A Geological Analysis of the Appalachian Basin and How It Affects the Oil & Gas Industry

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Purpose

- **The oil & gas industry is dependent on geology**
- **Identify attributes that are advantageous**
- **Identify attributes that may cause some challenges**

Introduction

- **An epicenter for one of the fastest growing industries in the country**
- **The largest natural gas reserve in the United States**
- **Produced 28 trillion cubic feet of natural gas and 102 million barrels of crude oil and condensate from 2011 to 2016**
- **Expected to account for 35% of total U.S. production**
- **Has provided abundant fossil fuels for over 150 years**

Industry Overview

- **The fountainhead of the American petroleum industry**
- **Oil and natural gas were discovered in the Appalachian Basin long before they were ever commercially produced**
- **The first Americans to drill for oil and natural gas were salt miners**
  - **1814 – Noble County, Ohio**
  - **1815 – Charleston, West Virginia**
- **Most well known:**
  - **1859 – Titusville, Pennsylvania**
- **Others:**
  - **1859 – Petroleum, West Virginia**
  - **1860 – California, West Virginia**
  - **1860 – Burning Springs, West Virginia**
  - **1860 – Washington County, Ohio**

Geology

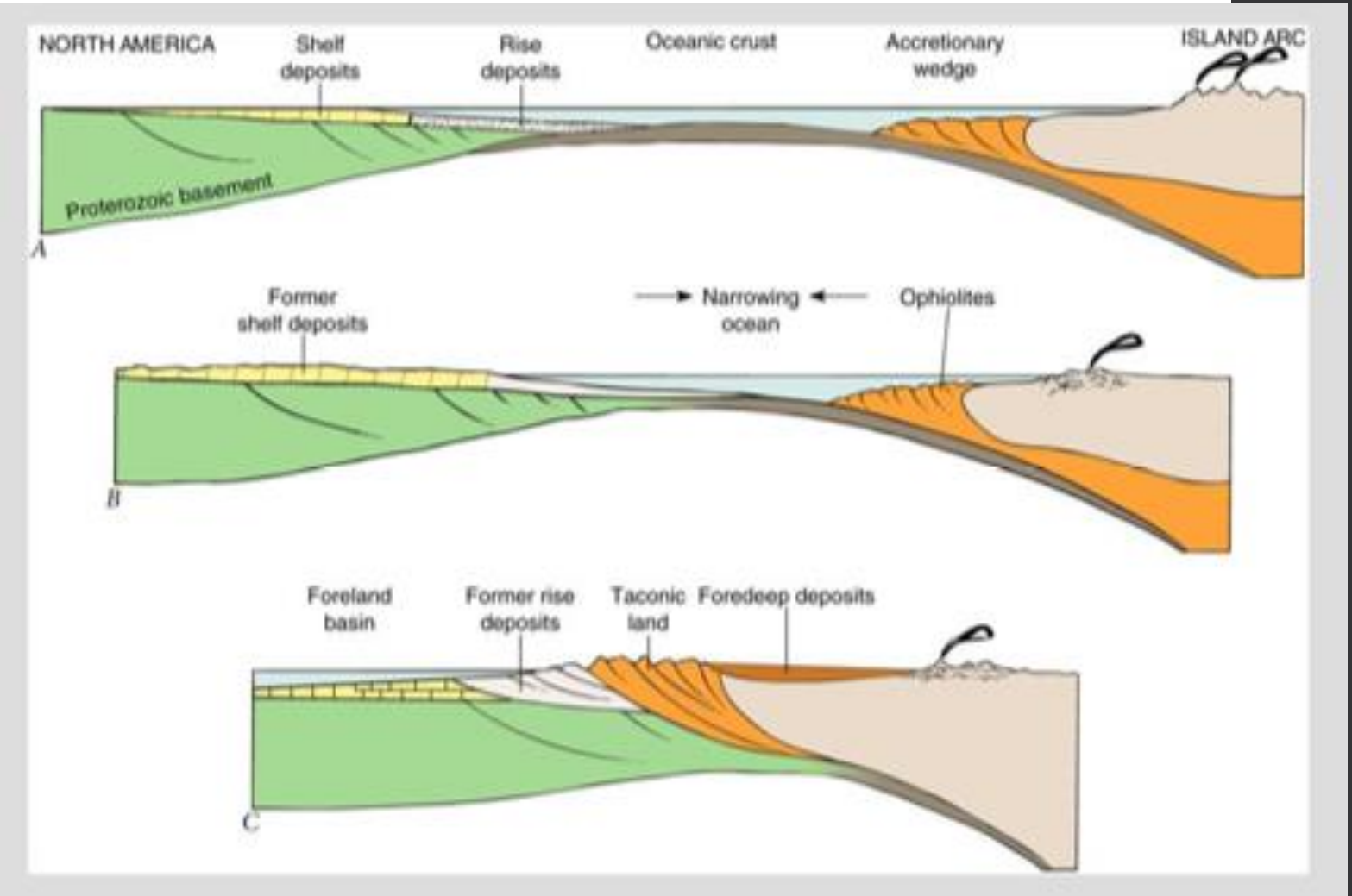
- Geological History
- Structural
- Oil and Gas Capabilities

Geological History

Eon	Era	Period	Epoch	
Phanerozoic	Cenozoic	Quaternary	Holocene	Today
			Pleistocene	
		Neogene	Pliocene	
			Miocene	
		Paleogene	Oligocene	
			Eocene	
			Paleocene	
	Mesozoic	Cretaceous	-	66 MYA
		Jurassic	-	
		Triassic	-	251 MYA
	Paleozoic	Permian	-	
		Pennsylvanian	-	
		Mississippian	-	
		Devonian	-	
		Silurian	-	
		Ordovician	-	
		Cambrian	-	542 MYA
Proterozoic	Precambrian	-	-	
Archean	-	-	-	
Hadean	-	-	-	

Taconic Orogeny

- A change in plate motions (mid Ordovician)
- Iapetus Plate collided with th North American Plate
- Resulted in the deposition of the Utica Shale

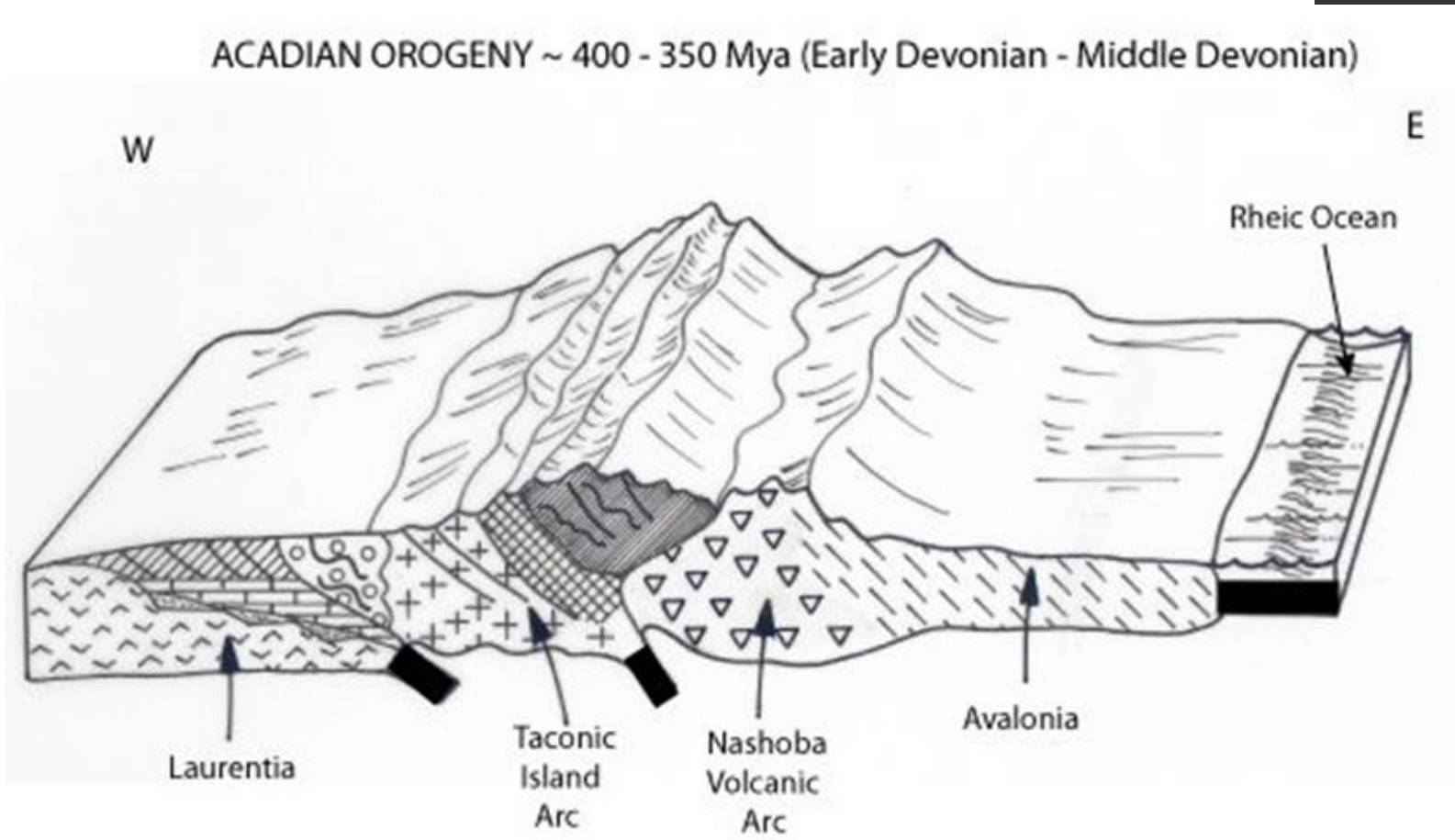


After the Taconic Orogeny

- **Laurentia formed and the early Appalachians were born**
- **Volcanoes grew coincident with the initiation of subduction**
- **Thrust faulting uplifted and warped older sedimentary rocks**
- **Erosion set in and sediments were carried downslope to be deposited in nearby lowlands**
- **Shallow-marine conditions returned depositing primarily shale and limestone**

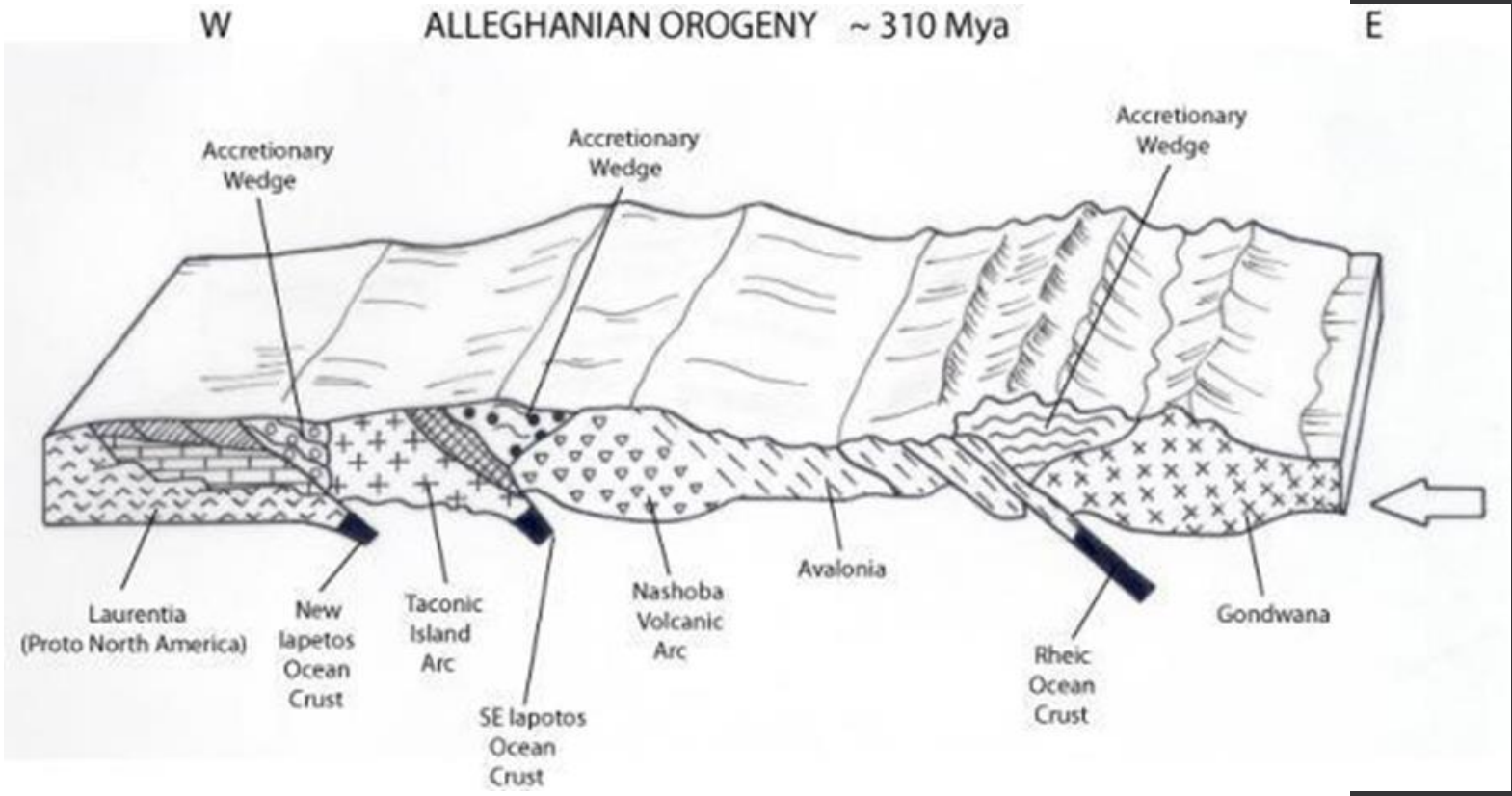
Acadian Orogeny

- **The Baltica Plate collided with the northern part of the Laurentia Plate**
- **Pennsylvania received enormous quantities of river and delta sediment – Catskill Delta**
- **The Marcellus Shale was deposited during the initial stage**



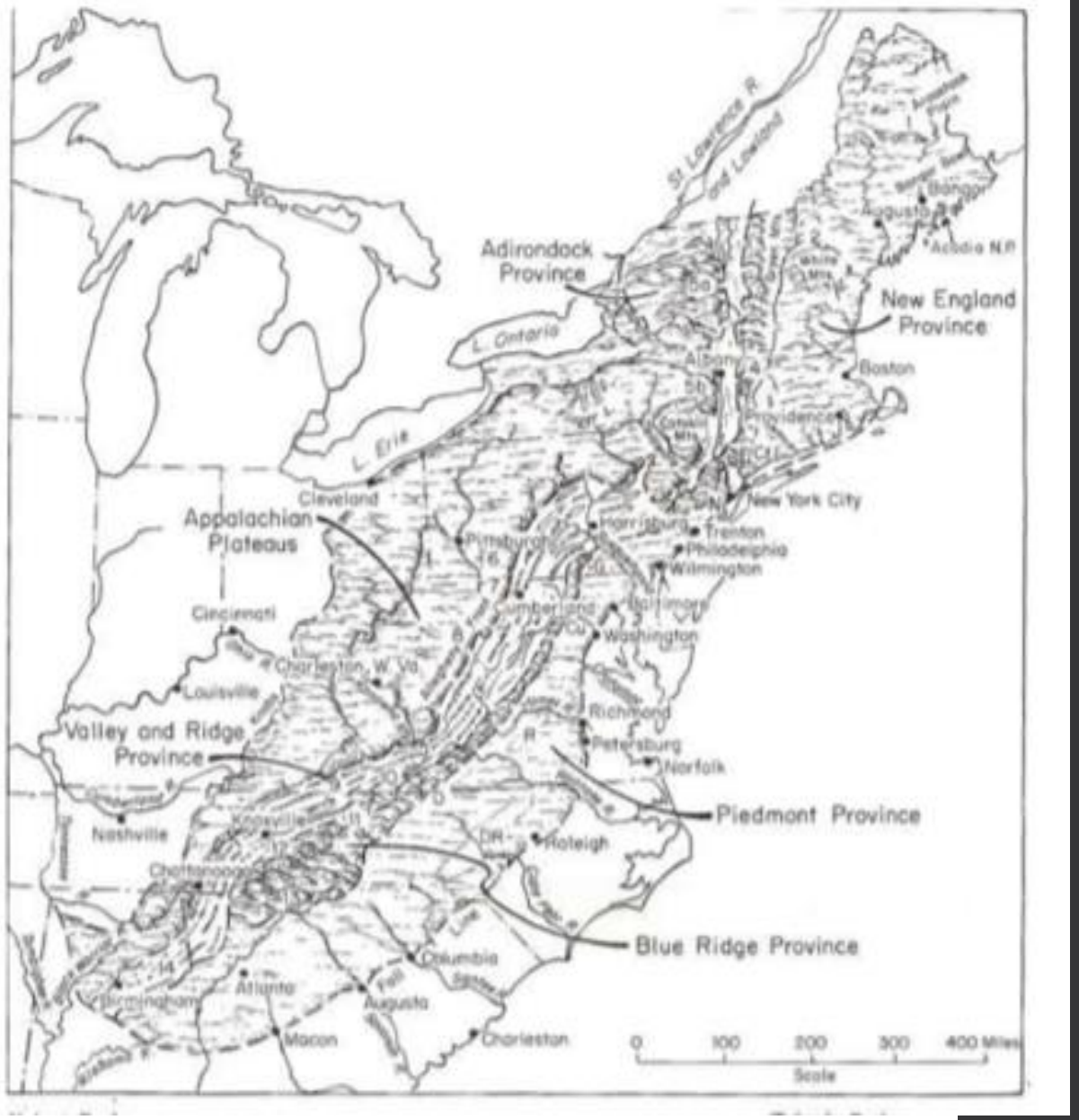
Alleghanian Orogeny

- Gondwana and Laurentia collided
- Large portions of the Laurentian crust and overlying sedimentary sequence were thrust westward
- Above the thrust planes, the sedimentary strata were warped and folded as they were forced west
- During this time the Marcellus and Utica Shales were naturally fractured



Structural

- **Comprises 230,000 sq mi of all or parts of ten states and some segments of Lakes Erie and Ontario**
- **Length – 1,000 miles from the Canadian border to Alabama**
- **Width – 75 to 350 miles; larger near the border and decreasing south**
- **Consists of:**
  - **Appalachian Plateau**
  - **Valley and Ridge**
  - **Blue Ridge**
  - **Piedmont**

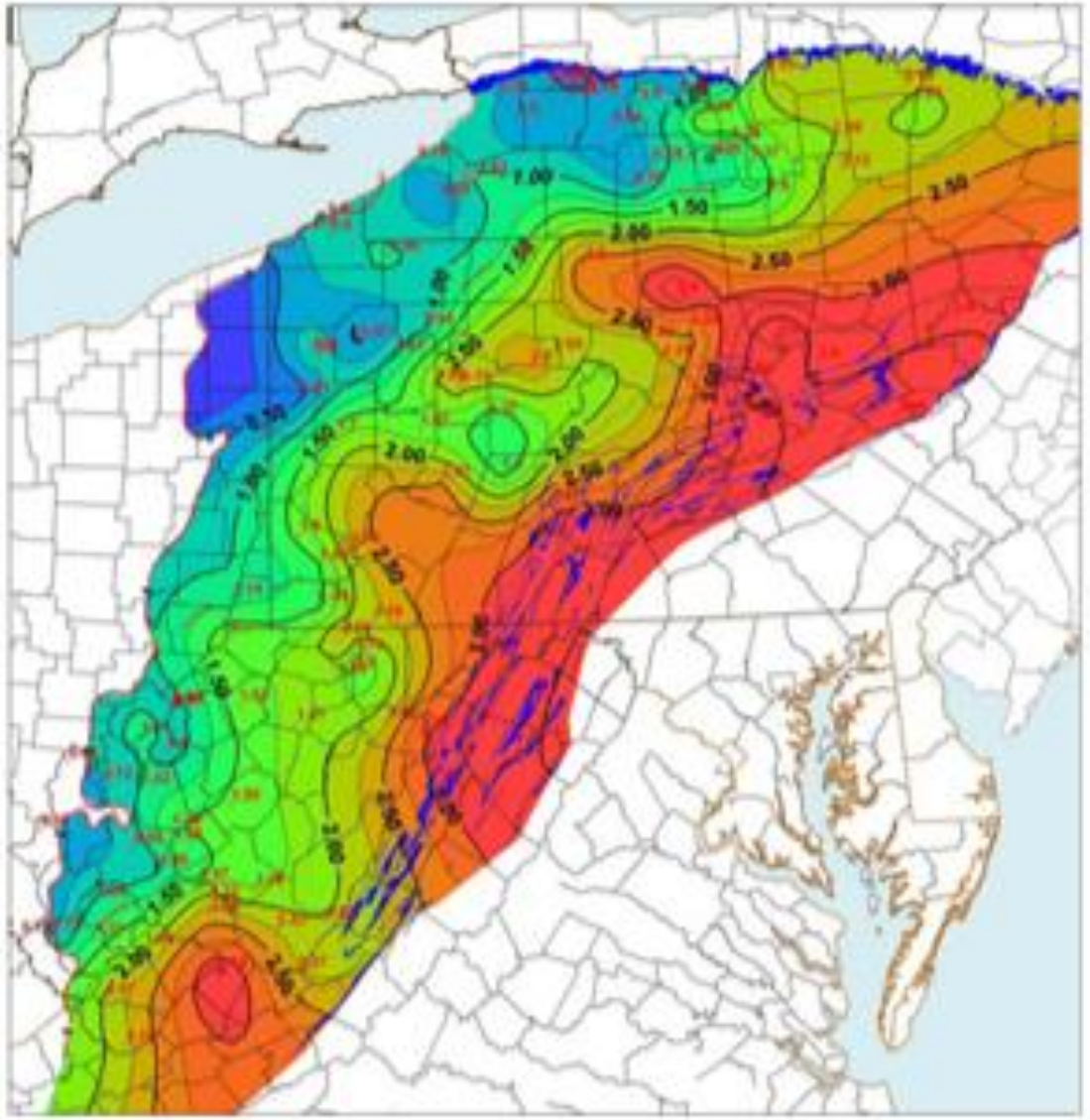


- Asymmetrical with the rocks on the west flank dipping eastward
- Appalachian Plateau – generally gently dipping strata
- Valley and Ridge – greatly thrust-faulted, folded, and telescoped during the Alleghanian Orogeny
- A major thrust-fault system which commonly formed anticlines
  - Known as the Eastern Overthrust Belt
    - Structural traps and zones of fracture porosity

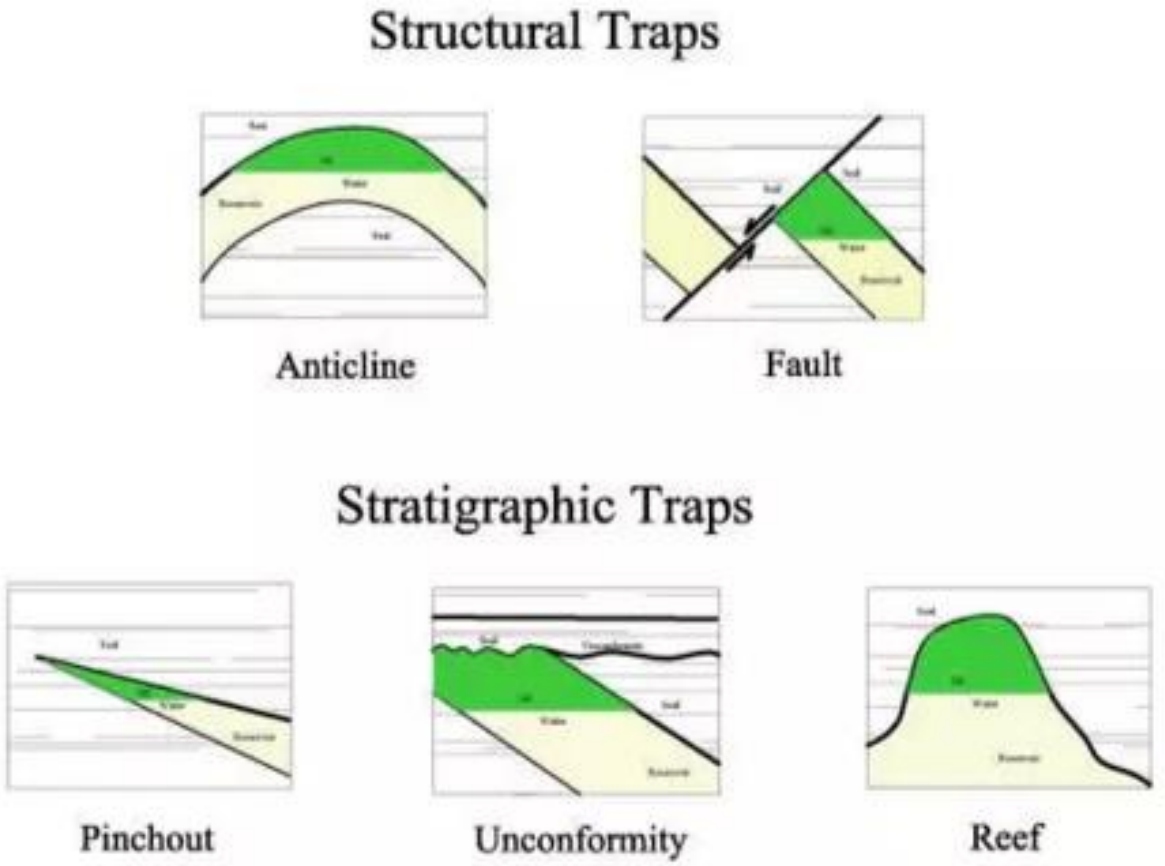
Oil and Gas Capabilities

- **Source:**
  - **A source rock contains organic-rich material (kerogen) that will expel hydrocarbons after being heated during burial**
  - **Organic-rich black shales, coal, and oil shales**
  - **Marcellus, Utica, and Devonian Shales along with several smaller formations**
  - **Virginia's valley coal fields and eastern Pennsylvania's anthracite fields**

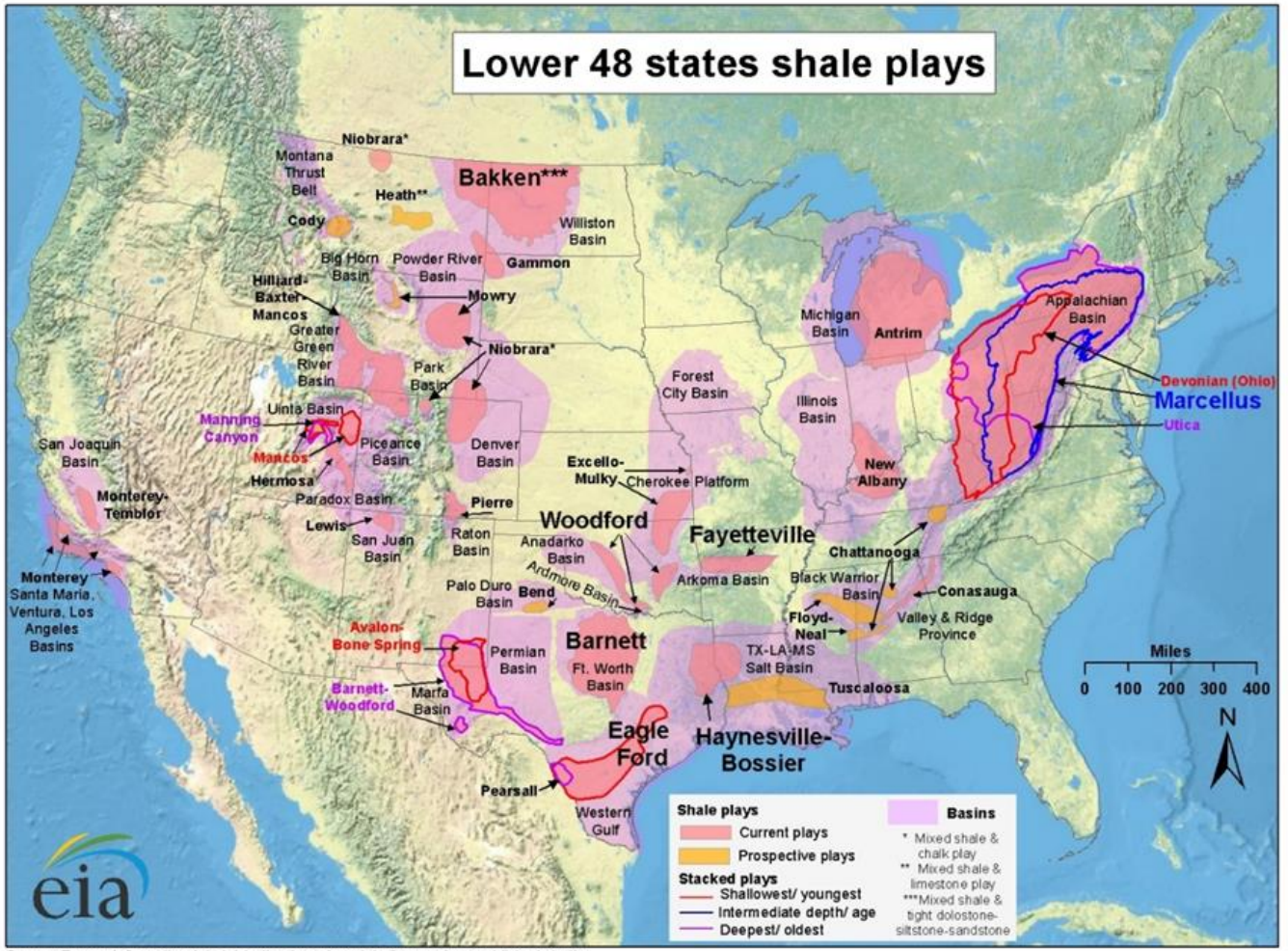
- **Thermal Maturation:**
  - **The extent of heat-driven reactions that alter the composition of organic matter**
  - **Depends largely upon the thickness of sediment, depth of burial, and existing thermal gradient**
  - **Low thermal maturity = oil**
  - **High thermal maturity = gas**
  - **Overmatured = nothing**
  - **The basin's Paleozoic sequence thickens from west to east**
    - **Thermal maturity increases west to east**
    - **Oil in the west and gas in the east**



- **Seal:**
  - An impermeable layer that prohibits the migration of hydrocarbons
  - Common ones include gypsum and halite
  - Most important and most common is shale
  - Conventional reservoirs require a separate seal from the source rock
  - Unconventional reservoirs are considere self-sealing since the source acts as a sea
- **Trap:**
  - A three-dimensional geometry within the s that allows the hydrocarbons to accumu
  - Structural traps: the sedimentary layers been deformed to form a shape within wh hydrocarbons can accumulate
  - Stratigraphic traps: the deposition of sediments results in an isolated reservoi surrounded by impermeable sediments



- **Reservoir:**
  - Conventional:
    - A porous and permeable rock in which hydrocarbons accumulate
    - Sandstone and limestone
  - Unconventional:
    - Lack adequate porosity and permeability to permit the flow of hydrocarbons
    - Shales, tight sands, and coal beds
    - Make up many of the most important trends in hydrocarbon industry plays today



Source: Energy Information Administration based on data from various published studies.
Updated: May 9, 2011

Industry Challenges

- Pad/Lease Road Construction and Location
- Water Supply and Brine/Cuttings Disposal
- Geomechanics

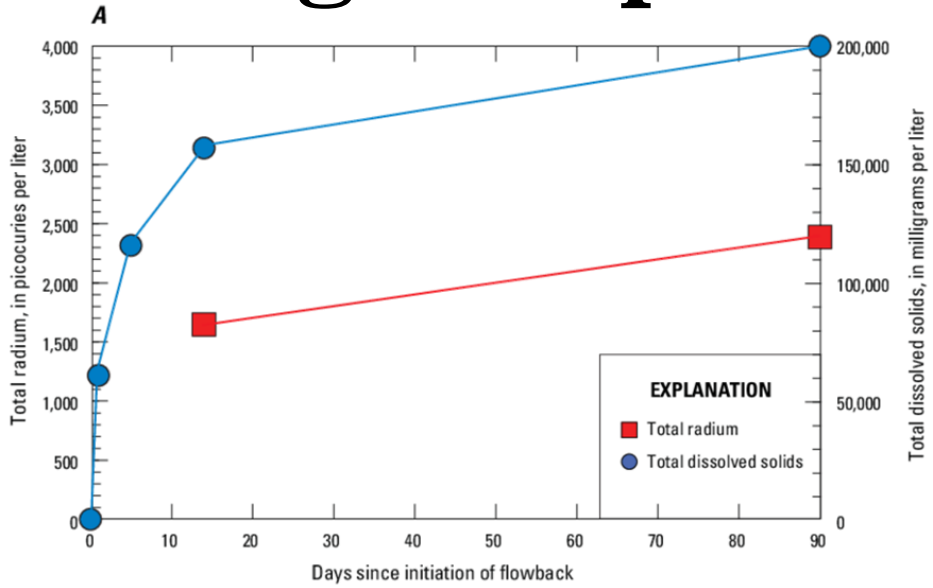
Pad/Lease Road Construction and Location

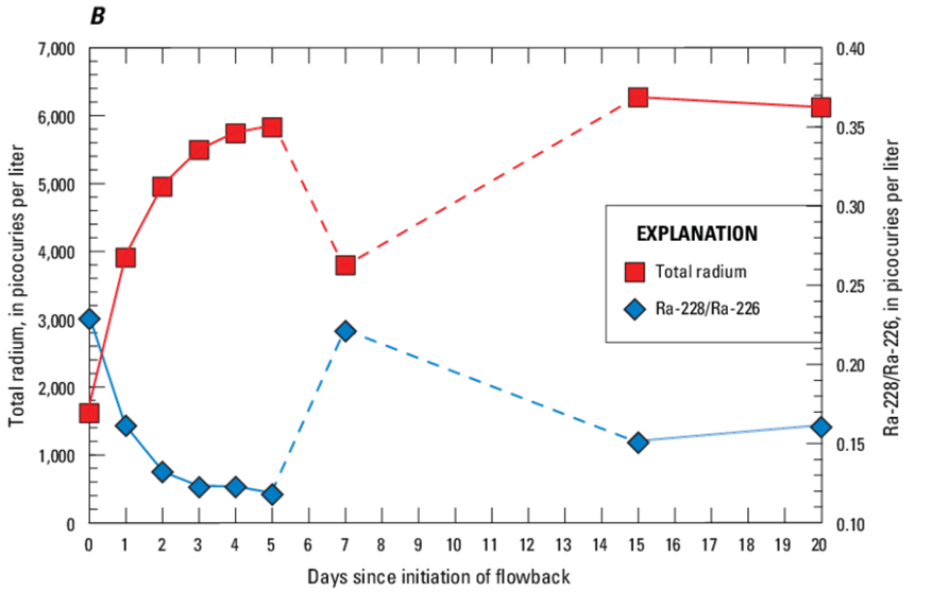
- **The average pad size is between 4 and 25 acres**
- **The average number of wells per pad is about 10, however super pads containing up to 40 wells are starting to make appearances**
- **Also need space for the equipment, other vehicles, and people**
- **Longer lease road may be needed if location is farther away from already implemented roads**
- **Local roads may have weight, height, width and/or length restrictions**
- **The area tends to be very hilly and covered in trees**
  - **Vegetation may need to be removed in order to create open space**
  - **Dirt may need moved in order to create a flat space that's large enough**
- **It is very easy for costs to accumulate during this stage**

- **What can be done:**
  - **Only have necessary equipment/amenities on pad at a certain time**
  - **Limit size, amount, and shape of the equipment/amenities**
  - **Try to find spaces in areas that are relatively flat and need little vegetation or dirt moved**
  - **Locate the pad not too remote in order to keep lease road construction costs down**
  - **Make sure local roads are able to handle the increase in traffic and weight they will see**

Water Supply and Brine/Cuttings Disposal

- **Water plays a large role**
  - **Present when drilling, preparing for production, and producing the well**
  - **The largest need is during hydraulic fracturing**
    - **About 4 to 6 million gallons per well**
    - **A high production year in the Marcellus requires about 80 million gallons of water per day**
- **Sources include:**
  - **Local ponds or streams**
  - **Constructed reservoirs**
  - **The public water supply**
  - **Wastewater from other wells**
- **Complicated by the rapid changes in water quantity and quality over time**





- **Wastewater Management Techniques:**
  - **Injection into a disposal well**
  - **Removing metals and other contaminants to create clean brine**
  - **Desalinizing clean brine to create clean freshwater**
  - **Evaporating the water to dryness or crystalline form**
  - **Filtering the water to remove suspended solids and blending it with freshwater**
- **Reuse is being done in large amounts**
  - **Options for injection wells are limited**
- **More water being produced than can be recycled**

- **Problematic Constituents:**
  - **Barium**
    - **Can combine with sulfate and cause sediment build up**
  - **Uranium, Strontium, and Radium**
    - **Can mobilize under acidic conditions**
  - **Bromine**
    - **Can react with organic compounds in surface water to produce trihalomethanes**
      - **Chloroform, Bromodichloromethane, Dibromochloromethane, and Bromoform**
    - **Exposure has been linked to :**
      - **Increases in certain cancers**
      - **Heart, lung, kidney, liver, and central nervous system damage**
- **The geologic variability and the legacy of coal and mineral mining, oil and gas production, and other industrial activities greatly complicate water quality studies within the Appalachian Basin**

Geomechanics

- **The earth's crust is constantly subjected to forces that push, pull, or twist it**
- **If we visualize a point within the earth as a cube it can be visualized as shown in Fig. A**
  - **The point is subjected to three normal stresses and six shear stresses**
- **A simple rotation can be applied which results in the principal stresses shown in Fig. B**

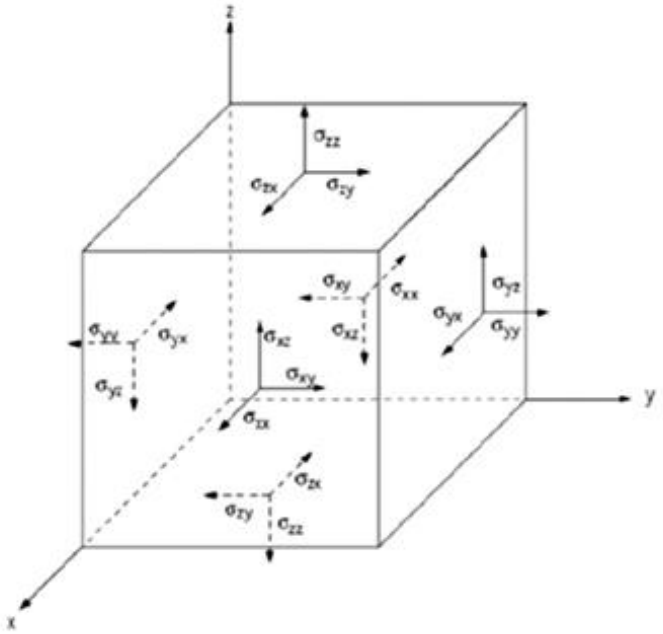


Fig. A

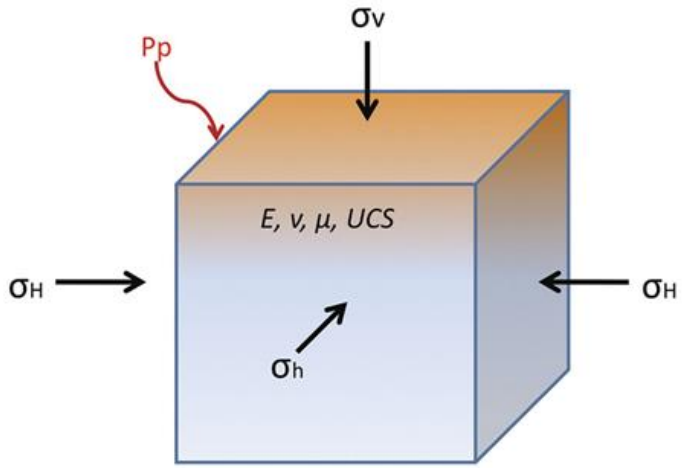
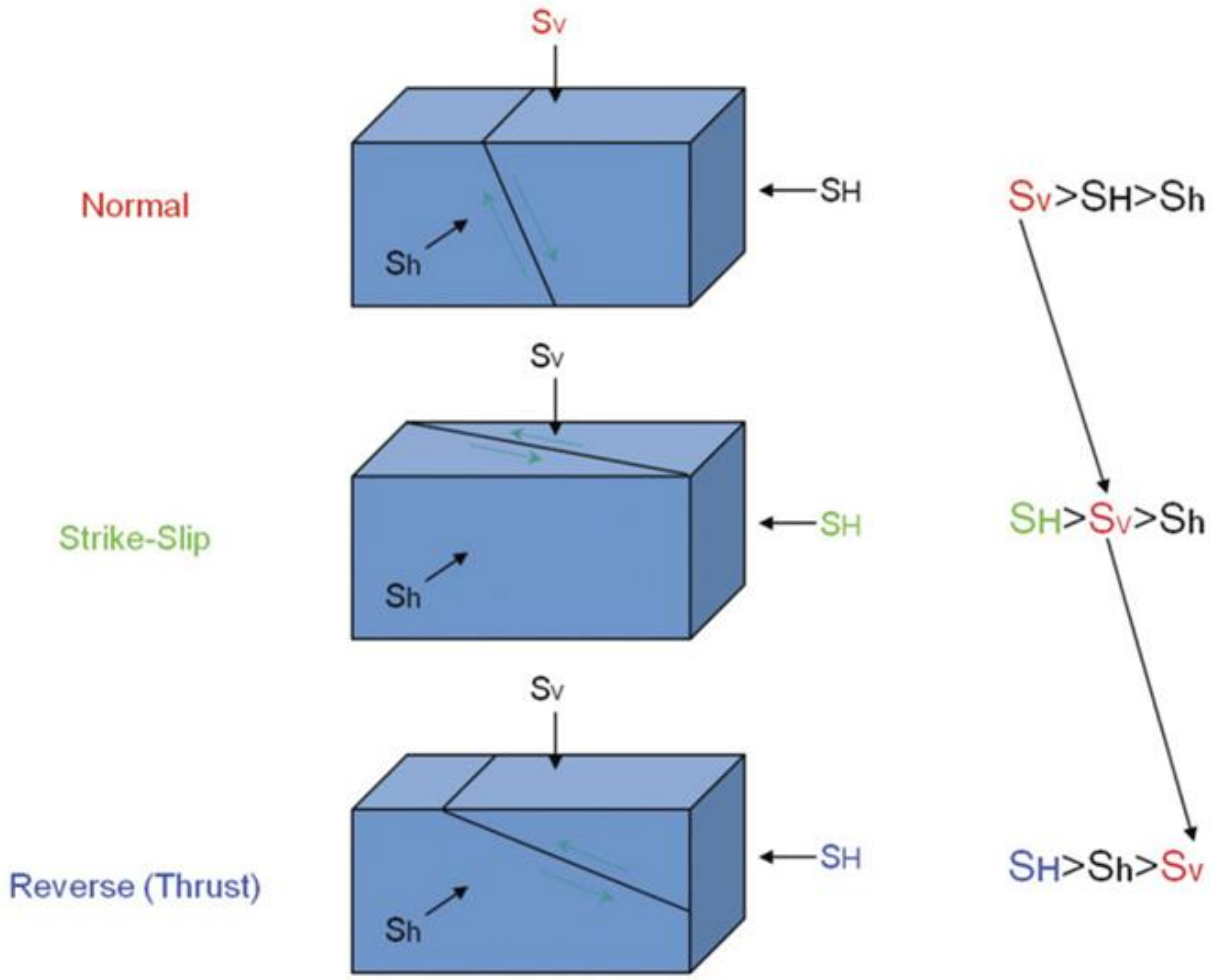


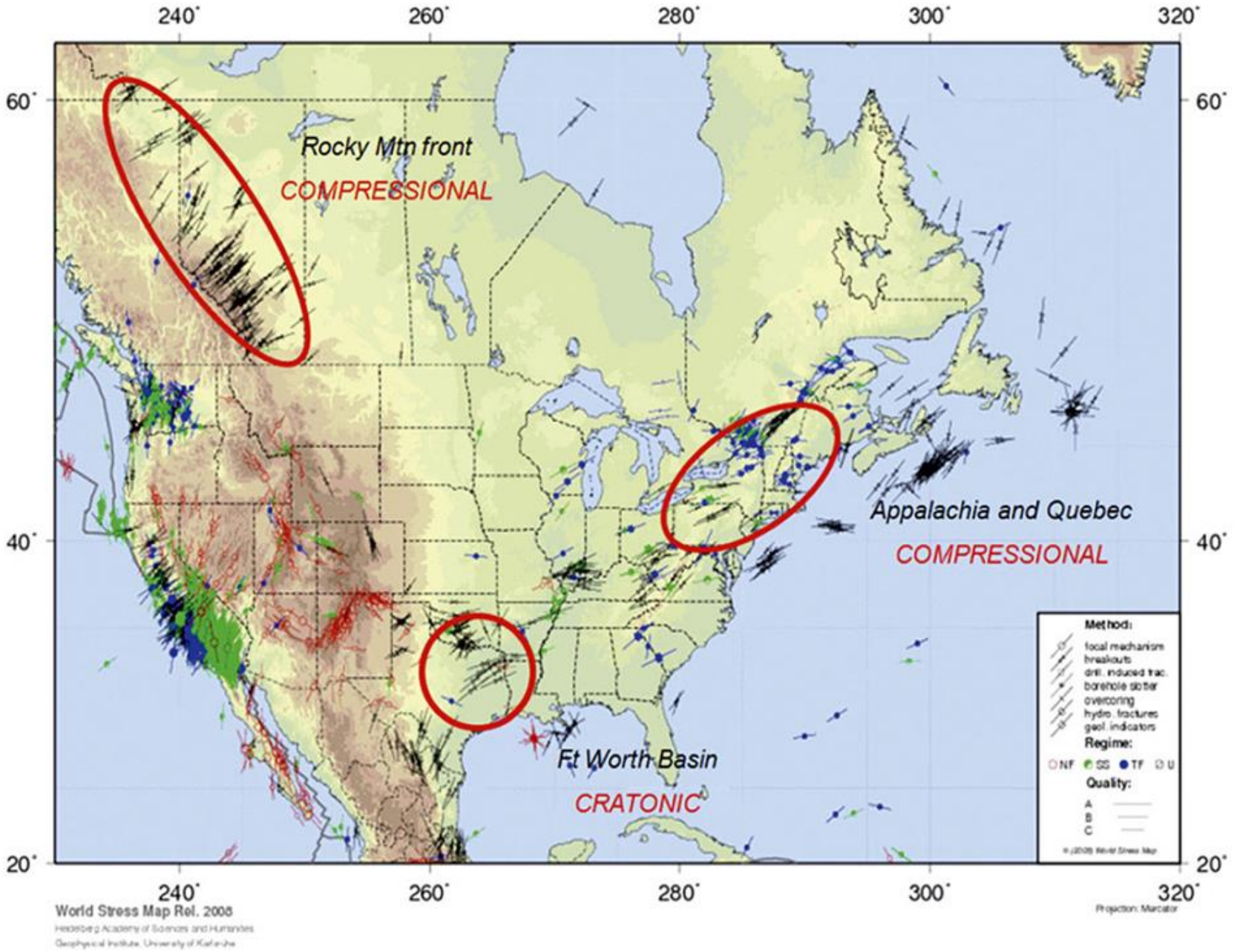
Fig. B

- **Before we drill a well, the formation is in a state of stress equilibrium**
- **Drilling of the wellbore disrupts that equilibrium**
  - **Causes stress to redistribute around it**
- **Use mud weight to balance this dis-equilibrium**
  - **Commonly not enough to stop breakout or wellbore instability completely**
- **Stress directions can be estimated by looking at the damage in the borehole from drilling**
- **Breakouts occur in the direction of minimum horizontal stress**
  - **Maximum compression (where breakout occurs) happens 90 degrees from the maximum horizontal stress**
    - **Can estimate σH, the maximum horizontal stress direction**

- **Estimate their magnitudes**
  - **Overburden (σv) – information from density logs**
  - **Minimum horizontal (σh) – leak off tests, offset completion data, or mini fracture tests within the wellbore**
  - **Maximum horizontal (σH) – the hardest to estimate; advanced sonic measurements or the severity of wellbore breakouts**
- **The magnitudes define the type of faulting regime that the formation of interest lies in**



- **The Appalachian Basin is almost all strike-slip or thrust faults with high horizontal stress ratios**



- **Horizontal wells are drilled in the direction of minimum horizontal stress**
  - **Contacts and props open the largest amount of reservoir**
  - **Makes fractures perpendicular to the wellbore**
    - **σH controls the direction of stimulation propagation**
- **High horizontal stress anisotropy does not allow the growth of induced complex fracture networks**

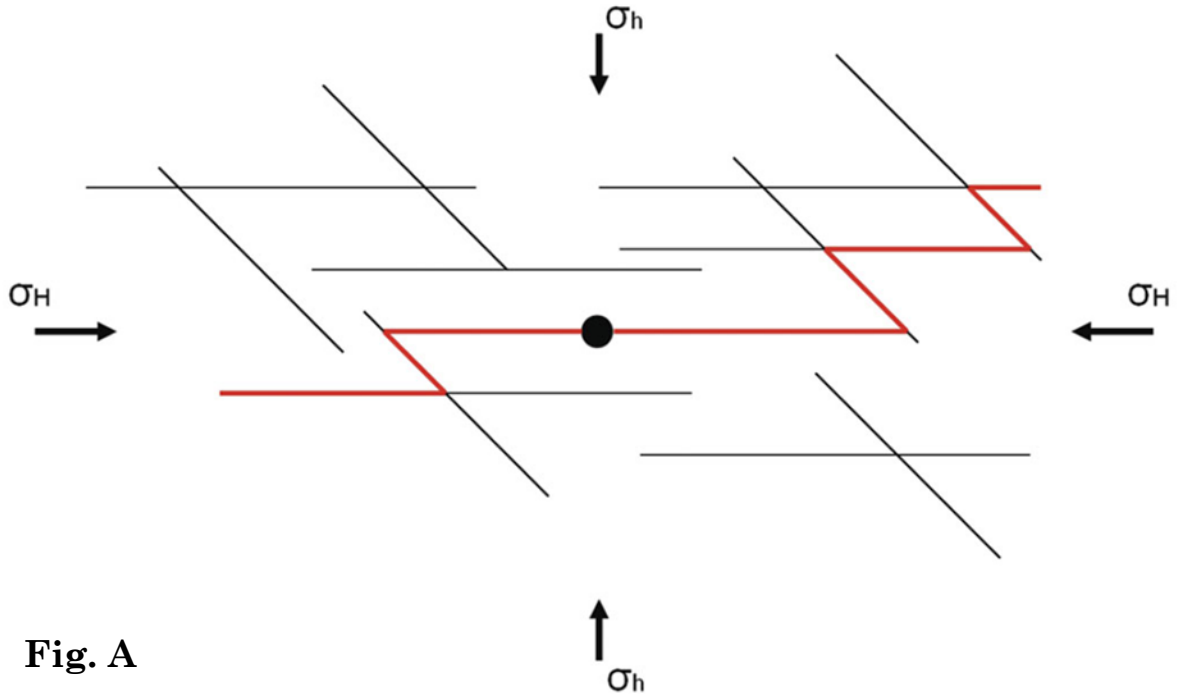


Fig. A

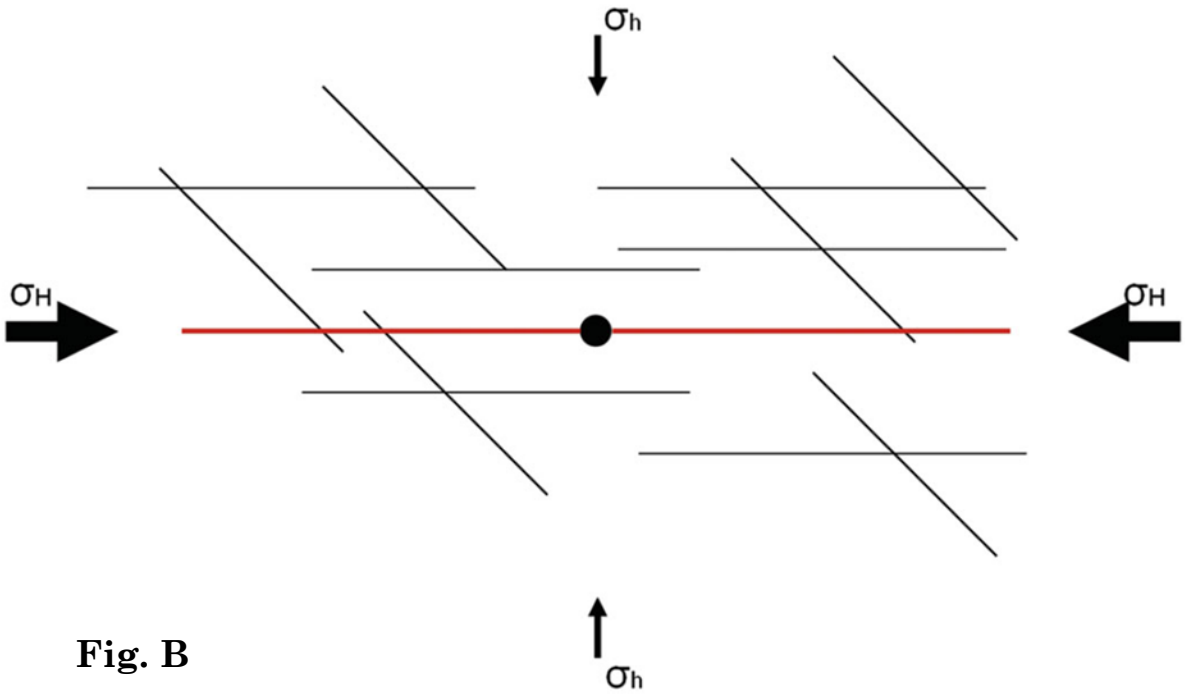


Fig. B

- **Ratios of stresses also control how the wellbore breaks out in both the vertical and horizontal sections of the well**
- **Highly compressive environments, like strike-slip or thrust fault regimes, breakout on the top and bottom of the wellbore instead of the sides**
- **May experience operational issues from stuck pipe, hole cleaning, well logging, and cement jobs**

Fig. A

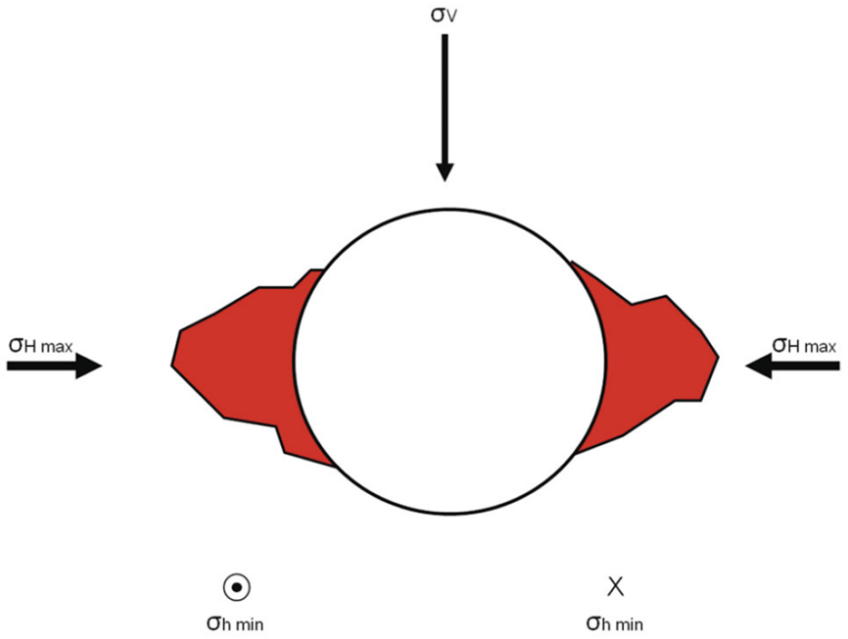
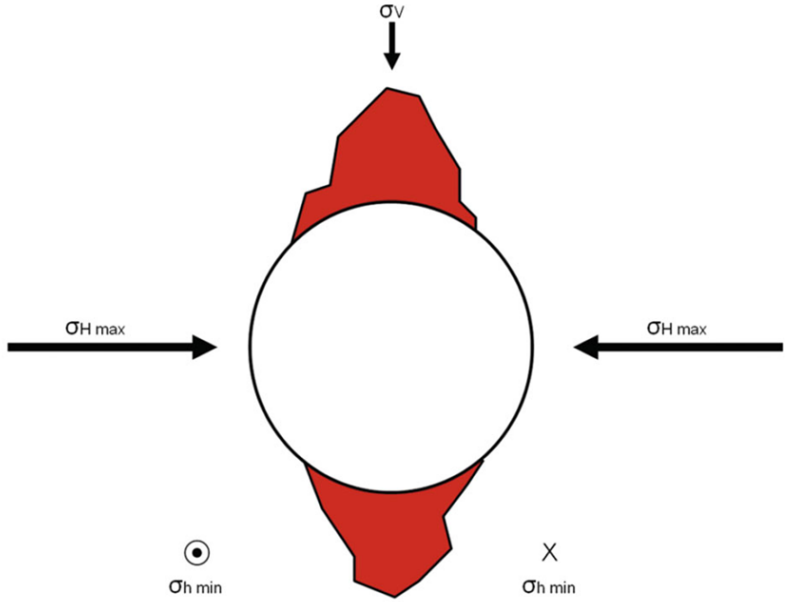


Fig. B



Conclusion

- **The unique geology of the Appalachian Basin is what makes it possible for the industry to be so prosperous in this area**
- **If one feature had even the slightest change, everything could be completely different**
- **Aspects such as water quality and geomechanics still pose operational complexities**
- **The industry continues to evolve every day and make advances in technology that will allow for safer, more efficient, and higher recoverability practices**

Thank You!
Questions?