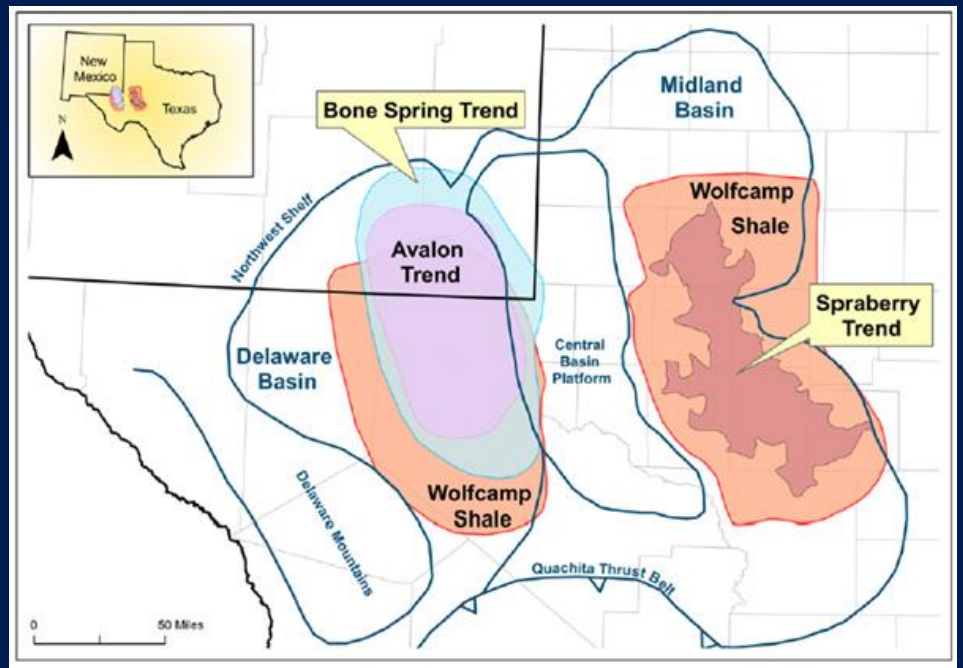


// 9. Stacked Play

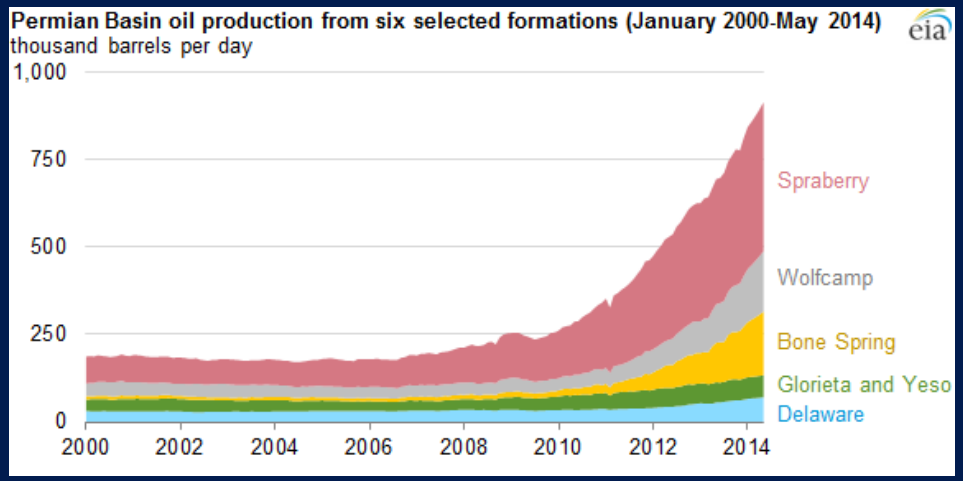
Permian Basin

- Permian basin is located in the western part of Texas and southeastern New Mexico
- Two adjoining basins, the Delaware and the Midland, are separated by a platform.
- Conventional production since 1920.
- In 2010, unconventional formations created a large, stacked play.
  1. Early Permian Wolfcamp Shale
  2. Spraberry Sandstone ("Wolfberry")
  3. Bone Spring Limestone ("Wolfbone")
  4. Glorieta Sandstone
  5. Yeso Formation
  6. Middle Permian Delaware Mountain Group
- Currently running short of pipeline capacity.

Source: EIA



Permian Basin tight oil plays.



// 10. Utica-Point Pleasant Shale

Appalachian Basin

- Middle Ordovician Utica Shale overlies Trenton-Black River limestones throughout the Appalachian basin.
- Production began in 2011-2012 from dual-completion wells with Marcellus in western PA. Chesapeake is by far the major developer.
- Focus shifted to southeastern Ohio where Utica is rich in NGL.
- Record-setting wells (19,500 ft lateral, 125+ stages, IP=73 MMcf/d)
- Point Pleasant is equivalent formation that outcrops in KY; Ohio GS uses both.

Indian Castle/Dolgeville contact in Utica Shale in NY

Photos by Dan Soeder

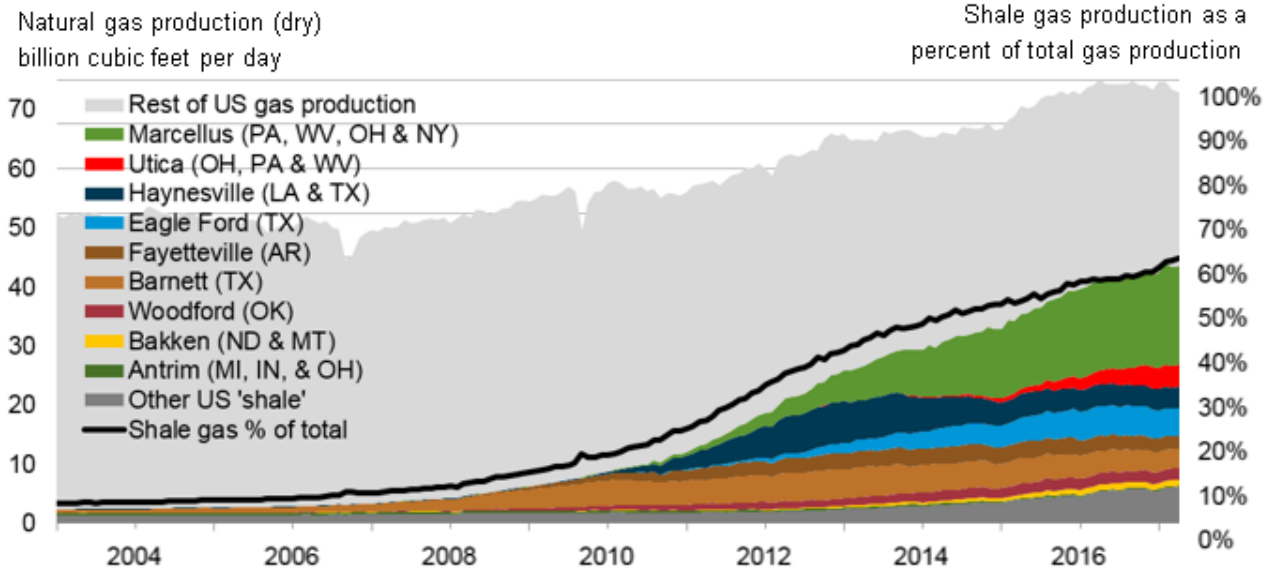
Point Pleasant Fm. below the Kope in Kentucky

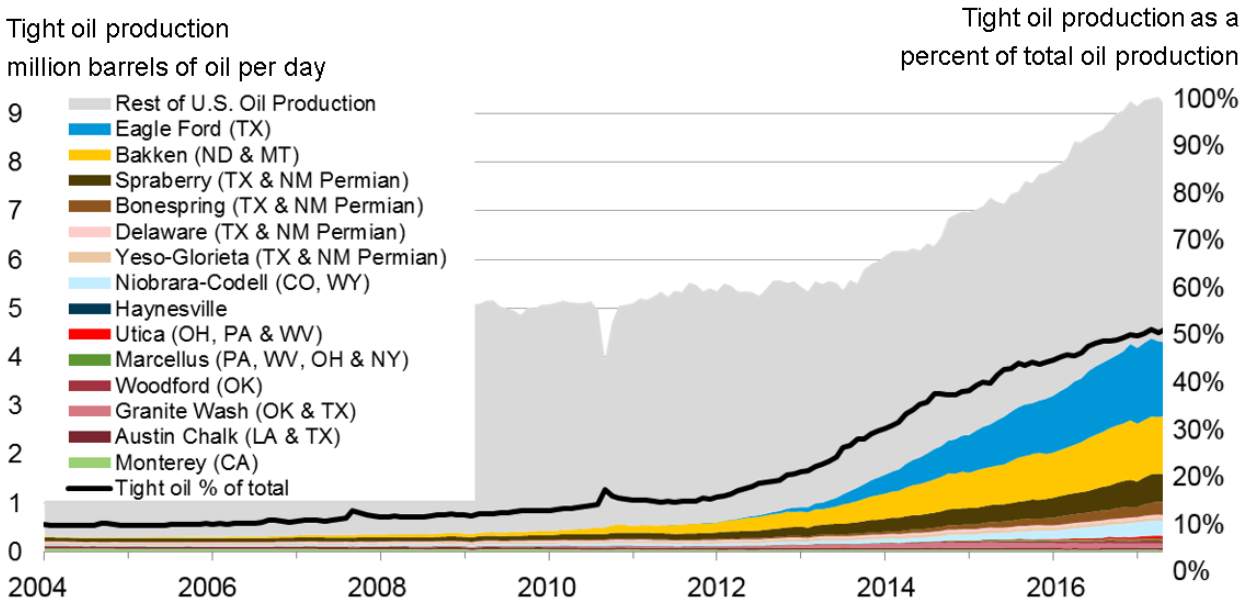
// Shale Gas Development

Emerging U.S. Plays

Formations	Age	Basins & Location	Rock Type	Production	Potential Resource	Problems
Granite Wash	Pennsylvanian	Anadarko, OK	Submarine fans	Oil, NGL, gas	114 billion BOE	Very complex geology
Austin Chalk	Late Cretaceous	Texas Gulf Coast	Chalk & marl	Oil, NGL, gas	4.1 billion bbl oil 18 TCF natural gas 1 billion bbl NGL	Brittle, hard to drill and frack
Tuscaloosa Trend	Late Cretaceous	Louisiana-Mississippi border region	Marine shale	Oil, NGL	"comparable to the Eagle Ford"	Too soft to frack well, crumbles
Upper Devonian	Late Devonian	Appalachian, WV, PA	Black shale	Dry gas	11 TCF gas	Shallow, less productive
Rogersville Shale	Middle Cambrian	Rome Trough, Appalachian, KY-WV	argillaceous shale & limestone	Dry gas	"comparable to the Marcellus"	Very deep and expensive to drill
Atlantic Rift Basins	Mesozoic	Atlantic Coastal Plain	Rift basin fill	Gas, NGL	3.86 TCF gas; 135 million bbl NGL	Strong local opposition
Monterey Formation	Middle to Late Miocene	San Joaquin basin, California	organic-rich, siliceous shale	Oil, NGL, gas	21 million bbl oil 27 BCF gas 1 million bbl NGL	80 dry holes, shale may be spent
Shublik Formation, Kingak Shale, and Brookian shale	Triassic to Cretaceous	North Slope, Alaska	limestone, shale, siltstone, and tuff	Oil, NGL, gas	2 billion bbl oil 500 mill bbl NGL 80 TCF gas	Economics of Arctic location

// Summary and Conclusions





- The single largest gas producing formation in the United States is the **Marcellus Shale**.
- The second-largest oil producing state in the U.S. is North Dakota due to the **Bakken Shale.**
- The largest oil producing state in the U.S. is Texas due to tight oil from the **Eagle Ford** and **Permian Basin**.
- Source: U.S. Energy Information Administration (Popova et al, 2018)